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Review Article

The settlement of fruit crop arthropod pests and their natural enemies in New Zealand: an historical guide to the future

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Abstract

Fruit crops in New Zealand are infested by 117 arthropod pests, which, in turn, are attacked by 135 arthropod natural enemies. Most pests (100) and natural enemies (116) are exotic, and have arrived during the *ca* 150 years of European colonization. Ninety-two species of natural enemies have established accidentally, compared with 24 through classical biocontrol introductions. Many fruit crop pests now have diverse, exotic natural enemy guilds, which are becoming increasingly important both economically and ecologically in integrated fruit production (IFP) and organic growing systems. It seems likely that exotic pests and natural enemies of fruit crops will both continue to establish in New Zealand at the long-term average rate of *ca* seven species per decade. Additionally, the reduced use of broad-spectrum insecticides in fruit crops may result in a greater number of native insects becoming pests. The increasing pest load poses a significant threat both to the livelihood of fruit growers and to the New Zealand economy. Biological control of pests by natural enemies, both native and exotic, and deliberately or accidentally established, will inevitably be further developed as pest management strategies. Ecological studies should aim to provide, on the one hand, the economic sustainability required by fruit growers, and, on the other, the environmental sustainability demanded by conservationists. Ecological analysis of the existing guilds of exotic natural enemies in managed environments may help to predict the potential impact of new natural enemies on non-target species.

Introduction

The first European fruit growers in New Zealand quickly took advantage of a benign climate ideally suited to the cultivation of exotic temperate and sub-tropical fruits, and recognizable orchards had been developed by 1865. Sessile insects (e.g. scale insects), and those with sessile or diapausing stages (e.g. eggs or pupae in soil), appear readily to have survived the sea journey from Europe, and the first exotic arthropod pests probably arrived with the first fruit trees and vines. Initially, there were no professional entomologists, and for many years pests were identified by amateur taxonomists, and control measures designed by fruit growers themselves, with assistance from experts in other countries, especially England and the USA (Ramsay & Singh, 1982).

Insectivores were soon being promoted as essential for the control of insect pests in the colony, but, although carabids and ichneumons were acknowledged as insect 'predators', greater emphasis was placed on the introduction of insectivorous birds (Fereday, 1873). The superior value of insect natural enemies in fruit crops was recognized with the dramatic control of the cottony cushion scale, *Icerya purchasi* Maskell (Hom., Margarodidae) in California in 1890, by *Rodolia cardinalis* (Mulsant) (Col., Coccinellidae) ladybirds sourced from New Zealand (Cameron *et al*., 1989). This was one of the success stories that led to the world-wide acceptance of biological control by natural enemies, and considerable biological control research in New Zealand until the 1940s.

It should also be remembered that the start of the 'chemical' insecticide era had preceded the success of *Rodolia* by 20 years, and that, even by the 1890s, the use of natural enemies was seen as a welcome alternative to dangerous insecticides. Paris Green (arsenate of copper) was first described in 1872, and soon found grower acceptance, despite a composition of 28% arsenic and extreme toxicity to humans. Lead arsenate, paraffin oil, extract of quassia, sulphur, nicotine and caustic soda/potash as insecticide sprays, and carbon bisulphide and hydrogen cyanide as fumigants, were all in use by 1899 (Ormerod, 1890; Theobald, 1899), and were all widely used in New Zealand at various times until 1940.

After the Second World War, horticultural industries in New Zealand embraced the new era of synthetic pesticides

with the same enthusiasm as those in other countries, and soon faced the same problems of new pests, pesticide resistance and environmental degradation, including the destruction of natural enemies. The value of using selective pesticides, while retaining natural enemies in integrated pest management (IPM) programmes was clearly demonstrated in the 1970s. Now, in the 1990s, with diminishing use of broad-spectrum insecticides and the implementation of integrated fruit production (IFP) and organic crop management systems, the ecological balance of the arthropod fauna in fruit crops is changing yet again, and biological control is once more a preferred method of pest control (Walker *et al*., 1997).

Some recent, diverse syntheses of our knowledge of insect natural enemies in New Zealand have been made. Cameron *et al*. (1989) reviewed the classical biological control programmes from 1874. Valentine & Walker (1991) compiled an annotated catalogue of the New Zealand Hymenoptera, and the taxonomy of some families (especially the Encyrtidae (Noyes, 1988)) was described for the first time in volumes of the 'Fauna of New Zealand' series. Despite these initiatives, detail of the biology, taxonomy and history of many of the natural enemies that attack New Zealand's fruit crops is sparse, incomplete, and scattered through the literature. This is partly because there has been substantial, unplanned, and frequently unrecognized invasion of many exotic natural enemy species over the past 150 years. For example, whereas two deliberately introduced, exotic species of natural enemies for mealybug control had established by 1922 (Charles, 1989), a further 12 uninvited species had arrived by 1993 (Charles, 1993).

This paper attempts to collate the establishment of the known pests and natural enemies of fruit crop pests in New Zealand from an historical perspective.

Methods

Lists of arthropod pests and their arthropod natural enemies occurring on *ca* 24 fruit crops were compiled from the scientific literature, and by consulting specialist entomologists within New Zealand. Fruit crops in New Zealand are predominantly temperate and subtropical in origin, and include avocado, berryfruit (including blackberry, blackcurrant, blueberry, boysenberry, raspberry, and strawberry), citrus (including lemon, orange, tangelo and mandarin), feijoa, grape, kiwifruit, nashi, persimmon, pipfruit (apple and pear), summerfruit (including apricot, cherry, nectarine, peach, plum) and tamarillo.

The date of introduction of a species was usually taken as the first published record, even though it may have actually arrived prior to that date. Endemic species were, by definition, present before European colonization, so have no establishment date.

Pests

Most of the adventive and native phytophagous mite and insect species that have been recorded feeding on fruit crops in New Zealand were deemed to be pests. Species such as *Nysius huttoni* White (Het., Lygaeidae), which are largely of phytosanitary concern, were also included, but insects which colonize overripe or rotting fruit (e.g. *Drosophila* spp. (Dipt., Drosophilidae) or *Carpophilus* spp. (Col., Nitidulidae)) were omitted.

Natural enemies

A list of the arthropod natural enemies was more difficult to compile. Not all of the species ever associated with a pest were included. Most omissions were of records considered to be mis-identifications or trivial associations of little ecological significance to the pest (e.g. single records). The natural enemies were divided into three groups:

(**a**) Endemic, or at least native (pre-European) species that attack either native or introduced fruit crop pests.
(**b**) Exotic species that were deliberately introduced to, and established in, New Zealand – the 'classical biocontrol' (or CBC) agents.
(**c**) Exotic species which have established 'accidentally' since the start of European colonization, either by natural migration/dispersal (usually assisted by wind), or through human activity. All Australian species were deemed to be exotic.

Records were extracted from many sources. Apart from the well-documented classical biocontrol programmes (Cameron *et al*., 1989) it was often very difficult to determine, or even estimate, the actual date of arrival of exotic natural enemies. A significant number of mite predators and Chalcidoidea (Hym.) were documented for the first time by Dr Elsie Collyer (e.g. Collyer, 1964a, b) and Mr Errol Valentine (Valentine, 1963, 1967), respectively. For some species, a more accurate estimate of arrival date, as opposed to documented date, was obtained from the first accession date of specimens in the New Zealand Arthropod Collection (NZAC). The literature referenced may not give the earliest record of a natural enemy, but may provide an appropriate entry to the literature by providing additional taxonomic or historical context.

With the exception of the first two hymenopterans recorded in the nineteenth century (included for historical reasons), the natural enemies of predators and obligate secondary and tertiary parasitoids were not listed. There are only a few species recorded (*ca* six to 12), and there is no evidence yet that any one of them regularly inhibits biological control of a fruit crop pest. Neither the taxonomy nor biology of most are known with any clarity. They will be discussed in a future publication.

Results and Discussion

Numbers of pests and natural enemies

One hundred exotic and 17 endemic (total = 117) species of fruit crop pests were selected (see Table 2). Not all are regarded as major pests, but most are regularly recorded as at least a minor pest on one or more of New Zealand's fruit crops.

Nearly half of the pest species (50) are Homoptera. Acari (22), Lepidoptera (19), and Coleoptera (nine) account for most of the others, with Thysanoptera (five), Heteroptera (three), Hymenoptera (five), Diptera (two) and Dermaptera and Orthoptera (each with one) providing the remainder (Table 1). There are significant differences in the exotic *vs* endemic composition of the pests. Whereas 49 of the homopteran pests are exotic, having arrived here from many different countries around the world, more than half of the Lepidoptera (11) and one third of the Coleoptera (three) are endemic. Most of the mites are cosmopolitan or Australasian.

The 135 arthropod natural enemies (see Table 3) include the principal species of predators and parasitoids in fruit crops currently known to be present in New Zealand. Nineteen species (14%) are New Zealand natives, 24 (18%) have established as the result of deliberate classical biological control programmes, while 92 (68%) are exotic species which have established accidentally (Table 1).

Thus nearly four times as many natural enemies have established through accidental immigration as through classical biocontrol programmes. The ratio of predators to parasitoids (approximately 40:60) for all natural enemies is the same for both the exotic and native fauna. A few species of Hymenoptera, especially within the Pteromalidae (*Ophelosia* spp.) and Encyrtidae, may be predators and/or primary and secondary parasitoids. Nine of the endemic natural enemies are predators. Two species of generalist predators (*Micromus tasmaniae* (Walker) (Neur., Hemerobiidae) and *Melanostoma fasciatum* (Macquart) (Dipt., Syrphidae)) are very commonly found feeding on a range of introduced species in many crops and habitats.

Pest groups attacked

Species within the superfamily Coccoidea are the most numerous pest group, and are exclusively or regularly attacked by about half of the natural enemies (*ca* 65 species) including both generalist predators, and parasitoids. Few of the parasitoids are strictly monophagous. Some are very polyphagous, some are facultative hyperparasitoids, and a few are both predators and primary and secondary parasitoids. Despite this array of diverse natural enemies, some of the Coccoidea in New Zealand remain poorly attacked (e.g. *Pseudococcus viburni* (Signoret); Hom., Pseudococcidae (Charles, 1993)), illustrating how, under natural conditions, oligophagous parasitoids often exhibit marked host or habitat specificity, despite the availability of several potential host species.

Phytophagous mites are attacked by a group of 18 specialist predators, including exotic and native mites, coccinellids and a cecidomyiid. This group, which effectively preys only on mites, includes 13% of all natural enemy species, and 30% of all predators. One native species, the ladybird *Stethorus bifidus* Kapur (Col., Coccinellidae), has adapted well to horticultural environments where it may have significant impact on introduced spider mite pests (Acari, Tetranychidae) (Collyer, 1964b; Cameron *et al.*, 1989). Mites are also attacked by several other generalist predators.

About the same number of natural enemies (also a mixture of predators and parasitoids) attack leafroller (Lep., Tortricidae) eggs, larvae and/or pupae. They include native hymenopteran (*Glyptapanteles demeter* (Wilkinson); Braconidae) and dipteran (*Pales funesta* (Hutton) and *P. feredayi* (Hutton); Tachinidae) parasitoids, all of which have adapted well to living in fruit crops.

Most of the remaining species of endemic hymenopteran parasitoids attack only native pests, and only two (*Dolichogenidea carposinae* (Wilkinson) (Braconidae) and *Xanthocryptus novozealandicus* (Dalla Torre) (Ichneumonidae)) are commonly found in fruit crops. Detailed ecological studies of the native and exotic parasitoids of the more important native pests, such as leafrollers and lemon tree borer (*Oemona hirta* (F.); Col., Cerambycidae), are long overdue.

There are several 'missing groups' of natural enemies. Noticeably absent are any nymphal parasitoids of leafhoppers (Hom., Cicadellidae), and there are virtually no natural enemies of fruit-damaging weevils (Col., Curculionidae). Under IFP, some generalist predators such as various Araneae and Heteroptera are becoming increasingly common. Yet little is known of their biology, let alone how they impact on populations of pests and/or 'innocuous' prey in the orchard ecosystem. Far greater knowledge of the structure of the natural enemy guilds of the various fruit crop pests, and the regional distributions of their natural enemies, will be required for IFP to be fully effective in all fruit crops.

Historical establishment of pests

More than a quarter of the species (31 exotic and about four native) were recognized pests of tree and vine fruits by 1900. Many of these remain economically important pests today, and include codling moth (*Cydia pomonella* (L.); Lep., Tortricidae), woolly apple aphid (*Eriosoma lanigerum* (Hausmann); Hom., Pemphigidae), two-spotted mite (*Tetranychus urticae* Koch; Acari, Tetranychidae), several relatively sessile Homoptera (scale insects, mealybugs), passionvine hopper (*Scolypopa australis* (Walker); Hom., Ricaniidae), lemon tree borer (*Oemona hirta*), bronze beetle (*Eucolaspis brunnea* (F.); Col., Chrysomelidae) and native tortricid leafrollers (Table 2). In the 1990s, the level of scrutiny of export fruit crops has never been more detailed, and new pests are most likely discovered within a year or two of their actual arrival.

If the peaks and troughs of arrivals over the past 140 years are considered to be mostly stochastic artefacts of human observation, or lack of it, then new fruit crop pests have arrived in New Zealand at a long term average rate of about seven species per decade (Figure 1). The Homoptera have contributed most to the exotic fauna (Tables 1 & 2). The two peaks in the 1870s and 1920–30s were due largely to identifications and discoveries by Mr W. M. Maskell (an amateur entomologist)

Table 1. Summary of the numbers of pest and natural enemy taxa found on fruit crops in New Zealand.

Pest or natural enemy group	No. of pest species			No. of natural enemy species			
	Exotic	Native	Total	CBC[1]	Accidental	Native	Total
Acari	22		22	4	10		14
Araneae					2	1	3
Opiliones					1		1
Coleoptera	6	3	9	5	7	3	15
Dermaptera	1		1		1		1
Diptera	2		2	2	2	4	8
Heteroptera	3	1	4		6		6
Homoptera	49	1	50				
Hymenoptera	5		5	13	59	10	82
Lepidoptera	7	11	18				
Neuroptera					3		3
Orthoptera	1		1				
Thysanoptera	4	1	5		1	1	2
Totals	100	17	117	24	92	19	135

[1] CBC = classical biological control.

and staff of the newly formed Cawthron Institute, respectively. Homoptera established at a rate of *ca* four species per decade for the one hundred years prior to 1960, since when the rate appears to have steadily declined. Many Homoptera are relatively sessile and probably entered New Zealand on plant material, so the decline since 1960 may be due to ever-improving plant quarantine procedures.

Despite the seemingly sizeable list of pests, New Zealand fruit growers should consider themselves fortunate that there are some critical absences. Many pests that would be devastating to our export industries have never established. They include several species of fruit flies (Dipt., Tephritidae), psyllids (Hom., Psyllidae), leaf and planthoppers (Hom.) and tortricid leafrollers.

However, every new species that does arrive adds to the pest load that orchardists must manage in order to provide marketable export fruit, and even minor pests in their country of origin frequently prove to be major pests in a new country. Although New Zealand's extreme geographical isolation has limited pest establishment in the past, the isolation barrier is now dramatically lower. Transcontinental trade and tourism, by air and sea, and a flourishing international yachting community, all increase the chances of new pest establishment. The recent eradication in Auckland of Mediterranean fruit fly (*Ceratitis capitata* (Weidemann); Dipt., Tephritidae) but establishment of other insect pests (e.g. ash whitefly *Siphoninus phillyreae* (Haliday) (Hom., Aleyrodidae), and willow sawfly *Nematus oligospilus* Förster (Hym., Tenthredinidae)) have shown how such concerns are justified.

Historical establishment of deliberately imported natural enemies

Nine predators and 15 parasitoids have been deliberately introduced and established since 1888 (Tables 1 & 3, Figure 1). Only six pest species (woolly apple aphid, pear leafcurling midge *Dasyneura pyri* Bouché (Dipt., Cecidomyiidae), greenhouse whitefly *Trialeurodes vaporariorum* (Westwood) (Hom., Aleyrodidae), codling moth, cherryslug *Caliroa cerasi* (L.) (Hym., Tenthredinidae) and green vegetable bug *Nezara viridula* (L.) (Het., Pentatomidae)) were individually selected for control by sometimes monophagous natural enemies. Other pests were selected as homogeneous groups (e.g. tetranychid mites, aphids, soft scale insects, armoured scale insects, mealybugs and leafrollers) for which oligophagous parasitoids and predators or, in the early years of classical biocontrol, polyphagous predators were introduced (see Cameron *et al*., 1989 for full details).

The classical biocontrol programmes fall into four periods.

(**a**) 1888–1906: predators and parasitoids for Homoptera and codling moth. Introductions were largely instigated by an orchardist at Paeroa, Mr R. A. Wight, (the "father of economic entomology" in New Zealand (Miller, 1963)), who was instrumental in developing strong linkages between New Zealand, Australian and Californian biological control practitioners during this period.

(**b**) 1920–1937: predators and parasitoids for Homoptera and codling moth. Biological control was given high priority by both the Cawthron Institute (founded in 1921) and the Department of Agriculture. Biocontrol projects after 1937 continued at the Entomology Research Station at Nelson, but with the focus on pests of pasture, rather than of fruit crops.

(**c**) 1967–1978: predators and parasitoids for leafrollers and mites were introduced as part of new IPM programmes, and a resurgence of research into biological control in fruit crops. Introductions were made by Entomology Division, Department of Scientific and Industrial Research (DSIR) in Nelson, Auckland and Christchurch.

(**d**) 1987 – present: current programmes against Diaspididae, Pseudococcidae and other pests.

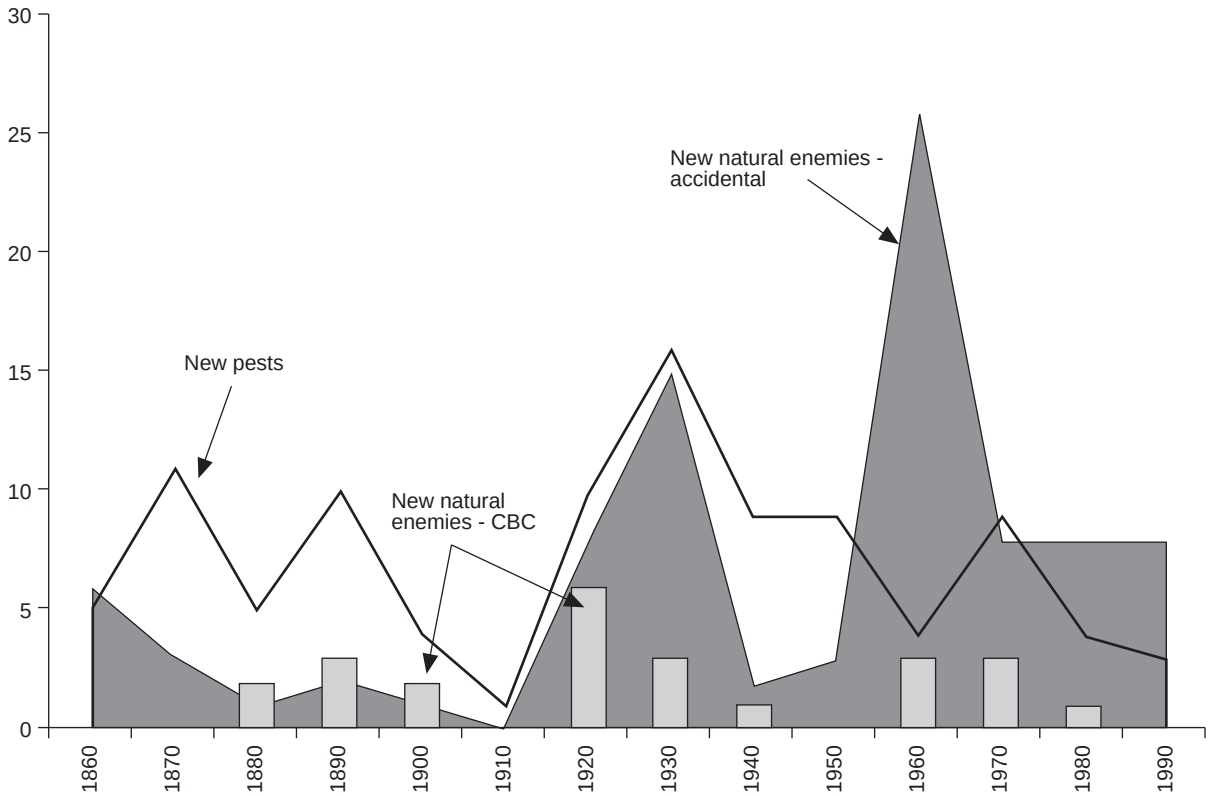

Figure 1. Arrival in New Zealand of exotic arthropod pests of fruit crops and their natural enemies by decade: 1860–1997.
CBC = classical biological control.

Table 2. Pest arthropods of fruit crops in New Zealand, 1860–1997.

Name	Family	First record	Reference
Cydia pomonella (L.)	Tortricidae	1860	Cameron *et al*. 1989
Eriosoma lanigerum (Hausmann)	Pemphigidae	1862	Spiller & Wise 1982
Otiorhynchus sulcatus (F.)	Curculionidae	1866	Kuschel 1972
Glaucias amyoti (Dallas)	Pentatomidae	1867	Wise 1977
Synanthedon tipuliformis (Clerck)	Sesiidae	1869	Spiller & Wise 1982
Caliroa cerasi (L.)	Tenthredinidae	1870	Spiller & Wise 1982
Tetranychus urticae Koch	Tetranychidae	1873	Cameron *et al*. 1989
Icerya purchasi Maskell	Margarodidae	1877	Cameron *et al*. 1989
Pseudococcus calceolariae (Maskell)	Pseudococcidae	1878	Cox 1987
Scolypopa australis (Walker)	Ricaniidae	1878	Cameron *et al*. 1989
Aonidiella aurantii (Maskell)	Diaspididae	1879	Spiller & Wise 1982
Aspidiotus nerii Bouché	Diaspididae	1879	Spiller & Wise 1982
Aulacaspis rosae (Bouché)	Diaspididae	1879	Spiller & Wise 1982
Coccus hesperidum L.	Coccidae	1879	Spiller & Wise 1982
Hemiberlesia rapax (Comstock)	Diaspididae	1879	Spiller & Wise 1982
Lepidosaphes ulmi (L.)	Diaspididae	1879	Spiller & Wise 1982
Saisettia oleae (Olivier)	Coccidae	1884	Spiller & Wise 1982
Parthenolecanium corni (Bouché)	Coccidae	1885	Wise 1977
Saisettia coffeae (Walker)	Coccidae	1885	Spiller & Wise 1982
Viteus vitifoliae (Fitch)	Phylloxeridae	1885	Wight 1890
Trialeurodes vaporariorum (Westwood)	Aleyrodidae	1889	Cameron *et al*. 1989
Pseudococcus longispinus (Targioni-Tozzetti)	Pseudococcidae	1890	Cox 1987
Epiphyas postvittana (Walker)	Tortricidae	1891	Cameron *et al*. 1989
Parthenolecanium persicae (F.)	Coccidae	1892	Wise 1977
Phlyctinus callosus (Schönherr)	Curculionidae	1893	Kuschel 1972
Araecerus palmaris (Pascoe)	Anthribidae	1894	Holloway 1982
Myzus cerasi (F.)	Aphididae	1895	Spiller & Wise 1982
Eriophyes pyri (Pagenstecher)	Eriophyidae	1896	Manson 1984b
Lindingaspis rossi (Maskell)	Diaspididae	1897	Wise 1977
Caedicia simplex (Walker)	Tettigoniidae	1898	Wise 1977
Forficula auricularia L.	Forficulidae	1898	Cameron *et al*. 1989
Eriococcus coriaceus Maskell	Eriococcidae	1900	Wise 1977
Myzus persicae (Sulzer)	Aphididae	1905	Spiller & Wise 1982
Quadraspidiotus perniciosus (Comstock)	Diaspididae	1909	Spiller & Wise 1982
Siphanta acuta (Walker)	Flatidae	1909	Wise 1977
Dasineura pyri (Bouché)	Cecidomyiidae	1916	Cameron *et al*. 1989
Brachycaudus helichrysi (Kaltenbach)	Aphididae	1921	Wise 1977
Edwardsiana crataegi (Douglas)	Cicadellidae	1921	Knight 1976
Brachycaudus persicae (Passerini)	Aphididae	1922	Wise 1977
Eriosoma lanuginosum (Hartig)	Pemphigidae	1922	Wise 1977
Pseudococcus viburni (Signoret)	Pseudococcidae	1922	Ben-Dov & Matile-Ferrero 1995
Sephena cinerea Kirkaldy	Flatidae	1922	Wise 1977
Zygina dumbletoni Ghauri	Cicadellidae	1924	Knight 1976
Aphis spiraecola Patch	Aphididae	1927	Wise 1977
Colomerus vitis (Pagenstecher)	Eriophyidae	1927	Manson 1984a
Parlatoria pittospori Maskell	Diaspididae	1929	Spiller & Wise 1982
Aphis gossypii Glover	Aphididae	1930	Wise 1977
Haplothrips niger (Osborn)	Phlaeothripidae	1930	Mound & Walker 1986
Heliothrips haemorrhoidalis (Bouché)	Thripidae	1930	Mound & Walker 1982
Toxoptera citricida (Kirkaldy)	Aphididae	1930	Wise 1977
Aceria erineus (Nalepa)	Eriophyidae	1932	Manson 1984b
Ceroplastes sinensis Del Guercio	Coccidae	1933	Spiller & Wise 1982
Bryobia rubrioculus (Scheuten)	Tetranychidae	1934	Cottier 1934
Chaetosiphon fragaefolii Cockerell	Aphididae	1934	Spiller & Wise 1982
Frankliniella occidentalis Pergande	Thripidae	1934	Mound & Walker 1982
Panonychus ulmi (Koch)	Tetranychidae	1934	Cottier 1934
Eutorna phaulocosma Meyrick	Oecophoridae	1936	Charles *et al*. 1987
Otiorhynchus ovatus (L.)	Curculionidae	1936	Kuschel 1972
Priophorus morio (Lepeletier)	Tenthredinidae	1936	Valentine & Walker 1991
Heteronychus arator (F.)	Scarabaeidae	1937	Helson 1974
Panonychus citri (McGregor)	Tetranychidae	1937	Lamb 1952
Planococcus mali Ezzat & McConnell	Pseudococcidae	1937	Cox 1987
Pantomorus cervinus (Boheman)	Curculionidae	1940	Kuschel 1972
Ceroplastes destructor Newstead	Coccidae	1940	Spiller & Wise 1982
Phalaenoides glycine Lewin	Noctuidae	1940	Spiller & Wise 1982
Pseudococcus similans Lindinger	Pseudococcidae	1942	NZAC
Nezara viridula (L.)	Pentatomidae	1944	Cameron *et al*. 1989

Continued

Table 2. *Continued*

Name	Family	First record	Reference
Cecidophyopsis ribis (Westwood)	Eriophyidae	1945	Manson 1984a
Vespula germanica (F.)	Vespidae	1945	Cameron *et al.* 1989
Acalitus essigi (Hassan)	Eriophyidae	1948	Manson 1984b
Ribautiana tenerrima (Herrich-Schäffer)	Cicadellidae	1949	Knight 1976
Aculus fockeui Nalepa & Trouessart	Eriophyidae	1950	Manson 1984a
Dasineura mali (Kieffer)	Cecidomyiidae	1950	Cameron *et al.* 1989
Megalurothrips kellyanus (Bagnall)	Thripidae	1950	Mound & Walker 1982
Aphis idaei van der Goot	Aphididae	1952	Spiller & Wise 1982
Quadraspidiotus ostreaeformis (Curtis)	Diaspididae	1952	Spiller & Wise 1982
Aceria sheldoni (Ewing)	Eriophyidae	1953	Manson 1984b
Eotetranychus sexmaculatus (Riley)	Tetranychidae	1953	Lamb 1953
Toxoptera aurantii (Boyer de Fonscolombe)	Aphididae	1953	Spiller & Wise 1982
Edwardsiana lethierryi Edwards	Cicadellidae	1957	Knight 1976
Philaenus spumarius (L.)	Cercopidae	1960	Scott 1984
Phytoptus avellanae Nalepa	Phytoptidae	1960	Manson 1984a
Phenacoccus graminicola Leonardi	Pseudococcidae	1962	Cox 1987
Eupteryx melissae Curtis	Cicadellidae	1965	Knight 1976
Phytonemus pallidus (Banks)	Tarsonemidae	1970	Manson 1983
Polyphagotarsonemus latus (Banks)	Tarsonemidae	1971	Spain & Luxton 1971
Acalitus orthomerus (Keifer)	Eriophyidae	1972	Manson 1984b
Phyllocoptruta oleivora (Ashmead)	Eriophyidae	1975	Manson 1984a
Aculus schlechtendali (Nalepa)	Eriophyidae	1976	Manson 1984a
Grapholita molesta (Busck)	Tortricidae	1976	Cameron *et al.* 1989
Diptacus gigantorhynchus (Nalepa)	Diptilomiopidae	1976	Manson 1984a
Prays nephelomima Meyrick	Yponomeutidae	1976	Dugdale 1988
Hemiberlesia lataniae (Signoret)	Diaspididae	1977	Cameron *et al.* 1989
Tarsonemus waitei Banks	Tarsonemidae	1980	Manson 1983
Calepitrimerus vitis Keifer	Eriophyidae	1982	Manson 1984a
Vespula vulgaris (L.)	Vespidae	1983	Cameron *et al.* 1989
Aceria diospyri Keifer	Eriophyidae	1987	Manson 1989
Bemisia tabaci (Gennadius)	Aleyrodidae	1991	Martin 1991
Siphoninus phillyreae (Haliday)	Aleyrodidae	1995	Matthews 1995
Nematus oligospilus Förster	Tenthredinidae	1997	Berry 1997a
Amphisalta sp.	Cicadidae	Native	
Capua semiferana Walker	Tortricidae	Native	
Cnephasia jactatana (Walker)	Tortricidae	Native	
Costelytra zealandica White	Scarabaeidae	Native	
Ctenopseustis herana (Felder & Rogenhofer)	Tortricidae	Native	
Ctenopseustis obliquana (Walker)	Tortricidae	Native	
Eucolaspis brunnea (F.)	Chrysomelidae	Native	
Graphania mutans (Walker)	Noctuidae	Native	
Harmologa oblongana Walker	Tortricidae	Native	
Heterocrossa rubophaga Dugdale	Carposinidae	Native	
Nysius huttoni White	Lygaeidae	Native	
Oemona hirta (F.)	Cerambycidae	Native	
Planotortrix excessana (Walker)	Tortricidae	Native	
Planotortrix octo Dugdale	Tortricidae	Native	
Pyrgotis plagiatana Walker	Tortricidae	Native	
Stathmopoda horticola Dugdale	Oecophoridae	Native	
Thrips obscuratus (J.C. Crawford)	Thripidae	Native	

NZAC denotes a labelled specimen in the New Zealand Arthropod Collection, Landcare Research, Auckland.

The introductions of natural enemies against fruit crop (and other agricultural) pests, together with some of the prevailing socio-economic views of the times, have been analysed in detail by Cameron *et al.* (1993).

Historical establishment of accidentally imported natural enemies

Ninety-two species of exotic natural enemies have established accidentally since 1850 (Tables 1 & 3, Figure 1), arriving either through commerce or other human activity, or by natural dispersal or migration. They, like their exotic hosts, have accumulated at a long-term average rate of *ca* seven species per decade.

The world-wide interest in predators during the last two decades of the nineteenth century extended to New Zealand where 14 of the 16 natural enemies recorded before 1900 (Figure 1) were predators. The two recorded parasitoids, *Diplazon laetatorius* (F.) (Hym., Ichneumonidae) and *Anacharis zealandica* Ashmead (Hym., Figitidae), attacked predators, so were presumably not highly regarded. As the biology, taxonomy and appreciation of the value of parasitoids became better known, so were they found more frequently. A further 29 natural enemies established accidentally between 1900 and 1960. Nineteen of these were parasitoids. However, predators continue to arrive, with ten new species recorded since 1970 (compared with 15 new parasitoids).

Most of the species recorded for the first time during the

1960s reflect the impetus given to IPM in fruit crops by Entomology Division, DSIR in Nelson during that period. In particular, Mr E. W. Valentine and Dr E. Collyer surveyed and recorded for the first time many of the hymenopteran parasitoids (18 species) of homopteran pests, and phytoseiid mites (four species) and other predators (one species) of phytophagous mite, respectively, the presence of which in most orchards are today taken for granted. Many of the mite predators – which, until the 1960s, had been hardly studied at all – may have been in New Zealand for some time. However, the parasitoid fauna of Homoptera were probably more recent additions to the New Zealand fauna. They had been quite intensively studied from 1920–40 (Gourlay, 1930), and it is unlikely that many of the quite distinctive species recorded by Valentine (1963, 1967) would not have been found then had they been present. Furthermore, some species that Valentine recorded (*loc. cit.*) in the early 1960s from only one district (often close to a shipping port such as Auckland or Tauranga) are now widespread and common. It appears reasonable to conclude that Valentine's records in the 1960s documented a gradual accumulation of species since the 1930s.

Since 1970, accidentally introduced natural enemies (n=24) have established more frequently than pests (n=16). Pests in fruit crops have been intensively studied since the 1960s, and there has been unprecedented taxonomic study of New Zealand's Hymenoptera since the mid-1980s. So it seems likely that most of the recent records reflect fairly accurately the date of arrival of those species, rather than just the first records of long-established species. Although there are more extensive data on host-associations from commercial fruit crops than from native habitats, it is clear that most native taxa are attacked solely by native hymenopteran parasitoids, and most exotic taxa are attacked solely by exotic parasitoids (e.g. Noyes, 1988; Noyes & Valentine, 1989; Berry, 1995).

The future role of natural enemies in fruit crop pest control

Implementation of IFP will see a rapid reduction in the use of broad-spectrum pesticides, leading to increased numbers and species of natural enemies in fruit crops (e.g. Wearing, 1997). Such measures do not, however, presage a return to the crop environments that existed before 1945, or even before 1900. Thirty-eight new pests and 63 new natural enemies have been recognized in fruit crops in New Zealand since 1940. Crops, varieties, quality standards, management techniques and whole pest complexes have changed almost beyond recognition during the course of this century. The current tritrophic ecological dynamics in fruit crops are unique, and the pest control strategies of the future will stem from current research, in the current environment.

Fruit crops under IFP may become freer of broad-spectrum pesticides than at any time since the mid-nineteenth century, and biological control is set to play an increasing role in pest management. The advances in hymenopteran taxonomy and improved accessibility to taxonomic databases over the past decade have coincided with the decline in broad-spectrum pesticide use, and have resulted in a new appreciation of the potential practical value of natural enemies in mainstream, commercial fruit crop production. The value of accidentally established natural enemies cannot be overlooked. There are four times as many accidentally established species as deliberately introduced (91:24), and they are now a key component of many natural enemy guilds. In this context, it is very significant that natural enemies of fruit crop pests continue to arrive accidentally in New Zealand at a far greater rate than introductions through classical biological control programmes. Some new species will be effectively oligophagous – some mealybug parasitoids, for example, as already discussed by Charles (1993) – and add to existing guilds. Others may arrive at more or less the same time as their host. This is exemplified by the case of the ash whitefly, *Siphoninus phillyreae*, which was first found in New Zealand in May 1995. *Encarsia inaron* (Walker) (Hym., Aphelinidae), a putatively host-specific parasitoid of *S. phillyreae*, was imported into quarantine (Charles & Froud, 1996) but was then reared from ash whitefly in Auckland in April 1997 before host-testing procedures had been completed, and before any had been released. It seems likely that *E. inaron* arrived in New Zealand together with *S. phillyreae*.

For the future, it will be important to determine the key natural enemies of the pest complexes in different fruit crops, their geographical distributions through the country, and to quantify their impacts on pests in increasingly pesticide-free (or at least -benign) environments. By extrapolation from the current databases, it can be predicted that, for the most part, existing and new exotic pests will be attacked by existing and new exotic natural enemies, and native pests will be attacked by native natural enemies. It is improbable that classical biological control of a native insect pest will ever again be seriously considered, so native natural enemies are a critical resource, and their management is likely to become a key factor for successful native pest control. Notwithstanding the example of the ash whitefly cited above, new pests may well *not* be attacked by any existing or accidentally imported natural enemies, so that classical biological control remains a valuable option for pest control.

Conclusions

Although New Zealand has relatively few horticultural pests compared with other countries, and is currently free of some of the most damaging species, there is no room for complacency. History tells us that New Zealand will continue to be invaded by a steady stream of uninvited new pests. Well-funded campaigns to eradicate 'critical' pests such as fruit flies remain essential, but the pest load of 'non-critical' pests continues to increase at about seven species per decade. It is very difficult to determine whether, or when, the combination of all these pests, not considered individually to be as damaging as fruit flies, will also become a constraint to fruit production or export. Controlling the ever-increasing pest load is a daunting task for orchardists, who regard biological control as an essential tool for reducing insecticide use, as demanded by consumers world-wide. They regard exotic natural enemies as beneficial because they regulate pests and increase the biodiversity of the horticultural ecosystem – both being vital components of IFP. For some pests there is undoubtedly scope to improve biological control by better management of the existing natural enemy guilds. This may become easier with the gradual accumulation of natural enemies establishing accidentally. For others, the most effective natural enemies are simply not present in New Zealand, and may have to be imported.

Biological control has been recognized as a potentially valuable pest control strategy by New Zealand orchardists for more than 130 years. Throughout that period the perceived relative value of biocontrol *vs* insecticides has waxed and waned according to current interactions between the economic fortunes of the industry, new technological developments in pest control, and

Table 3. Natural enemies of fruit crop arthropod pests in New Zealand, 1860–1997.

Name	Family	First record	Origin	Type	Reference
Typhlodromus pyri Scheuten	Phytoseiidae	1850	A	Pr	Collyer 1982
Drepanacra binocula (Newman)	Hemerobiidae	1863	A	Pr	Wise 1977
Oechalia schellenbergii (Guérin-Méneville)	Pentatomidae	1866	A	Pr	Wise 1977
Cermatulus nasalis (Westwood)	Pentatomidae	1867	A	Pr	Wise 1977
Glaucias amyoti (Dallas)	Pentatomidae	1867	A	Pr	Wise 1977
Micromus tasmaniae (Walker)	Hemerobiidae	1869	A	Pr	Wise 1977
Rhyzobius fagus (Broun)	Coccinellidae	1870	A	Pr	Kuschel 1990
Adalia bipunctata (L.)	Coccinellidae	1872	A	Pr	Cameron *et al*. 1989
Diplazon laetatorius (F.)	Ichneumonidae	1878	A	Pa	Valentine & Walker 1991
Cryptochetum iceryae (Williston)	Cryptochetidae	1888	CB	Pa	Cameron *et al*. 1989
Rodolia cardinalis (Mulsant)	Coccinellidae	1889	A	Pr	Cameron *et al*. 1989
Rhyzobius forestieri (Mulsant)	Coccinellidae	1889	CB	Pr	Kuschel 1990
Harmonia conformis (Boisduval)	Coccinellidae	1896	CB	Pr	Cameron *et al*. 1989
Polistes humilis (F.)	Vespidae	1896	A	Pr	Valentine 1967
Cryptolaemus montrouzieri Mulsant	Coccinellidae	1897	CB	Pr	Cameron *et al*. 1989
Forficula auricularia L.	Forficulidae	1898	A	Pr	Cameron *et al*. 1989
Halmus chalybeus (Boisduval)	Coccinellidae	1899	CB	Pr	Kuschel 1990
Rhyzobius ventralis (Erichson)	Coccinellidae	1900	CB	Pr	Kuschel 1990
Anacharis zealandica Ashmead	Figitidae	1900	A	Pa	Valentine & Walker 1991
Liotryphon caudatus (Ratzeburg)	Ichneumonidae	1906	CB	Pa	Cameron *et al*. 1989
Aphelinus mali (Haldeman)	Aphelinidae	1921	CB	Pa	Cameron *et al*. 1989
Coccidoctonus dubius (Girault)	Encyrtidae	1921	CB	Pa	Noyes 1988
Microterys flavus (Howard)	Encyrtidae	1921	CB	Pa	Noyes 1988
Goniozus sp.	Bethylidae	1922	A	Pa	Cameron *et al*. 1989
Metaphycus lounsburyi (Howard)	Encyrtidae	1922	CB	Pa	Noyes 1988
Gelis cinctus (L.)	Ichneumonidae	1922	A	Pa	Russell 1987
Aphanomerus pusillus Perkins	Platygastridae	1922	A	Pa	Gourlay 1930
Encarsia citrina (Craw)	Aphelinidae	1923	A	Pa	Cameron *et al*. 1989
Lathrolestes luteolator (Gravenhorst)	Ichneumonidae	1923	CB	Pa	Cameron *et al*. 1989
Tetracnemoidea brevicornis (Girault)	Encyrtidae	1924	A	Pa	NZAC
Platygaster demades Walker	Platygastridae	1925	CB	Pa	Cameron *et al*. 1989
Nabis kinbergii Reuter	Nabidae	1926	A	Pr	Wise 1977
Cryptoscenea australiensis (Enderlein)	Coniopterygidae	1927	A	Pr	Kimmins & Wise 1962
Encyrtus infelix (Embleton)	Encyrtidae	1928	A	Pa	Noyes 1988
Aphelinus gossypii Timberlake	Aphelinidae	1930	A	Pa	Valentine 1963
Diaeretiella rapae (M'Intosh)	Braconidae	1930	A	Pa	Cameron *et al*. 1989
Dinocampus coccinellae (Schrank)	Braconidae	1930	A	Pa	Valentine & Walker 1991
Metaphycus aurantiacus Annecke & Mynhardt	Encyrtidae	1930	A	Pa	Noyes 1988
Sejanus albisignata (Knight)	Miridae	1930	A	Pr	Dumbleton 1938
Zetzellia longisetus (Gonzalez)	Stigmaeidae	1931	A	Pr	Collyer 1964b
Ascogaster quadridentatus Wesmael	Braconidae	1931	CB	Pa	Cameron *et al*. 1989
Stethorus histrio Chazeau	Coccinellidae	1932	A	Pr	Houston 1990
Anagyrus ustulatus Haliday	Mymaridae	1932	A	Pa	Cameron *et al*. 1989
Coccophagus gurneyi Compère	Aphelinidae	1933	CB	Pa	Cameron *et al*. 1989
Encarsia formosa Gahan	Aphelinidae	1933	CB	Pa	Cameron *et al*. 1989
Feltiella acarisuga (Vallot)	Cecidomyiidae	1934	A	Pr	Gagne 1995
Amblyseius largoensis (Muma)	Phytoseiidae	1934	A	Pr	Collyer 1964b
Agistemus longisetus (Gonzalez-Rodriguez)	Stigmaeidae	1934	A	Pr	Collyer 1964b
Aphytis mytilaspidis (Le Baron)	Aphelinidae	1935	A	Pa	Valentine 1967
Aphytis diaspidis (Howard)	Aphelinidae	1935	A	Pa	Valentine 1967
Dolichogenidea tasmanica (Cameron)	Braconidae	1935	A	Pa	Cameron *et al*. 1989
Bdellodes lapidaria (Kramer)	Bdellidae	1937	A	Pr	NZAC
Inostemma boscii (Jurine)	Platygastridae	1938	A	Pa	Cameron *et al*. 1989
Scymnus loewii Mulsant	Coccinellidae	1941	A	Pr	Kuschel 1990
Phalangium opilio L.	Phalangiidae	1947	A	Pr	Forster 1947
Trissolcus basalis (Wollaston)	Scelionidae	1949	CB	Pa	Cameron *et al*. 1989
Metaphycus timberlakei (Isii)	Encyrtidae	1951	A	Pa	NZAC
Encarsia perniciosi (Tower)	Aphelinidae	1959	A	Pa	Valentine & Walker 1991
Parectromoides varipes (Girault)	Encyrtidae	1959	A	Pa	Noyes 1988
Epitetracnemus zetterstedtii (Westwood)	Encyrtidae	1960	A	Pa	NZAC
Zaomma lambinus (Walker)	Encyrtidae	1960	A	Pa	NZAC
Moranila californica (Howard)	Pteromalidae	1960	A	Pa	Berry 1995
Signiphora merceti (Malenotti)	Signiphoridae	1960	A	Pa	NZAC
Centrodora scolypopae Valentine	Aphelinidae	1961	A	Pa	Valentine 1966
Tetracnemoidea peregrina (Compère)	Encyrtidae	1961	A	Pa	NZAC
Aphytis chilensis Howard	Aphelinidae	1962	A	Pa	Valentine 1963

Continued

Table 3. *Continued*

Name	Family	First record	Origin	Type	Reference
Aphytis chrysomphali (Mercet)	Aphelinidae	1962	A	Pa	Valentine 1963
Aphytis ignotus Compère	Aphelinidae	1962	A	Pa	Valentine 1963
Coccophagus ochraceus Howard	Aphelinidae	1962	A	Pa	Valentine 1963
Coccophagus scutellaris (Dalman)	Aphelinidae	1962	A	Pa	Valentine 1963
Euxanthellus philippiae Silvestri	Aphelinidae	1962	A	Pa	Valentine 1963
Adelencyrtus aulacaspidis (Brèthes)	Encyrtidae	1962	A	Pa	NZAC
Arrhenophagus chionaspidis Aurivillius	Encyrtidae	1962	A	Pa	Noyes 1988
Gyranusoidea advena Beardsley	Encyrtidae	1962	A	Pa	Noyes 1988
Tetracnemoidea sydneyensis (Timberlake)	Encyrtidae	1962	A	Pa	Noyes 1988
Signiphora flavella Girault	Signiphoridae	1962	A	Pa	Valentine 1963
Ophelosia keatsi Girault	Pteromalidae	1963	A	PP	Berry 1995
Anystis baccarum (L.)	Anystidae	1964	A	Pr	Cameron *et al*. 1989
Neoseiulus cucumeris (Oudemans)	Phytoseiidae	1964	A	Pr	Collyer 1982
Amblyseius limonicus Garman & McGregor	Phytoseiidae	1964	A	Pr	Collyer 1982
Neoseiulus longispinosus (Evans)	Phytoseiidae	1964	A	Pr	Collyer 1982
Anthoseius caudiglans (Schuster)	Phytoseiidae	1964	A	Pr	Collyer 1982
Gelis tenellus (Say)	Ichneumonidae	1965	A	Pa	Russell 1987
Ophelosia bifasciata Girault	Pteromalidae	1966	A	PP	Berry 1995
Ceranisus menes (Walker)	Eulophidae	1967	A	Pa	Valentine 1967
Glabridorsum stokesii (Cameron)	Ichneumonidae	1967	CB	Pa	Cameron *et al*. 1989
Xanthopimpla rhopaloceros Krieger	Ichneumonidae	1967	CB	Pa	Cameron *et al*. 1989
Trigonospila brevifacies (Hardy)	Tachinidae	1967	CB	Pa	Cameron *et al*. 1989
Poecilopachys bispinosa Griffith & Pidgeon	Araneidae	1972	A	Pr	NZAC
Amblyseius fallacis (Garman)	Phytoseiidae	1973	CB	Pr	Cameron *et al*. 1989
Midus pygmaeus Blackburn	Coccinellidae	1974	A	Pr	Kuschel 1990
Encarsia pergandiella Howard	Aphelinidae	1975	A	Pa	Cameron *et al*. 1989
Trichogrammatoidea bactrae Nagaraja	Trichogrammatidae	1975	A	Pa	Valentine & Walker 1991
Amblyseius occidentalis (Nesbitt)	Phytoseiidae	1976	CB	Pr	Cameron *et al*. 1989
Diadiplosis koebelei (Koebele)	Cecidomyiidae	1978	A	Pr	Charles 1985
Eusemion cornigerum (Walker)	Encyrtidae	1978	A	Pa	Noyes 1988
Phytoseiulus persimilis Athias-Henriot	Phytoseiidae	1978	CB	Pr	Cameron *et al*. 1989
Trichogramma funiculatum Carver	Trichogrammatidae	1978	A	Pa	Valentine & Walker 1991
Polistes chinensis (F.)	Vespidae	1979	A	Pr	Valentine & Walker 1991
Alamella mira Noyes	Encyrtidae	1981	A	Pa	Noyes 1988
Haplothrips kurdjumovi Karny	Phlaeothripidae	1982	A	Pr	Mound & Walker 1986
Ophelosia charlesi Berry	Pteromalidae	1985	A	PP	Berry 1995
Hemisarcoptes coccophagus Meyer	Hemisarcoptidae	1987	CB	Pr	Hill *et al*. 1993
Trichogrammatoidea sp.	Trichogrammatidae	1987	A	Pa	Noyes & Valentine 1989
Badumna longinquus (Simon)	Desidae	1988	A	Pr	Forster 1970
Ancistrocerus gazella (Panzer)	Eumenidae	1988	A	Pr	Berry 1989
Encarsia koebelei (Howard)	Aphelinidae	1989	A	Pa	Noyes & Valentine 1989
Aphidius similis Stary & Carver	Braconidae	1989	A	Pa	Valentine & Walker 1991
Meteorus cinctellus Nees	Braconidae	1991	A	Pa	Valentine & Walker 1991
Orius vicinus Ribaut	Anthocoridae	1992	A	Pr	Lariviere & Wearing 1994
Rhyzobius sp.	Coccinellidae	1992	A	Pr	Charles 1993
Anagyrus fusciventris (Girault)	Encyrtidae	1992	A	Pa	Charles 1993
Fidiobia ?citri (Nixon)	Platygastridae	1992	A	Pa	NZAC
Moranila comperei (Ashmead)	Pteromalidae	1994	A	Pa	Berry 1995
Meteorus pulchricornis (Wesmael)	Braconidae	1996	A	Pa	Berry 1997b
Encarsia inaron (Walker)	Aphelinidae	1997	A	Pa	NZAC
Aphanistes kayi Gauld	Ichneumonidae		Native	Pa	
Apterygothrips collyerae Mound & Walker	Phlaeothripidae		Native	Pr	
Coccophagoides sp.	Aphelinidae		Native	Pa	
Dolichogenidea carposinae (Wilkinson)	Braconidae		Native	Pa	
Episinus sp.	Theridiidae		Native	Pr	
Euceros coxalis Barron	Ichneumonidae		Native	Pa	
Glyptapanteles demeter Wilkinson	Braconidae		Native	Pa	
Melangyna novaezelandiae (Macquart)	Syrphidae		Native	Pr	
Melanostoma fasciatum (Macquart)	Syrphidae		Native	Pr	
Pales feredayi (Hutton)	Tachinidae		Native	Pa	
Pales funesta (Hutton)	Tachinidae		Native	Pa	
Rhyzobius sp.	Coccinellidae		Native	Pr	
Spilomena sp.	Sphecidae		Native	Pr	
Stethorus bifidus Kapur	Coccinellidae		Native	Pr	
Stethorus griseus Whitehead	Coccinellidae		Native	Pr	
Tetracnemoidea zelandica Noyes	Encyrtidae		Native	Pa	
Trichogramma sp.	Trichogrammatidae		Native	Pa	
Xanthocryptus novozealandicus (Dalla Torre)	Ichneumonidae		Native	Pa	
Zelaphycus aspidioti (Tachikawa & Valentine)	Encyrtidae		Native	Pa	

Pr = predator, Pa = parasitoid, and PP = both predator and parasitoid. A = accidental introduction, CB = classical biocontrol.
NZAC denotes a labelled specimen in the New Zealand Arthropod Collection, Landcare Research, Auckland.

political and social patronage of science. In the twenty-first century it seems possible that the use of natural enemies for pest control may achieve a more permanent status. Perhaps for the first time, there is both commercial and political acceptance that continued economic and scientific resources for the early discovery and identification of both pests and natural enemies are vital. There is a prolonged market-led demand for the removal of broad-spectrum insecticides and the development of environmentally stable pest control solutions, such as biological control. Finally, there is emerging a scientific framework of population and community ecology within which the inter-trophic interactions of a whole orchard can at least be defined, if not exactly predicted.

Perhaps paradoxically, biological control has, at the same time, been challenged as an appropriate pest management tool because of perceived negative side-effects on the environment – particularly that natural enemies move out of target crops and attack native fauna (e.g. Cameron *et al.*, 1993). In recent years some have argued that the detrimental effects of a classical biological control agent will always outweigh the benefits, and have called for a complete halt to any further deliberate introductions of natural enemies. The data summarized in this paper suggest that any risks posed by classical biological control activities cannot sensibly be viewed in isolation from the continuing, serendipitous arrival of pests and other exotic natural enemies. Although one strategy for biocontrol of fruit crop pests is to do nothing and await the arrival of appropriate natural enemies over time, surely a planned and informed programme is preferable? Biological control ecologists accept that they must improve their ability to quantify the risks posed by a planned introduction. They must equally reject the unscientific argument which, based on the assumption that it is impossible to predict how they will behave in a new environment, says that no natural enemy should ever again be deliberately introduced. The current scientific challenge is to describe the ecology behind the control of a pest by its natural enemies, and to improve the predictability of the various inter-trophic relationships that will arise when new species enter an ecosystem.

Several research programmes have begun, or are being planned, to investigate how the environmental impact of exotic natural enemies in New Zealand might better be predicted. For fruit crops, the exotic natural enemies that have established here over the past 150 years are a valuable research resource. Analyses of their *realized* impact on both exotic and native fauna over time and in different habitats, may well point to reliable, ecologically valid techniques for *predicting* impacts of future natural enemies, regardless of whether their arrival is contrived or accidental.

Additionally, any environmental risks from biological control agents must also be weighed against the positive side to fruit growing. Horticulture is an expanding, socially accepted and economically vital activity in New Zealand. IFP signals the introduction of sustainable management strategies, which aim to ensure that fruit crop growers maintain or enhance the quality of the land and environment they temporarily occupy. These strategies should surely be encouraged.

Finally, just as classical biological control introductions cannot be viewed in isolation from other natural enemy immigrants, the risks to the environment stemming from horticultural practices should not be viewed in isolation from other activities of a modern society. Although economically important, orchards comprise a relatively small (*ca* 40,000 ha) part of New Zealand's modified environments. Within this broader landscape, land and air modifications through urban and rural development, human recreation, forestry, and other accepted requirements of *Homo sapiens* are likely to have a far greater impact on the overall structure and health of native fauna and flora than horticultural use, including classical biological control.

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