AN INVESTIGATION INTO THE INSECT ECOLOGY OF CITRUS ORCHARDS, WITH SPECIAL REFERENCE TO CITRUS MUSSEL SCALE

(*LEPIDOSAPHES BECKII* NEWM.)

THESIS FOR THE DEGREE OF
MASTER OF SCIENCE,
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C O N T E N T S

ILLUSTRATIONS

INTRODUCTION

In the course of the last fifteen years the general insect ecology of citrus orchards in the Eastern Cape has provided the subject matter of four theses presented for the degree of M.Sc. of Rhodes University. The false codlin moth, Argyroploce leucotreta Meyr., formed the subject of a thesis by Horne in 1939. Then in 1941 the same insect formed the subject matter of a thesis by Harris. The general ecology of a citrus orchard, with special regard to the biological control of citrus red scale, Aonidiella aurantii Mask., was the subject matter of Whitehead's thesis in 1948. This was a much more general investigation than the preceding two theses, and touched on many more aspects of citrus ecology. Another thesis dealing with more general citrus ecology was that of Smithers in 1953.

It might be thought that in the course of these four theses, the subject of citrus ecology would be practically exhausted, and a very thorough knowledge of what actually takes place in a citrus orchard would be gained; but, in fact each investigation merely indicates how vast a subject citrus ecology is, and how much more still remains to be clarified.

The ecology of a citrus orchard, or indeed any other

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orchard, is completely unnatural and it is to be expected that its fauna is quite different from that of the surrounding countryside. In origin the citrus tree is Asiatic, and with its introduction into new countries, there have been introduced also various insects which are associated with the tree. These insects may actually attack the tree, for example, the various types of citrus scale, or they may be parasitic or predacious. Such imported insects frequently thrive more readily in their country of adoption than in the country from which they came, and unless steps are taken, or a state of natural biological control exists, they may destroy the imported tree. It is obvious that under orchard conditions, where trees are grown as a permanent stand, close together in rows, with the ground between them kept free of vegetation, conditions are ideal for the welfare and increase in numbers of insects which attack the tree. The success of the citrus industry in South Africa is due largely to the killing of noxious insects by chemical control, but is due also to the biological control effected by parasitic and predacious insects attacking the plant-eating species. Indeed, in some cases spraying and fumigating may often do more harm than good, as beneficial insects as well as harmful ones are killed.

In South Africa the most prominent among insects

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attack citrus trees is the citrus red scale, Aonidiella aurantii Mask. This scale has been in evidence in this country almost since the commencement of the citrus industry, and considerable work has been done on it. The general biology of red scale formed a large part of Whitehead's thesis in 1948, but in none of the four theses already mentioned has anything but passing reference been given to citrus mussel scale, Lepidosaphes beckii Newm. In recent years mussel scale, or as it is sometimes called, purple scale, has become more and more apparent in South Africa and is now to be found in most citrus growing areas. It is not an indigenous insect, having been introduced probably on hot house plants from England, but local conditions are apparently ideal for its survival, and in many areas it is causing great concern. Astudy of the general biology of mussel scale forms the greater part of this work. This scale has been previously worked on extensively in the United States of America and elsewhere, including the Transvaal. Little, however, has been done in the Eastern Cape, and it was thought that a detailed study of this insect's habits under local conditions would be of interest and of value.

The main field work for this thesis was carried out in the Bathurst area on the farm of Mr. Ross Purdon,

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approximately twenty miles from Grahamstown. The orchards on this farm contained trees of various ages and under various conditions of cultivation. The species of citrus used in this investigation were:-

The Lemon (*Citrus limonia*)

The Grapefruit (*Citrus grandis*)

The Orange (*Citrus sinensis*)

Both "Valencia" and "Navel" varieties of orange were included. The orchards were not irrigated, but during 1954 the trees were in particularly good condition, and had not suffered in any way from drought or from any other physical adversity. Several visits to the Sundays River Valley have enabled conditions there to be compared with conditions in the Bathurst area.

Opportunities have also been offered for investigations into the habits of the common brown house ant, *Pheidole megacephala* Fabr., under different conditions, and also for a superficial investigation into the fauna of orchard soils.

PART I

THE BIOLOGY OF MUSSEL SCALE, *LEPIDOSAPHES BECKII* NEWM.

CHAPTER ONE

Introduction.

Mussel scale, *Lepidosaphes beckii* Newm., (Fig. 4), is an armoured scale of the family Coccidae. In the United States of America it is generally known as purple scale. Since the insect was first made known in 1869 it has been known by the following names:-

Aspidiotus citricola Packard
Coccus Beckii Newman
Mytilaspis fulva Targioni
Mytilaspis citricola Comstock
Lepidosaphes pinnaeformis Kirkaldy
Mytilococcus beckii (Newm.)
Lepidosaphes beckii Newm.

Although the insect had been described from Germany by Bouché in 1851, it was first made known in the English publication "The Entomologist" in February, 1869. In the same year Packard in the United States of America described the same insect, but the first complete description was given by Comstock in his 1880 report.

The citrus tree, with which mussel scale is usually associated, is oriental in origin, and the original home of this scale is thought to be China or Tropical America, as indicated by various host plants indigenous to those areas.

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The scale was subsequently introduced into North America and rather more recently into the Mediterranean regions. Today it is found in most citrus growing areas of the world, including Bermuda, Cuba, Honduras, British Guiana, Brazil, Peru, Porto Rico, Argentine, Paraguay, Colorado, California, Florida, Louisiana, Java, Formosa, Fiji, Hawaiian Is., Australia, New Zealand, Tasmania, Mauritius, West Africa, Madeira, South Africa, Mozambique, Uganda, Belgian Congo, Japan, China, Ceylon, Burma, Malaya, Spain, Italy, Sicily and Palestine.

It is not certain from which country mussel scale was introduced into South Africa. Its occurrence was first reported in 1896 in two districts, Cape Town and Stellenbosch. In one case the trees had been imported from Natal in 1889, and in the other case the scale had been introduced on trees from hot houses in England.

Distribution in South Africa.

Stofberg (1937) states that mussel scale assumes the proportions of a "pest" only in the Transvaal lowveld, Swellendam district, Natal mist belt, and Portuguese East Africa; but in recent years this scale has spread so rapidly and its numbers have increased so rapidly, that it has caused great concern in many areas. The insect prefers a humid climate and is found mainly in the coastal belt. It has been reported in the Cape Peninsula, Stellenbosch,

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Somerset West, Worcester, Swellendam, East London district, Bathurst, Port Elizabeth, Uitenhage, the Natal coast, Greytown, Pietermaritzburg and the Eastern Transvaal. In 1950 this scale was ranked as a "major pest" in the western and eastern Transvaal, the Eastern Cape Coastal area, parts of the North Eastern Cape and in the Swellendam and Heidelberg areas of the Western Cape Province. In the Sundays River Valley mussel scale has been known for about twenty years and in the last six or seven years has become firmly established, and in some places it seems to be taking the place of red scale.

Economic Importance of Mussel Scale.

Mussel scale has always been of great economic importance as it yields less readily to treatment than do most other scales. Where the scale occurs on leaves it causes a yellowing of the leaf and may cause leaf drop. In only exceptional cases are entire trees killed by this scale, but frequently a portion of the tree is killed. In the course of this work it was repeatedly observed that the more shady south eastern side of a tree was partly lacking, almost certainly as a result of heavy mussel scale infestation. Injury to the tree is caused directly by the feeding of the scale which does not secrete honey-dew. Where the scale occurs on ripening fruit it often delays the colouring, and a green spot persists around the scale while

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the rest of the fruit ripens. The insect is tough and becomes firmly attached to the plant, and ordinary packhouse brushing will not remove it. Mussel scale is very resistant to both fumigation and spraying.

Host Plants.

The chief host plants of mussel scale are *Citrus* spp., and all varieties are attacked. Laboratory experiments carried out in the course of this work have failed to establish a preference for any particular variety of citrus, but in the field it was observed that lemon trees were less heavily infested than grapefruit and orange trees.

Besides citrus, mussel scale is recorded from fig, olive, croton, oak, coleus, murraya, pecan, palm, mango, *Eleagnus*, *Banksia integrifolia*, *Taxus cuspidata*, *Cercidiphyllum japonicum*, *Pomaderris apetala*, *Balsamocitrus*, *Poncirus*, *Malpighia glabra*, *Cassia*, *Hibiscus*, *Lavanga*, *Allamanda*, *Cycas*, *Viscum*, *Magnolia*, *Toddelia*, *Wigandia*, and others.

During 1954 mussel scale was observed on no plant other than citrus, although careful inspections were made of those indigenous plants bordering the orchards investigated.

CHAPTER TWO

Life History of Mussel Scale.

In order to study the life history of mussel scale and observe the different stages, adults were reared from active crawlers taken from beneath adult females and released on to two clean, unripe oranges. These oranges were placed on the mouths of two small bottles so that the stems were immersed in water, and the scales completed their life cycle before the condition of the fruits deteriorated. The bottles containing the fruit were covered with lamp glasses, over the upper ends of which were clamped pieces of organdie. In this way the scale on the fruit was protected from any parasites or predators which may have been present in the laboratory. Four crawlers were released on one fruit and nine on the other. They were all released on the upper surface of the fruit, and all but one settled almost exactly where they were placed. One wandered to the lower surface and was discarded, as it could not be observed without inverting the fruit. Measurements of the scales' external dimensions were made at three-day intervals with the aid of a compound microscope removed from its normal stand and mounted on a retort stand, (Fig.1). By this means, both the fruit and the bottle could be placed beneath the microscope. A graduated eye-piece enabled dimensions to be determined. It was possible to measure only the external

-dimensions...

Figure 1

Compound Microscope mounted on Retort Stand.

dimensions, i.e. the dimensions of the scale armour, because if the scale is inverted it is killed. The external dimensions, however, reflected the condition of the insect beneath the scale covering, and the condition of the naked insect could be determined by examining scales of corresponding dimensions on fruit from the orchards. Of the twelve crawlers originally released only three females and one male reached maturity. The stages of development of these four insects were recorded, (Figs. 2 and 3).

Fig. 2 shews the length and width of a female scale plotted against the corresponding length and width of a male scale. Fig. 3 shews the corresponding dimensions of the other two females, and it is striking how closely they correspond. The females used in Fig. 3 were both fertilised, and growth of the scale armour stopped with the production of eggs; both females had laid eggs by the time the experiment was abandoned. The female used in Fig. 2, however, was never fertilised, and at the time the experiment was abandoned the scale armour was still increasing in length, although the female beneath was quite small, and had produced no eggs.

In the early stages of development, the insects occasionally shew a decrease in size. This is due to the fact that the growth of the insect causes distortion of the early rather flimsy cottony secretions, and alters the

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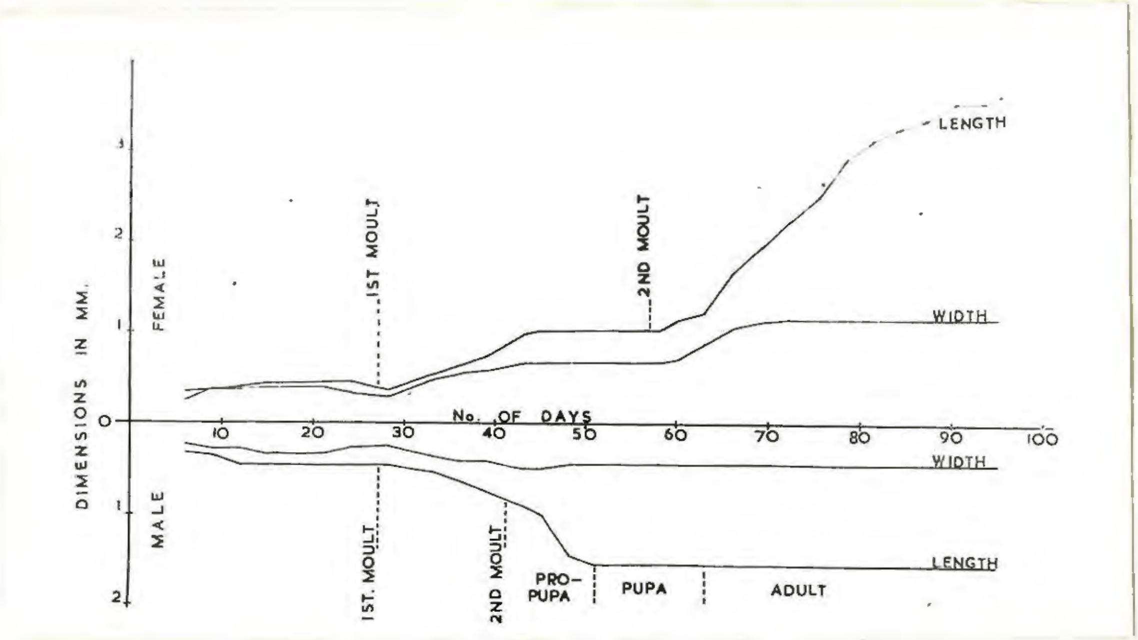

Figure 2
External Dimensions of Male and Female Mussel Scales.

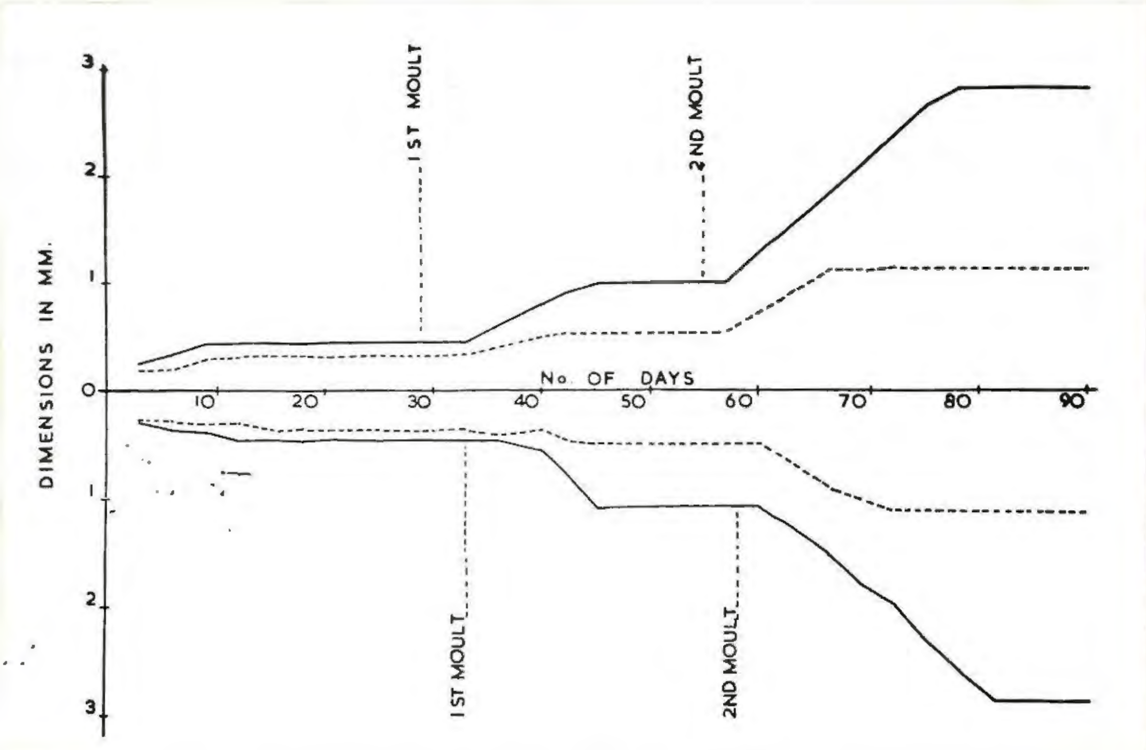

Figure 3
External Dimensions of two Female Mussel Scales.

external dimensions.

The experiment lasted from the 28th August, 1954 until the 1st December, 1954. The actual dimensions of the scales are given in Table I of the Appendix.

The Egg.

The Egg, (Fig.4) is pearly white in colour, with the surface slightly granulate. They are oval when laid, but usually become laterally compressed under the dorsal armour of the female, and the oval shape is frequently lost. Twelve eggs were measured using a compound microscope with a graduated eye-piece and it was found that their lengths ranged from 0.294 mm. to 0.266 mm., and their widths from 0.175mm. to 0.125 mm.

The eggs are protected by the dorsal armour of the adult female under which they are arranged in rows and stand partly on end. The total number of eggs produced by one female varies, but it is considerably larger than the number found beneath the scale armour at any one time, because as fresh eggs are laid the more mature ones are hatching at the posterior end of the scale armour, and active crawlers are emerging. The greatest number of eggs counted was ninety-four, but so high a figure was unusual, and the average number was usually between forty and sixty. The maximum number of eggs produced would be considerably higher, as vacated egg cases were usually found beneath the females examined. Eggs

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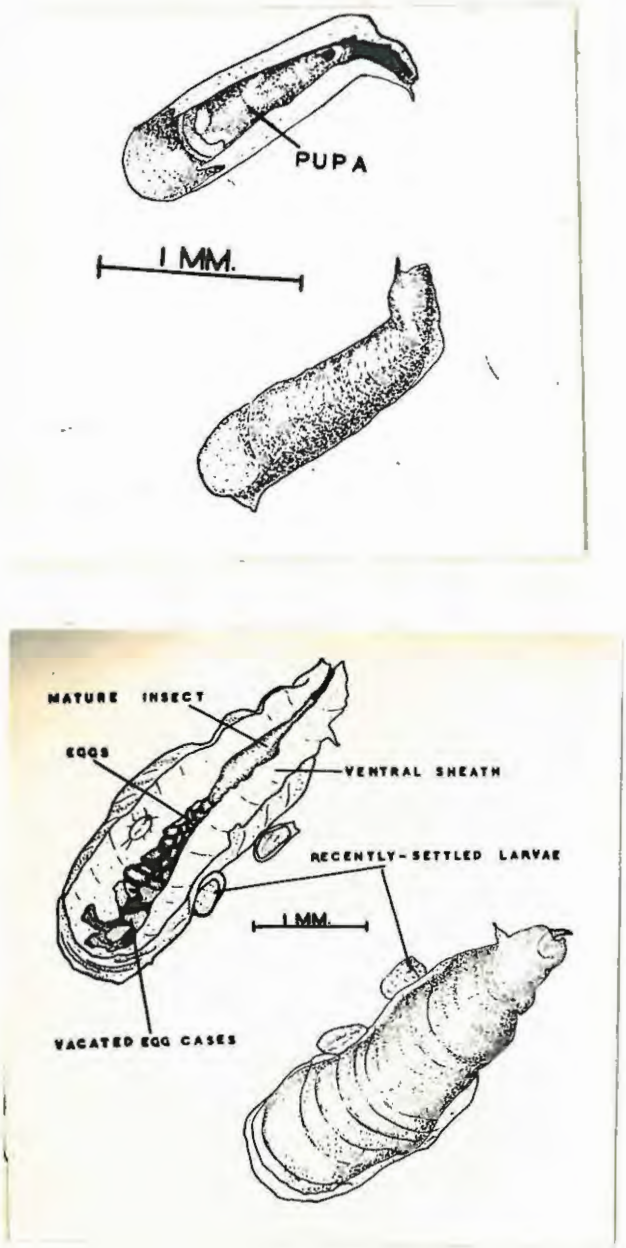

Figure 4

Adult Male and Female Mussel Scale.
Dorsal and Ventral Aspects.

are deposited over a period of three to four weeks and hatching occurs two to four weeks after oviposition, depending on climatic conditions. The area beneath the scale armour is limited, and in order to accomodate the eggs the female has to contract as eggs are deposited, (Fig.5).

The Active Larva.

The active larva, or crawler, (Fig.6), hatches beneath the female armour and emerges from beneath the posterior end, where the armour is not fixed to the plant surface. Measurements shewed that the dimensions of crawlers were slightly greater than those of the eggs, the lengths varying from 0.322 mm. to0.294 mm., and the widths from 0.175 mm. to 0.146 mm. The active crawler is flat and oval, yellowish-brown in colour, with the posterior tip rather more brown than the rest of the insect. The antennae are six-jointed with the first joint broader than the others, and the last joint annulate.

Apart from the winged male, the crawler is the only active stage in the life cycle of mussel scale, and therefore its movements determine the fate of the adult. Crawlers are reported wandering for as long as three days before settling, but during this work they were never observed to wander for more than a few hours, and seldom travelled far from the parent scale.

The crawlers were considered to play so important a

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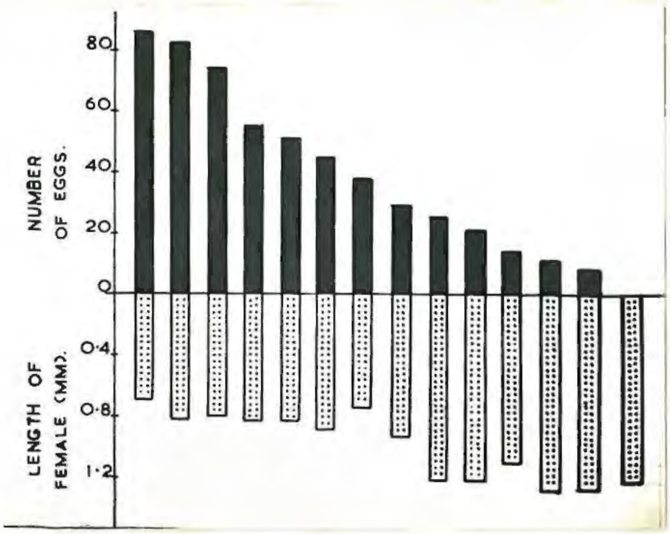

Figure 5

Relation between size of adult female mussel scale and number of eggs present.

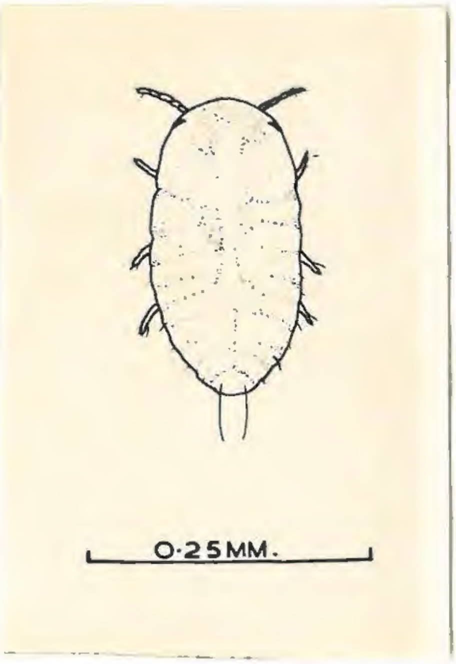

Figure 6

Active mussel scale crawler.

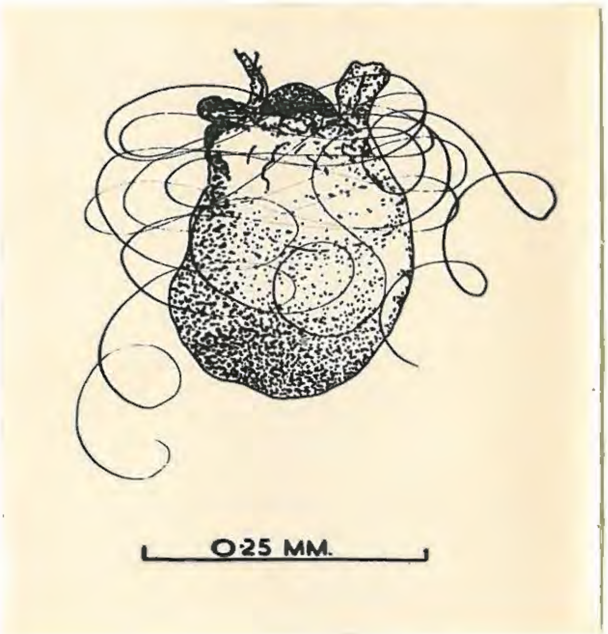

Figure 7

Mussel scale 60 hours after settling.

rôle in the life history of mussel scale that a separate section is later devoted toa discussion of their behaviour.

During one experiment under protected laboratory conditions it was found that of twelve crawlers released on to the surface of two oranges eleven became established, but under natural conditions probably only a very small percentage actually settle. Quayle (1912) found that even under protected conditions only about 50% became established.

Second Stage.

Once the crawler settles and begins to feed, its mobile stage is terminated, and it takes on a new form. At this stage there is still no apparent difference in the sexes, and it is not until after the first moult, which was found to occur approximately twenty-seven days after settling, that differences could be distinguished.

It was observed that within four hours of settling two silky threads were secreted from the anterior end of the insect's body, apparently from beneath the margin. They were very long, and their numerous coils completely enveloped the body of the newly-settled crawler, (Fig.7). These threads seem to serve a protective function, and it was observed that many predators on encountering them turned away. Some coccinellid larvae, e.g. Platynaspis spp.(Fig.55), which are covered with waxy strands, can become completely entangled when scales at this stage are present in large numbers.

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Until the secretion of the permanent scale armour these silky threads are the only protection the insect has. This is commonly known as the "fuzz" stage, and frequently gives the fruit the appearance of being covered by some fungous mould. These strands may persist even after the more compact permanent covering has been secreted.

After the secretion of the silky threads, the secretion of the permanent scale covering is begun. This is produced as very fine threads which cover the insect far more compactly than did the first two threads. It was observed that the covering started at the posterior end and gradually moved forward, until by sixty hours the greater part of the insect was covered, (Fig.7). This secretion extends anteriorly over the antennae. As the insect becomes older the scale covering becomes more compact. It is, however, semi-transparent, and it was noticed that where crawlers had settled on marks made on the fruit surface with indian ink, the marks shewed through the covering even of adult scale.

After approximately twenty-seven days the insect undergoes a moult, and from then onwards there are considerable differences in the development of the two sexes.

The second stage insect, (Figs. 8 and 9), is purplish-white with a brown posterior tip. It has no distinct eyes, but in the case of the male towards the end of this stage two pairs of eyes become apparent from the coalescence of

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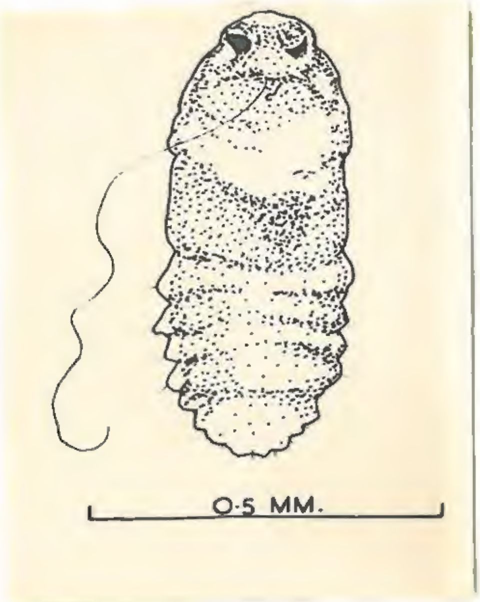

Figure 8

Second stage mussel scale. Male.

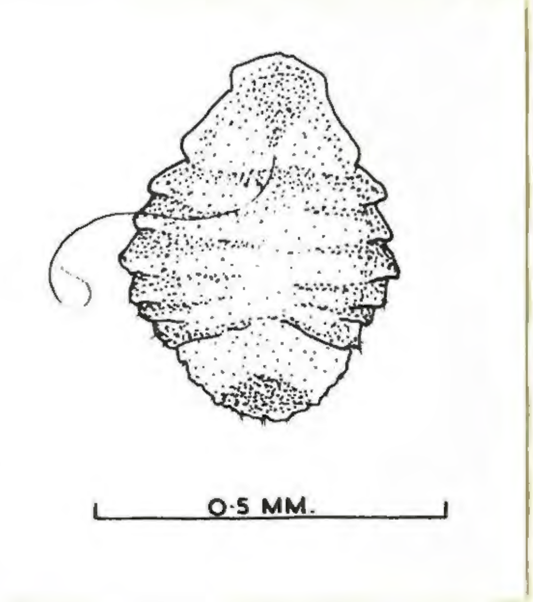

Figure 9

Second stage mussel scale. Female.

Figure 10
Female at 46 days. External.

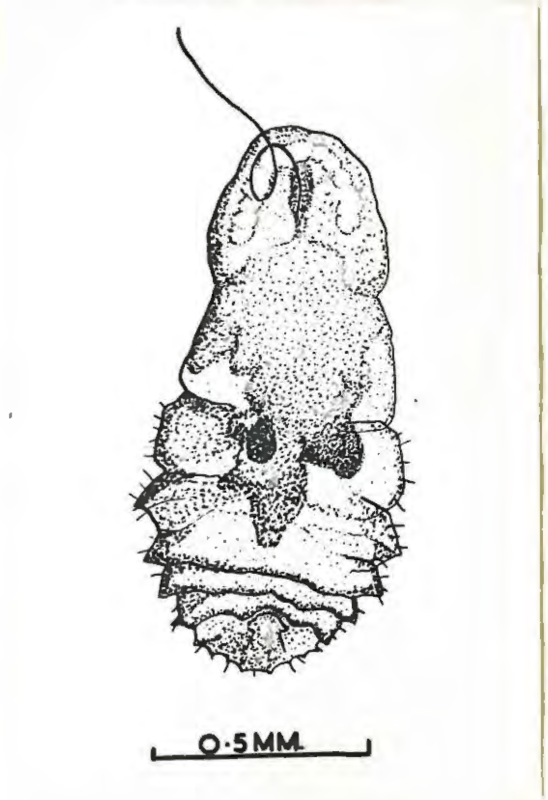

Figure 11
Naked adult female mussel scale.

purple granules. The length of the second stage male is about 0.65 mm. and its width about 0.25 mm. The length and breadth of the corresponding female are about 0.50 mm. and 0.40 mm. respectively.

Development of the Female.

After the first moult the female grows steadily for about two weeks and much wax is laid down, (Fig.2). Fig. 9 shews the appearance of the naked female shortly after the first moult. All signs of limbs, antennae and eyes have been lost. It is translucent and purplish white in colour. Fig. 10 shews the external appearance of the female after forty six days, approximately half way between the first and second moults. The first exuviae is seen at the anterior end incorporated in the dorsal scale, and above it are the remains of the original silky strands.

A further period of approximately two weeks follows during which no growth of the scale armour occurs. The second moult then occurs and brings the female to maturity. Growth however, continues for some time after this, and wax continues to be laid down. It was found that if the female was fertilised, wax ceased to be laid down about eighty days after settling, but where fertilisation did not occur, wax continued to be secreted although the female did not grow. Fig. 11 shews the adult naked female. It is pale yellowish white to purplish white in colour, with its

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posterior end reddish brown. Its pygidium is rather large and broad and is not heavily chitinised. Its width is approximately 0.7 mm. and its length varies according to the number of eggs it has produced, (Fig.5). It will be seen that the maximum length obtained by a female is approximately 1.3 mm. after which eggs are produced and the length diminishes. Where eighty six eggs were present the length of the parent was only about 0.7mm. The data used in Fig. 5 are given in table VII of the appendix.

Fig. 12 shews the external appearance of a female seventy one days after settling. The illustration was made from the same insect used for Fig. 10, and its dimensions after the first moult may still be seen. The width of this insect did not alter after this stage, although it continued to increase in length.

As the female matures and egg laying begins a film is secreted from the ventral lateral portions and forms a sheath protecting the ventral side of the insect and the newly-laid eggs, (Fig.4). In the illustration the sheath has been split to expose the female beneath it, but normally it is continuous for approximately two-thirds of the body length, opening posteriorly in the region of emerging crawlers.

Oviposition begins approximately fifteen days after fertilisation, which is approximately seventy-five days after settling, (Fig. 3), and continues for up to one month. The

-female...

Figure 12
Female 71 days. External.

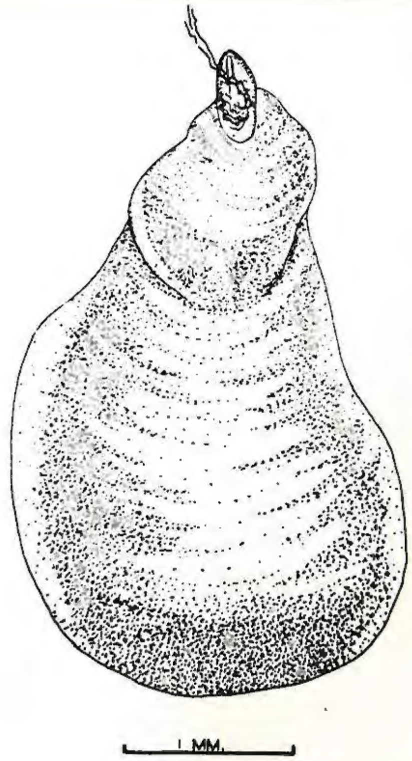

Figure 13
Male 33 days. External.

female dies after the deposition of her complete quota of eggs, and her entire life cycle takes from four to six months, which would permit three or four generations a year. The maximum quota of eggs was not determined, but according to Stofberg it is about two hundred and sixty-four.

The adult female is the most conspicuous form ofthe scale, and is easily recognised on infested trees. The scale armour is mussel-shaped, elongate, and generally slightly curved. It is narrower anteriorly, and broadened posteriorly with flattened paler marginal areas. At the posterior end there is a portion of the armour where it is not fixed to the plant substrate; by way of this "flap" the crawlers emerge and the style of the male is inserted during copulation. The scale is transversely rugose, bearing conspicuous lines of growth. It is purplish brown to yellow brown in colour. The female is considerably larger than the male, (Fig.4).

<u>Development of the Male</u>.

After the first moult wax is laid down in semicircular bands posteriorly and the male grows steadily for approximately two weeks, (Figs. 2 and 13). Fig. 13 shews a male mussel scale thirty three days after settling. At the anterior end can be seen the more woolly early covering and posterior to this are circular bands of harder more shiny waxy covering which began to be laid

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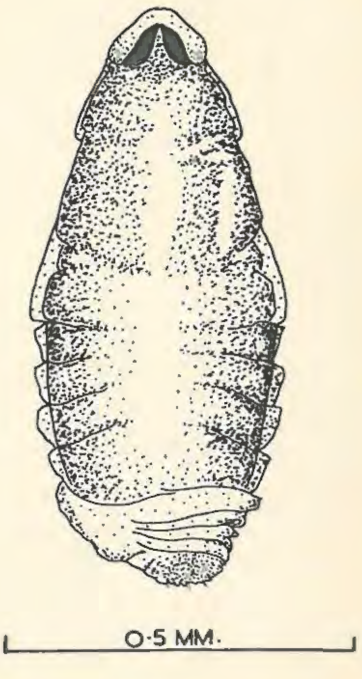

Figure 14
Propupa.

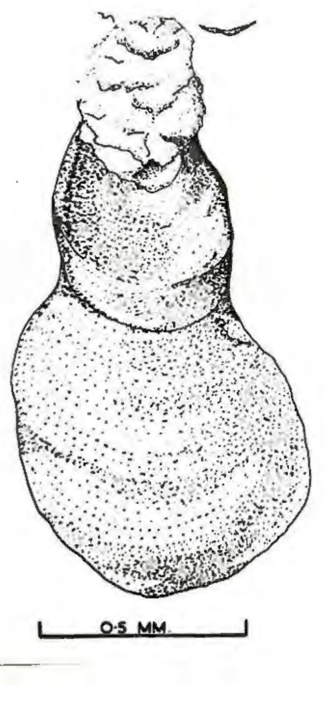

Figure 15
Male 46 days. External.

down after the first moult.

About forty one days after settling the male moults a second time which brings it to the propupal stage, (Fig.14). This stage is distinguished from the true pupa by its less fully developed appendages shewn by their enclosing sheaths. The propupa is rather fleshy and is purple in colour. Ventral eyes are large, dark and close together. The dorsal eyes are smaller and farther apart. The length is approximately 0.80mm. and the width approximately 0.45mm. It is between the second and third moults that wax ceases to be laid down, and growth of the scale armour ceases, (Figs.15 and 16).

The propupa gives rise, after eight or ten days, to the pupa, (Fig.17). This stage is approximately 0.85mm. in length (including the style) and about 0.30mm. wide, at its widest point, which is towards the posterior end. It is similar in colour to the propupa, but the sheaths of the legs, antennae and wings are more conspicuous and are more-or-less free from the body. The eyes are dark purple, and the ventral pair is closer together than the dorsal pair.

After a further period of approximately twelve days the pupa moults and gives rise to the adult male, (Fig.18). The adult male emerges from the pupal exuviae approximately sixty to seventy days after the crawler settled, but may not leave the scale covering for some time, depending on

-external...

Figure 16

Male 51 days. External.

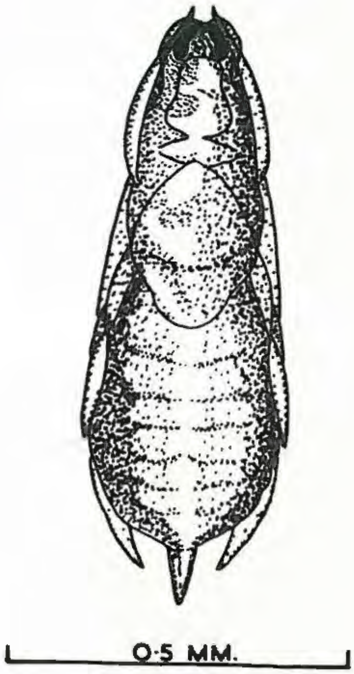

Figure 17

Male pupa.

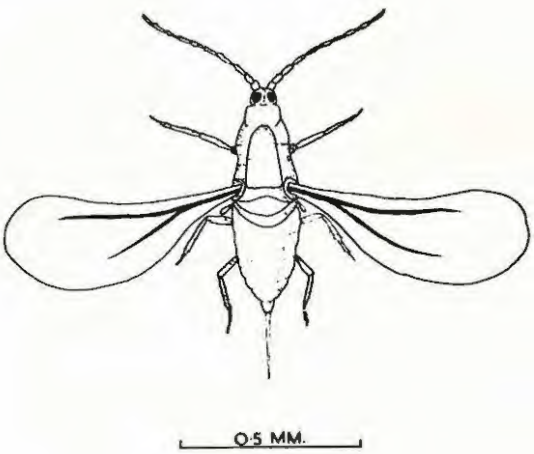

Figure 18

Adult Male.

external climatic conditions.

The adult male is of a general yellow colour with purple areas especially towards the anterior end. The antennae are ten-jointed. At the posterior end there is a style which is used during copulation. The wing expanse is approximately 1.5mm. and the body length, excluding style and antennae is approximately 0.6mm.

The Behaviour of the Adult Male Mussel Scale.

The length of time spent by the adult male mussel scale beneath the scale covering before emerging seems to depend on the temperature, for it can be shewn that a sudden rise in temperature will be followed by the simultaneous appearance of numerous winged males.

During the period March 25th to April 22nd 1954 parasite emergence boxes were employed in the laboratory. These were ordinary cardboard boxes with circular holes in them in which were placed glass test-tubes. Into the boxes was placed mussel scale-infested orange material - fruit, leaves, and twigs - and the boxes sealed. It was hoped that sufficiently large numbers of the parasite *Aspidiotiphagus lounsburyi* (Berlese and Paoli) would enter the illuminated tubes to enable a study of its life history to be made. In fact, very few parasites were obtained, but winged male mussel scale appeared in such large numbers that it was

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considered worth while to keep records. The numbers of males in the tubes were therefore counted each evening at sundown and the temperature in the laboratory at the time of counting was recorded. Fig. 19 shews the daily numbers of male mussel scale entering the tubes with corresponding temperatures plotted above them. It can be seen that the numbers of males correspond very closely to the temperatures. It can be seen also that a sudden rise in temperature brings forth large numbers of males. The males could obviously not all be developing at exactly the same rate and time, and they must therefore be fully mature for some time before they actually emerge. Where two hot days followed closely, e.g. 2nd and 3rd April, it is possible that most mature males emerged on the 2nd April, and there were comparatively few left to emerge the following day, although the temperature was greater. The numbers fall off towards the end of that period, because the plant material was never replenished.

Similar experiments were carried out for the periods 28th July to 2nd September, 9th September to 9th October, and 10th October to 9th November, 1954,(Figs.20, 21, 22 and 23). (Figs. 22 and 23 cover the same period, but for Fig.22 orange material was used, and for Fig.23 grapefruit material was used. This was done in connection with parasites, and will be discussed later (Page 70). In

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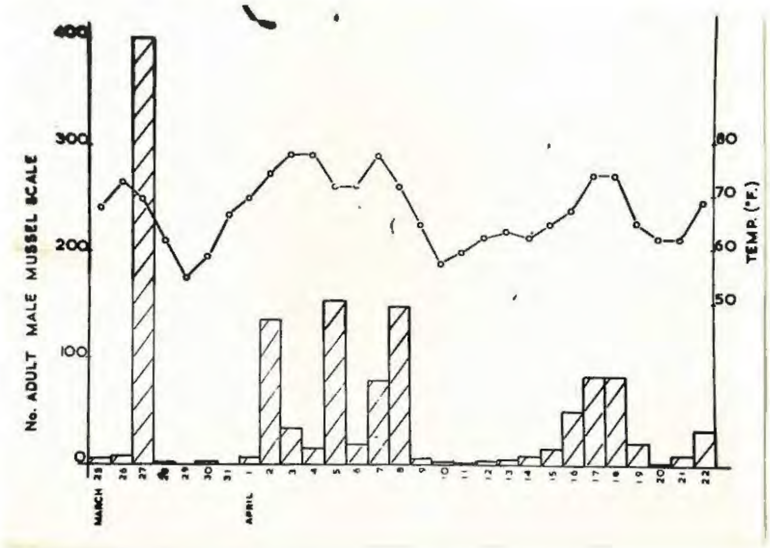

Figure 19

Emergence of winged male mussel scale in the laboratory, March 25th to April 22nd, 1954.

these experiments the parasite boxes were placed on a verandah and were shielded from direct sunlight. A ma ximum and minimum thermometer was placed on the shady side of the box and readings taken every evening. At the same time counts were made of what had emerged into the tubes. Except in the cases of Figs. 19 and 23 the same cardboard box was used for each set of experiments. In this way it was possible to use approximately the same amount of infested grapefruit material for each period covered by the experiment. Only twigs and leaves were used in the last four experiments as it was found that fruit tended to develop mould. It is unlikely that any males entering the tubes returned subsequently to the box, as the high humidity in the tubes usually caused the males to adhere to their inner walls.

The results of these four experiments are plotted in the same manner as the first experiment, but both maximum and minimum temperatures are shewn. Again it is seen that the numbers of males emerging correspond closely to the temperatures, and it suggests that it is a sudden rise in the maximum temperature that brings forth large numbers of males.

The tabulated results of these experiments are given in Tables II, III, IV, V and VI of the appendix. The numbers include winged male red scale, but their numbers

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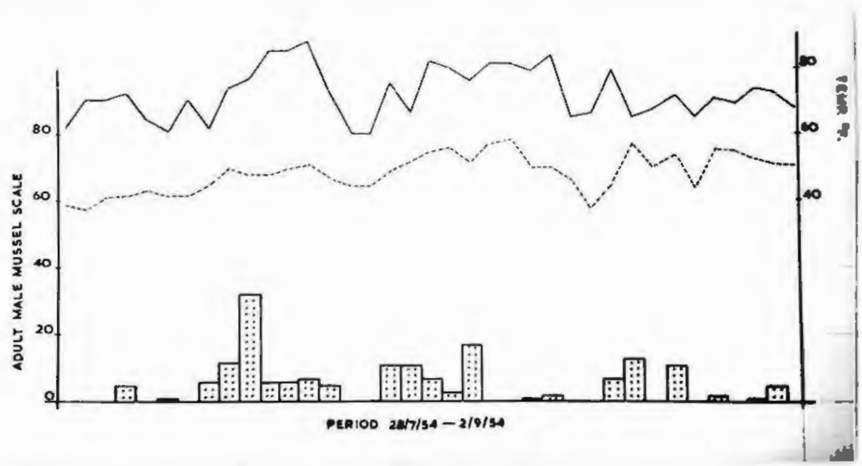

Figure 20

Emergence of males,
28th July to 2nd September.

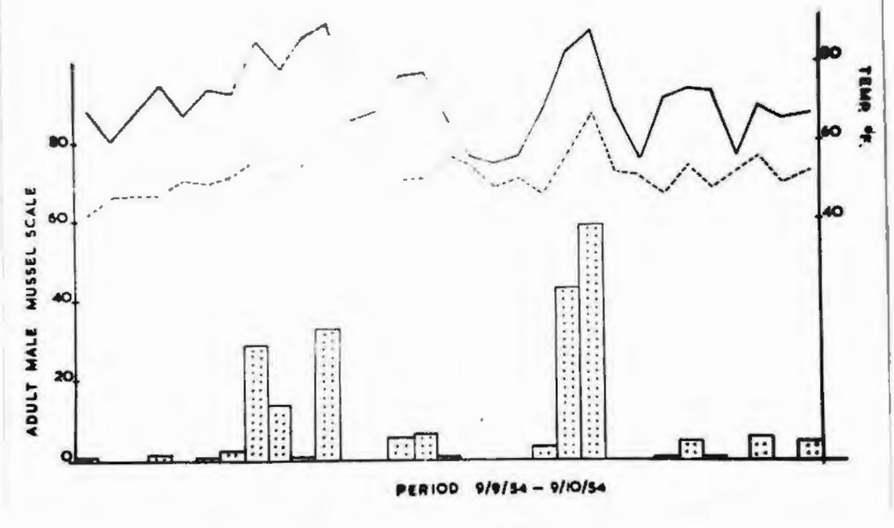

Figure 21

Emergence of males,
9th September to 9th October.

were very small and would not alter the appearance of the figures.

It can beseen that males emerge and are active throughout the winter months, although their numbers increase as summer approaches. (See also Fig. 37).

They usually emerge with their wings fully expanded, but one was observed to leave the scale covering with its wings crumpled, and to rest for over three hours while they expanded.

Quite a number of males seem to perish as a result of being trapped under their scale armour. During the extensive scale counts made in connection with seasonal distribution, (Page 56), dead but undamaged males were frequently found beneath their scale armour.

The length of life of a male once it has left its scale covering is probably not more than about twenty-four hours, for a large proportion of those trapped in the parasite emergence tubes during the day were dead by the evening, and those used for fertilising females did not remain alive in the laboratory for more than about twelve hours.

Although adult male mussel scales are delicate and small, observations in the laboratory shewed that they are quite active fliers and fly determinedly in the direction of a light or a window. Under natural conditions, however,

-they...

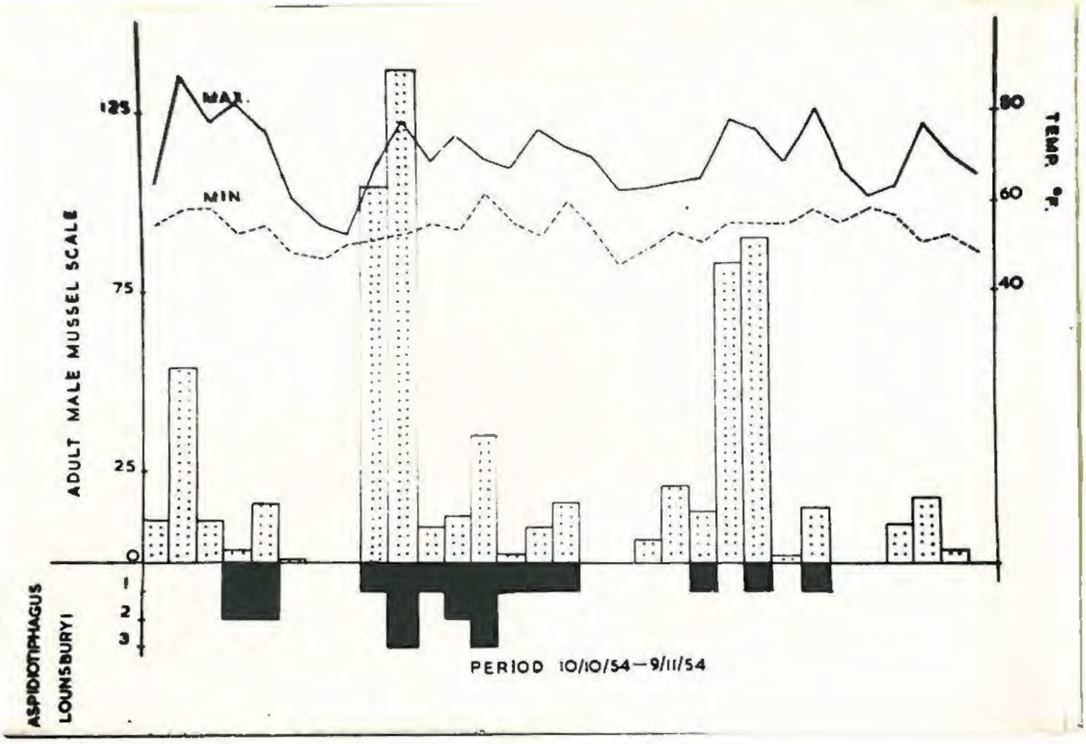

Figure 22
Emergence of male scale, and the parasite Aspidiotiphagus lounsburyi, from orange material. 10.10.54 - 9.11.54

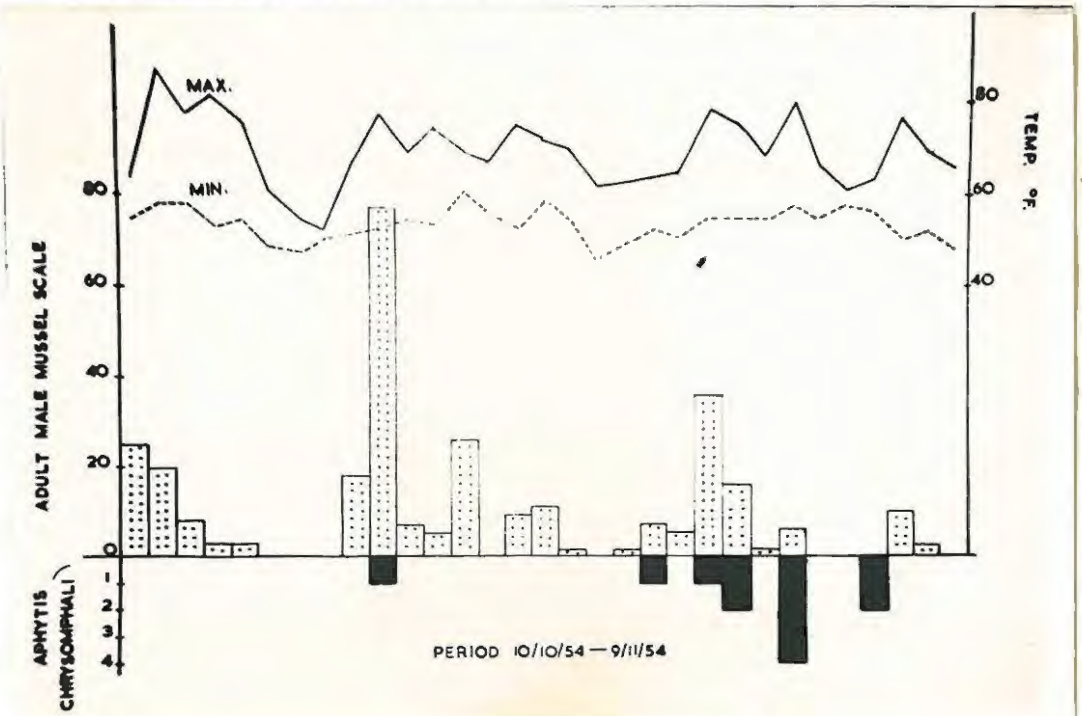

Figure 23
Emergence of male scale, and the parasite Aphytis chrysomphali, from grapefruit material. 10.10.54 - 9.11.54.

they must be very much atthe mercy of the wind.

Fertilisation of the Female.

Copulation between mussel scale was observed on certain occasions in the laboratory when male mussel scale were released on to a scale-infested fruit or leaf placed under a bright light. A male would walk round and round a group of scales in narrowing circles until a suitable female was found. It would then take up a position with its antennae and wings pointing vertically upwards and its posterior abdomen directed downwards towards the posterior end of the female to be fertilised. The style would then be inserted beneath the posterior end of the female scale armour, and a series of jerking movements effected by bending and stretching the hind legs, would be performed by the male. At the same time the male would revolve in circles using its style as its axis of rotation. This process would continue for about four minutes, after which the male would clean its style with its hind legs and continue wandering over the plant surface. Usually the male would return several times to the same female and the process would be repeated.

Frequently a single suitable female was selected from extremely dense patches of scale and it was only after removing many scales that the actual female fertilised was subsequently discovered.

-Parthenogenesis...

Parthenogenetic breedings were carried out by Bodenheimer (1951) but parthenogenesis is not the normal procedure.

Moulting.

The actual process of moulting was not observed as it takes place beneath the scale armour. According to Quayle (1912) the rent in the cuticle occurs on the ventral side, and the exuviae become incorporated in the dorsal covering; the antenal and pygidial characters are not changed as the insect pulls itself from within. He states that the first and second cast exuviae of the male are incorporated in the scale covering, but with the female only the first cast exuviae is incorporated. The succeeding male exuviae are pushed posteriorly from beneath the scale covering. In the case of the male whose growth curves are plotted in Fig. 2, the discarding of the pupal exuviae was observed. Sixty three days after settling, the posterior one-third of the insect projected from beneath the scale covering and the pupal exuviae was discarded outside the covering on the surface of the fruit. According to Stofberg (1937), the second and third cast exuviae are usually pushed out together.

CHAPTER THREE

The Behaviour of Mussel Scale Crawlers.

The distribution and spread of mussel scale is effected entirely by the crawlers which, apart from the winged males, are the only form of the insect which is mobile. Attention was drawn to the behaviour and habits of crawlers when attempts were made in the laboratory to try to breed mussel scale in large numbers.

Experiment 1.

The method first employed was that described by Campbell and Moulton, and was the method used by Yust and Munger in California, and by Whitehead in Grahamstown; in both cases the method was employed in connection with the breeding of citrus red scale, (*Aonidiella aurantii* Mask). The apparatus is essentially that shewn in Fig. 24, except that the bottle and oranges are placed in a darkened box which is open at the top only. The lower fruit, whose stem is in water, is scale-infested and is separated from the upper clean fruit by a 3.5 inch cone of grey paper. The apparatus worked well with red scale, and the crawlers readily travelled upwards to the illuminated fruit, but when used in connection with mussel scale no crawlers migrated.

Since mussel scale tends to be more densely distributed on the shady side of trees (see section on Distribution,

-page...

Figure 24

Figure 25

Figure 26

Figure 27

Figure 28

Apparatus used in Experiments 1, 2 and 3 for investigating the behaviour of mussel scale crawlers.

page 49), and in view of the fact that in literature it is frequently stated that mussel scale crawlers are negatively phototropic, a modified form of the above apparatus was set up.

Experiment 2.

This time the illumination was from below, (Figs, 25 and 26). The bottles and oranges were placed on a glass platform with white paper beneath to reflect the light upwards, (Fig. 25). A cardboard box was then placed over the bottles, (Fig. 26). This apparatus was set up together with the one previously described, and both were left from the 19th April to the 26th June 1954, after which time the fruits were inspected under a binocular microscope. There had been no migration from one fruit to another. The lower fruit, however, had become even more densely covered with mussel scale, and had acquired a fluffy appearance as a result of the "fuzz" from the newly settled crawlers.

The conclusion from these two experiments was that mussel scale crawlers do not wander far from the parent scale, and it was later decided to set up another experiment in which the fruits would be closer together.

Experiment 3.

The apparatus used for this experiment is shewn in Figs. 27 and 28. The contaminated fruit was placed in the mouth of a bottle in the lower box which had large

-rectangular...

rectangular holes cut in its sides so that the lower fruit could be well illuminated. The upper (clean fruit) made contact with the lower fruit through a small hole in the top of the lower box. A small cardboard box was used to keep the upper fruit in darkness (Fig. 28). This box was moistened from time to time to prevent the fruit from becoming too dry. All but adult female scales were removed from the lower fruit. The apparatus was set up on the 14th September and examined again on the 5th October 1954.

It was found that a total of seventy four had migrated. Of these, thirty one had gathered at the point of contact between the two fruits, thirteen had settled at the other pole of the lower fruit around the mouth of the bottle, and twenty six were scattered over the lower fruit surface.

The results of this experiment suggested that crawlers are attracted to the points of contatt and are not particular averxe to strongly-illuminated surfaces.

It was then decided to repeat Experiment 3 rather more extensively, using several sets of different fruits so that the crawlers could indicate any preference for a particular fruit.

Experiment 4.

The previous apparatus was modified so that migrations on to three different fruits as well as a control could be carried out at onee. The apparatus used is shewn

-in...

Figure 29

Apparatus used in Experiment 4.

in Fig. 29, and consisted of four units similar to that used in Experiment 3. The upper fruits in thi s experiment were covered by shortened cardboard bottle- covers which could be dipped in water to prevent the fruits beneath them from drying up. The unit on the left served as a control and its upper fruit was not kept in darkness.

The lower fruits were all green fresh oranges from which all forms of scale had been removed. Any flaws in the surface of the fruits were filled with "Plasticine" so that no crawlers should be lost.

For convenience the units are referred to as A, B, C, and D reading from left to right, so that the control becomes A.

In this experiment the upper fruit in B was an orange, C was a lemon, and D was a grapefruit. Two oranges were used in the control unit. Each fruit was examined and cleaned before being placed in position.

The apparatus was set in position with four lights shining on the lower fruits, and twenty active mussel scale crawlers were placed on each of the lower fruits. These cra wlers were taken from beneath mature female scales on fresh orange leaves. The leaves were first placed for a few minutes beneath a bright and rather hot light which tended to activate the crawlers and cause them to emerge from beneath the parent. The leaves were examined in

-turn...

turn and any freely moving crawlers were transferred to the lower fruits by means of a very fine needle. The crawlers adhere very readily to such a needle and need be damaged in no way provided they are handled carefully. Further crawlers were obtained by inverting mature female scales. Only crawlers which had either been removed from beneath the parent or which had been seen emerging from the parent were used. This overcame the possibility that crawlers might have been active for some time and might have been about to settle before being removed.

The experiment was set up in the evening of the 11th October, when the laboratory temperature was 75°F. The apparatus was left in a state of constant illumination for thirty six hours, by which time any crawlers which were going to settle should have done so. Both fruits of each section were then examined under a binocular microscope, care being taken not to remove any crawlers while handling the fruit. The results are shewn in Table 1, (Page 30).

The results do not suggest that the crawlers shew any preference in choice of fruit, neither do they suggest that they are attracted towards dark regions. In the control section all but two crawlers were accounted for, and of these all but one had not moved from the fruit on which they were placed. Most of them, however, had moved slightly from their actual position in which they were placed.

-Nine...

Nine had settled on the part of the orange which was actually in the mouth of the bottle, two had settled at the point of contact between the two fruits and one had migrated to the upper fruit.

TABLE 1.

	Lower fruit	Upper fruit	Contact point	Total settled
Control	orange 17	orange 1	2	18
B.	orange 3	orange 1	0	4
C.	orange 9	lemon 1	0	10
D.	orange 8	grapefruit 0	0	8

As far as sections B, C, and D were concerned, nothing like the total number of crawlers was accounted for, and they must therefore have migrated downwards on to the bottle. Of those that had settled, the majority had settled on the lower fruit almost exactly where they were originally placed. (The stems and the lower thirds of the lower fruits of sections B, C, and D had been dipped in wax so that the crawlers should not settle in the bottle mouths.)

It was then decided to carry out a similar experiment without actually handling the crawlers.

-In...

In the course of this work it has been found the handling of crawlers tends to upset their normal behaviour. Earlier in 1954 experiments were carried out in which active crawlers were placed on the bright side of an orange illuminated from one side only. Subsequently the fruit was examined to see how many crawlers had settled on the bright side and how many on the dark side. The results of these experiments are shewn in Table 2.

TABLE 2.

Date 1954	No. of crawlers released	No.settled on bright side	No.settled on dark side	Total number settled
21/6/	9	9	0	9
22/6/	4	1	0	1
22/6/	21	17	4	21

It can be seen that there is a tendency for the crawlers to move very little or not at all after being handled, although under natural conditions, as shewn by Experiment 3, if crawlers emerge from the parent into conditions of bright light, they do tend to migrate to darker regions and especially to points of contact. The crawlers are undoubtedly thigmotactic, (see section on Distribution on Fruit and Leaves, page 54), and the handling of them may cause physiological disturbances

-resulting...

resulting in their settling and feeding almost at once.

Experiment 5.

In this experiment the upper fruits were clean and were the same varieties used in Experiment 4. The lower fruits were oranges which had adult scales on them, but all recently settled crawlers were removed. It was hoped that the migrating crawlers would be able to be calculated as a percentage of the total number settled. The lower fruit was supported by a match stick, one end of which pierced the fruit and the other end of which was stuck into a cork in the mouth of the bottle. The match stick was smeared with petroleum jelly to prevent crawlers migrating downwards. The upper and lower fruits were connected by a centimeter length of match stick.

The experiment was set up on the 13th October and left until the 23rd October 1954 when it was inspected. The resultsare shewn in Table 3.

TABLE 3.

	Crawlers settled on clean fruit	Crawlers settled on lower fruit
Control	1	2
Orange	2	2
Lemon	0	17
Grapefruit	Both fruit covered with mould	

-the...

The results were unsatisfactory as insufficient crawlers had settled to indicate anything definite, and mould had appeared where the fruit was damaged. This mould would hinder the progress of any crawlers migrating from one fruit to another. Nevertheless, the experiment did suggest once again that crawlers are not averse to illuminated conditions.

Experiment 6.

In this experiment, set up on the 26th October 1954, the same varieties and combinations of fruits were used as before, but this time care was taken that the fruits were not damaged, and the bottle covers were washed out with a 4% solution of sodium borate to prevent the growth of mould. All newly settled crawlers were removed from the lower fruits which were heavily infested with mussel scale. After one week the experiment was inspected and the results are shewn in Table 4.

TABLE 4.

	Crawlers settled on clean fruit	Crawlers settled on lower fruit
Control	1	164
Orange	1	4
Lemon	0	40
Grapefruit	5	293

-The...

The results shew that in spite of the illumination, the crawlers tend not to migrate. (It is interesting to see from the table that in Section D, two hundred and ninety eight crawlers were produced in the course of one week. There were only sixty four adult females present in this section, and of these probably not all were producing crawlers).

In Experiment 6 the upper clean fruits were less ripe than the lower ones, and in case this should have proved a repelling factor to the crawlers, the experiment was repeated on the 4th November 1954 using ripe clean fruit. Six days later the experiment was dismantled and the results tabulated in Table 5.

TABLE 5.

	Crawlers settled on clean fruit	Crawlers settled on lower fruit
Control	0	26
Orange	1	92
Lemon	0	33
Grapefruit	1	20

These results merely give further indication that the crawlers migrate very short distances and are not averse to conditions of bright light.

-As...

As a final experiment, two units were set up in an inverted position with the scale-infested fruit uppermost and in darkness and the clean fruit illuminated from both sides and supporting the scale-infested fruit. After six days the fruits were examined and the results tabulated in Table 6. They indicate nothing further, except that the crawlers apparently migrate just as willingly into conditions of bright light as into conditions of darkness.

TABLE 6.

	Crawlers settled on clean (lower) fruit	Crawlers settled on upper (infested) fruit
Orange	3	166
Lemon	1	43

The main conclusion to be drawn from the above experiments is that mussel scale crawlers are not negatively Phototropic but are indifferent to conditions of light.

It will be shewn on a later page (page 49) that the shady regions of trees, i.e. the southern and eastern sides and the centre, are more heavily infested with mussel scale than the parts of the tree which receive direct sunlight. This probably is the reason why mussel scale crawlers are frequently described as being negatively phototropic. The actual activity of the crawlers however, is so slight that the chances of their travelling from lighter regions of

-the...

the tree to darker regions seem very remote. It has been noticed that crawlers do not usually travel far from the parent scale, and some actually settle beneath the parent. Greater numbers would probably settle beneath the parent were it not for the fact that the continuous production of eggs limits the space beneath the scale armour and crawlers are forced out. When the illustration shewn in Fig. 4 was being made, the specimen from which it was drawn was placed on the platform of a binocular microscope. During the course of the drawing an egg hatched and the crawler which emerged wandered for some time over the parent before venturing on to the smooth microscope platform. It then travelled a few centimeters at a time away from the parent but always returned to her. It never wandered more than two or three centimeters from the parent, and usually rather less. The latter observations support the conclusion that crawlers are thigmotactic and do not like smooth uninterrupted surfaces.

It has been observed that the activity of crawlers depends on temperature, and that placing scale-infested material beneath a hot electric lamp brought out crawlers from beneath the parent. If they were actually averse to light this could not be expected to happen, and their activity would be greatest at night. It can be easily shewn that this is not the case. In the orchards the

-numbers...

numbers of crawlers increased rather suddenly with the advent of warm weather in October and November (Fig. 38), and are noticeably active during the daylight hours.

It has been shewn, (Fig. 33) that more scale settle on the upper, lighter surface of the leaf than on the lower, darker surface. Also, on the fruit the region around the calyx is more heavily infested than the rest of the fruit surface (Table 10), although the fruit usually hangs with the calyx region uppermost. The attraction to this part of the fruit is probably partly because it is the region nearest the stem along which the original crawlers came, but mainly because the original crawlers tend to settle beneath the calyx, or in the surface creases frequently found in that region.

A Possible Explanation of the Fact that the More Shady Regions of Citrus Trees Support Relatively Larger Numbers of Mussel Scale.

It seems that the crawlers are indifferent to conditions of light. They are undoubtedly wind-dispersed and will therefore be distributed indiscriminately to all parts of the tree. Predators and parasites however, are attracted to regions of bright light, as was shewn repeatedly in connection with parasite emergence boxes (Tables II to VI of appendix), and they will therefore be attracted to the brighter side of the tree, Their activities will reduce the numbers of mussel scale in the brighter regions of the

-tree...

tree, and their comparative scarcity in the darker regions will permit greater numbers of mussel scale to become established. Once the scale becomes established in a darker part of the tree it will increase there, because that part of the tree is visited by fewer of its natural enemies. This is supported by the fact that during the winter months, when there were fewer parasites and predators about, the distribution of mussel scale on different parts of the tree was more even (Fig. 39). Direct sunlight is probably avoided by crawlers, and many of them probably perish as a result of bright sunlight, but they apparently have no aversion for harmless light. The fact that crawlers tend to settle under the calyx, along the midrib of leaves, and in other secluded regions, can easily be explained by the fact that the crawlers are thigmotactic.

The distribution of other species of scale on different parts of the tree was not investigated, but observation suggested that red scale and soft scale (Coccus hesperidum Linn.) are not more prevalent on one part of the tree than on another. Soft scale however, is mobile throughout its life, and red scale crawlers are very much more active than mussel scale crawlers. The crawlers of both red scale and soft scale are attracted towards regions of bright light, and were frequently observed in the tubes of parasite emergence boxes (Tables II to VI of Appendix). No

-mussel...

mussel scale crawler was ever observed in the parasite emergence tubes. Further evidence of the activity of red scale crawlers was shewn in the experiment described on page 25.

CHAPTER FOUR

The Distribution of Mussel Scale.

The distribution of this scale throughout the world and especially in South Africa was discussed in Chapter One.

Distribution Under Different Conditions of Cultivation.

On one part of the farm in the Bathurst district there was a grapefruit orchard part of which had been completely abandoned for several years and was slowly being replaced by the natural forest on which it bordered. This section of orchard was thoroughly overgrown by indigenous shrubs and small trees around the citrus trees, and by tall grass between the trees. A few large indigenous trees such as Cussonia spicata had already become established. This completely abandoned section extended up a slope for seven rows of trees where it was continued as a section of orchard whose trees had been abandoned, but in which natives had ploughed between the rows at right angles to the slope of the land, and had planted maize each year. In this second section there were a few indigenous shrubs under some of the trees, but far fewer than in the lower section, and there were no large indigenous bushes or trees. Short grass grew between the trees. This section of orchard extended for twelve rows and was separated from a fully cultivated orange orchard further up the slope by fifty six yards of ploughed land in which maize was planted annually. The cultivated

-orange...

orange orchard was kept free of all weeds and grass.

There was apparently far less mussel scale in the overgrown sections of orchard than in the cultivated sections, and it was decided to compare infestations by taking numerical samples from each section of orchard. Samples were taken also from a cultivated grapefruit orchard some three hundred yards from the abandoned orchard. Three fruits were taken from the south eastern side of each tree sampled, and the total numbers of mussel scale and red scale on each fruit were counted with the aid of a binocular microscope. By considering the fruit as a sphere the numbers of each species of scale per square inch of surface area was calculated, and average numbers of scale per fruit worked out for each tree. Four trees were sampled from the completely abandoned section, and three trees from each of the other sections. Any other insects on the fruit were also noted. The results of this sampling are shewn in Fig.30, and are tabulated in Table VIII of the Appendix.

Discussion of Fig. 30.

In the figure, Section I represents the compaetely abandoned section, Section II the section with ploughing in between the rows, Section III represents a cultivated grapefruit orchard some distance away from the others, and Section IV a cultivated orange orchard separated from Section II by fifty six yards of ploughing. Above the

-horizontal...

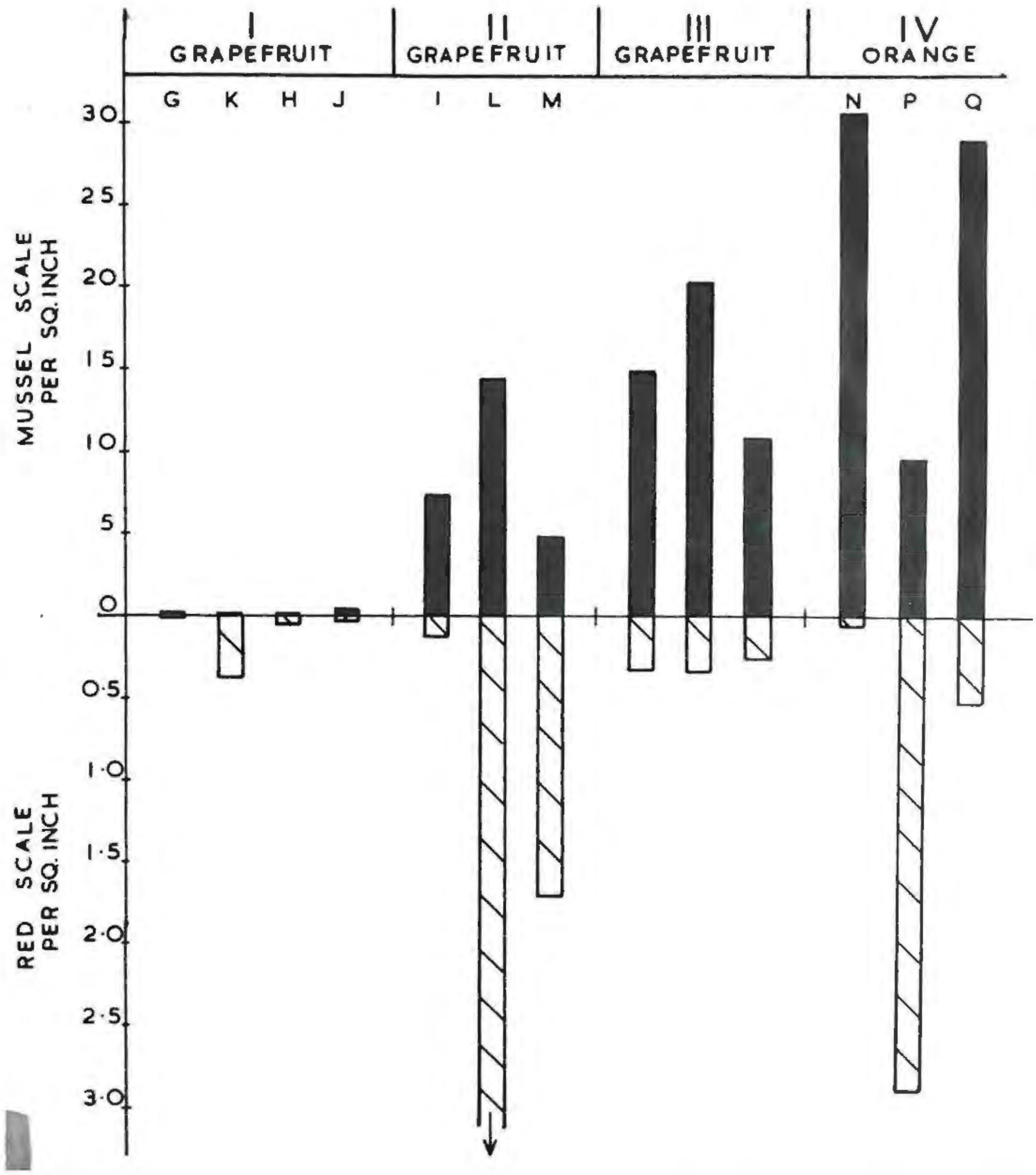

Figure 30

Distribution of red scale and mussel scale in orchards under different conditions of cultivation.

horizontal axis are plotted the numbers of mussel scale per square inch of fruit for each tree sampled. The trees are plotted in order of progression up the slope, tree G being in the first row sampled and tree Q in the last row. The trees sampled in the cultivated orchards were taken at random wherever fruit remained on the trees, for the sampling was done on the 18th August 1954, by which time a lot of the fruit had been harvested. Below the horizontal axis are plotted the numbers of red scale per square inch. As there were far fewer red scale, a different numerical scale was used.

It can be seen that the scale infestation, especially that of mussel scale, increased with the greater degree of cultivation, and where the orchard was completely abandoned the numbers of scale present were negligible.

The probable explanation is that the indigenous vegetation surrounding the citrus trees formed a kind of "reservoir" in which natural enemies of the scale could collect. General predators such as certain coccinellid beetles probably find their food normally on the indigenous plants, but will at the same time eat any young citrus scale they encounter, and the scale never get a chance to become established. Many predators, especially coccinellid and neuropterous larvae probably wander from plant to plant eating any suitable soft-bodied insects they encounter,

-and...

and in the cultivated orchards the barren areas between the trees may act as a barrier to their progress. Also, the indigenous vegetation in the abandoned sections may act as a "sieve" in preventing wind dispersal of scale crawlers. Wind-carried crawlers, or for that matter, crawlers carried by other insects or birds may come to rest on indigenous plants on which they cannot survive.

As will be seen in Table VIII of the Appendix, all coccinellids found on the fruit sampled came from the abandoned part of the orchard. This was probably chance, as the more heavily scale-infested trees would be most likely to support larger numbers of predators. In the abandoned orchards the coccinellids present probably prevented scale outbreaks, by destroying most of those crawlers or young scale which became established on the trees.

The yield of fruit in the completely abandoned section was meagre compared with the other sections, but in Section II the yield of fruit was prolific. All the trees were approximately twenty years old.

Distribution of Scale in Different Parts of an Orchard.

In order to find out whether mussel scale or red scale prefers one part of an orchard to another, leaf samples were taken from one end of an orchard to another. A large orange orchard on sloping ground was selected, and every

-second...

second tree of a row running north west to south east was sampled. This sampling was done on the 12th October 1954 and nine trees were used.

From each tree selected three twigs were broken off on the south east side; one twig was taken from the lower branches, one from the middle region, and one from the upper region of the tree. From each twig one leaf was selected at random and with the aid of a binocular microscope the total numbers of both red scale and mussel scale on both surfaces were counted. The leaves chosen were of approximately the same size and age. The row of trees was divided in two places, once by a wind-break and again by a small orchard road. The wind break was about twelve yards wide and was made up of fir trees and such indigenous bushes as Royena pallens and Rhus spp., and various grasses. The orchard road was small and little used and could be of no consequence.

The plotted results of the first sample are shewn in Fig. 31. As this graph suggested one or two things, e.g. a decrease in red scale towards the interior of the orchard, a more extensive sampling was done the following day by taking material from the alternate trees omitted in the first sampling. The results of both samplings are graphed in Fig. 32, and the numbers from which the figure was drawn are given in Table IX of the Appendix.

The most striking point about Fig. 32 is the decrease

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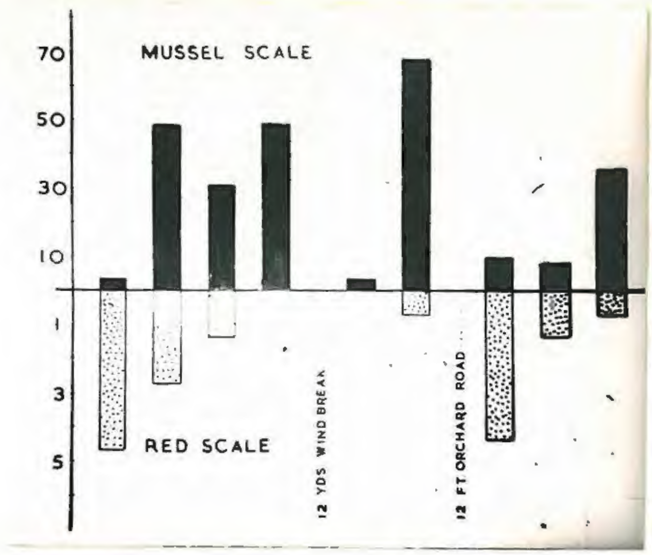

Figure 31

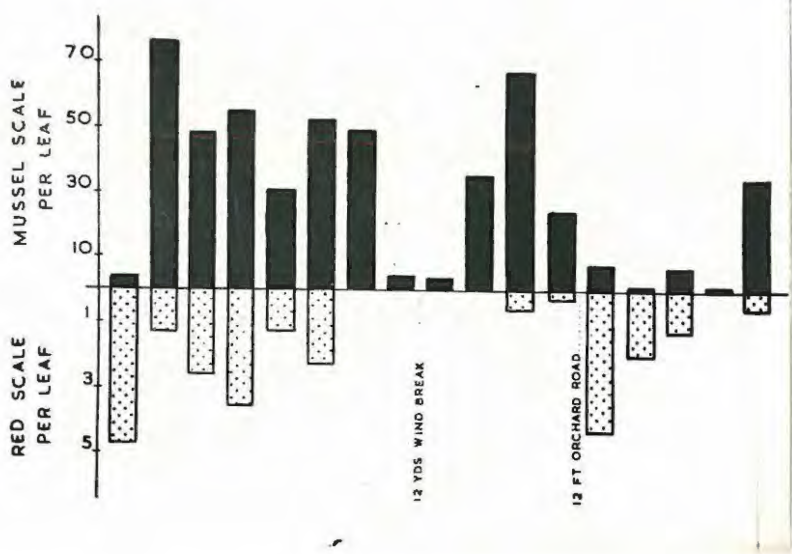

Figure 32

Relative numbers of mussel scale on orange trees in one orchard row.

in numbers of mussel scale and absence of red scale on either side of the wind-break. It is quite possible that, as in the case of the indigenous plants in the abandoned orchard discussed on page 42, the wind-break harboured predators and parasites which kept the numbers of scale on the adjoining trees in check. Also, the wind-break may have served to trap some of the scale crawlers which would have otherwise have been blown on to the adjacent trees. The graph shews a tendency for there to be fewer red scale in the centre of the orchard, but the numbers of red scale were so small that it would be rash to make any generalisation. Smithers, however, in 1953 found that there was a tendency for red scale to be abundant in the outer rows of orchards, and Whitehead in 1948 found the same thing. As far as mussel scale was concerned there was no marked decrease in numbers towards the centre of the orchard, except on either side of the wind-break.

In the case of both species of scale there was a tendency for the numbers to be greater on the left hand side of the graph which represents the north western end of the row. It was noticed in the course of numerous visits made to these orchards that the general direction of the wind was from the south east down the slope of the orchard. The large numbers of scale on the leeward side of the row may be a result of crawlers being blown there from the more south easterly

-side...

side of the orchard. The accumulation of crawlers would result in a large scale population.

Distribution of Mussel Scale on the Tree.

Mussel scale can be described as a "disease" of old trees, which tend to be attacked to a far greater extent than young trees. According to Bodenheimer (1951) trees are usually attacked in their ninth or tenth year. The reason for this is probably that the foliage of older trees provides a greater degree of protection for the young crawlers, whose establishment on younger trees would be prevented by sun, wind and natural enemies.

Mussel scale attacks all aerial parts of the tree, and it is doubtful whether any part of the plant is particularly preferred. Infestation is usually the heaviest on the twigs and branches, probably because they are the most persistent parts of the plant and scale accumulates on them. Comparisons made between numbers of mussel scale per square inch on upper and lower surfaces of leaves and on fruit from the same trees (Table 9) shewed that there was a slightly denser distribution of scale on the fruit. These comparisons however, were made from samples taken on the 12th July at a time when the fruit was at its ripest and infestation was very high (see Fig. 35). Fruit does not become heavily infested for some time, as it is surrounded by new leaf growth which the crawlers tend to avoid. Once the fruit becomes infested, its continuous growth in size will keep the numbers of scale per unit

-area...

area more-or-less constant; but when growth of the fruit becomes less and it begins to ripen, the numbers of scale perunit area will increase. The surface area of the leaf

TABLE 9.

		No. of Mussel Scale per sq. inch, (12/7/54)		
		LEAF		FRUIT
		Upper Surface	Lower Surface	
Tree A	N.	1.7	1.3	2.3
	S.	3.3	0.3	5.8
	E.	1.8	1.2	4.2
	W.	3.0	2.7	4.7
	C.	2.9	3.7	7.9
Tree C	N.	0.3	0.4	0.4
	S.	2.2	1.1	3.0
	E.	2.9	0.7	5.9
	W.	0.0	0.6	0.2
	C.	1.3	0.7	6.0
Tree E	N.	0.1	0.0	0.4
	S.	1.0	0.4	2.1
	E.	0.2	1.0	1.3
	W.	0.0	0.1	0.1
	C.	0.1	1.2	1.1

-enlarges...

enlarges more rapidly than that of the fruit, and this may be the reason for a larger number of scale per unit area on the fruit. Possibly, also, the shelter afforded by various parts of the fruit, e.g. beneath the calyx and in the "navel" may lead to the survival of greater numbers of female scale, and consequently to the production of greater numbers of offspring. From the monthly samples (to be discussed later) it was found that on the 6th April, 8th June, and 12th July 1954 the percentages of dead females on fruits were 17.0, 14.4, and 17.3 respectively, and on leaves were 27.5, 48.9, and 28.1 respectively. (These were the only months in which such comparisons could be made, because the fruit was harvested in August, and no leaf samples were taken in May).

It was clear that certain areas of the tree were attacked more heavily than others and it was decided to investigate this by taking both fruit and leaf samples.

On the 8th March 1954 samples of fruit and leaves were taken from six trees chosen at random in an orange orchard. The orchard chosen was the one represented by Section IV of Fig. 30, and was very heavily infested with mussel scale.

Method of Sampling.

Samples of fruit and leaves were taken from northern, southern, eastern, western and central regions of each tree. From each region six fruits and six leaf-bearing twigs

-were...

were taken, two of each from lower, middle and upper regions of the tree. These samples were later examined in the laboratory with the aid of a binocular microscope. One leaf was taken from each twig sample. Tables were then compiled of:-

Number of immature mussel scale, (alive and dead),

Number of adult female mussel scale, (alive and dead),

Number of adult male mussel scale, (alive and dead).

In the case of the leaves, the numbers of scale on the upper and lower surfaces were recorded separately. The counts were made with the aid of a manual counter. In the case of very heavily infested fruit, the fruit surface was divided up into sections with the aid of a ball-point pen to facilitate counting.

The original tables made from these counts were of necessity vast, and totals only are shewn in Tables 7 and 8.

From these tables it can beseen that there is definitely a tendency for some regions of the tree to be more heavily infested than others. The totals for each region of the tree sampled shew that in the case of the fruit (Table 7) the southern region had the most scale, and in the case of the leaves (Table 8) the central regions had the most scale. In both cases it is clear that the more shady southern, eastern and central regions of the tree supported the greatest numbers of mussel scale. Comparatively few

-scale...

scale were found on the northern side of the tree, which received all available sunlight.

TABLE 7.

Numbers of Scale per Six Fruits

		Larvae	Males	Females	Total
Tree 1	N.	302	26	42	370
	S.	1636	51	65	1752
	E.	651	10	23	694
	W.	154	6	18	178
	C.	691	65	41	797
Tree 2	N.	280	15	19	314
	S.	2236	133	180	2599
	E.	892	60	107	1059
	W.	262	22	18	302
	C.	1139	106	103	1348
Tree 3	N.	276	21	25	322
	S.	1234	99	67	1400
	E.	259	21	11	291
	W.	389	53	50	492
	C.	182	23	18	223
Tree 4	N.	244	10	11	265
	S.	1395	108	131	1634
	E.	401	18	48	467
	W.	553	58	32	643
	C.	527	42	40	609
Tree 5	N.	1226	113	150	1489
	S.	1228	184	101	1513
	E.	1237	151	133	1521
	W.	1023	265	165	1453
	C.	1728	328	224	2280
Tree 6	N.	876	107	60	1043
	S.	1312	128	112	1552
	E.	879	68	63	1010
	W.	724	130	104	958
	C.	1329	241	98	1568

TOTALS:-

N.	3803
S.	10490
E.	5042
W.	4026
C.	6825

-Fewer...

Fewer scale were found also on the western side which received the intense afternoon sunshine. The possible explanation of the variation in scale numbers on different parts of the tree was discussed in Chapter Three, (Page 37).

Distribution on Branches and Twigs.

Branches and twigs become very heavily infested with mussel scale, and where scale has been present for many years several layers may be found on top of one another. On the younger twigs the scales shew a tendency to congregate in crotches where two twigs divide or at the points of contact between two contiguous twigs or branches; but on older branches mussel scale becomes more-or-less evenly distributed.

Distribution on Leaves.

Counts made from monthly samples taken over the period April to November, 1954, shewed that there were always more scale on the upper surfaces of leaves than on the lower surfaces, (Fig. 33). In the figure the total numbers of scale from each monthly leaf sampling are shewn. Those on the upper surface are plotted above the horizontal axis, and those on the lower surface are plotted below it. The numbers on northern, southern, eastern,and western and central regions of the tree are plotted separately.

It is not clear why there should be more scale on the upper surface, but it seems as if the crawlers shew an actual preference. It will be seen in Fig. 33 that it was not until the numbers on the upper leaf surface had become very high

-TABLE 8.

TABLE 8.

Numbers of Scale per Six Leaves.

		Larvae			Males			Females			Total
		U.	L.	T.	U.	L.	T.	U.	L.	T.	
Tree 1	N.	80	17	97	19	9	28	14	0	14	139
	S.	395	92	487	141	59	200	85	19	104	791
	E.	86	24	110	54	24	78	16	6	22	210
	W.	54	11	65	22	13	35	8	5	13	113
	C.	170	149	319	229	115	344	30	7	37	700
Tree 2.	N.	55	4	59	21	5	26	7	1	8	93
	S.	316	109	425	226	88	314	59	23	82	821
	E.	100	18	118	70	28	98	16	13	29	245
	W.	22	8	30	16	17	33	2	1	3	66
	C.	192	42	234	136	32	168	31	4	35	437
Tree 3.	N.	35	23	58	9	8	17	11	2	13	88
	S.	44	42	86	13	10	23	14	5	19	128
	E.	47	10	57	10	9	19	5	7	12	88
	W.	173	19	192	91	14	105	18	2	20	317
	C.	90	44	134	51	39	90	14	11	25	249
Tree 4.	N.	44	4	48	3	1	4	1	1	2	54
	S.	256	66	322	52	41	93	17	20	37	452
	E.	13	5	18	5	1	6	4	1	5	29
	W.	123	47	170	36	16	52	6	7	13	235
	C.	137	92	229	103	20	123	43	17	60	412
Tree 5.	N.	94	36	130	85	45	130	40	23	63	323
	S.	141	171	312	219	96	315	153	65	218	845
	E.	225	36	261	120	93	213	118	66	184	658
	W.	123	39	162	69	17	86	56	23	79	327
	C.	331	215	546	604	367	971	234	162	396	1913
Tree 6.	N.	54	9	63	23	4	27	8	2	10	100
	S.	280	179	459	203	231	434	135	75	210	1103
	E.	257	39	296	58	32	90	40	20	60	446
	W.	69	32	101	71	59	130	18	26	44	275
	C.	346	100	464	442	179	621	165	62	227	1312

TOTALS:-

N.	797
S.	4140
E.	1676
W.	1333
C.	5023

U.= Upper Surface
L.= Lower Surface
T.= Total

-that...

that those on the lower surface began to increase (October and November). This may have been due to over crowding on the upper surface - the crawlers prefer to settle against the midrib or the curled over edges of leaves, or it may have been that the sunlight on the exposed upper leaf surfaces became more intense in the summer months. The lower surface of the leaf is rather less smooth than the shiny upper surface, and this may hinder the progress of crawlers. The upper surface faces the branch from which it arises and may be better protected than the lower surface, which during windy weather is probably brushed by other leaves and branches. Under hot or dry conditions the leaves may tend to fold along the midrib, and the more sheltered conditions of the upper surface may attract crawlers. It was noticed that honey dew secretions from various insects fall upon the upper surfaces of leaves, and dust and grit which adheres to this surface causes an uneven face which may attract crawlers.

If the crawlers were attracted to regions of bright light their predominence on the upper exposed surfaces could be easily explained, but as was discussed in Chapter Three the crawlers appear to be indifferent to conditions of light.

In one way Fig. 33 does suggest that light intensity may have something to do with distribution, because it

-shews...

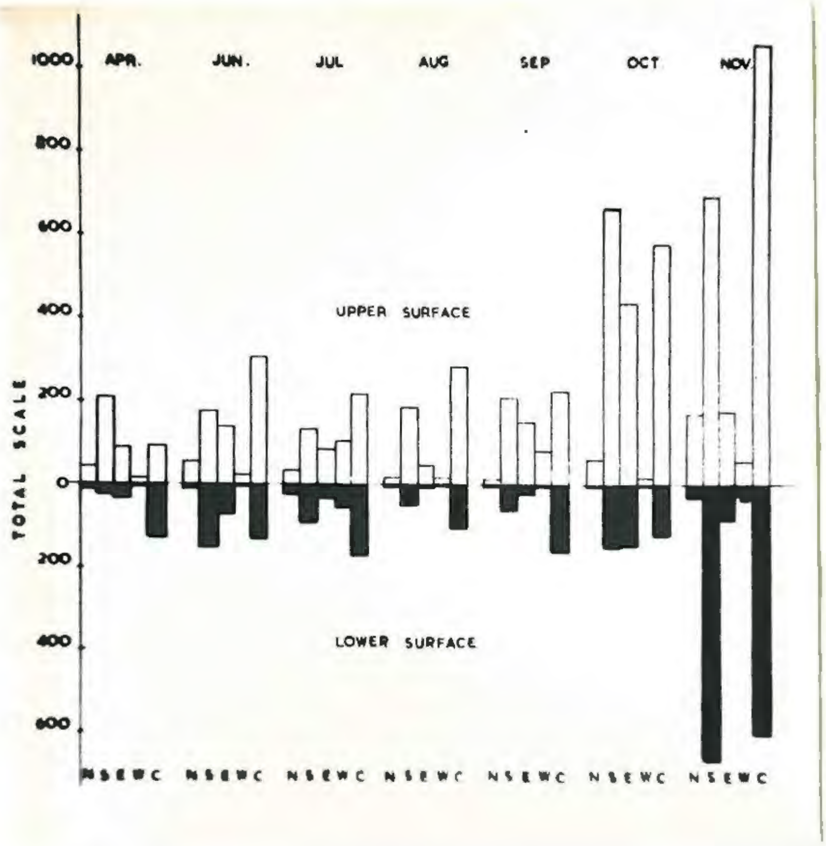

Figure 33

Relative numbers of mussel scale on upper and lower surfaces of orange leaves at different times of the year.

shews that the nearest approach to equality of numbers on either leaf surface usually occur on the more shady southern and central regions of the tree. The only occasion where more scale were recorded on the lower surface than on the upper surface occurred in April in the central region of the trees.

On either lamina of the leaf a preference was shewn for any uneven surface. Where only a few scale were present they were usually settled along the midrib and large veins or on the leaf edge at points where it was rough or where the leaf had become curled over. Once a crawler settles on a smooth part of the plant surface its presence will interrupt the smoothness of the surface, and more crawlers, including its own progeny, will settle around it. This is quite likely the reason why mussel scale is usually found in groups.

Distribution on the Fruit Surface.

Observation has shewn that in the field the parts of the fruit beneath the calyx are the first to become scale-infested. On one occasion in the Sundays River Valley an orchard which had been declared free of mussel scale was found on closer inspection to harbour the scale under the calyx of certain fruits. Counts made of scale on nineteen valencia oranges collected at random in an orchard in the Sundays River Valley, shewed that a large percentage

-of...

of the mussel scale present was established beneath the calyx, (Table 10).

TABLE 10

Total Scale		Scale Under Calyx		% Scale Under Calyx	
Adults	Larvae	Adults	Larvae	Adults	Larvae
46	51	34	29	70.8	56.8
10	24	6	10	60.0	41.6
33	49	22	24	66.6	48.1
18	28	7	21	38.8	75.0
36	26	28	21	77.7	80.7
69	83	43	55	62.3	66.2
24	38	17	22	70.8	57.9
6	28	4	24	66.6	85.7
24	27	14	21	58.3	77.7
52	78	34	50	65.3	66.9
26	24	21	15	80.7	62.5
46	59	34	42	73.9	70.6
55	77	45	52	81.8	67.5
28	33	18	24	64.3	72.7
40	22	31	20	77.5	90.9
29	61	20	48	68.9	78.6
33	47	22	32	66.6	68.0
32	33	29	25	90.6	75.7
27	55	24	54	88.8	98.0

Relatively large numbers of scale are frequently found in the "navel" of fruits, and at points on the surfaces of two contiguous fruits; and mussel scale tended to collect also in places where abrasions received during windy conditions had caused pits and scars in the fruit surface.

In general, on all parts of the plant mussel scale tend to settle on uneven parts of the surface or in protected positions. During the monthly scale counts

-made...

made in connection with seasonable distribution, it was frequently found that crawlers had settled beneath vacated male scale coverings, or beneath the scale armour of dead females. Frequently more than one crawler had settled in such positions. Scale settled in such protected positions are far less liable to attack by predators and parasites, which probably play an important part in preventing their becoming established on the more exposed surfaces.

Seasonal Fluctuations of Mussel Scale Numbers.

In order to study the variations in mussel scale numbers at different times of the year, monthly samples were taken from six navel orange trees. These trees could not be selected from a very large area as spraying of heavily scale-infested trees was in progress throughout the orchard; but in the lower part of one orchard six trees were chosen and it was arranged that they should not be sprayed, (Fig. 34). The orchard chosen contained twenty-year-old navel orange trees, and was situated on sloping ground and surrounded by wind-breaks.

Method of Sampling.

The method of sampling was similar to that described on page 48 but was somewhat modified, so that subsequent laboratory examination should not take too long. Only three fruits and twigs were taken from each of the five regions examined. These were taken from upper, middle

-and...

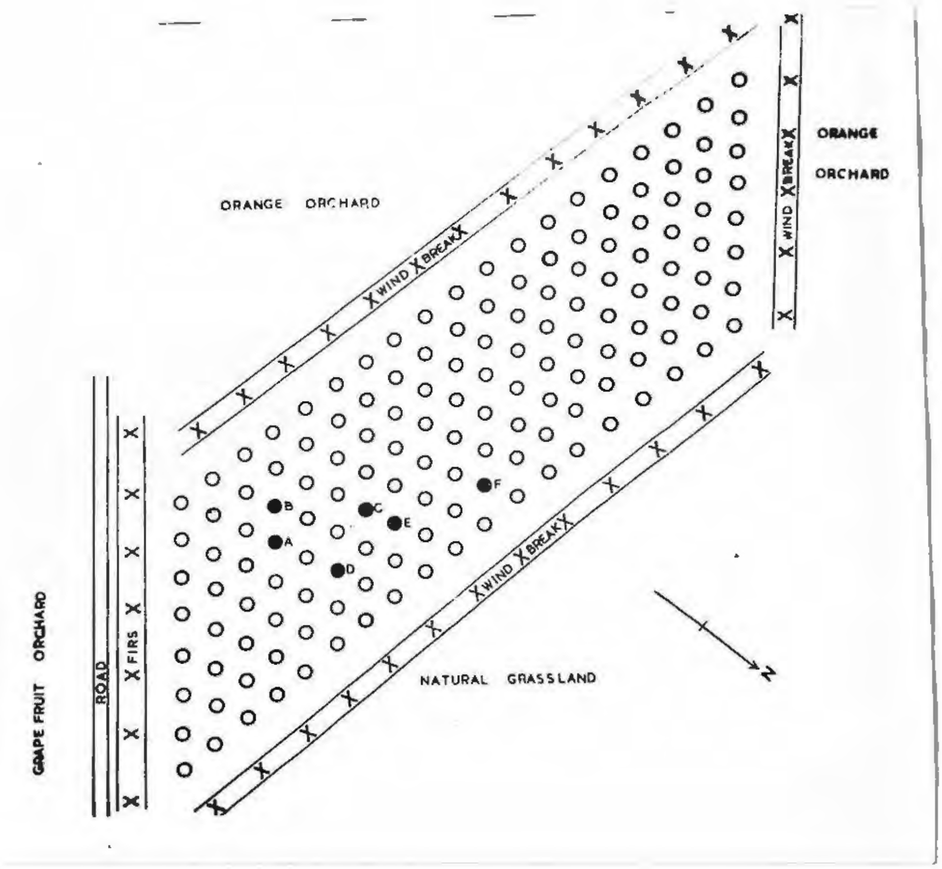

Figure 34

Plan of orchard from which monthly mussel scale counts were made.

and lower levels of each tree once a month from April to November. No leaves were examined in May, and no fruits were taken after July as they had been harvested. These samples were subsequently examined under a binocular microscope in the laboratory, and the following items recorded:

For the Fruit

Total numbers of larvae (i.e. immature forms),
Total numbers of males,
Total numbers of females,
Numbers of dead males,
Numbers of dead females,
Average number of eggs per female,
Diameter of fruit (after April).

In the case of the average number of eggs, they were not counted for every female examined, but various females were selected in the course of the examining, and average numbers of eggs determined. Under "Larvae" were included males up to the third moult (propupa, about fifty days after settling), and females up to about seventy days after settling (about fifteen days after the second moult - Figs. 2 and 3). Both living and dead forms were included together. After all males and females had been counted, each one was inverted with the aid of a scalpel and the numbers of dead ones were recorded. Among "dead" males were included the vacated

-scale...

scale coverings, which means that in many cases, although the life of the adult male is not long (see page 22), they did emerge and quite possibly fertilised females before they died.

For the Leaves

The same items were recorded as in the case of the fruit, but the numbers for upper and lower surfaces of each leaf were recorded separately.

A summary of the results of each sampling was given in Tables X to XX of the Appendix. The detailed results were very extensive, and are therefore not given in full. Each total given in the Table is the total of the numbers of scale on three leaves and fruits examined.

Various points arise from these results and graphs have been drawn to illustrate them. These graphs will be discussed separately.

Fig. 35 summarises graphically the results obtained from the fruit samples. Above the horizontal 0-axis are plotted total numbers of immature forms, adult males, and adult females for each month. These are plotted relatively, and both living and dead mussel scale were included. Below the horizontal axis are plotted the relative numbers of dead males and females for each month.

It will be seen that the greatest number of scale recorded was in June, after which the numbers of both

-living...

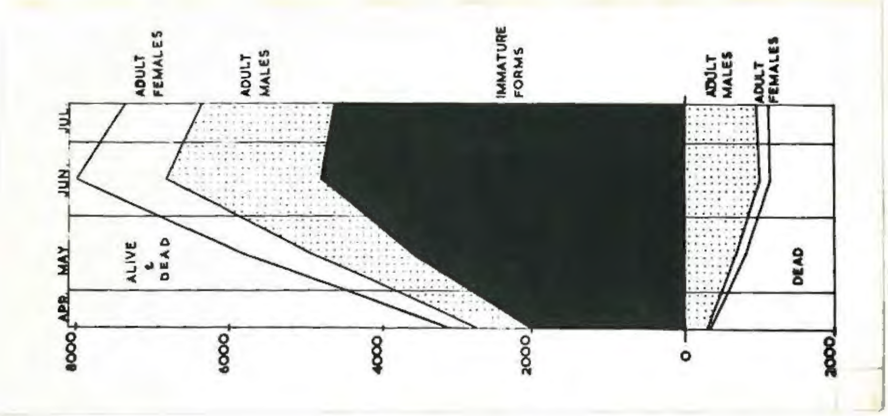

Figure 35

Mussel scale fluctuations on fruit, April to July.

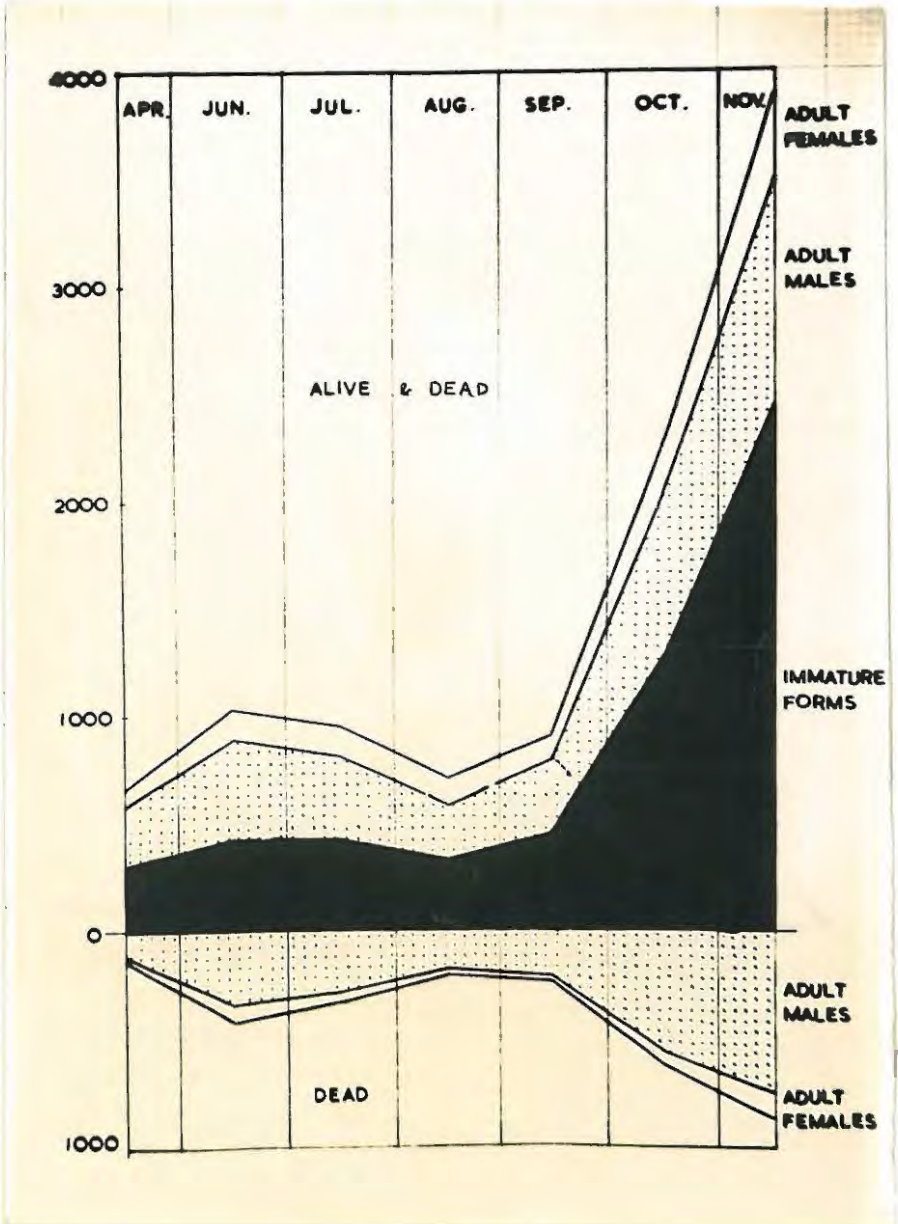

Figure 36

Mussel scale fluctuations on leaves, April to November.

living and dead scale decreased, although there were relatively fewer dead scales in July than in June. The greater percentage of dead scale in July was probably the result of the very cold weather which occurred towards the end of June and in early July (Table 11). A less striking

TABLE 11

Mean Monthly Temperatures - Grahamstown

	1954 degrees Centigrade	Normal (17 years) degrees Centigrade
January	19.9	20.2
February	20.7	20.6
March	19.5	19.7
April	16.9	17.1
May	15.0	14.7
June	11.9	12.4
July	10.5	11.6
August	13.9	12.9
September	14.9	14.6
October	15.1	16.1
November	17.0	17.4
December	18.8	19.2
Average	16.2	16.4

increase in percentage of dead scale occurred at the same time in the case of the leaf samples (Fig. 36). Fig. 35 shews also that the rate of increase in scale numbers

-dropped...

dropped slightly after May. Unfortunately the fruit was harvested early in August, and no more samples could be taken.

Fig. 36 shews the results of the leaf samples presented in the same manner as the fruit samples. The numbers include scale on both upper and lower surfaces of the leaf. It can be seen that the numbers increased from April to June, after which they decreased until August, at which time the weather was still cold. Thereafter the numbers incfeased until the final sample was taken in November. Towards the end of winter, from August to September, the increase was rather small, but after September the increase in numbers of all forms was rapid and constant. The percentage of dead males was lowest actually in September (60%), but increased in October and November, (74.4% and 73.1% respectively). This was probably because under "dead" males were included vacated scale coverings, and with the warm weather there were greater numbers of active winged males, (see also Figs.21, 20 and 23).

Fig. 36 gives the impression that male numbers are always higher than female numbers; but when living males and females are plotted together (Fig. 37), it can be seen that this is not always so, and that there were more living females than males in the winter months of July and August. The life of the male is shorter than that of the female

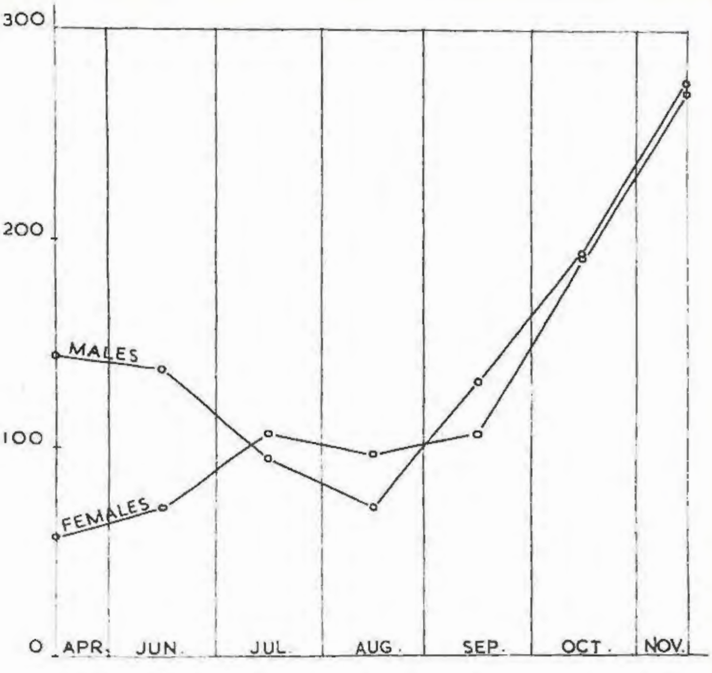

Figure 37
Relative numbers of adult living male and female mussel scale.

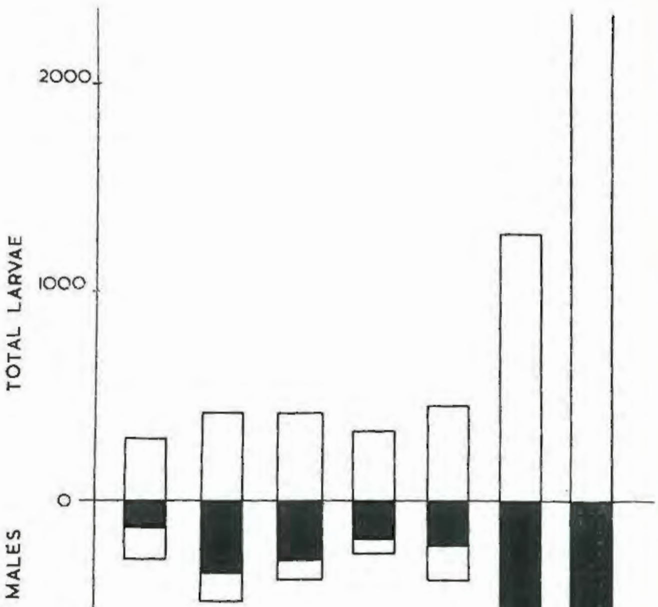

Figure 38
Relative numbers of adult male and immature mussel scale.

(see Fig. 2), and the vacated scale covering of the adult male persists for some time after the winged male has emerged. Fig. 37 shews a decrease in numbers of living males from April to August. At the same time Table 12 shews

TABLE 12

Month	Total Males	Dead Males	% Males Dead
April	264	120	45.44
June	488	349	71.52
July	377	282	76.54
August	252	180	71.44
September	338	205	60.66
October	761	566	74.37
November	1024	748	73.05

an increase in percentage of dead males (vacated scale coverings) from April to July, indicating that more males had emerged. Then from August onwards there was an increase in the numbers of living males. From July to September there was a decrease in the percentage of dead males (vacated scale coverings), suggesting that fewer were emerging, until after September when the numbers of males emerging again increased. During July, August and September the numbers of living females were more-or-less constant and there was no sudden increase in numbers until October. The numbers of living males and females conformed very closely towards the end of the year.

Fig. 38 shews a comparison between males and immature

-forms...

forms at different times of the year. The immature forms are plotted above the horizontal axis and the males are plotted below. The shading shews the numbers of dead males. It can be seen that the sudden increase in percentage of dead males, or vacated scale coverings, which occurred from September to October was followed in October and November by a very marked increase in the number of immature forms. A similar, although less striking state of affairs occurred between April and July. The increase in numbers of active males would result in the fertilisation of more females and the production of greater numbers of eggs and crawlers.

The seasonal fluctuations in numbers of mussel scale in the orchard and on the various parts of the trees are summarised in Fig. 39. Above the horizontal axis are shewn totals of males and females only. Each column represents the total number of males and females, and the proportion dead are represented by the shaded areas. Below the axis are shewn total numbers of scale for each month. The general pattern of this graph is similar to that of Fig.36. It will be noted that in this graph, as in Fig. 33, the greater extremes of distribution between shady and illuminated regions of the tree generally occurred in the hotter months (see page 38).

<u>Sex Ratios of Mussel Scale</u>.

Sex ratios from breedings were not obtained,

-but...

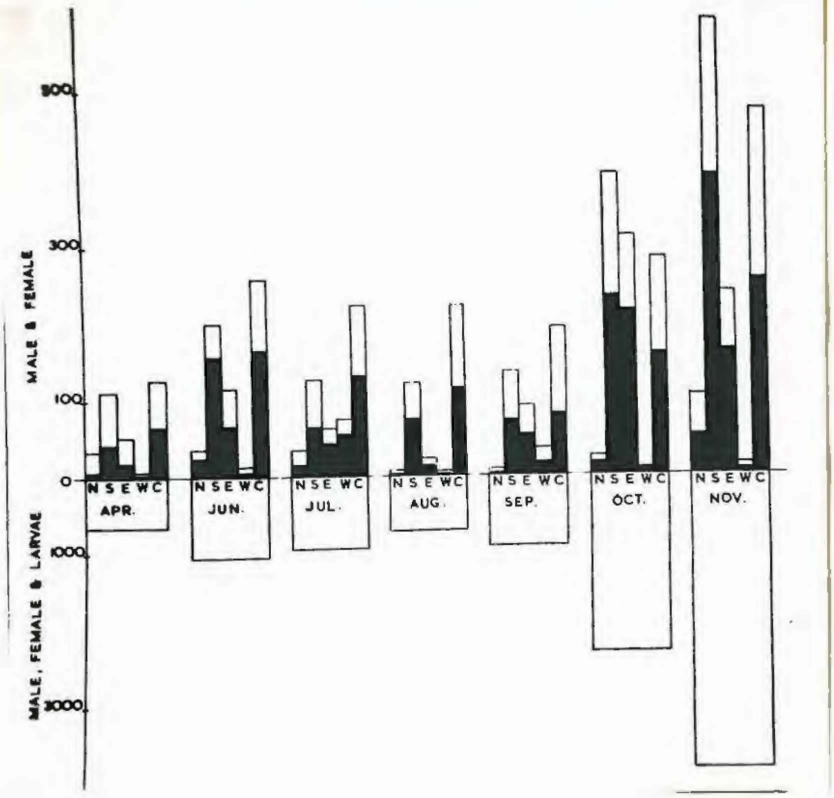

Figure 39
Summary of mussel scale fluctuations.

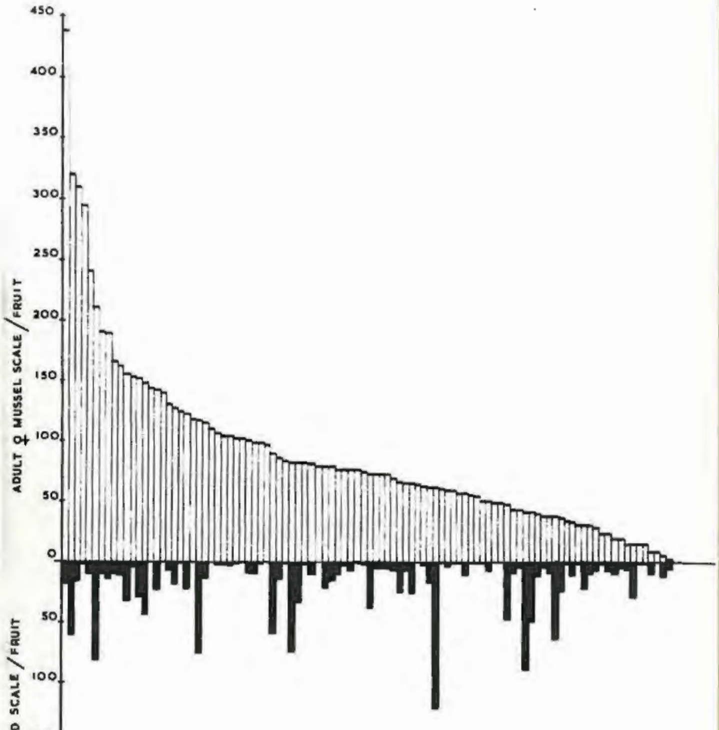

Figure 40
Relative numbers of red scale and mussel scale on 100 grapefruits.

but were determined from the monthly samples, and it was found that they varied with the time of the year (Table 13).

TABLE 13

Month	Alive Males	Alive Females	% Male	% Female
April	144	58	71.4	28.6
June	139	73	60.8	39.2
July	95	107	42.0	58.0
August	72	97	42.6	57.4
September	133	107	55.4	44.6
October	195	193	50.2	49.8
November	276	270	50.5	49.5

These figures do not indicate what percentage of the progeny is male or female, because the life cycles of the sexes differ.

Stofberg (1937) found that unfertilised females did not oviposit, but continued to extend their scale coverings. The same phenomenon was observed in the course of this work, (see page 15).

Factors causing the Distribution of Mussel Scale.

The spread of mussel scale infestation is caused by the active crawlers being transferred from one plant to another. This can be brought about in several ways, but over small areas the most important agent is wind. The crawlers are very light and can easily be blown from one part of an orchard to another. They are probably transported also by birds on to which they crawl while they roost in the trees, and by various insects such as coccinellid beetles, honey-dew insects, and insects visiting the flowers.

-The...

The optimum conditions for producing activity among the crawlers will cause activity also among other insects, and this will increase their chances of being transported from tree to tree. Some crawlers may be transported also on implements and fruit boxes which are taken from one orchard to another.

It was found that mussel scales lived for very long periods on picked or fallen fruit, and in this manner they could easily be transported over long distances.

The chances of crawlers migrating across the ground from one tree to another are practically nil. Crawlers appear to be slightly adhesive and their progress even over fine clean sand is extremely slow. Over the type of ground surface found between orchard trees progress would be almost impossible.

Relationship between Mussel Scale and other Species of Scale.

In the orchards investigated, soft scale (*Coccus hesperidum* Linn.) and red scale (*Aonidiella aurantii* Mask.) coexisted with mussel scale. The possible relationship between soft scale and the other two species of scale is discussed later under the section on ants, Chapter Seven.

In order to investigate any possible relationship between mussel scale and red scale one hundred grapefruit were taken at random from an orchard (Sections I and II of Fig. 30) and the total numbers of adult female red scale

-and...

and adult female mussel scale on each fruit were recorded. The numbers of mussel scale were then arranged in order and plotted against the corresponding numbers of red scale, (Fig.40) The figure establishes no relationship between the two species, and they coexist in various ratios. In only four cases however, were there more red scale than mussel scale, and it can be seen that at the time of sampling mussel scale was the more common. Unfortunately records for each scale in these orchards in previous years do not exist.

Figs. 30 and 32, which involve both mussel scale and red scale do, however, suggest that there might be a relationship between the scale. In both these figures the numbers of the two insects were plotted to a different numerical scale, and it can be seen that generally speaking, where the number of one scale is unusually large, the corresponding number of the other scale is unusually small. Although the numbers of these two insects could not be expected to conform closely each time, the marked differences which repeatedly occur do seem significant. It is difficult to suggest a likely cause of this. Predators are not usually specific to one particular species of scale, although it has been observed that general predators tend to prefer the less tough red scale to mussel scale. Parasites are more specific, but so few mussel scale parasites were in evidence, that they could have had only slight effect on scale numbers. All trees from which

-these...

these samples were taken were approximately the same age, but it is possible that differences in microclimate could have existed in the different trees and would have had various effects on the scale. A tree with sparse foliage would probably harbour relatively more red scale and fewer mussel scale than would a tree with dense foliage. Also, trees on the edges of orchards might have contained relatively larger numbers of red scale than mussel scale (see page 45).

CHAPTER FIVE

Parasites of Mussel Scale.

Very few parasites of mussel scale have been recorded, and Bodenheimer (1951) states that in the course of his work in Palestine he never encountered any hymenopterous parasites of mussel scale. He goes on to state that this is apparently the case throughout the Mediterranean region. (One, however, has been reported from Spain).

Aspidiotiphagus citrinus (Crawford) is a cosmopolitan parasite of the family Aphelinidae, and attacks mussel scale, although it is reported as being more commonly associated with yellow scale, *Aonidiella citrina* (Coq.). Besides these two scales it has many other hosts and is recorded from over twenty five species of scale insects in the Unites States alone. Quayle (1912) and Ebeling (1949) both record *A. citrinus* from California. In South Africa, Stofberg (1937) records it from the Transvaal. It is a minute yellowish black parasite measuring about 0.5 mm. in length (including the antennae).

Aspidiotiphagus lounsburyi (Berlese and Paoli) (Fig.41). Determined by Dr. E. McC. Callan, 1954.

This was the only mussel scale parasite encountered in the course of this work. It is a minute parasite which closely resembles *A. citrinus*, but has several distinguishing features. It measures about 0.5 mm. in length (including

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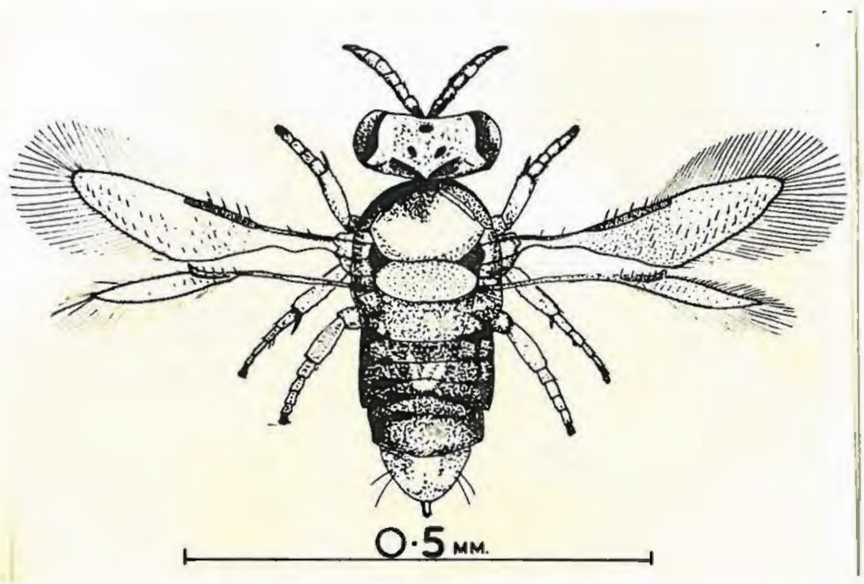


Figure 41

Aspidiotiphagus lounsburyi (Berlese and Paoli).

the antennae). The general colour is yellowish black, the head dull yellow, ocelli red, and compound eyes black. The thorax is dark yellow with darker areas above the bases of the wings. The abdomen is black becoming lighter at the tip. A fringe of bristles surrounds the margins of both front and hind wings. A short ovipositor is present in the female.

It is a widely distributed species originally described from Madeira, but it is known also from Argentina, Brazil, Puerto Rico, Florida, Trinidad, Spain and Nyasaland.

The egg of A. lounsburyi is oval and is deposited within the body of mussel scales during their second instar. At this stage the scale has shed its first exuviae and approaches very nearly the time when it should shed its second exuviae, (Fig. 9 and 10). It is strictly an internal parasite. The egg is deposited within the insect and from it hatches a very minute, white larva, with a tail-like appendage. The larva feeds upon the scale. The mature larva is about 0.9 mm. long and it pupates within the scale. The pupa is light in colour at first but becomes very dark prior to the emergence of the adult. On emerging the adult makes a circular exit hole in the dorsal armour of the scale. The emergence of parasites seems to be brought about by sudden rises in temperature, (see Fig. 22).

The following observations were made on the behaviour of an adult female parasite. On examining the

-surface...

surface of a scale-infested orange, a female _Aspidiotiphagus lounsburyi_ was seen shewing an interest in an immature female mussel scale, and before long oviposition began (9.55 a.m.). The parasite took up a position with its posterior end directed against the posterior end of the mussel scale and performed a series of jerking movements as if trying to penetrate the scale armour. During this process the wings were held folded over the abdomen and the antennae were directed vertically downwards. This operation lasted until 10.07 a.m., when the ovipositor was withdrawn and a cleaning process begun. The ovipositor was first cleaned, then the wings, legs and antennae. This cleaning process continued for five minutes, after which the parasite continued to wander over the surface of the fruit. On encountering another suitable scale, the parasite inspected it very carefully with its antennae and oviposited again from 10.14 a.m. until 10.19 a.m. A similar cleaning process followed, and, after careful inspection of another scale, oviposition again occurred. This lasted from 10.20 a.m. until 10.32 a.m., and was again followed by a process of cleaning.

There followed the inspection of five other scales, all of which, after careful inspection were abandoned. The antennae were cleaned from time to time between these inspections. The parasite oviposited again from 10.39 a.m.

-until...

until 10.46 a.m., and from 11.24 a.m. until 11.35 a.m., inspecting and abandoning the various other scales in its vicinity between these operations.

In order to distinguish the parasitised scales, the adjacent fruit surface was marked with the aid of a mapping pen and indian ink.

Examination of the scales which had been inspected and abandoned by the parasite, shewed that one contained an adult male scale about to emerge, another a dried up immature scale, a third was anempty male puparium, and a fourth had become detached from the fruit and the contents removed - probably by a predator.

The above observations were made on the 13th April 1954. On the morning of the 13th May an adult parasite emerged through a hole made in the dorsal scale armour. Dissection of two other parasitised scales shewed that each contained one mature parasite pupa. This pupa filled the scale and was ensheathed in the scale's cuticle.

The distribution of this parasite in the orchards examined was rather peculiar. The greatest number were obtained from material taken from an orange orchard heavily infested with mussel scale. None however, were observed in material taken from a very heavily infested grapefruit orchard separated from the orange orchard by fifty six yards of ploughed earth. Records were kept of the fauna

-emerging...

emerging from boxes containing material from each of these orchards. From the period October 10th to November 9th 1954, twenty *Aspidiotiphagus lounsburyi* adults emerged from the oragge orchard material, but none emerged from the grapefruit material. Over the same period eleven specimens of *Aphytis chrysomphali* Mercet., a parasite of red scale, emerged from a box containing material from the adjacent grapefruit orchard, and only one from the orange material, (Fig. 22 and 23). Both mussel scale and red scale were present in both orchards. In the course of previous ecological work it was found that certain predacious insects appear to be attracted to plants by the scent of their flowers rather than by the insects present, and it is possible that these parasites are similarly attracted more strongly to one species of citrus than to another.

In all the material examined during the counts made in connection with the monthly distribution of mussel scale in the orange orchard adjacent to the one mentioned above, only four scales contained parasite emergence holes. Therefore, even in the orchard where the parasite is most common, the percentage parasitism must be very low, and the part played by the parasite in the biological control of mussel scale must be almost negligible. Although thirty to forty percent parasitism by *Aspidiotiphagus citrinus* is reported from California, nothing like this

-state...

state of affairs exists in the local orchards investigated.

CHAPTER SIX

Predators of Mussel Scale.

The predacious habits of most insects observed in the orchards permitted them to be divided into three groups.

1. General Predators.

In this group can be included various neuropterous larvae, e.g. *Chrysopa* sp., some coccinellid beetles e.g. *Exochomus flavipes* Thunb., *Chilocorus* spp., and various other insects which feed more or less indiscriminately on other soft bodied insects.

2. Predators of Aphids.

Included in this group are those insects which are more or less specifically predacious on species of Aphididae. They include larvae of the dipterous family Syrphidae, and such coccinellid beetles as *Chilomenes propinqua* Muls. and *Liodalia flavomaculata* de Greer.

3. Scale Predators.

In this group are included most of the predacious insects which were studied in the field and in the laboratory. Some of these fed on several different species of scale e.g. *Lotis* spp., and others seemed to be specific to one particular citrus scale e.g. the unidentified coleopterous larva shewn in Fig. 60. This larva was seen to feed only on mussel scale.

Observations of scale predators were made both in

-the...

the field and in the laboratory. Larvae and adults of the family Coccinellidae were collected by shaking the foliage of scale-infested trees over plastic ground sheets. The beetles falling onto the sheets were then taken to the laboratory and their habits studied. Predacious insects were collected also during the laboratory inspection of heavily scale-infested citrus material from the orchards. It was found that several predators fed readily on mussel scale, and could be reared on a diet of that alone, but others died unless they were fed on some other soft bodied insect such as aphids or soft scale. Some beetles, e.g. *Exochomus flavipes* and *Chilocorus* spp. would feed on mussel scale only as a last resort, and many predators which normally fed on some other insect e.g. aphids or soft scale, or even red scale, experienced great difficulty in gaining access to the adult mussel scale insect concealed beneath its scale armour. Several predators, e.g. *Exochomus flavipes*, which are not mormally predacious on mussel scale, feed readily on the insect if it is inverted or removed from its scale armour. *Chilocorus solitus* was observed inverting a mussel scale and devouring the contents, but *E. flavipes* seemed disinclined to do this, and was only once observed inverting and eating a mussel scale. Of those insects which habitually eat mussel scale, some e.g. *Lotis neglecta* Muls. bite through the dorsal armour and devour

-the...

the contents, and others e.g. Species 5, lever up the scale covering and feed on the contents from the ventral side.

Method of Studying Mussel Scale Predators in the Laboratory.

Whitehead (1948) found that the best way to breed and study species of Coccinellidae was by keeping them in cages made by placing a celluloid cylinder over a scale-infested fruit and covering the upper end with organdie (Fig. 42). The cylinders were secured by means of a high-melting-point wax. The fruit rested on a bottle with its stem in water, and an artificially-heated insectory was used.

It was found in the course of this work however, that without the aid of an insectory in which the temperature and humidity could be controlled, the fruit tended to contract a way from the celluloid cylinder and the insects escaped. In addition, this method was found inconvenient for observing the habits of the beetles under a microscope.

It was found that if the organdie-covered celluloid cylinders were placed in Petri dishes, observations could be made more easily. In the Petri dish beneath the cylinder was placed a piece of white blotting paper, and on this was placed a section of scale-infested twig. The blotting paper was kept moist with a 4% solution of sodium borate which served the dual purpose of discouraging the growth of fungous moulds, and preventing the culture from becoming too dry. The celluliod cylinders were made so

-that...

Figure 42

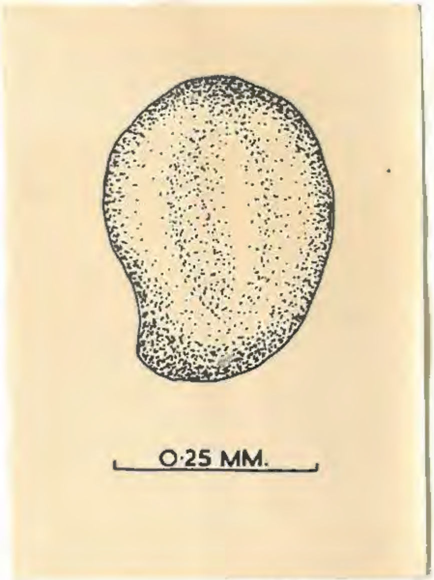


Figure 43
Lotis neglecta Muls.
Egg.

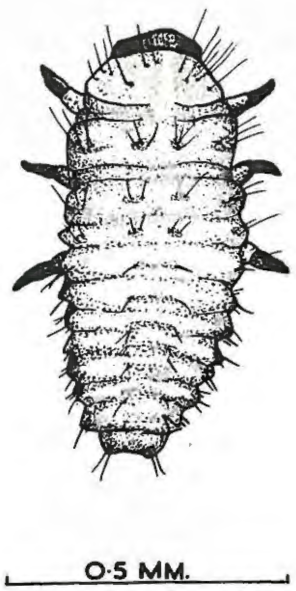


Figure 44
L. neglecta first instar larva.

Figure 45
L. neglecta second instar larva.

that they fitted exactly into the Petri dishes and no beetles could escape. With the aid of a pipette a few drops of water were occasionally added to the culture. At first, slices of fruit were used in the cultures, but they became mouldy very quickly, and twigs were found more satisfactory. This method of studying beetles was particularly convenient as it did not allow "steaming up", a thing which frequently happens if glass covers are placed over Petri dishes containing living material. Every few days the sections of twig were examined and replaced.

Discussion of Mussel Scale Predators.

In the following discussion all insects observed feeding on mussel scale are mentioned, and where possible their habits are discussed.

Coleoptera.

Determined by Dr. A.J. Hesse and Dr. Andreae.

Fam. Coccinellidae.

The most important mussel scale predators are included in this family. No detailed life history studies were made, but several species were reared from egg to adult on a diet of mussel scale alone, and notes were made of their behaviour.

Lotis neglecta Muls.

The adult of this beetle is about 2.4 mm. in length and the width is about 2.2 mm., but the dimensions of

-specimens...

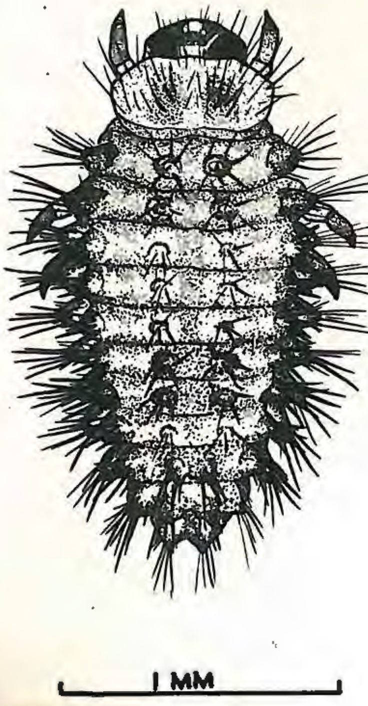


Figure 46
L. neglecta third instar
larva.

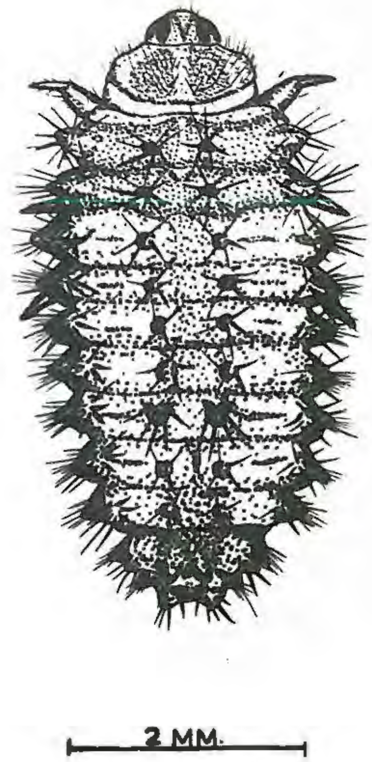


Figure 47
L. neglecta fourth instar
larva.

specimens varied. The adult is strongly convex and shiny black in colour with two bright red circular markings on each elytron (Fig. 49). The thorax is marginate. Punctuation on the dorsal surface is fine, becoming stronger towards the margins of the elytra. The scutellum is clear. The ventral surface, legs and head are dark brown.

The general colour of the larva is grey, and it is covered with fine bristles (Figs. 44 to 47).
The egg (Fig. 43) is pearly white in colour and is oval, and its length is about 0.5 mm. Oviposition was not observed in the laboratory, but eggs were frequently found among patches of mussel scale and were often inserted beneath empty scale covering.

The first instar larva (Fig. 44) is light grey in colour except for the head and the extremeties of the legs which are dark grey to black. The body is covered with small bristles, but groups of stouter bristles and spines are found along the lateral margins of the body, and in pairs along the dorsal surface. These bristles are stouter and more plentiful on the thoracic segments. The average length of first instar larvae is about 0.8 mm. It was found that prior to moulting, the first instar larva underwent a period of about forty eight hours immobility, after which the first exuviae was cast and the second instar larva emerged - ten days after hatching.

The second instar larva (Fig. 45) closely resembles the first, but is generally darker in colour and has stouter bristles. The average length was approximately 2 mm. The duration of this instar was six days.

The third instar larva (Fig. 46) is not very much larger than the second, but its segmentation is far more strongly pronounced, and its colour is less evenly distributed. The second and third thoracic segments and the fourth, fifth, and terminal segments of the abdomen are darker in colour than the other segments and carry stouter spines. The duration of this instar was five days.

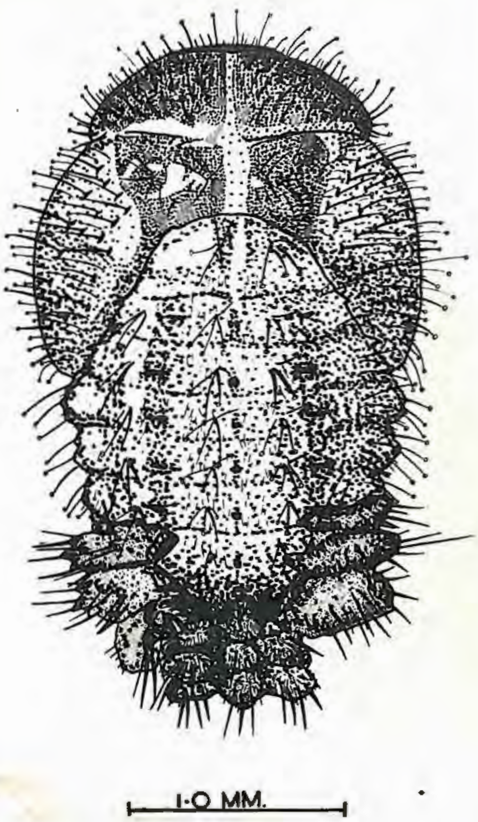
The final instar larva (Fig. 47) rather resembles the previous instar, but the insect grows considerably, and its length prior to pupation is 4 to 5 mm. The duration of this instar was about ten days, and a period of about thirty six hours immobility preceded pupation. The cuticle of the last instar larva split along the mid dorsal line, and by a series of contractions and expansions the exuviae was forced posteriorly and served finally to secure the pupa to the substrate.

The pupa (Fig. 48) is 3 to 4 mm. long and is covered with bristles. At the ends of the larger bristles there is a drop of liquid which probably serves a protective function. In colour it is light grey with grey-brown markings towards the anterior end. The pupal stage lasted from eight to ten

-days...

Figure 48.

L. neglecta pupa.



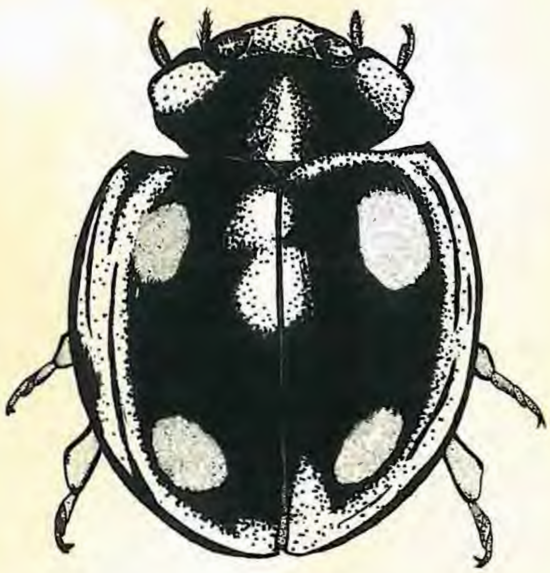


Figure 49

Lotis neglecta Muls.

adult.

days, and the adult emerged through asplit in the mid-dorsal line.

The head and thorax of the newly emerged adult are dark, but the elytra are creamy pink and transparent. The adult remained immobile for about twelve hours while the elytra darkened and hardened.

Both larvae and adults of Lotis neglecta were observed feeding on mussel scale in the field and in the laboratory. Both larvae and adults made a hole in the dorsal armour through which they fed on the insect within. A larva which was given a naked adult female scale fed on it by puncturing the cuticle and sucking out the body contents. When the scale was quite deflated it was suddenly inflated by the larva and then rapidly deflated again. It looked almost as if a process of external digestion was in progress. A third instar larva which was observed took exactly thirty minutes to consume the body contents of a naked adult female scale; the empty cuticle was finally discarded. It took young larvae a very long time to penetrate the dorsal scale armour of mussel scale, and even mature larvae apparently experienced difficulty. Under natural conditions, the young larvae probably feed largely on crawlers and young newly-settled scale. The larvae of this beetle were not repelled by the "fuzz" of young scales.

-Adults....

Adults fed in a similar manner to the larvae, a hole being made in the dorsal armour of the scale and the body contents removed. The adults however, consumed the whole insect, and frequently ate the dorsal armour; the process took about thirty minutes. When adults in the laboratory were given soft scale they fed on it but no more readily than on mussel scale. They would not eat aphids, but readily ate red scale in the same way as mussel scale. Whitehead (1948) reared Lotis neglecta on a diet of red scale alone.

This insect became very common in the orchards in September, and occurred in large numbers until field work ceased in December, 1954. It is common in the Albany and Bathurst districts, and is recorded from the Western Province, the Transvaal and Southern Rhodesia. It was one of the most active mussel scale predators encountered in the course of this work, but was not confined to citrus orchards and was observed in the Peddie district associated with the pineapple scale, Diaspis bromeliae.

Lotis sp.

The adult of this beetle (Fig. 53) rather resembles L. neglecta but is smaller, measuring about 1.8 mm. in length and 1.5 mm. in width. The adult is convex and is shiny black in colour. Two circular red markings of varying intensity are present on each elytron. These

-markings...

Figure 50

Lotis sp.

egg.

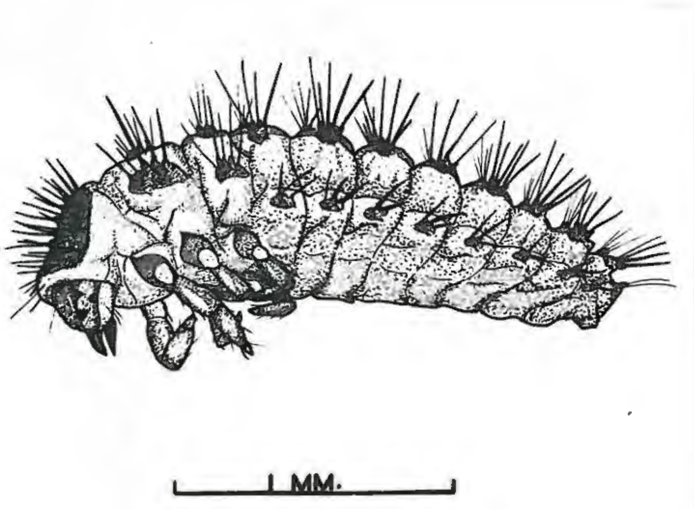


Figure 51

Lotis sp.

larva.

markings may be prominent, scarcely distinguishable or apparently absent. Punctuation is extremely fine which accounts for its shiny appearance. The thorax is distinctly marginate. The ventral aspect is dark brown, and the appendages black.

The egg is pale white and elliptical, but it becomes darker before hatching. Fig. 50 shews an egg just prior to hatching in which various features of the future larva may be seen.

The larvae (Fig. 51) are pale immediately after eclosion, but become darker after a few hours. They bear stout black bristles, and in their later instars vary in colour from a shiny dark grey to a sort of purple. Each larval instar lasted from four to six days, and pupal stages (Fig. 52) lasted from seven to eleven days.

Both larvae and adults were active predators of mussel scale. Larvae were seen eating only young scales, but the adults ate all forms. Adults which were observed amongst a group of mussel scale in the field were trying to lever up adult female scales from the posterior end by edging their mouth parts and heads beneath the scales' posterior margins. In the laboratory Lotis sp. adults were observed inverting scales by standing on the armour and forcing their heads beneath the scale margin. Others were seen removing eggs and crawlers from beneath the

-posterior...

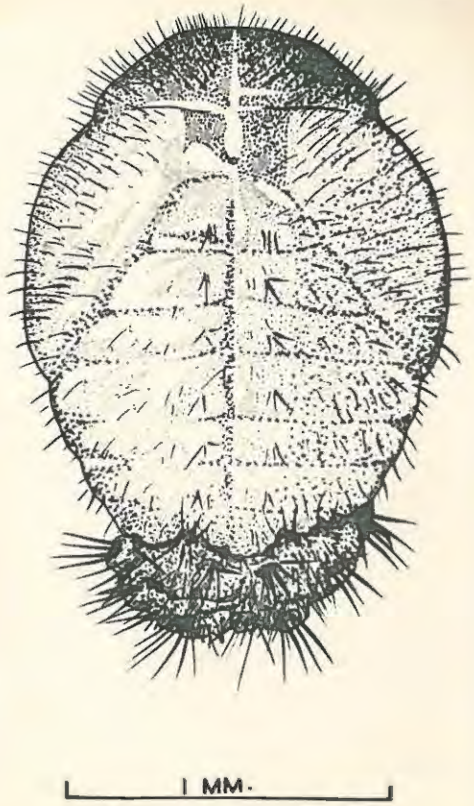


Figure 52

Lotis sp. pupa.

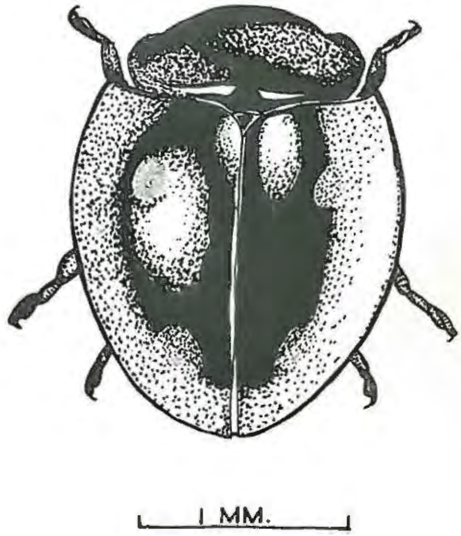


Figure 53

Lotis sp. .

adult.

posterior end of female scales and devouring them, and one was seen biting through the scale armour.

Copulation was observed, but eggs were not obtained in the laboratory. On more than one occasion copulation was followed by a peculiar procedure in which the male moved forwards over the elytra of the female and attacked her head from above. This violence was continued for some time, but it apparently did the female no harm.

Lotis sp. became common in the orchards at about the same time as L. neglecta, and must destroy large numbers of mussel scale. The beetle fed equally readily on red scale but would not eat aphids.

It is reported as being associated also with a scale infesting the kaffirboom (Erythrina caffra), and with the white peach scale, (Diaspis pentagona Targ.).

Scymnus sp.

The adult beetle (Fig. 57) is about 1.6 mm. long and about 1.3 mm. wide. It is shiny black in colour and is covered by a grey pubescence. Two spots are present on each elytron. The ventral surface and appendages are black.

The egg is pale white in colour. They were usually found inserted beneath empty scale coverings (Fig. 54). The incubation period was at least six days.

The larvae (Fig. 55) have a flocculant waxy covering

-which...

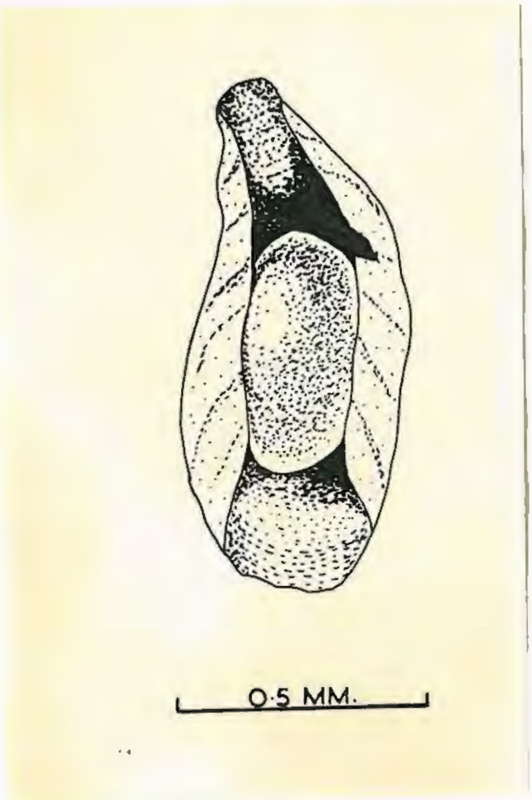


Figure 54.
Egg of Scymnus sp.).
inserted beneath mussel
scale armour.

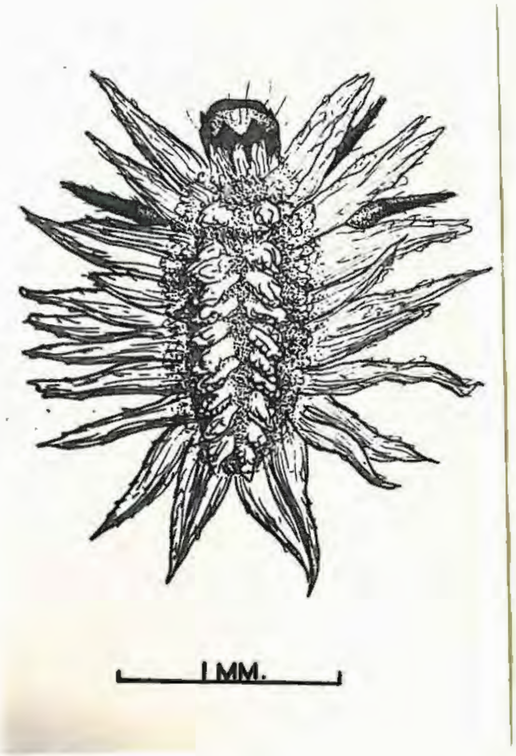


Figure 55
Scymnus sp. , larva

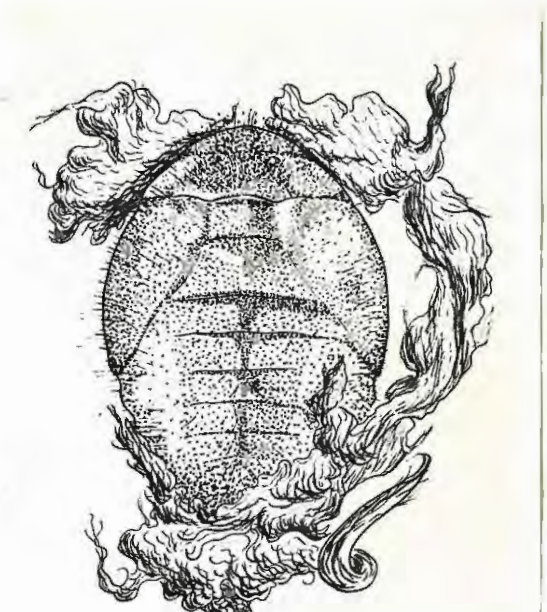


Figure 56
Scymnus sp. . pupa.

which appears shortly after hatching and shortly after each moult. The legs and head are free of this waxy covering and are shiny black in colour. In the early stage of each instar the colour beneath the waxy covering is brown but it darkens to black before the next moult. The larval period lasted about twenty seven days.

The pupa (Fig. 56) is light brown in colour and is covered by a fine pubescence. It is surrounded by the remains of the waxy strands of the last larval instar. The adult emerged eleven to fifteen days after pupation.

In the course of this work the larvae of Scymnus sp. were encountered more frequently than any other coccinellid larvae, although the adults were not as common as Lotis spp. In the field the light grey colour of their waxy covering made the larvae very conspicuous. They wandered slowly over mussel scale or red scale-infested trees, and were usually found with their heads beneath the scales, eating the contents from below. They did not seem to have very powerful mandibles, and were never seen biting through scale armour. These larvae easily become entangled in the silky threads secreted by newly-settled mussel scales; but under natural conditions, owing to the action of other insects and wind, the "fuzz" stage of mussel scale is not nearly so persistent as it is in the laboratory. In the laboratory larvae of Scymnus sp.

-shewed...

shewed great difficulty in inverting a fully grown mussel scale. In the field, however, where heavy scale infestations are present, the scale become settled beneath one another and so lever eachother up, and therefore these larvae probably do not experience any difficulty in obtaining sufficient food.

Scymnus sp. adults seemed unable to invert mussel scales and did not eat through the scale covering, although when the scale was inverted for them they fed on it very readily. One adult which was inactive and sheltering under the twig in its Petri dish, became active when placed under the warm light on the microscope stand and tried to eat mussel scales on the twig by turning them over, but it did not seem to have the strength to do so. It paid no attention to aphids (Toxoptera aurantii (Fonsc.)), which were placed in the dish. When finally a mussel scale was inverted for it, it fell upon it eagerly but continued to try turning it over. When it finally found the ventral side of the scale it ate it by penetrating the cuticle and sucking out the body fluids. This beetle was seen also eating recently settled mussel scale and active crawlers.

The larvae of Scymnus sp. were fairly common in the orchards throughout the year, but became particularly common from about the middle of September onwards.

-Cranophorus...

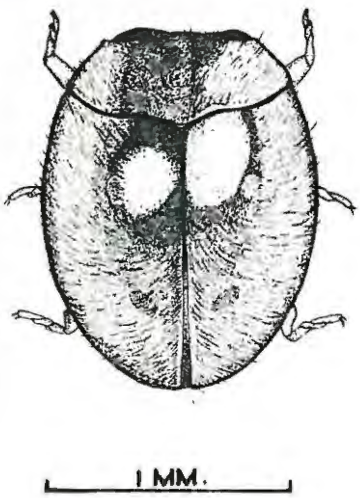


Figure 57
Scymnus sp.
adult.

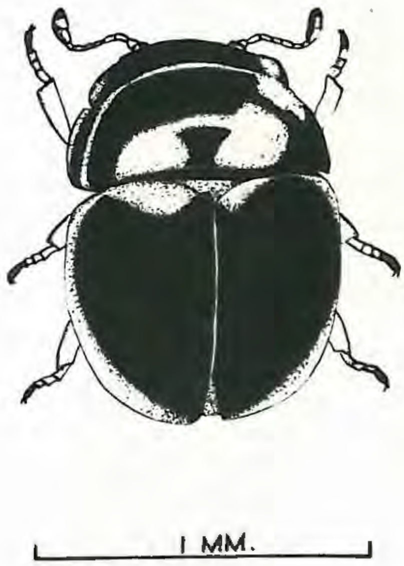


Figure 58
Cybocephalus sp. adult.

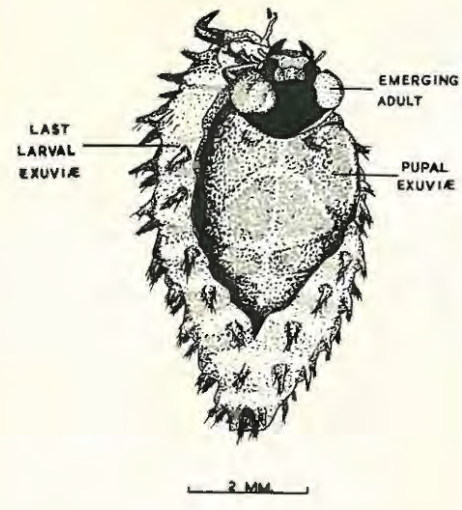


Figure 59
Exochomus flavipes (Thunb).
Adult leaving pupal exuviae which is surrounded by the exuviae of the last larval instar.

Pharoscymnus pictus Sic.

Three larvae of this beetle were found in November on grapefruit material which was very heavily infested with mussel scale, and on which there appeared a few red scale and soft scale. They were kept in the laboratory and one adult was reared. The larva superficially resembles that of *Scymnus* sp.   , but is lighter in colour and far more active. The adult is oval and about 2 mm. long. It is rather dark in colour and each elytron bears four light irregular markings. The entire body is covered with a grey pubescence.

Neither larvae nor adults was seen eating mussel scale in the laboratory, but they readily ate soft scale, and it is quite possible that they do eat mussel scale. In the field adults were seen in the middle of groups of mussel scale on leaves and fruit, but it could not be seen whether they were feeding on them or not.

Fam. Nitidulidae
Sub-fam. Cybocephalinae
Cybocephalus sp.

The adult of this beetle (Fig. 58) is extremely small, being just over 1 mm. long and rather less than 1 mm. wide. It is shiny black in colour and markedly convex. When it dies it withdraws its appendages and curls ventrally. The antennae are clubbed, and quiver continuously while the beetle is active. It is possible that the larva of this beetle is that shewn in Fig. 60 (see page 91).

-The...

The adults of Cybocephalus sp. are active mussel scale predators, and large numbers were kept in the laboratory. Adults which were placed on the surface of a scale-infested fruit registered excitement on encountering the "fuzz" of young scale, and immediately levered them up and fed on the contents from the ventral side. These beetles were slow feeders - more than three minutes being taken to consume an active mussel scale crawler. High power observation shewed that the body of the crawler was inflated and deflated during feeding as in the case of Lotis neglecta larvae, and the empty cuticle was discarded. Cybocephalus sp. attacked both mature and immature mussel scale by inserting the rather wedge-shaped head and thorax beneath the posterior margin of the scale armour and levering it up. It then fed onthe insect from the ventral side.

This beetle was present in mussel scale-infested orchards throughout the year but was not common during the winter months.

Attempts to feed the beetles on red scale, soft scale and aphids failed, although adults were seen in the field associated with the scale Diaspis bromeliae on pineapples, and they are therefore not specific to mussel scale. Copulation was observed but eggs were never obtained.

Fam. Coccinellidae
Lotis nigerrima Casey

This beetle resembles Lotis neglecta but is rather

-larger...

larger and had no red markings on the elytra.

Several specimens were kept in the laboratory but were seldom observed eating mussel scale. One beetle ate an adult female scale by biting through the dorsal armour, and another by inverting it and consuming the naked insect. The entire insect, including the cuticle was consumed.

In the field this beetle was observed on trees which were heavily infested with mussel scale, but there was always soft scale present as well, and the beetles were usually closely associated with it.

L.nigerrima became common in early summer, and was quite plentiful in the orchard, but the part played by it in the control of mussel scale is probably rather small.

Exochomus flavipes (Thunb).

The adult of this beetle is rather larger than those previously mentioned and was very common in all orchards visited. It is shiny black in colour with two prominent red spots anteriorly, (Fig. 59).

Many adults were kept in the laboratory, but attempts to keep them alive on a diet of mussel scale always failed. They seemed quite unable to penetrate the mussel scale armour.

E. flavipes adults were starved for a week and then placed on a fruit which was heavily infested with mussel

-scale...

scale. They wandered over the fruit surface trying to eat the scales but could not penetrate the scale armour. One beetle managed to invert a male pupa and ate the contents from the under side; it then wandered on and tried to feed on every scale it encountered but was unable to do so. It readily imbibed the exudations from a scale which had been pricked with a needle. After five days the scales on this orange were untouched. Even the young scales were not eaten, although the beetles shewed no aversion to the "fuzz". These beetles readily ate inverted mussel scales, and adults were kept alive for several weeks on a diet of soft scale, aphids and mealy bugs.

This beetle is a very general feeder and was extremely common in the orchards throughout the year. The part played by it in keeping down the numbers of harmful insects must be enormous. It is unlikely, however, that it destroys much mussel scale, and it cannot be considered as a mussel scale predator.

E. flavipes is common throughout Africa.

Stethorus sp.

This beetle is a very small, black, oval, rather pubescent beetle. Larvae were never seen, but adults were quite frequently seen in the field during the hotter months and were always associated with dense patches of mussel scale. Of those studied in the laboratory only one was seen trying to eat mussel scale, and this one did so by

-biting...

away the dorsal armour.

Species 9.

The adult of this beetle rather resembles Stethorus sp. but is brown in colour. It was never determined whether or not the adult is predacious on mussel scale as only one specimen was reared, and had to be dispatched for identification. Larvae, however, were reared on mussel scale, and although very small, they were able to eat young scales. The larva resembles that of Lotis sp. but is less pubescent and has dark transverse bands on the dorsal surface of the abdominal segments. The pupa is surrounded by a mass of long silky threads which are covered with minute droplets of a sticky fluid.

Only three larvae of this species were obtained, and from them only one adult was reared. No adults were seen in the field.

Chilocorus solitus Muls.

This is a large ladybird which measures about 6.5 mm. in length, and about 6.0 mm. in width. It is black in colour with a large orange-coloured spot on each elytron.

A few specimens were taken in the Bathurst district and in the Sundays River Valley. Only one specimen was seen eating mussel scale, and this one did so by levering up a scale and eating out the contents. The scales placed with those in the laboratory were always untouched, and the beetles did not live long.

-They...

They fed readily on soft scale and aphis, and Whitehead states that this beetle ate red scale and a species of scale (Chionaspis sp.) infesting the aloe.

Rhizobius sp.

Adults of this beetle were not common in the orchards, but one adult was reared from larvae kept in the laboratory. The adults are approximately the same size as Lotis neglecta, and are black and shiny in colour and covered with a rather coarse white pubescence. The larvae are grey in colour, and superficially resemble the larvae of L. neglecta.

Two larvae of this beetle were fed on a diet of mussel scale in the laboratory and from them one adult was reared. The other adult emerged, but the last larval stage had been damaged and the adult was badly deformed.

This species was not commonly seen in the orchards visited, although it was reported as being common throughout the Albany district.

Neuroptera.

Fam. Chrysopidae.

Chrysopa sp. (probably C. vulgaris Schon.) .

Both larvae and adults of this common insect were frequently encountered. The larvae, which are carnivorous, are grey in colour and oval in shape, with long pointed mandibles. The dorsal side of the larva becomes covered with discarded fragments of the insects which it has eaten.

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These larvae were never observed feeding on mussel sca le in the field, but in the laboratory they would very occasionally lever up an adult mussel scale with their mandibles and eat the body contents. In the field they probably do not eat many mussel scales if there are other soft-bodied insects available.

Unidentified Mussel Scale Predators.

Coleoptera.

Fig. 60 illustrates a coleopterous larva which was first observed in the field in September, 1954. It was first noticed during the inspection of mussel scale-infested twigs and leaves in a search for eggs of Coccinellidae Repeated attempts were made to rear adults in the laboratory, but they always failed. Larvae were kept on scale-infested twigs in a Petri dish, and had access to both moist and dry sand into which they burrowed when mature. It was thought that they burrowed in order to pupate, but they were frequently observed imbibing water from the moist sand, and it may possibly have been the moisture that attracted them. On one occasion an adult of *Cybocephalus* was found on material in the Petri dish containing these larvae, and it is just possible that they are the larvae of *Cybocephalus* sp. but as only one beetle was observed, it would be rash to draw definite conclusions. The material which was placed in the dish was always inspected very closely beforehand, but *Cybocephalus* is a very small beetle, and it could have been concealed

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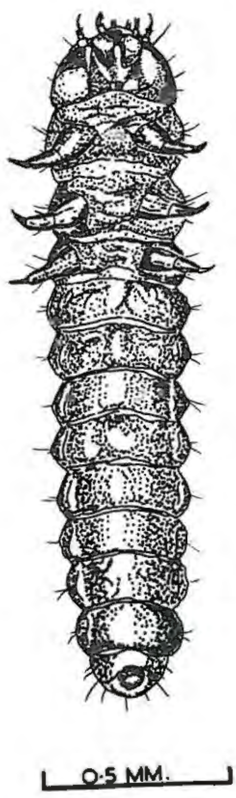

Figure 60
Unidentified coleopterous larva.

Figure 61
Unidentified thrips.

and been passed unnoticed.

These larvae measured up to 2 mm. in length and when first observed were mistaken for female mussel scale, being the same colour and very much the same size with very few bristles. They are averse to light and were always found beneath the scale armour. They gradually eat the scale insect and take its place beneath the scale armour which remains untouched. It was presumed that they pupate in the soil, as pupae were never found under scale armour or anywhere else on the plant, and when given sand, the larvae burrowed readily into it.

From September onwards these larvae occurred in very large numbers, and they must play an important part in the control of mussel scale. They were never found associated with any other scale.

Thysanoptera.

Fig. 61 illustrates the adult of a thrips which was frequently observed associated with groups of mussel scale. The authority to whom specimens were sent for identification was unable to identify it, and it may be a new species. Under natural conditions the adults are rather smaller than the illustration suggests as the abdomen becomes extended in preserving fluid. The entire body is somewhat flattened dorso-ventrally, and the wings are carried folded over the abdomen. The adult is black and shiny with red eyes, but

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the egg and immature stages are a light reddish brown. Although this insect was reared in open containers, no adults ever flew away and the wings may be functionless.

In order to observe the habits of this insect specimens were kept on sections of scale-infested citrus leaves which were floated on a 4% solution of sodium borate in a Petri dish. This solution served the dual purpose of preventing the leaf from drying and preventing the growth of fungous mould. The leaf sections were invariably attracted to the edges of the container, and they were secured therefore by a pin which passed through the leaf and into a piece of india rubber placed on the bottom of the dish. The insects were surrounded by liquid and could not escape. Although adults frequently mounted the pin which passed through the leaf tissue, they always descended again without attempting flight.

All forms spent the greater part of their time beneath the armour of mussel scales, and no specimen was ever observed actually feeding. The insects were not very active and moved only in order to pass from one group of scale to another. Both immature stages and adults which were already under a mussel scale resented the intrusion of another specimen, and demonstrated this resentment by curving the abdomen towards the intruder. Whether they fed on the mature insect or just on the eggs and crawlers

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was never determined. One adult was observed to leave its position beneath an empty scale in order to seize a mussel scale crawler between its fore-legs and return with it to its original position.

Eggs were not obtained in the laboratory culture, although copulation was observed. The male mounted the female dorso-ventrally and the posterior abdominal segments were passed to and fro across those of the female. For a period of about fifteen minutes after copulation the female became very active and tried repeatedly to escape from the culture, but she never attempted to fly.

This species of Thysanoptera was occasionally seen in the course of the monthly samplings, and was quite frequently seen on material from a heavily mussel scale infested grapefruit orchard. They were not however very common, and probably do not play a very big part in the biological control of mussel scale. They were never seen associated with other species of scale, but were present in the orchard throughout the year.

Lepidoptera.

Mention should perhaps be made of a lepidopterous larva of which two specimens were taken from scale-infested grape-fruit material. Both larvae died very shortly after being taken to the laboratory, but one of them did eat the greater part of a female mussel scale. The larva was encased in a cottony covering which extended at right angles to the

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plant substrate and was approximately 5 mm. long. Into the covering were incorporated numerous empty mussel scale coverings which suggested that it might be an a ctive mussel scale predator.

After the one female mussel scale had been eaten both lepidopterous larvae became stationary and it was presumed that they had pupated. Subsequent examination, however, revealed that they were both dead and had shrivelled up; and adults were therefore never observed.

Besides the fourteen predators already mentioned, the following beetles of the family Coccinellidae are also reported as being predacious on mussel scale in the Bathurst district:-

Pharoscymnus sexguttatus (Gryll.)
Cryptolemus montovzieri
Rodolia iceryae (Janson)
Chilocorus distigma (Klug.)
Cidonia Lunata (Fab.)
Four species unidentified Scymnini.

Of these, *Pharoscymnus sexguttatus* and *Chilocorus distigma* were observed in the laboratory but neither was seen to feed on mussel scale.

Acarina.

In the course of this work several mites were encountered which appeared to be predacious on mussel

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scale. During the monthly samples leaves were often seen which supported rather large colonies of mites in the midst of patches of newly settled dead mussel scales. Whether the mites actually killed the scales or whether they fed on the dead scales was never determined. Mites were very frequently seen on plant material which supported large numbers of mussel scale, and some were seen passing in and out beneath the armour of the scales. Possibly some of them fed on the egg cases or even on the eggs beneath the scale covering of female scales; and the possibility of their feeding on living adult scale is not remote. One species of mite was particularly common wherever the unidentified coleopterous larva (Fig. 60) was found, and usually inhabited the empty scale coverings from which the occupants had been eaten by the beetle larvae. No detailed investigations were made of any of these mites.

It was impossible to estimate the actual numbers of mussel scale accounted for by one individual predator, because the entire scale was not always eaten, and frequently crawlers and eggs were undamaged. Mussel scale is a particularly tough scale and except where gross overcrowding occurs, the adults are fixed very firmly to the substrate. For this reason it is probable that general predators will eat mussel scale only when other food sources, including red scale, are exhausted, which is probably why mussel scale spreads so rapidly. It is the general predators which

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normally effect the biological control of a noxious species of insect, because when supplies of the noxious species become exhausted, the predators feed on other insects. Such a state of affairs does not seem to exist in the case of mussel scale, because the few species which do eat it readily, seem to be more-or-less specific to mussel scale or to mussel scale and red scale.

PART II

THE ACTIVITY OF THE BROWN HOUSE ANT, *PHEIDOLE MEGACEPHALA* (FABR.).

CHAPTER SEVEN

Observations on the Activity of the Brown House Ant, *Pheidole megacephala* (Fabr.)

Many species of ant are known to visit plants which support honey-dew-secreting insects in order to feed on the sugary secretions and take them to the nest where they are used to feed other members of the colony. There is frequently a continuous stream of foraging workers travelling up and down the plant between the nest and the honey-dew insects, and it can be shewn that a numerical relationship frequently exists between the ants concerned and the attended insects. Outbreaks of sap-sucking insects are often encouraged by ant colonies and in this connection the activities of various ants have attracted considerable attention. It is in the interests of the exploiting ants to protect the insects they attend, and it has been shewn that they do infact attack both predators and parasites of such insects. At the same time, however, the natural enemies of other insects may be attacked, as many predators are general in their feeding habits, and many parasites have more than one host. Therefore, the presence of ants and corresponding scarcity of predators and parasites in general on a tree may well encourage outbreaks of non-honey-dew secreting insects which would otherwise be controlled. Also, ants may discourage specific predators

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and parasites of harmful insects, as well as those of the possibly less-harmful insects they attend.

Smithers (1953) shewed from data obtained in the Sundays River Valley that a numerical relationship existed between red scale (Aonidiella aurantii Mask.) and the custodian ant (Anoplolepis custodiens Smith), and that trees with heavy red scale infestation were usually visited by large numbers of this ant. Steyn (1954) reported the same state of affairs to exist at Letaba in the case of both this ant and the brown house ant (Pheidole megacephala).

In order to investigate the scale-ant relationship in the Bathurst district, the following procedure was adopted. Between 11 a.m. and 3 p.m. on the 24th November 1954 samples of leaves were taken from thirteen orange trees and the numbers of both mussel scale and red scale compared with the number of ants on the tree trunk in unit time. The trees to be sampled were selected at random and were distributed over two large orchards. Wherever possible the trees chosen were those with only the trunk making contact with the ground so that ants were obliged to visit the tree by one route only. On the few occasions where trees whose branches touched the ground were used, care was taken that there was no ant activity at the points of contact. The degree of ant activity was estimated by counting the number of ants passing up and down the trunk in ten minutes. As

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the ants tended to travel in waves, it was decided that ten minutes was the minimum time interval for a fair estimation to be made. Table 14 shews ant activity on a tree trunk during consecutive half-minute intervals over a total period of seven minutes and it can be seen how the numbers per half-minute vary.

TABLE 14.

Half-minute Intervals	Numbers of Ants	
	Ascending	Descending
½	0	3
1	7	2
1½	1	2
2	2	2
2½	1	1
3	1	5
3½	1	1
4	5	3
4½	6	0
5	1	6
5½	3	0
6	1	5
6½	0	2
7	3	1

Scale counts were made by breaking off three small branches from lower, middle and upper regions of each tree on the south eastern side, and counting all stages of both mussel scale and red scale on six leaves of approximately the same size. Temperatures were taken after each count, and fluctuations were sufficiently small to have had little,

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if any, effect on the activity of the ants. The results were expressed as a graph (Fig. 62), and the full results are given in table XXI of the Appendix.

The graph shews the number of ants on the trunk in ten minutes plotted below the horizontal axis, with the corresponding numbers of mussel scale (blacked) and red scale above the axis. The total numbers of red scale on six leaves were plotted, but in the case of mussel scale average numbers per leaf were used.

The investigation established no definite relationship in either case, although both the greatest and least numbers of both scale were more frequent where ants were more numerous. Every tree investigated supported ants and both species of scale, but it is quite common to find trees with ants and no scale, or vice versa, and some trees support neither insect. Therefore, an investigation on these lines would need to be very extensive before a convincing relationship might be established.

Where ants are numerous before scale becomes established on a tree, their continuous activity may impede the progrees of scale crawlers or destroy newly-settled scale, and in this way hinder the establishment of scale infestation. In that case the time factor would play a part in scale - ant relationship.

In the orchards investigated in the Bathurst district

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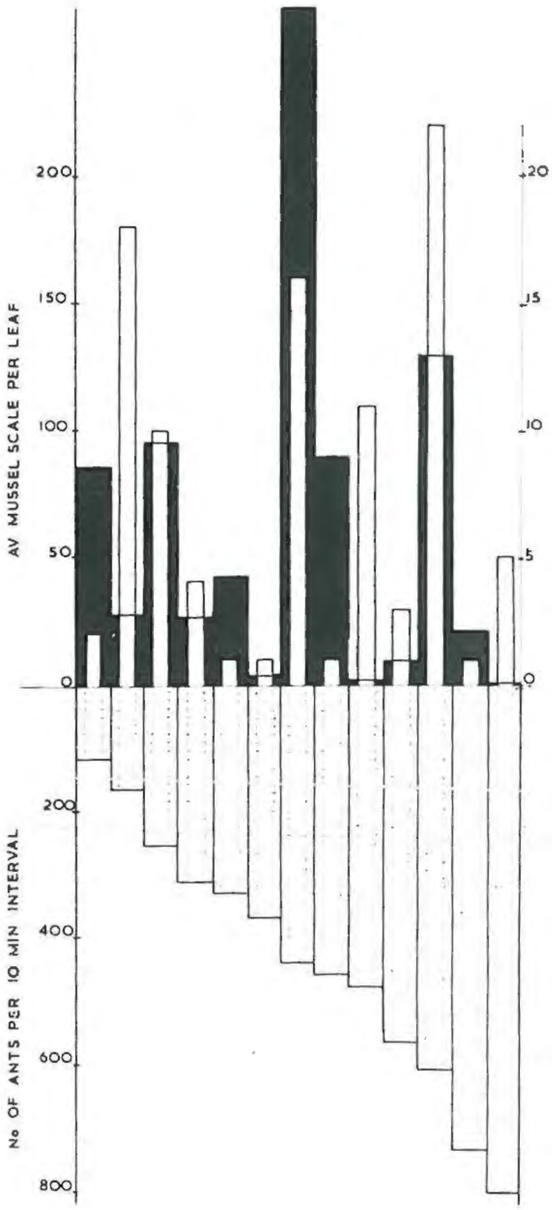

Figure 62

Relative numbers of red scale, mussel scale and the ant, Pheidole megacephala on 13 orange trees.

in 1954, the most common honey-dew secreting insects were soft scale, Coccus hesperidum Linn., and the black citrus aphis Toxoptera aurantii (Fonsc.).

Coccus hesperidum occurred in all the orchards investigated and almost always had ants associated with it. The infestation was sometimes very heavy, and as a result of the honey-dew the trees were frequently covered with sooty mould. This scale was often associated with both red scale and mussel scale, and was almost always attended by P. megacephala.

Toxoptera aurantii occurred quite frequently in the orchard, but its numbers varied considerably at different times of the year, and under different conditions. For example, it was usually far less numerous after rainy or windy weather. It attacked the young leaves and shoots and therefore tended to be confined to the outer regions of the tree. It was attended by several species of ant, including P. megacephala.

P. megacephala was seen also attending mealy bugs.

In order to investigate the activity of this ant in the orchard at various times and under various conditions, counts were made of the numbers of worker ants on the trunk of an orange tree in unit time at different times of the day. The orchard used for these counts was on the farm of Mr. L.D. Purdon in the Grahamstown district.

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The tree chosen was a ten year old Valencia orange tree with a rather narrow trunk unbranched for the first eighteen inches. On no side did the foliage touch the ground. At the base of the trunk beneath the soil there was a P. megacephala nest, and the worker ants were using one runway on the south eastern side to gain access to the upper regions of the tree. The ants were attending soft scale, but the tree was rather heavily infested with red scale as well.

Counts were made throughout the daylight hours and into the night as well, in both winter and early summer. The days on which the counts were made were sunny and dry, and were rather warm for the particular time of the year. With the aid of a manual counter it was possible to count the numbers of ants both ascending and descending the tree at the same time. The counter was used to count those ascending, and those descending were counted in the usual way. Each count extended over a period of fourteen and one half minutes at the end of which period the temperature and, in the case of the summer counts, the relative humidity were recorded. In the winter counts, each fifteen minute period throughout the day was employed so that it could be seen whether minor temperature fluctuations were registered by the ants, but in the summer counts only fifteen minutes out of each forty five minute period were employed. For

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the counts made after dark and before dawn, either a dim hurricane lamp was used, or else a torch with tissue paper clamped over the glass. Neither of these lights upset the ants. The air temperatures beneath the tree were measured with a "Casella" whirling thermometer. Relative humidity measurements were given by a "Casella" thermohydrograph which was placed in a Stevenson screen beneath the tree.

In addition to the counts made in the orchard, counts over a twenty four hour period were made on the stem of an Australian flame tree, _Sterculia sp_. in Grahamstown. This tree was quite heavily infested with _Coccus hesperidum_ which was attended by the same species of ant. In this case fifteen minute counts were made every two hours, and temperature and relative humidity were recorded.

The graph results of these counts are discussed separately below.

Fig. 63.

On this graph are plotted the results of the counts made on the 24th June, 2nd July and 12th July 1954. Each column above the horizontal axis represents the number of ants ascending the trunk in fourteen and one half minutes, and each column below the axis represents those descending the trunk over the corresponding period. No ants were counted between 12.45 p.m. and 1 p.m. Ant numbers are shewn on the left hand side and temperatures on the right

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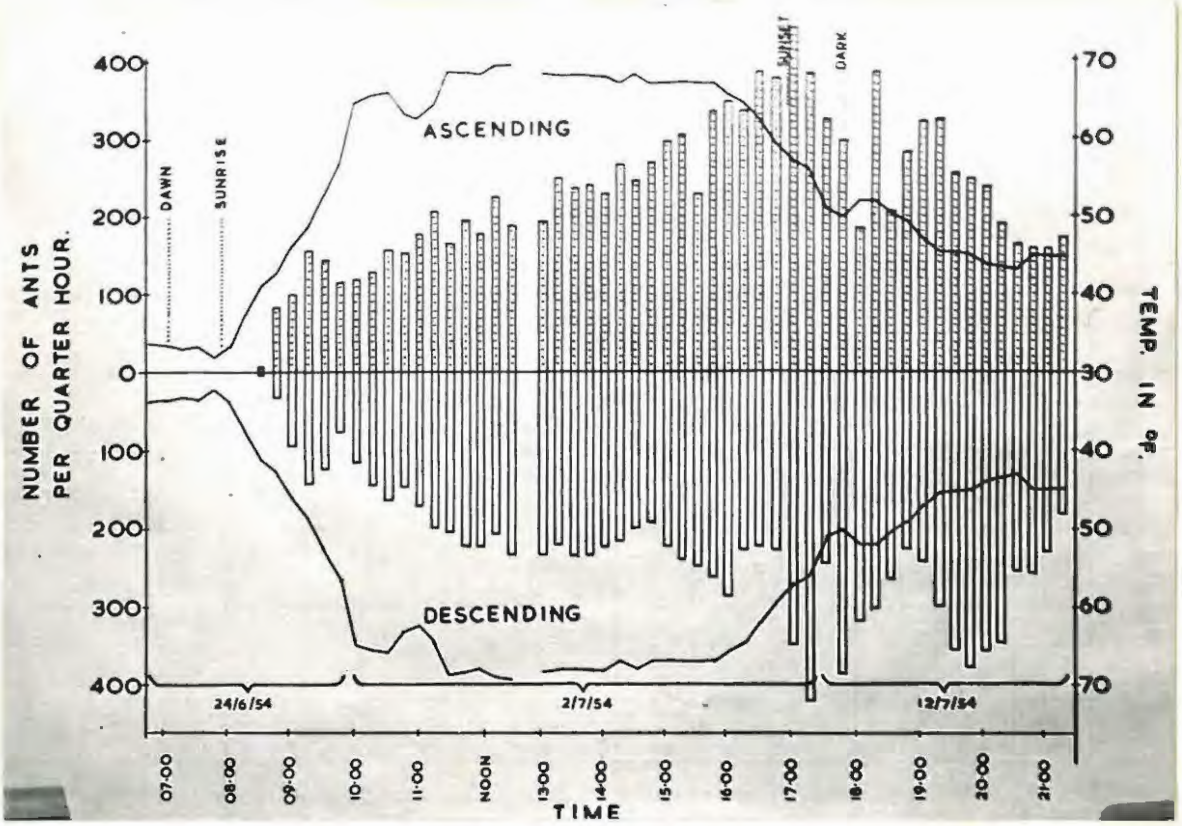

Figure 63
Activity of *Pheidole megacephala* on an orange tree in winter.

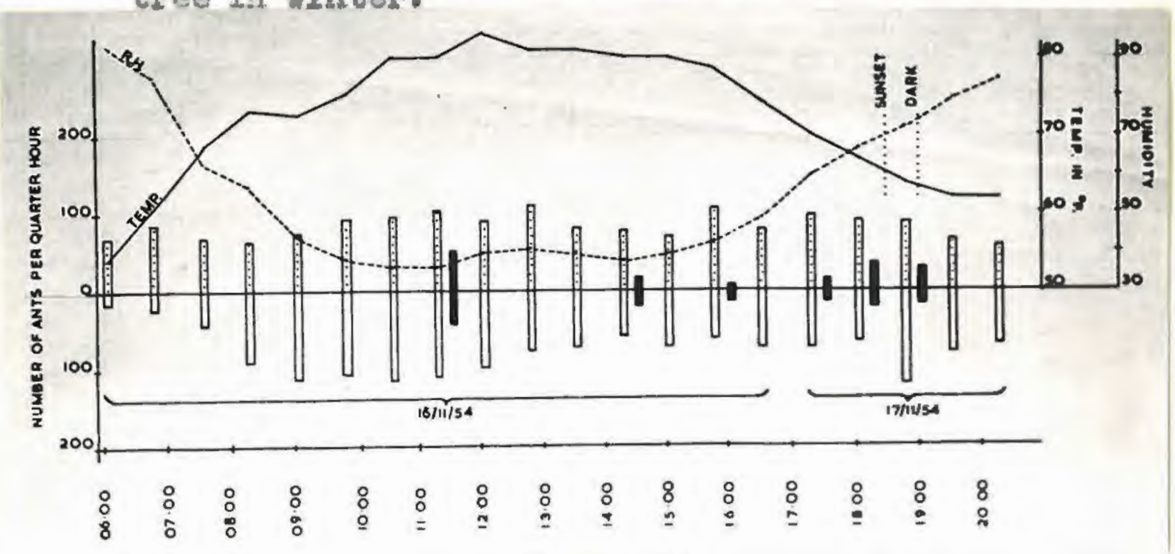

Figure 64
Activity of *P. megacephala* on the same tree in early summer.

hand side. For convenience, temperatures are plotted on both sides of the axis. All three days on which counts were made were very similar. The orchard was warm for that time of year and there was a slight breeze blowing. There was no rain. As the orchard was situated in a valley the sunrise and sunset times recorded on the graph are not true to the district, but they are absolute for the orchard. Observations began before dawn, but no ants were seen until after sunrise when sunlight had actually struck the trunk of the tree. At 8.15 a.m. two worker ants appeared at the nest entrance at the base of the trunk, and shortly afterwards ants began to ascend the trunk of the tree, and within the same quarter hour period those which had spent the night in the tree began to descend. The numbers ascending the tree were at first greater than those descending, possibly because the soil temperature was rather higher than that of the tree, but the counts made on the 2nd July shew that by mid-day there were more ants descending the tree than ascending - probably because the tree heated up more quickly than the soil. Even in winter many ants must spend the entire night in the tree, as descending ants make their appearance at almost the same time as ascending ants. Whether it was the sunlight on the nest entrance or the rise in temperature that provoked the activity of the ants is difficult to say; but judging by Fig. 65, which shews that

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under conditions of higher temperature ants are active all night, it would seem that the early morning low temperatures, (32^{o}F. at 7.45 a.m.) prevented ant movement. Further counts shewed that numbers of ants both ascending and descending the tree increased until absolute sundown, after which the numbers both ways fell off rather rapidly, with more ants descending than ascending. This, and the counts in the early morning suggest that many more workers spend the colder nocturnal hours underground, where the temperature is more constant than in the tree. The graph shews a sudden increase in number of descending ants between 6.45 p.m. and 7.45 p.m. At what time ant activity ceased altogether was not determined, but data obtained on the 24th June, shew that it obviously did so. If one were to speculate and continue the general lines of the graph beyond the time when actual counts were made, ant activity would appear to stop at approximately 1 a.m. but this would probably depend on the rate at which the temperature fell. Relative humidity readings are not shewn in Fig. 63, but the graph shews how the ants respond to small temperature variations. This is particularly well marked in the case of the ascending ants. There was a lag in time before the drop in temperature was registered, and as the day progressed and the temperature in the tree rose, this time lag became greater. A drop in temperature at 10.45 and 11.00 a.m.

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was registered at 11.30 a.m., but although the temperature began to fall at 4 p.m., the numbers of ascending ants did not decrease until after sundown - 5.15 p.m. Similarly, a sudden rise in temperature frequently produced an increase in ant numbers.

Fig. 64.

This graph was drawn from data obtained on the 16th and 17th November. The graph is plotted in a similar manner to Fig. 63, with ascending ants above the horizontal axis and descending ants below it. The period of time covered was similar to that of Fig. 63, but counts were made less frequently. Both temperature and relative humidity readings are shewn. The most striking thing about this graph is the great decrease in numbers of ants since the counts made in July and August. The same tree was used on all occasions, and no chemical treatment of any sort had been carried out in the orchard since the previous counts. It is possible, of course, that the members of the colony had decreased owing to the ageing of the nest, but those members which were present were just as active as they had been in July. The path used by the ants had moved slightly to the south of that used in July, and in addition another runway on the western side of the trunk was in existence; but occasional counts made on the western side, (shewn on the graph in black), shew that it

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could not account for the decrease in numbers. On the tree, the ants of the two different paths never mixed, but served two different parts of the tree. It is possible however that intermingling occurred underground. It is quite likely that the decrease in numbers of workers was a result of many being killed by the cold weather in August. The general pattern of Fig. 64 is similar to that of Fig. 63; but, with less marked temperature variations, there are less marked variations in activity. As in the previous graph the early morning readings shew a greater number of ants ascending the tree than descending it, and after sundown there was again a sudden increase in the number of ants descending the tree before a gradual decrease in the numbers of both those ascending and descending. Activity started earlier than in the previous investigation, and it might quite possibly have continued through the night. In general, the ant activity fluctuated with changes in temperature, although the temperature at that time of the year probably did not drop very low even at night. Relative humidity readings are inversely proportional to temperature readings to such a marked degree, that it is difficult to say to which of them ant activity responded. It corresponded to fluctuations in both factors. Although at the maximum temperature recorded, 83° F. at 12 noon, there was a drop in the number of active ants on the

-trunk...

trunk, it is doubtful whether this temperature could be sufficiently high to cause a decrease in activity through torpor, which is what Steyn found while studying the activity of the pugnacious ant (Anoplolepis custodiens Smith) in the Transvaal. (It should perhaps be mentioned however, that on examining the flame tree mentioned in the following paragraph during extremely hot weather which occurred about three weeks after the counts were made, ant activity was found to be practically at a standstill). At the point on the graph representing 12 noon the relative humidity increases with the temperature, and thereafter until 7 p.m. the ant activity follows the relative humidity curve remarkably closely. Unfortunately conditions of simultaneously low temperatures and humidities did not arise. If suitable laboratory facilities were available it would be interesting to study the activity of this ant under controlled conditions of temperature and humidity. It could then be determined to what factors the ant responds, and under what conditions of temperature and humidity thresholds of activity occur.

Fig. 65.

This graph shews the activity of P. megacephala attending soft scale on an Australian flame tree. The period covered by the graph is twenty four and a quarter hours, and extended from 10.15 a.m. on the 18th November

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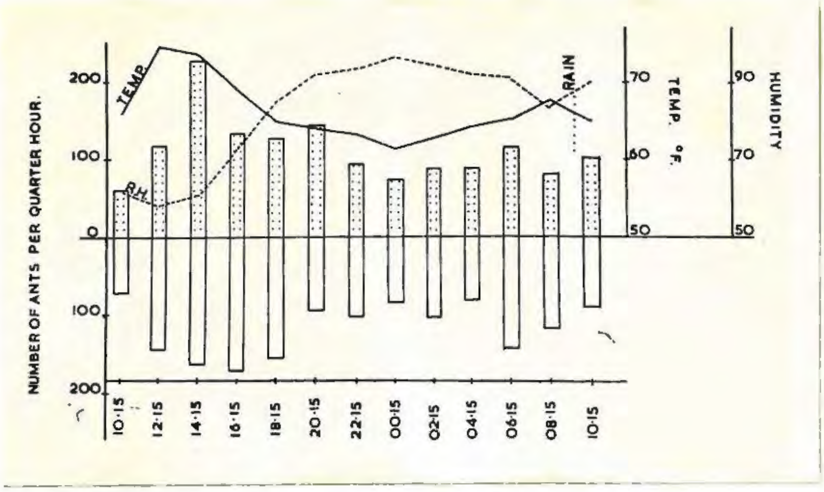

Figure 65
Activity of P. megacephala on an Australian flame tree over a 24-hour period in early summer.

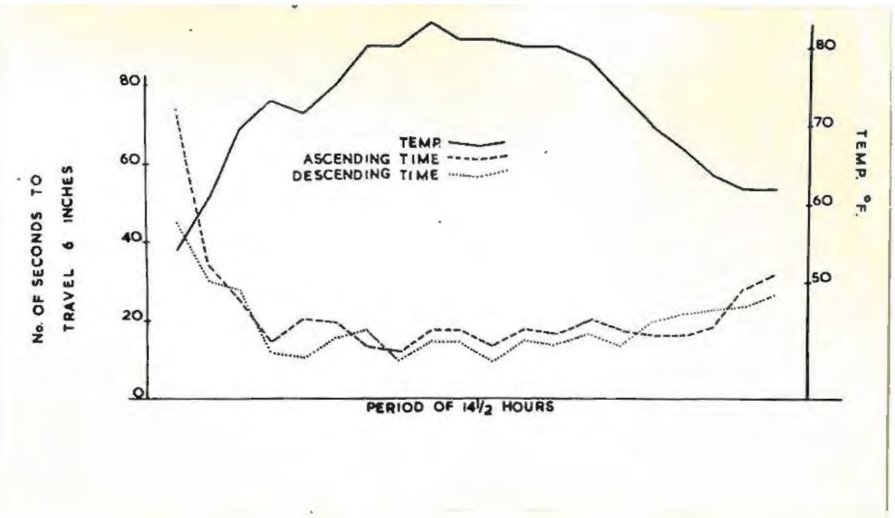

Figure 66
Rate of movement of P. megacephala at different times of day.

to 10.30 a.m. on the 19th November. Ascending ants and descending ants are again plotted on either side of the horizontal axis, and temperature and relative humidity fluctuations are also plotted. The weather during this period was warm and rather cloudy, and the night especially was rather warm for the time of the year.

The main object of this investigation was to find out how active the brown house ant was during the night. As in the previous graphs, the activity of the ant corresponds very closely to the temperature curve and to the relative humidity curve, which in this case is almost a "mirror image" of the temperature curve. The graph shews that as in the other graphs the ant was more active during the daylight hours, but in this case its activity by no means ceased at night, and it is not a diurnal ant in the same sense that A. custodiens is.

Fig. 65, in contrast with Figs. 63 and 64 does not shew decrease in the descending ants around 2 and 3 p.m., neither does it shew an increase in the number of descending ants after sundown. It differs from the others also, in that it shews a greater number of ants descending than ascending in the early morning. This is probably due to the smaller range in temperature.

Fig. 66.

At the completion of each fifteen minute count made

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on the 16th and 17th November, ants were timed both ascending and descending the tree trunk, and the times taken by them at different temperatures were recorded. They were timed over a distance of six inches. Fig. 66 shews the relation between the rate of movement of the ants and the corresponding temperatures. Humidities are not shewn here, but are shewn in Fig. 64 and vary inversely with the temperatures.

The graph shews how the speed of the ants increases with increases in temperature, and that the ascending time is usually rather longer than the descending time.

Figs. 63, 64 and 65, especially Fig. 63, give an idea of the enormous number of ants which visited one tree in the course of a day. The stream of ants was more-or-less steady, although the ants did tend to come in waves (Table 14), probably because some slow-moving individuals held up a number of others. It is impossible to say, by observation, how many scale were visited by one ant during its time in the tree. It was observed on both the orchard tree and the Australian flame tree that different streams of ants attended different groups of scale, and kept to their own particular path whatever way they were moving. Frequently more than one ant was seen at one scale and one individual frequently wandered to and fro from one

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scale to another. The ants stroked the scale very rapidly with their antennae and then passed the antennae rapidly across their mouth parts. On several occasions P. megacephala has been seen attacking predacious coccinellid beetles in the field. Chilocorus sp. was seen being attacked by ants which bit the beetle's legs and pronotum with their mandibles; and two ants which were attending soft scale were seen to mount the elytra of Lotis nigerrima Casey and beat it with their abdomen as if trying to sting it.

It is an important point that, according to observations, the ant was most active under conditions of high temperature which is exactly the case with predators and parasites. Therefore, the more predators and parasites there are about, the more ants there are present to disturb them. It is true also that under conditions of high temperature scale crawlers are at their most active and some, such as delicate mussel scale crawlers, may be killed by worker ants, although it is unlikely that the larger soft scale crawlers would suffer.

It is certain that the main activity of the ant observed was in connection with soft scale secretions, but descending ants were often seen carrying to the nest such things as dead insects, exuviae of beetle larvae and aphids, insect wings, and dead ants.

-Fig. ...

Fig. 67 shews the tracings on a thermohydrograph left in the orchards over a seven-day period in early summer. The thermohydrograph was placed in a Stevenson screen under the tree on which ant counts were made. On the last three days included, the weather was dry and fluctuations were regular, but it can be seen how conditions are altered by rain, which occurred on the second, third and fourth days.

The data used for Figs. 63 to 66 are given in Tables XXI to XXIV of the Appendix.

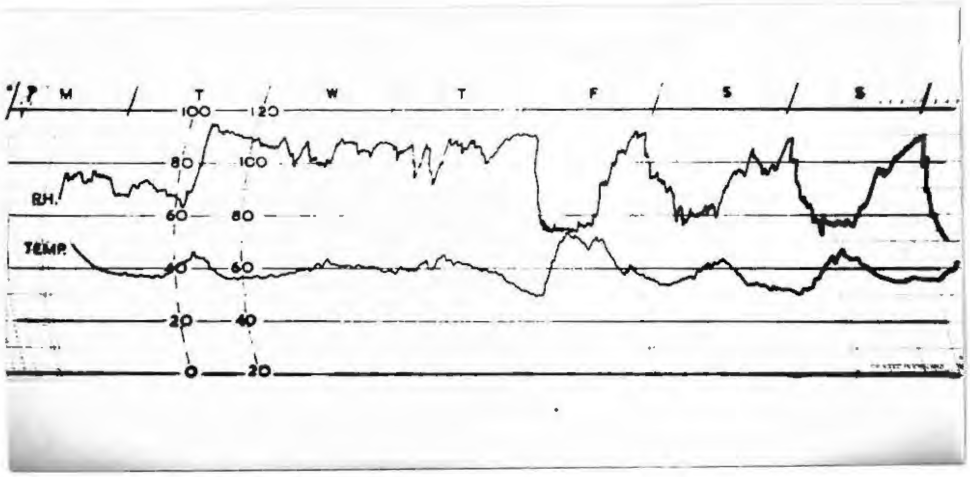

Figure 67
Tracing on Thermohydrograph chart left in orchard for one week.

PART III

FAUNA OF ORCHARD SOILS

CONCLUSION

SUMMARY

CHAPTER EIGHT

Fauna of Orchard Soils.

Soil samples were taken from three of the orchards used in the investigation of mussel scale and red scale numbers under different conditions of cultivation, (Fig.30, sections I, II, and IV). The three orchards used merged into one another, and ranged from conditions of complete abandonment and reversion to natural forest, (Tree G), through less overgrown conditions, (Tree H), and abandoned trees with ploughing between the rows, (Trees I and M), to cultivated orchard, (Tree N). The samples were taken during a spell of dry weather on two consecutive days in August. The soil of each orchard was similar, and was a dark brown sandy loam type.

Method of Sampling.

With the aid of a pick a hole was dug under the tree about two feet from the stem. Sufficient soil to fill two "Ball" jars was scooped out from a clean vertical earth face immediately below a depth of five inches. The jars were shaken until the soil was level with the top and the lids screwed on tightly. Such a sample was taken from beneath each of the five trees.

Method of Separating Fauna from Soil.

For the separation of the fauna a Berlese funnel was

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used. The soil was spread on the sieve of the funnel and left under a bright light and a source of heat for twenty-four hours. Beneath the funnel outlet was placed a tube of 70% alcohol in which the soil fauna was collected.

The contents of the tube were then placed in a Petri dish of 70% alcohol and examined and separated under a high-power binocular microscope. The total fauna obtained is shewn in Fig. 68.

The various organisms may be grouped according to the percentage of their lifetime spent in the soil.

True soil-inhabiting organisms, or Geobionts, included Nematoda, Pauropoda, Oligochaeta, Acarina, Collembola, Protura, Diplura and Formicidae. The ants were included in this group, for although the greater part of their foraging was carried out above ground, the nest is subterranean.

Organisms which spend a large part of their lifetime underground included Diptera, Coleoptera, Gryllidae, Heteroptera, Chilopoda, Pseudoscorpionida, and various unidentified insect larvae. Some part of the life cycle of such organisms may be spent in the soil as egg, larva or pupa, or the organism may hibernate in the soil.

Chance visitors to the soil, or Geoxenes, included the Araneida.

-Discussion...

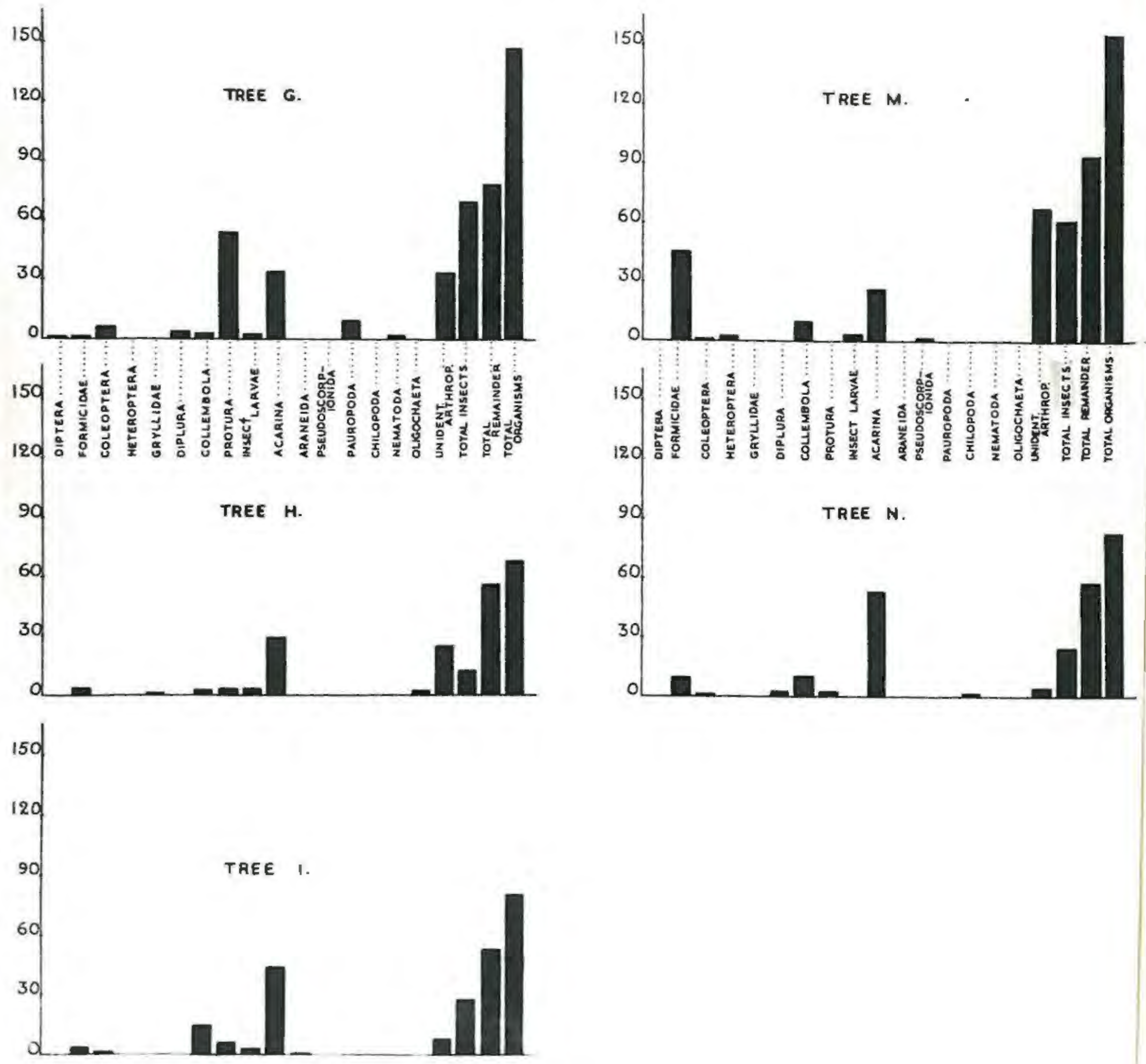

Figure 68
Relative numbers of organisms in soil samples taken from beneath trees under different conditions of cultivation.

Discussion of Soil Fauna and Different Orchard Conditions.

The soil of Tree G which was almost part of natural forest shewed the richest fauna. This soil had probably a higher humidity and humus content than the other soils examined, and the darker conditions resulting from thicker vegetation undoubtedly produced a more secluded habitat. It is quite possible that at a greater depth, the other soils would have contained a richer fauna. The sample from beneath tree G shewed by far the greatest number of Protura, and was the only soil which contained Pauropoda and Nematoda. This soil had, however, surprisingly few Collembola.

Acarina were common to all soils, and were most prevalent in the soil of the cultivated orchard. Their numbers were lowest in the soil which contained the greatest number of ants, (Tree M), whose activity probably kept the numbers down. (Incidentally, Tree M had more red scale than any other tree sampled - see Fig. 30).

About the poorest fauna was shewn by the soil of the cultivated orchard, (Tree N). The surface of the soil was continuously disturbed, and was kept free of weeds. This soil did however contain the greatest number of Acarina.

Although these samples gave an indication of the organisms to be found in typical citrus orchard soil, it would require very much more extensive sampling to establish any relationship between the soil fauna of these various types of orchard.

CONCLUSION

In the scale-infested orchards investigated during 1954 the state of biological control which normally prevails in plant and animal communities was being upset mainly by the presence of mussel scale, Lepidosaphes beckii Newm. This scale is a hardy highly-resistant insect which adheres very closely to its host plant, and for these reasons it is not in a satisfactory state of biological control. General insect predators tend to avoid mussel scale if there is any other source of food available, not necessarily because they are averse to consuming the actual insect but because in many cases it is physically impossible for them to do so. The more active predators of mussel scale are not necessarily the largest and toughest insects, but are those which are able most easily either to penetrate the scale armour or to lever the scale off the substrate and consume the insect from underneath. For this reason many predators probably eat mussel scale only where infestations are large, for under such over-crowded conditions the scales tend to lever one another out of position, and predators may then gain access to the insect beneath its armour. Normally, the young stages of armoured scales are susceptible to attack by a predator, but in the case of mussel scale the secretion of long cottony strands by the newly-settled crawlers constitutes a repelling factor for many predators,

-and...

and serves to protect the young scales until the tough adult scale armour is secreted. Therefore mussel scale thrive and, as far as the tree is concerned, constitutes a "disease" which attacks the tree in its later years and frequently kills part of it. Mussel scale is said to take the place quite frequently of red scale which can be regarded as a "disease" of young trees, and one which does not necessarily come to stay.

In the Eastern Cape the effects of hymenopterous parasite Aspidiotiphagus lounsburyi (Berlese and Paoli) as a control factor of mussel scale must be almost negligible.

All varieties of citrus are attacked by mussel scale and all parts of the tree may be affected, although there is a tendency for the scale to occur in larger numbers on the more shady parts of the trees.

The first stage larvae, or crawlers, of mussel scale are delicate and easily wind-dispersed. They are idle, and unless aided, do not wander far from the parent scale, and are not influenced by conditions of light and shade. They are thigmotactic, and prefer to settle on uneven surfaces.

All stages of mussel scale occur at all times of the year but their numbers are greater during the summer months. Between September and the end of November, the numbers of all stages increase very rapidly. There are three to

-four...

four generations a year.

Greater intensities of cultivation result in greater numbers of mussel scale, because indigenous plants which would normally harbour natural enemies are eliminated. Such circumstances also facilitate wind dispersal of crawlers.

It is possible that a numerical relationship exists between the numbers of mussel scale or red scale on a tree and the numbers of the ant Pheidole megacephala Fabr. visiting the tree, although neither scale secretes honey-dew, and there is no reason why there should be any direct relationship between either scale and the ant.

The activity of the ant P. megacephala is regulated by temperature, and it is not necessarily a diurnal ant although in winter it is far more active during the daylight hours, and under conditions of low temperature activity ceases.

The soils of orchards harbour a typical soil fauna, but the fauna is richer under conditions of less intense cultivation.

SUMMARY

After an introduction in which previous citrus work done at Rhodes University and the object of this present work are briefly discussed, there is a section dealing with the history, world distribution, economic importance, and host plants of mussel scale, Lepidosaphes beckii Newm. This section is followed by a discussion of the life history of mussel scale as it occurred under laboratory conditions in the Eastern Province. Each stage of the insect and its process of development are described. The behaviour of the active winged male is discussed at some length, and mention is made of the process of moulting.

A separate chapter is devoted to the behaviour of mussel scale crawlers. Descriptions are given of various laboratory experiments designed to compare their activity under different conditions of illumination, and to determine whether they shew a preference for any particular variety of citrus fruit.

There follows a section on the distribution of mussel scale. Firstly, distribution under different conditions of cultivation is discussed. Secondly, distribution in different parts of the orchard is mentioned. Thirdly, distribution on different parts of the tree is discussed, and finally there is a discussion of seasonal fluctuations in numbers of mussel scale and its possible relation with

-other...

other scale.

Two chapters in which the parasites and predators of mussel scale are discussed at some length bring to an end the section on the biology of mussel scale.

There follows a section on the activity of the brown house ant, *Pheidole megacephala* Fabr. in the orchards investigated. The activity of this ant under different conditions of temperature and humidity is described, and results are given of observations of its diurnal and nocturnal activity. This section contains also a very brief discussion of relationships between ants and non-honey-dew-secreting insects.

The section on *P. megacephala* is followed by the discussion of a very superficial investigation into the fauna of orchard soils.

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APPENDIX

TABLE 1

Length and Breadth of Mussel Scale reared on Oranges between 28.8.54 and 1.12.54.

. of ys.	Scale 1. Female		Scale 4. Female		Scale 10. Female		Scale 11. Male	
	L.	B.	L.	B.	L.	B.	L.	B.
	0.28	0.22	0.29	0.28	0.28	0.24	0.28	0.22
	0.33	0.22	0.32	0.24	0.32	0.24	0.32	0.22
	0.48	0.33	0.36	0.28	0.33	0.33	0.35	0.28
	0.48	0.35	0.42	0.28	0.39	0.36	0.48	0.29
	0.48	0.36	0.42	0.31	0.41	0.36	0.48	0.32
	0.48	0.36	0.43	0.31	0.41	0.39	0.48	0.32
	0.49	0.36	0.41	0.32	0.42	0.39	0.48	0.32
	0.49	0.36	0.42	0.32	0.42	0.31	0.48	0.29
	0.49	0.36	0.42	0.33	0.39	0.28	0.49	0.28
	0.49	0.36	0.42	0.33	0.53	0.49	0.53	0.39
	0.62	0.42	0.42	0.39	0.62	0.54	0.63	0.42
	0.81	0.53	0.52	0.36	0.72	0.59	0.76	0.42
	0.93	0.56	0.71	0.42	1.00	0.67	0.93	0.50
	1.00	0.56	1.06	0.48	1.02	0.67	1.06	0.50
	1.00	0.56	1.06	0.48	1.02	0.67	1.48	0.44
	1.00	0.56	1.06	0.48	1.02	0.67	1.59	0.44
	1.00	0.56	1.06	0.48	1.02	0.67	1.59	0.44
	1.00	0.57	1.06	0.48	1.02	0.67	1.59	0.44
	1.28	0.72	1.06	0.48	1.14	0.70	1.59	0.44
	1.54	0.95	1.26	0.67	1.24	0.89	1.59	0.44
	1.82	1.12	1.48	0.86	1.68	1.09	1.59	0.44
	2.10	1.12	1.79	0.98	1.98	1.12	1.59	0.44
	2.35	1.17	1.96	1.06	2.26	1.17	1.59	0.44
	2.66	1.17	2.24	1.12	2.52	1.17	1.59	0.44
	2.80	1.17	2.52	1.12	2.94	1.17	1.59	0.44
	2.80	1.17	2.80	1.12	3.16	1.17	1.59	0.44
	2.80	1.17	2.80	1.12	3.27	1.17	1.59	0.44
	2.80	1.17	2.80	1.12	3.36	1.17	1.59	0.44
	2.80	1.17	2.80	1.12	3.53	1.17	1.59	0.44
	2.80	1.17	2.80	1.12	3.53	1.17	1.59	0.44
	2.80	1.17	2.80	1.12	3.61	1.17	1.59	0.44

Note: Scale 10 was never fertilised, and the production of wax had not ceased by 95 days.

Date.	Male M.S. and R.S.	R.S. Crawl.	Soft Scale.	Mealy bugs.	Cocc-inell.	Thrips.	Hy. Par.	Mites.	[illegible] cids.	Misc.	Temp.
March											
25	5					2				1	68.50 °F.
26	6	2						3			73.00
27	400	13									70.00
28	2	6						5			62.00
29			1					3			55.00
30	2	5						1			59.00
31	1		4			1		2			67.00
April											
1	6		7	1				4	1		70.50
2	133		7					3			74.25
3	42		7					2			78.00
4	15		11						1		78.00
5	152		6						1		73.00
6	18		2					2			72.00
7	78							1			78.25
8	144		2					1			72.00
9	5							1			65.00
10	2		1								57.75
11	1										59.50
12	2						1				62.50
13	4		1		1		1				63.50
14	7		1			1					62.25
15	15		2								65.00
16	50		1								67.75
17	81		3					1			74.00
18	81	1	1								74.00
19	18		1				2				65.00
20	1							1			62.00
21	8										62.00
22	33		1				1				69.00
23											68.25
24											64.00
25											60.00
26	2										61.00

(R.S. = Red Scale; M.S. = Mussel Scale; Hy. Par. = Hymenopterous parasite).

TABLE III

Fauna from Parasite Boxes, July 28th to September 2nd, 1954.

Winged Males.	Aphids.	Mealy bugs.	Coccin.	Thrips.	Hy.Par.	Mites.	Psocids.	Misc.	Max. Temp.	Min. Temp.
									62.5	39.5
					1			2	71.0	39.0
					1		1		69.0	41.5
5	1		1					1	72.5	41.5
	1				1				65.0	43.5
1	1								61.0	41.5
		1			1			1	70.5	41.5
6									62.0	45.0
12									74.0	50.0
32		1						1	76.5	48.0
6					1			1	84.5	48.0
6									85.0	50.0
7				1	1				88.0	51.0
5									73.0	47.0
									60.0	45.0
									60.0	44.5
11									75.0	49.0
11					1				66.0	52.0
7						1			82.0	55.0
3					2				80.0	56.0
17									76.5	51.0
					2				81.0	57.5
					3				81.5	58.0
1					1				79.0	50.0
2					1				83.5	50.0
									65.0	46.0
									66.0	37.5
7					1			1	79.0	45.0
13							1		65.0	48.5
			1						65.5	50.0
11					2				71.0	54.0
									65.5	44.0
2									71.0	54.5
									69.5	54.5
1					2	1			74.0	53.0
5		2							73.0	51.0
		3							68.0	51.0

Aphids = Black Citrus Aphis, *Toxoptera aurantii* (Fonsc.)

TABLE IV

Fauna from Parasite Boxes, September 9th to October 9th, 1954.

	Aphids.	Soft Scale.	Mealy bugs.	Coccin.	Thrips.	*Aphytis chrysomphali*	Other Parasites.	Mites.	Psocids.	Misc.	Max. Temp.	Min. Temp.
	2										69.0	42.0
	1		1	1				1			61.0	47.0
								2			68.0	47.5
			2								75.5	47.5
				1							67.5	51.0
							1			1	74.0	50.0
3				2	1						72.5	52.0
)		1		1	2	1	1				86.0	56.0
+				1				1			79.0	57.5
L				1		1					86.5	55.0
3											90.0	62.0
			1								66.0	57.5
			2				1				68.0	56.0
6						1					76.5	51.0
7						2				2	77.5	51.0
1											66.5	57.5
											56.5	55.0
											55.0	49.0
											56.5	51.0
4				1		2					68.0	47.0
+3								1		1	83.0	57.0
59						5				1	88.0	67.5
											68.0	53.0
											56.0	52.0
1				2							70.5	47.0
5											73.0	54.0
1						1					73.0	48.5
											57.0	52.5
6				1							69.0	56.0
				1							66.0	50.0
5											67.0	53.0

<u>TABLE V</u>

. from ORANGE Material in Parasite Boxes, 10.10.54 - 9.11.54.

	A. chrysomphali	*A. lounsburyi*	Other Hy.Par.	Coccinellids.	Thrips.	Mealy bugs.	R.S. Crawlers.	Soft Scale.	Mites.	Spiders.	Aphids.	Misc.	Max. Temp.	Min. Temp.
											17		64.0	55.0
											33		88.0	59.0
						1					10	1	78.0	59.0
		2							2		8		82.0	53.5
		2				1	1				5		76.0	55.0
													61.0	49.0
													55.0	48.0
											1		53.0	51.0
4		1		1		1			1				67.5	52.0
9	1	3				1		1	1				78.0	53.0
9		1						1	2				67.5	55.0
2		2											72.5	54.0
0		3						2					69.5	61.5
2		1					2		1				66.5	56.0
9		1						2	4				76.0	53.5
4		1											72.0	60.0
						1	2		1				70.0	54.0
							1		1				62.5	46.0
7							1						63.5	46.5
22													64.0	53.0
3													65.0	51.0
30		1	1										78.5	55.0
37		1					1						76.0	55.0
2			1				3						69.0	55.0
5		1					2						80.0	58.0
												1	67.0	55.0
							1						61.0	58.0
9							1						63.0	57.0
19					1		2						77.0	51.0
3							1						69.5	52.5
							1						66.0	49.0

TABLE VI

... from GRAPEFRUIT Material in Parasite Boxes, 10.10.54 - 9.11.54.

	A. chrysomphali.	*A. lounsburyi*.	Other Hy.Par.	Coccinellids.	Thrips.	Mealy bugs.	R.S. Crawlers.	Soft Scale.	Mites.	Spiders.	Aphids.	Misc.	Max. Temp.	Min. Temp.
5										1	7		64.0	55.0
0			1	3							6	1	88.0	59.0
3			1								1		78.0	59.0
3				1					1				82.0	53.5
3				1					3				76.0	55.0
													61.0	49.0
													55.0	48.0
				1					1	1			53.0	51.0
.8			2			1						1	67.5	52.0
77	1					1		1	1				78.0	53.0
7								1	3				67.5	55.0
5						1							72.5	54.0
26						3							69.5	61.5
			2		1	3			1				66.5	56.0
9			2			2	1		3				76.0	53.5
11			1			3							72.0	60.0
1			1						2				70.0	54.0
									2				62.5	46.0
1													63.5	49.0
7	1			1									64.0	53.0
5													65.0	51.0
36	1		1						1				78.5	55.0
16	2			1									76.0	55.0
1			1		1				1				69 .0	55.0
6	4		1							1			80.0	58.0
													67.0	55.0
													61.0	58.0
	2												63.0	57.0
10			1						3				77.0	51.0
2									1				69.5	52.0
													66.0	49.0

Table VII

Relationship between size of Adult Female Scale, and Number of Eggs Present.

No. of EGGS.	SIZE of FEMALE in mm.
0	1.20
8	1.25
11	1.25
14	1.10
21	1.20
25	1.20
29	0.95
38	0.75
45	0.90
51	0.85
55	0.85
74	0.80
83	0.85
86	0.70

Table V111.

Average Numbers of Red Scale and Mussel Scale per Square Inch Surface Area of Fruit from Sections of Orchard under Different Conditions of Cultivation.(18/8/54.)

Section	Tree	M.S./Sq."	R.S./Sq."	Other Insects.
I	G	0.045	0.015	
	K	0.013	0.375	
	H	0.270	0.036	1 coccin.1 mealybug.
	J	0.444	0.025	2 thrips.1 "
II	I	7.370	0.123	1 coccin.
	L	14.550	9.010	3 " 1 "
	M	4.820	1.710	
III		14.830	0.320	1 mealybug.
		20.280	0.326	
		10.930	0.248	
IV	N	30. 510	0.050	
	P	9.610	2.870	
	Q	29.030	0.518	

Table IX

Average numbers of Red Scale and Mussel Scale per Leaf, sampled from Trees in One Row.

TREE No.	Total Scale/Leaf		Average Scale/Leaf	
	Red	Mussel	Red	Mussel
1	14	11	4.66	3.66
2	4	232	1.33	77.30
3	8	145	2.66	48.33
4	11	165	3.66	55.00
5	4	93	1.33	31.00
6	7	159	2.33	53.00
7	0	148	0.00	49.33
8	0	12	0.00	4.00
9	0	11	0.00	3.66
10	0	106	0.00	35.30
11	2	203	0.60	67.66
12	1	72	0.33	24.00
13	13	26	4.33	8.66
14	6	3	2.00	1.00
15	4	24	1.33	8.00
16	0	3	0.00	1.00
17	2	107	0.66	35.66

TABLE X

Numbers of Mussel Scale on FRUIT samples, April, 1954.

Tree.	Total Larvae.	Total Males.	Total Females.	Grand Total.	Dead Males.	Dead Females.
A.						
N.	49	33	17	99	19	2
S.	33	11	8	52	6	1
E.	158	61	32	251	19	7
W.	19	4	8	31	2	0
C.	30	9	6	45	3	2
B.						
N.	24	26	3	53	15	0
S.	181	17	13	211	5	1
E.	64	44	13	121	20	5
W.	51	17	14	82	6	4
C.	34	27	13	74	3	3
C.						
N.	0	0	2	2	0	1
S.	85	34	14	133	8	1
E.	117	59	16	192	29	4
W.	2	1	2	5	1	0
C.	28	6	2	36	3	2
D.						
N.	2	1	3	6	1	1
S.	40	15	3	58	2	0
E.	77	20	2	99	5	1
W.	9	1	1	11	1	0
C.	75	12	6	93	4	1
E.						
N.	0	0	0	0	0	0
S.	88	16	13	117	5	0
E.	33	18	7	58	5	2
W.	4	1	0	5	1	0
C.	54	9	7	70	6	3
F.						
N.	13	1	1	15	0	0
S.	454	238	69	761	76	7
E.	97	8	5	110	2	1
W.	6	0	3	9	0	0
C.	177	98	39	314	28	6
TOTAL	2004	787	322	3113	275	55

TABLE XI

Numbers of Mussel Scale on FRUIT samples, May, 1954.

Tree.	Total Larvae.	Total Males.	Total Females.	Grand Total.	Dead Males.	Dead Females.
A.						
N.	46	45	25	116	29	11
S.	242	104	109	455	45	16
E.	14	9	10	33	2	0
W.	14	7	14	35	4	4
C.	215	63	62	340	18	7
B.						
N.	10	4	5	19	4	1
S.	149	128	48	325	48	10
E.	13	5	7	24	4	1
W.	67	31	19	117	9	6
C.	113	57	27	197	28	1
C.						
N.	1	1	0	2	0	0
S.	137	76	32	245	38	7
E.	68	37	25	130	17	5
W.	1	2	4	7	1	1
C.	116	75	29	220	50	11
D.						
N.	47	7	1	55	2	0
S.	25	2	13	40	1	1
E.	41	26	11	78	16	2
W.	6	3	3	12	2	1
C.	141	36	22	199	17	3
E.						
N.	1	0	0	1	0	0
S.	230	60	35	325	23	0
E.	151	14	22	187	8	3
W.	3	0	1	4	0	0
C.	729	171	63	963	52	2
F.						
N.	18	6	7	31	4	2
S.	421	248	110	779	167	26
E.	295	63	67	425	36	14
W.	124	21	24	169	11	11
C.	164	59	56	279	23	12
TOTALS	3602	1360	851	5813	679	158

TABLE XII

Numbers of Mussel Scale on Fruit samples, June, 1954.

Tree.	Total Larvae.	Total Males.	Total Females.	Grand Total.	Dead Males.	Dead Females.
A.						
N.	258	129	101	488	72	10
S.	139	19	16	174	9	7
E.	61	43	30	134	15	6
W.	18	15	9	42	9	1
C.	652	504	149	1305	238	17
B.						
N.	22	7	3	32	5	2
S.	163	94	106	363	40	13
E.	65	44	27	136	23	1
W.	6	2	5	13	1	1
C.	275	147	59	481	73	3
C.						
N.	105	28	19	152	22	4
S.	77	16	10	103	7	2
E.	319	113	73	505	64	9
W.	0	0	0	0	0	0
C.	139	39	30	208	18	6
D.						
N.	37	4	9	50	3	2
S.	103	41	48	192	28	8
E.	55	8	22	85	3	4
W.	29	5	18	52	3	1
C.	49	26	41	116	11	11
E.						
N.	0	3	1	4	2	0
S.	209	48	48	305	32	9
E.	213	54	29	296	21	7
W.	22	2	5	29	1	0
C.	122	48	22	192	10	3
F.						
N.	115	29	7	151	18	7
S.	677	272	131	1080	142	17
E.	592	219	114	925	95	15
W.	0	0	1	1	0	1
C.	291	78	59	428	41	5
TOTAL	4813	2037	1192	8042	1005	172

TABLE XIII

Numbers of Mussel Scale on FRUIT samples, July, 1954.

Tree.	Total Larvae.	Total Males.	Total Females.	Grand Total.	Dead Males.	Dead Females.
A.						
N.	152	52	49	253	32	8
S.	335	192	74	601	119	12
E.	289	34	37	360	18	6
W.	370	113	54	537	40	11
C.	249	202	127	578	131	9
B.						
N.	38	6	9	53	4	5
S.	470	201	130	801	125	19
E.	137	73	29	239	53	7
W.	225	106	52	383	61	13
C.	166	68	58	292	42	8
C.						
N.	23	8	5	36	5	2
S.	178	87	37	302	42	6
E.	350	61	31	442	15	6
W.	10	0	1	11	0	0
C.	377	242	63	682	105	8
D.						
N.	23	0	2	25	0	1
S.	111	12	11	134	5	1
E.	93	36	32	161	27	6
W.	63	14	8	85	6	0
C.	81	62	26	169	35	4
E.						
N.	22	2	7	31	1	3
S.	142	20	21	183	4	7
E.	123	9	7	139	4	2
W.	7	0	2	9	0	1
C.	98	12	17	127	3	9
F.						
N.	41	0	0	41	0	0
S.	131	23	14	168	15	2
E.	236	66	28	330	47	7
W.	6	0	1	7	0	1
C.	97	44	23	164	24	2
TOTAL	4643	1745	955	7343	963	166

TABLE XIV

Numbers of Mussel Scale on LEAF samples, April, 1954.

Tree.	Total Larvae.		Total Males.		Total Females.		Grand Total.		Dead Males.		Dead Females.	
	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.
A.												
N.	7	1	10	10	10	0	27	11	4	0	1	0
S.	10	3	2	1	1	0	13	4	0	1	0	0
E.	15	4	12	3	4	1	31	8	0	0	0	0
W.	1	0	3	0	0	0	4	0	1	0	0	0
C.	3	2	3	0	0	1	6	3	1	0	0	0
B.												
N.	6	0	6	0	0	0	12	0	3	0	0	0
S.	65	9	43	6	12	1	120	16	15	5	2	0
E.	5	2	15	3	3	0	23	5	7	0	1	0
W.	6	1	3	1	0	0	9	2	1	1	0	0
C.	32	17	14	17	6	10	52	44	3	8	2	4
C.												
N.	0	0	0	0	1	0	1	0	0	0	1	0
S.	4	0	3	1	2	0	9	1	2	1	0	0
E.	5	1	1	4	1	1	7	6	1	4	1	1
W.	0	0	1	0	0	0	1	0	0	0	0	0
C.	7	13	4	5	3	1	14	19	1	4	3	0
D.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	3	0	5	0	0	0	8	0	2	0	0	0
E.	4	1	2	1	0	0	6	2	1	1	0	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	2	1	4	0	3	0	9	1	4	0	0	0
E.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	17	2	11	1	3	0	31	3	4	1	3	0
E.	7	2	0	0	0	1	7	3	0	0	0	1
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	0	0	5	1	1	0	6	1	3	1	0	0
F.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	10	0	14	2	4	0	28	2	4	2	1	0
E.	9	7	3	0	2	0	14	7	2	0	0	0
W.	0	0	1	0	0	0	1	0	0	0	0	0
C.	1	18	4	39	1	7	6	64	3	29	0	1
TOTAL	219	84	169	95	57	23	445	202	62	58	15	7

Up. = Upper surface of leaf, and Low. = Lower surface.

TABLE XV

Numbers of Mussel Scale on LEAF samples, June, 1954.

Tree.	Total Larvae.		Total Males.		Total Females.		Grand Total.		Dead Males.		Dead Females.	
	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.
A.												
N.	20	2	22	5	9	1	51	8	17	4	3	0
S.	21	21	33	98	7	13	61	132	21	87	6	13
E.	8	1	9	1	2	2	19	4	6	1	2	0
W.	5	0	7	1	2	0	14	1	2	1	0	0
C.	14	18	101	40	26	1	171	59	64	30	12	1
B.												
N.	0	0	1	0	0	0	1	0	0	0	0	0
S.	34	2	18	1	1	1	53	4	14	1	0	1
E.	3	2	1	2	2	2	6	6	1	1	1	0
W.	5	0	0	0	0	0	5	0	0	0	0	0
C.	3	11	1	8	4	3	8	22	1	4	1	1
C.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	1	0	0	0	0	0	1	0	0	0	0	0
E.	11	7	13	7	0	6	24	20	6	2	0	3
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	7	4	9	6	5	0	21	10	7	4	4	0
D.												
N.	2	0	0	1	0	0	2	1	0	1	0	0
S.	18	3	6	0	1	0	25	3	2	0	0	0
E.	21	7	20	9	8	4	49	20	14	8	4	2
W.	0	0	0	0	1	0	1	0	0	0	0	0
C.	28	8	6	4	8	2	42	14	5	3	7	1
E.												
N.	1	0	0	0	0	0	1	0	0	0	0	0
S.	7	5	1	2	2	0	10	7	1	1	0	0
E.	8	8	7	2	0	0	15	10	5	1	0	0
W.	0	0	1	0	0	0	1	0	1	0	0	0
C.	26	8	10	1	10	1	46	10	8	1	3	1
F.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	8	4	14	3	1	0	23	7	7	2	1	0
E.	14	1	7	3	6	6	27	10	6	3	2	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	9	5	6	1	5	1	20	7	5	1	1	0
TOTAL	304	117	293	195	100	43	697	355	193	156	47	23

TABLE XVI

Numbers of Mussel Scale on LEAF samples, July, 1954.

Tree.	Total Larvae.		Total Males.		Total Females.		Grand Total.		Dead Males.		Dead Females.	
	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.
A.												
N.	7	9	6	8	6	1	19	18	5	4	0	0
S.	15	1	13	2	2	1	30	4	13	1	1	0
E.	9	2	7	8	2	3	18	13	7	7	2	3
W.	10	12	15	10	6	1	31	23	14	9	1	1
C.	10	26	18	21	5	5	33	52	12	15	1	1
B.												
N.	0	0	1	2	0	0	1	2	1	0	0	0
S.	27	23	17	31	6	10	50	64	15	23	3	2
E.	12	2	7	1	4	5	23	8	3	1	0	1
W.	44	2	17	11	4	8	65	21	15	11	2	0
C.	18	44	23	35	9	8	50	87	16	23	2	1
C.												
N.	1	2	3	2	0	0	4	4	3	1	0	0
S.	5	6	9	6	8	0	22	12	3	3	1	0
E.	13	2	14	5	1	0	28	7	14	5	0	0
W.	0	6	0	0	0	0	0	6	0	0	0	0
C.	11	7	4	1	3	2	18	10	4	1	1	0
D.												
N.	1	0	0	0	1	0	2	0	0	0	0	0
S.	5	0	1	2	4	1	10	3	1	1	0	0
E.	4	0	2	0	0	0	6	0	1	0	0	0
W.	4	2	3	1	0	0	7	3	3	1	0	0
C.	12	7	11	6	6	1	29	14	4	5	0	0
E.												
N.	2	0	1	0	4	0	7	0	1	0	0	0
S.	4	2	6	2	2	1	12	5	5	1	1	1
E.	2	1	1	0	1	0	4	1	0	0	0	0
W.	0	0	0	0	0	1	0	1	0	0	0	0
C.	0	2	0	2	1	0	1	4	0	1	0	0
F.												
N.	1	0	0	0	0	0	1	0	0	0	0	0
S.	8	1	2	1	0	1	10	3	2	0	0	0
E.	0	8	1	0	1	1	2	9	0	0	0	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	29	1	32	6	23	0	84	7	22	5	17	0
TOTAL	254	168	214	163	99	50	567	381	164	118	32	10

TABLE XVII

Numbers of Mussel Scale on LEAF samples, August, 1954.

Tree.	Total Larvae.		Total Males.		Total Females.		Grand Total.		Dead Males.		Dead Females.	
	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.
A.												
N.	1	0	0	0	0	0	1	0	0	0	0	0
S.	10	2	10	2	3	5	23	9	7	2	1	1
E.	8	1	1	1	0	0	9	2	1	1	0	0
W.	1	2	0	0	0	0	1	2	0	0	0	0
C.	28	18	41	14	18	4	87	36	30	10	4	1
B.												
N.	5	1	3	1	4	1	12	3	2	0	0	0
S.	1	0	0	0	0	0	1	0	0	0	0	0
E.	3	3	2	0	0	1	5	4	1	0	0	1
W.	8	0	4	0	2	0	14	0	2	0	0	0
C.	7	7	3	0	5	2	15	9	3	0	0	0
C.												
N.	2	0	0	0	0	0	2	0	0	0	0	0
S.	34	6	21	7	17	2	72	15	15	5	4	1
E.	1	0	3	0	1	1	5	1	0	0	1	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	16	18	21	6	10	4	47	28	12	3	3	1
D.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	12	5	11	5	7	1	30	11	11	11	1	0
E.	0	0	0	0	0	0	0	0	0	0	0	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	33	2	17	3	11	3	61	8	13	3	2	0
E.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	29	5	16	2	5	6	50	13	7	2	1	4
E.	11	0	9	1	5	0	25	1	4	1	1	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	36	2	32	11	2	1	70	14	28	4	1	0
F.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	5	0	4	0	1	0	10	0	2	0	1	0
E.	3	0	0	0	0	0	3	0	0	0	0	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	2	8	0	1	0	4	2	13	0	0	0	0
TOTAL	256	80	198	54	91	35	545	169	138	42	20	9

TABLE XVIII

Numbers of Mussel Scale on LEAF samples, September, 1954.

Tree.	Total Larvae.		Total Males.		Total Females.		Grand Total.		Dead Males.		Dead Females.	
	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.
A.												
N.	2	0	2	0	1	0	5	0	0	0	1	0
S.	6	0	1	0	1	0	8	0	0	0	0	0
E.	15	2	19	3	4	2	38	7	15	3	0	0
W.	6	0	2	1	1	0	9	1	2	1	0	0
C.	20	7	16	11	6	3	42	21	11	5	2	0
B.												
N.	1	0	2	1	1	1	4	2	0	1	0	1
S.	28	4	8	5	7	2	43	11	5	5	3	0
E.	12	1	7	1	5	1	24	3	2	1	2	0
W.	8	0	14	1	3	0	25	1	12	0	0	0
C.	44	35	24	39	20	9	88	83	12	13	2	0
C.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	20	9	43	6	11	1	74	16	26	5	0	0
E.	15	5	7	5	3	0	25	10	3	5	2	0
W.	0	1	0	0	0	0	0	1	0	0	0	0
C.	24	22	12	11	2	4	38	37	3	10	0	3
D.												
N.	1	0	0	0	0	0	1	0	0	0	0	0
S.	16	10	10	5	3	1	29	16	10	0	0	0
E.	3	1	5	0	3	0	11	1	4	0	2	0
W.	30	1	9	0	6	0	45	1	3	0	0	0
C.	16	4	11	10	3	2	30	16	6	5	2	0
E.												
N.	0	0	0	1	0	0	0	1	0	0	0	0
S.	23	4	8	11	10	2	41	17	7	10	1	0
E.	15	0	6	2	7	0	28	2	4	0	2	0
W.	1	0	0	0	0	0	1	0	0	0	0	0
C.	6	1	3	1	1	0	10	2	2	1	0	0
F.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	10	2	2	0	1	0	13	2	2	0	0	0
E.	12	0	7	0	4	0	23	0	7	0	2	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	6	4	6	0	2	0	14	4	4	0	1	0
TOTAL	340	113	224	114	105	28	669	255	140	65	22	4

TABLE XIX

Numbers of Mussel Scale on LEAF samples, October, 1954.

Tree.	Total Larvae.		Total Males.		Total Females.		Grand Total.		Dead Males.		Dead Females.	
	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.
A.												
N.	15	0	7	0	3	1	25	1	5	0	2	0
S.	49	4	27	5	10	0	86	9	15	5	3	0
E.	23	4	12	5	1	0	36	9	11	4	1	0
W.	2	0	0	0	1	0	3	0	0	0	1	0
C.	151	23	52	38	23	12	226	73	38	30	6	2
B.												
N.	5	0	2	0	2	0	9	0	2	0	1	0
S.	53	9	30	5	6	2	89	16	14	3	0	1
E.	26	12	45	29	7	5	78	46	40	29	3	3
W.	2	1	0	0	0	0	2	1	0	0	0	0
C.	16	5	4	4	2	3	22	12	4	2	0	1
C.												
N.	2	2	2	0	0	2	4	4	2	0	0	2
S.	51	30	71	28	15	8	137	66	62	19	7	4
E.	20	11	79	13	29	4	128	28	70	13	9	1
W.	1	0	0	0	1	0	2	0	0	0	0	0
C.	31	23	6	15	1	4	38	42	5	8	0	0
D.												
N.	1	0	2	0	0	0	3	0	1	0	0	0
S.	17	5	10	1	1	1	28	7	10	0	0	0
E.	66	42	24	10	9	3	99	55	15	4	1	0
W.	3	0	1	0	0	0	4	0	1	0	0	0
C.	93	18	29	9	2	3	124	30	18	7	1	0
E.												
N.	15	0	1	1	3	0	19	1	0	1	0	0
S.	88	23	56	3	24	0	168	26	27	2	0	0
E.	38	5	10	4	10	1	58	10	8	2	0	0
W.	0	0	2	0	1	0	3	0	2	0	1	0
C.	69	25	12	15	17	3	98	43	7	6	0	1
F.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	80	15	59	9	21	0	160	24	50	5	9	0
E.	30	4	3	1	8	1	40	6	2	0	1	0
W.	2	1	0	0	0	0	2	1	0	0	0	0
C.	53	14	14	7	5	6	72	27	11	6	1	6
TOTAL	1002	276	559	202	202	59	1757	535	420	146	47	21

TABLE XX

Numbers of Mussel Scale on LEAF samples, November, 1954.

Tree.	Total Larvae.		Total Males.		Total Females.		Grand Total.		Dead Males.		Dead Females.	
	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.	Up.	Low.
A.												
N.	78	10	60	10	21	3	159	23	33	10	5	1
S.	91	101	83	135	15	29	189	265	62	117	7	20
E.	60	17	14	2	11	4	85	23	10	2	6	2
W.	25	7	5	0	1	0	31	7	4	0	0	0
C.	407	56	91	39	45	28	543	123	63	29	17	3
B.												
N.	3	1	1	1	2	1	6	3	1	1	0	0
S.	47	4	6	2	4	1	57	7	5	2	0	0
E.	56	5	17	2	14	0	87	7	16	2	2	0
W.	15	10	0	0	1	0	16	10	0	0	0	0
C.	93	125	24	15	15	7	132	147	19	13	5	1
C.												
N.	1	0	0	0	0	0	1	0	0	0	0	0
S.	94	139	78	51	25	14	197	204	52	44	10	2
E.	72	20	63	16	23	1	158	37	48	15	9	0
W.	0	0	0	0	1	0	1	0	0	0	0	0
C.	100	99	72	31	17	8	189	138	47	19	7	4
D.												
N.	3	5	2	1	0	1	5	7	1	0	0	0
S.	48	32	34	17	8	19	90	68	24	10	2	5
E.	38	2	31	4	15	1	84	7	29	3	4	1
W.	2	7	1	1	2	1	5	9	1	0	0	1
C.	27	46	11	2	7	1	45	49	5	2	0	0
E.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	26	1	3	1	3	2	32	4	2	1	1	0
E.	38	2	15	2	4	0	57	4	11	2	0	0
W.	4	1	1	0	0	0	5	1	1	0	0	0
C.	42	40	7	2	4	1	53	43	5	2	0	0
F.												
N.	0	0	0	0	0	0	0	0	0	0	0	0
S.	85	105	33	14	14	2	132	121	17	5	3	2
E.	4	7	1	0	0	0	5	7	1	0	0	0
W.	0	0	0	0	0	0	0	0	0	0	0	0
C.	62	89	14	9	12	7	88	105	9	3	3	2
TOTAL	1521	931	667	357	264	131	2452	1419	466	282	81	44

TABLE XXI

Relative Numbers of the Ant *Pheidole megacephala*, Red Scale and Mussel Scale on Thirteen Orange Trees.

Tree.	Scale sp.	Total for 6 Leaves.	Av. No. per Leaf.	Ants per 10 mins.	Temp. °F.
1.	Mussel	3	0.50	800	73.5
	Red	5	0.83		
2.	Mussel	131	21.83	726	76.0
	Red	1	0.17		
3.	Mussel	778	129.83	604	75.0
	Red	22	3.67		
4.	Mussel	45	7.50	486	76.0
	Red	3	0.50		
5.	Mussel	4	1.33	478	77.0
	Red	11	1.83		
6.	Mussel	539	90.00	468	77.0
	Red	1	0.17		
7.	Mussel	1585	264.17	454	77.0
	Red	16	2.67		
8.	Mussel	24	4.00	362	78.0
	Red	1	0.17		
9.	Mussel	228	38.00	339	77.5
	Red	1	0.17		
10.	Mussel	152	25.33	321	75.0
	Red	4	0.66		
11.	Mussel	578	96.33	213	77.5
	Red	10	1.67		
12.	Mussel	173	28.83	178	77.0
	Red	18	3.00		
13.	Mussel	488	81.33	120	75.0
	Red	2	0.33		

TABLE XXII

Counts made of the Ant Pheidole megacephala
on Orange Tree, 24.6.54, 2.7.54, 12.7.54.

Time.	No. of Ants. Up.	Down.	Temp. °F.
24.6.54.			
06.30	0	0	34.00
06.45	0	0	33.75
07.00	0	0	33.50
07.15	0	0	33.00
07.30	0	0	33.25
07.45	0	0	32.00
08.00	0	0	33.25
08.15	0	0	37.25
08.30	8	1	41.00
08.45	85	30	42.50
09.00	100	96	46.00
09.15	156	141	48.75
09.30	142	124	52.50
09.45	116	76	56.75
2.7.54.			
10.00	119	116	64.50
10.15	129	144	65.25
10.30	157	164	65.75
10.45	152	147	63.00
11.00	176	171	62.25
11.15	205	200	64.00
11.30	164	206	68.50
11.45	198	222	68.25
12.00	179	223	68.00
12.15	224	206	69.00
12.30	188	236	69.25
12.45	No readings taken.		
13.00	193	234	68.25
13.15	249	222	68.00
13.30	234	237	68.00
2.7.54.(Cont.)			
13.45	238	236	68.00
14.00	228	226	68.00
14.15	265	216	67.00
14.30	242	200	68.00
14.35	269	194	67.00
15.00	292	223	67.00
15.15	302	241	67.00
15.30	328	248	67.00
15.45	331	261	67.00
16.00	348	289	65.00
16.15	332	228	64.50
16.30	382	225	62.00
16.45	377	228	59.50
17.00	438	348	57.00
17.15	383	410	56.00
12.7.54.			
17.30	321	252	51.00
17.45	296	387	50.00
18.00	183	318	52.00
18.15	384	301	52.00
18.30	206	266	50.25
18.45	282	226	49.25
19.00	320	242	47.00
19.15	322	300	45.25
19.30	253	352	45.25
19.45	247	376	45.00
20.00	236	352	44.00
20.15	190	344	43.50
20.30	161	254	43.00
20.45	158	256	45.00
21.00	157	230	45.00
21.15	173	183	45.00

TABLE XXIII

Counts of the Ant *Pheidole megacephala* on Orange Tree
16.11.54 and 17.11.54.

Date.	Time.	Temp. °F.	Rel. Hum.	Nos. of Ants. Up.	Down.	Travel Time(secs.) Up.	Down.
16.11.54	06.00	54.0	93.0	70	16	75	45
	06.45	61.0	85.0	87	26	34	30
	07.30	68.5	62.5	70	45	25	28
	08.15	73.0	57.0	65	95	15	12
	09.00	72.5	44.0	75	115	21	11
	09.45	75.0	38.0	92	107	20	16
	10.30	80.0	36.0	96	117	14	18
	11.15	80.0	36.0	101	111	13	10
	12.00	83.0	40.0	90	100	18	15
	12.45	81.0	41.0	111	79	18	15
	13.30	81.0	39.5	81	75	14	10
	14.15	80.0	38.5	79	62	18	15
	15.00	80.0	39.5	70	74	17	14
	15.45	78.5	42.5	106	64	20	17
	16.30	74.0	48.5	80	75	18	14
17.11.54	17.15	70.0	60.0	96	74	17	20
	18.00	67.0	66.5	90	69	17	22
	18.45	64.0	72.0	86	122	19	23
	19.30	62.0	79.0	66	81	28	24
	20.15	62.0	84.0	59	71	32	27

TABLE XXIV

Counts of the Ant *Pheidole megacephala* on Australian Flame Tree 18.11.54 and 19.11.54.

Date.	Time.	Temp. °F.	Rel. Hum.	Nos. of Ants. Up.	Down.	Travel Time(sec Up.	Down.
18.11.54	10.15	66.0	63.0	62	73	18	13
	12.15	74.5	58.0	117	145	9	17
	14.15	73.5	60.0	225	162	20	10
	16.15	69.0	73.0	132	173	16	13
	18.15	65.0	85.5	127	156	18	23
	20.15	64.0	92.0	142	96	19	17
	22.15	63.0	93.0	91	101	22	18
19.11.54	00.15	61.5	96.0	72	87	19	30
	02.15	62.5	94.0	87	105	20	25
	04.15	64.0	92.0	89	83	18	15
	06.15	65.0	91.0	113	142	22	20
	08.15	67.5	83.0	80	118	23	15
	10.15	65.0	90.0	101	92	18	22