A STUDY OF THE PREDATORS AND PARASITES OF PLANOCOCCUS CITRI (RISSO) (HOMOPTERA) ON VINES IN THE WESTERN CAPE PROVINCE, SOUTH AFRICA.

Thesis submitted for the Degree of M. Sc.,
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November, 1957.

ACKNOWLEDGEMENTS.

The author wishes to express his appreciation of the interest shown in this work by Professor D.W. Ewer and Dr. E.McC. Callan of Rhodes University and of their useful advice and criticism.

This work was undertaken as part of the research programme of the Western Province Fruit Research Station and is used for thesis purposes by permission of the Director, Dr. R.I. Nel.

The author is indebted to the British Museum for identification of Coccinellidae and Hymenoptera and to the South African Museum for identification of Coccinellidae. Mr. Bo Tjeder identified the Neuroptera and the <u>Homalotylus</u> species were identified by Dr. C. Ferrière through Dr. E.McC. Callan.

The author wishes to thank Professor C.J. Theron of the Stellenbosch-Elsenburg Agricultural College, and Mr. M.J. le Roux of Paarl for the use of vineyards for experimental purposes, and Dr. A.C. Myburgh of the Western Province Fruit Research Station for useful advice concerning field experiments. Collection of field results was made possible by the assistance of Messrs. I.P. Bosman, M.N. van Niekerk, A.G. Valentine and M. Siebert, while Miss D. Brooke-Smith and Mr. D.J. Rust assisted with the photography.

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PART I

FIELD STUDIES OF SOME INSECTS ASSOCIATED WITH PLANOCOCCUS CITRI (RISSO) (HOMOPTERA), ON VINES IN THE WESTERN CAPE PROVINCE, SOUTH AFRICA.

INTRODUCTION.

In the Western Cape Province the mealybug, Planococcus citri (Risso), was first reported on vines in 1930 by Joubert (1943a). By 1935 this mealybug had spread to the Hex River Valley, and subsequently to all the main table grape producing ~~are~~ areas of the Western Cape Province. At present Pl. citri is the most important insect pest of the table grape industry and can, if not effectively controlled, result in a loss of at least five per cent. of the export table grape crop (Kriegler, 1954).

Some preliminary work on the natural enemies of Pl. citri on vines was carried out by Stubbings in 1948, but no further work of this nature has been undertaken in this area since then.

The fact that the natural enemies can be an effective check to this mealybug on vines in the Western Cape Province has been known for a number of years (Potgieter, 1937; Hattingh, 1943; Joubert, 1943a; Myburgh, 1951). The present work is an attempt to obtain some basic knowlege of the population fluctuations of the insects concerned in this biological control.

Surveys undertaken have shown that there is a complex of primary, secondary and possibly tertiary Hymenopterous parasites associated with *Pl. citri*. The presence of hyperparasites reduces the efficiency of the primary parasitic Hymenoptera. The usefulness of these primary parasites is further reduced as they only occur in effective numbers for a short period of the year. On the other hand, although attacked by some parasites, the numerous coccinellids found preying on *Pl. citri* are of more importance in reducing the mealybug populations, as they are present on the vines in effective numbers for the greater part of the year.

Broadly speaking, there are two methods of vine cultivation in the Western Cape. Vines for the production of wine and raisins are pruned to form a low bush (fig. 1) or are trained on a low single wire trellis. For the production of table grapes, however, the vines are trained up a higher trellis (fig. 2). Several types of trellis are used, but the result is always a lengthening of the main stem. The choice of cultural method is mainly economic, although factors such as grape variety and availability of water also play a role. As the lengthening of the stem is generally accompanied by an increase in leaf area, it is possible that the microclimates of trellised and bush vineyards differed appreciably. Some differences noted in this work may be ascribed to this, but these are thought to be the result of regional climatic variations.

METHOD OF COLLECTING MATERIAL FOR THE POPULATION FLUCTUATION STUDIES.

Investigations commenced at Stellenbosch in September, 1953, on the experimental farm of the Stellenbosch-Elsenburg Agricultural Collegs. The

Fig. 1.
A wine grape vine, pruned as a bush.

Fig. 2.
Table grape vines on a four foot high trellis.

plot used consisted of approximately one acre of bush-type vines of the variety Alecante Bouchet, a variety used for the production of port wine. Grapes used for this purpose are harvested extremely late, with the result that mealybug infestation, and consequently parasitism, in the grape bunches was much higher than in a vineyard used for table grape production. Mealybugs in the bunches which are harvested for table grape production are removed with the crop, resulting in a large decrease in the mealybug population at a time when the parasite activity is at its greatest.

In this plot no insecticidal control sprays were applied either for mealybugs or for Iridomyrmex humilis, the Argentine ant. Fungicidal dusts and sprays, however, were applied in spring and early summer, but as these contained only copper compounds and sulphur, they had little if any effect on the insects studied.

The survey at Paarl was carried out on the farm "Sonneskyn", owned by Mr. H.J. le Roux. This farm lies in the Paarl North area, a district which produces the earliest table grapes in the Western Cape. Vines used were either Waltham Cross or Alphonse Lavallee, trained on a four-foot wide trellis. Work on this farm was conducted over a period of two seasons. In the 1954-55 season the plot used consisted of one acre of Alphonse Lavallee. Ants were not controlled but, as the grapes were grown for the export market, one parathion spray was applied against mealybug at the beginning of December. In the 1955-56 season a plot of similar size, comprising both Waltham Cross and Alphonse Lavallee, was used. In this plot no mealybug control was applied, although DDT and lead arsenate were used in early summer against vine snoutbeetles. The usual sulphur fungicide was applied in spring and early summer in both plots.

The mealybug position on this farm was exceptional in that, although the crop was earlier than other areas, the mealybug cycle was practically normal. For this reason, a single parathion spray against mealybug was sufficient to ensure a clean grape harvest. Normally it required two spray applications to control the mealybug, but in this area the grapes were harvested before reinfestation could take place. In the 1955-56 season the mealybug were so late that, for an early grape variety such as Queen of the Vineyard, it was not necessary to control the mealybug with parathion sprays, as, at harvest, infestation of the bunches had not yet taken place.

Collections were also made in the Hex River Valley and at Rawsonville in the Worcester area. The Hex River Valley is several miles in length, starting at De Wet Siding a few miles north-east of Worcester and extending north-eastwards to Orchard and De Doorns at the further end. Some collections were made at De Wet Siding, but the majority of material came from Orchard and De Doorns. The main grape variety grown in this area is the Barlinka, cultivated essentially for its late maturity, a quality which insures it a good sale on the overseas table grape market, but which exposes it to a long period of attack by insects such as the mealybug.

Rawsonville, situated on the Du Toits Kloof side of Worcester, is a wine and raisin producing area, consequently all the vines are of the bush type.

Sporadic collections of parasites and predators were made at Rawsonville and at the De Wet Siding, both in the Worcester area. Monthly collections were made at Orchard in the Hex River Valley, starting from May, 1955. Collections were also made at Ceres, Groot Drakenstein and in the Devon and Banhoek Valleys near Stellenbosch. No collections were made at Constantia.

Two vines known to be infested with mealybugs were stripped of their bark every week throughout the period of investigation except when the weather intervened or where otherwise stated. Results were expressed as a monthly total. At Paarl, in the 1955-56 season, one plot was investigated every three weeks instead of weekly. In the winter months the bark was removed from the main vine stem and any Pl. citri colonies present were carefully examined for predators or possible parasitised mealybugs. In the summer months the foliage was searched before the bark on the main stem was removed. The soil and clods around the base of the vine were also examined in summer, as coccinellids often pupated there. Only Pl. citri females definitely known to be parasitised were collected in the field, and were placed in covered battery jars, the emerging wasps being fed on honey if required alive. All coccinellids and chrysopids not adult, were reared in the laboratory on Pl. citri on sprouted potatoes.

ANNUAL CYCLE OF THE MEALYBUG ON THE VINE.

The mealybug has a definite migration cycle on the vine, regulated mainly by both its food supply and seasonal temperature. Kriegler (1954), working in Stellenbosch, found ohly slight variations of this cycle on the different grape varieties. Queen of the Vineyard, Alphonse Lavallee, Barlinka and some wine varieties were investigated.

The mealybug overwinters in colonies under the bark on the main stem of the vine and, in a few cases, in sheltered spots on the leaders higher up on the plant. The following information was obtained from the work of Kriegler (1954). Upward migration, mostly of the young stages, commenced in the middle of September. These mealybugs formed colonies at the bases of the shoots and infested the young buds, reaching a peak in November, while the mealybug population in December was found mainly on the leaves. Infestation of the grape bunches commenced in February and continued until harvest. After harvest, however, the majority of Pl. citri were found on the leaves, but when these leaves started to dry out, the mealybugs began moving back to the stem to form the nucleii of the winter colonies. Not all the mealybugs moved to the stem, but some found shelter on the leaders of the vine. Kriegler could not establish a definite date for the commencement of the downward migration, as this movement is dependent upon the availability of the food supply. There appeared to be a portion of the mealybug population which moved about the vine at random, especially on sunny winter days when adult females were often seen walking on the vine stem. The migration of Pl. citri is important to the insects associated with this pest, as it determines the quantity and accessibility of their food supply.

Mealybug Migration Cycle at Stellenbosch.

Observations made during the 1953-54 season in a vineyard other than that used by Kriegler showed much the same migration cycle of the mealybug on the vines. During the period September to October the weather was cool and development slow. Pl. citri was mainly under the bark on the stem of the vine but was beginning to move to the upper part. From October to January the majority of mealybugs were on the foliage. At first large exposed colonies formed at the bases of the young shoots, and at the end of this period the population dispersed to the leaves. After December Pl. citri could be found in any sheltered spot on the vine, though seldom under the bark on the main stem. From January onwards, infestation of the grape bunches took place. Any mealybugs remaining after harvest were either on the leaves or under the bark, forming the nucleii of the winter colonies.

Mealybug Migration Cycle at Paarl.

The migration of Pl. citri on the vine followed the same pattern in Paarl as in Stellenbosch. Upward migration to the foliage and shoots commenced at the end of September, and formation of colonies at the bases of the shoots occurred during October and November. From the end of December very few mealybugs were found under the bark of the main stem.

The first bunches were infested in January and the first formation of winter colonies under the bark on the main stem took place at the beginning of March.

Mealybug Migration Cycle in the Hex River Valley.

In the late winter, a few small colonies of mealybugs were found under the bark near the crown on the main stem of the vines. During spring and early summer mealybugs were scarce, single immature stages being found on the main stem. By midsummer single adult females were found in the leaf axils, on leaves and in the bunches. In contrast to Stellenbosch and Paarl, no large winter colonies were formed at the bases of the young shoots in early to midsummer. The mealybug infestation of leaves and bunches occurred simultaneously and large colonies were only formed late in the season.

Figures 3 and 4 give the mean monthly screen temperatures and the monthly rainfall for the areas under discussion. The average monthly minimum winter temperature, especially of June, July and

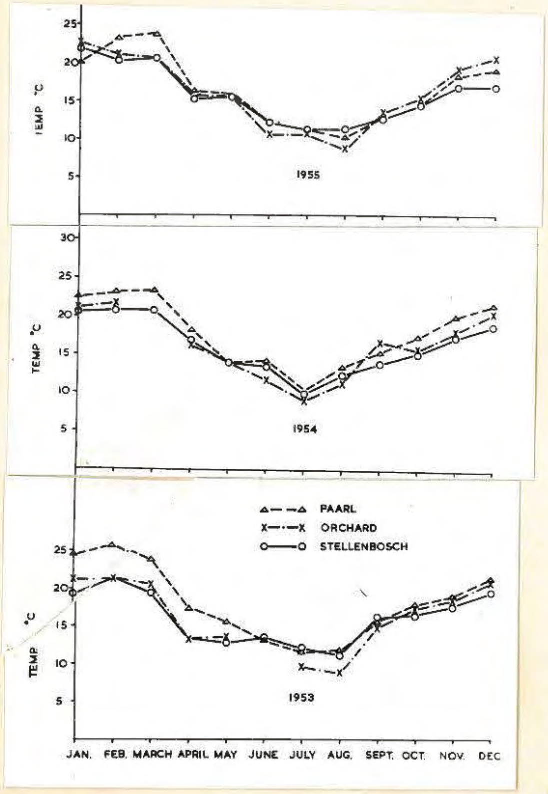


Fig. 3.
Mean monthly temperatures for Paarl, Orchard and Stellenbosch, 1953, 1954 and 1955.

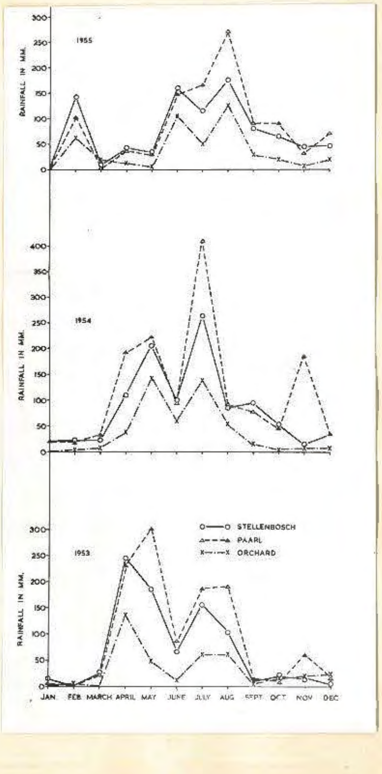


Fig. 4.
Monthly rainfall for Stellenbosch, Paarl and Orchard, 1953, 1954 and 1955.

August, was several degrees lower in the Hex River Valley than in either Paarl or Stellenbosch, which may account for the difference in the mealybug migration cycle on vines in the Hex River Valley. Light frosts occurred occasionally in winter at Paarl and Stellenbosch, while heavy frosts and an occasional fall of snow occurred in the Hex River Valley. In summer Stellenbosch was cooler than the Hex River Valley, while the highest temperatures were recorded at Paarl, where the maximum winter temperature was also the highest.

INSECTS COLLECTED.

Rivnay and Perzelan (1943) who studied the insects associated with *Pseudococcus comstocki* on citrus in Palestine, collected natural enemies belonging to the orders Coleoptera and Hymenoptera. The Neuroptera were represented by the Chrysopidae and the Hemerobiidae. In addition they found a predatory larva of the Dipterous family Cecidomyidae. Joubert (1943a) in the Western Cape Province notes, in addition to the Coleoptera and Hymenoptera, two families of Diptera, namely, the Cecidomyidae and the Ochthiphilidae, found in association with mealybugs. Joubert also mentions an Hemerobiid as being a predator.

In the present work insects from three orders have been found definitely preying on Pl. citri on vines. These are the Hymenoptera, the Coleoptera and the Neuroptera. A fourth order, the Psocoptera, were on occasion very numerous, but their role is uncertain. No predaceous Diptera have been found to date on Pl. citri infested vines, although they were bred in large numbers from a Pseudococcus sp. on citrus from the Banhoek Valley near Stellenbosch. Of the Neuroptera, only specimens of the family Chrysopidae fed on Pl. citri, although some coniopterygid larvae, pupae and adults were found on the vines in the Hex River Valley.

PSOCOPTERA.

Psocids feed on fragments of vegetable and animal matter and particularly on fungus and lichens (Imms, 1938). Large colonies of Psocids were noted at Paarl on numerous occasions under the bark of the vines. At times they were associated with colonies of live mealybugs, but on several other occasions they were found around old mealybug colonies of which only the empty egg sacs remained. Kirkpatrick (1926) reported nine species of Psocoptera predaceous on _Pl_. _citri_ on coffee in Kenya. In Paarl it could not be decided whether the psocids were predatory or not, but it was considered that, because they occurred in as large numbers among old colonies as they did among live mealybug colonies, they were not necessarily predaceous and probably only fed on debris.

NEUROPTERA.

CONIOPTERYGIDAE.

All stages of _Coniopteryx_ _turnei_ Kimmins were collected in late summer on vines in the Hex River Valley. As the autumn passed into winter, the number of pupae steadily increased until only this stage was present. The cocoon is very conspicuous with its white fluted, conical outer covering. The larvae were never seen to feed on mealybugs and it was presumed that they preyed on a species of mite found in fairly large numbers at old mealybug colonies.

CHRYSOPIDAE.

In all the areas investigated there were only two species of chrysopids collected, both as yet unidentified. Ac.FR. 672 has larvae which cover themselves with bundles of debris and are thus designated "covered larvae". These are the "trash carriers" of Smith (1922). The larvae of Ac.FR. 671 do not carry bundles of debris and will be called "naked larvae". The Chrysopidae were never numerous and occurred mainly in midsummer. The adults were easily flushed from the foliage but the larval stages were difficult to detect. Besides only occurring in small numbers for a limited period of the year, these insects were also attacked by several Hymenopterous parasites.

Occurrence at Stellenbosch.

At Stellenbosch the lacewings were more prevalent than in either Paarl or the Hex River Valley. In contrast to these areas, the covered species, that is, Ac.FR. 672, predominated. Larvae were collected from September to June with the largest numbers (all stages) occurring from December to February.

Occurrence at Paarl.

Here the Chrysopidae were ~~also~~ most numerous in February and March, but eggs, laid singly and in clusters, appeared on the vines from December; no lacewings were collected after March. Ac.Fr. 671 was the more prevalent.

Occurrence in the Hex River Valley.

Lacewings of both species were most prevalent during February and March, but were also collected during the other summer months, and some unemerged pupae were collected in August. These insects were never numerous, but were the only predators collected in one area in the summer of 1955. As at Paarl, the majority were of the naked species (Ac.FR. 671).

HYMENOPTERA.

There are some fifteen species of wasps, belonging mainly to the families Pteromalidae and Encyrtidae, which are associated with Pl. citri on vines. As far as could be ascertained, only two of these were primary parasites; the rest appeared to be a complex of hyperparasites. The primary parasites occurred throughout the year, but were most numerous in the autumn months, whereas the hyperparasites occurred mainly in summer, attaining a peak in autumn which corresponded to the peak of the primary parasites. There was some difference in the variety of species collected in the various areas.

Occurrence at Stellenbosch.

From Figure 5 it can be seen that, although the parasites were present in early summer, they did not increase to any extent before January, and by April they had again declined to insignificant numbers. The occurrence of the most prevalent parasites which emerged from Pl. citri females is given in Figure 6, and in Figure 7 the occurrence of the primary and secondary parasites is given graphically. Leptomastix sp. and Anagyrus sp. were the only primary parasites present. In the spring months, while the weather was still cool, only the primary parasites

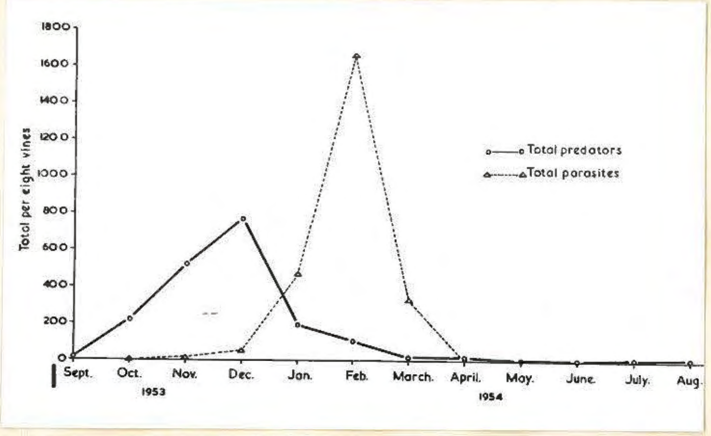


Fig. 5.

Fluctuation of coccinellid predators and hymenopterous parasites. Stellenbosch 1953-54.

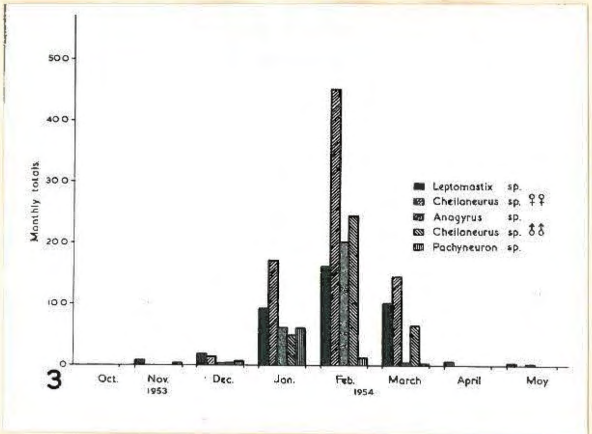


Fig. 6.

Hymenopterous parasites collected at Stellenbosch, 1953-54.

were collected, but as the summer progressed, the hyperparasites increased enormously at the expense of these two primary parasites. In the late autumn months the hyperparasites declined with the decrease in primary parasite populations and eventually only the primary parasites were collected. During the winter months some parasitised mealybugs, from which *Anagyrus* sp. and *Leptomastix* sp. emerged, were collected in the field. *Leptomastix* sp. emerged during warm spells in June and July from parasitised *Pl. citri* females collected in the field in April and May and kept in an outdoor insectary. The secondary parasite, *Cheiloneurus carinatus* Comp. and one specimen of Ac.FR. 637 also emerged in July from the same mealybug females.

Leptomastix sp.

From laboratory breeding it was found that this wasp was a primary parasite of *Pl. citri* females. *Leptomastix* sp. was first collected in October (fig.~~7~~6), after which it increased slightly in December and was then attacked by *C. carinatus*. In spite of this the population increased steadily in January and February (fig. 6), but began to decline in March, and

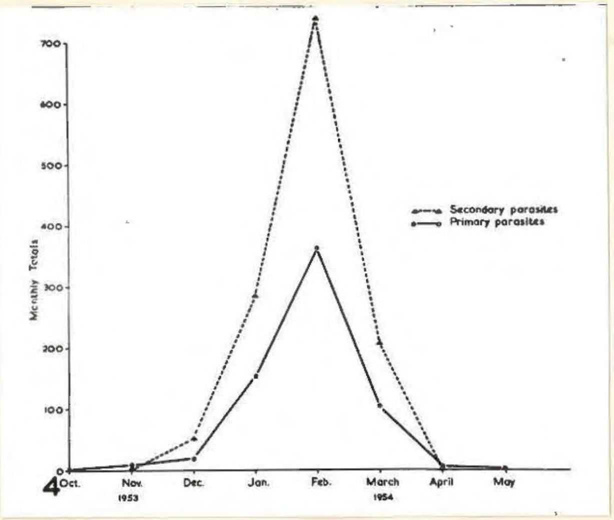


Fig. 7.

Primary and secondary hymenopterous parasites.

Stellenbosch 1953-54.

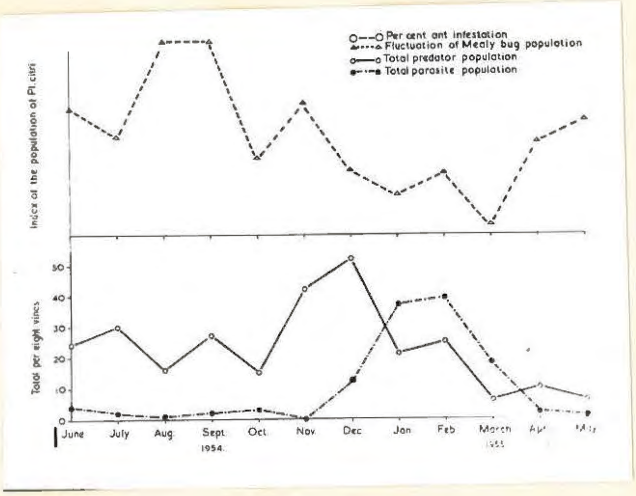


Fig. 8.

Fluctuation of coccinellid predators and hymenopterous parasites. Paarl 1954-55.

by April and May was as low as in early summer. As mentioned earlier, these wasps occurred only in small numbers in winter.

Anagyrus sp.

Breeding in the laboratory also established this wasp as a primary parasite. The first of this species was collected in December, their numbers were greatest in February and they declined rapidly in March. It was only during February that *Anagyrus* sp. was more numerous than *Leptomastix* sp. As was the case with *Leptomastix* sp., *Anagyrus* sp. emerged from parasitised mealybugs collected during winter.

Cheiloneurus carinatus Compere, Female.

Compere (1938) states that this genus is hyperparasitic on Chalcidoids, in scale insects, mealybugs and also other insects. The specimens which Compere described were bred from *Pseudococcus* sp., *Saissetia persimilis* and also from *Homalotylus* (in a coccinellid). From collections made in the Hex River Valley, where *Leptomastix* sp. was the only primary parasite, it appeared that *C. carinatus* was a secondary parasite through *Leptomastix* sp.

With the increase of Leptomastix sp. in December, these hyperparasites appeared and increased rapidly, to reach a peak with Leptomastix sp. (fig. 6), the proportion of Leptomastix sp. attacked also increasing. With the decline in populations in March, the proportion of parasitised Leptomastix sp. also decreased. By April C. carinatus populations were insignificant. This wasp emerged, at the same time as Leptomastix sp. and Anagyrus sp., from parasitised mealybugs collected in late autumn.

Cheiloneurus latiscapus Compere, Female.

Compere (1938) described this as a new species from Durban, from mealybugs parasitised by Anagyrus. At Stellenbosch, on vines, C. latiscapus emerged from parasitised Pl. citri females at the same time as Anagyrus sp. parasitised these mealybugs. In the laboratory it could not be established definitely that C. latiscapus was a secondary parasite through Anagyrus sp.

C. latiscapus never constituted more than five per cent. of the total monthly parasite population, while its host made up 17.9 per cent. at the peak period. *C. latiscapus* was most prevalent in February and was not collected after March.

Achrysophagus aegyptiacus Mercet, Female.

According to Compere (1938), Mercet's description did not cover all the variations within this species, as some of Compere's specimens did not absolutely fit the original description. Mercet's description was almost completely based on colour, especially that of the antennae, which is an exceedingly variable characteristic (Compere, 1938). The specimens described by Compere were reared from *Pl. citri* collected by C.J. Joubert at Stellenbosch, and from *Pseudococcus* sp. from Bukoba, Tanganyika. The specimens bred from *Pl. citri* on vines in the present work were closer to Mercet's description than the one described by Compere from Stellenbosch. This wasp is thought by Compere to be hyperparasitic, being reared from mealybug, *Coccus hesperidum*, and also from coccinellid larvae, through *Homalotylus* in the latter case. In the laboratory this wasp did not parasitise healthy *Pl. citri* females and attempts to breed it through *Leptomastix* sp. were unsuccessful, probably on account of the lack of technique. From field collections, it appeared to be hyperparasitic through Leptomastix sp. or Anagyrus sp.. A. aegyptiacus was even more scarce than C. latiscapus, being collected only in January and March. One specimen emerged in July from a parasitised Pl. citri female collected in April.

Males of Cheiloneurus carinatus, C. latiscapus and Achrysophagus aegyptiacus.

C. carinatus, C. latiscapus and A. aegyptiacus all show a striking sexual dimorphism, and the males of the three species are rather similar. In the present work the males are grouped together because of the original difficulty of separating them. From subsequent surveys it was possible to distinguish three males, the colour of the tegulae and legs, especially the third pair, being characteristic. The males, although never as numerous as the females, nevertheless followed the same fluctuations.

Pachyneuron sp.

All that is known of the biology of this species is that it emerged from parasitised Pl. citri females. They first occurred in November, when the only other parasite present was the primary, Leptomastix sp. It would thus appear that it was a primary parasite or a secondary parasite through Leptomastix sp. It is interesting to note that their numbers had already begun to decline in February, when all other parasites were at their peak (fig. 6). Pachyneuron sp. was not collected after March.

Other parasites.

During the height of parasite activity in December, January and February, nine undetermined parasites, some minute, occurred in small numbers. They were probably hyperparasitic. One specimen of these emerged in June from a parasitised Pl. citri female which was collected in the field in April and kept out of doors.

Occurrence at Paarl.

The 1954-55 season. Figure 8 gives the fluctuation of the total hymenopterous parasite populations during the season. It can be seen that the parasites were present throughout the year, but only increased to any extent from December onwards, with January and February as peak months, after which the populations declined sharply. A parathion spray, applied against the mealybug in December, did not seem to have any effect on the parasite population.

The 1955-56 season (fig. 9). This survey commenced in October, 1955. A few parasites were collected during spring and early summer, but their numbers only increased in January, with a peak in February and March. The season was three to four weeks late, and was reflected in the parasite population peaks. Small numbers of parasites were again collected during the winter months.

Figure 10 is a histogram giving the numbers and fluctuations of the most important parasites for the 1955-56 season.

Leptomastix sp.

This was the only primary parasite collected regularly. In both the 1954-55 and 1955-56 seasons it was present throughout the winter in small numbers. In the 1954-55 season these parasites began to increase in December, reaching a peak in January, and by March and April they had decreased again. The following season, which was late, Leptomastix sp. only increased in January to reach a peak in February.

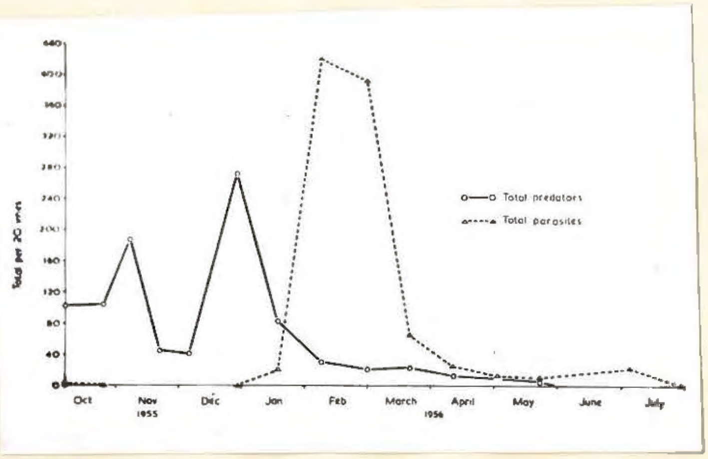


Fig. 9.

Fluctuation of coccinellid predators and hymenopterous parasites. Paarl, 1955-56.

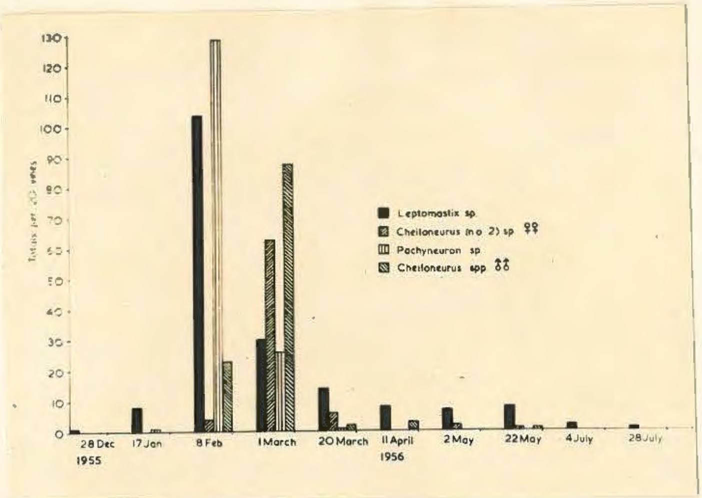


Fig. 10.

Hymenopterous parasites collected, Paarl 1955-56.

Although their numbers declined in March, they continued to be present in fair numbers until May.

Anagyrus sp.

One male of this species was all that was collected during the two seasons.

Cheiloneurus carinatus.

This was the most abundant hyperparasite. In the first season it was only collected during February and March, while in the second season it was present during March, April and May.

Achrysophagus aegyptiacus.

This was not as numerous as *C. carinatus*, but was collected earlier and was still present in the vineyard at a later period than *C. carinatus*.

Cheiloneurus latiscapus.

C. latiscapus was collected occasionally in January and February in both seasons. From the Stellenbosch survey, it seemed that this wasp was hyperparasitic through *Anagyrus* sp. but, as only one *Anagyrus* sp. was collected at Paarl, *C. latiscapus* must also parasitise *Leptomastix* species.

Pachyneuron sp.

As was the case in Stellenbosch, this wasp, in the 1955-56 season, was collected when the only other parasite present was Leptomastix sp. It was most abundant in February and was not collected after March.

Ac.FR. 634.

This wasp was collected on only one occasion in the 1954-55 season and not at all in the following season.

Occurrence in the Hex River Valley.

Leptomastix sp. were collected in all the months of the year except July and August, that is, mid-winter. The hyperparasites, Cheiloneurus carinatus and Pachyneuron sp. far outnumbered Leptomastix sp. during the autumn months (February, March, April and May) but were not collected during the other months.

The following were the parasites collected during March, April and May, 1956.

	26.3.56	24.4.56	25.5.56
Leptomastix sp.			
Males	1	2	2
Females	-	5	3
C. carinatus			
Males	-	15	4
Females	-	6	-
Pachyneuron sp.	20	62	18
Ac.FR. 637 and 638	-	1	-
Ac.FR 634	-	2	-

No Anagyrus sp. were collected and on one occasion only were two females of Cheiloneurus latiscapus taken. These were not on vines but on a fig tree infested with Pl. citri next to the vineyard.

Occurrence at Rawsonville.

In this area collections were made at a time when parasite populations of other areas had already passed their peaks. Leptomastix sp. were present in very small numbers.

The following parasites emerged from 143 parasitised Pl. citri females, collected on 9th April, 1954.

Anagyrus sp.	0
Leptomastix sp.	2
Cheiloneurus carinatus Females	16
Cheiloneuris latiscapus Females	3
Males of above two spp.	39
Pachyneuron sp.	79
Ac.FR. 634	1
Ac.FR. 637 and 638 ...	3

DISCUSSION.

The primary parasite Leptomastix sp. was always the first to be collected in spring and the first to begin the summer increase. In most areas Pachyneuron sp. appeared with Leptomastix sp., before the other hyperparasites were collected. It is of interest to note that Pachyneuron sp. has so far never been collected on vines during the winter. It is possible that this parasite came into the vineyard from an alternative environment, such as guavas or citrus infested by Pl. citri, and would thus be independent of the initial density of the primary parasite. This does not, however, explain why this wasp reaches its peak and declines before the other parasites do. The two Cheiloneurus spp. and Achrysophagus aegyptiacus are dependent on the primary parasites and were thus only collected in large numbers after Leptomastix sp. and/or Anagyrus sp. had become fairly plentiful. The primary and hyperparasitic wasps reached a peak together in autumn. At the end of the season, the primary parasites and hyperparasites declined together, but the hyperparasites became scarce and were not present when Leptomastix sp. reached its prewinter level. During the winter odd primary and hyperparasitic wasps were collected.

Of the four areas surveyed, the numbers of parasites were greatest at Stellenbosch. The Hex River Valley and Rawsonville could not be compared as collections in these areas were not regular. The greatest total of parasites collected per eight vines per month at Stellenbosch was 1666, while at Paarl, although twenty vines were investigated every three weeks, the greatest total was only 284. As pointed out previously, the opportunity for parasitism in the Stellenbosch plot was much greater as the grapes were left on the vines for a longer period. In Stellenbosch the grapes in the experimental plot were picked at the end of March, while at Paarl all grapes were picked by the first week of February.

In both Paarl and Stellenbosch parasites were present in small numbers in the winter, which is how they carry over to the following spring. Even in the colder areas such as the Hex River Valley, Leptomastix sp. emerged from parasitised Pl. citri females collected in August and September. Although no hyperparasites were collected in the winter at Paarl, they were collected in Stellenbosch, indicating that they too overwintered by continuing to breed during the cooler months.

In Stellenbosch the greatest number of parasites was collected during February, whereas in Paarl in the normal season this peak occurred in January and, in the late season of 1955-56, in February-March. By April and May in both Stellenbosch and Paarl, the parasites had returned to the lower prewinter level, while at Rawsonville and in the Hex River Valley, the parasites were still prevalent at this time of the year. They were more numerous at this period in the latter two areas than in February and March, which were the peak months for Paarl and Stellenbosch.

In the Hex River Valley only one species of primary parasite, namely Leptomastix sp., and two species of hyperparasites, *C. carinatus* and *Pachyneuron* sp. were collected. At Rawsonville, both species of primary parasites were collected and also the three species of hyperparasites, *C. carinatus*, *C. latiscapus* and *Pachyneuron* sp. In Paarl only one specimen of *Anagyrus* sp. was collected in in two years and *Leptomastix* sp. was the other primary parasite. *C. carinatus* was the most numerous hyperparasite, followed by *Pachyneuron* sp., while *C. latiscapus* and *A. aegyptiacus* were present in small numbers only.

The greatest variety of parasites was also collected at Stellenbosch. *Leptomastix* sp. was the most abundant primary parasite, although *Anagyrus* sp. was also prevalent. There was an abundance of *C. carinatus*. *C. latiscapus* and *A. aegyptiacus* were more numerous than at Paarl. Several minute unidentified parasites were also collected in small numbers at the peak of parasite activity.

COLEOPTERA.

COCCINELLIDAE.

There were six species of beetles, all of the family Coccinellidae, collected in association with Pl. citri. Both adults and larvae occurred on the vines throughout the year, with a definite peak during early to midsummer. During midsummer the adults and, on occasion, the larvae of several coccinellids other than the above six were collected. These were mainly aphid or scale feeders which were attracted to the mealybug infested vines when their normal food became scarce.

The larval and sometimes the pupal stages of most of the beetles were attacked by hymenopterous parasites. There was some variation in the species collected in the different areas.

Collections and observations of coccinellid predators of Pl. citri on vines were made in the following areas.

Occurrence at Stellenbosch.

In Figure 5 the continuous line graph represents the fluctuation of the total predators, consisting of the Coccinellidae and the Chrysopidae. The latter were so few that this line can be assumed to represent the total coccinellid population.

It can be seen that the coccinellids increased steadily as the summer progressed, to reach a peak at the beginning of December. They gradually declined in numbers during January and February, to be present in the winter months in much smaller numbers.

In Figure 11 is given the occurrence of the most numerous species of coccinellids collected, of which Hyperaspis felixi Muls. was by far the most abundant.

Hyperaspis felixi Muls.

The first larvae were collected in September and occurred until March, being most prevalent in November and December; after March only an occasional adult was taken in the vineyard. A small colony of adults, six in all, was collected in July in curled up dried vine leaves caught in the trellis wire. One pair was copulating. On all other occasions in winter, single adult beetles were collected. These beetles were only found on sunny winter days. Overwintering thus occurs in the adult stage.

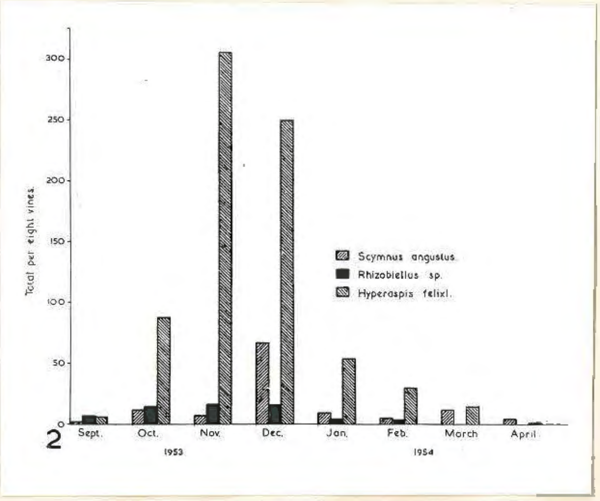
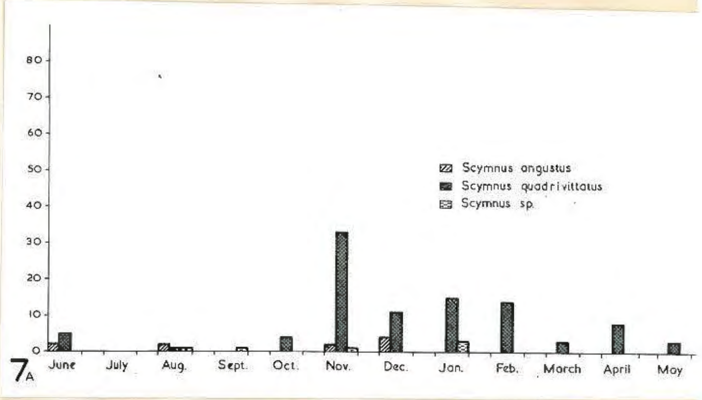


Fig. 11. Coccinellids collected, Stellenbosch, 1953-54.

Fig. 12. Coccinellids collected, Paarl, 1954-55.



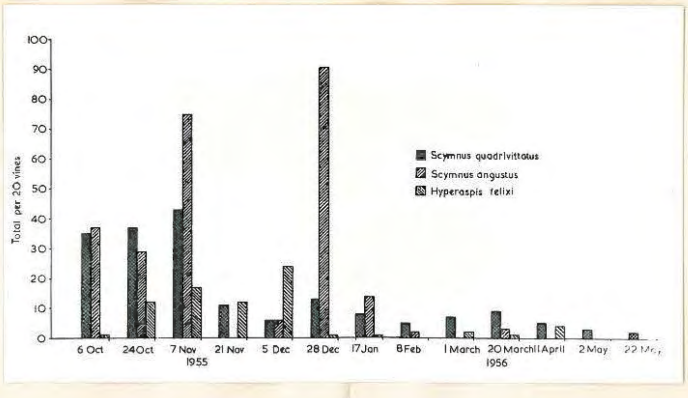


Fig. 13. Coccinellids collected, Paarl, 1955-56.

Scymnus (Nephus) angustus Casey.

The larvae were collected under the bark in spring, in the exposed mealybug colonies at the bases of the shoots in early summer, and feeding on mealybugs on the foliage and in the bunches later in the season. This species was second to H. felixi in numbers, but was not collected during May, June, July and August, that is, during the coldest winter months. The larvae first occurred in September, and were most numerous during December. After April they were not collected again before the following September. In most months there were more larvae collected than adults, as these beetles overwinter elsewhere.

Rhizobiellus sp.

This beetle was present practically throughout the year, the largest numbers being collected in November and December. Adults were also collected in May and August. Larvae, in contrast to the other wax covered beetle larvae, are a dull grey colour, making them difficult to detect. The pupae, which are a pale lemon yellow, were never collected in the field. On occasion, considerably more adults than larvae were collected. In September, 1953, Rhizobiellus sp. formed 43.7 per cent. of the beetles collected, this percentage decreasing to 1.9 per cent. in February and increasing again to 28.6 per cent. the following September. From field collections, it would appear that this beetle overwintered in the adult stage.

Scymnus (Sidis) binaevatus Muls.

Only small numbers of this beetle were collected, mostly feeding on mealybug colonies under the bark during spring and early summer. With Rhizobiellus sp. it was the only beetle collected in August.

Scymnus sp.

This beetle was more frequent than S. binaevatus, being collected from October to April, under the bark, in grape bunches and in the foliage.

Scymnus (Nephus) quadrivittatus Muls.

This coccinellid was less frequent than both S. binaevatus and Scymnus sp., and was collected in small numbers, from October to July. Adults were only occasionally taken in the vineyard.

Other coccinellids.

Of the beetles which occurred occasionally on the vine, Exochomus flavipes Thunb. was most numerous. Larvae and adults were collected during November, December, January and February, the greatest number occurring during December.

Cydonia lunata F. was collected in smaller numbers than E. flavipes, but was on the vine for a longer period. The adults fed mainly on mealybug egg sacs on the leaves during summer. No larvae were collected on the vine.

Scymnus morelleti Muls. adults were quite numerous on the vines in November and December, but they were never actually seen to feed on Pl. citri.

A few adult Adalia flavomaculata De Geer which were collected on vines during November, were seen to feed on Pl. citri.

Occurrence at Paarl.

Collections of Coccinellidae made during the 1954-55 season. The annual fluctuations of all the predators are given in Figure 8. The infestation of Pl. citri was greatest in August and September, when they increased enormously under the bark of the vines at the onset of spring weather. As the summer progressed, the population decreased, mainly as a result of the rapid increase of the predators and later the parasites. Towards autumn, the natural enemies became less active, resulting in an increase in the Pl. citri population again.

The predators were present in fairly large numbers throughout the winter. They increased to a maximum in November and December, after which they decreased gradually until March, when they attained their winter population level. In Figure 12 is given the annual fluctuation of the most important coccinellids during 1954-55.

The 1955-56 season (fig. 9). Work in this plot commenced in October, 1955. In spring the coccinellids were numerous, but their numbers declined at the end of November and increased again towards the end of December. After this peak, the population gradually decreased and no beetles were collected after May. This decline of the predator population during November was the direct result of a DDT application in summer for snout beetle control. Figure 13 represents the annual fluctuations of the most important coccinellids collected.

Scymnus quadrivittatus.

In the 1954-55 season this was the most abundant coccinellid, being collected in all months of the year, except July and September. It was the only beetle present during February, March, April and May. The larvae, which were collected while feeding on Pl. citri under the bark, on the foliage and in infested grape bunches, were always more numerous than adults. S. quadrivittatus was again abundant during the 1955-56 season, being most numerous in October and November, after which this species decreased gradually and was not collected after May.

Scymnus angustus.

This species occurred sporadically throughout the winter and summer months during the 1954-55 season, and was not collected after December. During the 1955-56 season, these beetles were more numerous than S. quadrivittatus in the early summer, reaching a peak in December, but were not collected after March. S. angustus larvae have the same feeding habits as the larvae of S. quadrivittatus, and are found on any part of the vine infested with Pl. citri.

Hyperaspis felixi.

Only a few larvae of this species were collected in the first season. In the second season slightly more larvae were present, being taken from October to April, and the largest numbers occurred in November. Adults of this species were collected on infested vines during the winter.

Scymnus sp.

Small numbers of this beetle were present during August, September, November and January, in the first season, but during 1955-56 smaller numbers were collected, and they were present only during October and November.

Rhizobiellus sp.

This species was collected only during November and December in 1954, but was present in slightly larger numbers the following season, being collected from October to April.

Scymnus binaevatus.

During both seasons this beetle was the least prevalent of the coccinellids, and was collected during November and December in the first season, and during October in the second.

Exochomus flavipes was the most numerous of the beetles present on the vine for short periods only. This coccinellid was only collected in the 1955-56 season, when, in December, both larvae and adults were present on the vines in fairly large numbers. Some larvae were collected as late as in June.

Cydonia lunata and *Adalia flavomaculata* were not present, while adults of *Scymnus morelleti* were present on a few occasions during December and January.

Occurrence in other areas.

At Orchard, where most of the collections were made in the Hex River Valley, no early summer build-up of coccinellids occurred, as the mealybug populations were low until late in the summer. *S. quadrivittatus* was the most important beetle, and was collected throughout the late summer and winter. *Rhizobiellus* sp. was fairly numerous in early winter, but only isolated specimens of *S. binaevatus* and *Scymnus* sp. were collected. *H. felixi* was totally absent.

Parathion has been extensively used for the past ten years in vineyards in this region, and may account for the low predator populations. During the 1955-56 and 1956-57 seasons, very little parathion was applied on the farm where the present survey was conducted, and a noticeable increase in the beetle population has taken place.

The small collections made at Rawsonville have only yielded *S. quadrivittatus*.

DISCUSSION.

The most important coccinellid species, *H. felixi* at Stellenbosch and *S. quadrivittatus* at Paarl, were collected throughout the winter, the former mainly in the adult stage, the latter in all stages. These beetles definitely overwintered in vineyards infested with *Pl. citri*. At Stellenbosch and at Paarl in the 1954-55 season, the coccinellids were most abundant during November and December, but, in the 1955-56 seaaon at Paarl, they reached a peak at the beginning of November, decreased, then reached another peak at the end of December. The splitting of the period of maximum beetle activity was the result of an application of DDT at the beginning of December. Apart from this disruption of predator activity, there was little difference between the time of occurrence of the beetles at Stellenbosch and at Paarl. There was, however, a difference in the abundance of the various coccinellid species collected. S. angustus was equally prevalent in both areas, but, while H. felixi was by far the most abundant species collected at Stellenbosch, it was of minor importance at Paarl. The summer application of parathion for the control of Pl. citri at the bases of the young vine shoots may have caused this difference, as the larvae of H. felixi, at the time of spraying, were feeding on these. The larvae of the other beetle species were at this stage still feeding on Pl. citri colonies under the bark on the main stem of the vine, and were thus not so exposed to the action of the parathion. Collections made at Paarl seem to bear this out. H. felixi was collected only in small numbers during the first season when a mealybug control spray was applied, whereas in the second season, when there was no mealybug control spray, considerably more H. felixi larvae were present. Spraying for Pl. citri on the experimental farm at Stellenbosch was kept to a minimum and no application was made in the block of vines used for the present work. It was here that H. felixi occurred in such large numbers.

In the Paarl area, S. quadrivittatus was by far the most important beetle, whereas at Stellenbosch it was of minor importance. The slightly milder winters of Paarl may have been more advantageous to it.

As in the case of the parasites, it will be noted that the actual numbers of beetles collected were considerably smaller at Paarl than at Stellenbosch. This was definitely the result of lower mealybug infestations.

From Figures 5, 8 and 9, it can be seen that the general pattern of beetle occurrence commenced with a gradual build-up in spring, resulting in a peak in early to midsummer, slightly in advance of the peak of the Hymenoptera population. These populations declined in the latter part of summer and remained more or less constant during the winter. Contributory causes to the summer decline will be discussed under factors limiting the population of the Coccinellidae.

PART II.

BIONOMICS OF SOME INSECTS ASSOCIATED WITH PLANOCOCCUS CITRI (RISSO) ON VINES IN THE WESTERN CAPE PROVINCE.

LABORATORY AND OUTDOOR BREEDING TECHNIQUE.

The breeding of both adults and immature stages of the coccinellid and chrysopid predators was carried out in three types of receptacles. It was found that 75 mm. Petri dishes with lids were admirably suited to the breeding of adults, especially of the larger beetle, *Hyperaspis felixi*. Metal tins fitted with glass topped lids were found to be unsatisfactory because of the condensation of moisture and the limitation of light. Petri dishes were also well suited to the mass rearing of coccinellid larvae. For feeding studies and the rearing of individual larvae, embryological watch glasses with glass lids were used. Outdoor work was carried out in a gauze insectary, roofed with plastic material and partially covered with slats so that no direct sunlight fell on the cages. Light is essential for breeding of H. felixi, as was shown when pairs were placed in a darkened incubator. No eggs were laid until the beetles were placed in a controlled temperature room receiving reflected sunlight. Studies at a controlled temperature were carried out at 24°C. The humidity was not controlled. Breeding material, collected in the field in the immature stages, was reared to maturity on Pl. citri. Field collected gravid females were also used, but the immature stages were easier to collect.

COCCINELLIDAE.

A description of the male genitalia and the terms used to describe them is given before commencing with the biology of the Coccinellidae.

NOMENCLATURE OF THE MALE GENITALIA.

During recent years the structure of the male genitalia of Coleoptera has been used to an increasing degree as a characteristic for the establishment of the identity of certain species. Two cases to illustrate this point are cited below. They both concern the genus Stethorus of the Coccinellidae.

Stethorus aethiops Weise and S. jejenus Casey, which have similar distribution, were suspected by Sichard, of being the same beetle, although different in size and colouration. They can be readily distinguished by the structure of the male genitalia (Kapur, 1948). In America S. punctum (Leconte) and and S. punctillum Weise were confused, the latter being a new introduction into that continent. They are only distinguishable by the structure of the male genitalia (Brown, 1950). Male genitalia were also used by Kapur, (1949) to separate some of the Rodolia species of India.

Review of the terms used by various authors dealing with male genitalia of Coleoptera.

Sharp & Muir (1912) reviewed the structure of the male genital tube of the Coleoptera and discussed the possible reclassification and affinities of the various groups. These authors, although they considered the male genitalia of Coccinellidae to be aberrant, did not consider this sufficient justification for separating them from the rest of the Coleoptera as Verhoeff

(1895) had advocated.

The terminology used by Sharp & Muir was derived from various authors, but new terms were adopted where the existing ones were deemed confusing or inadequate.

Snodgrass (1935), in an attempt to clarify the confusion in nomenclature of the male genital apparatus of insects, adopted a terminology which he maintained could be applied consistently to the major structures, regardless of their morphological relations to one another. Special structures occurring in each order were named individually. This author maintained that the genitalia of Coleoptera were entirely phallic and did not consider them related to the gonopods.

Michener (1944) retained the basic nomenclature of Snodgrass, but held that the genitalia of Coleoptera were not wholly phallic, although they did not firmly articulate with the ninth abdominal segment. Michener based his statement on the musculated processes (gonostyli) articulated with the fused gonocoxites.

Wood (1952), using the foundation established by

Michener, pointed out further homologies of the male genitalia of Coleoptera. He correlated, in tabular form, the terms used by Michener with those of other authors. The table is reproduced below, with the addition of terms used by Kapur (1948) and Bielawski (1955) in describing the genitalia of Coccinellidae. It must be pointed out that the table of Wood is not accurate in one instance. Wood equated the aedeagus of Michener (penis fused with penis valves, Michener's own definition) with the median lobe of Sharp & Muir, whereas in fact it is the median lobe plus part of the tegmen of Sharp & Muir. The penis of Michener represents the median lobe of Sharp & Muir.

Kapur and Bielawski have apparently used some of the terms of Verhoeff (1895), whose basal plate, parameren and spiculum gastrale correspond to the basal plates or basal part, parameres, and spiculum or spiculum gastrale of Kapur and Bielawski. These two authors use siphon to designate a different part of the genital apparatus from what Verhoeff calls the siphon. The sipho of Kapur and the siphon of Bielawski correspond to the median lobe of Sharp & Muir, whereas the siphon of Verhoeff is, according to Sharp & Muir, a structure within their median lobe.

Table I. Comparison of the terms used by various authors for the description of the male genitalia of Coleoptera.

Michener	Snodgrass	Sharp & Muir	Kapur	Bielawski
Gonoforceps	-	Tegmen	-	-
Gonocoxite	Phallobase	Basal Piece	Basal Plate	Basal part
Aedeagus	Aedeagus	-	-	-
Penis	-	Median Lobe	Sipho	Siphon
-	Phallus	Aedeagus	-	-
Penis Valves	Epimere	-	Penis	Penis
Gonostylus	Paramere	Lateral lobe	Paramere	Paramere
Expanded base of Penis	-	Expanded base of Median Lobe	Siphonal Capsule	Siphonal Capsule
Apodeme of Gonoforceps	Aedeagal Apodeme	Median Strut	Trab	Trabes

Description of the Male Genitalia.

Figure 14 is a diagrammatic representation of a generalised male coccinellid copulatory apparatus including the invaginated segments. The nomenclature used is that of Michener (1944).[*]

Theoretically, the male copulatory apparatus of Coleoptera, when evaginated, forms a long tube, portions of which are sclerotised and portions membranous. When the tube is retracted into the body, there is a folding of the membranous parts. This invagination results in the changing of the position of the parts in relation to the rest of the body. The gonopore (gp) (ejaculatory opening of the intromittent organ), which is the most distal part in copulation, becomes withdrawn and lies approximately midway in the retracted apparatus. The penis (p) is a long curved sclerotised tube with an expanded base, the shape of which is characteristic and can be used taxonomically. The ejaculatory duct (ej) passes into the tube at the open end of the expanded base. At the distal end of the penis is the gonopore (gp). The gonoforceps (gf) consists of three parts:-

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[*] Also used by Fischer (1956) in describing the male genitalia of Megachile fortis (Hymenoptera: Megachilidae).

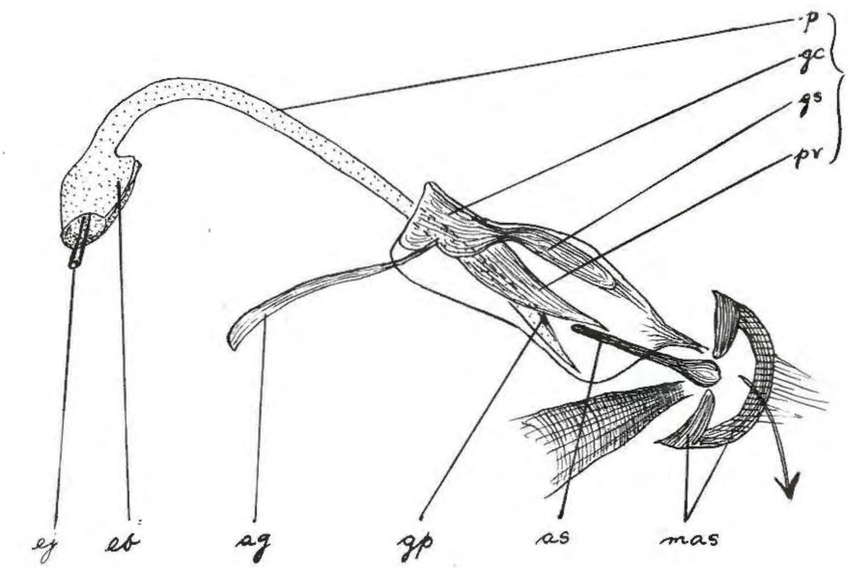


Fig. 14.

Diagram of the male copulatory apparatus of a coccinellid.

ag = apodeme of gonoforceps.
as = apodeme attached to modified abdominal segments.
eb = expanded base of penis
ej = ejaculatory duct
gc = gonocoxites
gf = gonoforceps
gp = gonopore
gs = gonostyli
mas = modified abdominal segmants
p = penis
pv = penis valves.

1. The fused gonocoxites (gc) forming a collar around the distal portion of the penis.
2. The gonostyli (gs) which are paired ligulate structures with setae on their free ends. They are attached to the gonocoxites.
3. The penis valves (pv) which are fused to form a pointed scletorised sheath, are attached to the fused gonocoxites ventral to the gonostyli (ventral when the genitalia are withdrawn). In copulation the genitalia are evaginated in an outwards and downwards direction, as shown by the arrow in the diagram, causing the penis valves to be dorsal to the gonostyli.

At the junction of the penis valves with the gonocoxites is an apodeme which is attached to the expanded base of the penis by means of muscles (Sharp & Muir, 1912).

With the invagination of the male organs into the body cavity certain modifications of the surrounding segments have taken place. Surrounding the genital chamber (an invagination between the ninth and tenth segments), forming a complete ring, is a structure considered by Snodgrass to be the ninth segment. Attached ventrally to this is an apodeme which lies in close proximity to the membrane enclosing the gonoforceps (second membrane of Sharp & Muir). This structure is the spiculum of Brown (1950) and the spiculum gastrale of Bielawski (195~~0~~5). Brown considers this apodeme to be attached to the modified abdominal tergites. The above apodeme varies in size and shape in the different species and can be used as a taxonomic characteristic.

STUDIES OF THE PREDATORY COCCINELLIDS.

The following are the coccinellid beetles to be discussed:-

Hyperaspis felixi Mulsant.
Scymnus (*Nephus*) sp. (*quadrivittatus* Muls.?)
Scymnus (*Nephus*) *angustus* Casey.
Scymnus (*Sidis*) *binaevatus* Muls.
Scymnus sp.
Rhizobiellus sp.

HYPERASPIS FELIXI MULSANT.

This beetle occurred in a two-spotted and a four-spotted form. The two-spotted form had a yellow apical spot on each elytron, whereas the four-spotted form had, in addition to the apical spot, a yellow spot in the middle of each elytron near the outer margin. The spot in the middle of the elytron is usually the larger. The two forms were described as separate species by Mulsant (1850), the two-spotted form being described as *Hyperaspis felixi* and the other form as *H. hottentota*. Crotch (1874) used the spelling *hottentotta*, as did the British Museum (personal correspondence). Controlled breeding experiments have shown that the two forms interbred freely, the immature stages being indistinguishable. The two forms also interbred in the field. In this work both forms will be known as *H. felixi*, as this form has page priority in the original description by Mulsant. When it is desired to differentiate between the two forms, the elytral pattern will be used.

Breeding experiments with the two forms.

The original breeding stock was collected in the pupal stage in the field at Stellenbosch. These were bred, brother to sister for three generations in one form, and for four generations in the other form. Owing to the scarcity of the two-spotted form it was only possible to collect females in the field. To obtain further material these females were bred to four-spot males and the two-spotted forms of the progeny inbred for three generations. Where possible, each cross was replicated five times.

The pure strains were then crossed, and gave only four-spotted progeny. These progeny were back crossed to both two-spotted and four-spotted parents.

As the experiment is still proceeding, the results are not conclusive, but it appears that the four-spot is dominant over the two-spot. It is interesting to note that in Stellenbosch the four-spotted variety was the predominant form, occurring in the ratio of 7.4 four-spot to 1 two-spot. The ratio was obtained from 772 beetles collected in the field. This beetle was much less numerous in Paarl and only 181 beetles were collected in one season. The ratio in Paarl was 2.6 four-spot forms to 1 two-spot form.

Description of the Adult.

This beetle is convex, slightly elongate and shiny black (figs. 15 and 16). The mean length of twenty females was 3.4 mm. and of twenty males 3.2 mm. Towards the basal margin of each elytron, parallel to the outer margin, is a slight raised area, the humeral carina. On the lateral margins of the prothorax are two semicircular yellow markings. On the outer margins of the ventral surface on each of the first four visible abdominal segments there is a small brownish area, which becomes less distinct posteriorly on each successive segment. The rest of the ventral surface is black. Females are distinguished by the black fronto-clypeal area, whereas in males this area is yellow. The anterior margin of the prothorax in males is either translucent or yellow. There is also a difference in colouration of the legs in the sexes. The basal two-thirds to three-quarters of the femora of the male are black, while the distal portions are brown. In the female the femora are entirely black.

Genitalia of the Male (figs. 17, 18 and 19).

The penis (median lobe of Sharp & Muir, sipho of Kapur) is strongly sclerotised and strongly curved, forming nearly a circle. There is a slight expansion of the tube just before the gonopore. The

HYPERASPIS FELIXI.

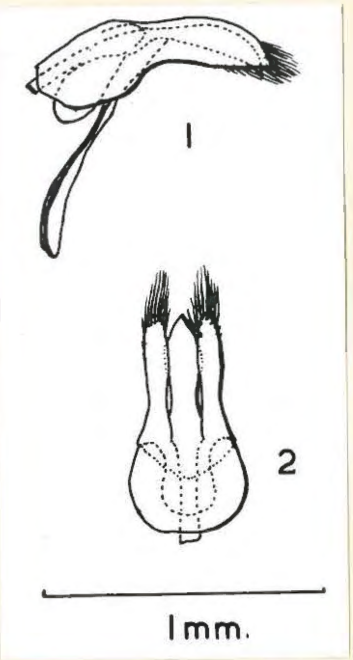


Fig. 18.

Gonoforceps.

1. Lateral view.
2. Dorsal view.

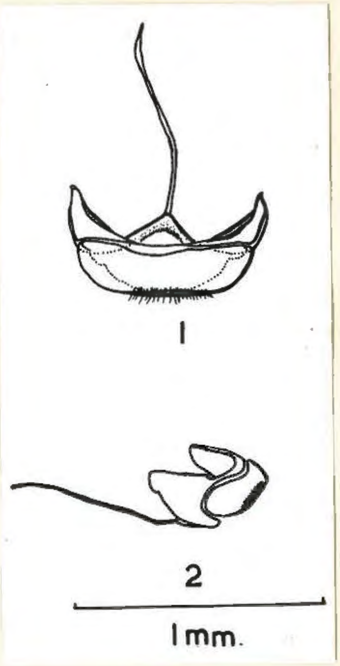


Fig. 19.

Modified abdominal segments.

1. Dorsal view.
2. Lateral view.

gonostyli (paramers of Kapur) are equal in length to the fused penis valves, in lateral view (fig. 18), practically concealing the penis valves. The apodeme of the modified abdominal segments (spiculum of Kapur) is thin and ribbon-like, expanding into a large triangular piece where it joins the modified abdominal segments (fig. 19).

Mandible (fig. 20).

The mandible is bifid at the apex, the outer tooth being smaller than the inner. The basal tooth is bicuspidate.

Antenna (fig. 22).

The antenna is short and ten segmented, being only slightly clubbed. the first segment is large, and nearly as wide as long, while the second segment is smaller, but of similar shape, and is also nearly as wide as long. The third segment is narrower than segments one and two, and longer than each of the succeeding four segments. The last three segments form a slight club, The terminal segment is short and tapers to a point.

HYPERASPIS FELIXI.

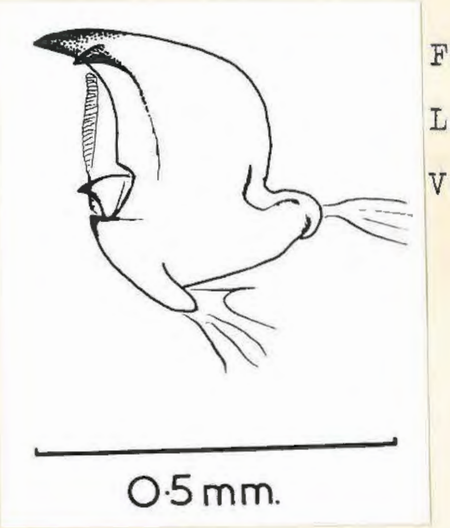


Fig. 20.

Left Mandible of adult.

Ventral view.

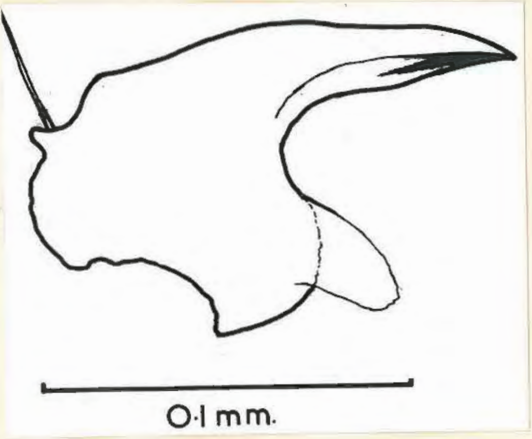


Fig. 21.

Left mandible of mature larva.

Dorsal view.

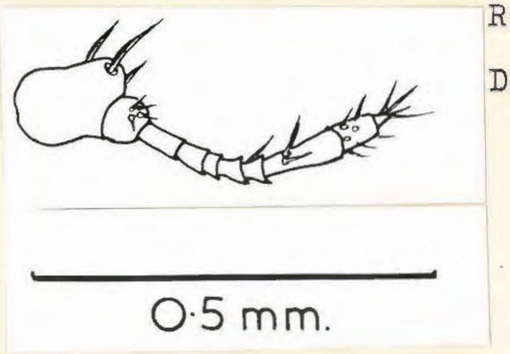


Fig. 22.

Right antenna of adult.

Dorsal view.

The egg (fig. 23).

The eggs are laid flat on the surface, singly or in groups. They are oval in shape and are attached to the substratum, from which they are difficult to remove without breaking.

When laid, the eggs are olive green in colour. Adhering to the surface of the eggs are sometimes fine particles of dirt and dust. As the eggs develop, the colour changes from olive to olive-fawn and finally to fawn. A dark brown patch appears as development continues and three dark spots in a line become apparent. These are the egg bursters. Three eye spots also become visible at the same end as the egg bursters. A few hours before the egg hatches, it appears a greyish white as the thoracic spines lift the chorion away from the embryo within. The eggs now have a tent-like appearance, due to the formation of a ridge down the length of the dorsal surface.

The three bursting spines, one to each thoracic segment, are either on the left or the right of the thorax, but never in the middle. One instance was observed, however, where there were two spines per segment. Of 63 larvae, 31 had spines on the right side and 32 on the left side. Only one had spines on both sides. The arrangement of the spines was not correlated to either the sex or form.

Eclosion of the egg.

The three bursting spines move independently, but in sequence, either all backwards, one after the other, or all forwards, in the general direction of the longitudinal axis of the egg. The middle spine has the greatest range of movement and pierces the chorion first. The anterior and posterior spines move slightly on the curve, with the result that a semicircular opening is made (fig. 23 (2)), through which the larva emerges by pushing outwards. The pressure of the emerging larva serves further to enlarge the opening at the corners.

During the hatching process, the larva rotates on its long axis. Viewed from above, the three spines can be seen on the left of the egg. These are the bursting spines on the right side of the embryo, which is lying on its left in the egg (fig. 24).

HYPERASPIS FELIXI.

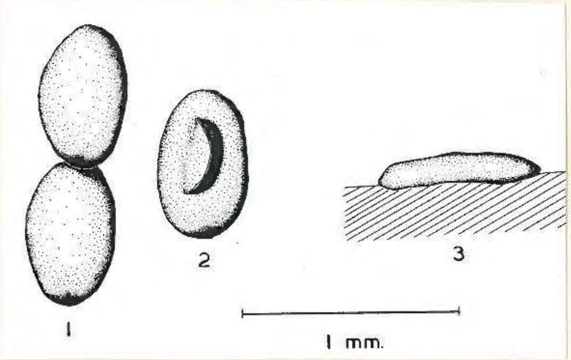


Fig. 23.

Eggs.

1. Dorsal view.
2. Hatched egg.
3. Lateral view.

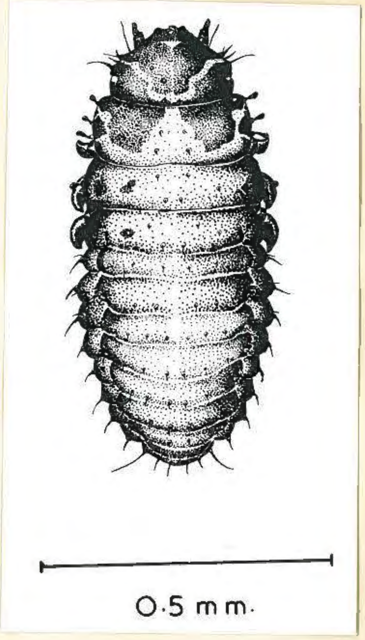


Fig. 25.

First instar larva.

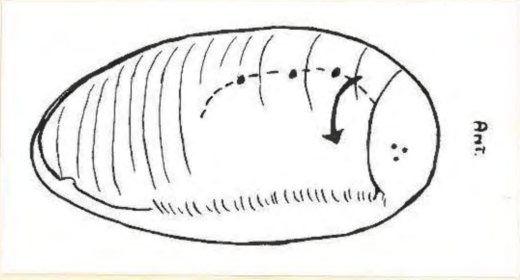


Fig. 24.

Diagram of an egg about to hatch.

Larval stages.

After repeated movements, the head and thorax of the first larval instar are thrust through the semicircular opening in the dorsal surface of the egg. The larva immediately crawls out and, without resting, seeks the shelter of an egg sac if available. It burrows deeply into this, but if egg sacs are not available, mealybugs of any size are attacked, including adult females.

On emergence, the head and appendages are yellow, the eyes black and the body a greyish yellow, devoid of any wax covering. There are peculiar spoon-shaped setae on the lateral margins of the thorax (fig. 25). Böving (1933) found similar structures on the larvae of Decadiomus pictus Chapin. The larvae become duller in appearance with age, and some have a fine powdering of wax, presumably from the egg sacs which they frequent. Prior to moulting, the insect attaches itself to the substratum by means of its anal sucker. In the last stages of the moult, the body is held at an angle of about 45°. The head and thorax are jerked up and down sharply with general sideways movements of the body. The body is sometimes held perpendicular with legs outstretched. The rupture of the larval skin commences behind the head and is lengthened by the body movements. The head is drawn out of the old skin, followed by the legs and the rest of the body.

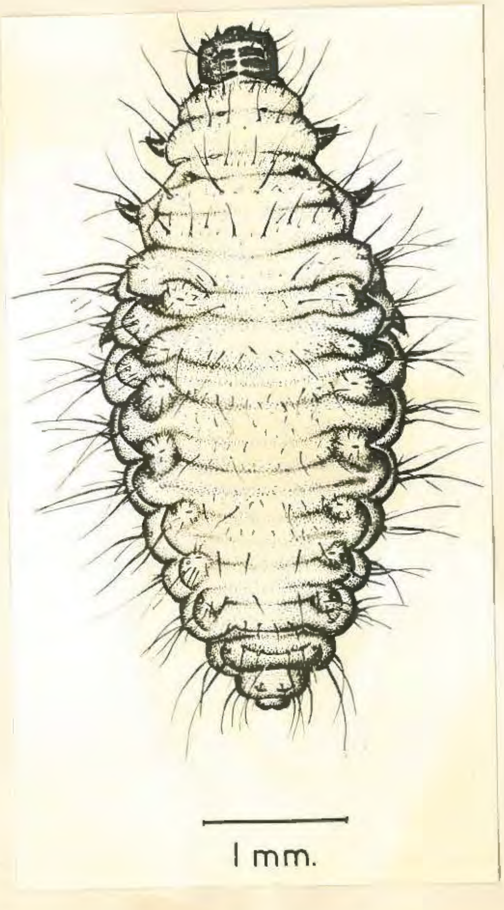
The second, third and fourth instar larvae are similar in appearance, differing only in size. All are covered with a dense coating of wax, not arranged in any definite pattern (fig. 26). Along the lateral margins of the body the wax covering forms short filaments, while on the mid-dorsal line the wax covering is longer than the surrounding wax, giving the larva a roofed appearance. The intersegmental areas of the thorax and abdomen are only visible when the larva is in motion. The head and legs, which are black, are often hidden by the wax covering of the thorax. The body is a greenish yellow.

Figures 27 and 28 are dorsal and lateral views of a mature larva with the wax covering removed. Figures 29 and 30 are dorsal and ventral views of the head of a mature larva.

HYPERASPIS FELIXI.

Fig. 26.
Mature larva.

Fig. 27.
Mature larva, wax removed.
Dorsal view.



Pupa (fig. 31).

Towards the end of the last larval instar the larva ceases to feed and attaches itself to the substratum by its anal sucker. Before the larva has finally settled, several attempts are made to attach itself. This was seen from the patches of yellow secretion on the bottom of the cage.

The last larval skin splits almost the length of the body, but does not recede to around the anal sucker. The transformation into the pupa is not easy to discern as the wax covering does not part completely, but adheres to the dorsal surface. It is only when the pupa darkens that it is easily noticed. The new pupa is a pale yellow which, after about a day changes to a grey-brown. The whole pupa is covered with grey-brown setae and on the surface of integument are minute bead-like droplets of a clear fluid.

Life History.

Overwintering.

Complete hibernation did not take place as the winter temperature seldom dropped below freezing.

HYPERASPIS FELIXI.

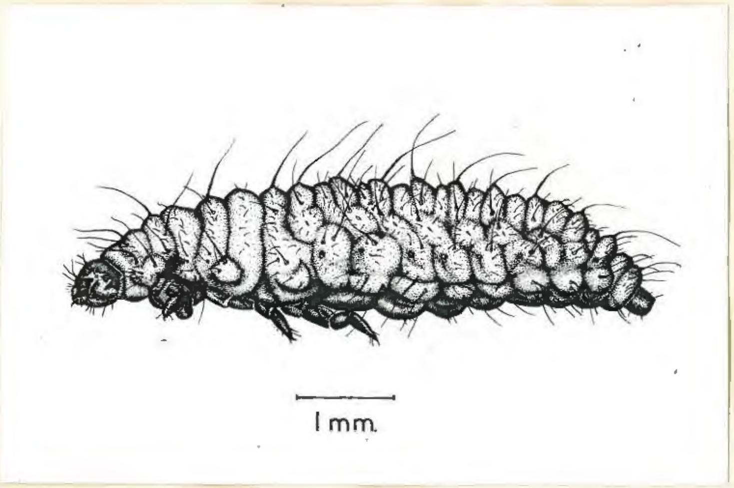


Fig. 28.

Mature larva, wax removed. Lateral view.

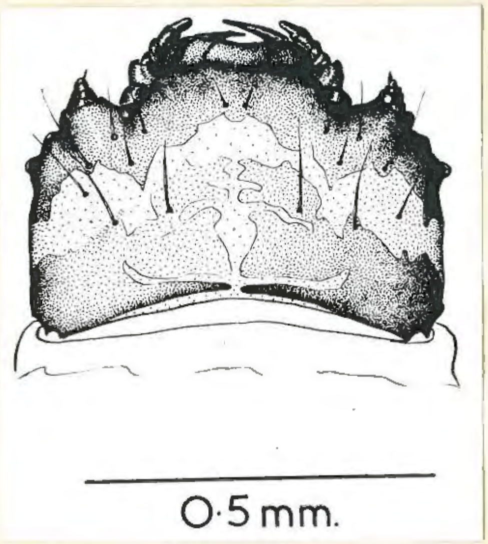


Fig. 29.

Dorsal view of head of mature larva.

Beetles of this species, kept in the laboratory, however, ceased to lay when the mean temperature dropped below 21°C. On the other hand, some females kept out of doors laid eggs sporadically throughout the winter period. The majority of these, however, discontinued egglaying in February, March and April, and commenced again from July to October. In the following table are given the dates of the last autumn and first spring eggs.

Table II. The last autumn and first spring eggs laid by H. felixi in the outdoor insectary.

Female	Last Autumn Eggs laid on:	First Spring Eggs laid on:
1	23.3.54	Died during winter.
2	22.4.54	17.6.54
3	Laid throughout period.	
4	15.3.54	13.9.54
5	27.3.54	2.7.54
6	24.2.54	2.7.54
7	19.2.54	4.10.54
8	Laid throughout period.	

Duration of Immature Stages.

Egg. At outdoor temperatures during February eggs required from 6 to 10 days to hatch, with a mean of 7.6

HYPERASPIS FELIXI.

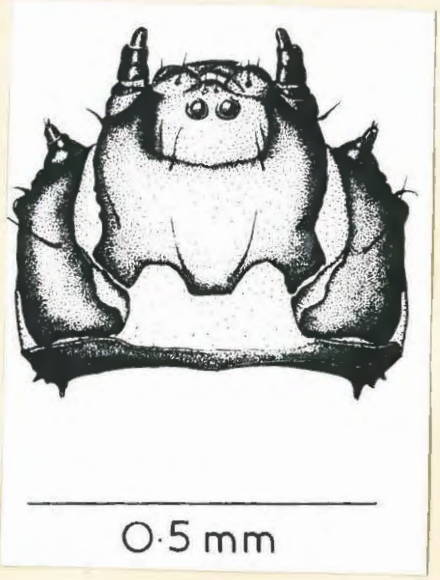


Fig. 30

Ventral view of head of mature larva.

Fig. 31.

Pupa.

days, while eggs kept at a constant temperature of about 24°C. hatched after five days. Eggs kept at a temperature of 14°C. emerged after 25 days, but the resultant larvae failed to survive.

Larval and pupal stages. The duration of the various immature stages kept in the laboratory was compared with stages kept out of doors during February and March.

Table III. Mean duration in days of the immature stages of *H. felixi* kept in the laboratory at 24°C. and out of doors when the mean temperature was 21.4°C.

		Outdoor			
Egg	Larval Stages 1	2	3	4	Pupa
7.6	3.8	2.8	5.4	13.6	11.4
8.2	4.0	2.7	14.3		13.3
		Laboratory			
5.0	4.0	2.3	4.1	9.1	9.0

The fourth larval instar included a prepupal period of two to five days in the outdoor beetles and two to four days in those beetles kept at constant temperature in the laboratory.

Of the 13 beetles kept out of doors, only five completed the four larval instars before pupating, while the remaining eight completed only three. By comparison of the duration of the larval instars of the other larvae, it appeared that the third and fourth instars were combined, which resulted in a shortening of the developmental period by several days. In all instances the second larval instar was the shortest and the fourth the longest, except where the third and fourth instars were combined.

On becoming fully developed, the adults, although free from the pupal skin, did not emerge, but remained concealed under the pupal covering for a period varying from three to six days. They were often found hanging upside down in the pupal case, facing the opposite direction to the pupa. If removed, they behaved normally and commenced to feed.

Longevity and Fecundity of Adults.

Egglaying and longevity experiments were conducted both out of doors and under constant temperature conditions in the laboratory.

Table IV. Fecundity and longevity of *H. felixi* kept out of doors and in the laboratory.

Outdoor								
Length of life in days						No. of Eggs laid.		
Males			Females					
Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
42	440	215.0	82	438	213.5	91	717	309.0
Laboratory 24°C.								
95	226	132.3	63	267	141.0	111	887	471.0

For the outdoor work twelve pairs of beetles were used, while for the controlled temperature experiments six pairs were used. The outdoor beetles were from a generation which had matured in late summer. Egg-laying, which had already commenced, was discontinued when the weather became unfavourable, and commenced again in spring.

The preoviposition period varied from 15 to 35 days out of doors, while under controlled conditions this period was from 3 to 13 days. The greatest number of eggs laid on one day was 62, by a female kept out of doors, but the rate of egglaying was higher in females kept in the laboratory than those kept at the fluctuating natural temperatures.

The pairs kept under natural conditions mated frequently, but sperm could apparently be stored for a considerable period, as was shown when males were removed from females at the commencement of egglaying. In one instance fertile eggs were laid 125 days after the male had been removed.

There was no appreciable difference between the longevity of males and females at either temperature. As would be expected, the life of beetles was extended considerably at outdoor temperatures where the cool weather slowed down development.

Sex Ratio.

At Stellenbosch the ratio of the two-spot form, males to females, was 44.4 : 55.7 and of the four-spot form, 47.1 : 52.9, giving a total ratio of 47.4 males to 52.6 females. These ratios were derived from 88 two-spot forms and 684 four-spot forms. At Paarl, where the total number of beetles collected was only 160, the ratio of two-spot males to females was 65.9 : 34.1, and four-spot males to females was 44.1 : 55.9, giving a total ratio for both forms of 50 : 50.

Seasonal History.

H. felixi occurred mainly in the early summer months, the greatest number being collected during November and December. Attacks by parasites and a reduction in the food supply caused a decrease towards the end of summer. After March no immature stages were collected. The beetles overwintered in the adult stage, and were collected in small numbers throughout the winter on sunny days, both at Paarl and Stellenbosch. From breeding experiments under near natural conditions, it was found that females, which had emerged in autumn, laid during the same season and in most cases discontinued laying during the cold weather. They resumed egglaying in the spring. In no cases did the adults overwinter again. The first larvae were collected in September at Stellenbosch and October at Paarl.

Food Habits.

Hosts attacked. Adults and larvae fed on all stages of Pl. citri on vines, and Ps. adonidum was eaten if no other food was available. The larvae have also been seen to feed on Ps. maritimus. Pl. citri on other plants such as guava, cassia and wild paw-paw, were also attacked. Adults and larvae have been collected feeding on an unidentified mealybug species on Plumbago capensis, on a soft scale on Leucospermum and on an Eriococcus attacking a veld shrub, Cliffortia ruscifolia. Starved adults consumed rose aphids. The host range appeared to be wide, Pl. citri being attacked on vines in early summer until the dense colonies dispersed. The scattered mealybugs remaining do not suit the feeding habits of this predator and the adults sought ovipositional sites elsewhere, such as the Eriococcus which was attacked in January.

Method of feeding. From a comparison of the mandibles of the adult (fig. 20) and of the mature larva (fig. 21), it can be seen that the mandible of the adult, with bifid apical tooth and strong bicuspidate basal tooth, is suited to chewing, while the delicate single apical tooth of the larva is adapted to piercing. Adults consume the host completely, whereas the larvae pierce them and suck out the body fluids, discarding the remains.

The larvae are prognathous and, when young, attack the mealybugs from the ventral surface, whereas the larger larvae attack them from the side. Larvae, with their heads encrusted in the secretion from the protective glands of the mealybug, were often encountered. Larger larvae survive this by moulting, but the younger stages die from lack of food. On removal of the encrustation, the larvae behave normally and continue to feed. The first instar larvae prefer to burrow into the mealybug egg sacs, tunnelling into the centre and feeding until all eggs are consumed. If no egg sacs are available, the first instar larvae feed on any other stage of the mealybug present.

Colonies of mealybug under the bark were not often attacked because they could not be reached by the larger larvae. The larvae thus attacked the more exposed colonies which formed at the base of the young shoots during early summer, and in the grape bunches later in the season.

Rate of feeding. Feeding experiments were conducted at 24°C. in embryological watch glasses. The larvae and adults were fed second and third nymphal instars of the mealybug *Pl. citri*. In some cases the first larval instar of the beetle were fed mealybug eggs. In the results, the number of eggs consumed was converted to number of nymphs. From comparative feeding records it was found that on an average, five mealybug eggs were equivalent to one mealybug nymph.

Table V. Mealybugs consumed by one female and the mean of seven male *H. felixi*.

Sex	Larval instars 1	2	3	4	Adult	Total
Male	10.3	7.6	14.5	132.8	578.3	744.4
Female	13	11	11	125	2630	2790

Of the immature stages, the large fourth instar larvae consumed most mealybugs. This was not only because they had the biggest appetites, but because their feeding period was the longest. They consumed an average of 12.2 mealybugs per day, compared with 3.8 of the third instar, 2.3 of the second and 2.3 of the first instar. The average rate of feeding during the whole of the immature stages was 7.6 mealybugs per day, while that of the adults was 6.8 per day, but the greater length of life of the adults resulted in a larger number of mealybugs being consumed. The average length of the feeding period of the adult males was 94 days, compared with 22.8 days of the immature stages.

Putman (1955a), investigating *Stethorus punctillum*, found that ovipositing females consumed twice as many mites as males did. Unfortunately only one female emerged from the larvae of *H. felixi* used. This female in the adult stage, while ovipositing, also consumed more than twice as many mealybugs as the greatest number consumed by any of the males.

Behaviour of the Adults.

General behaviour. The adults were very active during warm weather, flying readily if disturbed. They had the habit of hiding behind one of the vine canes when the vine was approached.

Oviposition. In the field eggs were laid singly, but in close proximity, on the vine bark in the vicinity of mealybug colonies. In the laboratory eggs were deposited on any surface providing this was near a mealybug colony. The habit of laying near mealybug colonies was used in egglaying experiments where mealybug egg sacs were placed on loose bits of cork. In captivity, when large numbers of eggs were laid, they sometimes overlapped or were laid on top of one another. On a few occasions the adults consumed the eggs laid, but this usually occurred when the food provided was insufficient.

Detection of Prey. No experiments were conducted to determine how the prey was detected, or how beetles were attracted to mealybug infested vines. Putman (1955a) concluded from experiments with Stethorus punctillum that both the larvae and adults detected their food solely by contact. Observations made in the laboratory showed that adults reacted to movement when the mealybug was within about 1 cm. The beetle immediately turned to face the moving mealybug and then devoured it.

Behaviour of the Larvae.

The larvae are generally slow moving, but move rapidly over the vine when in search of mealybug colonies. When disturbed, the larvae curl up hedgehog-wise, often dropping off the vine. If the stimulus is great enough, a yellowish fluid is secreted from the repugnatory glands on the abdomen. Prey is apparently detected by contact, as, when mealybugs are extremely close, within a millimeter, no notice is taken of them unless they are in the direct path of the larva. When a mealybug colony is detected, the larvae burrow into the egg sacs, or, if no egg sacs are present, feed on the edge of the mealybug colony. When about to pupate in the field, the larvae congregate either in a sheltered spot on the vine or under clods in the soil around the base of the vine.

SCYMNUS (NEPHUS) SPECIES (QUADRIVITTATUS MULS.?).

This beetle was identified as Scymnus (Nephus) species by the South African Museum and as Nephus quadrivittatus by the Division of Entomology, Pretoria. It will be referred to as Scymnus quadrivittatus in this work.

Description of the Adult.

The adult (fig. 32) is a small, convex, dark brown to black beetle. The average length of specimens measured was 1.5 mm. As males and females are only distinguishable by dissection of the genitalia, the above figure was obtained from a mixed population. A dense pubescence covers the whole beetle, the direction of the setae forming a shallow wave-like pattern on the elytra. On each elytron are two reddish brown circular spots; one, which is median, is a third of the length of the elytron from the apex. The other lies slightly towards the inner edge, one third of the length of the elytron from the basal margin. The anterior markings are variable in size and are reduced to such an extent in some instances that they are barely visible. The apical margins of the elytra are a lighter colour than the rest of the body.

Sex differences. The sexes could only be differentiated by dissection of the genitalia, although it was noticed during copulation that the male was invariably smaller than the female. The clypeo-

SCYMNUS QUADRIVITTATUS.

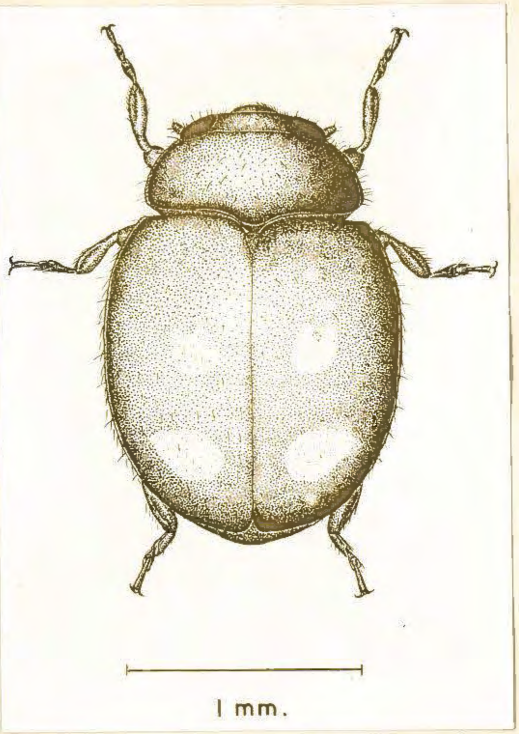


Fig. 32. Adult.

Fig. 33. Penis.

frontal region of the males is sometimes lighter in colour than that of the females.

Male Genitalia. The penis (fig. 33), which is sclerotised, curves strongly at the base, but is nearly straight at the distal end. The base of the penis is expanded to form a transverse apodeme, bi-lobed on the inner side. The gonostyli (fig. 34), which are slightly longer than the fused penis valves, curve down at a third of their length, to their points of attachment to the gonocoxites. They narrow slightly at this junction. The free ends of the gonostyli are sparsely adorned with setae. The gonocoxites are fused above and below to form a ring around the penis.

The apodeme of the modified abdominal segments (fig. 35) is well sclerotised, with the free end expanded and rounded. The structure narrows along a third of its length and expands again at the point of attachment to the modified abdominal segments.

Mandible of Adult (fig. 36). The mandible is bifid at the apex, the outer tooth being smaller than the inner. The basal tooth is bicuspidate.

SCYMNUS QUADRIVITTATUS.

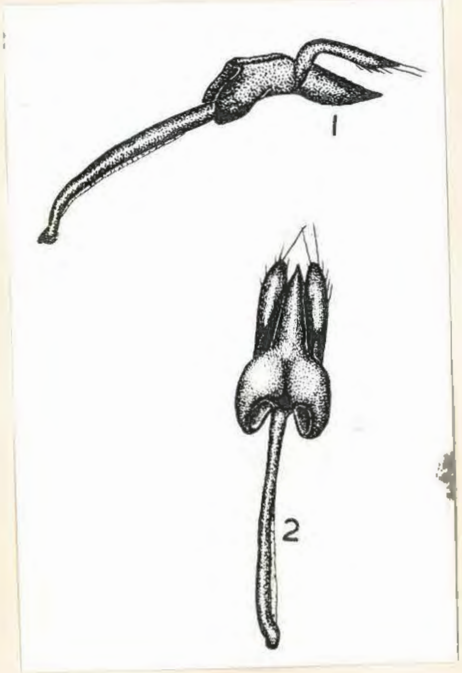


Fig. 34. Gonoforceps.

1. Lateral view.

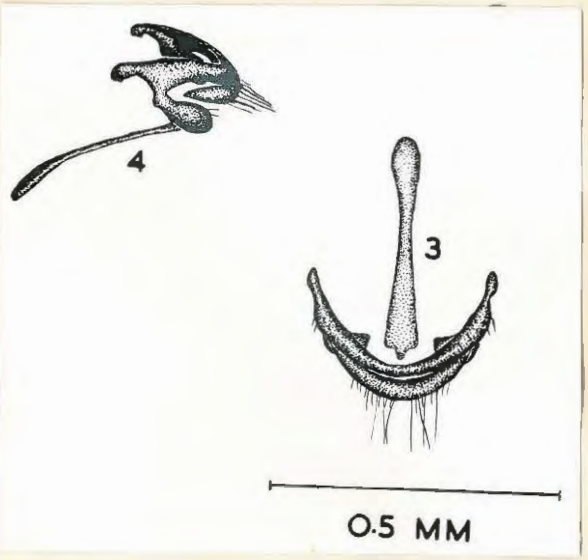
2. Dorsal view.

Fig. 35.

Modified abdominal segments.

3. Dorsal view.

4. Lateral view.



SCYMNUS QUADRIVITTATUS.

Fig. 36.

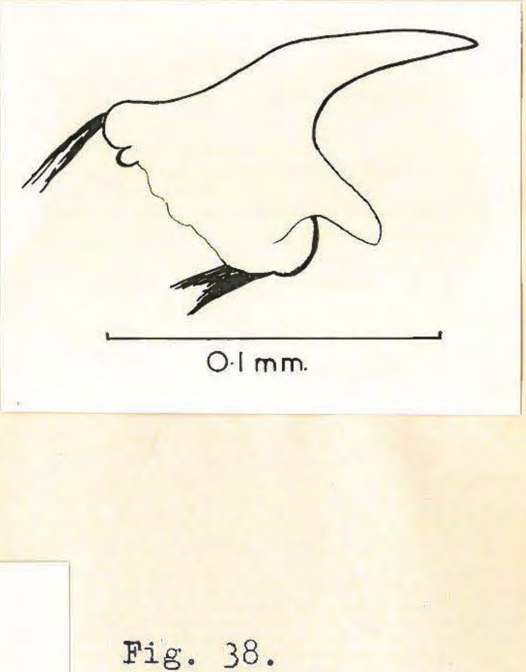
Left mandible of adult.

Ventral view.

Fig. 37.

Right mandible of mature larva.

Ventral view.



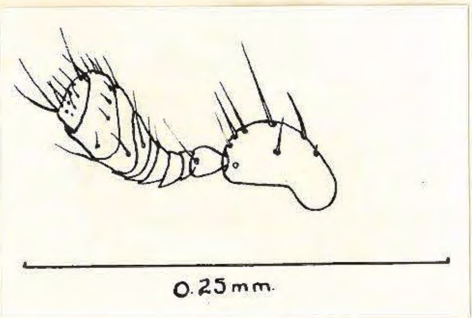


Fig. 38.

Left antenna of adult.

Dorsal view.

Antenna (fig. 38). The antenna is short and ten segmented, with a well developed club. The first segment of the antenna is kidney-shaped and is nearly as large as the club. Segment ten is small and has a large number of sensory setae embedded in it.

The egg.(fig. 39).

When first laid, the egg is a light orange, which changes to a light straw colour as the egg ages. With the development of the egg, a longitudinal indentation occurs and the eye spots and segmentation of the embryo become visible through the chorion. When laid, the eggs are lightly attached to the substratum and are inclined at a slight angle to the surface with the pointed ends downwards. At the centre of the more rounded end of the egg is a ring of minute papillae from the centre of which sometimes arises a long transparent filament.

Of 25 eggs measured, the mean length was 0.4 mm. and the mean breadth 0.2 mm.

Eclosion. The larva emerges by splitting the

SCYMNUS QUADRIVITTATUS.

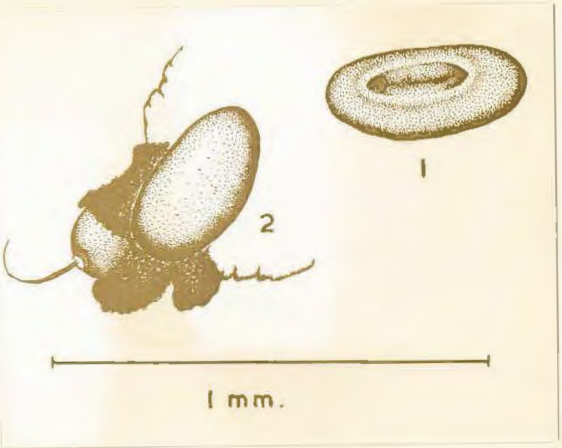


Fig. 39.

Eggs.

1. Developing egg with lateral indentation.
2. Laid under mealybug egg sac.

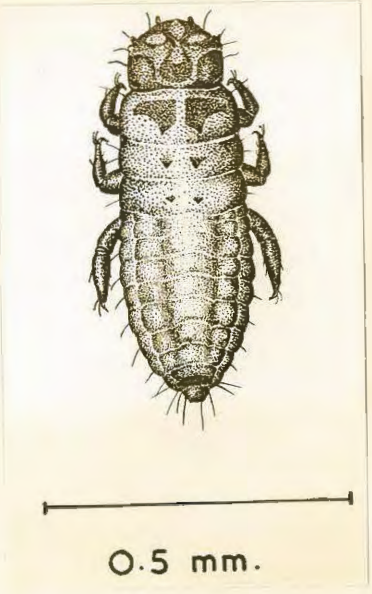


Fig. 40.

First larval instar - wax removed.

round end of the egg. The opening is jaggered and not clean cut as in _H_. _felixi_.

Immature Stages.

Larva. On emergence from the egg, the larva is straw coloured with a pair of dark egg bursting spines to each thoracic segment (fig. 40). The head is darker than the body, with three black eye spots on each side. Two of the eyespots are close together on the same level while the third is slightly lower and anterior to them. As the larva ages, parts of the head, as well as two large areas on the prothorax, darken. The subsequent instars are similar in appearance to the first larval instar, the most noticeable difference being that the size of the head decreases in relation to the body as the larva ages. A dorsal and lateral view of a mature larva with the wax covering removed is given in Figures 41 and 42 and of a mature larva feeding in Figure 43.

All larval stages are covered in wax which consists of two kinds, long filaments which are arranged in three double rows, and a short downy wax which covers the entire dorsal area of the body except for

SCYMNUS QUADRIVITTATUS.

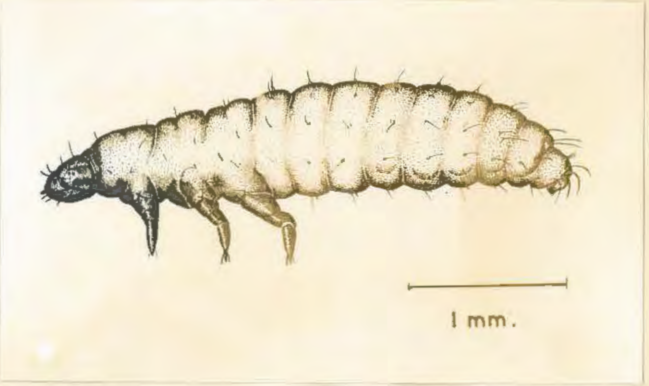


Fig. 42.

Mature larva - wax removed.

Lateral view.

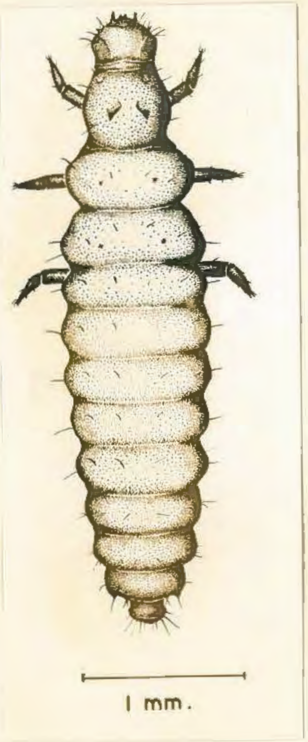


Fig. 41.

Mature larva -
wax removed.

Dorsal view.

Fig. 43.

Mature larva feeding on Pl. citri.

the intersegmental areas and the head. At least an hour and a half elapse after a moult before the wax secretion becomes visible again. The double rows of filaments situated dorsally, dorso-laterally and laterally, are longer posteriorly, that is at the end of the abdomen, than on the thorax. This is caused by the faster secretion of wax at the posterior end. A day after moulting, the posterior filaments are only slightly longer than those on the thorax, while after another day those at the posterior are nearly twice the length of the anterior filaments. On removal of the wax, the setae supporting the filaments become visible. The scletorised areas on the prothorax decrease in size in each successive instar and are sometimes completely absent in the fourth instar larva. The head of the mature fourth instar larva is only lightly scletorised on the lateral margins, that is, is only a light brown to straw-colour from the eye spots to the occipital margin. There is a small sclerotised area posterior to the clypeus, but no sclerotisation on the vertex. The body is a pale lemon yellow colour.

Life History.

Overwintering.

This beetle continues to breed throughout the year, even in the Hex River Valley, which is the coldest of the areas in which surveys were made. In this area both adults and first instar larvae were collected on vines during the middle of winter.

Duration of immature stages.

Egg. At outdoor temperatures during November and December, when the mean temperature was 18.1°C., the incubation period for 20 eggs varied from three to six days, with a mean of 5.3 days.

Larval stages. The fourth larval instar included a resting stage which, out of doors, was of three to four days duration. Of seventeen beetles kept in the outdoor insectary, two did not complete the normal three moults, while of six kept in the laboratory at a constant temperature, only one did not moult normally.

In *H. felixi* it was found that there was a lengthening of the larval life when moulting was abnormal, but in *S. quadrivittatus* the total duration of three instars was less than the normal four instars.

Table VI. Mean duration in days of the larval instars and pupa of S. quadrivittatus kept out of doors and in the laboratory.

Out of Doors, Nov. to Dec. (18.1°C.)

Larval instars				Pupa	Total of Mean.
1	2	3	4		
5.7	2.7	2.7	6.5	8.1	25.8
Laboratory (24°C.)					
3.4	4.7	4.8	4.8	12.1	29.8

It is interesting to note that the total duration of the immature stages was shorter at the lower mean temperature. It is feasible that this temperature was nearer the optimum temperature for development, as this beetle is more prevalent in the cooler summer months than in midsummer, although other factors, to be discussed elsewhere, also influence the prevalence of this and other beetles during the warm weather.

Longevity and Fecundity.

Egglaying and longevity experiments, using pairs of beetles were conducted in the laboratory at a temperature of 24°C.

Table VII. Longevity and fecundity of adults of S. quadrivittatus kept at 24°C.

Length of life in days.						Eggs laid.		
Males.			Females.					
Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
41	99	64.8	54	184	101.3	126	193	165

The preoviposition period varied from three to six days, with a mean of four days, while the largest number of eggs laid on one day varied from six to seventeen, with a mean of 8.8 eggs per day. In captivity copulation took place frequently. The longest period of the laying of fertile eggs after the removal of the male was 44 days.

Sex Differences.

Males were generally smaller than females, and could sometimes be distinguished by the lighter colour of the clypeo-frontal region. As the only sure way of distinguishing sexes was by dissection of the genitalia, no counts of the sexes were made.

Seasonal History.

S. quadrivittatus occurred throughout the year in Paarl and the Hex River Valley on vines infested with Pl. citri. Both adults and first instar larvae were collected during the winter, indicating that they continued to breed during even the coldest months. At Paarl the beetles were most abundant during November in both 1954 and 1955, and were the only beetles collected during the winter months. This species occurred only occasionally at Stellenbosch.

Food Habits.

Hosts attacked. Both Pl. citri and Pseudococcus maritimus on vines were attacked, as well as Pl. citri on figs and Ps. adonidum on pomegranates.

Method of feeding. Both adults and larvae fed on all stages of Pl. citri. The larvae, which have piercing mandibles (fig. 37) attack the host from underneath, and suck out its body juices, the remains being discarded. The adults, on the other hand, with chewing mouthparts, attack the host on any part of the body and consume it completely. When feeding on the mealybug eggs, the larvae did not burrow into the middle of the egg sacs as did the larvae of *H. felixi*, but fed on the periphery.

Rate of feeding. Six beetles, kept at temperature of 24°C. were fed second and third instar nymphs of *Pl. citri*.

Table VIII. The Mean number of second and third instar mealybug nymphs consumed by the larvae and adults of *S. quadrivittatus* at 24°C. in the laboratory.

Larval stages				Adults	Total Mealybugs.
1	2	3	4		
3	9.1	14.2	12.6	65	96.3

The adults consumed the largest number of mealybugs, followed by the third instar larvae. The average feeding rate for the whole of the immature stages was 2.3 mealybugs per day, while that of the adults was 0.8 mealybugs per day. The feeding rate for the entire life of the beetle was 1.1 mealybugs per day.

Behaviour of Adults.

General behaviour. The adults move rapidly over the vine in warm weather and take rapidly to flight when disturbed. Even in cold weather the beetles are fairly active, feeding on mealybug colonies under the vine bark. In the field, during warm weather, the adults often settle on one's arms and legs and on occasion inflict a sharp bite.

Oviposition. Eggs are laid singly in crevices of the bark near mealybug colonies or under the egg sacs themselves. When about to oviposit, the female investigates a likely crevice first with the antennae and the~~m~~n with the ovipositer before depositing the egg.

Behaviour of larvae. When in search of food, the larvae move rapidly over the vine bark, each crevice being examined until ~~of~~ a colony of mealybugs is found. When disturbed, the larvae do not curl up or exude any repugnatory fluid, but simply retreat from the mealybug colony to seek shelter under the vine bark. When a mealybug is discovered, the larva does not attack it from the side, but crawls underneath and pushes its head upwards to grip the host on the ventral surface. Pupation takes place on the vine, usually near the last feeding site.

SCYMNUS (NEPHUS) ANGUSTUS CASEY.

THis beetle was identified by the South African Museum and was doubtfully confirmed by the British Museum.

Description of Adult.

The adult (fig. 44) is not as convex nor as round as Scymnus quadrivittatus or Scymnus sp. and, as the name implies, it is narrower than long, 1 : 1.6. The mean length of ten males measured was 1.5 mm. and of females 1.6 mm. The general body colour is dark brown to black, but a fine overall pubescence gives the beetle a dull appearance. This pubescence makes a definite wave-like pattern on the elytra. The basal, inner and apical margins of the elytra are a dark brown colour, in contrast to the large oval light brown area in the centre of each elytron. The outer and apical edges of each elytron are also light brown.

Sex differences. Males have a light brown fronto-clypeal area in contrast to the dark brown to black fronto-clypeal area of the females.

SCYMNUS ANGUSTUS.

Fig. 44. Adult.

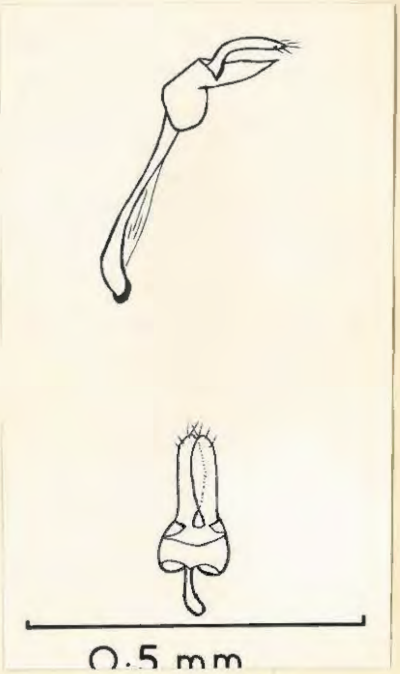


Fig. 46.

Gonoforceps.

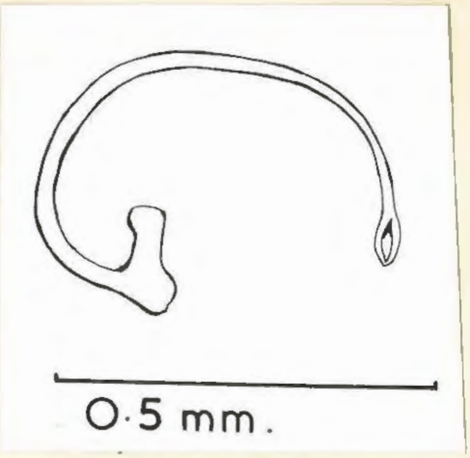


Fig. 45. Penis.

Male genitalia (figs. 45, 46 and 47). The penis, which is sclerotised, is strongly curved both at the basal and gonopore ends. The tube is slightly expanded at the gonopore. The apodeme at the base is expanded inwards to form an L-shaped structure. The gonostyli are slightly longer than the penis valves and curve down a third of their length to their points of attachment to the fused gonocoxites. Viewed from above, they overlap and completely conceal the penis valves. The apodeme of the gonoforceps is about one and a half times as long as the gonocoxites and penis valves together. The apodeme attached to the modified abdominal segments is long and narrow, and is only slightly expanded at the free end.

Mandible. The mandible is bifid at the apex, the outer tooth being the smaller. The basal tooth is single.

Antenna.(fig. 48). The eleven-segmented antenna is small and only moderately clubbed. The first segment is large and kidney-shaped.

SCYMNUS ANGUSTUS.

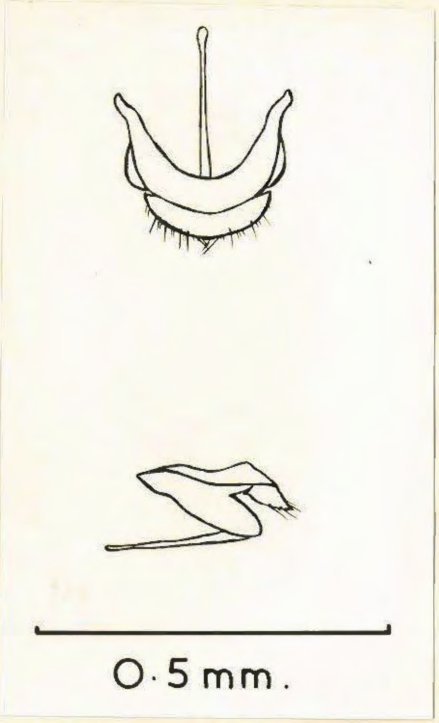


Fig. 47.

Modified abdominal segments.

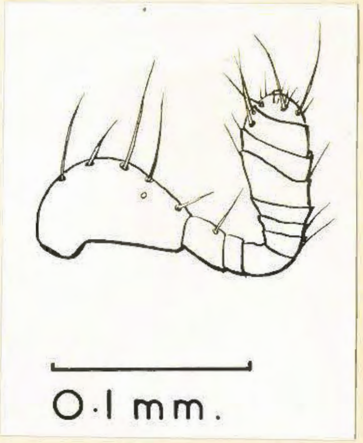


Fig. 48.

Right antenna.

Dorsal view.

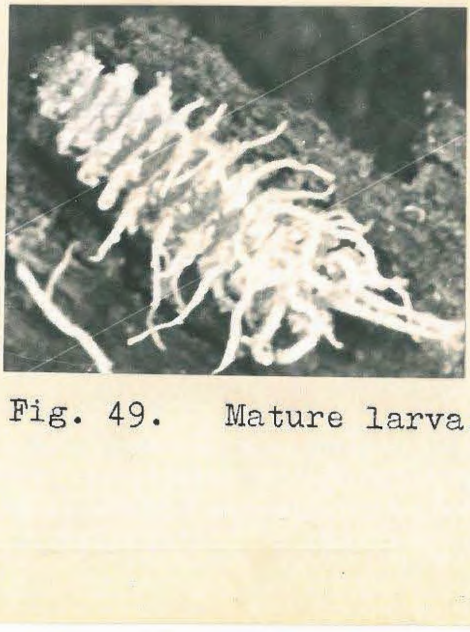


Fig. 49. Mature larva.

The egg.

The egg is similar in shape to that of *S. quadrivittatus* and is a pale lemon yellow colour. As development takes place, a longitudinal indentation occurs.

Immature Stages.

Larva. and Pupa. The first instar larva is never completely covered in wax but has only a few long straggly filaments attached to the posterior abdomen. The second, third and fourth instar larvae are similar in appearance to the first instar larva, but have a short wax covering through which the longer wax filaments protrude. These are arranged in six rows, as in *S. quadrivittatus*. Towards the posterior end of the body the filaments are much longer than those on the thorax or on the anterior portion of the abdomen (fig. 49). In the older larvae the two dorsal rows of filaments are only distinct posteriorly, while the dorso-lateral and lateral rows are distinct the length of the body. The intersegmental areas of the thorax and anterior abdomen are devoid of wax, and are as broad as or broader than the wax covered areas. The general body colour is yellow-orange with a dark median area in the thoracic and anterior abdominal regions. The dorsal body area, mainly of the thorax and anterior abdomen, is sometimes devoid of wax, probably because it is scraped off while the larva is searching for food. Three black eye spots are present in the heavily sclerotised lateral margins of the head. There are two large sclerotised areas on the dorsum of the prothorax and a pair of small sclerotised areas on the other two thoracic segments.

Life History.

Duration of the immature stages.

The mean periods of development for eggs kept out of doors from January to April varied from five to 9.3 days. The mean duration of the immature stages from egg to adult out of doors varied from 31.3 days in February to 54.5 days in March. The duration in the laboratory was 22.3 days.

Longevity and fecundity of Adults.

Six adults were kept at outdoor temperatures during the period from February to July, and ten adults were kept in the laboratory at 24°C.

Table IX. Comparison of the longevity and fecundity of *S. angustus* adults at outdoor temperatures and in the laboratory.

Out of Doors - February to July.

Males			Females			Eggs laid.		
Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
27	115	64	29	96	58.7	2	26	14.3
Laboratory - 24°C.								
44	69	55.8	25	80	54.6	17	72	40.2

From this table it is seen that although there was little difference between the longevity of the two sexes under outdoor and laboratory conditions, the beetles laid considerably more eggs at constant temperature.

Mating took place frequently both out of doors and in the laboratory, and the longest period during which fertile eggs were laid without the attendance of a male was 16 days.

Seasonal History.

After S. quadrivittatus, this was the most abundant beetle at Stellenbosch and during one season at Paarl. In Stellenbosch S. angustus was not collected during the colder months, while at Paarl it was present throughout the winter. At Paarl it was most prevalent during the months of November and December, and its peak occurred in November at Stellenbosch.

Food Habits.

Hosts attacked. Both larvae and adult beetles fed on all stages of Pl. citri on vines. The only other host attacked was an unidentified mealybug on agapanthus.

Method of Feeding. These larvae, in common with the larvae of S. quadrivittatus, S. binaevatus and Scymnus sp., being small, are able to reach any mealybug colonies sheltering under the bark in the autumn, winter and spring months. S. angustus larvae were also collected in summer, feeding on mealybugs infesting leaves and grape bunches. In contrast to the larvae of H. felixi, the larvae of S. angustus do not burrow into mealybug egg sacs but remain on the surface.

often lying between the egg sac and the substratum. Larvae of all stages, even newly emerged first instar larvae, attacked adult mealybug females. The larvae creep under the host and, by pushing upwards with the head, bite into the ventral surface of the mealybug. They attach themselves to one of the legs or the sternum between the legs. In several instances first instar larvae, attached in this manner, were seen to be dragged along as the mealybug female moved.

Rate of feeding. The data given in Table X were obtained from seven beetles kept at 24°C. On account of the minute size of the first instar larvae, difficulty was experienced in feeding this stage and feeding trials only commenced with the second larval instar.

The fourth larval instar with a rate of 1.2 mealybugs per day consumed mealybugs the fastest, but because of a longer feeding period, more were eaten by the adults. Over the whole feeding period a mean of 0.7 mealybugs was consumed per day.

Table X. Mean number of mealybugs consumed by the various stages of S. angustus in the laboratory at 24°C.

Larval Stages 2	3	4	Adult	Total.
1.7	3.5	6.7	25.4	43.6

Behaviour of Adults.

General. In the field the adults are extremely active, running rapidly up and down the vine stem and taking to flight at the slightest disturbance.

Oviposition. Eggs are laid singly or in batches of up to three in crevices near mealybug egg sacs. In contrast to Scymnus binaevatus and Scymnus sp., eggs are laid under mealybug egg sacs only when there are no other suitable egglaying sites.

Behaviour of larvae.

The larvae are active when moving over the vine surface seeking food. When disturbed, they do not curl up or drop from the vine, but move away from the feeding site and attempt to escape into a crevice in the vine bark.

SCYMNUS (SIDIS) BINAEVATUS MULS.

Identified as *Scymnus* (*Sidis*) *binaevatus* Muls? by the South African Museum and as *Sidis binotata* Weise? by the British Museum, this beetle will be designated *Scymnus binaevatus* in this work. *Scymnus binaevatus* is known to be predaceous on mealybugs at the Cape and was imported into California from Cape Town in 1921 in an attempt to control mealybugs on citrus (Smith, 1923).

Description of the Adult.

The adult beetle (fig. 50) is only slightly convex, and is oblong in shape, being longer than wide, 5 : 3. The general body colour is dark brown to black, with the entire beetle covered in a light coloured pubescence, which gives it a dull colour. The direction of the setae on the elytra form a wave-like pattern. At the apex of each elytron is a light brown circular marking, the size of which is variable. This mark is so reduced in size in some instances that it is difficult to descern. The legs as well as the apical margins of the elytra are a light brown.

SCYMNUS BINAEVATUS.

Fig. 50. Adult.

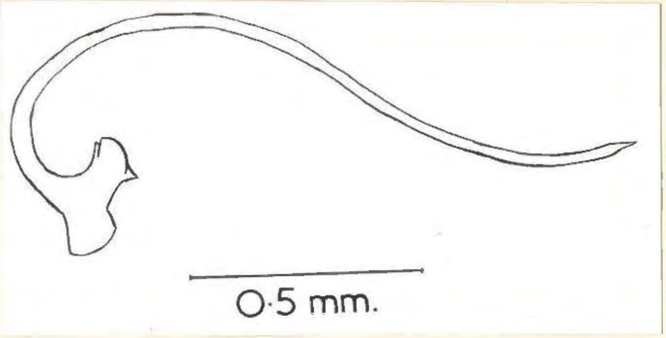


Fig. 51. Penis.

Male Genitalia. The genitalia are illustrated in Figures 51 to 53.

Mandible. The apical tooth is bifid, the outer portion being the smaller, and the basal tooth is single.

Antenna (fig. 54). The antenna is small and ten-segmented, with a moderately developed club. The first segment, which is kidney-shaped, is nearly as large as the club. Segments one and ten have extremely long and stout tactile setae.

The Egg.

The straw-coloured egg, when first laid, is shiny, but becomes dull due to the development of a roughened surface under the first layer of the chorion. At the more rounded end there is a ring of minute papillae from the centre of which often arises a transparent filament.

Larval Stages (figs. 55, 56, 57 and 58).

The first instar larva, which is yellow in colour, is sparsely covered in wax filaments, which are mainly

SCYMNUS BINAEVATUS.

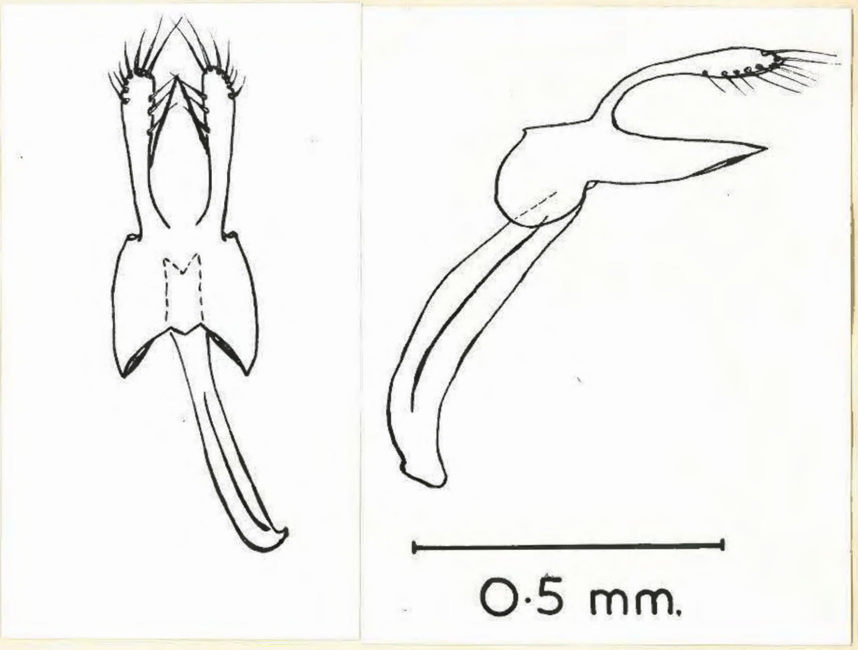


Fig. 52. Gonoforceps. Dorsal and lateral views.

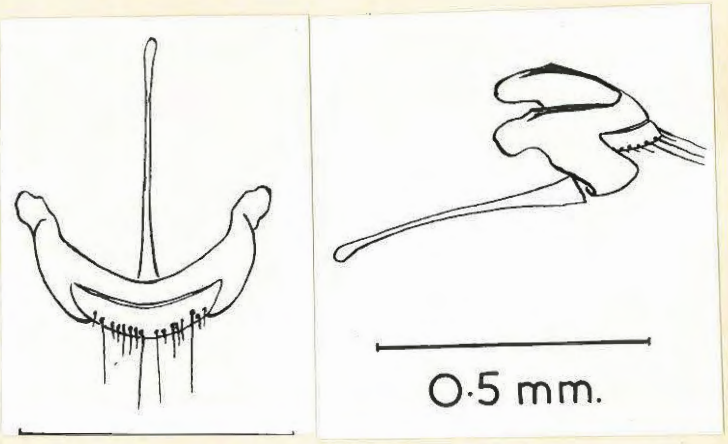


Fig. 53. Modified abdominal segments.
Dorsal and lateral views.

at the posterior end. There are two prominent sclerotised triangular areas on the dorsum of the prothorax, while on the meso- and meta-thorax only small sclerotised areas surround the egg bursting spines. The head has large sclerotised areas, and on the posterior margin of the penultimate segment is a small black pigmented area.

The second, third and fourth larval instars differ only slightly from the first instar. The head of the subsequent stages is relativlly smaller, while the wax covering is considerably denser. The sclerotised areas on the dorsum of the thorax and the pigmented area on the penultimate segment are retained. The head of the adult larva is shown in Figures 60 and 61. The sclerotised area on the vertex can be used to distinguish this larva from that of _S. quadrivittatus_, which has only the small sclerotised area posterior to the clypeus.

The larvae, as in the case of _S. angustus_ and _S. quadrivittatus_, have two forms of wax covering. There are rows of long distinct filaments, and a shorter fleece-like overall wax layer. Shortly after a moult,

SCYMNUS BINAEVATUS.

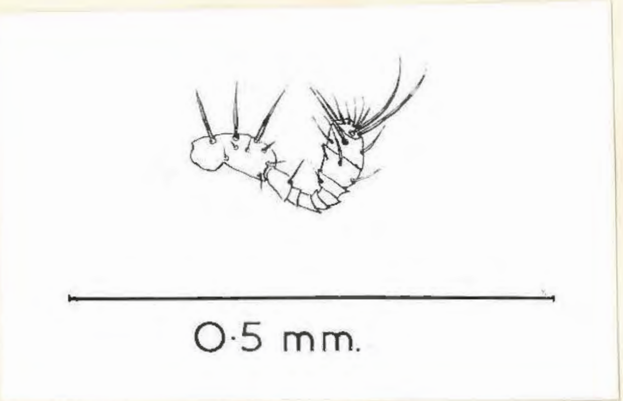
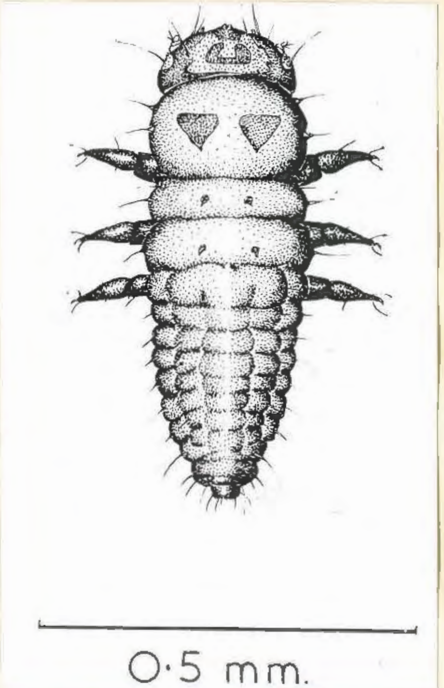


Fig. 54.

Antenna of adult.

Fig. 55.

First instar larva - wax removed.



all six rows of filaments are distinct, but as the wax covering becomes more dense, the two dorsal rows become entwined in the shorter overall wax covering and are no longer distinct. This characteristic is also used to distinguish *S. binaevatus* from *S. quadrivittatus*. There is no great difference in length of the posterior or anterior filaments. The body colour, which is a rich yellow, does not show through the wax covering.

Pupa (fig. 59).

In the laboratory larvae congregated prior to pupation but it is not known whether this occurs in the field as the beetles were never present in large numbers. The last larval skin, after splitting mid-dorsally, contracts slightly to show the brown pupa through the wax covering. The lateral filaments, as a result of the contraction, point slightly forward as in *S. quadrivittatus*.

Life History.

Duration of the immature stages.

The mean duration in days of the immature stages,

SCYMNUS BINAEVATUS.

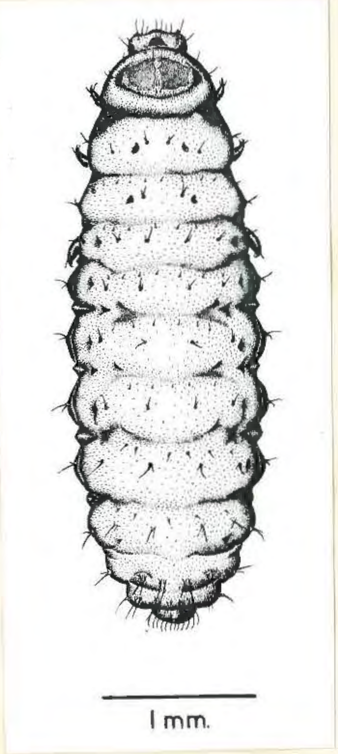


Fig. 56.

Mature larva - wax removed.

Dorsal view.

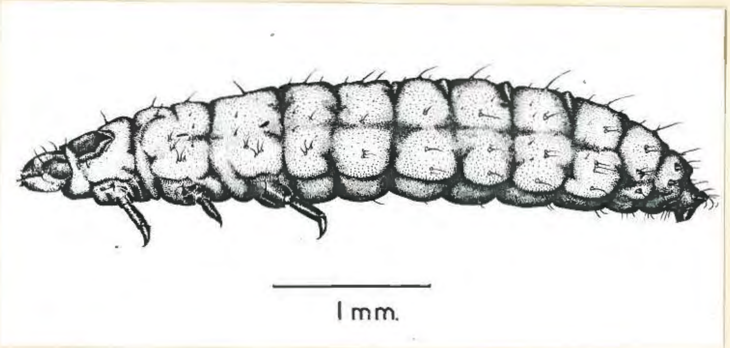


Fig. 57. Mature larva - wax removed.

Lateral view.

obtained from 17 beetles kept in the laboratory, was: eggs 4.8 days, first instar 4.4 days, second instar 2.5 days, third instar 2.8 days and the fourth instar 6.2 days. The pupa lasted 6.3 days, bringing the mean total to 27.3 days.

The prepupal stage, which is included in the fourth larval instar, varied from one to three days. The adults, after becoming fully developed, remained in the pupal covering for a further one to three days before emerging to feed.

Longevity and fecundity.

At 24°C. the mean length of life for five males was 32.2 days and for eight females, 49.7 days. The mean number of eggs laid was 100.7. The period of preoviposition varied from three to ten days, while the largest number of eggs laid on one day varied from eight to sixteen.

Seasonal History.

Although present in all three areas studied, S. binaevatus was never prevalent, and sporadic collections of both larvae and adults were made from August to January.

SCYMNUS BINAEVATUS.

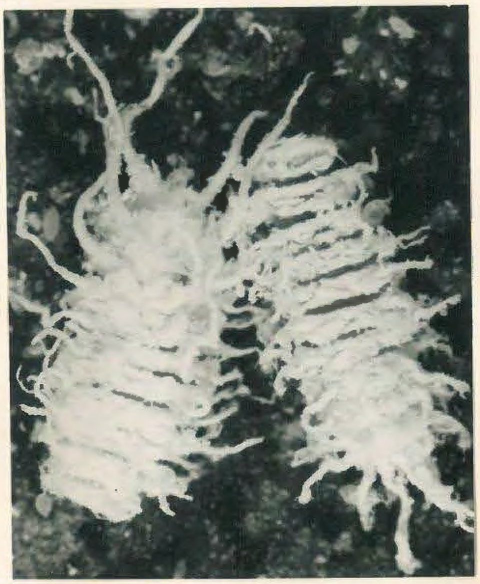


Fig. 58.

Two mature larvae.

Fig. 59. Pupa.

Food Habits.

Hosts attacked. *S. binaevatus*, as well as feeding on *Pl. citri* on vines, fed on *Pl. citri* on *Cassia* and wild paw-paw. Larvae also attacked *Ps. maritimus* on *Ilex mitis*, a mixture of *Ps. gahani* and *Ps. adonidum* on pomegranate, *Ps. gahani* on citrus and an unidentified mealybug on agapanthus.

Feeding hapits of larvae. These larvae resemble the larvae of *S. quadrivittatus*, not only in body form, but also in habits. The head of the larva is thrust under the host and pushed upwards until a hold is obtained on the ventral surface of the mealybug. Because of the relative unimportance of this beetle in the field, no controlled feeding studies were made.

RHIZOBIELLUS SP.

This coccinellid was identified as *Rhizobius* sp? by the South African Museum and as *Rhizobiellus* sp. by the British Museum. The latter name will be used in this work as the former was doubtfully identified.

SCYMNUS BINAEVATUS.

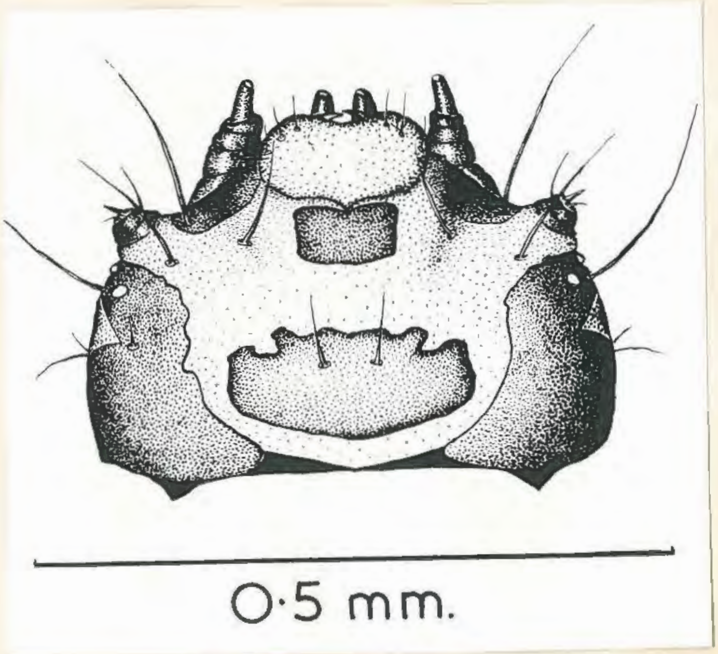
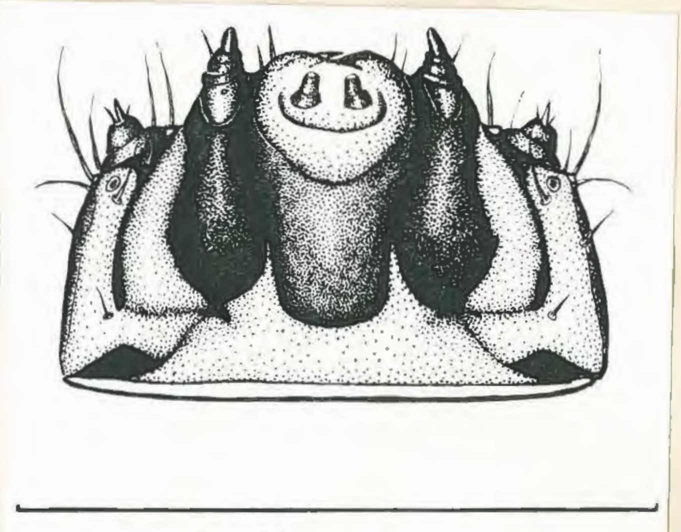


Fig. 60.

Dorsal view of head of mature larva.

Fig. 61.

Ventral view of head of mature larva.



Description of the Adult (fig. 62).

Rhizobiellus sp. is a moderately convex, oblong species, being longer than wide, 5.5 : 3. The colour is dark brown to black, while the legs are light brown. The body is covered in a grey pubescence which does not form a pattern on the elytra. On each elytron are two light brown maculae; the larger, roughly rhomboid in shape, is on the basal portion of the elytron, with one corner pointing into the humeral angle. The corner of the macula diagonally opposite this is slightly rounded. The smaller, nearly circular, marking is about one quarter of the length of the elytron from the apex. Both maculae are variable in size and occasionally co-alesce by the posterior extension of the basal macula. If gravid, females can be distinguished by their swollen abdomens, otherwise they can only be distinguished from the males by dissection. The mean length of ten beetles, from a population of both sexes, was 2.1 mm.

Male Genitalia. The genitalia are illustrated in Figures 63 to 65.

Antenna (fig. 66). The twelve-segmented antenna

RHIZOBIELLUS SP.

Fig. 62. Adult.

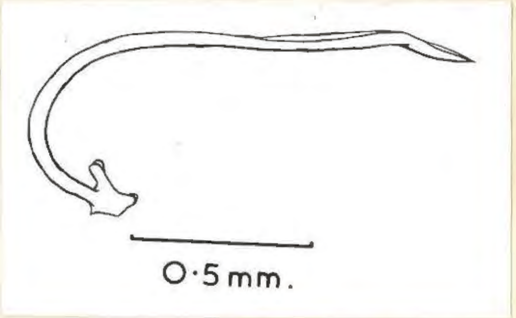


Fig. 63. Penis.

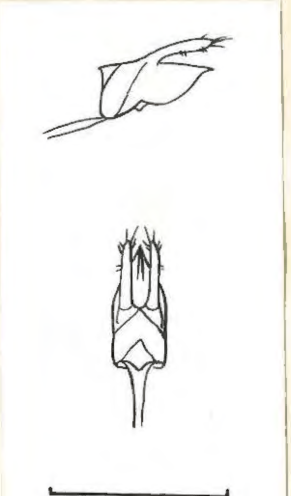


Fig. 64.
Gonoforceps.

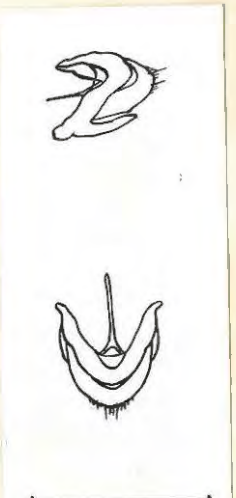


Fig. 65.
Modified
abdominal segments.

is long, with a moderate club. The first segment is large and curved and the third is as long as the first but much narrower. The club consists of five segments, the last of which is extremely small.

Mandible. The mandible is bifid at the apex, the outer tooth being the smaller. The basal tooth is single.

Immature Stages.

Egg.

The egg, which is a pale lemon yellow, is oval in shape. When newly laid, eggs have a shiny appearance, but become duller as they age.

Larval Stages (figs. 67 and 68).

On emergence from the egg, the larvae are a shiny grey-green, but as they develop, they become duller. They have no wax covering at any stage and all instars are similar in appearance. On the dorsal surface of the prothorax are two large sclerotised areas from which arise short, stout, black setae. The meso- and meta-thorax have similar, but smaller, areas. The first seven abdominal segments each have six

RHIZOBIELLUS SP.

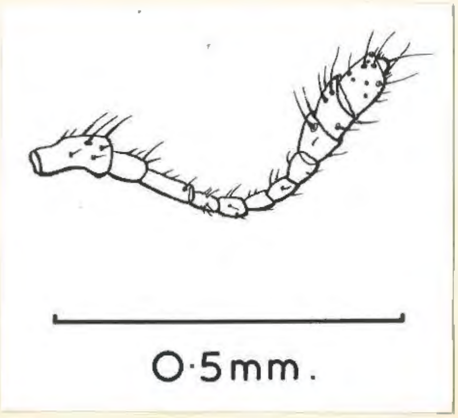


Fig. 66.

Right antenna of adult.

Dorsal view.

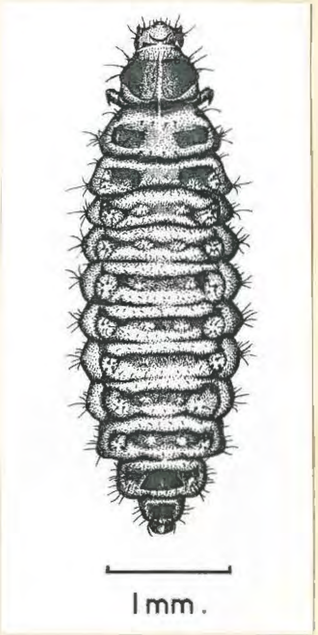


Fig. 67.

Mature larva.

Dorsal view.

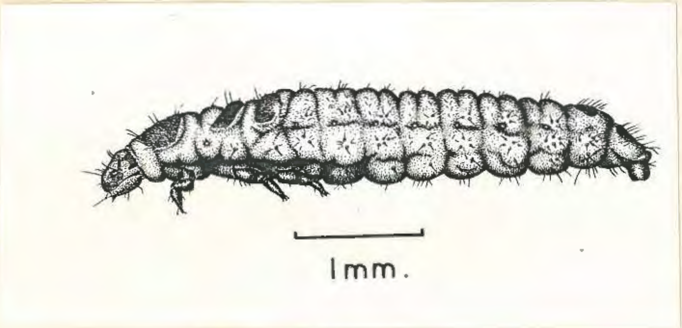


Fig. 68.

Mature larva. Lateral view.

tubercles, situated laterally, dorso-laterally and dorsally. On the eighth segment, the dorsal tubercles become incorporated in a sclerotised area. There is also a similar area on the dorsum of the penultimate segment. In some of the larvae the tubercular areas of the abdomen are slightly sclerotised. The entire body surface, except the intersegmental areas, is covered in minute pointed papillae, which give the larva a grey colour.

Pupa (fig. 71).

The pupa varies in colour from translucent white to pale lemon yellow. The last larval skin splits and is pushed back around the point of attachment. The entire pupa is covered in minute setae, each bearing a droplet of clear fluid at the point. These droplets, if removed, reappear after a few hours.

The pupal covering is thin and transparent and difficult to detect after the adult has emerged. On emergence, the thorax of the adult is brown, and the elytra pale yellow. The normal colour is attained after five hours.

RHIZOBIELLUS SP.

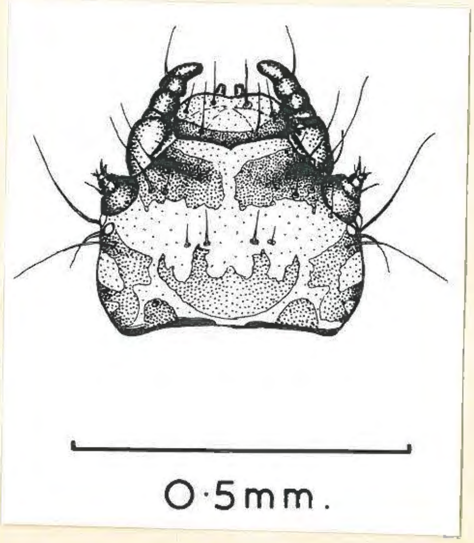


Fig. 69.

Head of mature larva.

Dorsal view.

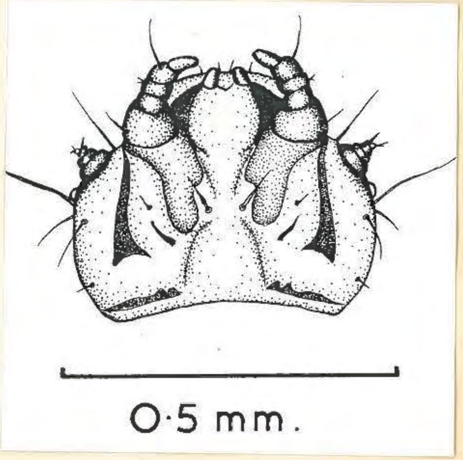


Fig. 70.

Head of mature larva.

Ventral view.

Fig. 71. Pupae.

Life History.

Immature Stages.

Four beetles were used for controlled temperature studies (24°C.) and eleven for outdoor work, where the mean temperature was 21.6°C. The fourth larval instar included the prepupal resting stage.

Table XI. Duration in days of the egg, larval and pupal stages of *Rhizobiellus* sp.

Egg	Larval instars 1	2	3	4	Pupae
Laboratory					
5	5	2.7	3	6.5	9.5
Outdoors in February.					
6.7	4.6	4.6	4.9	9.3	8.5

Longevity and Fecundity of the Adults.

The mean length of life of males and females kept out of doors during January and December was 144 days for males and 254 days for females. An average of 97.3 eggs was laid by each of seven females.

The preoviposition period varied from 11 to 22 days with a mean of 16.6 days.

These beetles are nearly as long-lived as *Hyperaspis felixi*. Some of the females laid fertile eggs for considerable periods after the males had been removed, the longest being 237 days.

Seasonal History.

At Stellenbosch this beetle was collected in fair numbers from September to February and from October to April at Paarl. In the Hex River Valley they were abundant during August and September and again during May, June and July. When first collected, it was thought that these beetles were important but the numbers collected during autumn never increased and, while the beetles occurred fairly regularly, they were never present in large enough numbers to be effective. Pupae were never collected in the field, probably because of their colour, which made them difficult to detect.

Food Habits.

Hosts attacked. The larvae have only been collected feeding on *Pl. citri* on vines, but adults have been taken on curcurbits infested with aleyrodid nymphs.

Feeding Habits. In the field the larvae were most often collected in mealybug egg sacs and apparently preferred to feed there, but in the laboratory they fed readily on mealybug adults. The larvae fed on the edge of egg sacs and, when disturbed, the bigger ones made convulsive backwards movements and left the egg sac. The younger larvae were much less active and did not leave the egg sacs even when disturbed.

Rate of Feeding. Feeding experiments using four larvae were conducted in the laboratory at 24°C.

Table XII. Mean number of mealybugs consumed by the various stages of Rhizobiellus sp. at 24°C.

Larval stages				Adult	Total
1	2	3	4		
10	4.3	6	11	74	108.7

The greatest number of mealybugs was consumed by the adults, and of the larval stages, the fourth larval instar ate most. The third larval instar showed the highest rate of feeding, with a mean of 2.1 mealybugs consumed per day, and the mean rate of feeding for the whole period was 0.5 mealybugs per day.

Behaviour of Adults.

General. The adults were slow moving even in warm weather and were never seen to fly, either in the field or in the laboratory. They were usually found under the bark low down on the vine and sometimes even in the soil under clods around the base of the vine.

Oviposition. Eggs were laid in egg sacs from which the mealybugs had already hatched, six to seven eggs being laid together. In cages, females readily oviposited in bits of cotton wool, and up to thirty eggs were collected in one piece of this material.

Behaviour of Larvae.

In contrast to the adults, the larvae were rapid in their movements, the larger larvae dropping readily to the ground if disturbed. There was seldom more than one larva per mealybug egg sac.

SCYMNUS SP.

The South African Museum could only determine the genus of this beetle. There was no specimen of it

SCYMNUS SP.

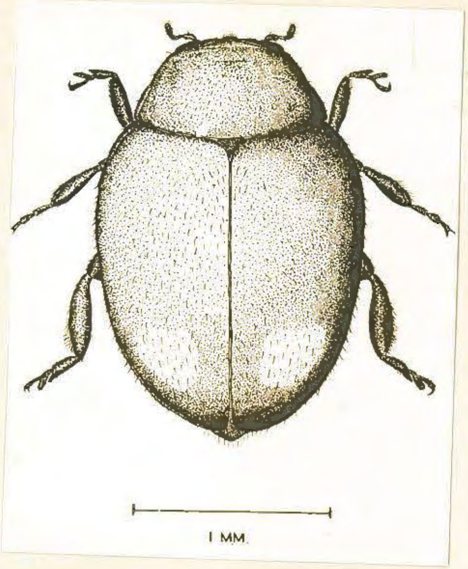
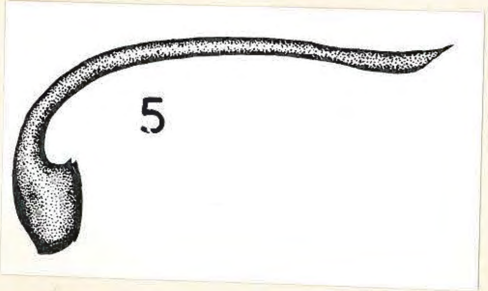


Fig. 72. Adult.

Fig. 73. Penis.



in their collection.

Description of the Adult.

The adult (fig. 72) is small, black and convex, slightly longer than broad, 3 : 2. The body is covered in a silvery pubescence, which forms a wave-like pattern on the elytra. The ventral surface of the beetle is dark brown, whereas the legs are black, a characteristic which distinguishes it from *S. binaevatus*, whose legs are a light brown. Males can only be distinguished from females by dissection of the genitalia. The length of the beetles varied from 1.2 to 1.4 mm. with a mean of 1.3 mm.

Male genitalia. The male genitalia are illustrated in Figures 73 to 75.

Antenna (fig. 76). The antenna is small and nine-segmented with a well defined club. The first segment is large and kidney-shaped.

Mandible. The apical tooth is bifid, the outer tooth being the smaller. The basal tooth is single.

The Egg.

The eggs are similar in shape to those of *S. quad-*

SCYMNUS SP.

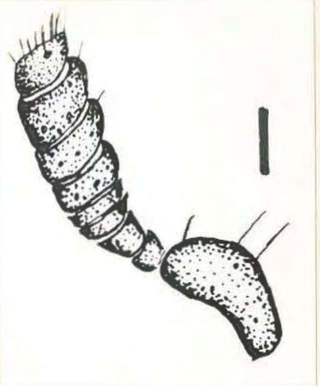


Fig. 76.

Left antenna of adult.

Dorsal view.

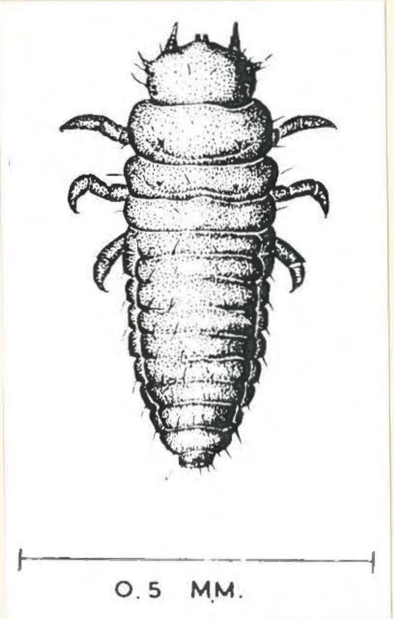


Fig. 77.

First instar larva.

rivittatus, but are slightly wider, and are off-white when laid, not yellow. At one end is a ring of minute papillae to the centre of which is sometimes attached a transparent filament.

Larval Stages (figs. 77 to 80).

The first instar larvae, which are pale lemon yellow, have a sparse covering of long wax filaments. After two to three days these become extremely long and consequently break off readily at the tips. There is no sclerotisation of either the head or thorax, and egg bursting spines are present only on the pro- and meso-thorax. The other larval instars are similar to the first larval instar, except for the absence of the egg bursting spines and the presence of a more dense wax covering. The entire larva is covered in long white wax filaments, entwined in each other, with no regular arrangement. They are more dense posteriorly, but are not noticeably longer than the anterior filaments. The lemon yellow body colour is not visible through the wax covering.

SCYMNUS SP.

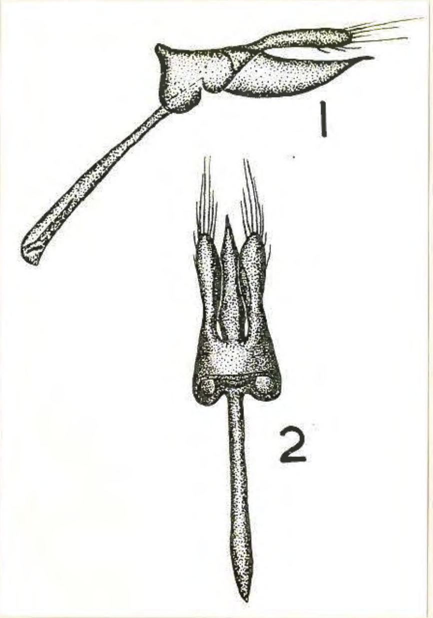


Fig. 74.

Gonoforceps.

(1) Lateral view.

(2) Dorsal view.

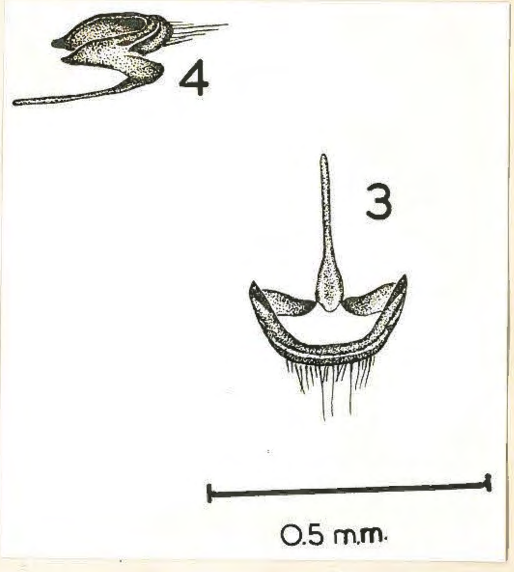


Fig. 75.

Modified abdominal segments.

(3) Dorsal view.

(4) Lateral view.

Pupa (fig. 8~~b~~1).

Prior to pupation a flocculent waxy covering, differing slightly in colour from the existing cover, is given off. The usual yellow gelatinous fluid is secreted from the anal sucker but the pupa, when formed, is never attached to the substratum and lies loose. It is sometimes caught up in the bark by the wax filaments of the larva. The last larval skin splits dorsally and does not recede, but remains around the light brown pupa.

Life History.

The life history was only studied in the laboratory under controlled temperature.

Duration of the Immature Stages.

At 24°C. the mean incubation period for ten eggs was four days. The mean duration of the larval stages, obtained from fourteen beetles, was 6.1 days for the first instar, 3.6 for the second, 5.0 for the third and 9.9 for the fourth instar. The pupal stage lasted 11.9 days, bringing the mean total from egg to adult to 40.7 days.

SCYMNUS SP.

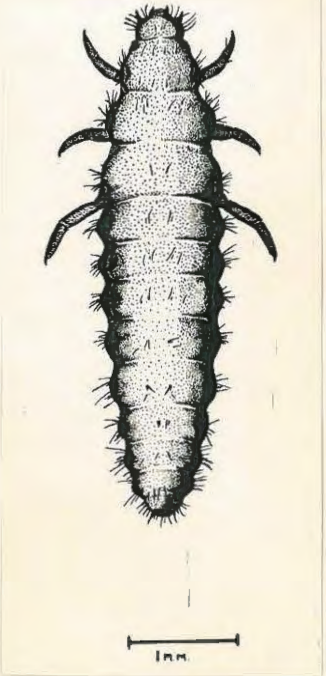


Fig. 78.

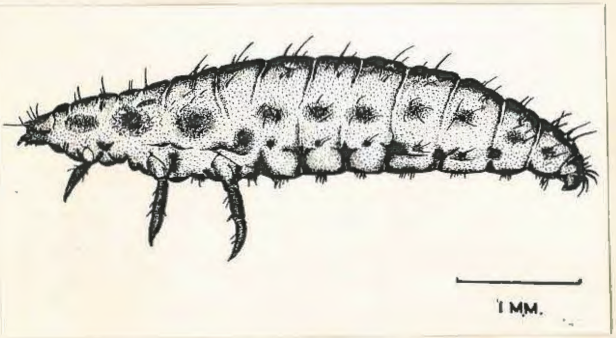
Mature larva - wax removed.

Dorsal view.

Fig. 79.

Mature larva - wax removed.

Lateral view.



Longevity and Fecundity of the Adults.

The preoviposition period varied from three to five days. One female laid fertile eggs forty days after the last copulation and again laid fertile eggs for a further 25 days after a male had been added for a single day. From five pairs it was found that, on an average, males lived 94.2 days and females 88.3 days. The average number of eggs laid per pair was 127.5.

Seasonal History.

This beetle was never abundant, and was collected only during the summer months.

Food Habits.

Host attacked. All stages of *Pl. citri* and *Ps. maritimus* on vines were attacked, but no other hosts were observed.

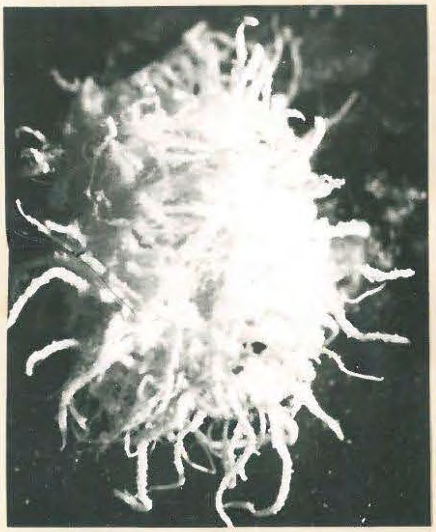
Feeding Habits. The first instar larvae were usually found next to or just under the edge of mealybug egg sacs, but never burrowing deeply into them as did the larvae of *H. felixi*. The first instar larva did not feed exclusively in egg sacs, but attacked any stage of the mealybug. They were often found attached to the ventral surface of the host and were dragged along as the female mealybug moved about. Third and

SCYMNUS SP.

Fig. 80.

Mature larva.

Fig. 81. Pupa.



fourth instar larvae preferred to feed on mealybugs and were seldom found at egg sacs.

Rate of Feeding. Owing to the smallness of the first instar larvae and the difficulty experienced in handling them individually, this stage was omitted from feeding trials.

Table XIII. Mean number of mealybugs consumed by the various stages of Scymnus sp. (excluding the first instar) kept at 24°C.

Larval Stages			Adult	Total
2	3	4		
4.5	13.3	26.9	68	109.3

The greatest rate of feeding occurred in the fourth larval instar. This stage consumed a mean of 3.4 mealybug per day, compared with 0.8 mealybug of the adult, 2.7 of the second larval instar and 0.9 mealybug per day of the third instar. The mean number of mealybugs consumed over the whole period was 1.0 mealybugs per day.

Behaviour of Adults.

General. In warm weather the adults were active on the vine, and when disturbed, took readily to flight.

Oviposition. Eggs were laid in crevices of the vine bark near mealybug egg sacs as well as under them; up to 18 eggs were deposited in one batch.

Behaviour of Larvae.

The larvae were sluggish and if disturbed, curled up and remained motionless for several minutes. Pupation took place on the vine in any suitable spot, usually near the last feeding site.

OTHER COCCINELLIDS OCCASIONALLY FOUND FEEDING ON VINES INFESTED WITH PL. CITRI.

Except for Exochomus flavipes, the rest of the beetles occasionally found feeding on Pl. citri infested vines never bred there, but only occurred as adults. A brief description of three of the beetles follows.

Exochomus flavipes Thunb.

This is a large, convex, shiny black beetle. Males measure 3.5 mm. and females 3.8 mm. Males are easily distinguished by the yellow fronto-clypeal area. On each lateral margin of the prothorax is a large yellow area. The larvae, which are covered in black spines, feed on all stages of Pl. citri. They were also collected feeding on aphids and soft scales such as Coccus hesperidum, Saissetia ~~a~~oleae and S. coffeae.

This beetle has been thoroughly studied by Geyer (1947) as a predator of the cochineal insect on prickly pear in the Eastern Cape Province.

Cydonia lunata F.

This was the largest of the Coccinellidae collected, being 6.2 mm. long. The body is shiny with yellow to red markings on a black background, the colour changing from yellow to red with the age of the specimens.

Scymnus morelleti Muls.

This is a small oval species, the head and thorax of which are a dark brown. The outer, inner and basal margins of the elytra are black with a reddish brown area in the centre of each elytron. The larvae, which are wax covered, feed exclusively on aphids.

FACTORS LIMITING THE POPULATION OF THE COCCINELLIDAE.

From Figures 5, ~~6~~9 and 8, showing the fluctuation of the predators (mainly Coccinellidae) at Stellenbosch and Paarl, it can be seen that the greatest numbers occurred in the early to midsummer months. After this there was a decrease in the coccinellid population in spite of the warm weather. This decrease is the result of a combination of several factors, climatic conditions, food and parasites being the most important.

The coccinellid larvae found feeding on Pl. citri infested vines can be divided into three groups, according to their appearance and their feeding habits. The larvae of H. felixi are covered in a short compact wax and are the "short filamentous" larvae. The other group, consisting of S. angustus, S. quadrivittatus and S. binaevatus, which have long wax filaments, are the "long filamentous" larvae. The latter larvae have a similar body form and method of attacking their hosts. Scymnus sp. also falls into this group, although easily distinguished by the absence of a pattern to the filaments. Rhizobiellus sp., not being wax covered, does not fall into either of the above groups. No parasites were in any case reared from this species.

Parasites.

All stages of the Coccinellidae, except the eggs, were attacked by parasites.

Larval parasites.

The final instar larvae of the "short filamentous" type, that is, *H. felixi*, were attacked by a *Pachyneuron* sp. As the beetles were able to pupate and the parasite emerged from the pupa, these parasites will be dealt with under pupae.

The encyrtid *Homalotylus africanus* Timberlake attacked all long filamentous larvae. Rivnay & Perzelan (1943) found that *Homalotylus quayli* attacked over 40 per cent. of all the larval stages of three *Scymnus* spp. feeding on *Pseudococcus comstocki* on citrus in Palestine. Figures 82, 83a and 83b present the percentage long filamentous larvae parasitised by *H. africanus* at Stellenbosch and Paarl. Parasitism in both areas was higher than 40 per cent., reaching 57.7 per cent. in November at Stellenbosch in the 1953-54 season. In both areas, the height of parasitism corresponded to the peak of the beetle population. In Stellenbosch, parasitism occurred continuously from September to April, with the emergence of overwintering parasites in August. In Paarl, during the 1954-55

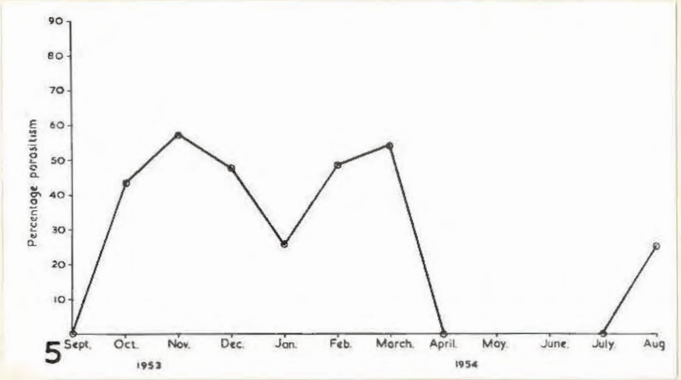


Fig. 82.

Parasitism of long filamentous larvae by *H. africanus* at Stellenbosch, 1953-54.

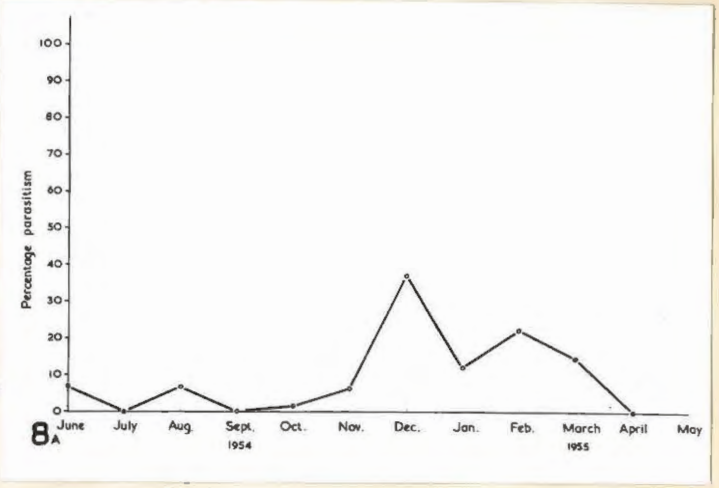


Fig. 83a.

Parasitism of long filamentous larvae by *H. africanus* at Paarl, 1954-55.

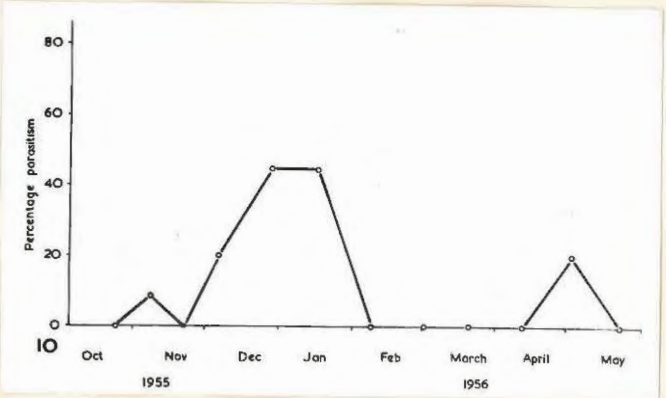


Fig. 83b.

Parasitism of long filamentous larvae by *H. africanus* at Paarl, 1955-56.

season, parasitism occurred throughout the summer until April, with the occurrence of some parasitised Coccinellidae during June and August. In the following season H. africanus was first collected during October and continued to be present until February, with the recurrence of some parasitised larvae during May.

In Palestine a redeeming feature of the Homalotylus attack was its short period of activity (Rivnay & Perzelan, 1943). The period of attack in the areas studied was certainly not short, extending as it did through summer and occurring sometimes in the winter.

Another species, H. flaminius (Dalman) attacked the larvae of Exochomus flavipes, Cydonia lunata and Adalia flavomaculata. This species can be distinguished from H. africanus by the metatarsi of the middle legs which are white, and the tarsi of the hind legs which are entirely black. The metatarsi of the middle legs of H. africanus are black, and the tarsi of the hind legs white (Callan, private correspondence). H. africanus differs further in that only one parasite emerged per host, whereas several emerged from the larvae attacked by H. flaminius, the greatest number collected being nine parasites from a larva of *Cydonia lunata* from Stellenbosch.

H. africanus was occasionally attacked in the mummified coccinellid larva by a small unidentified encyrtid.

From field observations, it was noted that *H. africanus* was most active in the warm months and that although long filamentous larvae occurred fairly frequently in the cooler spring and autumn months, parasitism was low. At the peak of beetle activity in summer this parasite undoubtedly caused a large reduction in the numbers of beetles reaching maturity and is consequently one of the important factors in reducing the effectiveness of the predators.

Pupal parasites.

At Paarl an unidentified hymenopterous parasite (Ac.FR. 611) attacked the pupae of *Scymnus angustus*, *S. quadrivittatus* and *S. binaevatus*. In all cases, three parasites emerged per host. In the laboratory three of these parasites, which had emerged from the pupa of *S. quadrivittatus*, were given access to a pupa of *S. binaevatus*. They were seen to oviposit and the resultant nine wasps were considerably smaller than the parents. In Figure 85 is given the percentage parasitism of the pupae of long filamentous larvae collected at Paarl, compared with the total number of pupae collected. From this figure it can be seen that, although the percentage of parasitism was high during the winter, the actual number of parasites was low.

At certain times of the year the pupae of H. felixi were heavily parasitised by a Pachyneuron sp. (Ac.FR. 620). Parasitism took place in the last larval stage, but parasitised larvae always pupated. Seven to nine adult wasps emerged from a single opening in the host. From Figure 86 it will be seen that the larval population of H. felixi decreased rapidly after December. One of the chief agents of this decline was undoubtedly the attack by these wasps. In Figure 87 is given the percentage parasitism of H. felixi pupae. If this is compared with Figure 86, it can be seen that a rapid decrease of H. felixi corresponded to an equally rapid increase in the percentage pupae attacked.

The first parasitised pupae were collected in December, after which parasitism increased rapidly to reach a peak in February. No parasitised pupae were

Fig. 84.

Adult Adalia flavomaculata parasitised by Perilitus sp.

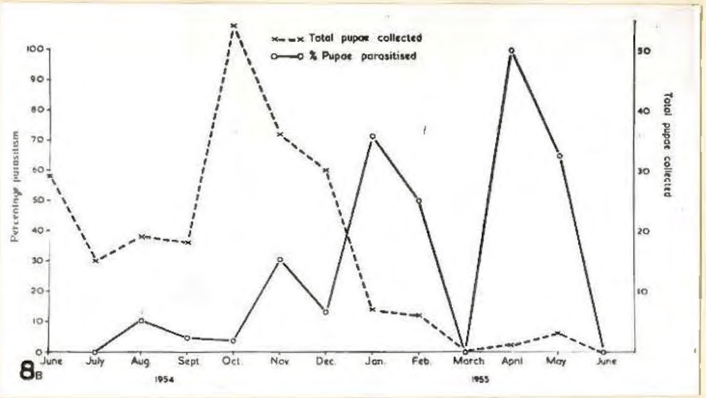


Fig. 85.

Parasitism of long filamentous pupae compared with number of pupae collected, Paarl.

collected after this.

At Paarl, where *H. felixi* was much less prevalent, only one parasitised pupa was collected.

Parasitism of Adult Coccinellidae.

Some of the Coccinellidae, found as adults feeding on *Pl. citri* on vines, were attacked in the adult stage by a braconid of the *Perilitus* species. According to Clausen (1940), oviposition was effected through the intersegmental membrane in the abdominal region of the adult. In captivity these wasps approached adult *H. felixi* from the rear with ovipositer bent downwards and forwards to protrude from between the front legs. Although oviposition was not observed, it appeared that the wasp was attempting to insert the ovipositer between the elytra and the abdomen of the coccinellid. Parasitism of *H. felixi* did not occur. The full grown parasite larva emerged from the living beetle to spin a cigar-shaped cocoon which lay the length of the host. The legs of the coccinellid became entangled in the outer covering of the cocoon (fig. 84). Several beetles collected in this position were still alive, and acted normally when released, but they died within

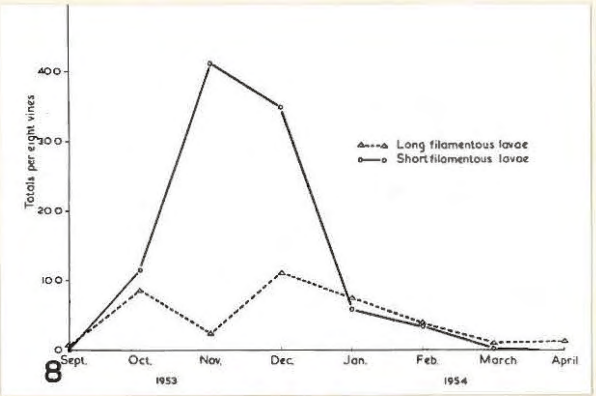


Fig. 86.

Long filamentous and short filamentous larvae collected at Stellenbosch.

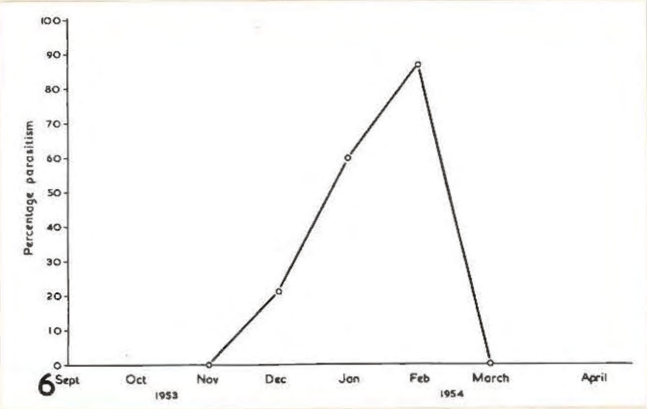


Fig. 87.

Parasitism of *H. felixi* pupae by *Pachyneuron* sp. at Stellenbosch.

a few days. Clausen (1940) mentions that parasitised coccinellids have been known to recover completely and have even been experimentally parasitised a second time.

Perilitus sp. was not collected from the coccinellids found regularly on vines. It was collected occasionally from Cydonia lunata at Stellenbosch and Paarl, but was more plentiful from Adalia flavomaculata from Worcester. A similar, if not the same, parasite was collected from Oenopia cinctella and Thea variegata from Stellenbosch.

Ant Activity.

Generally, in the absence of ants, it was apparently the efficiency and not the population of the predator which increased. On the contrary, a decrease in predator population, resulting from the destruction of the mealybug, occurred after ant control had been achieved. An increase of the predator population did take place, however, in one instance, where ant control resulted in a large mealybug population being free of ants during early summer. It is probable that an influ
of predators occurred from neighbouring blocks.

Food Supply.

The mealybug had a definite annual cycle on the vine. The biggest population occurred during late winter and early summer, with the formation of large colonies under the bark on the stem. These colonies were inaccessible to the larger beetle larvae. At Stellenbosch, later in the season, exposed colonies of mealybugs formed around the bases of young shoots. As the summer advanced, these colonies dispersed to the leaves and later to the grape bunches. *H. felixi* was never found on the vines in any numbers until there were large exposed colonies around the bases of the young shoots. This easily accessible and large food supply was able to support considerable numbers of these larvae. With the dispersal or the destruction of the mealybug colonies, there was an immediate reduction in the numbers bers of *H. felixi* larvae collected. At Paarl, where the mealybugs never formed large colonies at the bases of the young shoots, the number of *H. felixi* collected was considerably smaller than at Stellenbosch.

The smaller species of beetle, that is, those belonging to the long filamentous group, have much lower rates of feeding, and can complete their development on a lighter mealybug infestation. These larvae were not so readily affected by a dispersal of the food supply, and were present as long as there were still some mealybugs on the vines.

Beetles such as *Exochomus flavipes* and *Cydonia lunata* only occurred on mealybug infested vines during the hot summer weather, apparently when other food was scarce.

Cannibalism.

In captivity all the coccinellid larvae, with the exception of *Scymnus* sp. and *Rhizobiellus* sp., were cannibalistic. The long filamentous larvae only attacked their own kind when no other food was available. These larvae could thus be reared in large numbers in the same cage, provided that there was adequate food. The larvae of *H. felixi*, on the other hand, could not be reared in large numbers together as they attacked one another even though sufficient food was present. In the field cannibalism was noticed only on one occasion. This was where *S. quadrivittatus* larvae attacked larvae of their own species on a vine where the mealybug infestation had already been destroyed.

Although it is a factor to be considered in laboratory rearing, cannibalism is of minor importance in the field.

Climatic conditions.

Cooler conditions of course slowed down development of all the beetles. H. felixi, for instance, was found to lay less eggs at 24°C. than at 26°C. and hardly oviposited at all below 21°C. Beetles such as S. quadrivittatus and S. binaevatus, on the other hand, although less active in the cooler weather, continued to breed.

In some instances the cooler weather was advantageous to some of the coccinellids. The larval parasite Homalotylus africanus was active in the warm weather and caused considerable reduction in the number of beetles reaching maturity. In the cooler weather of autumn, winter and spring, however, Homalotylus was inactive, while beetles such as S. quadrivittatus and S. binaevatus, although retarded in development, nevertheless continued to breed.

Insecticides.

DDT, parathion, dieldrin and chlordane are four insecticides applied frequently to vineyards. Dieldrin and chlordane, if applied to the vine stems, destroyed any predators feeding there. It is for this reason that the soil application of these two insecticides is preferred. DDT, which was on occasion applied to the foliage in early summer to control snout beetles, caused an appreciable drop in the numbers of Coccinellidae collected, but parathion, the chemical used against _Pl_. _citri_, did not seem to have much overall effect on the predator population.

It is difficult to assess the relative importance of the reducing factors, but parasitism was the most obvious although it is doubtful whether it was the most important. The presence of the host on a particular vine was obviously an essential for the presence of predator larvae, but did not appear to be so essential to adults, as beetles were sometimes found in large numbers on uninfested vines. Climatic conditions were a basic factor controlling the mealybug cycle, rate of development of the predators and their parasites.

CHRYSOPIDAE.

Field and laboratory studies were made of the two chrysopid species collected on vines.

METHOD OF STUDY.

Most of the material used in the laboratory was collected in the field in the egg stage, but on occasion adults, collected at night, produced eggs which were used for study in the laboratory. All immature stages were kept in embryological watch glasses and were fed on *Pl. citri*.

GENERAL CHARACTERISTICS.

Characteristics common to both species are discussed before describing the species individually.

Egg.

The eggs of both species are stalked and are green in colour when laid, each with a button-like micropyle at the free end. A gelatinous substance, which is secreted at oviposition, is drawn out and hardens to form the stalk. The length of the egg stalks of the different species apparently varies directly according to the length of the abdomen (Smith, 1922). The stalk undoubtedly affords some protection from crawling predators, but Smith (1922) noted that larvae of Chrysopidae could ascend the stalk and consume unhatched eggs, and van der Weele (1909) found mites attacking stalked eggs of chrysopids.

Hatching.

Hatching of the egg in both species is brought about with the help of an egg-bursting apparatus which appears as a dark line between the eye spots on the ventral surface of the egg. This apparatus, according to K~~e~~illington (1936) lies over the labium and clypeus. Smith (1922) gives a detailed account of the eclosion of the egg of Chrysopa occulata. The egg burster, situated on the head, is forced through the chorion by the pressure of the abdomen and the rent in the egg shell is enlarged by the emergence of the head and thorax. The post-embryonic moult takes place as the larva emerges, and the exuvium, with the bursting apparatus, remains attached to the egg shell. After a varying period of rest, the larva descends by the egg stalk.

Larva.

Both species of larvae are spindle-shaped in outline, with setae set in raised tubercles on the thorax and abdomen. The length and form of these setae differ in the two species. The last two abdominal segments are telescopic, the last being equipped with a sucker which is used in locomotion and anchorage.

Larval Feeding.

The mandibles and maxillae are long and curved, and are hollow in their ventral and dorsal surfaces respectively. They fit together by means of a flange and groove to form a tube leading into the pharynx. The mouth is closed. The mandible, which is pointed, is the piercing agent (Smith, 1922). During feeding the mandibles remain stationary, while the maxillae move back and forth, together at the commencement of the meal, and singly, one side or the other, as the host's body fluids become less. Smith describes how the body fluids of the host are sucked out by the contraction and expansion of the lumen of the pharynx, assisted by the contraction of the maxillae themselves.

Smith (1922) could find no evidence of external digestion, but surmised that the movements of the maxillae may have assisted in the disintegration of the internal tissues. Killington (1936) was of the opinion that some external digestion probably took place.

Pupa.

A silk cocoon, which consists of a rough outer layer and a smooth inner layer, is spun by the prepupa. Pupation takes place within the cocoon, the last larval skin being visible as a black disc at one end. If the cocoon is opened before spinning is complete, the prepupa seals the rent so that it is not visible when the cocoon is completed.

The pupa, when ready to emerge, pushes a neat round cap off the cocoon. There is some doubt as to how this is achieved. Smith maintains that it is accomplished by pressure alone, while Balduf (1939) states that it is effected by the large mandibles of the pupa. Experiments in the laboratory showed that a cap could be pushed out at the end where the shed larval skin is situated, and at the opposite end, which is where the pupa emerges. A strip could be torn off parallel to the edge left when the cap was removed, simply by gripping the edge with forceps. No cap could be pushed out from the side of the cocoon and pulling here with forceps resulted in a jaggered tear. It would thus appear that pressure alone could effect the neat opening of the cocoon, but that this cap only came away in certain places, probably, as suggested by Smith, as a result of the method of spinning the cocoon.

Emergence from Cocoon.

The pupa, after emergence from the cocoon, walks around in an agitated manner before finding some place of attachment prior to bursting the pupal skin. It was found that mortality at this stage was high. According to Smith, this was caused by lack of a suitable place of attachment.

Adults.

Both adults are green and were difficult to distinguish from one another. They were seen to feed only on honeydew. During the day they rested on the vine foliage, but took to flight when disturbed.

CHRYSOPA SP. Ac.FR. 671 (NAKED LARVAE).

Studies were made both at a controlled temperature and in the field.

Life History.

This includes a study of the development and habits of all the stages.

Egg.

The eggs, which are laid singly, were collected mainly on the underside of vine leaves, but are sometimes deposited on the vine stem and grape berries. As the eggs develop, they change from green to a mixture of green and fawn and finally to fawn. The segmentation and eye spots of the developing embryo are clearly visible. Approximately a day before eclosion, the eye sopt area can be distinguished as five distinct spots arranged in a circle.

Larva (figs 88 and 89).

The first instar larva, after resting on the egg shell for a while, descends by the stalk, head first,

CHRYSOPA SP. Ac.FR. 671 (NAKED LARVA).

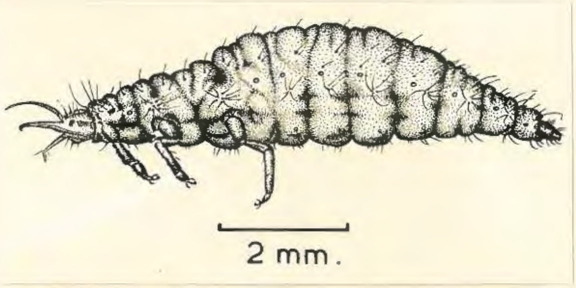


Fig. 88. Mature larva.

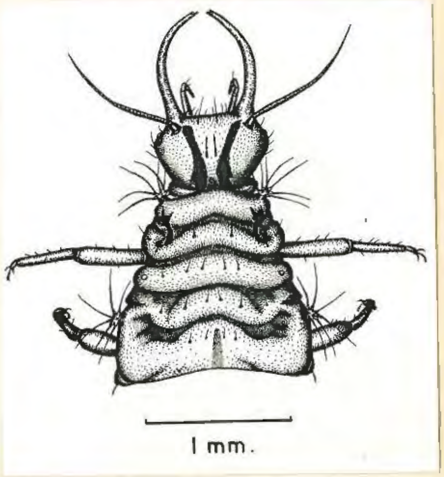


Fig. 89.
Head and first two thoracic segments.

CHRYSOPA SP. Ac.FR. 672 (COVERED LARVA).

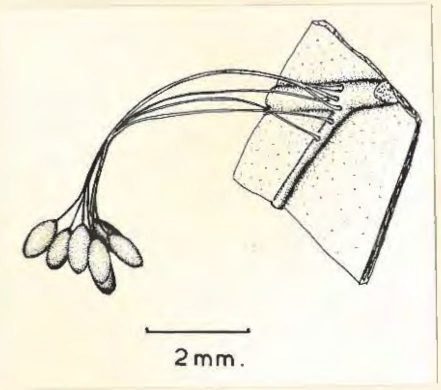


Fig. 90. Eggs on leaf.

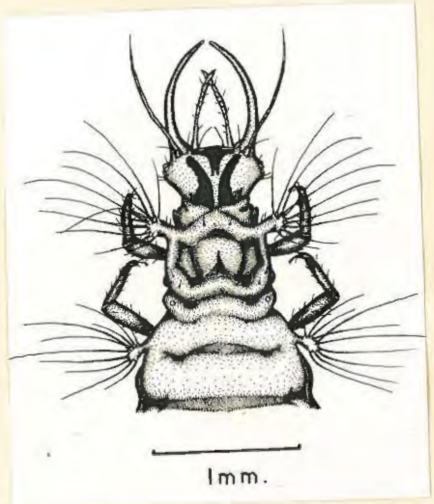


Fig. 91.

Head and first two thoracic segments.

frequently using the anal sucker for support. The head is translucent white with dark ocelli, and the body is pinky fawn. After three days the thorax and abdomen take on a reddish-brown colour while the edges of the thorax and the lateral tubercles of the abdomen become off-white. The legs are black to grey. The head and mouthparts of the first instar larva are extremely large in proportion to the body and make up about one third of its total length. All tubercles on the thorax and the lateral tubercles of the abdomen have two long setae. On the head, two slightly converging dark marks originate from the bases of the antennae and pass over the vertex of the head to the occipital margin. There is another marking from the base of each mandible, running through the ocelli along the outer margins of the head to the occipital margin. Sometimes there is a third but faint marking lying between the lateral marking and those on the vertex.

There are six ocelli, five of which lie in a circle, with the sixth in the centre.

The head markings of the second and third larval instars, although slightly broader than those of the first instar, are essentially the same. However, there is the addition of two faint parallel markings between the prominent converging lines on the vertex. On the thorax and abdomen are reddish-brown markings with tinges of green. In the third instar the setae on the thoracic and abdominal tubercles vary from seven to eight in number, and the longest setae are shorter than the narrowest part of the prothorax. In the second and third larval instars, although all six ocelli are still present, only three are well developed. These are situated anteriorly in an obtuse triangle. The remaining three less well developed ocelli are placed in an acute triangle, and are situated a little to the posterior.

Duration of the immature stages.

Great difficulty was experienced in keeping adults of Ac.FR. 671 alive in the laboratory. Smith (1922) experienced the same difficulty with some species. Consequently eggs of a known age were not procurable and the duration of this stage is not known.

Table XIV. Mean length of life in days of Chrysopa sp. (Ac.FR. 671) kept at 24°C.

Larval Stages 1	2	3	Pupa	Adult	Mean Total.
4.5	3.6	4.7	10.3	2.6	23.6

The duration of the pupal stage was calculated from the commencement of spinning to the emergence of the adult and thus included the prepupal period. Adult life under laboratory conditions was extremely short and no eggs were ever obtained from this species, in spite of the use of several types of cages.

Habits of larvae.

Larvae frequent any part of the vine infested by Pl. citri and, although it is not possible for them to reach the deep seated colonies under the bark, they feed on the more open colonies. The larvae have the habit of lying perfectly still, which, together with their brown and green colouration, makes them difficult to detect in the field. Their movements are short and swift, the larvae coming to an abrupt halt after each short dash. These sudden short movements made them more difficult to handle in the laboratory than the other species.

Food and Feeding.

As the Chrysopidae are only found on vines for short periods of the year, they must have alternative hosts, probably aphids, which are more attractive.

The host, which is pierced with the mouth parts, is sucked dry of its body juices, and the remains are discarded. On the vine, not only mealybug females, but also egg sacs and in fact anything edible, including coccinellid larvae, are attacked. In the field a lacewing larva was seen to attack and consume the larva of Hyperaspis felixi.

In the laboratory ten larvae were fed on Pl. citri of the second and third nymphal stages.

Table XV. Mean number of mealybugs consumed by the various stages of Chrysopa sp. (Ac.FR. 671) kept at 24°C.

	Larval Stages			Total
	1	2	3	
Mealybugs consumed	15	26.6	39.3	65.2
Average consumed per day	3.2	9.4	8.4	6.0

Prior to pupation larvae consumed considerably more per day than during the rest of the last larval instar.

Pupation.

Several days before spinning, a yellow gelatinous fluid is given off from the anal sucker. The cocoon, which is white, is oval in shape. In the field cocoons were found at the feeding sites and in sheltered spots such as a crevice in the vine stem or a curled up leaf. In the cages in the laboratory, cocoons were spun under or next to a piece of cork placed there for that purpose. When ready to emerge, the pupa pushes open a cap at the end of the cocoon, generally opposite the last larval exuviae.

Seasonal History.

In the areas where this work was undertaken, winter temperatures seldom drop below freezing and overwintering consisted of a lengthening of certain of the stages. No eggs or adults were collected in the field during winter. Although cocoons were collected in winter, it was not ascertained whether this lacewing overwintered as the prepupal or pupal stage. Smith (1922) found in the United States, that the majority of the Chrysopidae overwintered as prepupae, while some overwintered as adults and others continued to breed during the winter if the weather was suitable. Eggs collected during May and kept at outdoor temperatures gave rise to adults in July. On another occasion, mature larvae, collected during June and kept out of doors, became adult in August. This indicated that development could continue during the winter.

CHRYSOPA SP. Ac.FR. 672 (COVERED LARVAE).

The study of this species was carried out under the same conditions as Ac.FR. 671.

Life History.

Egg.

The eggs (fig. 90), which are similar to those of Ac.FR. 671, are green when laid, turning fawn with development. Although also laid on stalks, they can easily be distinguished from the previous species, as they are deposited in clusters. The number of eggs in a cluster varies from the occasional single egg to a maximum of eight. In the field eggs are usually laid on the under side of leaves, on the vine stem or on grape berries. In the laboratory eggs were laid on an overhanging surface. Most clusters have the stalks separate at the base and also at the attachment of the egg, but are fused at some point along the length of the stalk. In a few cases the stalks are not joined and the cluster consists of single eggs.

Larva.

On emergence from the egg, the larva is light grey with a tinge of fawn, becoming dark fawn and mottled grey on the second day. The thorax of the mature larva is creamy white to grey, whereas the abdomen is creamy white with a tinge of brown in the mid-dorsal region.

The markings on the dorsal surface of the head, although becoming broader and darker in each successive instar, are basically the same. These consist of two inner markings arising at the bases of the mouthparts and curving inwards and backwards along the middle line of the head. They do not extend further than half the length of the dorsal surface. The outer pair of markings arise near the bases of the antennae, converging and broadening, and they extend backwards to the prothorax. Variations of this pattern occur in the second and third instars, where the inner markings partially fuse or the outer markings broaden at the base to double back and form a small outer pair of markings (fig. 91). In a few instances, the markings are so broad that the entire head appears black with a light Y-shaped mark in the middle of the dorsal surface.

In the first instar the prothoracic tubercles bear two long setae, whereas there are three on the meso- and meta-thoracic tubercles. In the subsequent instars the tubercles are stalked, bearing ten to twelve long setae on the prothorax and less on the meso- and metathorax. The lateral tubercles of the abdomen are not stalked and bear the longest setae on segments five to seven. Recurved setae are present from the posterior metathorax to the fifth abdominal segment (figs. 93 and 94). Under the bundle of debris, the abdomen is humped. This results in a narrowing and deepening of the segments in that region (figs. 9~~4~~2 and 9~~5~~3).

Making of debris bundle.

After descending from the eggs, larvae, before feeding, seek bits of suitable material with which to

CHRYSOPA SP. Ac.FR. 672 (COVERED LARVA).

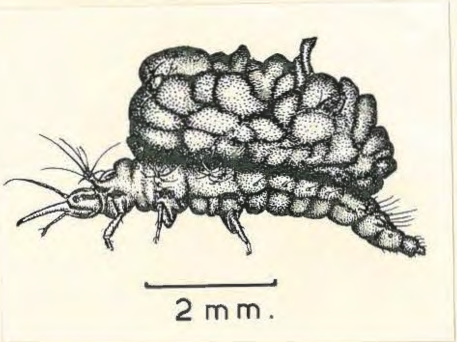


Fig. 92. Mature larva.

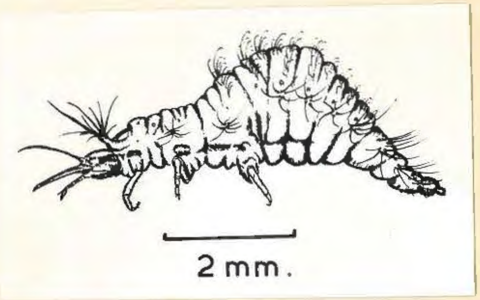


Fig. 93. Mature larva - bundle of debris removed.

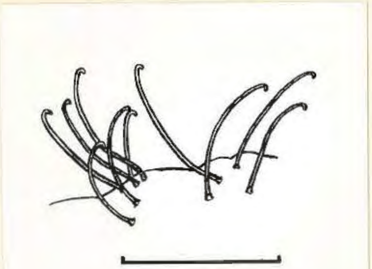


Fig. 94.

Recurved setae of mature larva.

cover themselves. Bits of cork, old egg shells or any bits of material of suitable size are accepted. Larvae feeding on mealybugs pull off pieces of the egg sac and, by rolling these into small balls with the mouthparts, are able to cover themselves completely with this material. The larva places the debris on the first of the recurved setae by curving the head back over the thorax. The front legs are lifted from the ground during this act.

Mealybugs, offered to larvae which had not yet placed any debris on the abdomen, were not consumed but were placed on the recurved setae. In another instance a larva assumed a threatening attitude and moved away.

As the points of the hooked setae curve backwards, any material pushed on to them from the anterior is able to move in the direction of the hooks but cannot return. The addition of more material at the front and the movement of the body help to push the debris back and build up the bundle. By patting any protruding pieces of material with the mouthparts, the larva keeps the whole bundle neat.

Duration of the various stages.

The duration of the various stages was obtained from ten individuals kept in the laboratory at a constant temperature.

Table XVI. Mean length of life in days of Chrysopa sp. (Ac.FR. 672) kept at 24°C.

Egg	Larval Stages 1	2	3	Pupa	Adult	Average Total Duration.
4.3	5.5	4.1	25.9	15.4	6	39.0

As in the naked lacewing species, the pupal stage included the prepupal period.

Habits of larvae.

The larvae are extremely active and are often seen walking about on infested vines in search of food. When feeding, the body is rocked gently from side to side, and sometimes when resting the sideways movements become faster and are interspersed with slower movements. These movements are not as pronounced as those made when feeding. If touched, the body of the larva tilts to the stimulated side.

Food and Feeding of larvae.

As with the naked lacewings, these chrysopids were found on the vines at certain periods of the year only, and presumably have other hosts. Covered larvae similar to this species have been collected feeding on aphids on chrysanthemum.

All stages of the mealybug, including eggs, are consumed.

Table XVII. Mean number of mealybugs consumed by the various stages of Chrysopa sp. (Ac.FR. 672) kept at 24°C.

	Larval Stages			Total
	1	2	3	
Mealybug eaten	6.5	8.4	63.3	79.7
Average per day	1.2	2.4	4.1	2.4

The remains of the hosts, after their internal juices have been consumed, are sometimes but not always placed on the bundle of debris. On vines, when the main food was Pl. citri females, the debris bundle consisted mainly of the remains of egg sacs, mixed with bits of bark, parts of other insects, the larva's own exuviae and a few dead mealybug females.

Pupation.

From two to fourteen days prior to pupation, the larva excretes blobs of yellow gelatinous fluid. During the spinning process the long setae are broken off and, with the bundle of debris, become incorporated into the outer network of the cocoon. Spinning is executed by movement of the last four abdominal segments. The body lies curled up half on its side, with the head lying near the posterior abdomen. The inner cocoon, which is oval, is thicker and of a finer texture than the outer.

In the field cocoons were located in any sheltered spot on the vine, usually near the last feeding site.

Adults.

The adults are light green with yellow green markings down the mid-ventral line. There is sometimes a red tinge to the area between the eyes and the mouthparts. Difficulty was also experienced in keeping adults of this species alive in the laboratory, although one pair, which was caught at a window at night, did lay in the cage provided. Over a period of ten days, a total of 67 eggs was laid in 14 clusters.

Seasonal History.

Covered lacewings were collected in all the areas during the midsummer months, and this species was the most abundant at Stellenbosch.

A COMPARISON OF THE TWO SPECIES OF CHRYSOPIDS.

The two chrysopids, consuming the same host under identical conditions, have several distinct and interesting differences. The clustered eggs and debris-carrying larvae easily distinguish Ac.FR. 672. The habits of these covered larvae are also distinctive, as when feeding, or even at rest, the body is continually rocked from side to side. The bundle of debris makes them rather conspicuous to the human eye, and the rocking movements make them even more so. Larvae of the other species, on account of their colour and manner of movement, blend extremely well with the surroundings and are thus more difficult to detect.

Other points of difference are the duration of the immature stages and the number of mealybugs consumed. The average duration of the immature stages of the naked larvae (excluding the incubation of the egg) is nearly 39 per cent. shorter than that of the covered lacewing larvae, whereas the number of mealybugs consumed is only 18 per cent. less. In other words, the naked larvae feed at a greater rate than the covered larvae.

No reliable method of differentiating the adults has been found, although there was a small, but not reliable, difference between the number of connecting veinlets in the forewings.

FACTORS REDUCING THE POPULATION OF BOTH SPECIES OF CHRYSOPIDS.

Of the factors contributing to the reduction of the Chrysopidae, parasitism was the most obvious, but was not necessarily the most important.

Egg parasites.

Collections of parasitised eggs were made on three occasions only. A single egg of Ac.FR. 671 and, on two occasions, clusters of eggs of Ac.FR. 672 were parasitised. In the latter case all eggs in both clusters were attacked. Parasitised eggs are easily recognisable by their dark grey to mottled black appearance. The cream coloured micropyle is very obvious. Two species of parasites may be involved, as one batch of eggs had jaggered emergence holes on any part of the egg, whereas in the other instance the parasites emerged by the removal of a neat cap at the micropyle end. The former eggs were unfortunately collected after the parasites had already emerged. All egg parasite collections were made at Paarl.

Larval and Pupal Parasites.

Clancey (1946), studying the parasites of Chrysopidae in the United States of America, found that if the egg parasites were excluded, all but one of the parasites attacked the larva, prepupa or pupa, and that all emerged from the cocoon. It was thus difficult to ascertain whether a parasite was larval or pupal, especially if only the pupae were collected.

The only parasite reared from Stellenbosch was an unidentified ichneumonid (Ac.FR. 612), one of which emerged from each host pupa, collected in the field as mature naked larva. Eight larvae, which were collected on 4th June, 1953, pupated normally on 16th June, and gave rise to three of the above parasites on 7th July. This parasite has been collected from neither Paarl nor the Hex River Valley.

Pupae of naked lacewings collected at Elsenburg near Stellenbosch, and at Orchard in the Hex River Valley, produced six to eight yellow parasites (*Isodrom~~y~~us* sp.?) from each parasitised cocoon. Several unidentified black parasites were reared from a cocoon of the naked species collected at Orchard.

Cannibalism.

Cannibalism was never observed, but Smith (1922) found that if confined without food, young larvae would eat their own kind. These conditions are unlikely to occur in the field, however.

Restriction of Food Supply.

Clancy (1946) stated that the Chrysopidae are only of secondary importance in controlling aphids in the United States of America, as a certain minimum density of the host is essential before they can maintain themselves. This may also apply to lacewings on the vines, for although the mealybug population is highest during spring, this population is largely under the bark and is thus unavailable to the lacewings. The mealybugs available, that is, those occurring on the foliage, are at their peak in autumn, which is when the lacewings occur. The scarcity of food, such as aphids, may cause an increase of the lacewings on vines, and the abundance of aphids elsewhere will conversely reduce the lacewing population in vineyards.

Other Factors.

Birds, expecially swallows, have been seen to feed on lacewings when they have been flushed during daylight, and bats probably consume considerable numbers at night.

ECONOMIC IMPORTANCE OF THE PREDATORS.

The first field observations were made in mealybug infested vineyards where the prevailing conditions were disturbed as little as possible. *Pl. citri* was not chemically controlled, nor were the ants disturbed.

This afforded a study of the existing balance between the mealybugs, their natural enemies and the ants. Neither the predators nor the parasites were able to exert any lasting influence on the host while ants were in attendance. This is what was expected, as infestations of Pl. citri had been prevalent for at least twenty years. From Figure 8 it can be seen that, although the mealybug population was considerably reduced at the time of maximum activity of the predators and parasites, sufficient mealybugs escaped to maintain the populations the following season. In practice, if no chemical control of the mealybug is undertaken, considerable damage to the grape crop results.

When ant control was correctly timed, the mealybug population was reduced to such an extent that no other control measures were necessary. This reduction is attributed mainly to the Coccinellidae. Laboratory studies of the coccinellid and chrysopid predators brought a few interesting points to light. The average number of mealybugs consumed by the various predators and their rates of feeding are given in the following table.

Table XVIII. Average number of mealybugs consumed and the rate of feeding of the various predators kept in the laboratory at 24°C.

Predator.	Number of mealybugs consumed during life	Average consumed per day
H. felixi male	744.4	6.4
H. felixi female (Egg laying) ..	2,790.0	13.9
S. quadrivittatus	96.3	1.1
S. angustus	43.6	0.8
Rhizobiellus sp.	108.7	0.5
Scymnus sp.	109.3	1.0
Chrysopa sp. Ac.FR. 671 (Naked)	65.2	6.0
Chrysopa sp. Ac.FR. 672 (Covered)	79.7	2.4

The larvae of H. felixi required large amounts of easily accessible food, and when this was not available, their numbers dropped appreciably. In Stellenbosch conditions favourable to their increase occurred in early summer, and they were the most important predator at that time, but when conditions became unsuitable, the population decreased rapidly. This beetle was of no great importance in Paarl, probably because of the absence of large exposed colonies of mealybugs at the bases of shoots during early summer. On the other hand, beetles such as S. quadrivittatus and S. angustus, with a considerably lower rate of feeding, could exist on a much smaller population of Pl. citri and consequently were more effective.

Obviously, factors other than feeding influence the importance of a beetle as a predator. Rhizobiellus sp. and Scymnus sp., for instance, had rates of feeding comparable with S. quadrivittatus and S. angustus but, for some unexplained reason, were of minor importance. Factors such as fecundity, longevity, climate and parasites, all played some part in determining the efficiency of predators.

HYMENOPTERA.

FACTORS LIMITING THE PRIMARY PARASITE POPULATIONS.

The action of hyperparasites, which emerged from over 50 per cent. of parasitised mealybugs at the height of parasite activity at Stellenbosch, was one of the major limiting factors. Unfavourable weather conditions decreased parasite activity considerably, resulting in low parasite populations in the winter months. The absence of hosts, resulting from predator activity, was also the cause of the small number of parasites collected in ant treated areas. Because of the interference of predators, it was not possible to determine the effect on the parasites of the absence of ants. Field observations, however, showed that ants definitely interfered with adult parasites.

ECONOMIC IMPORTANCE OF THE HYMENOPTEROUS PARASITES.

At Stellenbosch in February, 1953, parasitism on leaves varied from ten to fifty per cent., while at Orchard in the Hex River Valley, in March, 1955, parasitism on the leaves was 9.4 per cent and in the bunches 11.5 per cent. In both cases ants were present. It can thus be seen that parasitism can be quite high at the peak of parasite activity. The real value of parasite activity, however, lies in the attack on Pl. citri females on the leaves during the late autumn months. In some cases all mealybug females on the leaves at this time were parasitised. It can be argued, of course, that it was only the parasitised individuals which were unable to move off the leaves, but there were often unparasitised females present on the leaves as well.

Leptomastix sp. attacks Pl. citri females when they are adult. It was noted, however, that numbers of parasitised individuals were still able to lay eggs.

A disadvantage of both Leptomastix sp. and Anagyrus sp. is that they were attacked by secondary parasites. By the time the primary parasites had begun to build up to economic proportions, the hyperparasites became evident. From Figures 7, 9 and 10, it can be seen that over 50 per cent. of the primary parasites were destroyed by the hyperparasites at the time of peak activity.

It is difficult to gauge the actual effect of the parasites upon the mealybug population. Two attempts to do this, by controlling the ants first in autumn and then in spring, failed, as the coccinellid predators reduced the mealybug to economic proportions before the parasites had time to increase. A further attempt, by controlling ants prior to the normal peak of parasites, was this time foiled by both coccinellids and chrysopids.

It can be observed from Figures 5, 6 and 8 that the parasite populations at Paarl and Stellenbosch only reached a maximum in early autumn. At this time of year a large proportion of the mealybug infestation is centred in the grape bunches. Any remedy applied at this period is of little value as the damage has already occurred. In other words, unless the parasites are able to control the mealybug before midsummer, they are of little value to the table grape industry.

It is thus held that, although the parasites definitely reduced the mealybug population to some extent, they were not sufficiently active to bring the pest down to an economic level. They can only be considered as a useful adjunct to other natural enemies.

PART III.

CONTROL OF THE ARGENTINE ANT, IRIDOMYRMEX HUMILIS (MAYR), IN VINEYARDS AND THE EFFECT OF THIS CONTROL ON THE MEALYBUG, PLANOCOCCUS CITRI (RISSO), AND ITS NATURAL ENEMIES.

INTRODUCTION.

Before the advent of the organic insecticides, the control measures against the Argentine ant, Iridomyrmex humilis (Mayr), consisted of baiting and repulsion by means of sticky barriers. When the organic insecticides were developed, they were tested against various insects, including, of course, the Argentine ant, with the result that today we have insecticides, one application of which will give satisfactory control of this ant for a period of more than three years.

The object of the following work, undertaken during a biological control project, was to determine the effectiveness of dieldrin against the Argentine ant, to compare it with the older control measure of baiting, and to determine the subsequent effect of ant control on the mealybug and its natural enemies.

REVIEW OF PREVIOUS ANT CONTROL WORK.

Early Baiting Methods.

The Argentine ant appeared in the United States of America in 1891 (Gerhardt, 19~~46~~53), in South Africa in 1897 or 1898 (Dürr, 1952), and in Australia in 1939 (Hogan, 1940). According to Gerhardt (1953), Newel and Barber first used poison baits in 1910. These baits and tanglefoot bands were the standard control measures used until organic insecticides were developed and found to be more effective (Gerhardt, 1953).

In Australia, it was found that, although baiting was fairly successful if carried out thoroughly, it was dangerous to human beings because of the poison content of the bait. Other means of control were then sought (Wilson, 1951).

In South Africa baiting was also the standard method of control, but sticky barriers were occasionally used (Tucker, 1926; Potgieter, 1937; Hattingh, 1943; Dürr, 1952). Baiting was also advocated for supplementary use with the contact insecticides (Dürr, 1953a; Joubert & Walters, 1955).

Newer Developments.

DDT.

With the development of the contact insecticides, there was a new approach to ant control. Ingram (1944) in the United States of America, was the first to use DDT successfully as a contact insecticide against the Argentine ant. In Australia, Jenkins & Forte (1946) and Jenkins (1948) recommended spraying with DDT for Argentine ant control. Wilson (1951) obtained satisfactory results by spraying DDT on the foundations of houses in the residential areas of Melbourne.

CHLORDANE AND DIELDRIN.

Chlordane was first used by Eckert & West in 1948 against the Argentine ant in beehives, but unfortunately the bees were also affected. Pasfield & Greaves (1951), Dürr (1952) and Forte & Greaves (1953) showed that chlordane was more effective than DDT, and Gerhardt (1952), working on citrus, found that chlordane and dieldrin gave good ant control for about six months.

In 1954 Gerhardt, in comparing a poison bait with chlordane and dieldrin sprays applied to the stems of citrus, found that these sprays gave better ant control than the bait and were more economical to apply.

In South Africa, Joubert & Walters (1955) obtained equally good results with dieldrin and chlordane applied at the same concentration to the soil. At the time of writing, these insecticides have both been effective for over four years. Dürr (1955) found that, when applied to vine stems, dieldrin was more effective than chlordane.

Carman (1955), using granular formulations, found that dieldrin and chlordane were as effective when applied to the soil as when applied to the trunks of citrus trees. Recent work of Forte & Greaves (1956) showed that two per cent. dieldrin, sprayed on to the soil in household allotments, was effective for three years.

EFFECT OF APPLICATION METHOD ON EFFICIENCY.

The method of application of these insecticides in some cases played an important role in their efficiency. For instance, chlordane, sprayed on to the soil in a grid pattern, was effective for 13 weeks (Pasfield & Greaves, 195~~2~~1), but if broadcast on to the soil and worked in lightly, it lasted for at least four years (Joubert & Walters, 1955). Dieldrin, on the other hand, was found to be as effective when sprayed on to the soil (Forte & Greaves, 1956) as when it was broadcast and worked into the soil (Joubert & Walters, 1955). Dieldrin, sprayed on to the soil, was not effective in the Western Cape Province (Dürr; McIntosh, private correspondence).

EFFECT OF SURFACE ON EFFICIENCY.

The type of surface to which the insecticide is applied may also determine its efficacy. DDT applied to house foundations gave good control of ants, but if applied to the soil, was not effective (Wilson, 1951). On citrus tree trunks, Gerhardt (1954) found that ants were controlled for six months with dieldrin, while Dürr (1955) found that, applied to vine stems at even lower concentrations, dieldrin lasted for at least fourteen and a half months. Chlordane was as effective as dieldrin when broadcast on to the soil and worked in lightly (Joubert & Walters, 1955), but was less effective when sprayed on to vine stems (Dürr, 1955).

From the literature it appeared that dieldrin and chlordane were the two most promising insecticides, being equally effective if applied to the soil. Dieldrin appeared to be more effective than chlordane when aprayed on to various surfaces. The use of correct concentrations assured control of the Argentine ant for at least four years.

RESULTS OF ANT CONTROL WORK IN THE WESTERN CAPE PROVINCE.

In the present work it was found that baiting reduced the number of ants, and although the numbers of mealybug colonies were also reduced, they were not destroyed completely, with the result that similar mealybug populations were again present in the baited block the following season. The mealybugs were destroyed more quickly in the soil-treated blocks, although the ants disappeared more slowly here than in the stem-sprayed blocks. Stem application of the insecticide, although so effective against the ants, destroyed some of the natural enemies, especially coccinellid larvae which fed on the mealybug colonies on the main stem of the vine. The application of dieldrin to the stem or soil in the autumn was more effective than when applied in spring. Where ants were controlled, coccinellid predators were able to destroy or reduce the mealybug populations to such an extent that no hosts were available for the hymenopterous parasites which occurred only later in the season.

EXPERIMENTAL METHOD FOR ANT CONTROL.

The following experiments were undertaken to compare the older methods of control (baiting) with the newer dieldrin treatments. Various methods of application and different concentrations of the insecticide were tested at different times of the year.

EXPERIMENTAL DESIGN.

All ant control experiments were carried out on Mr. J.M. le Roux's farm, "Sonneskyn", in the North Paarl district, where the vineyards, which consisted of the varieties Alphonse Lavallee and Waltham Cross, received two irrigations during the summer.

In control experiments against the ant, Iridomyrmex humilis, Joubert & Walters (1955) found that it was desirable to use plots of at least half an acre. If smaller plots were used, they were invaded from the untreated areas. Moreover, subsequent work at Paarl has shown that, when plots smaller than half an acre were used, there was an invasion of predators, mainly adult coccinellids, from the ant free areas into the untreated control plots. This lowered the mealybug infestation in the untreated areas. Between each block of half an acre, three untreated rows were left, to ensure that reinfestation by ants could take place if the treatment allowed it. Owing to the size of the blocks, no replications could be made.

APPLICATION OF INSECTICIDE.

BAIT.

The bait consisted of a mixture of sodium arsenite, golden syrup and water.

Reed containers, each made of a reed cut above and below a node, were stuck upright into the ground, touching the base of the vine to be baited (Hattingh, 1943). Four ml. of the bait was poured into the portion of the reed above the node. A reed container was placed at every vine around the circumference of the treated area, but only at every third vine inside the block. The bait was replenished every month in winter and every two weeks in summer. The reeds, because they became dust covered and clogged with soil, were replaced twice a year.

DIELDRIN.

Dieldrin (a compound containing not less than 85 per cent 1, 2, 3, 4, 10, 10-hexachloro-6, 7a epoxy-1, 4, 4a, 5, 6, 8, 8a-octohydro-1, 4, 5, 8-dimethanonaphthalene), in the form of a 50 per cent. wettable powder, was the only organic insecticide used against ants. The various treatments were designed to show at what time of the year it should best be applied, the most advisable method of application and the most effective minimum concentration to be used.

For the soil treatment, the required amount of insecticide was mixed with enough sand to broadcast over an acre. Rubber gloves were used to prevent absorbtion of the insecticide through the skin, as the mixture was sown manually. The whole area between the vine rows was covered, with an overlapping of the material at the bases of the vines. To prevent invasion of ants by way of the anchor wires, the insecticide was broadcast beyond the vine rows at either end of the blocks.

To avoid loss of active ingredient and possible contamination of the vine foliage by dusting, the soil-insecticide mixture was damped. The mixture was of the correct consistency when, if squeezed in the hand, it just kept its shape. If over moistened, the mixture fell in lumps, resulting in an uneven distribution.

For the application to the vine stems, the required amount of insecticide was weighed off and mixed with four gallons of water. The mixture was applied with a knapsack spray pump to each vine stem, from knee height to ground level. Two spray operators working from each side of the row ensured complete coverage. This method was much slower than the soil-application method, and required more spray material.

METHOD OF TAKING RESULTS.

The counts of ant infestation, where possible, were made before, as well as after, the various treatments were applied; one or more ants per vine constituted an infestation. Counts were made weekly, using every third or fifth vine in a fixed number of rows in the middle of the blocks. As the vines used for these experiments produced grapes for the export market, a single parathion spray had to be applied to heavily infested vines during December or January. Total mealybug infestation counts were made annually prior to this parathion spray application. The figure thus obtained for the mealybug infestation was higher than the infestation of grape bunches, as it was found that in heavily infested vines it was seldom that more than 60 per cent. of the bunches were infested.

For collection of predators and parasites, two vines were examined weekly in each treatment, and all predator and parasite material collected was taken to the laboratory for identification. Because of the large numbers involved, no direct counts of mealybugs were made on each vine examined. Instead, the product of the number of colonies and the number of mealybugs in the largest colony per vine, was used as an index of the mealybug population.

EXPERIMENT I.

Comparison of the effectiveness of stem sprays against the Argentine ant, using dieldrin 0.5 per cent. emulsion, 0.5 per cent. wettable powder and ~~0,~~ 1·0per cent. wettable powder.

In previous experiments, Dürr (1955) found that dieldrin applied to the vine stems as a spray gave the best control of the Argentine ant. The present experiment was started by Dürr in 1953 to test dieldrin at lower concentrations than used in the previous work, and to determine any difference between the emulsifiable and wettable powder formulations. The experiment was primarily designed for ant control.

Both wettable powder and the emulsifiable forms were used for a 0.5 per cent. spray, whereas a 1.0 per cent. spray was made up from the wettable powder only.

RESULTS.

Dürr (1955) found that, after fourteen months, almost complete ant control was still being obtained in all the treatments, whereas there was a high infestation in the controls.

This experiment was later taken over by the author and subsequent ant and mealybug infestation counts are given in Figure 95 and Table XIX.

Table XIX. Vines infested with mealybugs prior to harvest, 1954-55, 1955-56 and 1956-57.

Treatment	% Vines infested		
	1954-55	1955-56	1956-57
0.5% emulsoin	0.5	2.1	7.3
Control 1	43.1	50.5	54.7
1.0% wettable powder	3.2	2.1	5.4
Control 2	53.1	48.1	54.1
0.5% wettable powder	4.8	9.6	15.7
Control 3	35.7	49.7	38.2

The figures for mealybug infestation for 1954-55 were obtained from Dürr (1955).

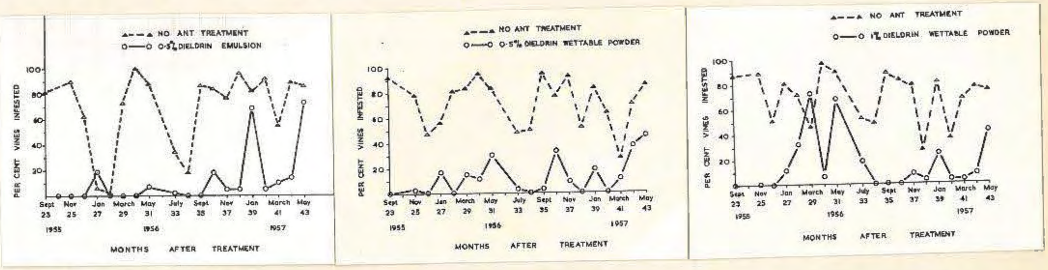


Fig. 95.

Experiment I. Ant infestation 23 to 43 months after treatment.

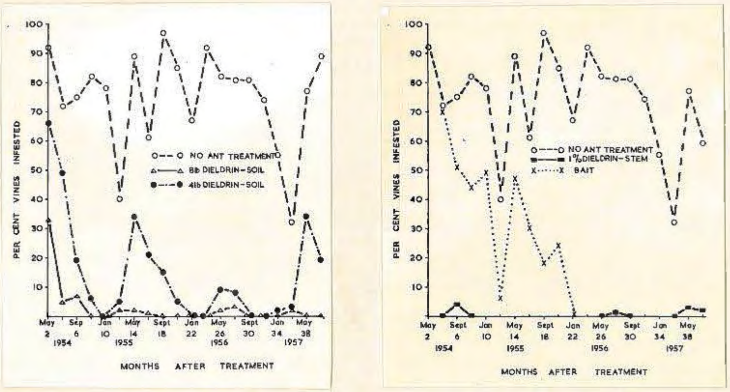


Fig. 96.

Experiment II. Ant infestation to 40 months after treatment.

DISCUSSION.

(a) Ant control.

The 0.5 per cent. emulsion gave good ant control, as in 37 months after treatment, ants were found on the vines on five occasions only. The 0.5 per cent. wettable powder was not as effective as the emulsion and the ants occurred sporadically after 20 months and until the end of the period. The 1.0 per cent. wettable powder gave good ant control until 27 months after treatment, whereupon ant activity increased and 72 per cent. of the vines were infested. Subsequently this infestation gradually decreased and ants occurred only sporadically.

It is interesting to note that the greatest invasion of the treated blocks by ants occurred from midsummer to early winter. The cause of this was probably the large increase of ants during the summer, resulting in a competition for food with the resultant foraging into insecticide-treated areas. Another contributory factor may have been that vine stems supplied ideal nesting sites during the wet winter and ants seeking winter nests also invaded treated areas.

(b) Mealybug infestation.

No mealybug counts were made in 1953 as the experiment was considered only from the ant control aspect. Mealybug control in the three subsequent years was satisfactory. In each treatment there was a slight increase in mealybug infestation in each successive year. This increase did not correspond to the increased ant activity in some of the treatments. Ant control in all these treatments, although not complete, was still sufficient to allow biological control of the mealybug to be maintained.

No counts of hymenopterous parasites or coccinellid predators were made.

CONCLUSION.

From the point of view of ant control, 0.5 per cent. dieldrin emulsion was better than the 0.5 per cent. wettable powder or the 1.0 per cent. wettable powder. There was a small difference in mealybug infestation, the 0.5 per cent. emulsion being better than the 0.5 per cent. wettable powder. The former spray gave better mealybug control than the 1.0 per cent. wettable powder in 1954, equal control in 1955 and was less effective in 1956. A stem spray of 0.5 per cent. dieldrin emulsion thus gave satisfactory control of the Argentine ant and was as effective as the higher concentration used.

EXPERIMENT II.

Comparison of soil and stem applications of dieldrin with the older method of baiting for ant control, and a study of the effect of the various treatments on the mealybug and the natural enemies attacking it.

In ant control studies so far, the application of the insecticide to the vine stems only had been attempted. Joubert (personal communication) advocated the application of the insecticide to the soil. As the soil application was quicker and more economical, it was compared with the stem application and baiting, for the efficiency of ant control.

MATERIALS USED.

Dieldrin wettable powder was applied to the soil at the rates of 8 lb. and 4 lb. actual technical material per morgen. These treatments were compared with a stem application of 1.0 per cent. dieldrin made up from the 50 per cent. wettable powder, and a block treated with sodium arsenite-golden syrup bait.

TIME OF APPLICATION OF THE INSECTICIDE.

Dieldrin was broadcast on to the soil surface immediately after the winter cover crop had been sown. The insecticide was not worked in and the vineyard was not cultivated again before the lupin cover crop was ploughed in in spring. Dieldrin spray was applied to the vine stems to knee height with a knapsack spray pump. The dieldrin treatments were applied in April, but the baiting only commenced in August.

RESULTS.

~~Weekly~~ Counts of the ant infestations made in each treatment are given in Figure 96. In Figures 97 to 100 are the ant, mealybug and natural enemy population fluctuations for the four treatments. The mealybug infestation of vines for the seasons 1954-55, 1955-56 and 1956-57 are given in Table XX.

Table XX. Vines infested with mealybug prior to harvest, 1954-55, 1955-56 and 1956-57.

Treatment	% Vines infested.		
	1954-55	1955-56	1956-57
8 lb. dieldrin - soil	8.5	0.0	5.7
4 lb. dieldrin - soil	9.4	9.4	4.2
1.0% dieldrin - stem	52.7	7.4	7.1
Arsenic - syrup Bait	64.3	11.7	-
Control	72.4	63.4	48.1

Fluctuations of Ant Population.

Ant infestation in the untreated block (fig. 97) remained high for most of the period, but was low on one occasion when the mealybug population was at its lowest. In the baited block (fig. 98) the pretreatment ant population was reduced by half within three months. A sudden further reduction in the ant population, similar to that which took place in the control block, occurred in February. Immediate ant control resulted from the application of dieldrin to the vine stems (fig. 99), and except for light sporadic infestations, the block remained free of ants. In the soil treatment (fig. 100) complete ant control was gradual,

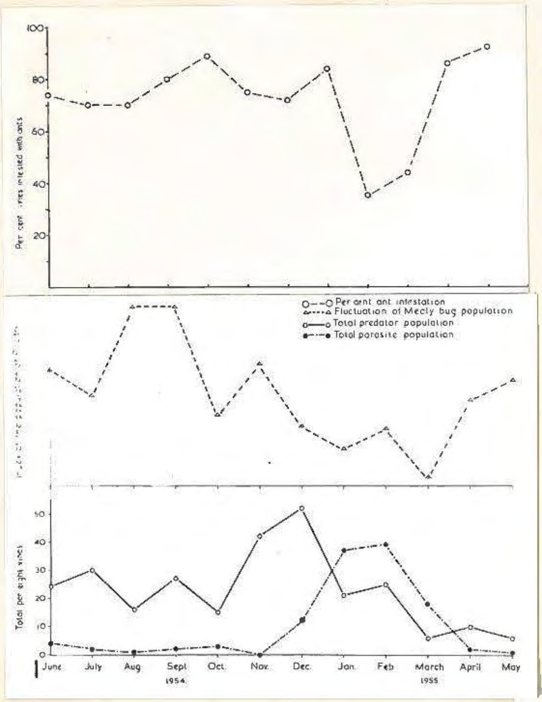


Fig. 97.

Experiment II, Control. Fluctuation of ant, mealybug and natural enemies populations.

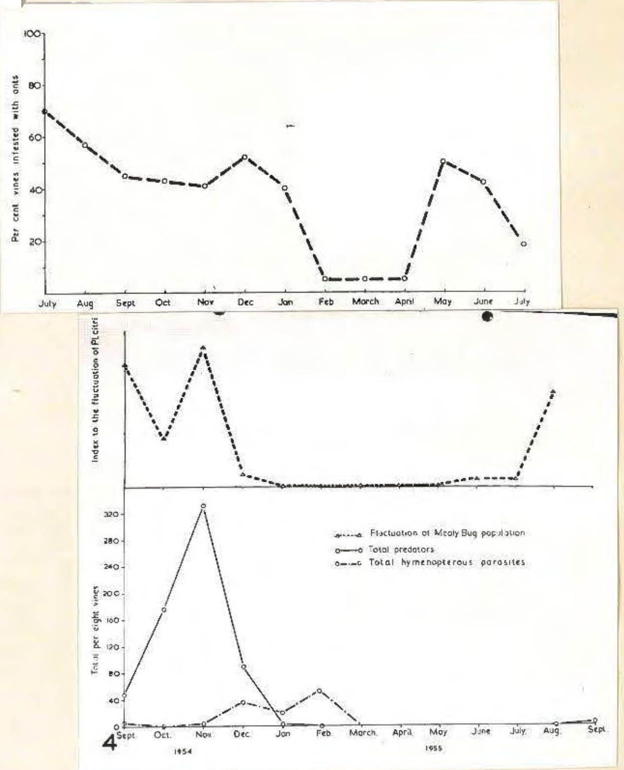


Fig. 98.

Experiment II, arsenic-syrup bait. Fluctuation of ant, mealybug and natural enemies populations.

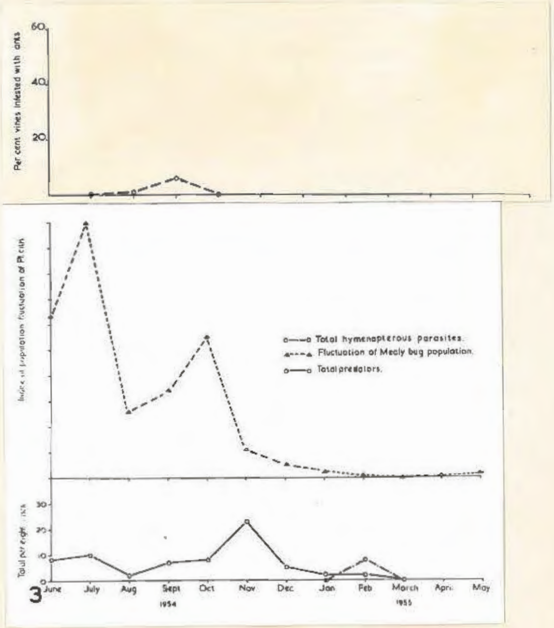


Fig. 99.

Experiment II, dieldrin stem application. Fluctuation of ant, mealybug and natural enemies populations.

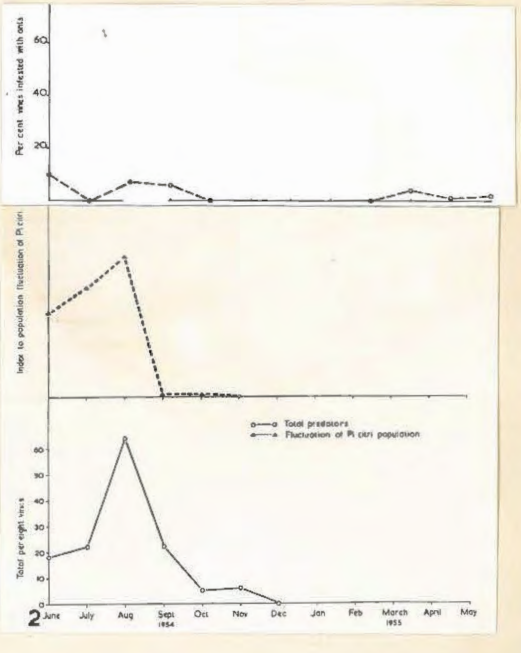


Fig. 100.

Experiment II, dieldrin soil treatment. Fluctuation of ant, mealybug and natural enemies populations.

and at least five months elapsed before the block was free of ants. Sporadic infestations occurred throughout the period, mainly during late autumn and early winter (fig. 96).

Fluctuations of Mealybug Population.

In the control (fig. 97) the winter mealybug population, which had increased to reach a peak in spring, gradually decreased to a minimum in late summer when the natural enemies were at their peaks, but increased again in autumn. The population in the baited block (fig. 98) followed a similar pattern, but the summer decrease was more rapid and the period at which low populations occurred was extended. In the stem-sprayed block, (fig. 99) the large mealybug population gradually decreased but mealybugs were still present a year after treatment. The first grape crop after stem-treatment was heavily infested, but infestation in the subsequent years was low (Table XX). The higher concentration of the two soil treatments showed an initial mealybug fluctuation pattern similar to the control but the decrease of the winter population was more rapid and no recovery followed. Both soil treatments gave a clean grape crop the first season.

Fluctuation of Natural Enemies Populations.

The Chrysopidae occurred sporadically only on heavily infested vines, mainly in the control or the baited blocks.

Both hymenopterous parasites and the coccinellid predators were few during winter in the control block (fig. 97), the coccinellids being the more numerous. The periodic summer increase of the beetles preceded that of the parasites by about two months. Attacks by hyperparasites on the primary parasites of the mealybug and of Homalotylus africanus on the Coccinellidae, in addition to cooler weather, caused a decrease in the number of natural enemies in autumn. The predators in the baited block (fig. 98) increased rapidly with the increase of the mealybug in spring, but a coincidental collapse of both host and predator populations occurred in the summer. A few hymenopterous parasites were collected during the summer. The winter and spring populations of the coccinellids in the stem-sprayed block (fig. 99) were low, but increased slightly in November, declining again in autumn. Small numbers of Leptomastix sp. were collected. In the soil-treated block (fig. 100) there was a rapid increase of predators, similar to but several months earlier than, the increase of predators in the baited block. This was probably caused by the favourable ant-free conditions. The subsequent decline of predators and host was equally rapid, resulting in the absence of both for the rest of the period of the experiment. S. quadrivittatus was the most abundant beetle, followed in numbers by S. angustus and Scymnus sp. H. felixi was only collected in the baited block.

CONCLUSION.

The treatment of soil with dieldrin, besides being the easiest ant control measure to apply, resulted in the destruction of both ants and mealybugs the same season. Although stem-application gave complete and immediate ant control, it affected the natural enemies to such an extent that the mealybug infestation persisted and mealybug control was only acheived the following year. Baiting, which was tedious to apply, never gave complete mealybug or ant control for any length of time.

EXPERIMENT III.

A study of the effect of soil- and stem-treatments of dieldrin at various concentaration, in spring, on ants, mealybugs and natural enemies of the mealybug.

The soil-treatment using dieldrin had so far only been applied in the autumn. Some stem-treatments had been applied in spring, but data for lower concentrations were required. This experiment was designed to determine whether any advantage lay in spring treatment, and at the same time to test lower concentrations of both the soil-aand stem-applications. The experiment was terminated after 18 months as the desired results had been obtained and the area was required for complete ant treatment by the owner.

Because of the shortage of a suitable vineyard, the control block of Experiment II, which was separated from Experiment III by an unplanted area twenty feet wide, also served as a control for the latter experiment.

MATERIALS USED.

Soil treatments consisted of dieldrin 50 per cent. wettable powder applied at the rates of 8 lb., 4 lb. and 2 lb. actual dieldrin per morgen. Dieldrin 50 per cent. wettable powder at ½ per cent, and ¼ per cent. strengths was applied to the vine stems.

RESULTS.

Figure 101 gives the monthly percentage ant infestations and Table XXI the preharvest mealybug infestation for all treatments. Monthly counts of mealybugs and natural enemies were only made in the control, the highest soil- and the highest stem-treatments.

Table XXI. Vines infested with mealybugs prior to harvest, 1954-55 and 1955-56.

Treatment	% Vines infested	
	1954-55	1955-56
8 lb. dieldrin - soil	75	7
4 lb. dieldrin - soil	63	3
2 lb. dieldrin - soil	60	0
½% - stem	67	3
¼% - stem	54	3
Control	72	64

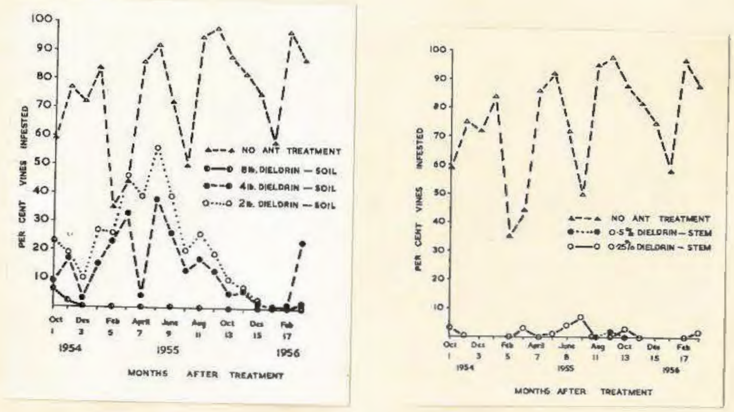


Fig. 101.

Experiment III. Ant infestation for whole period of experiment.

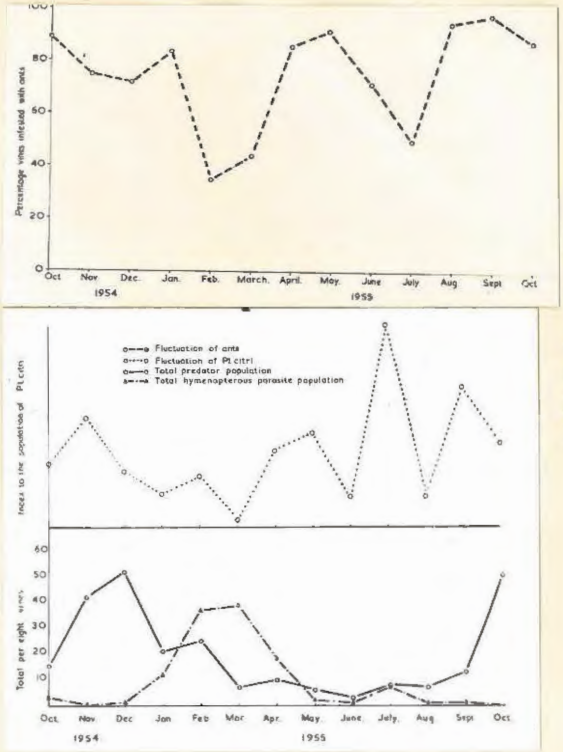


Fig. 102.

Experiment III, Control. Fluctuation of ant, mealybug and natural enemies populations.

Fluctuation of Ant Population.

In the control block (fig. 102) the ant infestation remained high except on two occasions, one due to adverse weather in winter and the other the result of the mealybug population being at its lowest. After the application of the stem spray (fig. 103), good ant control was obtained for the whole period of the experiment. The soil-treated block was free of ants two months after treatment (fig. 1o4).

Fluctuation of Mealybug Population.

The heavy spring mealybug infestation in the control block (fig. 102) declined to its lowest level in midsummer, at a time when the natural enemies were at their peaks. The population increased again to a high level in late winter and spring. In the stem-sprayed block (fig. 103) the high spring population decreased rapidly and remained at a low level for the rest of the experiment. The mealybug population in the soil-treatment (fig. 104) showed a collapse similar to but more rapid than that of the stem treatment.

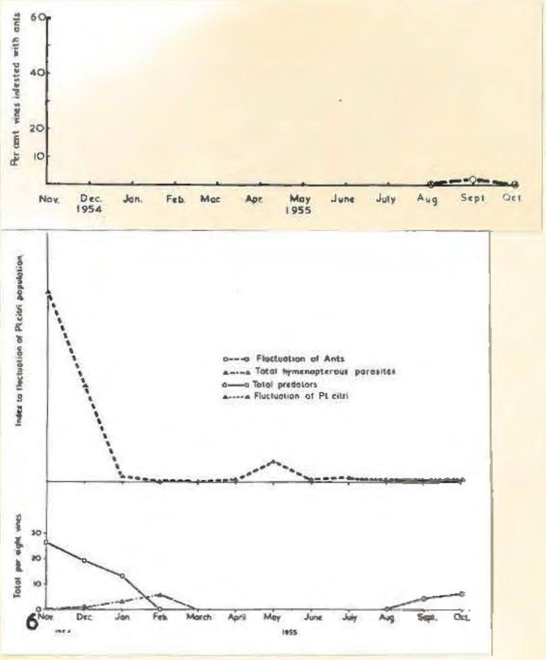


Fig. 103.

Experiment III, dieldrin stem application. Fluctuation of ant, mealybug and natural enemies populations.

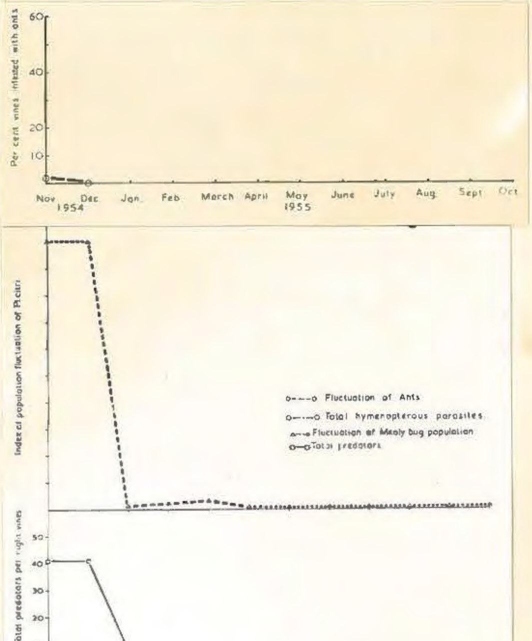


Fig. 104.

Experiment III, dieldrin soil treatment. Fluctuation of ant, mealybug and natural enemies populations.

Fluctuation of Natural Enemies Populations.

In the control (fig. 102) the peak of parasites occurred at the same time as the lowest mealybug populations. The greatest number of predators, however, occurred about two months before this. In early spring of the year following treatment, there was an increase of predators at the same time as there was a decline in the heavy mealybug infestation of the winter. The moderate numbers of predators collected in spring in the stem-sprayed block (fig. 103) became gradually smaller and were not collected after mid-summer. Nearly twice as many predators were collected in the soil-treated block (fig. 104) as in the stem-treated block, in the same period of time. In both the soil- and the stem-treated blocks, a small number of predators was collected in spring the following season. In both treatments _Leptomastix_ sp. attacked the few mealybugs present on the foliage in autumn. _S_. _quadrivittatus_ and _S_. _angustus_ were the main predators although _H_. _felixi_ was fairly numerous on the vine stems at the time of treatment.

CONCLUSION.

From the results it was seen that no advantage was gained from the control of ants in spring over control in the autumn. Even though ant control was achieved immediately, the mealybug was not brought under control until after the crop was harvested. The reason was that the coccinellid predators were on the decline at this time of year, while the hymenopterous parasites were not present in large enough numbers to control the infestation. A substantial reduction in the mealybug population occurred only in the second season, whereas the same result could have been obtained by delaying ant control until autumn when application of the insecticide was more convenient for the grower.

The lowest concentration of dieldrin applied to the soil, although it did not give as good ant control as the highest concentration, was nevertheless found to be as effective with respect to mealybug control.

CONCLUSIONS AND OBSERVATIONS RESULTING FROM THE THREE EXPERIMENTS.

The effect of ant control on the Coccinellidae was an eventual reduction in the beetle population as a result of the destruction of the mealybug. In the stem-treatments, however, some coccinellid predators were destroyed by the insecticide itself.

The parasitic Hymenoptera were plentiful where no ant control was applied, but in all other treatments, spring or autumn, the wasps occurred in very small numbers as a result of the reduction of the mealybug population earlier in the season. In the autumn soil-treatment, no parasitised mealybugs were recorded.

Up to the time of writing (September, 1957) dieldrin had an apparent residual effect of 41 months in the soil and the stem treatment had been effective for 46 months. It is possible that the continued absence of ants in the treated areas was due to the complete destruction of the mealybugs initially present. The question now arises as to whether the treated areas were free from ants because of the effect of the insecticide or because of the absence of mealybugs? Field observations showed that some mealybugs were still present in the treated areas and as these were not attended by ants, it was concluded that the treatments were still affective. This was confirmed by Dürr, Joubert,

~~Dürr~~ & Walters (195~~6~~5) who found that soil treated with dieldrin, was still toxic to the Argentine ant three years after treatment.

In most of the plots treated with dieldrin, some ant infestation took place every autumn and winter, but by spring no ants could be found. This infestation was probably caused by the movement of ants into winter nests. In the soil treatments, this infestation was destroyed when the ants moved into the soil again in summer.

It is a well known fact that ant control results in the control of the mealybug on vines in the Western Cape. From the above experimental work it appeared that complete ant control was not essential, although some reduction in ant activity was necessary. Baiting, which commenced in the late winter, only gave satisfactory ant control after 17 months and mealybug control in the second season. Baiting also required more labour than the other treatments and is not recommended for this reason. Spraying of the vine stems with dieldrin gave immediate and lasting ant control, but was not satisfactory with regard to mealybug control. A delay in mealybug control was caused by the adverse effect of the stem spray on the coccinellid predators and possibly the hymenopterous parasites which occurred sporadically in early summer. Spring treatment, either soil or stem application, was not satisfactory, for, although ants were destroyed, the mealybug infestation persisted until after the grapes had been harvested. Soil treatments, even at the lowest concentrations, although they did not always give complete ant control, eventually gave good mealybug control.

THE RELATIONSHIP BETWEEN ANTS AND MEALYBUGS.

Nixon (1951) gave a good review of the association between ants, aphids and coccids. The following discussion will take the same form as Nixon's review, with the addition of the most recent literature and comments on the relationship between _I_. _humilis_ and _Pl_. _citri_ on vines.

Mealybugs, in common with many other Homoptera, excrete large quantities of honeydew. This sweet substance is attractive to ants, giving them a continuous supply of easily accessible food.

THE NATURE OF THE ASSOCIATION BETWEEN ANTS AND MEALYBUGS.

Wheeler (1910) maintained that, as the coccids and membracids were of service to the ants by supplying them with food, they in turn benefitted from the companionship of the more active and aggressive insects, the ants. A special relationship thus existed between the honeydew producers and the ants attending them.

Nixon stated that many observers who had attempted to define this relationship had not always kept strictly to the facts. Flanders (1951) stated that ants did not attack or drive off natural enemies with the specific purpose of protecting the honeydew producing insects. This is illustrated by the fact that ants, while collecting honeydew from *Coccus hesperidum*, also caused an increase in the population of the diaspine scale, *Aonidiella citrina*, on the same tree (Flanders, 1945). Steyn (1954a), working on citrus in the Transvaal, also found that ants (*Anoplolepis custodiens*) attending *Coccus hesperidum* caused an increase of red scale *Aonidiella aurantii* on the same trees. The diaspine scales do not produce honeydew, but their natural enemies were disturbed by the ants collecting food from the co-incident infestation of the soft scale.

Wheeler, in attempting to show that ants were adapted to living with aphids, made several statements, but more recent work casts doubt on their correctness (Nixon, 1951). According to Wheeler, aphids show adaptation to ants in that they do not attempt to escape from them. The same has been observed of Pl. citri which makes no attempt to escape from I. humilis. It is difficult to decide whether this is proof of modification to co-existence, as mealybugs also make no attempt to escape from the coccinellid predators feeding upon them and only struggle when actually siezed.

Ants do sometimes attack mealybugs, as illustrated by Strickland (1947), who has found certain ants attending Ps. njalensis on cacao in West Africa, which eat the larval mealybugs. On vines ants were found carrying Pl. citri in their jaws on two occasions only. On both these occasions the mealybugs were dead, non egglaying females. It was not known whether they were killed by the ants.

Wheeler imputed a sense of reasoning to ants, but the modern interpretation is that the behaviour of the ants is governed by a series of behaviour patterns set in motion by certain physical stimuli. Smith (1942) studied Solenopsis geminata (F.) and Brachymyrmex heeri Forel attending Saissetia hemispherica Targ. According to Nixon, Smith maintained that the solicitation of the scales by the ants seemed aimless. One ant removed a droplet of honeydew from a scale, moved a little distance and returned to the same scale. On another occasion an ant was seen attempting to obtain honeydew from the caudal end of a coccinellid predator larva. Ants were also seen by Smith to solicit dead or immature scales.

From observations on I. humilis and Pl. citri on vines, it would appear that the obtaining of honeydew was partly at random and partly as a result of the stimulation of both the olfactory and visual senses by the action of the mealybug when solicited. Ants were seen to touch the adult mealybug females with rapidly vibrating antennae on any portion of the body but mainly in the mid-dorsal region, whereupon the mealybug, if ready to give up honeydew, lifted the posterior portion of the abdomen. This movement immediately attracted the attention of the attendant ant, which ceased the drumming to imbibe the droplet. One ant was observed to solicit a female mealybug, obtain the lifting of the abdomen and the accompanying honeydew, but, apparently not satisfied, proceded to drum again on the posterior part of the same mealybug. The mealybug did not respond, and the ant moved away about half a centimeter, but then returned to the same mealybug. The second attempt was rewarded by the lifting of the mealybug abdomen and the excretion of honeydew. Still not satisfied, however, the ant repeated the drumming of the posterior end but received no response, and for the second time the ant moved away and returned again to the same female. On receiving honeydew for the third time, the ant appeared satisfied and departed. On another occasion, ants attending mealybugs moved rapidly over the colony, feeling each individual with rapidly vibrating antennae, but when no response was given, the ants moved on without delay.

From these observations it would appear that the initial stroking by the ant was at random in that it took place on any part of the mealybug. On the other hand, as soon as the honeydew had been imbibed, the ant, if it returned to the same mealybug, immediately went to the posterior end where the last droplet of honeydew had been received. An olfactory sense could be involved here. After having received honeydew from one mealybug, would the ant go straight to the posterior end of the next mealybug to obtain honeydew, or would the initial drumming be at random again? Unfortunately no ants definitely falling into this category were observed, but as most of the ants drummed at random on each mealybug they came across, it must be assumed that there was no knowledge of the position of the source of the honeydew.

ADVANTAGE OF THE ASSOCIATION TO THE MEALYBUG.

The advantage of the association to the ants is easily seen, as to them it is a source of readily available food. The advantage to the mealybugs is not so obvious.

The natural enemies of coccids cannot be considered to be in competition with ants in the sense that they compete for honeydew. They are destructive to its source and receive scant toleration because of this (Nixon, 1951).

Nixon found much evidence in the literature to show that the manner in which ants react to the natural enemies is far from uniform. There seems little doubt, however, that on the whole their attitude is hostile.

(a) Behaviour of ants to natural enemies.

Nixon stated that the behaviour of ants to coccids depended on the temperament of the ant. Aggressive natured ants reacted more strongly to natural enemies than those of a milder temper.

Herzig (1937), studying three species of *Lasius*, came to the conclusion that these ants reacted to swiftly moving bodies as though they themselves were being attacked, incidentally protecting the aphids coming into their defence orbits. This author found that these ants very seldom interfered with the slow moving larvae and adults of coccinellids while they were feeding on aphids.

Anderson (1927) found that *Cryptolaemus montrou-*

zieri adults were all killed by ants three to four days after liberation, and breeding of this beetle for the control of the coffee mealybug in Kenya was therefore discontinued.

The Argentine ant attacked the adult coccinellids which fed on *Pl. citri* on vines. An adult of *H. felixi* was seen to enter a crevice in the vine bark which sheltered an ant-attended colony of *Pl. citri*. The ladybird re-emerged hurriedly, pursued by several ants. This attitude has also been demonstrated in the laboratory where starved *H. felixi* adults were placed with an ant-attended colony of *Pl. citri*. Each time the coccinellid attempted to feed, the ants made threatening motions and drove away the beetle. Ants paid little attention to larvae of this and other species of coccinellids feeding on *Pl. citri*. On coming across a larva feeding in a mealybug colony, ants paused and then retreated or moved around the larva. This behaviour differed from that of an ant to a mealybug.

All the above coccinellid larvae are covered in a flocculent waxy coating but when they were turned over to expose the unprotected ventral surface, they were immediately seized by the ants. It would thus appear that some difference between the coccinellid larvae and mealybugs was perceptable to the ants, and that the waxy covering of the larvae afforded protection.

The parasites, according to Nixon, were less affected by ant attendance, as they were exposed for the relatively shorter time required to oviposit. The behaviour of the parasite in the presence of ants is determined largely by its own excitability and the kind of response its presence evokes in the ant (Nixon, 1951).

Flanders (1951), in discussing the role of the ant in biological control, pointed out that many natural enemies were not subject to ant interference; Coccophagus capensis Comp., which attacked Saissetia oleae Bern., was such a case. Ant activity, by repressing other parasitic wasps and reducing competition, was advantageous to this species.

This author maintained that the natural enemies that feed on the body tissues of the host were those most likely with which to be interfered. Hyperparasitic wasps were more likely to suffer from ant activity than primary parasites, because the former, as a rule,, required more time to deposit an egg.

Protection is not a component of a behaviour pattern in which the Homoptera are intimately involved (Nixon, 1951). The mealybugs were not primarily protected because they were a source of food, but because they came into the defence orbit of the ants concerned. There is no doubt, however, that the mealybugs benefitted from the association.

(b) Furtherance of prosperity of mealybugs by ants.

The fact that mealybugs flourish when attended by ants has been noted by several writers. This can be attributed to two causes; first, ants reduce the effectiveness of the natural enemies and second, they introduce an element of hygiene by removing the waste products that would otherwise swamp the young stages.

Van der Groot (1916) found that the white cocoa mealybug Pseudococcus crotonis (Green) died out under experimental conditions when not attended by ants, but flourished in their presence. Kirkpatrick (1927) found that Pseudococcus kenyae le Pelley was able to increase slowly without ants but multiplied three times as fast when attended by them.

Kirkpatrick (1927) noted that the ants removed some of the wax covering of the mealybugs. This has also been observed by MacDougall (1926), Mallenotti (1938) and le Pelley (1943). I. humilis was never seen to remove wax from Pl. citri females on vines, but where only a few adult females were attended by large numbers of ants, the mealybugs had practically no wax on the dorsum. Adult females unattended by ants had a "woollier" appearance than ant-attended females, indicating that they had a thicker wax covering. Some wax was therefore removed by the ants. If the wax of the mealybug is protective, then its removal is detrimental. As far as Pl. citri was concerned, the removal of wax was thought to be the result of the constant tapping that the mealybugs received from the antennae of the attendant ants and not a purposeful removal.

Strickland (1947) working with Ps. njalensis in West Africa maintained that the accumulation of honeydew caused the growth of fungi, some of which were parasitic on the mealybug. Hanna, Judenko & Heatherington (1956), working with the same mealybug in the Gold Coast, found that the growth of mould, following the cessation of ant activity, was detrimental.

There are several references to the fact that ants cover coccids in shelters. Wheeler (1910) thought that this indicated an adaptation on the part of the ants to the association with the aphids. Essig (1921) found *I. humilis* building shelters for *Pl. citri* on gardenia in a greenhouse and Strickland (1947) noted that ants enclosed *Ps. njalensis* with carton shelters on cacao in West Africa. According to Nixon, Walcott & Sein (1933) described how the ant *Solenopsis geminata*, being deprived of its usual food after a devastating hurricane, was especially solicitous to a few *Icerya purchasi* which had survived. They built structures of carton and earth over the young colonies but as the colonies spread out on to new growth and became more abundant, they received less attention. Hanna et al. (1956) discussed the building of carton tents by *Crematogaster* sp. around *Ps. njalensis* colonies on cacao in the Gold Coast. These tents consisted of vegetable and wood particles glued together by means of glandular secretions from the mouth. Each tent had one or two holes large enough to admit ants but not large enough to allow entry of parasties and predators bigger than the ants. Adult mealybugs could not escape from this covering. The conditions which caused ants to build these shelters were not fully understood by these authors but it was demonstrated, by covering trees with rainproof shelters, that rain was one of the major factors concerned.

In the Western Cape Province the mealybug on vines was covered in shelters by Iridomyrmex humilis at any time of the year. These shelters occurred on any part of the vine and usually contained small isolated colonies. The materials used were the "down" from the under side of grape leaves, bits of bark and soil particles loosely stuck together (fig. 105). The shelters, which were fragile affairs, were easily destroyed. Kriegler (1954) found that Pl. citri was covered with shelters by I. humilis in spring, early summer and autumn. In this work oovered colonies were found also in midsummer. In the latter case, the vineyard had been partially freed of ants in autumn and most of the mealybugs had been destroyed by natural enemies, but a few isolated colonies persisted, and these were then covered by ants the following summer. During winter, soil was carried up and moulded around colonies under

Fig. 105.

Shelter built by ants around a mealybug colony in a grape bunch.

Fig. 106.

Ants attending a winter mealybug colony on vine stem. Soil particles in bottom left corner are remains of shelter around colony.

the bark (fig. 106), but making of shelters was at its lowest at this time of year.

Wallcott and Sein, as mentioned earlier, found that *Icarya purchasi* was covered by ants when their main source of food was scarce. It would appear to be a similar case with *Pl. citri* and *Iridomyrmex humilis*, where mealybug colonies were only covered when they were small, that is, when only a little honeydew was available. The construction of shelters by *I. humilis* over *Pl. citri* on vines would thus appear to be governed by the scarcity of the food supply. Low mealybug populations occurred seasonally in autumn, and it was at this period that most shelters were built. Low populations could be brought about artificially, as was the case when ants were partially controlled and the greater part of, although not all, the mealybug population was destroyed by natural enemies. Rain apparently played no direct part in causing ants to build shelters.

A suggestion by Ewer (personal communication) that the shelters may have been primarily concerned with the ants and only secondarily with the mealybugs cannot be contradicted, as the actual construction of these shelters was never observed. One observation, which casts doubt upon their use as nests by ants, is that no stage other than workers was ever found in them.

The observation that shelters are built at times of mealybug scarcity would seem to indicate some protective use for these shelters. The advantage gained by the mealybugs in shelters built by I. humilis is questionable as they are too flimsy to be proof against natural enemies. Coccinellid larvae as well as parasitised mealybugs have often been collected from sheltered colonies. Some advantage might be gained by an improved micro-climate under the shelters.

TRANSPORTATION AND DISSEMINATION OF MEALYBUGS BY ANTS.

There are numerous conflicting reports on whether ants assist in the dispersion of mealybugs. Dickison (1932) held that ants were important in the spread of Pseudococcus maritimus, and Hargreaves (1924, 1925) found that Pheidole punctulata caused the spread of Pl. citri on the roots of coffee, but Kirkpatrick (1927) stated that the same ant played no part in the dispersal of Ps. kenyae. In citrus groves of the Eastern Cape Province, Bishop (1931) thought that ants were the prime factor in spreading mealybugs from tree to tree. Strickland (1947) found that ants transferred mealybugs from felled cacao trees to living trees. Subsequent observations by the same author (1951a) and by Cornwall (1956) showed that, although ant-assisted migration took place, the numbers transported were very small. Other methods of transportation accounted for the greater part of the infestation.

In the Western Cape Province, I. humilis plays no part in the distribution of Pl. citri on vines, and although ants were seen to carry mealybug females on two occasions, the mealybugs were found, on examination, to be dead.

The few authors referred to above show how conflicting are reports of dissemination of mealybugs by ants. Transportation would seem to be dependent on the ant species concerned and not so much on the species of mealybug. For example, Pl. citri in one instance was spread by P. punctulata but not by I. humilis.

INTERDEPENDENCE OF ANTS AND MEALYBUGS.

To what extent is the advantage of the association of ants and mealybugs balanced? Nixon points out that the two genera *Lasius* and *Acropyga* of the Camponotinae and *Iridomyrmex* of the Dolichoderinae are almost wholly dependent on honeydew for their diet. There is no doubt what benefit the ants obtain here, but is their presence essential for the well-being of the mealybugs?

Hough (1922) found that the mealybug *Trionymus trifolii* Forbes depended on the ant *Lasius niger* var. *americanus* Emery for its transportation from one plant to another. The Kenya coffee mealybug *Ps*. *kenyae* was considered by Melville (1938) to have become a pest because of the attentions of *Pheidole punctulata*. On the other hand, some serious outbreaks of this mealybug occurred where the ant was not present. Strickland (1951b) showed that *Ps*. *njalensis* was independent of the attendance of ants and developed at a quicker rate without them, even though the colonies became covered in mould. Hanna et al. (1956) found that the population level of the same mealybug could be reduced considerably in the field if the attendant *Crematogaster* ants were eliminated. This occurred in spite of the fact that the mealybug thrived in the laboratory without ant attendance. The reason for this was not clear to these authors, but, according to them, was not due to the insect predators and parasites. In the laboratory at Stellenbosch, Pl. citri on potato sprouts was quite healthy without the presence of ants, and in the field, at periods of low natural enemy activity, mealybugs were quite normal where ants had been eliminated.

In most cases the presence of ants is advantageous to mealybugs. An exception to this is given by Speare (1922) who found that Pl. citri was not important in Florida as it was attacked by a fungus. Ants could in no way interfere with the work of a fungus and probably increased its efficiency by spreading the spores.

Some mealybugs are dependent for their survival on the ants attending them, whereas the presence of ants in other cases would seem to be detrimental. In most cases where parasites and predators were excluded, it would appear that mealybugs are not dependent for survival on the attendance of ants.

ECONOMIC SIGNIFICANCE OF THE ASSOCIATION.

The Homoptera on the whole benefit from the attention they receive from ants, but that ants are indispensable to the Homoptera is a controversial point.

It can be accepted, however, even when the association is loose, that honeydew producing insects remain a source of attraction to the ants.

(a) The Use of Ants.

Ants were the first insects to be utilised in biological control (Clausen, 1956). This author describes how the Chinese used *Oecophylla smaragdyna* F. in their citrus groves, and Nixon cites other instances where ants have been used to control pests of cultivated plants. However, the introduced ants usually caused an increase of honeydew producing insects which did more harm than could be compensated by the destruction of the other pests by these ants.

(b) Ants versus Predators and Parasites in Biological Control

The presence of ants must cause some disturbance in the balance between the honeydew producers and their natural enemies, no matter how loose the bond between them and the attractant pest insects. The control of the ants therefore must be part of the general control programme of the pest insect. There are several Hymenoptera, however, which are undisturbed by ant activity. Flanders (1944e) found that the control of

Ps. maritimus took place in spite of ants. The same author found that the black scale parasite, Coccophagus trifasciatus Comp., which oviposits rapidly, often worked effectively after scales, which were protected by the Argentine ant, had become sufficiently dense.

If a pest population attended by ants was large, it was very destructive; if small and localised, it may have served as the nucleus of a food supply for natural enemies. This enabled the latter to maintain the pest population in general at a lower level than would have been likely in the absence of ants (Flanders, 1951).

Flanders stated further that natural enemies which fed as adults on the body tissues of the host suffered most from ant interference. Natural enemies that did not feed on the host as adults suffered interference in relation to the time required to oviposit.

The larvae of the Coccinellidae which fed on Pl. citri on vines were not disturbed by I. humilis, whereas the adults were. Primary parasites were also disturbed but the effect of ants on hyperparasites was not determined.

In the following paragraph are some of the numerous examples of the interference of ants with the work of natural enemies.

Smit & Bishop (1934), working in the Eastern Cape Province on Citrus, showed that where *Anoplolepis* (*Plagiolepis*) *custodiens* was kept off the trees, the mealybug was controlled by indigenous ladybirds. Joubert (1943b) found that the parasite *Cocoophagus gurneyi* was severely hindered by the Argentine ant in its work of controlling *Ps*. *maritimus*. Compere (1940) noted that the incidence of *Saissetia oleae* in the Cape in 1936-37 had greatly increased since the introduction of the Argentine ant. *Coccus hesperidum*, a pest which is heavily parasitised in the Western Cape Province, is never of importance in the absence of the Argentine ant. *Pl*. *citri* on vines in this part of the Province is always attended by large numbers of the same ant. The control of this ant by baiting or, more recently, by the use of dieldrin or chlordane in the soil, has shown a spectacular decrease in the mealybug population. This has been brought about chiefly by six species of indigenous coccinellids, but two hymenopterous parasites also play a part.

The data on the effect of ants on biological control have been collected mainly from the above type of observation. On the other hand, De Bach, Fleschner & Dietrick (1944) and De Bach (1946), using chemical and biological check methods, have shown empirically that ants upset the balance between certain pest insects and their natural enemies.

CONCLUSION.

In most cases the presence of ants was detrimental to the biological control of the ant-attended pest, but there were some instances in which the effective parasite was not disturbed by the attendant ants. In natural control, ants are a factor to be considered, but their significance varies and each case must be examined independently (Nixon, 1951). In conclusion, Nixon pointed out that the association between ants and honeydew producing insects was not as rigid as had formerly been supposed. The attitude of the ants to the honeydew producing insects was compared by Nixon with their attitude to a nectar producing flower. Any protection offered was incidental and took the form of

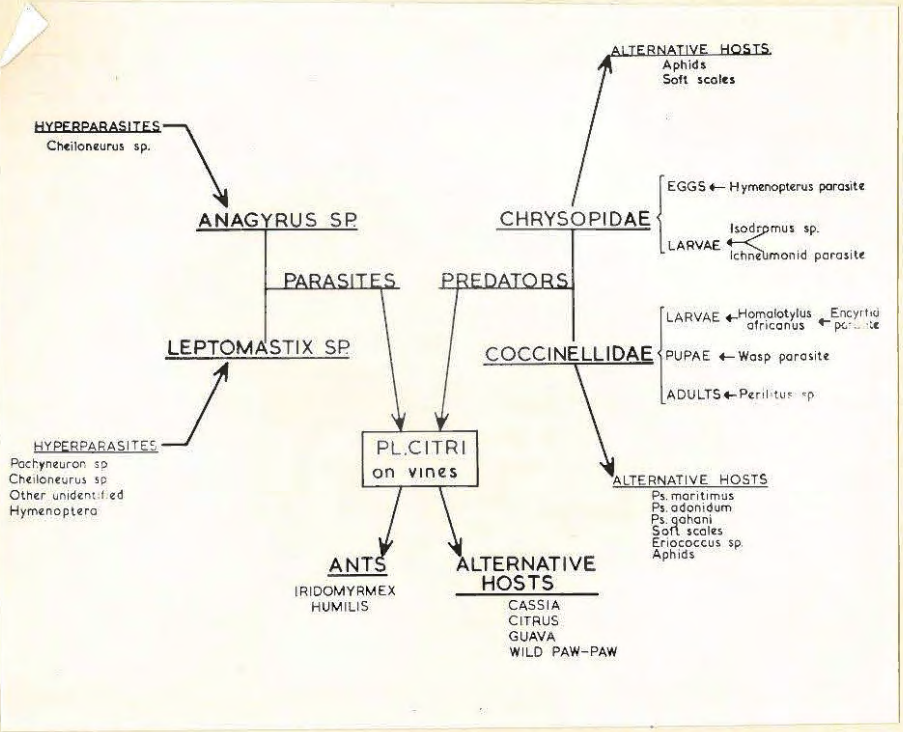


Fig. 107.

Diagram of the inter-relationship of the insects associated with *Pl. citri* on vines.

self-defence on the part of the ant.

The Argentine ant definitely interfered with both the coccinellid predators and the primary parasites of *Pl. citri* in the vineyards of Stellenbosch and Paarl. Control of this mealybug by the natural enemies took place only if the ants were destroyed or considerably reduced.

A BRIEF REVIEW OF SOME OF THE THEORIES CONCERNING FACTORS AFFECTING INSECT ABUNDANCE.

"Nature functions as an indivisible complex in which no species, plant or animal, exists in total isolation and no factor, physical or biotic, operates in complete independence" (Glen, 1954). This is the modern approach to the study of fluctuations in natural populations. Earlier, Howard & Fiske (1911) and Nicholson (1933) stressed the biotic factors such as predators and parasites, whereas Bodenheimer (1928) and Uvarov (1931) attributed the fluctuations of insect populations mainly to the influence of climate. Thompson (1929) related the importance of biotic factors to physical factors and found that physical factors were more important where the climate was more favourable. Glen (1954) noted that physical factors were more important in controlling insect abundance at the periphery of an environment. This view was also held by Andrewartha & Birch (1954) who found that weather was of greater importance than other factors at the edge of a particular population in space. The density of the population on the outskirts of an environment was less abundant and fluctuated more than the population in the centre of a particular environment.

Smith (1935) divided the factors which influenced natural populations into density-dependent and density-independent factors. Density-dependent factors were those which controlled a population in proportion to its numbers at a given time. A parasite-host relationship is an example of this type of factor. Density independent factors were those which were unrelated to the population density, for example heat, light and moisture. Physical factors were mainly density-independent and biotic factors were density-dependent, but certain combinations emphasised the inter-dependence of the various factors.

Andrewartha & Birch (1954), on the other hand, demonstrated that no component of the environment was such that its influence was likely to be independent of the population density. They concluded that density-independent factors did not exist. Why then should any importance be attached to density-dependent factors? These authors considered the following factors to be the most important with which to explain the limitations of animals in a natural population:-

(a) Shortage of material resources, such as food, place to live, nesting sites.

(b) Inaccessibility of the above essential resources in relation to the capacity of the animal to disperse or to search.

(c) The shortage of time when the rate of increase was positive.

In (c) the rate of increase can be affected by the weather or predators and parasites. In (b) the authors stress the inaccessibility of the resource whether in times of abundance or scarcity. Andrewartha & Birch did not claim that any one of the above factors would completely explain the behaviour of an animal in a complex system, but that these factors were intended to help analyse a population into simpler components in order that they may be better understood.

Thompson's 1956 view was that natural populations were not selfgoverning systems which regulated their own densities, as was stated by Nicholson (1954). They were collections of individuals, each continuing to exist without regard to its neighbour. The change in environment was the intrinsic factor causing fluctuations. Thompson stated further that populations were not truly regulated but merely varied. Variations which assumed a cyclic aspect were attributed to chance and not to factors producing oscillations according to definite laws.

Solomon (1957) retained the idea of regulation by density-dependent factors but preferred the term "density-dependent processes" which gave the expression a wider scope. Solomon held that these regulat~~i~~o~~n~~rs must themselves respond to some extent to the change in that which was regulated. The pattern of increase and decrease in time of any natural population was sometimes controlled by density-dependent processes, but at others on processes such as weather, which were independent of density. Solomon did not agree with the statement of Andrewartha & Birch that fluctuations were sometimes accounted for by chance.

Most of the authors agree that all animal populations have an ability to increase but that this increase is never allowed to continue unhindered, as, in time, one or more regulating process comes into play. These processes often have a cyclic effect and the importance of the controlling processes varies with each situation.

The terminology used and some of the causes of fluctuations were the main points of disagreement among modern animal ecologists.

The fluctuation of Planococcus citri in relation to its natural enemies in the light of the theory of Andrewartha & Birch (1954).

Andrewartha & Birch (1954) conclude that the numbers of animals in a natural population are limited by the three factors enumerated on Page 206.

In the following discussion, an attempt is made to analyse the population fluctuations of the natural enemies in relation to the mealybug on vines. The effect of the ants will be discussed.

Referring to Figure 97, where no ant control took place, it would appear that the scarcity of natural enemies in winter was a direct result of weather on their rates of increase, while in autumn the decline in their numbers was caused both by the weather and the wasp parasites which attacked them. One species, H. felixi, was also reduced in summer by the inaccessibility of the food supply. The mealybug, on the other hand, was favoured by the cool weather, as well as by the scarcity of natural enemies at this time.

Under these donditions, there was never a lack of food for the natural enemies and there always remained enough mealybugs to carry over the population after the natural enemies had subsided. Ant populations remained fairly constant.

Where ants were controlled or reduced, however, (figs. 98 and 100), a different situation arose. The predators were present in slightly larger numbers but at an earlier time of year than when ants were present. This resulted in a rapid decline in the mealybug population. The earlier increase in predator numbers under ant free conditions indicated that the retarding effect of the ants was greater than the effect of the weather at this time of year. The cause of the retardation of the predator population by the ants must be sought in the adult predators as the ants did not interfere directly with the larvae. Beetles, thus interfered with, probably consumed less mealybugs per colony, but, what is more important, laid fewer eggs than if there were no ants. The most important effect of the ants is thus the limitation of the number of eggs laid by the predators and possibly the parasites also.

The fluctuations of both mealybugs and their natural enemies on vines were found to be dependent on all the points enumerated by Andrewartha ~~and~~ & Birch.

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