Mealybugs (Hemiptera: Pseudococcidae) and their natural enemies in New Zealand vineyards from 1993-2009

CHARLES JG[1], BELL VA[2], LO PL[2], COLE LM[2], CHHAGAN A[1]

[1] *The New Zealand Institute for Plant & Food Research Limited (PFR), Private Bag 92169, Auckland 1142, New Zealand. E-mail: john.charles@plantandfood.co.nz*

[2] *The New Zealand Institute for Plant & Food Research Limited (PFR), Private Bag 1401, Havelock North, Hastings 4157, New Zealand*

ABSTRACT

Mealybugs (Hemiptera: Pseudococcidae) and their insect natural enemies were collected from vineyards in the major winegrowing regions of New Zealand from 1993 to 2009. Mealybugs were identified from 131 separate collections, and their presence on grapevines compared with that on neighbouring citrus trees in Hawke's Bay and Gisborne in 2003. *Pseudococcus longispinus* and *P. calceolariae* were the most common mealybugs found in vineyards throughout the country. Both species were present and widespread in most vineyards, and on many grape varieties, but there was often marked (and unpredictable) spatial and temporal separation. Two other mealybug species were found, each on one occasion: the exotic *Pseudococcus viburni* from Hawke's Bay in 1998, and the endemic *Paracoccus abnormalis* from Auckland in 2008. Natural enemies were collected or reared from their mealybug hosts from 51 of the collections. Seven species of parasitoids and four species of predators were commonly collected, with no apparent regional constraints. The parasitoids were: *Anagyrus fusciventris*, *Gyranusoidea advena*, *Tetracnemoidea brevicornis*, *T. sydneyensis*, *T. peregrina* (all Hymenoptera: Encyrtidae), *Coccophagus gurneyi* (Hym: Aphelinidae) and *Ophelosia charlesi* (Hym: Pteromalidae); and the predators were: *Cryptolaemus montrouzieri*, *Midas pygmaeus* (Coleoptera: Coccinellidae), *Diadiplosis koebelei* (Diptera: Cecidomyiidae) and *Cryptoscenea australiensis* (Neuroptera: Coniopterygidae). The faunas of vineyards and citrus orchards were similar, except that *Parectromoides varipes* (Hym: Encyrtidae) was collected only from citrus orchards. *Linepithema humile*, the Argentine ant, was collected from one Gisborne and three Hawke's Bay vineyards in 2003. The widespread presence of natural enemies shows that mealybugs are regularly attacked by both predators and parasitoids in vineyards, but additional data are required to quantify the effectiveness of biological control of mealybugs, and its contribution to limiting the spread of the economically important grapevine leafroll disease.

KEYWORDS

Pseudococcus longispinus, *Pseudococcus calceolariae*, parasitoids, predators, vineyards, monitoring.

INTRODUCTION

Three exotic mealybug species, *Pseudococcus longispinus* (Targioni-Tozzetti), *P. calceolariae* (Maskell) and *P. viburni* (Signoret) (as *P. affinis* or *P. obscurus*) (Hem: Pseudococcidae) have historically been found in New Zealand vineyards (Charles 1993). All three species transmit *Grapevine Leafroll-associated Virus 3* (GLRaV-3) (Petersen & Charles, 1997; Golino *et al.* 2002), and are the primary vectors of this economically important disease in New Zealand. Virus infected vines cannot be cured and mealybug control is crucial for limiting the spread of the disease.

Pseudococcus longispinus and *P. calceolariae* originate from Australia, while *P. viburni* probably originates from South America (Charles unpublished). Until relatively recently, mealybug control strategies relied heavily on broad-spectrum insecticides, which indiscriminately killed each species (and other insects) so that biological differences between them were not considered important for pest management. Insecticides are likely to remain an important part of future mealybug management strategies but they have become increasingly selective (i.e. targeted at specific pests or selected life-stages) and 'soft' (i.e. relatively harmless to natural enemies and the environment). Under this scenario, sustainable pest management strategies in viticulture (and horticulture in general), will increasingly rely on biological control by natural enemies (Charles 2008). Decisions on whether to import new natural enemies as part of classical biocontrol programmes will depend, in part, on what species are already present in New Zealand's vineyards, and what impact they are already having on vineyard pests.

Existing natural enemies of pest mealybugs in New Zealand arrived both accidentally (Charles 1989) and through classical biocontrol programmes (Charles *et al.* 2004). A survey in fruit crops throughout New Zealand between 1990 and 1992 indicated that there were few parasitoids present in vineyards compared with other crops. However, only eight vineyards were surveyed from three North Island regions (Auckland/Waikato, 2; Gisborne, 2; Hawke's Bay, 4) (Charles 1993). The winegrape production area has increased considerably in the intervening 20 years, from 4,800 ha in 1990 to 31,000 ha in 2009, and extended into regions with no previous history of viticulture (Anon. 2009).

Since 1993, records of mealybugs and their natural enemies from vineyards have continued to be collected from around the country, and here we collate these data from 1993 to 2009. Studies from which the data are drawn include a comparison of mealybug faunas in vineyards and neighbouring citrus orchards in 2003 and surveys of mealybugs in Gisborne, Martinborough and Marlborough vineyards, and across vineyards in the Gimblett Gravels area of Hawke's Bay from 2005 to 2009. The Gimblett Gravels vineyards are now considered to be a viticulture sub-region of Hawke's Bay, limited to a discrete 800 ha north-west of Hastings, and mostly planted within the last 20 years (Overton & Heitger, 2008). With an emphasis on premium quality Bordeaux-style red wine "the Gravels" is an increasingly important production area, and is currently at the centre of nationwide efforts to control mealybugs to minimise the spread of GLRaV-3.

METHODS

Mealybugs were collected from vineyards in Auckland (code AK) Waikato (WO), Gisborne (GB), Hawke's Bay (HB), Martinborough (Wairarapa, WA), Marlborough (MB) and Nelson (NN), and identified at PFR centres at Auckland or Havelock North. Area codes are from Crosby *et al*. (1998). Many samples were collected or received on an *ad hoc* basis, often as a result of requests from growers or consultants for identification of species, or as part of targeted research projects. From 2005 to 2009, Hawke's Bay vineyards, including those in the Gimblett Gravels sub-region, were more intensively surveyed for mealybugs by collecting samples of 200 leaves from selected grape blocks. Leaf samples (n=200 per site) were also collected from vineyards in GB (n=11), WA (10) MB (12) and NN (1) in March 2009.

In early March 2003, mealybugs were collected from two vineyards and five citrus sites (orchards or small groups of trees) in GB, and four vineyards and three citrus sites in HB. Mealybugs were collected from leaves, fruit and bark but sampling was highly selective and based on two criteria: (1) only mealybug-infested plant parts were sought and collected in order to increase the probability of sampling parasitoids, rather than randomly collecting plant material that may or may not be infested with mealybugs; and (2) each separate search for mealybugs was strictly limited to 20 minutes/person, to ensure that there was some quantitative consistency between mealybug samples from the two, physically very different, host plants. During the 20-minute time-search, searchers visually scanned all parts of as many grapevines or citrus trees as possible to locate collectable mealybugs.

Mealybugs were identified to species either in the field or when samples were returned to the laboratory and examined for natural enemies. Adult natural enemies were usually disturbed while collecting the mealybugs from the vineyard and were rarely found in the collections, unlike the less mobile immature stages of predators, which were removed and identified. All laboratory samples of mealybugs and ovisacs were transferred to sprouting potatoes, and reared at ambient temperature (c. 21^{o}C) for up to 4 weeks. They were examined regularly and mealybug "mummies" (the typically swollen, cylindrical, hardened skins of dead, parasitised mealybugs), and pupae from ovisacs, were transferred to separate gelatin capsules to await individual parasitoid emergence.

Natural enemies were additionally trapped on yellow sticky traps in 12 of the Hawke's Bay vineyards between late October 2008 and May 2009. Nine vineyards were located in the Gimblett Gravels, and three on the margins of Havelock North, c.20 km east of the Gimblett Gravels. In each of the vineyards, two yellow 'sticky' traps (190 x 180 mm Corflute® sheets, covered with Tanglefoot® adhesive, The Tanglefoot Co., Grand Rapids, MI, USA) were placed within the same row about 40 m apart, hanging directly below the vine canopy (0.7 to 0.9 m above ground). The traps were replaced at c. 15-day intervals and returned to the laboratory where known parasitoids of mealybugs were identified and counted.

Finally, collections were often accompanied by ants, which, from their distended abdomens, were feeding on mealybug honeydew at the time. The ants were also identified to species.

For analysis, a mealybug 'collection' was deemed to be either spatially or temporally separated from others. Hence two samples taken from the same vineyard on the same date, but from different grape varieties, were recorded as two separate collections. Similarly, two samples taken from the same vineyard and variety, but on different dates, were also recorded as separate collections. However, two samples taken from the same vineyard from the same variety on the same date were considered to be replicates of a single collection, and data were merged into a single 'collection'.

RESULTS

Mealybug species

A total of 131 separate collections of mealybugs from about 80 different New Zealand vineyards were made between 1993 and 2009 (Table 1). *Pseudococcus*

Table 1. Collections of *Pseudococcus longispinus* and *P. calceolariae* from New Zealand vineyards between 1993 and 2009

Region (No. of vineyards)	No. of collections	No. with *P. longispinus*	No. with *P. calceolariae*	No. with both species
AK (6)	7	7	1	1
WO (2)	3	3	0	0
GB (25)	35	28	27	20
HB (33)	65	39	41	16
WA (10)	11	3	9	1
MB (8)	9	5	6	1
NN (1)	1	1	0	0
Total = 84	**Total = 131**			

longispinus and *P. calceolariae* were the most commonly found mealybug species, and both species were found in every region apart from WO and NN. *Pseudococcus longispinus* was found in more AK collections than *P. calceolariae*. Both species were present in about the same number of GB, HB and MB collections, but *P. calceolariae* was found in more WA collections than was *P. longispinus*. More than half the collections in GB, and about a quarter in HB contained both species, and both species co-existed on many individual vines. Twenty-two of the HB collections came from 11 vineyards in the Gimblett Gravels sub-region, and *P. calceolariae* was the only mealybug species found in those vineyards between 2005 and 2008. *Pseudococcus longispinus* was found in some of these vineyards in 2009, but was more frequently found in all years in other HB vineyards.

The only other mealybugs found in vineyards were the obscure mealybug (*P. viburni*) collected once from HB in 1998 and *Paracoccus abnormalis* Cox (identified by R Henderson, Landcare Research, Auckland) collected once from a south Auckland vineyard in 2008. This is the first record of this native mealybug on grapevines. It was well established in the vineyard, feeding and ovipositing on green shoots and leaves. Nothing further is known of its biology, host plant range or of its ability to transmit GLRaV-3.

Mealybugs were collected from at least 13 red and white grape varieties. Although there was no obvious resistance or susceptibility to mealybugs among them, the sampling methods were incapable of measuring whatever differences there may have been between them.

Spatial patchiness of mealybug populations was often pronounced. While collecting mealybugs on one occasion, it was observed that one species was almost exclusively present in the vine canopies at one end of the row and the other species at the other end of the row, less than c. 100 m away, with both species present equally in the middle. There was also evidence that the two species occupied different habitats on occasions. In two Gisborne vineyards in 2009, *P. longispinus* was dominant in the grapevine canopy, while *P. calceolariae* was the only species observed in the weedy understorey below and between rows of vines.

The *ad hoc* nature of most collections meant that the actual numbers of mealybugs in each collection were not comparable. Both *P. longispinus* and *P. calceolariae* were present on many of the 200 leaf samples from HB, GB, WA, MB and NN, but the numbers of each species ranged from zero to many thousand per collection. Leaves were often found with hundreds of mealybugs and it was impractical to count them all, but estimates of the average mealybug numbers ranged from zero to about 50/leaf. The patchy distribution of mealybugs, both between and within collections, and even within a leaf, compounded the sampling uncertainties and meant that a statistical comparison of numbers between samples was not possible from the data collected. Nevertheless, it was apparent that numbers of *P. longispinus* were usually greater than numbers of *P. calceolariae* where the two species occurred together on vines.

Comparison of mealybugs on grapevines and citrus trees

Numbers of mealybugs on some grape and citrus plant parts were very low, and so data from each collection were combined for comparison. Both *P. longispinus* and *P. calceolariae* were found on grapevines and citrus trees in GB and HB. In HB, many more mealybugs were collected on grapevines (14.5/minute) than on citrus trees (0.4/minute) (Table 2). Similar problems and variability in sampling grape leaves for mealybugs as above were noted, which is why no further attempts to compare numbers statistically were made. In addition, the differing spray programmes would have confounded any direct comparisons of mealybug populations on these two crops.

Table 2. Mealybugs (MB) and parasitoids collected from New Zealand citrus trees and grapevines (all samples combined) in March 2003.

Region	Crop (no. sites)	No. of live MB	Live MB/min search	No. of parasitoids	% parasitism
GB	Grape (2)	155	1.9	18	11.6
	Citrus (5)	155	0.8	29	18.7
HB	Grape (4)	2735	14.5	103	3.8
	Citrus (3)	51	0.4	13	25.5

Natural enemies reared from mealybugs

Natural enemies were found in, or reared from, 32 (24%) of the 131 mealybug collections, but this underestimated their presence because some mealybug samples suffered high mortality during transit to Auckland. The mortality did not prevent mealybugs from being identified, but did reduce the number of collections from which parasitoids emerged. Seven species of parasitoids and four species of predators were identified (Table 3). Their regional distributions were largely as reported by Charles (1993), and the presence on crops other than grapes in that survey indicates that all of the natural enemies found in grapes are widespread through the North Island. Four species of Encyrtidae (*Tetracnemoidea sydneyensis* (Timberlake), *T. peregrina* (Compere) *Gyranusoidea advena* Beardsley, and *Parectromoides varipes* (Girault)) were reared only from *P. longispinus*, to which they appear to be strictly host specific. However, *P. varipes* was only found in citrus trees in GB, and has yet to be found in grapes anywhere in New Zealand. *Tetracnemoidea brevicornis* (Girault) was reared from both mealybug species, but was the most common parasitoid of *P. calceolariae*, together with the aphelinid *Coccophagus gurneyi* Compere (the only mealybug parasitoid found that was deliberately introduced to New Zealand for mealybug control), which was also reared occasionally from *P. longispinus*. *Anagyrus fusciventris* (Girault) was also reared from both mealybug species and was common in both GB and HB (Table 3). Surprisingly, no encyrtid parasitoids were found in collections from MB. It is unknown whether this was a true measure of their absence, or just a reflection of the small sample size and perhaps relatively small mealybug populations compared with those of other regions.

Ophelosia charlesi Berry was reared also from *P. calceolariae*. This species is usually found as a predator of mealybug eggs inside ovisacs (and hence is usually associated with *P. calceolariae*), but it can also be reared as a primary parasitoid of both *P. calceolariae* and *P. longispinus*. *Ophelosia charlesi* is *Ophelosia* spB in Charles (1993), where *Ophelosia* spA is *O. bifasciata* Girault.

Larvae of the predatory ladybirds *Cryptolaemus montrouzieri* Mulsant and *Midas pygmaeus* Blackburn, the predatory midge *Diadiplosis koebelei* (Koebele) and the coniopterygid lacewing *Cryptoscenea australiensis* (Enderlein) were found on a few occasions. *Cryptolaemus montrouzieri* was usually found in the vine canopy only when mealybug density was very high, with >75% leaf infestation. The lacewing was occasionally parasitised, probably by the native *Anacharis zealandica* Ashmead (Hym. Figitidae), which is a known parasitoid of hemerobiid lacewings. Although uncommon, these and other records show that they are widespread throughout North Island vineyards.

No natural enemies were found on or reared from either *P. viburni* or *Paracoccus abnormalis*. Specimens of all natural enemies are held in reference collections at Plant & Food Research at Auckland and Havelock North.

Sticky traps

A total of 288 yellow sticky traps were examined and 402 mealybug parasitoids from three genera were identified. *Anagyrus fusciventris* (n=256) was trapped in all 12 HB vineyards and was the most frequently encountered species. *Tetracnemoidea* spp. (n=139), predominantly *T. brevicornis,* were also commonly trapped at 11 of the 12 sites. Time did not allow for the removal, cleaning and identification of the mealybug parasitoids, so the presence of *T. peregrina* on the traps could not be discounted. *Tetracnemoidea sydneyensis* (n=7) was found in three sites, only one of which was on the Gimblett Gravels. Ninety-four percent (94.3%) of *A. fusciventris* and *Tetracnemoidea* spp. specimens were trapped between 6 March and 4 May (when trapping concluded), coinciding with the seasonal peak numbers of both *P. calceolariae* and *P. longispinus*. *Ophelosia charlesi* was also found in three vineyards, two of which were on the Gimblett Gravels. Other mealybug parasitoids were also present, but were not counted because of the difficulty of accurate identification on the sticky traps. *Coccophagus gurneyi*, in particular, could not be separated reliably from other aphelinids that were caught in large numbers.

Table 3. Natural enemies reared or collected from mealybugs in New Zealand vineyards 1993-2009, and citrus in 2003, excluding data from yellow sticky traps

	MB host	AK	WO	GB	HB	WA	MB
Parasitoids:							
Encyrtidae							
Anagyrus fusciventris	Pl + Pc	a		●6	●2		
Gyranusoidea advena	Pl	a	a	1			
Tetracnemoidea brevicornis	Pc + Pl			●4	●3	1	
T. peregrina	Pl	1	a	●1	1		
T. sydneyensis	Pl	a	1	●4	●		
Parectromoides varipes	Pl	a		●			
Aphelinidae							
Coccophagus gurneyi	Pc + Pl	1	a	9	●8	1	
Pteromalidae							
Ophelosia charlesi	Pc + Pl?	a		a	1	1	
Ophelosia undet.	?	a			●2		1
Predators							
Coccinellidae							
Cryptolaemus montrouzieri	Pl + Pc	1		2	2		
Midas pygmaeus	Pl + Pc	a		●a	1		
Cecidomyiidae							
Diadiplosis koebelei	Pl + Pc	a		2	a		
Coniopterygidae							
Cryptoscenea australiensis	Pl + Pc	a		a	a	1	

Pl = *P. longispinus*; Pc = *P. calceolariae*
n = number of vineyard collections in which natural enemy was found
● present in citrus collections, 2003
a Found on fruit crops other than grapes (Charles 1993)

Comparison of mealybug parasitoids on grapevines and citrus trees

The suites of natural enemies reared from mealybugs were similar in both crops and regions, although neither *Gyranusoidea advena* nor *Parectromoides varipes* was collected south of Gisborne, and the latter was found only on citrus (Table 3). Percentage parasitism of mealybugs was generally higher in citrus than in grapes in both regions, but the data from these single points-in-time collections are insufficient to determine whether the natural enemies provided more effective biological control in citrus trees than in grapevines. In addition, sample sizes were not large and additional collecting would probably increase the known distribution of mealybug natural enemies.

Ants

All ant species found in association with mealybugs by Charles (1993) were again found in vineyards. A significant addition was the presence of the Argentine ant, *Linepithema humile* (Mayr), in one GB and 3 HB vineyards in 2003, although the ant was not found again when two of the Hawke's Bay vineyards were revisited in 2007. *Linepithema humile* was also found in one GB and one HB citrus collection.

DISCUSSION

Mealybug species

The records reported here show that the two most important mealybug pests in New Zealand's vineyards are *P. longispinus* and *P. calceolariae*. Both species are found throughout the main grape growing regions, but *P. longispinus* appears to be dominant in northern vineyards (AK, WO). The relative numbers of each varied both spatially and temporally – even within a single vineyard – for reasons that are not yet understood, but are most likely to be associated with mealybug preferences for grape variety, micro-climate/environment and natural enemy presence. Whether the dominance of *Pseudococcus calceolariae* in Gimblett Gravels vineyards as a whole in most years was due to the Gimblett Gravel 'terroir' or to purely stochastic variability remains to be investigated.

Few collections were received from MB, even though it is now the largest winegrape-producing region, occupying 50% of the total area planted (Anon. 2009). This result probably reflected the fact that the vineyards are generally newly established, with the region having attained much of its present size in the last 10 years or so. Within MB there appears to be an industry perception that mealybugs are not a major problem, but there is no biological reason why this should be so. Both *P. longispinus* and *P. calceolariae* are common in the neighbouring, well established fruit-growing area of NN, and the latter species is sometimes common on crops as far south as Central Otago (Cox 1987; Charles unpublished data).

On the basis of these data, *P. viburni* is an insignificant component of the vineyard mealybug fauna. However, the mealybug species composition is clearly dynamic, with the unexpected presence of *Paracoccus abnormalis* in a south Auckland vineyard illustrating that native mealybugs also have the potential to be pests. Several other mealybug species, not yet present in New Zealand, also have the potential to become major vineyard pests, especially through their ability to vector GLRaV-3. The wine industry must continue to remain vigilant for incursions of new mealybug species and be prepared to adapt or adopt new control measures against them, including new species of natural enemies.

The practical problems associated with estimating mealybug numbers in vineyards remains a major hurdle to comparing populations both between and within properties. Until this issue is resolved, it will be very difficult to measure and compare objectively the effectiveness of different mealybug management programmes, either chemical or biological, over time. The newly identified sex pheromones for both *P. longispinus* and *P. calceolariae* may eventually provide the basis for useful, quantitative monitoring tools for mealybugs.

Natural enemies

The very presence of natural enemies of mealybugs in vineyards today provides a stark contrast to their paucity 30 years ago, when vineyards received a largely calendar schedule of broad-spectrum insecticides (Charles 1981; 1982). Reductions in pesticide use in recent years mean that New Zealand's vineyards are now freer of insecticides than at any time in history, and the potential for natural enemies to exert their maximum impact on pests in fruit crops has never been greater (Charles 2008). The regular occurrence of mealybug parasitoids now provides a vivid illustration of how beneficial fauna can accumulate in vineyards under sustainable winegrowing practices. Biological control of mealybugs – especially by hymenopteran parasitoids in the family Encyrtidae – has been very successful in controlling these pests to acceptable levels in many countries (Moore 1988) and there is strong evidence that co-evolution of mealybugs and their parasitoids leading to effective host-specificity is the rule rather than the exception (e.g. Rosen & De Bach 1977).

Although the natural enemy data from these collections do not allow their impact on mealybug populations (and hence their effectiveness as biocontrol agents) to be measured, their ubiquity is an encouraging signal to develop further mealybug biocontrol programmes in vineyards. The use of yellow sticky bases has been considered to be an effective means of sampling airborne parasitoids to allow assessment of species diversity and relative abundance in vineyards (Thomson *et al.* 2004), and they may well have a place in monitoring future biocontrol programmes.

The presence of the host-specific *T. sydneyensis* and *T. peregrina* in vineyards with *P. longispinus*, and the essentially host-specific *T. brevicornis* in those with *P. calceolariae* was to be expected. Perhaps one of the most significant findings was the widespread presence of *A. fusciventris*, which has spread throughout much of the North Island since it was first reported as occurring only in AK (Charles 1993). In contrast to the *Tetracnemoidea* species, *A. fusciventris* was reared many times from both species of mealybug and is clearly oligophagous. It was particularly common in GB and HB vineyards, where both mealybug species were commonly present, and it is possible that its ability to utilise both species as hosts allows a quick numerical response to the spatial and temporal vagaries of these mealybugs. Whether this feature will prove to be an advantage to the long-term population regulation of either species remains to be measured. Predators of mealybugs are now a regular feature of vineyard biodiversity, but, as for parasitoids, their impacts on populations of their hosts have not been measured.

New natural enemies of mealybugs also continue to arrive accidentally in New Zealand, at a faster rate than deliberate introductions. *Cryptanusia aureiscutellum* (Girault) (Hym: Encyrtidae) was recently discovered in a Gisborne citrus orchard (Jamieson *et al.* 2009). This accidental arrival is presumed to originate from

Australia. It has since been reared from *P. longispinus* in New Zealand (Charles, unpublished data), but has not yet been found in a vineyard.

Regardless of the presence of parasitoids, the comparative trial in 2003 showed that mealybug numbers in grapevines were often higher than those in citrus trees. This may have been due to a number of reasons. Grapevine leaves, for example, are much larger than citrus leaves and each can hold many thousands of mealybugs, usually abaxially, where they are relatively protected against natural enemy attack by prominent veins and dense pubescence. Seasonal changes in the vineyard habitat may also play a crucial role in tri-trophic population dynamics. Grapevines are grown as a two-dimensional trellis, and are deciduous and heavily pruned every winter. Hence they are a relatively unstable habitat for insects compared with evergreen, three-dimensional citrus trees. This may explain why *Parectromoides varipes* has not been found on grapevines, but may be common in adjacent orange trees.

Ants

Any work to improve the effectiveness of existing natural enemies, or to import new species against *P. longispinus* or *P. calceolariae* should consider the role of ants, especially *L. humile*, in vineyards. The presence of Argentine ant in both GB and HB grapes and citrus trees is a recent development, and our inability to detect it again in two of the HB vineyards suggests that in these sites at least the incursions were unsuccessful. However, the fact that it was found in horticultural systems should be of concern. Argentine ant is regarded as one of the world's most invasive ant species (Silverman & Brightwell, 2008), and overseas research has shown that *L. humile* may interact with mealybugs in vineyards and alter mealybug abundance and disrupt mealybug biocontrol (Daane *et al.* 2007). Conversely, at least one mealybug parasitoid in New Zealand (*Acerophagus maculipennis* (Mercet) introduced against *P. viburni* as *Pseudaphycus maculipennis* Mercet) appears not to be affected by this ant (Panis & Brun 1971). Argentine ant was first recorded in New Zealand by Green (1990) and populations are still spreading through the country so it is unlikely that their impact in orchards or vineyards has reached anything like equilibrium (Ward *et al.* 2010). Their role as aggressive and destructive competitor *versus* beneficial predator in New Zealand's vineyards has yet to be evaluated, and potential management options need to be considered for future grape pest management programmes. Insecticides, repellent plant species, cultivation or other physical means may all be valuable techniques for ant control when used within an overall mealybug control programme.

The New Zealand wine sector considers environmental sustainability to be one of its key strategic goals (Gregan 2007). Natural enemies are an important component of this goal, but growers are likely to consider further radical changes in insecticide use against mealybugs only when biocontrol is shown to be an effective management option. Yet despite increasing knowledge of the species of natural enemies in vineyards, knowledge of their impact on mealybugs (i.e. their effectiveness as biological control agents) and how best to manage them so that they have maximum effect, is largely lacking. The immediate goal must be to develop a quantitative understanding of the interactions between mealybugs and their natural enemies, not only where they are well known, but also in regions such as MB where even their presence is uncertain.

In the meantime, existing suites of parasitoids and predators of mealybugs should be regarded as an essential and valued 'ecosystem service' – like abundant water and healthy soils. Incorporation of improved mealybug biocontrol into sustainable pest management of New Zealand's vineyards should become a cornerstone of the development of mealybug management strategies.

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