AN ECOLOGICAL PERSPECTIVE TO HOST-SPECIFICITY TESTING OF BIOCONTROL AGENTS

J.G. CHARLES and D.J. ALLAN

HortResearch, Private Bag 92 169, Auckland, New Zealand
Corresponding author: jcharles@hortresearch.co.nz

ABSTRACT

Classical biological control programmes have historically been viewed positively, but in the new social context of "all new invaders are bad", the perceived environmental threats from new natural enemies are regarded by some as unacceptable. Host-specificity testing of proposed biocontrol agents is required to provide environmental safety assurances, but laboratory methods are likely to be flawed and cannot mimic the reality of nature. It is proposed that analysis of the realised host-range of long-established exotic parasitoids may help to predict the impacts of proposed, new biocontrol agents and supplement laboratory testing. This approach was used in 1999 when applying to New Zealand's Environmental Risk Management Authority for approval to release the parasitoid *Pseudaphycus maculipennis* (Hymenoptera: Encyrtidae) against the obscure mealybug, *Pseudococcus viburni* (Hemiptera: Pseudococcidae). The data from New Zealand and elsewhere indicate that new encyrtid parasitoids of mealybugs have shown no propensity to attack native species over time.

Keywords: classical biocontrol, host-specificity testing, ecology, Pseudococcidae, Encyrtidae.

INTRODUCTION

Classical biological control (CBC) of insects (defined here as the deliberate introduction of natural enemies into a new country to control an exotic pest) has historically been accepted as an economically, ecologically and socially sound pest control strategy, and a welcome alternative to the use of broad spectrum pesticides. New Zealand has an extraordinarily high level of endemicity much of which is threatened by human activity and associated exotic species. As the concern for maintaining native biodiversity has increased in recent years, so has the perception that "all exotic organisms are bad" and the assertion that CBC is an unacceptable pest control option. Although there is a disproportionate focus on a few historical disasters borne of contemporary ignorance of vertebrate ecology - the "stoats and cane toad" litany – it is beyond dispute that a minority of insect classical biocontrol agents has attacked native fauna (Hawkins & Marino 1997; Funasaki et al. 1998). In New Zealand, there is open public critique of host-specificity testing (HST) procedures for proposed natural enemies, and new legislation governing CBC programmes reflects social pressure for complete safety-assurance.

Perhaps the biggest single drawback of HST procedures is that they must be carried out in quarantine laboratories and hence lack ecological reality. Despite many inventive ideas, practice has shown that laboratory HST methods for any biocontrol agent (BCA) are almost always flawed in some way (Withers et al. 1999). Perhaps the closest to a universal method for HST is the "centrifugal phylogenetic method" for testing weed biocontrol agents (Wapshere 1974, 1989). Similar test procedures for insect biocontrol agents have been proposed (Barratt et al. 1999), as have other ways in which non-target impacts can be measured (Hopper 2001). Nevertheless, potential new ecological interactions among insects are very much more numerous than for weeds so the arguments that insufficient new associations have been tested, or that the BCA may form unsuspected associations over ecological time, can never be adequately countered by HST. In New Zealand, this dilemma has been addressed by requests from the Environmental Risk

Management Authority (ERMA) that the impact of new BCAs on non-target hosts is measured for posterity in the years following release.

This request implies that any new ecological associations that develop in the field over time may help future decision making for similar BCAs. If that is so, then the existing database of the hundreds of species of exotic natural enemies that have established accidentally or deliberately in New Zealand since the arrival of humans may also be a valuable predictor of new BCA associations. Hence, when a new BCA is proposed, an initial approach is to estimate (through literature and collection searches) the non-target impacts of all of the closely related BCAs (both exotic and native) that are already present in New Zealand. These data can be supplemented by 'mimic' HST procedures (using established parasitoids), so that predicted host associations from HST in quarantine can be compared with what has actually materialised after decades in the real world. We can then test the null hypothesis that "this group of parasitoids shows a propensity to form unexpected associations with native insects" over time. If they remain restricted to the expected hosts then this evidence must count in favour of the proposed new BCA. In practice this approach may be limited by the number of 'closely related' species already established and the expected level of host specificity known from overseas data.

This paper describes how this approach was used in 1999 when applying to ERMA for approval to release the parasitoid *Pseudaphycus maculipennis* (Hymenoptera: Encyrtidae) against the obscure mealybug, *Pseudococcus viburni* (Hemiptera: Pseudococcidae). Laboratory HST in New Zealand (J.G. Charles, unpubl. data), Australia (D. Smith, Queensland Department of Primary Industries, pers. comm.) and Europe (J.P. Kaas, Biopré, pers. comm.), details of which were given in the application to ERMA, had already shown that *P. maculipennis* was effectively host-specific to obscure mealybug.

METHODS

Literature search

New Zealand has a known fauna of ca 115 species of mealybug, although this is estimated to be less than 50% of the total (Cox 1987). Only 16 of these species are exotic and 3 species (*Pseudococcus longispinus*, *P. calceolariae* and *P. viburni*) have been significant pests of fruit crops for more than 100 years. They have been the object of several classical biological control campaigns, but only one predator (*Cryptolaemus montrouzieri*, Col: Coccinellidae) and one parasitoid (*Coccophagus gurneyi*, Hym: Aphelinidae) have established (Charles 1987). Worldwide, the introduction of parasitoids, especially in the family Encyrtidae, has been the most successful strategy for controlling mealybug pests, with a number of spectacular successes (Moore 1988). The Encyrtidae is one of the most studied families of Hymenoptera in New Zealand, with about 35 genera and 67 species already known. More than half of these are thought to be either endemic or indigenous. Nearly all introduced species are associated with "pastures, gardens, orchards and forests", while endemic species appear to be associated with "native plants in gardens, native forests, or subalpine and alpine native grasslands" (Noyes 1988). At least six exotic parasitoids of mealybugs have arrived accidentally (many orchardists would say fortuitously), probably during the past 80-100 years (Charles 1993; Table 1).

Field tests

Many fruit orchards throughout New Zealand grow close to stands of native trees which retain a fauna of both native mealybugs and their native parasitoids despite competition from sometimes very high numbers of exotic orchard mealybugs and parasitoids (J.G. Charles, unpubl. data). We have reared a few species of parasitoids from many mealybugs collected from these environments over many years and thus have a small contemporary database of mealybug species and their associated parasitoids from orchard environments.

RESULTS AND DISCUSSION

The known mealybug host - encyrtid relationships for all New Zealand species are summarised in Table 1. The exotic Encyrtidae are known to develop only on exotic mealybugs, while native Encyrtidae develop almost exclusively on native mealybugs. The hosts of a few species of native encyrtids are known only as "Pseudococcidae sp.", but the plants on which they were found suggest that they were native mealybugs. In the absence of recently collected specimens from Australia, *S. ferus* is here considered a New Zealand native. *Tetracnemoidea brounii* is the only native encyrtid that is polyphagous on its native hosts and is also the only native species to attack exotic mealybugs. It has a wide geographical distribution and is taxonomically very variable. These features would likely count against *T. brounii* in any CBC programme against New Zealand native mealybugs that had established elsewhere in the world. In the same way, if significant host-switching was likely to occur in *P. maculipennis*, then it should already have been recognised as polyphagous.

Of the exotic encyrtids, *Tetracnemoidea brevicornis* is extremely common after 80 years in New Zealand, but is still recorded primarily from *Pseudococcus calceolariae*. It is occasionally reared from *Pseudococcus longispinus*. The common *Tetracnemoidea peregrina* is reared almost exclusively from *P. longispinus* after at least 40 years in New Zealand, while 4 other common species have only ever been recorded from that mealybug (Charles 1993; Table 1). *Anagyrus fusciventris* has colonised much of New Zealand since its arrival in Auckland in 1992, but despite its apparent invasive qualities has so far only been found from *P. longispinus* and *P. calceolariae*. Overseas host records suggest it may yet expand its host range (Beardsley 1969).

TABLE 1: Species of Encyrtidae in New Zealand and their mealybug hosts.

Encyrtid parasitoid	Estimated date of parasitoid arrival	Mealybug host (exotic)	Mealybug host (native)
Native			
Adelencrtoides unicolor			*Paracoccus glaucus*[1]
Odiaglyptus biformis			*Balanococcus poae*[1]
Rhopus anceps			*Balanococcus* sp.[1]
Subprionomitus ferus			Pseudococcidae sp.[1]
Tetracnemoidea bicolor			*Balanococcus* sp.[1, 3, 4]
Tetracnemoidea brounii		*Nipaecoccus aurilanatus*[1] *Pseudococcus calceolariae*[1]	*Crocydococcus cottieri*[1] *Dysmicoccus ambiguus*[1, 3] *Paracoccus zealandicus*[3] Pseudococcidae sp.[3]
Tetracnemoidea zelandica			*Planococcus mali*[1]
Tongyus costalis			Pseudococcidae sp.[1, 3]
Tongyus regis			Pseudococcidae sp.[1]
Exotic			
Alamella mira	1981	*P. longispinus*[1]	
Anagyrus fusciventris	1992	*Pseudococcus calceolariae*[2] *P. longispinus*[2]	
Gyranusoidea advena	1962	*P. longispinus*[2]	
Parectromoides varipes	1959	*P. longispinus*[2]	
Pseudaphycus maculipennis	2001[5]	*Pseudococcus viburni*[3]	
Tetracnemoidea brevicornis	1924	*Phenacoccus graminicola*[1] *Pseudococcus calceolariae*[1, 2] *P. longispinus*[2]	
Tetracnemoidea peregrina	1961	*Pseudococcus calceolariae*[1, 2] *P. longispinus*[2]	
Tetracnemoidea sydneyensis	1962	*P. longispinus*[1, 2]	

[1]Noyes 1988; [2]Charles 1993; [3]J.G. Charles (unpubl. data); [4]Cox 1987.
[5]Release programme initiated.

CONCLUSIONS

Internal parasitoids such as Encyrtidae are koinobionts, developing within the body of their host while the host itself continues to grow and moult. Their survival implies remarkable co-evolutionary adaptation, and leads to the expectation of a high degree of host specificity (Askew & Shaw 1985). This attribute appears to be particularly strong among those Encyrtidae that attack mealybugs, as shown here and elsewhere (Moore 1988). Once established, new encyrtid parasitoids of mealybugs in New Zealand have shown no propensity to attack native species over time. This can be seen also in Hawaii, where of the nine species of Encyrtidae introduced for control of Pseudococcidae between 1904 and 1936, eight attack only their target mealybug, while one attacks the target and one other exotic, pest mealybug (Funasaki et al. 1988) The laboratory HST for *P. maculipennis* conforms to the general model exhibited in the above examples, which, in turn, lend weight to the prediction that it will not expand its host range in New Zealand.

Not all koinobiont parasitoids share the high degree of host-specificity demonstrated by encyrtid/mealybug relationships. Hawkins & Marino (1997) showed that 16% of the parasitoids introduced into North America as BCAs have been found on native hosts. They could find no difference between the frequencies of idiobionts or koinobionts recorded from native hosts, but excluded hemimetabolous pests from their analysis. They concluded, at least for holometabolous insects, that it was not possible to predict from biological or ecological features when a new biocontrol agent would colonise natives. So, although other taxa of koinobiont parasitic Hymenoptera in New Zealand may show similar levels of host-specificity to that of the encyrtids that attack mealybugs, discovering these taxa may depend critically upon measuring host specificity at appropriate taxonomic and ecological detail, and this may vary between groups of both host and parasitoid.

In New Zealand, the relatively small number of deliberately introduced biocontrol agents of fruit crop pests increases the reference value of the accidentally introduced parasitoids, most of which presumably arrived unnoticed with insect hosts. There are about 135 species of mostly exotic natural enemies (only 24 of which were introduced through classical biological control programmes) which attack 120 mostly exotic arthropod pests of fruit crops (Charles 1998). The biggest impediments to extracting their full value are a lack of funding to carry out both population ecological studies at the interface between horticultural and ‘native’ habitats, and taxonomic analysis of the native fauna. Key issues to be resolved are likely to be (a) how many samples are needed to detect non-target attack (the ‘absence of evidence is not evidence of absence’ dilemma), and (b) how to measure the population impact of an exotic parasitoid that is occasionally reared from native hosts. From a conservation perspective this is the functional meaning of ‘non-target impact’, and should really be one of the key goals of ecological research for biological control and insect conservation.

ACKNOWLEDGEMENTS

We thank Dr Garry Hill for significant improvements to the draft manuscript. The work was funded by ENZAFRUIT New Zealand (International) and the Foundation for Research, Science and Technology, Programme No. C06X0004.

REFERENCES

Askew, R.R.; Shaw, M.R. 1985: Parasitoid communities: their size, structure and development. *In*: Waage, J.; Greathead, D. *ed.* Insect parasitoids. Academic Press, London, UK. Pp. 225-264.

Barratt, B.I.M.; Ferguson, C.M.; McNeill, M.R.; Goldson, S.L. 1999: Parasitoid host specificity testing to predict field host range. *In*: Withers, T.M.; Barton Browne, L.; Stanley, J. *ed.* Host specificity testing in Australasia. Scientific Publishing, Dept of Natural Resources, Queensland, Australia. Pp. 70-83.

Beardsley, J.W. 1969: The Anagyrini of the Hawaiian Islands (Hymenoptera: Encyrtidae) with descriptions of two new species. *Proc. Hawaiian Entomol. Soc. 20*: 287-310.

Charles, J.G. 1989: Pseudococcidae, mealybugs (Homoptera). *In:* Cameron, P.J.; Hill, R.L.; Bain, J.; Thomas, W.P. *ed.* A review of Biological Control of invertebrate pests and weeds in New Zealand 1874 –1987. Tech. Comm. CAB International, UK. Pp. 223-236.

Charles, J.G. 1993: A survey of mealybugs and their natural enemies in horticultural crops in North Island, New Zealand, with implications for biological control. *Biocontrol Sci. Technol. 3*: 405-418.

Charles, J.G. 1998: The settlement of fruit crop arthropod pests and their natural enemies in New Zealand: an historical guide to the future. *Biocontrol News Info. 19*: 47N-58N.

Cox, J.M. 1987: Pseudococcidae (Insecta: Homoptera). Fauna of New Zealand 11. DSIR Science Information Publishing Centre, Wellington, New Zealand. 230 p.

Funasaki, G.Y.; Lai, P-Y.; Nakahara, L.M.; Beardsley, J. W. ; Ota, A.K. 1998: A review of biological control introductions in Hawaii: 1890 to 1985. *Proc. Hawaiian Entomol. Soc. 28*: 105-160.

Hawkins, B.A.; Marino, P.C. 1997: The colonization of native phytophagous insects in North America by exotic parasitoids. *Oecologia 112*: 566-571.

Hopper, K.R. 2001: Research needs concerning non-target impacts of biological control introductions. *In*: Wajnberg, E.; Scott, J.K.; Quimby, P.C. *ed.* Evaluating indirect ecological effects of biological control. CABI publishing, UK. Pp. 39-56.

Moore, D. 1988: Agents used for biological control of mealybugs (Pseudococcidae). *Biocontrol News Info. 9*: 209-225.

Noyes, J.S. 1988: Encyrtidae (Insecta: Hymenoptera). Fauna of New Zealand 13. DSIR Science Information Publishing Centre, Wellington, New Zealand. 188 p.

Valentine, E.W.; Walker, A.K. 1991: Annotated catalogue of New Zealand Hymenoptera *DSIR Plant Protection Report* 4. 84 p.

Wapsphere, A. 1974: A strategy for evaluating the safety of organisms for biological weed control. *Ann. Appl. Biol. 77*: 210-211.

Wapsphere, A. 1989: A testing sequence for reducing rejection of potential biological control agents for weeds. *Ann. Appl. Biol. 114*: 515-526.

Withers, T.M.; Barton Browne, L.; Stanley, J. 1999: Host specificity testing in Australasia. Scientific Publishing, Dept of Natural Resources, Queensland, Australia. 98 p.