New Zealand Journal of Zoology, 1995, Vol. 22: 319–324
0301–4223/2203–0319 $2.50/0

Releases and recoveries of *Chilocorus* spp. (Coleoptera: Coccinellidae) and *Hemisarcoptes* spp. (Acari: Hemisarcoptidae) in kiwifruit orchards: 1987–93

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Abstract Three species of *Chilocorus* and two species of *Hemisarcoptes* were introduced into New Zealand kiwifruit (*Actinidia deliciosa*) orchards between 1987 and 1992 for armoured scale insect (Homoptera: Diaspididae) control. Species and numbers released were: *C. bipustulatus* (12 836), *C. cacti* (575), *C. infernalis* (5990), *H. coccophagus* (c. 500 000), and *H. cooremani* (c. 3000). A survey in 1993 of all North Island release sites ($n = 20$) failed to detect establishment of any *Chilocorus* species. *H. coccophagus* was found at sites in Northland, Auckland, Bay of Plenty, Gisborne, and Nelson, and is considered to be established. Post-release destruction of habitat may have limited establishment of both *Chilocorus* and *Hemisarcoptes*.

Keywords Diaspididae; kiwifruit; biological control; predators; *Chilocorus cacti*; *Chilocorus infernalis*; *Chilocorus bipustulatus*; *Chilocorus kuwanae*; *Hemisarcoptes coccophagus*; *Hemisarcoptes cooremani*

Received 24 January 1995; accepted 13 April 1995

INTRODUCTION

Three exotic species of armoured scale insects form an important pest complex of kiwifruit (*Actinidia deliciosa*) in New Zealand. Greedy scale (*Hemiberlesia rapax* (Comstock)) is the most widely distributed and commonly found species, but latania scale (*H. lataniae* Signoret) can be dominant in Gisborne and northern Northland orchards (Berry et al. 1989). Oleander scale (*Aspidiotus nerii* Bouché) is a minor pest species in some districts. Five to seven applications of organophosphate insecticides are routinely used in many orchards to ensure that these pests are controlled to the extremely low levels demanded by export markets. As the use of mineral oils for scale insect control becomes more common under the "Kiwigreen" programme (Steven et al. 1994), interest in, and opportunities for, biological control of these pests is also increasing.

Biological control of Diaspididae in New Zealand has received little attention. Twelve of the 13 species of hymenopteran parasitoids of Diaspididae recorded in New Zealand are cosmopolitan, and should be regarded as having been accidentally imported (probably with their hosts) during the past 100 years. Yet, before the programme described here, only three attempts (largely unsuccessful) had been made to introduce natural enemies for armoured scale insect control (Hill 1989). Despite occasionally high levels of attack by three species of hymenopterous parasitoids and one species of ladybird (Berry 1983; Steven 1990; MGH unpubl. data), economically damaging numbers of scale insects do sometimes occur, even in unsprayed kiwifruit orchards.

From 1987 to 1992 we undertook a programme to import and release two new groups of scale insect predators into New Zealand kiwifruit orchards. They were ladybirds in the genus *Chilocorus* and mites in the genus *Hemisarcoptes*. *Chilocorus* species feed predominantly on, and *Hemisarcoptes* exclusively on, Diaspididae. The heteromorphic deutonymphal stage (hypopus) of *Hemisarcoptes* is adapted for phoresy and is dispersed by *Chilocorus* adults. Hypopodes usually attach themselves under

the elytra around the antero-lateral margins, in a relationship that appears obligatory for continued ontogenesis (Houck & OConnor 1991; Izraylevitch & Gerson in press). We reported on early releases of *Chilocorus* and *Hemisarcoptes*, and the establishment and biology of *Hemisarcoptes* in New Zealand, in Hill et al. (1993).

This paper records complete details of the introductions, releases, and recoveries of three species of *Chilocorus* and two species of *Hemisarcoptes*. It covers the period of the programme from September 1987 to March 1993, and includes all releases of *Chilocorus* spp., and those of *Hemisarcoptes* spp. made specifically to kiwifruit orchards.

IMPORTATIONS

Chilocorus beetles were imported to New Zealand from Israel and the United States (Table 1). All species were imported as adults with various species of Diaspididae for food. *C. bipustulatus* beetles (colony A) were collected from orchards in Israel by MGH. All other consignments came from laboratory colonies held by researchers in the country of origin. Ladybirds were reared on a mixed colony of *Hemiberlesia rapax/lataniae* on pumpkins or potatoes for at least one generation before release.

Voucher specimens were deposited in the New Zealand Arthropod Collection (Landcare Research, Auckland, New Zealand).

Subsamples of all *Chilocorus* species were killed and examined for pathogens. A microsporidian and a gregarine (Protozoa) were discovered in quarantine during routine checks on the health of the field-collected *C. bipustulatus* (colony A). The protozoan was easily removed by washing eggs in a weak (0.01%) solution of sodium hypochlorite. The microsporidian (which was expected to be transovarially passed between generations) was removed by line breeding. The mothers of F_1 generation larvae were killed and examined for microsporidia. If found, then the larvae were killed; if not, then larvae were reared to adults and the process repeated until no further microsporidia were found. Both pathogens were successfully eradicated in quarantine before any releases were made. However, surviving individual beetles remained relatively unfit. The *C. bipustulatus* colony A remained weak, and eventually died out before the introduction to New Zealand of colony B.

The second shipment (colony B) arrived in December 1989. Although this colony was founded with only 25 adults, breeding success and fecundity were high. The resulting thriving colony formed the basis for the greater part of the *Chilocorus/Hemisarcoptes* research programme over the next 3 years.

No pathogens were found in the laboratory-reared *C. bipustulatus* (colony B), nor in the *C. cacti* or *C. infernalis* colonies. In part, the problems with pathogens in beetles collected from the wild led to the decision to import only from laboratory colonies.

In July 1989 we initiated the introduction of *C. kuwanae* to New Zealand. The proposal was initially supported, and 36 adult *C. kuwanae* were sent from a laboratory colony in Maryland, United States (courtesy D. Drea), entering quarantine in New Zealand on 17 August 1990. Then followed a year of debate among interested parties on the wisdom of allowing the importation of a specialist predator with a nevertheless relatively wide potential host range. Debate centred particularly on the possibility that *Chilocorus* would threaten endemic scale insects (Coccidae) and consequently disrupt parts of the avian ecosystem in native forests. In subsequent

Table 1 Importations of *Chilocorus* species.

Chilocorus species	Origin and date of import	Number imported
C. cacti (Linn.)	Arizona, U.S.A. (laboratory) (10 Jan 1988)	60
C. infernalis (Linn.)	Israel (laboratory) (14 Oct 1988)	100
C. bipustulatus (Linn.) (A)	Israel (field) (11–15 Sep 1987)	50–100
C. bipustulatus (B)	Israel (laboratory) (16 Dec 1989)	25
C. kuwanae Silvestri	Maryland, U.S.A. (laboratory) (17 Aug 1990)	36

Table 2 Importations of *Hemisarcoptes* species.

Hemisarcoptes species	Origin and date of import	Number imported
H. coccophagus Meyer	Israel (field + laboratory) (11–15 Sep 1987)	>1000
H. cooremani Thomas	Arizona, U.S.A. (laboratory) (10 Jan 1988)	<1000

laboratory studies (DJA unpubl. data), *C. kuwanae* did not feed on the species of most concern, the six-penny scale, *Ctenochiton viridis* Maskell. However, the Ministry of Agriculture and Fisheries (MAF) eventually declined permission to release the insect, on the grounds that the perceived risk to endemic fauna outweighed the potential economic benefits to the horticultural industry, and the colony was destroyed in quarantine on 16 June 1991.

Hemisarcoptes mites were also imported from Israel and the United States (Table 2). *H. coccophagus* were collected from the field as hypopodes under elytra of *C. bipustulatus* in Israel, and posted to Auckland, where they were placed in quarantine on 11 September 1987. MGH also returned from Israel with *H. coccophagus* adults and immatures in a laboratory colony of California red scale (*Aonidiella aurantii*), arriving in Auckland on 15 September 1987. All mites were separated from ladybirds in quarantine, and reared on a mixed colony of *Hemiberlesia rapax* and *H. lataniae*.

Hemisarcoptes cooremani were obtained from a laboratory colony in Arizona, courtesy of M. A. Houck. They arrived as hypopodes under the elytra of *C. cacti*, and as adults and immatures on *Aspidiotus nerii* on potatoes.

Although hypopodes require *Chilocorus* for completion of ontogeny, the hypopus stage is not obligatory. In our colony (held at 23°C, 16:8 photoperiod, with an ample food supply), populations of both species of *Hemisarcoptes* increased rapidly. Hypopodes were rare (usually <1%), although they could be readily produced by decreasing the food supply.

RELEASES

Predators were released at 20 sites adjacent to kiwifruit vines in the North Island and Nelson (Table 3). More than one species was released at some sites, and some sites received more than one release. At one property in Nelson, mites were released to kiwifruit vines and several other crops infested with scale insects. The numbers of individuals released are estimates for mites (arrived at by counting subsamples of those released) but are accurate for ladybirds.

Most ladybirds were released as adults, but some of the first *C. infernalis* were released as eggs and larvae. Adults were transported to release sites in 2 litre plastic ice-cream containers, each usually containing 150 beetles (range 50–150) and loosely filled with crumpled paper towelling to prevent injury. The containers and paper towelling were placed within the canopy of scale-infested trees or shrubs, and the beetles allowed to disperse without constraint.

H. cooremani, and the first few *H. coccophagus*, were released as deutonymphs in drinking straws, a technique used successfully for releasing phytoseiid mites (Thomas & Chapman 1978). Most *H. coccophagus* were subsequently released either as active colonies on scale-infested pumpkins or potatoes, or as hypopodes under the elytra of *Chilocorus* adults (Hill et al. 1993). Straws were pinned to branches on top of dense patches of scale insects. Pumpkins or potatoes were placed in plastic onion bags, and stapled to the plant so that the mites were able to crawl on to scale-infested branches.

Both ladybirds and mites were released into scale-

Table 3 Releases of *Chilocorus* and *Hemisarcoptes*, 1987–93.

District	Numbers of predators released (to no. of sites)					Total no. of release sites per region
	C. cacti	*C. infernalis*	*C. bipustulatus*	*H. cooremani**	*H. coccophagus**	
North Island						
Kerikeri	310 (2)	0	3509 (4)	550 (2)	120 000 (4)	4
Whangarei	118 (1)	1538 (1)	1255 (1)	750 (1)	92 000 (2)	2
Auckland	147 (1)	522 (1)	1227 (1)	600 (1)	82 000 (2)	2
Tauranga	0	300 (1)	4018 (5)	0	64 000 (5)	5
Te Puke	0	386 (1)	1908 (1)	1200 (1)	4200 (1)	1
Gisborne	0	2194 (4)	919 (6)	0	109 000 (6)	6
South Island						
Nelson	0	1050 (3)	0	0	9400 (5)	5
Totals	575 (4)	5990 (11)	12 836 (18)	3100 (5)	480 000(25)	25

*Estimated numbers of *Hemisarcoptes* released.

infested shelterbelt trees and/or woody weeds (especially woolly nightshade, *Solanum mauritianum* Scop.) adjacent to kiwifruit blocks. Release sites were chosen for (1) the high levels of scale insect present, and (2) their low or nil insecticide spraying regime. Sites were usually located at research orchards, commercial nurseries, or organically managed properties.

EVALUATION OF ESTABLISHMENT IN 1993

Irregular searches were made for predators at several of the release sites between 1987 and 1992. In January or March 1993, all of the North Island release sites (n = 20) were revisited. A structured evaluation of establishment of both *Chilocorus* and *Hemisarcoptes* was made by sampling in the release trees or shrubs, or in nearby habitats infested with Diaspididae. Samples from two Nelson release sites were also examined.

Ladybirds were sampled by beating and sweep-netting during 30 min time searches at each site. Mites were sampled from bark, leaf, or ladybird samples, depending on habitat:

(1) from diaspidid-infested bark samples on shelter-trees (40–80 cm^2 in total), collected at 1 m intervals (up to 5 m) above ground;
(2) from diaspidid-infested twig and branch samples on shrubs;
(3) from up to 250 kiwifruit leaves infested with adult Diaspididae, on vines adjacent to release trees; and
(4) from up to 50 adult *Orcus chalybeus* (Boisduval) (Col.: Coccinellidae: Chilocorini) collected by searching and beating nearby habitats likely to contain this species. These were frequently citrus trees within 100 m of the original release sites.

All scale insects were microscopically examined for the presence of *Hemisarcoptes*. *O. chalybeus* were killed and the underside of their elytra examined for the presence of *Hemisarcoptes* deutonymphs.

RESULTS AND DISCUSSION

Two adult *C. infernalis* were observed by a grower in Gisborne in November 1989, 8 months after release (Hill et al. 1993), and empty *C. bipustulatus* pupal cases were observed in kiwifruit in Auckland in January and February 1990, following releases of larvae in October and November 1989.

No *Chilocorus* were recovered during the 1993 survey, which suggests that none of the ladybird species has established. However, *Chilocorus* adults may have dispersed widely upon release and established well beyond the area searched. So it remains possible that they do survive elsewhere and will be recovered in the future.

H. coccophagus was recovered soon after its release at several sites in Kerikeri, Auckland, and Gisborne (Hill et al. 1993), and has continued to survive at those and other sites (Table 4). In Nelson, *H. coccophagus* has so far been recovered from only one property, from San José scale, *Quadraspidiotus perniciosus* (Comstock), on pear. We now regard *H. coccophagus* as having established in New Zealand. Attempts to distribute the mite from our laboratory colony to new sites within the country, to both kiwi-

Table 4 Recoveries of *H. coccophagus* from release sites.

	No. of sites			Mite stage recovered		
Location	Release	Recovery	Host	Adult	Immature	Hypopus
North Island						
Kerikeri	4	1	*H. lataniae*	+	+	
Whangarei	2	0				
Auckland	2	1	*H. lataniae*	+	+	
Bay of Plenty	6	1	*H. rapax*	+	+	+ (on *Orcus*)
Gisborne	5	3	*H. lataniae*	+	+	+ (on *Orcus*)
South Island						
Nelson (5)	5	1*	SJS† (pear)	+	+	

*One of two sites examined for recoveries.
†SJS = San José scale, *Quadraspidiotus perniciosus* (Comstock).

fruit and other scale insect infested crops, have continued into 1995.

H. cooremani, however, has not established. Our laboratory colony of *H. cooremani* was lost early in 1988, and Hill et al. (1993) reported that none had been recovered from the field. That situation remains unchanged.

Hill et al. (1993) and Charles et al. (in press) discussed how *H. coccophagus* might disperse in the absence of *Chilocorus* ladybirds, and raised the possibility that they might use other coccinellids (such as *Scymnus fagus* Broun (Scymnini) or *O. chalybeus*). We have recovered, on two separate occasions a single *H. coccophagus* hypopus under the elytra of each of two *O. chalybeus* collected from citrus trees (Table 4). We do not know if those deutonymphs could have completed their development to adults, but consider the possibility to be greater on *O. chalybeus* than on *S. fagus*, as the former species is more closely related to *Chilocorus*. We have determined that a population of *H. coccophagus* in a kiwifruit orchard in Gisborne has spread to isolated trees up to 200 m from the original release site, despite the apparent absence of *Chilocorus*. The establishment of, and scale insect regulation by, *H. coccophagus* in kiwifruit orchards in the absence of *Chilocorus* is the subject of continuing study.

The provision of an ample food supply in a stable habitat may be vital for the establishment of newly imported natural enemies. We considered this to be important, especially for *Hemisarcoptes*, which is small, slow moving, and very dependent on synchrony with its host phenology for survival. Scale insects are relatively k-selected compared with many other horticultural pests and may only be univoltine (although *Hemiberlesia lataniae* and *H. rapax* can be expected to develop through two or three generations a year in New Zealand). Thus, we expected it to take 2–3 years for a "permanent", viable population of natural enemies to establish at our release sites.

We found it difficult, however, to find release sites that had large numbers of scale insects but which were also insecticide-free and well enough regarded by their owners to be long-term and stable resources. Far too many of the release trees and shrubs were unsprayed (and thus held high numbers of scale insects) only because they were neglected, and thus more likely to be removed. Seven of the 20 release sites had been destroyed or extensively modified by the time of the survey in 1993. Sites at Kerikeri (3), Whangarei (1), Auckland (1), and Gisborne (2) had all changed substantially as a result either of growing different crops, or of changing land use (e.g., to residential subdivision). Some of the changes had occurred within a year of releases being made. It is possible that some of these habitat modifications may have prevented, or at least limited, the establishment of the predators.

In part, the high proportion of our original release sites that were subsequently modified also reflected the declining fortunes of kiwifruit growers during this period, especially in marginal growing areas. On a more positive note, the current trend towards declining organophosphate insecticide use across the industry as a whole bodes well for the future survival of natural enemies of all pests in New Zealand's kiwifruit orchards.

We have no plans to introduce any more coccinellids for Diaspididae control, even though several other species may be effective natural enemies (e.g., Drea & Gordon 1990). We do plan to investigate further the biology of *Hemisarcoptes coccophagus* in the absence of *Chilocorus*, and to develop studies on biological control of Diaspididae by hymenopteran parasitoids.

ACKNOWLEDGMENTS

We are indebted to M. A. Houck, U. Gerson, and D. Drea for the provision and transportation of mites and/or ladybirds, and to P. J. Wigley for assisting us to remove pathogens from *C. bipustulatus*. These studies were supported by the Public Good Science Fund, through the Foundation for Research, Science and Technology, and the New Zealand Kiwifruit Marketing Board.

REFERENCES

Berry, J. A. 1983: Aspects of the ecology and control of the greedy scale (*Hemiberlesia rapax* (Comstock)). Unpublished M.Sc. thesis, University of Auckland, New Zealand. 112 p.

Berry, J. A.; Morales, C. F.; Hill, M. G.; Lofroth, B. J.; Allan, D. J. 1989: The incidence of three diaspid scales on kiwifruit in New Zealand. *Proceedings of the 42nd New Zealand Weed and Pest Control Conference*: 182–186.

Charles, J. G.; Hill, M. G; Allan, D. J. in press: Persistence of the predatory mite, *Hemisarcoptes coccophagus* (Hemisarcoptidae), on low populations of *Hemiberlesia lataniae* (Diaspididae) in New Zealand. *Israel journal of entomology 24*.

Drea, J. J.; Gordon, R. D. 1990: Predators: Coccinellidae. *In*: Rosen, D. *ed.* Armoured scale insects. Their biology, natural enemies and control. World crop pests, Vol. 4B. Amsterdam, Elsevier. Pp. 19–40.

Hill, M. G. 1989: Diaspididae, armoured scales. *In*: Cameron, P. J.; Hill, R. L.; Bain, J.; Thomas, W. P. *ed.* A review of biological control of insect pests and weeds in New Zealand 1874–1987. *CAB International Institute of Biological Control technical communication 10.* Wallingford, United Kingdom, CAB International. Pp. 177–182.

Hill, M. G.; Allan, D. J.; Henderson, R. C; Charles, J. G. 1993: Introduction of armoured scale predators and establishment of the predatory mite *Hemisarcoptes coccophagus* (Acari: Hemisarcoptidae) on latania scale, *Hemiberlesia lataniae* (Homoptera: Diaspididae) in kiwifruit shelter trees in New Zealand. *Bulletin of entomological research 83*: 369–376.

Houck, M. A.; OConnor, B. M. 1991: Ecological and evolutionary significance of phoresy on the Astigmata. *Annual review of entomology 36*: 611–636.

Izraylevitch, S.; Gerson, U. in press: The hypopus of *Hemisarcoptes coccophagus* Meyer: distribution and apolysis. *Acarologia.*

Steven, D. 1990: Entomology and kiwifruit. *In*: Warrington, I. J.; Weston, G. C. *ed.* Kiwifruit science and management. Auckland, New Zealand, Ray Richards/New Zealand Society of Horticultural Science. Pp. 362–412.

Steven, D.; Tomkins, A. R.; Blank, R. H.; Charles, J. G. 1994: A first-stage integrated pest management system for kiwifruit. *Proceedings of the Brighton Crop Protection Conference—pests and diseases—1994*: 135–142.

Thomas, W. P.; Chapman, L. M. 1978: Integrated control of apple pests in New Zealand. 15. Introduction of two predacious phytoseiid mites. *Proceedings of the 31st New Zealand Weed and Pest Control Conference*: 236–243.