J. Appl. Ent. 106 (1988), 177–182

ISSN 0044-2240

Department of Zoology and Entomology, University of Natal, South Africa

Aspects of the feeding behaviour of *Chilocorus nigritus* (F.) (Col., Coccinellidae) relative to its effectiveness as a biocontrol agent

By M. J. Samways and S. J. Wilson

Abstract

The coccinellid *Chilocorus nigritus* (F.) is an important natural enemy against red scale *Aonidiella aurantii* (Maskell) on citrus in southern Africa. One reason for its success is the ability of the adults and mature larvae to completely remove the adult female scale from the fruit surface using their sharp-pointed mandibles. First-instar larvae, however, cannot attack the adult scale. In biocontrol programmes against high red scale infestations, the introduction of adult beetles, rather than eggs or young larvae, is therefore preferred. The beetle is mass-reared on Oleander scale *Aspidiotus nerii* Bouché, but larvae do not readily accept the change to red scale. In contrast, adult beetle feeding rate increases with the change in diet, again promoting the adult as the preferred developmental stage for field introduction. Despite *C. nigritus* consuming parasitized as readily as unparasitized scale, the beetle and parasitoids are jointly effective in reducing high red scale infestations.

1 Introduction

Chilocorus nigritus is indigenous to India and the Far East (Ahmad 1970; Chazeau 1971; Subramaniam 1923). It appeared of its own accord in southern Africa in the early 1970's. Since then, it has been reared and distributed to all citrus areas in the region to reduce red scale *Aonidiella aurantii* populations. In the hot lowveld, where red scale has often been severe, the beetle has been highly effective and commercially important (Samways 1984).

The economic impact has raced ahead of our knowledge of the beetle's behaviour. This paper addresses four diverse but fundamental aspects of the predator's feeding behaviour that have direct bearing on the beetle as a highly successful biocontrol agent:

1. One of the reasons that *C. nigritus* is effective over most other biocontrol agents is that it is able to attack the well armoured adult female stage of the red scale. How is the insect physically able to do this?
2. Both eggs and adults of *C. nigritus* have been used to establish the species in the field. However, red scale infestations are characterized by a predominance of adult females (Samways 1985). Can young larvae feed on this mature stage? If not, it would seem inappropriate to introduce beetle eggs (Samways and Mapp 1983) where red scale populations are very high.
3. For several reasons, by far the most suitable host on which to mass-rear *C. nigritus* is Oleander scale *Aspidiotus nerii* Bouché, and yet the beetle is released for control of quite a different host. Does this change of host reduce the possibility that insectary-reared beetles will establish in the field?
4. In the orchard, *C. nigritus* characteristically removes a higher number of host scale from a localized area of fruit, despite high levels of parasitism by various chalcids. Does the beetle avoid or consume the parasitized individuals? This is important because parasitism also plays an important role in biological control of red scale (Bedford 1968).

U.S. Copyright Clearance Center Code Statement: 0044-2240/88/0602-0177 $ 02.50/0

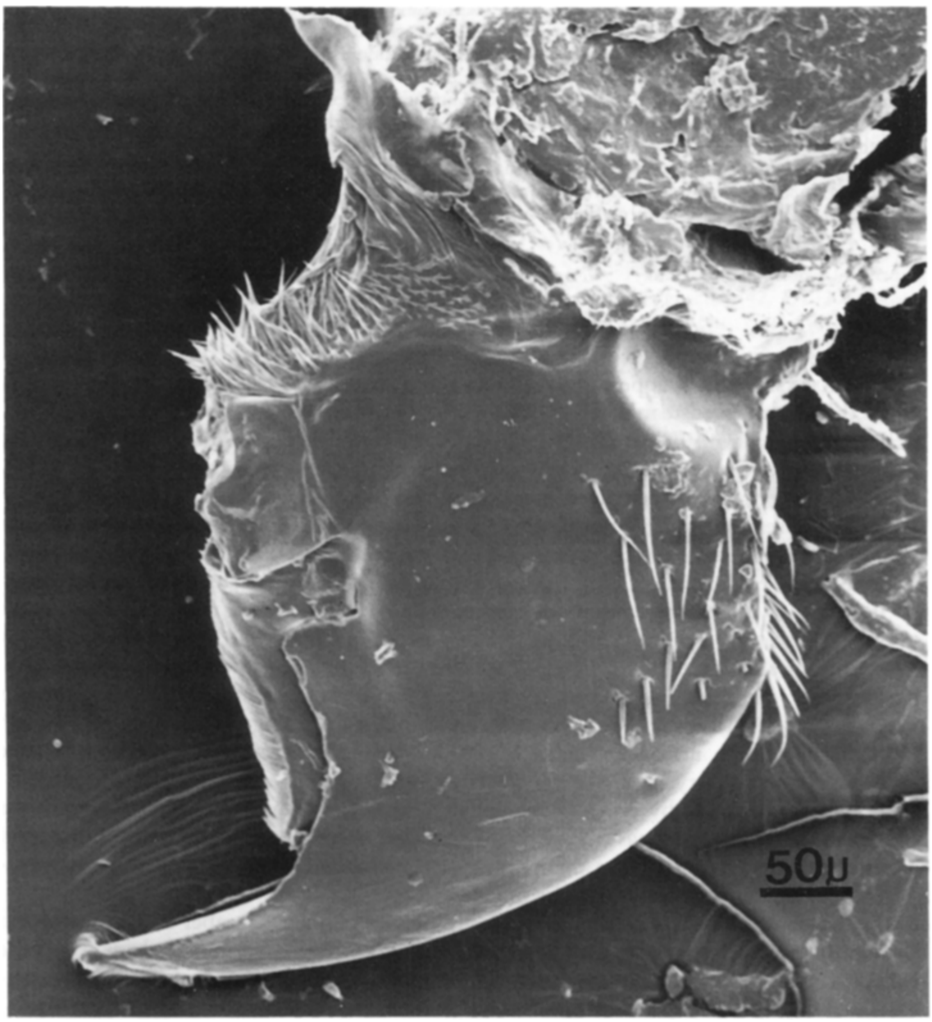
2 Materials and methods

C. nigritus was reared on a biparental strain of *A. nerii* infesting potatoes (*Solanum tuberosum* L.) or butternuts (*Cucurbita moschata* Turnhalle). Temperature was 26 ± 2 °C, humidity was 70 % r. h. and the light/dark cycle was 12 h/12 h. Beetles oviposited on surgical gauze strips (100 mm × 20 mm) draped over the infested butternuts. All developmental stages were maintained together in the same cages with only occasional cannibalism where the first instar larvae ate eggs.

Prior to all experiments, larvae and adults were starved. Using NAKAMATA's (1987) findings as a guideline, *C. nigritus* adults were deprived of food for 24 h by being confined to 32 mm diameter × 10 mm high glass collars attached to the surface of a clean orange or butternut. To reduce over-starvation of larvae they were deprived for only 18 h.

Observations on feeding behaviour were made by transferring adult beetles from the bare arena to one with host *A. aurantii*. A scanning electronmicrograph was made of *C. nigritus* mandibles.

Determination was made of which *C. nigritus* developmental stages were able to feed on which host stages. Larvae were confined, one at a time, to an arena affixed to a field-collected orange with the irrelevant stages carefully removed. The procedure was repeated until it was clear whether the



Scanning electronmicrograph of the mandible of *Chilocorus nigritus* particular predator stage could or could not survive on the presented host stage. In addition, feeding rates were determined for 3rd and 4th instar larvae and adults. For this study, unwanted scales, i.e. 1st and 2nd instar and dead or damaged older stages, were removed. Prior to confinement of the predator, the number of hosts were counted, and those removed during a 12-h period gave the feeding rate. Hosts included both *A. nerii* and *A. aurantii*, and results permitted a quantitative comparison. Additionally, 4th instar larvae and adults were transferred individually and directly from one host to another in arenas to determine the ability of larvae to switch hosts.

For interaction with parasitoids, beetles were given field-collected *A. aurantii* in glass arenas on the surface of citrus fruit. The parasitoid was *Comperiella bifasciata* Howard. Its pupa can be seen through the scale cover, which is important for determining whether the scale was parasitized or not prior to presentation to the beetles. All scales were carefully removed except for two young adult females, one of which was parasitized and the other unparasitized. These two hosts were surrounded by a glass collar. Three runs of 20 arenas were prepared. Single beetles were transferred from one arena to the next with a 24-h starvation period between each transferral. Note was taken of which scale, parasitized or unparasitized, was eaten first. Data were analysed with the One Sample Runs Test (SIEGEL 1956).

3 Results

3.1 Removal of scale cover

The adult climbs onto the scale, maintaining contact with the substratum with its mid- and hing-legs. The tarsi of the forelegs are splayed laterally against the rim of the scale. It then bends its head so that the mandibles are working in the same plane as the surface of the substratum. It bites into the edge of the scale with its extremely sharp mandibles (fig.), and pushes its body away from the substratum so lifting the far edge of the scale cover with the promixal edge acting like a hinge. If the scale cover cannot be lifted at first attempt, the beetle chews along the rim, and repeats the lifting procedure. On pulling back the cover, the beetle climbs over the ventral surface of the cover and eats all the soft parts which remain temporarily attached to the substratum. Fourth instar larvae feed in a similar way, but tend to chew around the rim before pulling back the scale cover. Third instar larvae usually chew around the whole rim when feeding on an immature adult female.

3.2 Feeding preferences

The older the larva, the greater the width of the feeding niche (table 1). Results were similar for both hosts.

The results of culturing adults and larvae of *C. nigritus* on *A. nerii*, then starving them, and finally presenting them with either *A. nerii* or *A. aurantii* are seen in table 2. Adults readily accepted the new host, and indeed the feeding rate on *A. aurantii* was highly significantly different from that on *A. nerii* (Mann-Whitney U-test, $z = 5.1$, $P < 0.0001$).

The situation with the larvae was the converse. Generally, they did not, or were unable to accept the change in host and entered premature pupation, which resulted in undersized

Table 1. **Ability of larvae of *Chilocorus nigritus* to feed on the various developmental stages of two scale insects**

C. nigritus larval instar	Scale developmental stages: *Aspidiotus nerii* 1	2	Immature adult	Mature adult	*Aonidiella aurantii* 1	2	Immature adult	Mature adult
1st	+	–	–	–	+	–	–	–
2nd	+	+	–	–	+	+	–	–
3rd	+	+	+	+	+	+	+	–
4th	+	+	+	+	+	+	+	+

Table 2. **Feeding rate (per 12-h period) of adults, 3rd and 4th instar larvae of *Chilocorus nigritus* when presented with mature adult female *Aspidiotus nerii* and *Aonidiella aurantii* after being reared on *A. nerii* and then starved for 24 h (adults) and 18 h (larvae) prior to determining these feeding rates**

C. nigritus Developmental stage		No. of adult scales consumed *A. nerii*	*A. aurantii*
Adult	(*n*)	24	24
	Range	3–19	2–40
	$\overline{X}$	11.4	21.6
4th instar larva	(*n*)	12	12
	Range	5–26	2–25
	$\overline{X}$	18.0	2.25
	Mode	17	0
3rd instar larva	(*n*)	6	6
	Range	4–12	0–4
	$\overline{X}$	9	1.20
	Mode	9	0

adults. (Hence the mode is zero for *A. aurantii* in table 2.) The differences between feeding rates on the two hosts and between adults and fourth-instar were all significantly different at the 0.1 % level using the Mann-Whitney U-test.

3.3 Feeding on parasitized scale

Table 3 gives the data for *C. nigritus* predation on parasitized and unparasitized scale. The null hypothesis is that *C. nigritus* preys on the first scale it encounters, whether that scale is parasitized or not. Using the One Sample Runs Test, this hypothesis could not be rejected at the 5 % level, despite an indication that parasitized scales are generally preferred first (table 3).

Consumption of the parasitized host by the beetle was total, with the parasitoid abdomen being consumed first and finally leaving only a few remains of the head capsule.

Table 3. **Feeding by three individuals of *Chilocorus nigritus* on mature scale (*Aonidiella aurantii*) that is either parasitized by *Comperiella bifasciata* or not**

	Chilocorus nigritus individual A	B	C
No. unparasitized scale first chosen	2	7	6
No. parasitized scale first chosen	18	13	14
Critical values for minimum and maximum no. of runs	2–N/A	5–15	5–14
No. parasitized scale completely consumed	13	12	6

4 Discussion

4.1 Scale removal

C. nigritus is a proven biocontrol agent. One reason for the beetle's great success is that it removes all of the scale body and cover. Such total descaling turns an otherwise culled fruit into an exportable one. The parasitoids *C. bifasciata* and *Aphytis* spp., although contributing to control of red scale populations, do not have the same cleaning ability. The characteristic tin-opener shape and action of the mandibles enable *C. nigritus* to completely remove the whole of the adult red scale. These findings suggest that biocontrol projects should take cognizance of the mandible type and feeding behaviour where improved short-term cosmetic appearance of the fruit is an added bonus to the longer-term host population control.

4.2 Introduction of eggs into the field?

Table 1 suggests that the introduction of the predator in its egg form on polyester fibre pads (SAMWAYS and MAPP 1983) is not the optimal method of predator establishment against severe red scale infestations. Most of the young larvae starve when the host population in composed mostly of adult females. This is borne out by several unpublished field observations where egg introductions into severe red scale populations have come to nothing, apparently from high early-instar larval mortality. In short, eggs should be used for medium red scale infestations, while adult beetles should be introduced when levels are high.

4.3 Introduction of larvae into the field?

Introduction of later-instar larvae would seem to overcome the disadvantages of using young larvae yet without the problem of immediate dispersal so characteristic of adults. The results here, however, show that older larvae, after having been reared on Oleander scale, do not readily accept the change to red scale. This means that larvae mass-reared on Oleander scale are not suitable for introduction into the field. Again, adults are the preferred stage, and further research should aim at finding ways of preventing adults from flying off.

4.4 Consumption of parasitized scale

The results here clearly indicate that any living scale, whether parasitized or not, is readily eaten. These experiments could be carried out only on *C. bifasciata*, which plays a minor regulatory role in southern Africa compared with *Aphytis* spp. (ATKINSON 1977; SAMWAYS 1986). The results nevertheless demonstrated that, despite automatic consumption of parasitized scale, the beetle and parasitoids operate together, but not mutualistically, resulting in a major impact upon red scale populations. Quite simply, the coccinellid is most effective at high population levels, while the parasitoids appear to play a regulatory role at lower population levels.

4.5 Conclusions

C. nigritus has been a highly fortuitous natural enemy. As such, it is interesting to analyse its feeding behaviour in hindsight, and to identify some of the factors that have made it so successful. Principally, *C. nigritus* is so effective because it can readily consume large numbers of adult female scales. Other factors have also played a role, such as the beetle's ability to totally remove all scales from a fruit. Such attributes should be borne in mind in furture, predictive biocontrol projects.

Acknowledgements

We thank indeed Mr B. TATE, Outspan Citrus Centre, for supplying the seed culture of beetles and scale. We also thank Mrs B. BAUER to permitting us to use Doornhoek Citrus Estate, and Mrs B. WHITE for taking the scanning electronmicrograph. Mrs A. BEST very kindly typed the manuscript and Prof. Dr W. SCHWENKE arranged for translation of the summary.

Zusammenfassung

Zum Fraßverhalten von Chilocorus nigritus (F.) (Col., Coccinellidae) hinsichtlich der Wirksamkeit des Käfers als Schädlingsvertilger

In südafrikanischen Zitrusplantagen stellt *Chilocorus nigritus* einen wichtigen natürlichen Feind der Schildlaus *Aonidiella aurantii* (Maskell) dar. Der Erfolg des Prädators ist darin begründet, daß sowohl die Käfer als auch die ausgewachsenen Larven die Fähigkeit haben, mit ihren scharfen Mandibeln die adulten weiblichen Schildläuse vollständig von der Fruchtoberfläche entfernen zu können. Erstlarven hingegen können adulte Schildläuse nicht angreifen. Daher ist für die biologische Bekämpfung von *A. aurantii* das Einbringen von Käfern gegenüber dem Einbringen von Eiern bzw. Junglarven vorzuziehen. Die Massenzucht von *C. nigritus* erfolgt mit der Oleanderschildlaus, *Aspidiotus nerii* Bouché. Von Larven wird der Wirtswechsel allerdings nicht sofort akzeptiert; im Gegensatz dazu steigt bei den Adulten die Fraßrate nach dem Wirtswechsel noch an. Auch dies führt dazu, daß Käfer für die biologische Bekämpfung zu bevorzugen sind. Obwohl *C. nigritus* sowohl nicht parasitierte als auch parasitierte Schildläuse frißt, ist der kombinierte Einsatz von Käfern und Parasitoiden erfolgreich für die Reduktion der Schildlauspopulation.

References

Ahmad, R., 1970: Studies in West Pakistan on the biology of one nitidulid species and two coccinellid species (Coleoptera) that attack scale insects (Hom., Coccoidea). Bull. Entomol. Res. **60**, 5–16.

Atkinson, P. R., 1977: Preliminary analysis of a field population of citrus red scale, *Aonidiella aurantii* (Maskell), and the measurement and expression of stage duration and reproduction for life tables. Bull. Entomol. Res. **67**, 65–87.

Bedford, E. C. G., 1968: The biological control of red scale, *Aonidiella aurantii* (Mask.), on citrus in South Africa. J. entomol. Soc. sth. Afr. **31**, 1–15.

Chazeau, J., 1981: La lutte biologique contre la cochenille transparente du cocotier *Temnaspidiotus destructor* (Signoret) aux Nouvelles-Hébrides (Homoptère, Diaspididae). Cahiers O.R.S.T.O.M., Série Biologique **44**, 11–22.

Nakamuta, K., 1987: Diet rhythmicity of prey-search activity and its predominance over starvation in the lady beetle *Coccinella septempunctata bruckii*. Physiol. Entomol. **12**, 91–98.

Samways, M. J., 1984: Biology and economic value of the scale predator *Chilocorus nigritus* (F.) (Coccinellidae). Biocontr. News Info. **5**, 91–105.

— 1985: Relationships between red scale *Aonidiella aurantii* (Maskell) (Hemiptera: Diaspididae), and its natural enemies in the upper and lower parts of citrus trees in South Africa. Bull. Entomol. Res. **75**, 379–393.

— 1986: Combined effect of natural enemies (Hymenoptera: Aphelinidae and Coleoptera: Coccinellidae) with different niche breadths in reducing high populations of red scale, *Aonidiella aurantii* (Maskell) (Hemiptera: Diaspididae). Bull. Entomol. Res. **76**, 671–683.

Samways, M. J.; Mapp, J., 1983: A new method for the mass-introduction of *Chilocorus nigritus* (F.) (Coccinellidae) into citrus orchards. Citrus and Subtropical Fruit Journal No. 598, 4–6.

Samways, M. J.; Tate, B. A., 1986: Mass-rearing of the scale predator, *Chilocorus nigritus* (F.) (Coccinellidae). Citrus and Subtropical Fruit Journal No. 630, 9–14.

Siegel, S., 1956: Nonparametric statistics for the behavioral sciences. New York: McGraw-Hill.

Subramaniam, T. V., 1923: Some coccinellids of South India. Proc. Fifth Entomol. Meet., Pusa, Part 18, 108–118.

Authors' address: Prof. Dr M. Samways and S. J. Wilson, University of Natal, Department of Zoology and Entomology, P.O.B. 375, Pietermaritzburg 3200, R.S.A.