CLASSICAL BIOLOGICAL CONTROL OF ARTHROPODS IN AUSTRALIA

D.F. WATERHOUSE
D.P.A. SANDS

CSIRO ENTOMOLOGY

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Cover: An ichneumonid parasitoid *Megarhyssa nortoni* ovipositing on a larva of sirex wood wasp, *Sirex noctilio.*

Foreword

WHEN THE CSIR Division of Economic Entomology, now Commonwealth Scientific and Industrial Research Organisation (CSIRO) Entomology, was established in 1928, classical biological control was given as one of its core activities. This was indicative of the emphasis to be placed on biological control in Australia for the foreseeable future and was logical when one considers the potential targets for this approach amongst the many exotic pests of the introduced plants on which Australia still depends almost entirely for its agricultural productivity. Biological control has continued as a mainstay of pest management to the present time, with an impressive number of successes over the years.

The first comprehensive review of biological control projects in Australia (which also included those in Papua New Guinea) was that of Wilson (1960). This covered attempts against 53 arthropod pests or groups of pests and 12 weeds. There followed coverage of the world scene by Clausen (1978a), which added brief accounts on Australian projects.

Worldwide projects on weeds have been regularly summarised in an abbreviated form by M.H. Julien (Julien and Griffiths 1999) but a comprehensive account of the entire range of arthropod projects in Australia up to the present time, now totalling 98 arthropod pests or groups of pests, has been sorely needed for some time. The authors are to be congratulated on their dedication and persistence in amassing the extensive and scattered information required for the task.

Congratulations are also due to the Australian Centre for International Agricultural Research (ACIAR), the publisher of this book. This project further extends our close collaboration on biological control activities in the oceanic Pacific and Southeast Asia. ACIAR has already published an impressive number of volumes relevant to the development of significant programs (Li Li-ying et al. 1997; Waterhouse 1993a,b, 1994, 1997, 1998; Waterhouse and Norris 1987, 1989; Waterhouse et al. 1999; Klein Koch and Waterhouse 2001; Morris and Waterhouse 2001). One spectacular success has been the effective control of a serious defoliator, the

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banana skipper in Papua New Guinea. This has, so far, halted its spread to Australia, with an extraordinarily high estimated benefit–cost ratio of 607:1. This is an excellent example of ACIAR's policy of taking pre-emptive action to help an overseas country and, at the same time, Australia, by dealing with a threat to Australian agriculture before it reaches our shores.

Classical biological control has the capacity to yield extensive and enduring returns in pest management, though success is not always guaranteed. In their brief overview, the authors estimate an overall success rate of about two-thirds for all projects. This in itself represents a remarkable return on the scientific investment made. I warmly commend this volume not only for the wealth of information it contains, but also as an invaluable record of what can and has been achieved by this approach and as an indication of the opportunities that still exist to extend and improve the approach further for Australia's benefit.

Jim Cullen
Chief, Division of Entomology
CSIRO, Canberra

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A Tribute

IN HIS retirement from 1981 to 2000, the late Dr Doug Waterhouse authored or co-authored 12 books on the biological control, distribution and importance of pests and weeds. These publications are of immense importance and relevance to the objectives of both CSIRO Entomology and ACIAR as they promote the economic, social and environmental benefits to be had with appropriate management of insects. His texts have drawn together relevant information available from as many sources as possible, enabling students and research workers to locate easily, most or all of the information on pests and weeds of Pacific and Southeast Asian countries. The books are essential for planning future biological control projects in the region.

This most recent book by Dr Waterhouse, *Classical Biological Control of Arthropods in Australia* co-authored with Dr Sands, is the last in the series on regional biological control programs. It covers the history until 1999, of arthropod biological control introductions into Australia, and updates information on biological control projects carried out since the publication by Wilson (1960). Entomologists, including the scientists affiliated with CSIRO Entomology, are deeply indebted to Dr Waterhouse for the contributions he has made in all the books published after his retirement. They will be referred to for years to come, guiding new initiatives and recording part of the history of safely and successfully controlling pests and weeds, by classical biological control in Australia and the neighbouring developing nations.

R.J. Clements
Director, ACIAR

Abstract

AN ACCOUNT is provided of attempts at biological control of arthropod pests in Australia. Ninety-eight pests or groups of pests have been involved, totalling some 150 species, most of which are exotic. Some 70 were targetted in specific projects.

The pests are listed alphabetically under Collembola (1), Hemiptera (56), Thysanoptera (1), Orthoptera (2), Coleoptera (9), Diptera (7), Lepidoptera (13), Hymenoptera (4), Acari (4) and Diplopoda (1).

In addition to a summary table of results, a short dossier on each pest species or group provides (a) a precis of the outcomes, together with basic data on biology and pest status, (b) information on native natural enemies and (c) an account of the attempt(s) at biological control and the biology of the most important natural enemies.

Without recent evaluations it is often not possible to assess accurately the level of successful control, but a general overview indicates that about 30 of the target pests are very well controlled and a further 20 are no longer important pests, indicating an overall success rate for target pests of about two-thirds. With the exception of the dung-breeding bush fly, native pests have not proved susceptible to classical biological control.

Acknowledgments

MANY COLLEAGUES within CSIRO Entomology, State Departments of Agriculture and universities have provided valuable information and comment, often providing more accurate and up-to-date accounts of the various projects than is available from publications. Although it is not possible to acknowledge all of the many individuals involved, very special thanks are due to Dr M. Carver for much unpublished information on the aphid pests listed. Mr D. Smith of the Queensland Department of Primary Industries (QDPI), Nambour, Queensland provided most valuable information on scales and mealybugs. Mr J. Feehan supplied unpublished information on the distribution and impact of dung beetles and this was supplemented by Drs M. Tyndale-Biscoe, T.J. Ridsdill-Smith and J.N. Mathiessen. Others in CSIRO Entomology include Drs G.H. Baker, J. Daly, P. Greenslade, B.H. Halliday, G.A. Macqueen, W. Milne, R.J. Milner, L.A. Mound, K.R. Norris, J.L. Readshaw, J.P. Spradbery, R.W. Sutherst and K.G. Wardhaugh.

Valuable inputs were also provided by

Queensland	G.K. Waite, QDPI Nambour; B.C.G. Scholtz and D.A.H. Murray, QDPI Toowoomba; Prof. R.A.I. Drew, Griffith University; J.F. Grimshaw and B.M. Waterhouse, Northern Australia Quarantine Strategy (NAQS) Mareeba; K.H. Halfpapp, QDPI, Mareeba; K.J. Chandler and Dr P.G. Allsopp, Bureau of Sugar Expermiment Stations
New South Wales	Dr B.J. Fletcher (retired CSIRO); Major S.P. Francis, Army Malaria Research Unit; J. McIntosh, Australian Museum

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Australian Capital Territory	Dr P. Ferrar, ACIAR; Dr G.V. Maynard, Australian Quarantine and Inspection Service (AQIS)
Victoria	Dr R.P. Field, National Museum; Dr T.R. New, La Trobe University
South Australia	Dr F.D. Morgan, formerly Waite Institute
Western Australia	A.C. Postle, NAQS, Broome; G.R. Strickland, Department of Agriculture
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We are most grateful for the valuable data processing inputs provided by Mrs Leanne Slarke and Mrs Bev Johnstone. To Dr Mary Webb, Mrs Kerry Highley and Mr Peter Lynch (ACIAR), we extend our thanks for invaluable editorial advice and help during the later stages of preparation of the text, tables and maps for the book.

It would not have been possible to undertake a major task such as this, when in retirement, without the encouragement, support and patience of Dawn and Susan, our wives, to whom very special appreciation and thanks are due.

Introduction

MANY INSECTS that are of little or no economic importance in their country of origin become important pests when they are introduced to another country without their own natural enemies. Classical biological control is the term used when some or all of these natural enemies are introduced and established in the new country. Areas of the world where much of today's agriculture is based on introduced crops (e.g. Australia, New Zealand, Hawaii and California) are notable for two facts. One is that a high proportion of their important arthropod pests are exotic; the other is that classical biological control has resulted in many important successes. Worldwide, biological control—either standing alone or as a component of integrated pest management—is attracting increasing interest, partly in order to reduce dependence upon pesticides. Much can be learnt from successes (and failures) with classical biological control projects around the world. A major aim of this publication is to provide ready access, in a single table, to a summary of information on the natural enemies that have been liberated for classical biological control of arthropods in Australia up to 2000, including (when available) their origin, year(s) of liberation, whether they have been established and with what effect. We have adopted, in the 'Effect' column of Table 1 page 29, a simple rating system where an introduced natural enemy has become established. The number of '+' symbols in this column is an indication either of (a) when known, the impact of the presence of the natural enemy on the pest population or (b) the resulting abundance of the natural enemy, when the relationship between its abundance and the pest population has not been established. In many cases the indication of effect is a very subjective one, since there has often been no adequate evaluation in recent years, if at all. It is, perhaps, also not surprising that some species have been introduced into quarantine but not liberated. Sometimes this has been due to the very low numbers of living natural enemies imported, to difficulties in breeding them on the target host, or a decision not to liberate because of real or apparent lack of specificity or effectiveness.

A further problem when considering the effectiveness of introductions is the very wide range of situations (agroecosystems) in which a pest may occur in a country as large and diverse as Australia. Introduced natural enemies are sometimes very highly effective in one of a set of microclimates or one group of crops, but far less effective in another set. An example of this is provided by the parasitoid *Trissolcus basalis* and the once very widespread green vegetable bug, *Nezara viridula*. The bug is now suppressed by the parasitoid in much of south-eastern New South Wales and Victoria to the extent that it has become an uncommon pest. However, in southern Queensland (particularly where soybeans are grown) and also in a strip of inland New South Wales, extending even into Victoria, it is still regarded as a serious pest. Thus biological control has undoubtedly been highly successful over a vast area, although the pest continues to be a problem elsewhere. It should be pointed out that, whatever the level of suppression brought about by natural enemies, it is highly likely that any contribution they can give to the suppression of pest numbers will be a useful contribution to the integrated management of the pest.

In addition to records in the main table (Table 1 page 29), a brief dossier is provided on each pest and Australian locations mentioned in the text are shown in Map 1 page 22. Only about one-third of the target pests were subjected to major, as contrasted with minor, biological control projects. Since a great deal more information is available on the major attempts than on the remaining targets, these pests are dealt with in considerably greater detail in the individual dossiers. The dossiers outline relevant aspects of biology and pest status and provide details of the attempt(s) at biological control and native natural enemies. It would not be feasible in a book of this size to deal exhaustively with all these aspects. However, key references are provided to facilitate access to the sometimes very extensive literature.

Eleven of the pests have already been dealt with, often in far greater depth, in dossiers published elsewhere (Waterhouse 1993a, 1998; Waterhouse and Norris 1987, 1989) and these have been drawn on extensively in the present accounts of these pests.

Australia's first involvement with classical biological control was when it served as a source of parasitoids and predators of insect pests (including the Australian cottony cushion scale, *Icerya purchasi*) that had become established in California and Hawaii. This occurred when A. Koebele visited Australia in 1888 and 1891. The natural enemies sent to California included the predaceous coccinellid beetles *Rodolia cardinalis*, *Rhyzobius ventralis* and *Cryptolaemus montrouzieri* and the parasitic flies *Cryptochetum iceryae* and C. *monophlebi*.

Information on early attempts at classical biological control of insects in Australia was assembled in a valuable review by Wilson (1960), but the names of many of the insects involved have since undergone taxonomic changes. The first record of an attempt at establishment of a biological control agent in Australia was of the coccinellid *Harmonia conformis* sent from New South Wales to Western Australia in 1896. However, it only later became established from Tasmanian adults in 1902, following fruitless liberations in intervening years from New South Wales and Tasmania. Although both South Australia and Tasmania, as well as Western Australia, introduced various coccinellids from other parts of Australia on several occasions before 1900, it was Western Australia that took the lead in relation to the introduction of exotic species when, in 1901, it appointed G. Compere as entomologist to its Department of Agriculture. His task was to introduce natural enemies of the main pests. He travelled widely around the world until 1910, sending back many parasitoids and predators. Wilson (1960) commented that many of these species were not identified and much of this early work was very poorly documented. Modern classical biological control should certainly not be carried out in this way.

The precise identity of a pest is of minor significance for chemical control, since very few insecticides are sufficiently selective for the exact identity to influence the situation. However, it is quite different for classical biological control. It is then highly desirable (a) that it is the target pest species that suffers by far the greatest adverse effect from the introduction of a natural enemy, (b) that even close relatives, and especially species less closely related to the pest, are not attacked and (c) if they are attacked, that the impact on their abundance is relatively minor.

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There have been many changes over the years in the nomenclature of the natural enemies referred to in this publication. Although these have usually not been indicated in the text, where the generally-accepted modern name is used, the older, sometimes more familiar name may be found in the arthropod index, referring to its modern counterpart. It is to be expected that further name changes will be made in the future. The name of the author of each valid species is given in the arthropod index.

It is necessary here to issue a word of caution in relation to the validity of the name changes that have been made because, in the majority of cases, it is only the published name of the natural enemy that has been changed. It has not been feasible to check the identity of the natural enemies against voucher specimens and it is possible that the published name has, on occasion, been wrongly applied to the species concerned. Valuable advice on taxonomic problems has been given by colleagues associated with the Australian National Insect Collection, Canberra: Hemiptera, Dr M. Carver; Hymenoptera, J.C. Cardale; Lepidoptera, E.D. Edwards; Diptera, Dr K.R. Norris; Coleoptera, T.A. Weir and Dr E.C. Zimmerman; and Acari, Dr B.H. Halliday.

Taxonomic treatment has generally followed that in *Insects of Australia* (1991). The present nomenclature has been based, inter alia, on the *Australian Standard List of Common Names* (Naumann 1993), the *Catalogue of the Chalcidoidea of the World on CD-ROM* (Noyes 1998) and the *CABI Arthropod Name Database on CD-ROM* (CABI 1995). The nomenclature of mites is based on Halliday (1998) and that of economic plants follows of Lazarides and Hince (1993).

The number of aphid pest species considered to be targets in Table 1 (page 29) cannot be defined easily. This is due to an early adopted practice of introducing polyphagous parasitoids for a particular target species (e.g. *Aphis craccivora*), but with the hope that they might also assist in the control of one or more non-target pest species (Carver 1989), by developing 'reservoirs' of parasitoids in non-target species nearby.

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With regard to aphid parasitoids (Table 2 page 107):

1. many of the effective parasitoids are polyphagous, although some are restricted to an aphid genus or to a particular habitat (e.g. to aphids on cereals);
2. polyphagous parasitoids have been intentionally introduced that will (or might) attack a range of pest species (Stary 1967b; Carver 1989). Any important pest species attacked by the parasitoid can, therefore, be regarded as a legitimate target of the introduction, and several have been included for this reason; and
3. in earlier years, aphid parasitoids introduced intentionally were often not adequately identified. Whether from this cause, or because they have arrived unaided, the origin and year of arrival of a number of exotic aphid parasitoids that have become established is undocumented. An incomplete picture would be presented if these species were excluded from being listed, so they appear with the symbol (U) for unknown time and method of arrival. At times, additional (often more host-specific) strains of these same species have been introduced to increase the range of pest aphids attacked.

In addition, a deliberate attempt was made to establish, on several non-target aphid pest species already present in Australia, parasitoid species that would be established and waiting should the highly damaging Russian wheat aphid, *Diuraphis noxia*, arrive in Australia (Hughes et al. 1994).

Thus, it was decided to record in Table 1 page 29 a number of pest species which were not primarily or intentionally targetted. These species are annotated throughout the book by the symbol †. Although it would not be reasonable to include such species in calculations of the success of biological control, the information presented is relevant to a consideration of the impact of parasitoids on non-target species.

It was also decided to include attempts to control several native pest species by the introduction of exotic natural enemies, although this procedure does not fit the strict definition of classical biological control. The native species involved are: the Queensland fruit fly, *Bactrocera tryoni*; the native budworm, *Helicoverpa punctigera*; several native mosquitoes; the pink sugarcane mealybug, *Saccharicoccus sacchari*; the wingless grasshopper, *Phaulacridium vittatum*; and the black field cricket, *Teleogryllus commodus*. Another species, the citrophilus mealybug, *Pseudococcus calceolariae*, is believed to be native to the Sydney region, where it is rare.

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When it appeared in inland areas of South Australia, Victoria and New South Wales, two parasitoids from the Sydney region were introduced to extend biological control of this mealybug to these regions.

Not all host records of exotic agents and natural enemies of exotic arthropods have been included in this book, particularly when the information was incomplete. For example, studies on exotic and native natural enemies of *Bemisia tabaci* biotype B are current (De Barro et al. 2000), but all are not yet completed or documented (P.J. De Barro, pers. comm.). Other records may have been overlooked. However, we hope that an opportunity will be found to add this additional information to a revised edition of this book.

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Map 1. Locations of places mentioned in the text

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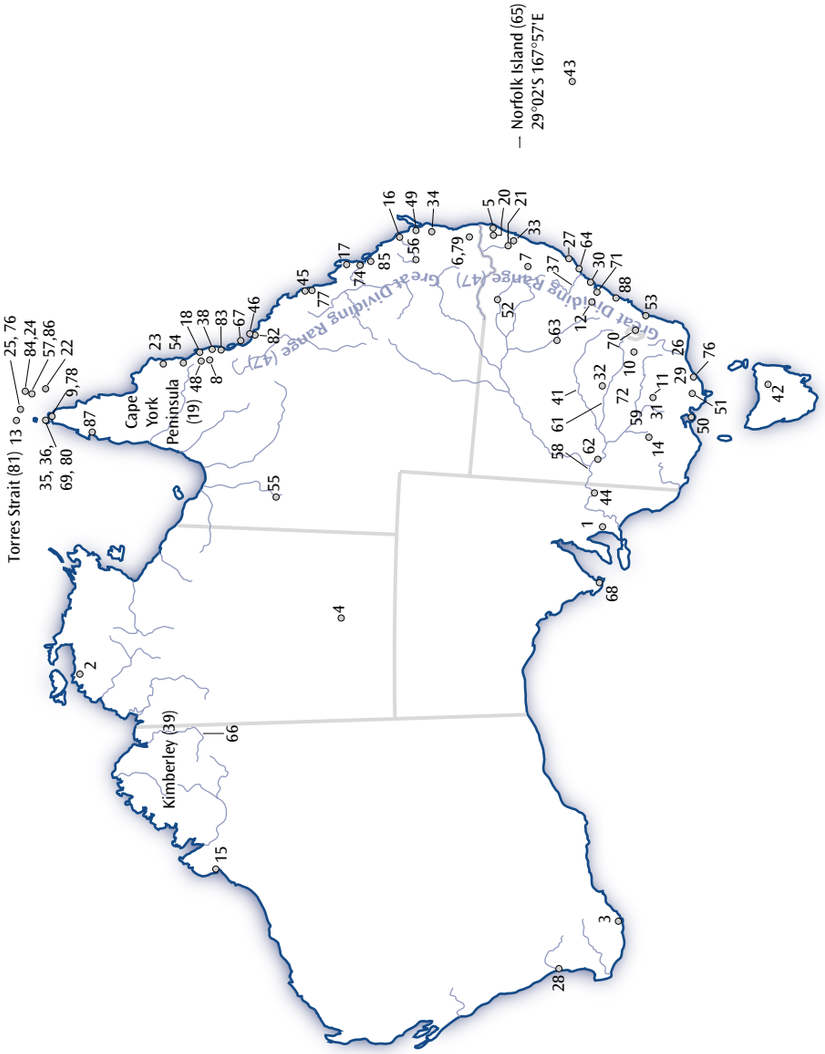
2	Adelaide River	46	Magnetic Island
3	Albany	47	Main Divide
4	Alice Springs	48	Mareeba
5	Alstonville	49	Maryborough
6	Applethorpe	50	Mornington Peninsula
7	Armidale	51	Moe
8	Atherton	52	Moree
9	Bamaga	53	Moruya
10	Batlow	54	Mossman
11	Benalla	55	Mount Isa
12	Bilpin	56	Mundubbera
13	Boigu Island	57	Murray Island
14	Bridgewater	58	Murray River
15	Broome	59	Murray Valley
16	Bundaberg	60	Murrumbidgee Irrigation Area
17	Byfield	61	Murrumbidgee River
18	Cairns	62	Nangiloc
19	Cape York Peninsula	63	Narromine
20	Casino	64	Newcastle
21	Clarence River	65	Norfolk Island
22	Coconut Island	66	Ord
23	Cooktown	67	Palm Island
24	Darnley Island	68	Port Lincoln
25	Dauan Island	69	Prince of Wales Island
26	East Gippsland	70	Queanbeyan
27	Elizabeth Beach	71	Richmond
28	Fremantle	72	Riverina
29	Gippsland	73	Riverland
30	Gosford	74	Rockhampton
31	Goulburn Valley	75	Sabai Island
32	Griffith	76	Sale
33	Grafton	77	Sarina
34	Gympie	78	Seisia
35	Hammond Island	79	Stanthorpe
36	Horn Island	80	Thursday Island
37	Hunter River	81	Torres Strait
38	Innisfail	82	Townsville
39	Kimberley	83	Tully
40	Kuranda	84	Yam Island
41	Lachlan River	85	Yarwun
42	Launceston	86	Yorke Island
43	Lord Howe Island	87	Weipa
44	Loxton	88	Wollongong


Norfolk Island (65)
29°02'S 167°57'E
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Great Dividing Range (47)
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Target arthropod pests and natural enemies released

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Table 1 provides a condensed record of the published attempts at biological control of 98 species or groups of species of Australian arthropod pests. Eight of these species or species groups are native to Australia and 18 have only been incidental targets, leaving 72 species that have been direct targets of classical biological control attempts. Further details are provided in the next section for each target pest.

The pests are arranged alphabetically under each order and the insect orders arranged from the most primitive to the most advanced. More detailed explanations and clarification of table inclusions are given in the *Introduction.*

Explanation of abbreviations and symbols used:

†	pest not primarily targetted
?	not certain
	A blank space indicates that information was either not available or not relevant.
Biological control agent	
(U)	unknown time and method of arrival; an exotic natural enemy which apparently arrived unaided
(#)	introduced primarily against another target pest species (specified at the end of each pest entry)
Host stage	**(H.S.)**
E	egg
L	larva (or nymph) (with 1, 2 etc. representing larval instar stages—in later tables)
PP	pre-pupa
P	pupa
A	adult

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Origin of agent/Liberation location

N	north or northern
S	south or southern
E	east or eastern
W	west or western
ACT	Australian Capital Territory
NSW	New South Wales
NT	Northern Territory
NZ	New Zealand
Qld	Queensland
SA	South Australia
Tas	Tasmania
UK	United Kingdom
USA	United States of America
Vic	Victoria
WA	Western Australia

Liberation date

Where liberations of a natural enemy have been made at various times spanning a sequence of years (e.g. 1963–72), this does not necessarily indicate that all the intervening years were involved.

Established (Est.)

+	successfully established
(+)	established, but only briefly
–	did not establish

Effect (on pest status in the absence of disruption by pesticides) (Eff.)

+++	effective biological control, sometimes only regionally
++	partially effective
+	little effect
–	no known effect

Table 1. Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**	**Est.**	**Eff.**	**Host(s)** **References**
1. *Sminthurus viridus* Collembola: Sminthuridae						legume pastures
ACARI						
BDELLIDAE						
Bdellodes lapidaria (U)	L,A	Europe	<1931		+	++ Womersley 1933
Neomolgus capillatus	L,A	Netherlands	1965	WA	–	Wallace 1967, 1974, 1981
		France, Morocco	1969	WA	+	++ Ireson 1984; Ireson & Paterson 1991
		France	1985–90	Tas	+	+++ Ireson & Paterson 1991
ANYSTIDAE						
Anystis wallacei	L,A	France	1965	WA	+	++ Waterhouse 1978; Wallace 1981
		WA	1976	Vic	–	Berg 1991
		WA	1991	Vic	–	Berg 1991
		WA	1993	Vic	+	Gardner & Gardner 1994
		WA	1993	Tas	+	Ireson & Webb 1995
2. *Acyrthosiphon kondoi* Hemiptera: Aphididae						lucerne, clover
HYMENOPTERA						
APHELINIDAE						
Aphelinus abdominalis (U)	L,A	Tas	1979	NSW	+	– Milne 1986a; M. Carver pers. comm. 1998
BRACONIDAE						
Aphidius ervi	L,A	Tas, Japan via USA	1977–79	NSW	+	+ Milne 1986a; M. Carver pers. comm.
		Japan via USA via NZ, Europe	1980–81	NSW	+	+++ Milne 1986a; W.M Milne pers. comm.
Aphidius pisivorus (#)	L,A	USA	1980	NSW	–	M. Carver pers. comm.

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Ephedrus plagiator	L,A	Japan via USA, NZ	1977–79	NSW	–		Milne 1986a
FUNGI							
Pandora kondoiensis (U)	L,A				+	+	Milner 1982; Milner et al. 1983
Pandora neoaphidis (U)	L,A			NSW	+	+	Milner 1978; Milner et al. 1980
(#) introduced against *Acrythosiphon pisum*							
3. *Acrythosiphon pisum* Hemiptera: Aphididae							lucerne, clover, pea
HYMENOPTERA							
APHELINIDAE							
Aphelinus abdominalis (U)	L,A	Tas	1979	NSW, Vic	+	–	Milne 1986a; M. Carver pers. comm. 1998
Aphelinus asychis (#)	L,A	France	1978	NSW, Vic	+	–	Carver 2000
		USA	1980	NSW, Vic	–		
		South Africa	1981	NSW, Vic	–		
BRACONIDAE							
Aphidius eadyi	L,A	via NZ	1980		–		Carver 1989
Aphidius ervi (#)	L,A	Japan via USA, Europe, Tas	1980–81	NSW, Vic	+	+++	Milne 1986a, 1999
Aphidius pisivorus	L,A	USA	1980	NSW, Vic	–		Carver 1989; M. Carver pers. comm.
Aphidius smithi	L,A	India via USA	1980–81	NSW, Vic	+	?	Carver 1989
Aphidius urticae group	L,A	? via NZ	1980	NSW, Vic	–		Carver 2000
FUNGI							
Pandora neoaphidis (U)	L,A	?	?	NSW	+	++	Milner et al. 1983
(#) introduced against *Acyrthosiphon kondoi*							

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
4. *Aleurodicus dispersus* Hemiptera: Aleyrodidae							polyphagous
HYMENOPTERA							
APHELINIDAE							
Encarsia sp.		Trinidad via Fiji	1992	Boigu Is.	+	+++	Lambkin 1992, 1996, 1998
		Trinidad via Fiji via Torres Strait	1995	Cape York	+	+++	Lambkin 1998
5. *Aonidiella aurantii* 6. *Aonidiella citrina* Hemiptera: Diaspididae							citrus, passionfruit
COLEOPTERA							
COCCINELLIDAE							
unidentified spp.		Spain	1903	WA	–		Compere 1903; Jenkins 1946; Wilson 1960
unidentified sp.		Israel	1904	WA	(+)	?	Jenkins 1946; Wilson 1960
unidentified sp.		China	1905	WA	+	?	Jenkins 1946
Chilocorus 3 spp.		India	1960–63	WA	–		Houston 1991
Chilocorus bipustulatus	L,A	Israel	1904	WA	+	?	Rosen & DeBach 1978
Chilocorus circumdatus (#)[a]	L,A	Hong Kong	1902	WA	–		Wilson 1960; Smith & Papacek 1993
		India	1960–63	NSW via WA	–		Smith et al. 1997a; Elder et al. 1998; Houston 1991
			<1990	Qld	+	++	Houston 1991
HYMENOPTERA							
unidentified sp.		China	1902	WA	?		Wilson 1960
unidentified sp.		Japan	1907	WA	?		Jenkins 1946; Wilson 1960
unidentified 2 spp.		Sri Lanka	1907	WA	–		Jenkins 1946; Wilson 1960

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	**Host(s)** References
unidentified 8 spp.		China	1907	WA	?		Jenkins 1946; Wilson 1960
unidentified 7 spp.		India	1907	WA	?		Wilson 1960
unidentified 6 spp.		Japan	1909	WA	–		Jenkins 1946
unidentified >6 spp.		Far East	1909	WA	?		Wilson 1960
APHELINIDAE							
Aphytis riyadhi		USA	?1979	SA	–		Furness et al 1983; Noyes 1998
Aphytis chrysomphali	L	China	1905	WA	+	++	Wilson 1960; Furness et al. 1983
		WA	1925–26	NSW	+		
		USA	1954	Vic	+		
Aphytis coheni		USA	?1979	SA	(+)		Furness et al. 1983
Aphytis lingnanensis	L	China	?1906	WA	+	+++	Wilson 1960; Furness et al. 1983
		WA	1925–26	NSW	+		
		USA	1962	Vic	–		
Aphytis lingnanensis (#)[b]	A	Hong Kong via Florida	1977		+	+	Smith et al. 1995
		Japan	1980		+	+	
		Thailand	1988		+	+	
Aphytis melinus	L,A	Pakistan	1961	Vic	+	+++	Smith 1978a; Furness et al. 1983
		Vic	1974	Qld	–		
Coccophagus lycimnia (#)[c]	L,A	USA	1907	WA	+	+	Wilson 1960; Noyes 1998
Encarsia citrina	L	China, USA	ca 1900	Vic	+	++	Smith et al. 1997a
		Israel	1970		+		Noyes 1998
Encarsia perniciosi	L	NSW	ca 1900	NSW, Vic, SA	+	++	McLaren 1971; Furness et al. 1983; Smith et al 1997a
		Israel via USA	1970–73		+		

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
ENCYRTIDAE							
Comperiella bifasciata (*A. citrina* biotype)	L,A	Japan	1909	WA	+	+++	Brewer 1971
Comperiella bifasciata (*A. aurantii* biotype)	L,A	China via USA	1943–44	all States	+	+++	Jenkins 1946; Wilson 1960; Rosen & DeBach 1978; Furness et al. 1983
			1947–49	Qld, Vic, NSW			
Habrolepsis rouxi	L,A	USA	?1980	SA, Vic	–		Furness et al. 1983
EULOPHIDAE							
Pteroptrix chinensis	L	China	?1907	?	+	+	Wilson 1960
			1983	NSW			
(#) introduced against [a]*Comstockaspis perniciosus*; [b]*Unaspis citri*; [c]*Coccus hesperidum*							
7. *Aonidiella orientalis* Hemiptera: Diaspididae							pawpaw
COLEOPTERA							
COCCINELLIDAE							
Chilocorus circumdatus (#)[a]	all	Hong Kong	1902	WA	–		Wilson 1960; Smith & Papacek 1993
		India	1960–63	NSW via WA	–		Smith et al. 1997a
				Qld			Elder et al. 1998
		unknown	<1990		+	+	Houston 1991
HYMENOPTERA							
APHELINIDAE							
Aphytis chrysomphali (#)[b]	L	China	1905	WA	+	+	Furness et al. 1983; Elder et al. 1998
		WA	1925–26	NSW	+		
		USA	1954	Vic	+		

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Aphytis lingnanensis (#)[b]	L,A	China	1906	WA	+	–	Wilson 1960; Furness et al. 1983; Noyes 1998
		WA	1925–26	NSW	+		
		USA	1962	Vic	+		
Aphytis melinus (#)[b]	L,A	Pakistan	1961	Vic	+	+	Smith 1978a; Elder et al. 1998; Noyes 1998
		Vic	1974	Qld	–		
Encarsia citrina (#)[b]	L	China	ca 1900	Vic	+	++	Noyes 1998
		Israel	1970		+		
ENCYRTIDAE							
Comperiella lemniscata	A	China, Torres Strait, Qld	1991	Qld	+	+++	Elder et al. 1998
(#) introduced against [a]*Comstockaspis perniciosus*; [b]*Aonidiella aurantii*							
8. *Aphis craccivora* Hemiptera: Aphididae							legumes, polyphagous
HYMENOPTERA							
APHELINIDAE							
Aphelinus gossypii (U)	L,A				+	+	Carver et al. 1993
Aphelinus mariscusae (U)	L,A				+	+	Carver 2000
BRACONIDAE							
Aphidius colmani (U)	L,A				+	++	Grylls 1972; Carver & Stary 1974; Room & Wardaugh 1977; Carver 2000
Aphidius similis (U)	L,A				+	+	Carver & Stary 1974
Diaeretiella rapae (U)	L,A	Europe	?		+	–	Carver 2000
Lysiphlebus fabarum	L,A	France, Greece, Turkey	1982–83		+	–	Carver 1984; Carver & Franzmann 2001

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Lysiphlebus testaceipes (U)	L,A	California	1981–83		+	–	Carver 1984; Carver & Franzmann 2001
Trioxys indicus	L,A	India	1985–86	WA, NSW, Vic	–		Carver 1989
FUNGI							
Pandora neoaphidis (U)	L,A				+		M. Carver pers. comm.
9. *Aphis gossypii* Hemiptera: Aphididae †							cotton, cucurbits
HYMENOPTERA							
APHELINIDAE							
Aphelinus gossypii (U)	L,A				+	++	Carver et al. 1993
Aphelinus humilis (U)	L,A				+	–	Carver 2000
BRACONIDAE							
Aphidius colemani (U)	L,A				+	+++	Carver & Stary 1974; Room & Wardhaugh 1977
Lysiphlebus fabarum (#)	L,A	Greece	1982–83		+	–	Carver 1984, 1989; Carver & Franzmann 2001
		Turkey	1982–83				
Lysiphlebus testaceipes (#)	L,A	California	1981–83		+	–	Carver 1984, 1989; Carver & Franzmann 2001
FUNGI							
Neozygites fresenii (U)	L,A		<1984		+	+	Milner & Holdom 1986

(#) introduced against *Aphis craccivora*

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
10. *Asterodiaspis variolosa* Hemiptera: Asterolecaniidae							oak
HYMENOPTERA							
ENCYRTIDAE							
Habrolepis dalmanni	L	USA via NZ	1931–32	Tas	–		Evans 1939b
			1933	Tas	+	++	Wilson 1960
		USA via NZ, Tas	1937	ACT, NSW, Vic	+	++	Evans 1939b
11. *Brevicoryne brassicae* Hemiptera: Aphididae							brassicas
COLEOPTERA							
COCCINELLIDAE							
Adalia bipunctata	all		1900s	WA	+		Pope 1988
Coccinella septempunctata	all	Mediterranean	1903	WA	–		Wilson 1960
Coccinella undecimpunctata	all		1900s	WA	+		Pope 1988
Halmus chalybeus	all	E. Australia	1902	WA	+	?	Jenkins 1946
Harmonia conformis	all	NSW	1896	WA	–		Wilson 1960; Clausen 1978a
		Tas	1901–02	WA	+	+	Clausen 1978a
Orcus lafertei	all	E. Australia	1902	WA	–		Jenkins 1946
HYMENOPTERA							
? BRACONIDAE							
unidentified 2 spp.[a]	L,A	NSW	1902	WA	+	+++	Jenkins 1946; Wilson 1960
		Qld	1902	WA	?	?	Wilson 1960
unknown family 1 sp.		Sri Lanka	1907	WA	+	?	Wilson 1960
'chaldid' 1 sp.		India	1907	WA	+	?	Wilson 1960

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
unknown family 1 sp.		'Orient'	1909	WA	–		Wilson 1960
[a]probably *Diaeretiella rapae* and possibly the hyperparasitoid *Alloxysta fuscicornis*							
12. *Cavariella aegopodii* Hemiptera: Aphididae							carrot, umbellifers
HYMENOPTERA							
BRACONIDAE							
Aphidius salicis	L,A	California	1962	Vic	+	+++	Stubbs 1966; Carver 1988, 1989
13. *Ceroplastes ceriferus* Hemiptera: Coccidae †							citrus, persimmon, native plants
HYMENOPTERA							
APHELINIDAE							
Coccophagus lycimnia (#)[a]	L	USA	1907	WA	+	+	Noyes 1998
PTEROMALIDAE							
Scutellista caerulea (#)[b]	E	South Africa	1902–03	WA	–		Jenkins 1946
		Sri Lanka	ca 1903	WA	–		Wilson 1960
		Brazil	1904	WA	–		Jenkins 1946
		USA	1903–04	WA	+	+++	Jenkins 1946
Scutellista caerulea (#)[c]	E	Uganda, Kenya	1935–38	NSW	–		Wilson 1960; Sands 1984
(#) introduced against [a]*Coccus hesperidum*; [b]*Saissetia oleae*; [c]*Ceroplastes destructor*							

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
14. *Ceroplastes destructor* Hemiptera: Coccidae							citrus
LEPIDOPTERA							
NOCTUIDAE							
Coccidiphaga scitula	L,A	South Africa	1969–70	NSW	–		Sands et al. 1986
HYMENOPTERA							
APHELINIDAE							
Euxanthellus philippiae	A	NZ	1971	NSW	–		Sands et al. 1986
ENCYRTIDAE							
Anicetus communis	L,A	South Africa	1968–72	NSW	+	++	Snowball 1978
					+	+++	Sands et al. 1986
			1973–74	WA	+	+	R.G. Lukins pers. comm.
Anicetus nyasicus	L,A	South Africa	1968–71	NSW	+	++	Snowball 1978
				Qld	+	+++	Sands et al. 1986
			1988	Norfolk Island	+	+++	D.P.A. Sands unpubl.
Diversinervis elegans	A	Uganda, Kenya	1935–38	NSW	–		Wilson 1960
		South Africa	1971	NSW	+	+	D.P.A. Sands unpubl.
Metaphycus helvolus (#)[a]	L	USA	1943–47	NSW	+	+	Sands et al. 1986
				Qld, SA	–		Wilson 1960
Microterys nietneri (#)[b]	L,A	South Africa	1902	WA	+	–	Prinsloo 1976; Noyes 1998
		USA	1907		?		
Trichomasthus ingens	A	South Africa	1969–70	NSW	–		Sands et al. 1986

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
EULOPHIDAE							
Aprostocetus ceroplastae	L,A	South Africa	1972	NSW	+	+	Sands et al. 1986
PTEROMALIDAE							
Scutellista caerulea (*C. destructor* biotype)	A	Uganda, Kenya	1935–38	NSW	–		Wilson 1960
		South Africa	1969–70	NSW	+	++	Sands et al. 1986
(#) introduced against [a]*Saissetia oleae*; [b]*Coccus hesperidum*							
15. *Ceroplastes floridensis* Hemiptera: Coccidae †							citrus, *Ficus* spp.
HYMENOPTERA							
APHELINIDAE							
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	++	Wilson 1960; D.P.A. Sands unpubl.
Coccophagus lycimnia (#)[b]	L	USA	1907	WA	+	+	Noyes 1998
ENCYRTIDAE							
Diversinervis elegans (#)[c]	A	Uganda, Kenya	1935–38	?	+	+	Sands et al. 1986; Smith et al. 1997a
		South Africa	1971	NSW			
Metaphycus lounsburyi (#)[d]	L,A	South Africa via Israel, Holland	1998	Vic, SA	+	+	Malipatil et al. 2000
Microterys nietneri (#)[b]	A	South Africa	1907	WA via USA	+	+	Malipatil et al. 2000
EULOPHIDAE							
Aprostocetus ceroplastae (#)[c]	L,A	South Africa	1972	NSW	+	++	Sands et al. 1986; Smith et al. 1997a
PTEROMALIDAE							
Scutellista caerulea (#)[d]	E	South Africa	1902–03	WA	–		Jenkins 1946

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Scutellista caerulea (#)[d]		Sri Lanka	ca 1903	WA	–		Wilson 1960
		Brazil	1904	WA	–		Jenkins 1946
		USA	1903–04	WA	+	+++	Jenkins 1946
Scutellista caerulea (#)[c]		Uganda, Kenya	1935–38	WA, NSW	?		Wilson 1960
(#) introduced against [a]*Ceroplastes rubens*; [b]*Coccus hesperidum*; [c]*Ceroplastes destructor*; [d]*Saissetia oleae*							
16. *Ceroplastes rubens* Hemiptera: Coccidae							citrus, mango, ornamentals
HYMENOPTERA							
CHALCIDOIDEA							
unidentified		Hawaii	1899		–		Wilson 1960
APHELINIDAE							
Coccophagus ceroplastae	L,A	Japan via Hawaii	1901	NSW	+	++	Wilson 1960; Smith et al. 1997a
ENCYRTIDAE							
Anicetus beneficus	L,A	Japan	1977	Qld	+	+++	Smith 1986
			1990	Norfolk Island	+	+++	D.P.A. Sands unpubl.
Diversinervis elegans (#)[a]	L,A	South Africa	1971	NSW	+	+	Sands et al. 1986; Loch 1997
Metaphycus helvolus (#)[b]	L	USA	1943–47	NSW, Qld, SA	+	+	Wilson 1960; Sands 1984
Microterys nietneri (#)[c]	L,A	South Africa	1902	WA	+	++	Wilson 1960; Malipatil et al. 2000
		USA	1907				

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
EULOPHIDAE							
Aprostocetus ceroplastae (#)[a]	L,A	South Africa	1972	NSW, Qld	+	+	Loch 1997; Malipatil et al. 2000
PTEROMALIDAE							
Moranila californica[d]	E	NSW	1902	WA	+	+	Perkins 1906
		China	1896	Qld	–		Wilson 1960
Scutellista caerulea (#)[b]	E	USA	1904	WA	–		Wilson 1960
				NSW	+	++	Sands 1984
				Qld	+	++	Smith 1997b
(#) introduced against [a]*Ceroplastes destructor*; [b]*Saissetia oleae*; [c]*Coccus hesperidum* [d]an Australian native species. Re-introduced as *Tomocera chinensis*							
17. *Ceroplastes sinensis* Hemiptera: Coccidae †							citrus, mango
HYMENOPTERA							
APHELINIDAE							
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	++	Wilson 1960; Sands 1984
Coccophagus lycimnia (#)[b]	L	USA	1907	WA	+	+	Noyes 1998
ENCYRTIDAE							
Metaphycus helvolus (#)[c]	L	USA	1943–47	NSW, Qld, SA	+	+	Snowball 1970; Sands 1984

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
EULOPHIDAE							
Aprostocetus ceroplastae (#)[d]	L,A	South Africa	1972	NSW, Qld	+	+	Sands 1984
PTEROMALIDAE							
Scutellista caerulea (#)[c]	E	South Africa	1902–03	WA	–		Jenkins 1946
		Sri Lanka	ca 1903	WA	–		Wilson 1960
		Brazil	1904	WA	–		Jenkins 1946
		USA	1904	WA	+	+++	Jenkins 1946
Scutellista caerulea (#)[d]		Uganda, Kenya	1935–38	NSW	?		Wilson 1960
(#) introduced against [a]*Ceroplastes rubens*; [b]*Coccus hesperidum*; [c]*Saissetia oleae*; [d]*Ceroplastes destructor*							
18. *Chrysomphalus aonidum* Hemiptera: Diaspididae							citrus, palms, ornamentals
HYMENOPTERA							
APHELINIDAE							
Aphytis chrysomphali (#)	L,A	China	1905		+	+	Wilson 1960
Aphytis holoxanthus	L,A	Hong Kong via Israel	1974	NSW	+	+++	Snowball & Lukins 1975; Lukins & Snowball 1977a; Smith 1978b
			1976	Qld	+	+++	
Encarsia citrina (#)	L	China	ca 1900		+	++	Lukins and Snowball 1977a
Pteroptrix chinensis (U)	L	China	<1907	?	+	+	Wilson 1960
(#) introduced against *Aonidiella aurantii*							

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated	Est.	Eff.	Host(s) References
19. *Coccus hesperidum* Hemiptera: Coccidae						citrus, passionfruit, fig, ornamentals
HYMENOPTERA						
unidentified 2 spp.		China	1905	WA	–	Wilson 1960
unidentified spp.		China	1906	WA	–	Wilson 1960
unidentified sp.		USA	1907	WA	–	Wilson 1960
unidentified spp.		Sri Lanka	1907	WA	–	Wilson 1960
unidentified spp.		India	1907	WA	–	Wilson 1960
unidentified 2 spp.		Italy	1908	WA	–	Wilson 1960
unidentified sp.		Egypt	1908	WA	–	Wilson 1960
unidentified spp.		China	1909	WA	–	Jenkins 1946
unidentified spp.		India	1909	WA	–	Jenkins 1946
APHELINIDAE						
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	+++ Wilson 1960; Malipatil et al. 2000
		India	1907–09	WA		
Coccophagus lycimnia	L	USA	1907	WA	+	++ Wilson 1960; Noyes 1988
Coccophagus semicircularis	L	?Europe			+	+ Smith 1997a; Malipatil et al. 2000
ENCYRTIDAE						
Cristatithorax sp.		China	1905–06	WA	+	+ Wilson 1960
Diversinervis elegans (#)[b]	A	unknown			+	+++ Wilson 1960; Smith et al. 1997a
		Uganda, Kenya	1936–38	NSW	+	+
Encyrtus aurantii		?Europe			+	+ Malipatil et al. 2000
Encyrtus infelix	L,A	USA			+	+ Smith 1997a; Malipatil et al. 2000

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Metaphycus anneckei (#)[c]	A	South Africa	1902	WA	+	+++	Malipatil et al. 2000
Metaphycus helvolus (#)[c]	L	USA	1943–47	NSW, Qld, SA	+	++	Wilson 1960; Smith et al. 1997a
Metaphycus lounsburyi (#)[c]	L,A	South Africa via Israel & Holland	1998	Qld	+	+	Malipatil et al. 2000
Metaphycus luteolus	L	USA	1999	Qld	+	+	Malipatil et al. 2000
Microterys nietneri (? = *Microterys* sp.)	L,A	South Africa	1902	WA	+	+	Wilson 1960; Smith et al. 1997a
		USA	1907		–		Malipatil et al. 2000
PTEROMALIDAE							
Scutellista sp.		Philippines	1907	WA	–		Wilson 1960
Scutellista sp.		Sri Lanka	1907	WA	–		Wilson 1960
Scutellista sp.		Sri Lanka	1908	WA	–		Wilson 1960
Scutellista sp.		China	1909	WA	–		Jenkins 1946
Scutellista sp.		India	1909	WA	–		Jenkins 1946
Scutellista caerulea (#)[c]	E	South Africa	1902–03	WA	–		Jenkins 1946
		Sri Lanka	ca 1903	WA	–		Wilson 1960
		Brazil	1904	WA	–		Jenkins 1946
		USA	1903–04	WA	+	+	Jenkins 1946
Scutellista caerulea (#)[b]	E	Uganda, Kenya	1935–38	NSW	–		Wilson 1960
				NSW			Malipatil et al. 2000

(#) introduced against [a]*Ceroplastes rubens*; [b]*Ceroplastes destructor*; [c]*Saissetia oleae*

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**	**Est.**	**Eff.**	**Host(s)** **References**
20. *Coccus longulus* Hemiptera: Coccidae †						citrus, custard apple, lychee, carambola, fig, leucaena, ornamentals
HYMENOPTERA						
APHELINIDAE						
Coccophagus ceroplastae (#)	L,A	Japan via Hawaii	1901	NSW	+	++	Wilson 1960; Smith et al. 1997a
(#) introduced against *Ceroplastes rubens*						
21. *Coccus pseudomagnoliarum* Hemiptera: Coccidae †						citrus
HYMENOPTERA						
APHELINIDAE						
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	+	Wilson 1960; Noyes 1998
		India	1907–09	WA			
Coccophagus lycimnia (#)[b]	L	USA	1907	WA	+	+++	Wilson 1960; Malipatil et al. 2000
Coccophagus semicircularis (#)[b]	L	?Europe			+	+++	Smith et al. 1997a; Malipatil et al. 2000
ENCYRTIDAE						
Diversinervis elegans (#)[c]	A	unknown			+	+	Wilson 1960; Noyes 1998
		Uganda, Kenya	1935–38	NSW	?		
Encyrtus aurantii (#)[b]		?Europe			+	+	Noyes 1998
Metaphycus helvolus (#)[d]	L	USA	1943–47	NSW, Qld, SA	+	+	Wilson 1960; Malipatil et al. 2000
Metaphycus luteolus (#)[b]	L	USA	1999	Qld	+	+	Noyes 1998; Malipatil et al. 2000

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Metaphycus lounsburyi (#)[d]	L,A	South Africa	1902	WA	+	+	Noyes 1998; Malipatil et al. 2000
		Israel	1998	Qld	+	+	
Microterys nietneri (#)[b]	L,A	South Africa	1902	WA	+	+	Wilson 1960; Noyes 1998
		USA	1907	WA	–		
(#) introduced against [a]*Ceroplastes rubens*; [b]*Coccus hesperidum*; [c]*Ceroplastes destructor*; [d]*Saissetia oleae*							
22. *Coccus viridis* Hemiptera: Coccidae							coffee, citrus, ornamentals
HYMENOPTERA							
APHELINIDAE							
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	++	Malipatil et al. 2000
		India	1907–09	WA	?		
Coccophagus lycimnia (#)[b]	L	USA	1907	WA	+	+	Noyes 1998
Coccophagus sp. nr *rusti*	L				+	+	Smith et al. 1997a
ENCYRTIDAE							
Diversinervis elegans (#)[c]	A	Uganda, Kenya	1935–38	NSW	+	+	Malipatil et al. 2000
Diversinervis nr *stramineus*	L,A	Kenya	1999	NSW, Qld	+	+++	Malipatil et al. 2000; D. Smith pers. comm
Encyrtus aurantii (#)[b]		?Europe			+	+	Noyes 1998
Metaphycus helvolus (#)[d]	L	USA	1943–47	NSW	+	+	Wilson 1960; Noyes 1998
				Qld, SA	–		
Microterys nietneri (#)[b]	L,A	South Africa	1907	WA	+	+	Wilson 1960; Noyes 1998; Malipatil et al. 2000
		USA					
(#) introduced against [a]*Ceroplastes rubens*; [b]*Coccus hesperidum*; [c]*Ceroplastes destructor*; [d]*Saissetia oleae*							

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
23. *Comstockaspis perniciosus* Hemiptera: Diaspididae							apple, pear, stone fruit
COLEOPTERA							
COCCINELLIDAE							
unidentified		Spain	1903	WA	–		Jenkins 1946
Chilocorus circumdatus		Hong Kong	1902	WA	–		Wilson 1960
		India	1960–63	WA	–		Houston 1991
Chilocorus circumdatus (U)			<1990	Qld	+	++	Houston 1991; D. Smith pers. comm.
Chilocorus stigma			1927	NSW	–		Wilson 1960
HYMENOPTERA							
unidentified spp.		USA	1907	WA	–		Wilson 1960
APHELINIDAE							
Aphytis aonidiae					+	+	CSIRO unpubl.
Aphytis chrysomphali (#)	L	China	1905	WA	+	++	Wilson 1960; Furness et al. 1983
		WA	1925–26	NSW	+		
		USA	1954	Vic	+		
Aphytis diaspidis	L,A				+	+	Noyes 1998; CSIRO unpubl.
Encarsia citrina (#)	L	China	ca 1900	Vic	+	++	Smith et al. 1997a; Noyes 1998
		USA, Israel	1970		+		
Encarsia perniciosi (red scale strain) (#)	L	China	ca 1900	NSW	+	+	McLaren 1971; Furness et al. 1983
		Israel via USA	1970–73	Vic, SA	+	+	

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Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Encarsia perniciosi (San José scale strain)		Germany	1977	NSW	+	+	Snowball et al. 1975; Milne & Snowball 1977
		Germany	1977–78	Vic	+	+	
(#) introduced against *Aonidiella aurantii*							
24. *Diaspis bromeliae* Hemiptera: Diaspididae †							pineapple, bromeliads
HYMENOPTERA							
APHELINIDAE							
Encarsia citrina (#)	L,A	China	ca 1900	Vic	+	++	Noyes 1998
		Israel	1970		+	++	
Encarsia sp.[a]					+	++	Murray 1982a
(#) introduced against *Aonidiella aurantii* [a]possibly *Encarsia citrina*							
25. *Edwardsiana froggatti* Hemiptera: Cicadellidae							apple, prune
HYMENOPTERA							
MYMARIDAE							
Anagrus armatus	E	USA via NZ	1935	Tas	+	++	Evans 1937b; Wilson 1960
26. *Eriococcus araucariae* Hemiptera: Eriococcidae							araucaria pines
COLEOPTERA							
COCCINELLIDAE							
Cryptolaemus montrouizieri (#)	L,A	NSW	1902	WA	+	+++	Wilson 1960
(#) introduced against Pseudococcidae							

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
27. *Eriosoma lanigerum* Hemiptera: Aphididae							apple
COLEOPTERA							
COCCINELLIDAE							
Cheilomenes sexmaculata	all	WA	1911	Vic	–		Wilson 1960
Exochomus melanocephalus	all	South Africa	1900	NSW	–		Wilson 1960
Harmonia conformis	all	NSW	1896	WA	–		Jenkins 1946; Wilson 1960
		Tas	1901–02	WA	+	++	Wilson 1960
HYMENOPTERA							
APHELINIDAE							
Aphelinus mali	L,A	USA via NZ	1923–25	all States	+	+++	Wilson 1960
28. *Hyperomyzus lactucae* Hemiptera: Aphididae							lettuce, sowthistle
HYMENOPTERA							
APHELINIDAE							
Aphelinus asychis	L,A	South Africa	1981	NSW	–		Carver & Woolcock 1986
BRACONIDAE							
Aphidius sonchi	L,A	Japan	1981–83	ACT, NSW	–		Carver & Woolcock 1986
		France	1981–83	Qld	+	++	Carver & Woolcock 1986; CSIRO files
		France	1981–82	NSW, Vic, ACT, SA, WA	+	+++	Sandow 1993
Praon volucre	L,A	France, Greece, Turkey	1981–83	ACT, all States	– + (Tas)	?	Carver & Woolcock 1986; Hughes 1989

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
FUNGI							
Pandora neoaphidis (U)	L,A	unknown	unknown		+	++	R. Milner pers. comm. 1998
29. *Lepidosaphes beckii* Hemiptera: Diaspididae †							citrus, avocado, pecans, ornamentals
HYMENOPTERA							
APHELINIDAE							
Aphytis chrysomphali	L	China	1905	WA	+	+	Furness et al. 1983; Elder et al 1998; Noyes 1998
		WA	1925–26	NSW	+	+	
		USA	1954	Vic	+	+	
Aphytis lepidoaphes	L,A	China	?1960s	?	+	+++	Snowball & Sands 1970; Smith et al. 1997a
Aphytis lingnanensis (#)	L,A	China	1906	WA	+	+	Lukins & Snowball 1977b; Smith et al. 1997a; Malipatil et al. 2000
		WA	1925–26	NSW	+	?	
		USA	1962	Vic	+	?	
Encarsia citrina (#)	L	China	ca 1900	Vic	+	++	Snowball 1967; Smith et al. 1997a
		Israel	1970		+	+	
EULOPHIDAE							
Pteroptrix chinensis	L	China	?1907	?	+	+	Wilson 1960

(#) introduced against *Aonidiella aurantii*

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**	**Est.**	**Eff.**	**Host(s)** **References**
30. *Lepidosaphes gloverii* Hemiptera: Diaspididae †						citrus, macadamia, coconut, palms
COLEOPTERA						
COCCINELLIDAE						
Chilocorus circumdatus (#)[a]	L,A	Hong Kong	1902	WA	–	Wilson 1960; Smith & Papacek 1993; Smith et al. 1997a; Elder et al. 1998
		India	1960–63	WA	–	
			<1990	NSW via WA	+	+
				Qld	+	+ Houston 1991
HYMENOPTERA						
APHELINIDAE						
Aphytis chrysomphali (#)[b]	L	China	1905	WA	+	++ Wilson 1960; Furness et al. 1983; Noyes 1998
		WA	1925–26	NSW	+	+
		USA	1954	Vic	+	+
Aphytis lingnanensis (#)[b]	L,A	China	?1906	WA	+	+++ Wilson 1960; Furness et al. 1983
Aphytis lingnanensis (#)[c]		WA	1925–26	NSW	+	+
		USA	1962	Vic	–	
		Hong Kong via Florida	1977–78	Qld	–	Smith et al. 1995; Noyes 1998
		Japan	1981–82	Qld	+	+ Field 1984
		Thailand	1988–90	Qld	+	+ Smith & Papacek 1993

(#) introduced against [a]*Comstockapsis perniciosus*; [b]*Aonidiella aurantii*; [c]*Unaspis citri*

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
31. *Macrosiphum rosae* Hemiptera: Aphididae							roses
DIPTERA							
SYRPHIDAE							
unidentified	L,A	Philippines	1907	WA	–		Jenkins 1946
HYMENOPTERA							
APHELINIDAE							
Aphelinus gossypii (U)	L,A				+	–	Maelzer 1977
BRACONIDAE							
Aphidius ervi (#)	L,A	Tas, Japan via USA; Japan via USA via NZ, Europe	1908–81	SA	+	+	Milne 1991
Aphidius rosae	L,A	Italy	1993	SA	+	++	Kitt & Keller 1998
(#) introduced against *Acyrthosiphon kondoi*							
32. *Metopolophium dirhodum* Hemiptera: Aphididae							roses, cereals
HYMENOPTERA							
BRACONIDAE							
Aphidius ervi (#)	L,A	Tas, France, Greece, Italy, California, NZ	1977–81		+	+	Carver 2000
Aphidius rhopalosiphi	L,A	France via Chile	1985–86	ACT, NSW, Vic	–		CSIRO files
		UK & France via NZ	1987–88	ACT, NSW, Vic, Tas	+	+++	CSIRO files
(#) introduced against *Acyrthosiphon kondoi*							

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
33. mirid bugs Hemiptera: Miridae							cotton
FUNGI							
Beauveria bassiana	L,A	USA	1994	NSW	–		AQIS 1999b; R.K. Mensah pers. comm.
34. *Myzus persicae* Hemiptera: Aphididae †							peach, vegetables etc.
HYMENOPTERA							
BRACONIDAE							
Aphidius colmani (U)	L				+	+	Carver 1989, 1995
Aphidius similis (U)	L				+	+	Stary & Carver 1979
Ephedrus persicae (U)	L				+	+	Carver 1989
35. *Nezara viridula* Hemiptera: Pentatomidae							maize, cotton, legumes, sorghum, grains, vegetables, nuts
DIPTERA							
TACHINIDAE							
Bogosia antinorii	L,A	Kenya	1958		–		Greathead 1971
Trichopoda giacomellii	L,A	Argentina	1996–99		+	+++	Coombs & Sands 2000
Trichopoda pennipes	L,A	Florida	1941–43		–		Wilson 1960
			1949–50		–		
			1952–53		–		
			1980		–		Michael 1981
		Hawaii	1980		–		

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Trichopoda pilipes	L,A	West Indies	1952–54		–		Wilson 1960
			1980		–		Michael 1981
		Hawaii	1980		–		
HYMENOPTERA							
ENCYRTIDAE							
Ooencyrtus submetallicus	E	Trinidad	1953–58	NSW	–		Wilson 1960
			1962	Vic, Qld, SA, WA, ACT			Waterhouse & Norris 1987; Waterhouse 1998
SCELIONIDAE							
Telenomus chloropus	E	Japan	1962–63		–		Bornemizza 1963; Clarke 1990; Waterhouse 1998
			1980–81				
Trissolcus basalis	E	Egypt	1933–43	all mainland States, ACT	+	+++	Wilson 1960
			1949–50	Lord Howe Island			
		West Indies	1953–57	all mainland States, ACT	+	?	
		USA	1979–82		+	?	Field 1984; Clarke 1990
		Brazil	1979–82		+	?	Clarke 1990; Waterhouse 1998
		South Africa	1979–82		+	?	
Trissolcus crypticus	E	Pakistan	1961		–		Ratcliffe 1965; Clarke 1993a,b
Trissolcus mitsukurii	E	Japan	1962–63		+	+	Callan 1964; Clarke 1990; Johnson 1991
Trissolcus sp. (as *Trissolcus basalis*)	E	Italy	1956–59	all mainland States, ACT	+	?	Wilson 1960; Clarke 1990

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**	**Est.**	**Eff.**	**Host(s)** **References**
36. *Parasaissetia nigra* Hemiptera: Coccidae †						citrus, custard apple, avocado, guava, hibiscus
HYMENOPTERA						
APHILINIDAE						
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	++ Noyes 1998
Coccophagus lycimnia (#)[b]	L	USA	1907	WA	+	+ Noyes 1998
ENCYRTIDAE						
Diversinervis elegans (#)[c]	A	Uganda, Kenya	1935–38	NSW	+	+ Wilson 1960; Malipatil et al. 2000
Encyrtus aurantii (#)[b]		?Europe			+	+ Noyes 1998
Encyrtus infelix (#)[b]	L,A	USA	?		+	+ Noyes 1998
Metaphycus helvolus (#)[d]	L	USA	1943–47	NSW, Qld, SA	+	+ Wilson 1960; Noyes 1998
Microterys nietneri (#)[b]	L,A	South Africa	1902	WA	+	+
		USA	1907			
PTEROMALIDAE						
Scutellista caerulea (#)[d]	E	South Africa	1902–03	WA	–	Jenkins 1946
		Sri Lanka	ca 1903	WA	–	
		Brazil	1904	WA	–	Wilson 1960
		USA	1903–04	WA	–	Jenkins 1946
Scutellista caerulea (#)[c]		Uganda, Kenya	1935–38	NSW	?	Wilson 1960; Malipatil et al. 2000

(#) introduced against [a]*Ceroplastes rubens*; [b]*Coccus hesperidum*; [c]*Ceroplastes destructor*; [d]*Saissetia oleae*

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
37. *Parthenolecanium persicae* Hemiptera: Coccidae							grapevine, plum
HYMENOPTERA							
CHALCIDOIDEA							
unidentified sp.		France	1903	WA	–		Wilson 1960
unidentified 2 spp.[a]		USA	1907	WA	–		Wilson 1960
unidentified 3 spp.[a]		Philippines	1909	WA	–		Wilson 1960
APHELINIDAE							
Coccophagus lycimnia (#)	L	USA	1907	WA	+	+	Wilson 1960; Noyes 1998
ENCYRTIDAE							
Cristatithorax sp. (#)		China	1905	WA	+	+	Wilson 1960
Metaphycus timberlakei	L,A	?Japan via USA	1907	WA	+	+++	Jenkins 1946
		?Philippines via USA	1909	WA	+	+++	Bartlett 1978a
		WA	1923, 1933	Vic	+	+++	Wilson 1960
		WA	1926–27	NSW	+	?	
?ICHNEUMONIDAE							
unidentified sp.		France	1903	WA	–		Wilson 1960

[a]probably included *Metaphycus timberlakei*
(#) introduced against *Coccus hesperidum*

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
38. *Pentalonia nigronervosa* Hemiptera: Aphididae †							banana
HYMENOPTERA							
BRACONIDAE							
Aphidius colemani (U)	L,A	India			+	?	M. Carver pers. comm.
Aphidius sp. (U)	L,A				+	+	Hely et al. 1982
39. *Pineus boerneri* 40. *Pineus pini* Hemiptera: Adelgidae							pines
NEUROPTERA							
HEMEROBIIDAE							
Wesmaelius concinnus	L,A	UK	1936–37	ACT, NSW	–		Wilson 1960
COLEOPTERA							
COCCINELLIDAE							
Exochomus quadripustulatus	L,A	UK	1934–35	ACT, NSW	+	?	Wilson 1960; Pope 1988
			1937–39	ACT, NSW			
DIPTERA							
CHAMAEMYIIDAE							
Leucopis atrifacies	E,L,A	California	1938	ACT, NSW	–		Wilson 1960
Leucopis obscura	E,L,A	UK	1932–36	ACT, NSW	–		Wilson 1960
			1938–39	ACT, NSW			
Leucopis praecox	L,A	UK	1933	ACT, NSW	–		Wilson 1960

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
41. *Planococcus citri* Hemiptera: Pseudococcidae							citrus, many other crops
COLEOPTERA							
COCCINELLIDAE							
Cryptolaemus montrouzieri	all	NSW	1902	WA	+	+++	Wilson 1960
unidentified	all	Spain	1903		–		Wilson 1960
HYMENOPTERA							
ENCYRTIDAE							
Anagyrus sp. (U)					+	++	Smith et al. 1988
Coccidoxenoides peregrinus (U)	L	Oriental			+	+++	Smith et al. 1988
Leptomastidea abnormis (U)	L	?Mediterranean	<1959		+	++	Smith et al. 1988
Leptomastix dactylopii	L,A	Brazil via California	1980–87	Qld	+	++	Smith et al. 1988
Ophelosia crawfordi (U)	E	California via ?			+	+	Murray 1978
PLATYGASTERIDAE							
Allotropa sp. nr *citri* (U)		?China			+	?	Malipatil et al. 2000

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**	**Est.**	**Eff.**	**Host(s)** **References**
42. *Pseudococcus calceolariae* Hemiptera: Pseudococcidae †						citrus
COLEOPTERA						
COCCINELLIDAE						
Cryptolaemus montrouzieri	all	NSW	1990	SA	+	+	Altmann & Green 1992
DIPTERA						
CECIDOMYIIDAE						
Diadiplosis koebelei	all	NSW	1990	SA	+	+	Altmann & Green 1992
HYMENOPTERA						
APHELINIDAE						
Coccophagus gurneyi	L	NSW	1990–92	SA	–		Altmann & Green 1992; Baker & Keller 1998, 1999
		NSW	1996	SA	+	?	
ENCYRTIDAE						
Tetracnemoidea brevicornis	L	Vic	1989–92	SA	+	+	Altmann & Green 1992; Baker & Keller 1998, 1999
43. *Pseudococcus longispinus* Hemiptera: Pseudococcidae						citrus, pear, grapes
COLEOPTERA						
COCCINELLIDAE						
Cryptolaemus montrouzieri	all	NSW, Qld	1902	WA	+	+++	Jenkins 1946; Wilson 1960
unidentified	all	Spain	1903	WA	–		Wilson 1960

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Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
HYMENOPTERA							
ENCYRTIDAE							
Tetracnemoidea brevicornis	L		1990	SA	+	++	Altmann in Baker & Keller 1998
Tetracnemoidea peregrina	L	Israel	1972–74	Vic, SA	+	+	Smith et al. 1997a,b
Tetracnemoidea sydneyensis	L,A	NSW	1972–74	Vic, SA	+	+	Smith et al. 1997a,b; Baker & Keller 1998
PTEROMALIDAE							
Anagyrus fusciventris	L	NSW	1970s	SA	+	++	Furness 1976; Baker & Keller 1998
44. *Pseudococcus viburni* Hemiptera: Pseudococcidae							citrus
HYMENOPTERA							
ENCYRTIDAE							
Pseudaphycus maculipennis		UK	1997	Qld	+	–	F.D. Page pers. comm. 1999
Tetracnemoidea peregrina (#)		Israel	1972–74	SA, Vic	+	–	Bartlett 1978b; Smith et al. 1997a,b
(#) introduced against *Pseudococcus longispinus*							
45. *Pulvinaria polygonata* Hemiptera: Coccinidae †							citrus
HYMENOPTERA							
APHELINIDAE							
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	+	Malipatil et al. 2000
Coccophagus lycimnia (#)[b]	L	USA	1907	WA	+	+	Noyes 1998
(#) introduced against [a]*Ceroplastes rubens*; [b]*Coccus hesperidum*							

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Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
46. *Rhopalosiphum maidis* Hemiptera: Aphididae †							corn
HYMENOPTERA							
APHELINIDAE							
Aphelinus varipes (U)	L,A				+	+	Hughes et al. 1994; Carver & Franzmann 2001
		Ukraine	1990		–		Hughes et al. 1994
47. *Rhopalosiphum padi* Hemiptera: Aphididae †							cereals
HYMENOPTERA							
APHELINIDAE							
Aphelinus varipes (U)	L,A				+	–	Carver & Franzmann 2001
	L,A	Ukraine	1990		–		Aeschlimann & Hughes 1992; Hughes et al. 1994
BRACONIDAE							
Aphidius colemani (U)	L,A				+	++	Hughes et al. 1994; Milne 1995
Aphidius similis (U)	L,A				+	++	Hughes et al. 1994; Milne 1995
Diaeretiella rapae (#)	L,A		<1900		+	+	Hughes et al. 1994
Lysiphlebus testaceipes	L,A	Nearctic via USA	1982	NSW	+	+	Carver & Franzmann 2001; CSIRO files

(#) presumably introduced against *Brevicoryne brassicae*

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
48. *Saccharicoccus sacchari* Hemiptera: Pseudococcidae							sugarcane
HYMENOPTERA							
ENCYRTIDAE							
Anagyrus saccharicola	L,A	Philippines via Hawaii	1935	Qld	–	–	Anon. 1953, 1954; Wilson 1960; Carver et al. 1987
		Philippines via Hawaii	1953	Qld	+	++	
FUNGI							
Aspergillus parasiticus (U)					+		Drummond et al. 1991
49. *Saissetia coffeae* Hemiptera: Coccidae †							coffee, citrus, avocado, ornamentals
HYMENOPTERA							
APHELINIDAE							
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	++	Wilson 1960; Malipatil et al. 2000
Coccophagus lycimnia (#)[b]	L	USA	1907	WA	+	+	Wilson 1960; Noyes 1998
ENCYRTIDAE							
Diversinervis elegans (#)[c]	A				+	+	Wilson 1960; Noyes 1998; Malipatil et al. 2000
		Uganda, Kenya	1935–38	NSW	?		
Encyrtus aurantii (#)[b]		?Europe			+	+	Noyes 1998

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Encyrtus infelix (#)[b]	L,A	USA			+	+++	Smith et al. 1997a
		Israel	1996	Qld	+	+++	D. Smith pers. comm.
Metaphycus anneckei (#)[d]	A	South Africa	1902	WA	+	+++	Malipatil et al. 2000
Metaphycus helvolus (#)[d]	L	USA	1943–47	NSW	+	++	Wilson 1960; Noyes 1998
				Qld, SA	+	+	
Metaphycus lounsburyi (#)[d]	L,A	South Africa via Israel & Holland	1998	Qld	+	+	Noyes 1998
Metaphycus luteolus (#)[b]	L	USA		Qld	+	+	Noyes 1998
Microterys nietneri (#)[b]	L,A	South Africa	1902	WA	+	+	Wilson 1960
		USA	1907		–		Noyes 1998
PTEROMALIDAE							
Scutellista caerulea (#)[d]	E	South Africa	1902–03	WA	–		Jenkins 1946
		Sri Lanka	ca 1903	WA	–		Wilson 1960
		Brazil	1904	WA	–		Jenkins 1946
		USA	1903–04	WA	+	+++	
Scutellista caerulea (#)[c]		Uganda, Kenya	1935–38	NSW	?		Wilson 1960; Smith et al. 1997a

(#) introduced against [a]*Ceroplastes rubens*; [b]*Coccus hesperidum*; [c]*Ceroplastes destructor*; [d]*Saissetia oleae*

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
50. *Saissetia oleae* Hemiptera: Coccidae							citrus, custard apple, olive, ornamentals
COLEOPTERA							
COCCINELLIDAE							
unidentified sp.		USA	1907	WA	?		Wilson 1960
Rhyzobius sp.		Sri Lanka	1909	WA	?		Wilson 1960
HYMENOPTERA							
unidentified 3 spp.		China	1903	WA	–		Wilson 1960
unidentified		USA	1904	WA	?		Wilson 1960
APHELINIDAE							
Coccophagus capensis	L	China					Noyes 1998
Coccophagus ceroplastae (#)[a]	L,A	Japan via Hawaii	1901	NSW	+	++	Wilson 1960; Noyes 1998
Coccophagus lycimnia (#)[b]	L	USA	1907	WA	+	+	Wilson 1960; Malipatil et al. 2000
Coccophagus semicircularis(#)[b]	L	?Europe			+	+	Smith et al. 1997a; Malipatil et al. 2000
ENCYRTIDAE							
Baeoanusia minor[c]	L,A	South Africa	1903	WA	+		Wilson 1960
Diversinervis elegans (#)[d]	A	unknown	?	?	+	+++	Wilson 1960; Malipatil et al 2000
		Uganda, Kenya	1935–38	NSW	?		
Encyrtus aurantii (#)[b]		?Europe			+	+	Noyes 1998
Encyrtus infelix (#)[b]	L,A	USA	?		+	+	Smith 1997b; Noyes 1998
Metaphycus anneckei	A	South Africa	1902	WA	+	+++	Malipatil et al. 2000

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Metaphycus helvolus	L	USA	1943–47	NSW	+	++	Wilson 1960; Malipatil et al. 2000
				Qld, SA	+	+	
Metaphycus inviscus	L,A	Africa	?	?	+	+	Malipatil et al. 2000
Metaphycus lounsburyi	L,A	South Africa via Israel & Holland	1998	Qld	+	+	Malipatil et al. 2000
Microterys nietneri (? = *Microterys* sp.) (#)[b]	L,A	South Africa	1902	WA	+	+	Wilson 1960
		USA	1907				Noyes 1998
EUPELMIDAE							
Lecaniobius utilis		Brazil	1904	WA	?		Wilson 1960
PTEROMALIDAE							
Scutellista caerulea	E	South Africa	1902–03	WA	–		Jenkins 1946
		Sri Lanka	ca 1903	WA	–		Wilson 1960
		Brazil	1904	WA	–		Jenkins 1946
		USA	1903–04	WA	+	+++	
Scutellista caerulea (#)[d]		Uganda, Kenya	1935–38	NSW	–		Wilson 1960
Scutellista sp.		China	1905	WA	–		Wilson 1960
Scutellista sp.		Timor	1905	WA	–		Wilson 1960
Moranila californica[e]	E	USA	1902				Bartlett 1978a

(#) introduced against [a]*Ceroplastes rubens*; [b]*Coccus hesperidum*; [d]*Ceroplastes destructor*
[c]hyperparasitoid
[e]re-introduction: the species is indigenous to Australia

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
51. *Therioaphis trifolii* forma clover Hemiptera: Aphididae †							clover, lucerne
HYMENOPTERA							
APHELINIDAE							
Aphelinus asychis (#)	L,A	France	1978–79		+	+	W. Milne pers. comm 1998
BRACONIDAE							
Trioxys complanatus (#)	L,A	USA			+ (see text)	–	Wilson et al. 1982; Hughes et al. 1987; W. Milne pers. comm. 1998
		Iran	1978				
(#) introduced against *Therioaphis trifolii* forma maculata							
52. *Therioaphis trifolii* forma maculata Hemiptera: Aphididae							lucerne
HYMENOPTERA							
APHELINIDAE							
Aphelinus asychis	L,A	France	1978–79	all States	+	+	Hughes 1989
BRACONIDAE							
Praon exsoletum	L,A	Cyprus	1977	all States			Hughes et al. 1987; Hughes 1989
		Iran	1978		+	++	
		Pakistan	1979				
Trioxys complanatus	L,A	Iran via USA	1977	all States			Wilson et al. 1982; Walters & Dominiak 1984; Hughes et al. 1987
		Iran	1978		+	+++	
FUNGI							
Zoophthora radicans	L,A	Israel	1979		+	+	Milner et al. 1982; Hughes 1989

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
53. *Toxoptera aurantii* 54. *Toxoptera citricidus* Hemiptera: Aphididae							citrus
COLEOPTERA							
COCCINELLIDAE							
Harmonia conformis	L,A	NSW	1896	WA	–		Wilson 1960
		Tas	1901–02	WA	+	++	
unidentified sp.		France	1903		?		Wilson 1960
HYMENOPTERA							
unspecified sp.		France	1903	WA	?		Wilson 1960
		Algeria	1906	WA	–		Jenkins 1946
		Sri Lanka	1907, 1909	WA	–		Jenkins 1946
APHELINIDAE							
Aphelinus gossypii (U)	L,A				+	+	Carver 1978b
Aphelinus mali (U)[a]	L,A	USA via NZ	1923		+	+	Jenkins 1946; Wilson 1960
Aphelinus spp. (U)	L,A				+	++	Smith et al. 1997a
BRACONIDAE							
Aphidius colemani (U)	L,A	India			+	+	Carver 1978b
Aphidius spp. (U)	L,A				+	++	Smith et al. 1997a
Lysiphlebus testaceipes	L,A	Nearctic via USA	1982		+	?	Carver & Franzmann 2001; L. Woolcock pers. comm.

[a]this was almost certainly *Aphelinus gossypii* (M. Carver, pers. comm.)

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
55. *Trialeurodes vaporariorum* Hemiptera: Aleyrodidae							greenhouse vegetables
HYMENOPTERA							
APHELINIDAE							
Encarsia formosa	L	Central America via UK via NZ	1934	ACT	+	+++	Tonnoir 1937; Wilson 1960; Martin 1989
56. *Tuberculatus annulatus* Hemiptera: Aphididae							oak
HYMENOPTERA							
APHELINIDAE							
Aphelinus subflavescens (U)	L,A	UK	<1939		+	+	Wilson 1960; Carver & Stary 1974
	L,A	UK	1939	Tas	+	++	
BRACONIDAE							
Trioxys tenuicaudus (U)	L,A	UK	<1939		+	++	Wilson 1960; Carver & Stary 1974
57. *Unaspis citri* Hemiptera: Diaspididae							citrus
COLEOPTERA							
COCCINELLIDAE							
Chilocorus circumdatus (#)[a]	all	Hong Kong	1902		+	+++	Wilson 1960; Smith & Papacek 1993
HYMENOPTERA							
APHELINIDAE							
Aphytis chrysomphali (#)[b]		China via WA	1925–26	NSW	+	+	Summerville 1934
Aphytis gordoni		S. China	1986	Qld	–		Smith & Papacek 1993

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Aphytis lingnanensis (#)[a]	A	China via California	1965–69	Vic, SA	+	+	Anon. 1971
		Hong Kong via Florida	1977–78	Qld	–		D. Smith pers. comm. 1984
		Japan via Florida	1981–82	Qld	+	+	Field 1984
		Hong Kong via Florida	1985	Qld	+	+	Smith & Papacek 1993
		Thailand	1989–90	Qld	+	+	
Encarsia inquirenda		S. China	1986	Qld	–		Smith 1993a; Smith & Papacek 1993
(#) introduced against [a]*Comstockaspis perniciosus* or accidentally introduced; [b]*Aonidiella aurantii*							
58. *Heliothrips haemorrhoidalis* Thysanoptera: Thripidae							citrus
HYMENOPTERA							
EULOPHIDAE							
Goetheana shakespearei (U)	L	California	1987–88	NSW	?		Beattie & Jiang 1990
Thripobius semiluteus (U)	L	?Africa or India			+	++	Beattie & Jiang 1990
59. *Phaulacridium vittatum* Orthoptera: Acrididae							pastures, crops
FUNGI							
ENTOMOPHTHORALES							
Entomophaga grylli	L,A	USA	1984–85	ACT	–		Milner 1985
Mucor racemosus	L,A	South Africa	1898, 1904	Qld			Wilson 1960
			1899	Vic	–		
			1900–03	NSW			
			1902	WA			

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
60. *Teleogryllus commodus* Orthoptera: Gryllidae							Brassicaceae
FUNGI							
Nosema locustae		USA	1978	Vic			AQIS 1999b; T. Hogan pers. comm.
61. *Brontispa longissima* Coleoptera: Chrysomelidae							palms
HYMENOPTERA							
EULOPHIDAE							
Tetrastichus brontispae	L,PP, P	Java via Samoa	1982	NT	(+)		Fenner 1984, 1992
			1982	Qld	–		Fenner 1992
		Java via New Caledonia	1984	NT	+	++	Waterhouse & Norris 1987; Fenner 1992
		Guam	1994	Qld	+	+++	K. Halfpapp pers. comm.
				NT	+	+	D. Chin pers. comm. 1998; K. Halfpapp pers. comm.
				WA	?		K. Halfpapp pers. comm.
62. *Bruchus pisorum* Coleoptera: Chrysomelidae							peas
HYMENOPTERA							
BRACONIDAE							
Triaspis thoracicus	L	France	1939	WA	–		Jenkins 1946
		USA	1942	WA	–		Wilson 1960

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated	Est.	Eff.	Host(s) References
63. canegrubs: *Antitrogus* spp., *Dermolepida albohirtum*, *Lepidiota* spp., *Rhopaea magnicornis* Coleoptera: Scarabaeidae						sugarcane
DIPTERA						
TACHINIDAE						
Microphthalma michiganensis	L	Canada	Qld	1931–33	–	Wilson 1960; P. Allsopp pers. comm.
HYMENOPTERA						
SCOLIIDAE						
Campsomeris aureicollis	L	Philippines	Qld	1931–32	–	K. Chandler pers. comm.
Campsomeris marginella	L	Philippines	Qld	1931	–	Wilson 1960
BACTERIA						
Bacillus popilliae	L	Japan	Qld	1942–43	+	++ Wilson 1960; Agnew 1997
FUNGI						
Botrytis tenella	L	France	NSW, Qld	1894	+	+ Wilson 1960
Metarhizium anisopliae	L	Samoa	Qld	ca 1914	+	++ Wilson 1960; Agnew 1997
AMPHIBIA						
Bufo marinus	A	South America via Hawaii	Qld	1935–36	+	– Wilson 1960

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
64. *Cosmopolites sordidus* Coleoptera: Curculionidae							banana
COLEOPTERA							
HISTERIDAE							
Hololepta quaridentata			1934	NSW	–		CSIRO file B1/19
Plaesius javanus	L,P	Java	1921–24	Qld	–		Weddell 1932; Clausen 1978a
			1926, 1928		(+)		
		Java	1922	NSW	–		
		Java via Fiji	1924		–		Wilson 1960
		Fiji	1934	NSW	(+)		CSIRO file B1/19
HYDROPHILIDAE							
Dactylosternum hydrophiloides	L,P	Malaysia	1939	Qld	+	+	Smith 1944; CSIRO file B1/19; Wilson 1960
			1940–41	NSW	+	+	
DIPTERA							
RHAGIONIDAE							
Chrysopilus ferruginosus	L,P	Java	1928	Qld	–		Wilson 1960
65. *Ips grandicollis* Coleoptera: Curculionidae							*Pinus* spp.
COLEOPTERA							
CLERIDAE							
Thanasimus dubius	L,A	USA	1982–90	mainland States	–		Neumann 1987; Ips Committee 1990

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
TROGOSSITIDAE							
Temnoscheila virescens	E,L,A	USA	1984–90	mainland States	?		Neumann 1987; Ips Committee 1990; Lawson & Morgan 1992, 1993
HYMENOPTERA							
BRACONIDAE							
Coeloides sympitus	L	USA	?1983	SA	–		S. Lawson pers. comm.
Dendrosoter sulcatus	L,P	USA	1984–90	mainland States	+	?	Neumann 1987; Ips Committee 1990
PTEROMALIDAE							
Dinotiscus dendroctoni	L	USA	1982	SA	–		Ips Committee 1990
Rhopalicus pulchripennis	L	USA	1983	Vic	–		Ips Committee 1990
Roptrocerus xylophagorum	L,PP, P	USA	1982–90	mainland States	+	++	Samson & Smibert 1986; Neumann 1987; Ips Committee 1990; Lawson 1993
66. *Listroderes difficilis* Coleoptera: Curculionidae							polyphagous
DIPTERA							
TACHINIDAE							
Epiplagiops littoralis	L	Argentina, Uruguay	1958	ACT	–		Wilson & Wearne 1962
HYMENOPTERA							
ICHNEUMONIDAE							
Stethantyx argeninensis	L	Argentina, Uruguay	1958	ACT, NSW, Qld	?		Wilson & Wearne 1962
Stethantyx parkeri	L	Argentina, Uruguay	1959	ACT	+	+	CSIRO files
			1961–62	all mainland States			

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Stethantyx n.sp.	L	Argentina, Uruguay	1963–64	ACT, NSW, Vic	?		CSIRO reports 1960–61 to 1964–65
67. *Pyrrhalta luteola* Coleoptera: Chrysomelidae							elm
HYMENOPTERA							
EULOPHIDAE							
Oomyzus gallerucae	E	Europe via California	1990–92	Vic	(+)		Field & Kwong 1994; Kwong & Field 1994; New 1994
68. *Rhabdoscelus obscurus* Coleoptera: Curculionidae							sugarcane
DIPTERA							
TACHINIDAE							
Lixophaga sphenophori		Papua New Guinea	1896	Qld	+	+	Wilson 1960
			1910				
		Fiji	1914				
FUNGI							
Metarhizium anisopliae (#)	L	Samoa	ca 1914	Qld	+	+	Wilson 1960
AMPHIBIA							
Bufo marinus (#)	A	South America via Hawaii	1935–36	Qld	+	–	Wilson 1960

(#) introduced against canegrubs (Scarabaeidae)

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
69. *Sitona discoideus* Coleoptera: Curculionidae							medic pastures, lucerne
HYMENOPTERA							
BRACONIDAE							
Microctonus aethiopoides	A	Morocco	1977–79	ACT	+	+	Cullen & Hopkins 1982; Hopkins 1982, 1984, 1989; Aeschlimann 1983a
			1979–81	NSW, SA			
		Greece	1979–81	ACT, NSW, SA	+	+	Aeschlimann 1983a, 1995
MYMARIDAE							
Anaphes diana	E	France, Greece, Syria	1976–89	SA	–		Aeschlimann 1989; Aeschlimann et al. 1989
			1977–83	NSW, ACT	(+)		
			1981	Vic	–		
FUNGI							
HYPHOMYCETALES							
Beauveria bassiana	L,P	France	1982	SA	–		Bailey & Milner 1985
NEMATODA							
HETERORHABDITIDAE							
Heterorhabditis heliothidis	L	NZ	1982	SA	–		Bailey & Milner 1985

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
70. *Bactrocera tryoni* Diptera: Tephritidae							many fruits, some vegetables
HYMENOPTERA							
BRACONIDAE							
Biosteres fullawayi	L	Nigeria via Hawaii	1933	NSW	–		Noble 1942
Diachasmimorpha longicaudata	L	SE Asia via Hawaii	1956–57	NSW	–		Snowball et al. 1962b
			1958–59	Qld, NSW	+	+	Snowball 1966; G.J. Snowball & R.G. Lukins unpubl. 1964
Fopius arisanus	E,L	Malaysia via Hawaii	1956–57	NSW	–		Snowball et al. 1962b
			1958–59	Qld, NSW	+	+	Snowball 1966; G.J. Snowball & R.G. Lukins unpubl. 1964
Fopius vandenboschi	L	SE Asia via Hawaii	1956–59	Qld, NSW	–		Snowball et al. 1962b; Snowball & Lukins 1964
Psyttalia concolor	L	South Africa via Hawaii	1932	NSW	–		Noble 1942
Psyttalia incisi	L	SE Asia via Hawaii	1956–59	Qld, NSW	–		Snowball et al. 1962b; Snowball & Lukins 1964
CHALCIDIDAE							
Dirhinus anthracina	L	W. Africa via Hawaii	1958–59	Qld, NSW	?		Snowball et al. 1962b; Snowball & Lukins 1964
EULOPHIDAE							
Aceratoneuromyia indica	L	India	1937–38	NSW, Qld	–		Snowball et al. 1962b; Snowball & Lukins 1964
			1958–59	Qld, NSW	–		
Tetrastichus giffardianus	P	W. Africa via Hawaii	1932–33	NSW	–		Noble 1942
			1958–59	NSW	?		Snowball & Lukins 1964

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated	Est.	Eff.	Host(s) References
71. *Ceratitis capitata* Diptera: Tephritidae						many fruits, some vegetables
COLEOPTERA						
STAPHYLINIDAE						
unidentified spp.	PP,P	Brazil	1904–05	WA	–	Wilson 1960
HYMENOPTERA						
BRACONIDAE						
Biosteres fullawayi	L	Nigeria via Hawaii	1933	NSW	–	Noble 1942
Diachasmimorpha longicaudata	L	SE Asia via Hawaii	1956–59	NSW, WA	–	Snowball et al. 1962b
Diachasmimorpha tryoni	L	Qld	1901, 1913	WA	–	Wilson 1960
		Australia via Hawaii	1932–33	NSW	+	? Noble 1942
Doryctobracon areolatus	L	Brazil	1904	WA	–	Wilson 1960
Fopius arisanus	E,L	Malaysia via Hawaii	1956–59	NSW, WA	–	Snowball et al. 1962b
Fopius vandenboschi	L	SE Asia via Hawaii	1956–59	NSW, WA	–	Snowball et al. 1962b
Opius bellus	L	Brazil	1904	WA	–	Wilson 1960
Psyttalia concolor	L	South Africa via Hawaii	1932	NSW	–	Noble 1942
Psyttalia incisi	L	South Africa via Hawaii	1956–59	NSW, WA	–	Snowball et al. 1962b
unidentified sp.		India	1907	WA	–	Wilson 1960
CHARIPIDAE						
Trybliographa braziliensis	L	Brazil	1904	WA	–	Wilson 1960

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
EULOPHIDAE							
Aceratoneuromyia indica	L	India	1908–10	WA	–		Wilson 1960
		India	1937–38	NSW, Qld	–		
Tetrastichus giffardinus	P	Nigeria via Hawaii	1932–39	NSW	–		Noble 1942
		Nigeria via Hawaii & Fiji	1936	NSW	–		Wilson 1960
unidentified sp.	L	India	1907	WA	–		Wilson 1960
72. *Haematobia exigua* Diptera: Muscidae							cattle, horses
COLEOPTERA							
HISTERIDAE							
Hister calidus	E,L	South Africa	1971	Qld, NSW, WA, NT	+	–	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Hister cruentus	E,L	South Africa	1972	NSW	+	–	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Hister nomas	E,L	South Africa via Hawaii	1967	Qld, NSW	+	+	Legner 1978; J. Feehan pers. comm.
Pactolinus caffer	E,L	South Africa via Hawaii	1968	Qld	+	–	Tyndale-Biscoe 1996
Pactolinus chinensis	E,L	Indonesia via Fiji	1944–46	Qld	+	–	Legner 1978; Bornemissza 1976; Tyndale-Biscoe 1996
			1961–62		+		
SCARABAEIDAE							
Coptis elphenor	E,L	southern Africa	1977	Qld	+	+	Tyndale-Biscoe 1996
Eouniticellus africanus	E,L	South Africa	1972	NSW	+	+	Tyndale-Biscoe 1996

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Euoniticellus intermedius	E,L	South Africa	1971	Qld, NSW	+	+++	Tyndale-Biscoe 1996
Liatongus militaris	E,L	South Africa via Hawaii	1968	Qld, NSW	+	+	Tyndale-Biscoe 1996
Onitis alexis	E,L	South Africa, Malawi, Mozambique, Zimbabwe	1972	Qld, NSW	+	+++	Tyndale-Biscoe 1996
Onitis pecuarius	E,L	South Africa	1976	Qld	+	+	Tyndale-Biscoe 1996
Onitis viridulus	E,L	South Africa	1976	Qld, NSW	+	+	Tyndale-Biscoe 1996
Onthophagus binodis	E,L	South Africa	1971	Qld, NSW, WA, NT	+	+	Tyndale-Biscoe 1996
Onthophagus gazella	E,L	South Africa, Africa via Hawaii	1967	Qld	+	++	Tyndale-Biscoe 1996
Onthophagus nigriventris	E,L	Kenya	1975	Qld	+	+	Tyndale-Biscoe 1996
Onthophagus sagittarius	E,L	Sri Lanka via Hawaii	1968	Qld	+	+	Tyndale-Biscoe 1996
Sisyphus rubrus	E,L	South Africa	1973	Qld, NSW	+	+	Tyndale-Biscoe 1996
Sisyphus spinipes	E,L	South Africa	1972	Qld, NSW	+	++	Tyndale-Biscoe 1996
HYMENOPTERA							
PTEROMALIDAE							
Spalangia nigroaenea	P	Java	1932–33	NT, WA	(+)	–	Wilson 1960
ACARI							
MACROCHELIDAE							
Macrocheles peregrinus	E	South Africa	1980	Qld, NT	+	+	Wallace & Holm 1983
			1981				

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
73. *Lucilia cuprina* Diptera: Calliphoridae							sheep, carrion
DIPTERA							
SARCOPHAGIDAE							
unnamed sp.		Japan via Hawaii	1911	WA	–		Wilson 1960
HYMENOPTERA							
BRACONIDAE							
Alysia manducator		England	1928–29	NSW, WA	–		Newman 1928; Wilson 1960
		NZ	1928–29	NSW, WA	–		Wilson 1960
Aphaereta aotea (#)		NZ	1976	NSW	+	–	Hughes & Woolcott 1976
CHALCIDIDAE							
Brachymeria podagrica (U)					+	–	JBC 1933
Dirhinus anthracia (U)					+	–	Wilson 1960
PTEROMALIDAE							
Nasonia vitripennis (U)					+	+	Wilson 1960
Spalangia endius (U)					+	–	Wilson 1960

(#) introduced against *Musca vetustissima*

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
74. mosquitoes Diptera: Culicidae							humans, livestock
PISCES							
CYPRINIDAE							
Carassius auratus (U)	L				+	+	Wilson 1960
PERCIDAE							
Perca fluviatilis (U)	L				+	+	Wilson 1960
POECILIIDAE							
Gambusia holbrooki (U)	L	Italy	1926	NSW, Qld	+	++	Wilson 1960
Heterandria formosa (U)	L		1925	NSW, Qld	+	+	Wilson 1960
Poecilia reticulata (U)	L		1929	Qld	+	+	Wilson 1960
75. *Musca vetustissima* Diptera: Muscidae							humans, livestock
COLEOPTERA							
HISTERIDAE							
Hister calidus	E,L	South Africa	1971	(see text)	–		Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Hister cruentus	E,L	South Africa	1972		–		Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Hister nomas	E,L	Africa via Hawaii	1967		+	++	Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Pactolinus caffer	E,L	Africa via Hawaii	1968		+	+	Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Pactolinus chinensis	E,L	Java via Fiji	1967		+	?	Bornemissza 1976; Tyndale-Biscoe 1996

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
SCARABAEIDAE							
Allogymnopleurus thalassinus	E,L	South Africa	1979		–		Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Aphodius lividus (U)	E,L	?South Africa	?		+	+	Snowball 1941; Ridsdill-Smith & Hall 1984; Ridsdill-Smith et al. 1989
Bubas bison	E,L	France, Spain, Turkey	1983		+	+	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Canthon humectus	E,L	Mexico via Hawaii	1969		–		Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Chironitis scabrosus	E,L	South Africa	1972		–		Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Copris bornemisszai	E,L	Zimbabwe	1977		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Copris diversus	E,L	Kenya	1976		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Copris elphenor	E,L	southern Africa	1977		+	+	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Copris fallaciosus	E,L	Kenya	1977		–		Bornemissza 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Copris hispanus	E,L	France, Spain	1983		+	+	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Copris incertus	E,L	Mexico	1969		+	?	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Copris lunaris	E,L	France	1983		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Euoniticellus africanus	E,L	South Africa	1971		+	+	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Euoniticellus fulvus	E,L	France, Turkey	1978		+	+++	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Euoniticellus intermedius	E,L	South Africa	1971		+	+++	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Euoniticellus pallipes	E,L	Iran, Turkey	1977		+	++	Bornemissza 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Geotrupes spiniger	E,L	France	1979		+	++	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Liatongus militaris	E,L	South Africa via Hawaii	1968		+	+	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis alexis	E,L	Malawi, Mozambique, South Africa, Zimbabwe	1972		+	+++	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis aygulus	E,L	South Africa	1977		+	+	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis caffer	E,L	South Africa	1979		+	+	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis deceptor	E,L	South Africa	1979		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis pecuarius	E,L	South Africa	1976		+	++	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis tortuosus	E,L	South Africa	1976		+	?	Bornemissza 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis uncinatus	E,L	South Africa	1979		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis vanderkelleni	E,L	Kenya	1974		+	+	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Onitis viridulus	E,L	South Africa	1976		+	+	Bornemissza 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onitis westermanni	E,L	Zimbabwe	1977		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus binodis	E,L	South Africa	1971		+	+++	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus bubalus	E,L	South Africa	1972		–		Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus cameloides	E,L	South Africa	1980		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus depressus (U)	E,L	South Africa	<1900		+	–	Waterhouse 1974; Doube et al. 1991
Onthophagus foliaceus	E,L	Angola	1975		–		Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus gazella	E,L	South Africa	1968		+	+++	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus nigriventris	E,L	Kenya	1974		+	++	Bornemissza 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus obliquus	E,L	Nigeria	1976		+	+++	Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus opacicollus	E,L	Greece	1982		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus sagittarius	E,L	Sri Lanka via Hawaii	1968		+	+	Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus taurus	E,L	Greece, Italy, Spain, Turkey	1975		+	+++	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Onthophagus vacca	E,L	France	1980		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
Sisyphus fortuitus	E,L	South Africa	1976		–		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Sisyphus infuscatus	E,L	South Africa	1976		+		Tyndale-Biscoe 1996; J. Feehan pers. comm.
Sisyphus mirabilis	E,L	South Africa	1972		–		Bornemissza 1976; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Sisyphus rubrus	E,L	South Africa	1973		+	+++	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
Sisyphus spinipes	E,L	South Africa	1972		+	+++	Bornemissza 1976, 1979; Tyndale-Biscoe 1996; J. Feehan pers. comm.
HYMENOPTERA							
BRACONIDAE							
Aphaereta aotea	L	NZ	1973–74	NSW	–		Hughes & Woolcott 1978
ACARI							
MACROCHELIDAE							
Macrocheles peregrinus	E,L	South Africa	1980–81	NT, Qld	+	++	Wallace & Holm 1983
76. *Stomoxys calcitrans* Diptera: Muscidae							horses, cattle, dogs
HYMENOPTERA							
PTEROMALIDAE							
Spalangia nigroaenea	P	Java	1932–33	NT	(+)	–	Wilson 1960; Legner 1978

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
77. armyworms/cutworms Lepidoptera: Noctuidae							crops, pastures, pine seedlings
unidentified		Orient	1909	WA	?		Newman 1909
HYMENOPTERA							
BRACONIDAE							
Cotesia kazak	L	Greece	1983	WA	+	+	Michael et al. 1984
Cotesia marginiventris	L	USA	1982	WA	+	+	Titmarsh 1980; Michael et al. 1984
Cotesia ruficrus	L	Pakistan	1979–83	WA	+	++	Michael 1973, 1989; Learmonth 1981
	L	Pakistan via NZ	1979	Qld	+	?	Broadley 1986
ICHNEUMONIDAE							
Campoletis chlorideae	L	Pakistan	1982–83	WA	+	+	Titmarsh 1980; Michael et al. 1984
Hyposoter didymator	L	Greece	1983	WA	+	+	Titmarsh 1980; Michael et al. 1984
	L	WA	1991	Vic, Qld	+	?	Ridland et al. 1993
SCELIONIDAE							
Telenomus remus	E	SE Asia	1982	WA	?		Michael et al. 1984
	E	Dominican Republic	1982	WA	?		Michael et al. 1984
TRICHOGRAMMATIDAE							
Trichogramma sp.	E	USA		WA	?		Michael et al. 1984
78. *Cryptophlebia ombrodelta* Lepidoptera: Tortricidae							macadamia, lychee
HYMENOPTERA							
EULOPHIDAE							
Elachertus nr *lateralis*		China	1993–94	Qld	+	?	Waite & Elder 1996

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
79. *Cydia pomonella* Lepidoptera: Tortricidae							apple, pear, quince
HYMENOPTERA							
BRACONIDAE							
Ascogaster quadridentatus	E	Canada	?1964	?	–		Clausen 1978a
ICHNEUMONIDAE							
Liotryphon caudatus	L	Spain via California	1904–05	WA	–		Johnston 1928; Wilson 1960
TRICHOGRAMMATIDAE							
Trichogramma minutum (U)	E	Spain via California	1928	Qld, NSW	+	–	Wilson 1960
80. *Grapholita molesta* Lepidoptera: Tortricidae							peach, nectarine, quince
HYMENOPTERA							
BRACONIDAE							
Ascogaster carpocapsae	E	France, Italy via USA	1937–38	Vic	–		Helson 1947
Macrocentrus ancylivora	L	USA	1935–41	Vic	–		Helson 1947
			1939	NSW	–		Wilson 1960; CSIRO files
			1977–78	SA	–		Bailey 1979
Macrocentrus delicatus	L	USA		Vic	–		Helson 1947
ICHNEUMONIDAE							
Agathis diversus	L	Japan via USA	1937	Vic	–		Helson 1947
Glypta rufiscutellaris	L	USA	1938	Vic	–		Helson 1947
Diadegma molestae	L	Japan, Korea via USA	1937–40	Vic	–		Helson 1947

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated	Est.	Eff.	Host(s) References
81. *Helicoverpa armigera* 82. *Helicoverpa punctigera* Lepidoptera: Noctuidae						maize, cotton, grains, legumes, sorghum, vegetables, tobacco grain legumes
HYMENOPTERA						
BRACONIDAE						
Cotesia kazak	L	Greece	1983	WA	+	+	Michael et al. 1984; Michael 1989; Ridland et al. 1993
		NZ, WA	1991	Vic, Qld	?		Ridland et al. 1993
Cotesia marginiventris[a]	L	USA	1982	WA	+	+	Michael 1989
Cotesia ruficrus	L	Pakistan	1979	WA	+	+	Michael 1973, 1989
		NZ	1983	WA	+	+	
ICHNEUMONIDAE						
Campoletis chlorideae[a]	L	Pakistan	1982	WA	+	+	Michael et al. 1984
Hyposoter didymator	L	Greece	1983	WA	+	+	Michael 1989
	L	WA	1991	Vic	?		Ridland et al. 1993
	L	WA	1991	Qld	?		Ridland et al. 1993; D.A.H Murray pers. comm.
SCELIONIDAE						
Telenomus remus	E	SE Asia	1982	WA	?		Michael et al. 1984
	E	Dominican Republic	1982	WA	?		
TRICHOGRAMMATIDAE						
Trichogramma pretiosum	E	USA	1974	WA	+	++	Michael et al. 1984; Strickland & Lacey 1996; B.C.G. Scholz pers. comm.
		WA	1995	Qld	+	++	

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
FUNGI							
Beauveria bassiana (commercial strain)	L	USA	1994	NSW	–		R.K. Mensah pers. comm.
[a]recovered only from *Helicoverpa punctigera* (Waterhouse & Norris 1987)							
83. *Hellula undalis* Lepidoptera: Pyralidae							Brassicaceae
HYMENOPTERA							
BRACONIDAE							
unidentified		India	1907	WA	–		Jenkins 1946; Wilson 1960
84. *Oncopera* spp. Lepidoptera: Hepialidae							grassy pastures
DIPTERA							
TACHINIDAE							
Hexamera alcis	L	NZ	1932	Vic	–		CSIR 1932–1939; Wilson 1960
			1934–39				
Protohystrichia orientalis			1939	ACT	–		
85. *Phthorimaea operculella* Lepidoptera: Gelechiidae							potato, tobacco, tomato
HYMENOPTERA							
BRACONIDAE							
Agathis unicolorata	L	S. America via India	1967–70	E. Australia	–		CSIRO 1967–1970

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Apanteles subandinus	L	S. America via California	1965–69	all States except WA, Tas	+	+++	CSIRO 1966; Oatman 1978a
		S. America via India	1965–69		+	+++	CSIRO 1967–1969
		S. America via California	1965–69		+	+++	CSIRO 1967–1969
Bracon gelechiae	L	S. America via California	1944–49	all States	–		Wilson 1960
Chelonus phthorimaeae	L	S. America via California	1944–49	all States except WA	–		Wilson 1960
Orgilius lepidus	L	S. America via India	1965–69	all eastern States	+	++	CSIRO 1966–1970; Oatman 1978a
ENCYRTIDAE							
Copidosoma desantisi	E	Chile via California	1946–49	NSW, ACT, Vic	+	++	Wilson 1960
Copidosoma koehleri	E	Uruguay via California	1964–68	all mainland States	+	+	CSIRO 1966–1969
ICHNEUMONIDAE							
Campoplex haywardi	L	S. America via India	1968–71	Qld, NSW, Vic	–		CSIRO 1969–1971
Campoplex phthorimaeae	L	S. America via California	1947–49	NSW, ACT, Vic	–		Wilson 1960
Temelucha minuta	L	S. America via India	1968–69		–		CSIRO 1968–1970

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
86. *Phyllocnistis citrella* Lepidoptera: Gracillariidae							citrus
HYMENOPTERA							
ENCYRTIDAE							
Ageniaspis citricola	L	Thailand	1983		–		Beattie & Smith 1993; Smith 1997a
			1992	Qld	+	+++	
				NSW, VIC, SA	–		Neale et al. 1995; Smith 1997a
EULOPHIDAE							
Cirrospilus ingenuus	L	S. China	1983–88		–		Neale et al. 1995; Smith 1997a; Smith et al. 1997a
			1992	Qld	+	+	
				NSW	(+)		
				Vic, SA	?		
			1996–97	WA, NT	?		
Citrostichus phyllocnistoides	L	S. China	1983–88		–		Smith et al. 1997a
			1992	Qld	+	+	Smith 1997a
Semielacher petiolatus	L	Qld	1994	Vic, SA, WA	+	++	Smith 1997a
87. *Pieris rapae* Lepidoptera: Pieridae							brassicas
HYMENOPTERA							
BRACONIDAE							
Cotesia glomerata	L	Canada	1942	ACT	+	+	Wilson 1960
		UK	1943–50	all States			
Cotesia rubecula	L	Switzerland	1943	Tas	–		Miller & Hudson 1953
			1949–51	ACT, all States	+	+	Edwards 1951; Wilson 1960; Anon. 1981

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
PTEROMALIDAE							
Pteromalus puparum (U)	P	NZ	1941–44	Vic	+	++	Fish 1945; Wilson 1960
			1943	Tas, WA	+	++	Miller 1947, 1949b; Wilson 1960; Anon. 1981
			1945	SA	+	++	Strickland 1945
88. *Plutella xylostella* Lepidoptera: Plutellidae							Brassicaceae
HYMENOPTERA							
BRACONIDAE							
Cotesia plutellae	L	Italy	1951–55		+	+	Wilson 1960; Yarrow 1970
ICHNEUMONIDAE							
Diadegma fenestrale	L	UK via NZ	1938–39		–		Wilson 1960
Diadegma semiclausum	L	UK via NZ	1947–51		+	+++	Wilson 1960; Goodwin 1979; Hamilton 1979a
Diadromus collaris	L,P	Netherlands via NZ	1947–51		+	+	Wilson 1960; Yarrow 1970
		Italy	1951–52		+	+	
Nythobia tibialis	L	Italy	1951–52		–		Wilson 1960
unidentified 2 spp.[a]		NSW	1902		+	?	Wilson 1960
unidentified 2 spp.		Spain	1903		+	?	Wilson 1960
unidentified sp.		Sri Lanka	1907		?		Wilson 1960
unidentified sp.		India	1908		+	?	Wilson 1960
unidentified sp.		China	1909		?		Wilson 1960

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
TRICHOGRAMMATIDAE							
Trichogramma minutum (#)[b]	E		1927–28		–		Veitch 1928, 1931; Wilson 1960
Trichogramma pretiosum (#)[c]	E	USA	1974		+	++	Liu 1998
[a]it is probable that one of these was *Diadegma rapi* (Wilson 1960) (#) introduced against [b]*Cydia pomonella*; [c]*Helicoverpa* spp.							
89. *Sitrotroga cerealella* Lepidoptera: Gelechiidae							stored grain
HYMENOPTERA							
ICHNEUMONIDAE							
2 spp.	L	Spain	1903	WA	?		Compere 1903; Wilson 1960
90. *Caliroa cerasi* Hymenoptera: Tenthredinidae							cherry, pear
HYMENOPTERA							
ICHNEUMONIDAE							
Polyblastus phygadeuontoides	L	France, ? UK	? 1928	NSW	–		Wilson 1960
91. *Sirex noctilio* Hymenoptera: Siricidae							*Pinus radiata*
HYMENOPTERA							
IBALIIDAE							
Ibalia leucospoides leucospoides	E,L	UK via NZ	1959–60		+	+++	Taylor 1967a, 1976
		Europe, Morocco, Turkey	1963–72		+	?	
Ibalia leucospoides ensiger		Canada, USA	1963–72		+	?	Taylor 1967a, 1976
Ibalia rufipes rufipes	E,L	Canada	1963–72		+	?	Taylor 1976

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Ibalia rufipes drewseni	E,L	Europe, Turkey	1963–72		+	+	Taylor 1967a, 1976
ICHNEUMONIDAE							
Megarhyssa nortoni nortoni	L	USA	1965–67		+	++	Taylor 1967a
Megarhyssa nortoni quebecensis	L	Canada	1965–67		?		
Megarhyssa praecellens	L	Japan	1972		–	–	Taylor 1976
Odontocolon geniculatum	L	Europe	1965–70		?		Taylor 1976
Rhyssa hoferi	L	USA	1963–66		+	–	Taylor 1981
Rhyssa lineolata	L	N. America via NZ	1962–72		–	–	Taylor 1967a
Rhyssa persuasoria persuasoria	L	UK via NZ	1957		+	++	Taylor 1967a, 1976
		Europe, Morocco, Turkey, Japan, USA	1963–72		+	++	
Rhyssa peruasoria himalayensis	L	Canada, India	1963–72		+	++	Taylor 1967a, 1976
STEPHANIDAE							
Schlettererius cinctipes	L	USA	1967		+	+	Taylor 1967a,b
NEMATODA							
NEOTYLENCHIDAE							
Beddingia siricidicola	L,PP, P	Hungary	1970		+	+++	Bedding 1993
92. *Vespula germanica* 93. *Vespula vulgaris* Hymenoptera: Vespidae							nuisance pests
HYMENOPTERA							
ICHNEUMONIDAE							
Sphecophaga vesparum	PP,P	Europe	1989	Vic, Tas, SA	?		Field & Darby 1991

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
94. *Boophilus microplus* Acari: Ixodidae							cattle
AVES							
ARDEIDAE							
Ardea ibis	L,N,A	UK	1933	WA	–		Jenkins 1946; Wilson 1960
95. *Halotydeus destructor* Acari: Penthaleidae							legume pastures
ACARI							
ANYSTIDAE							
Anystis wallacei	L,A	France	1965	WA	+	++	Waterhouse 1978; Wallace 1981
		WA	1976	Vic	–		Berg 1991
		WA	1991	Vic	–		Berg 1991
		WA	1993	Vic	+	?	Gardner & Gardner 1994
		WA	1993	Tas	?		Ireson & Webb 1995
96. *Panonychus ulmi* Acari: Tetranychidae							apple, pear, plum
ACARI							
PHYTOSEIIDAE							
Galendromus occidentalis (U)	E,L,A	USA	<1969		+	++	Readshaw et al. 1982
Galendromus occidentalis (#)			1971–75	all mainland States	+	++	
			1977–78	Tas	+	++	
Phytoseiulus persimilis (U)	E,L,A	?			+	+	Waite 1998a,b

Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc. (for explanation of abbreviations and symbols, see pp. 26–27).

Target **Biological control agent**	**H.S.**	**Origin of agent**	**Liberated**		**Est.**	**Eff.**	**Host(s)** **References**
Typhlodromus pyri (U)	E,L,A	NZ	<1969		?		
			1974–77	ACT	+	+++	Readshaw et al. 1982
				NSW	+	+++	Readshaw et al. 1982; Bower 1984
			1978	Tas	+	+++	Williams 1978
(#) introduced against *Tetranychus urticae*							
97. *Tetranychus urticae* Acari: Tetranychidae							fruit trees, cotton, vegetables etc.
ACARI							
PHYTOSEIIDAE							
Galendromus occidentalis (U)	E,L,A	USA	<1969		+	+++	Field 1974, 1976, 1978; Readshaw 1975b, 1979;Williams 1978; Thwaite & Bower 1980; Anon. 1981; J.L. Readshaw pers. comm.
			1971–73	ACT			
			1973–77	all mainland States			
			1974–78	Tas			
Neoseiulus fallacis	E,L,A	USA via NZ	1976	Tas	–		Williams 1978; Readshaw 1979
Phytoseiulus persimilis (U)	E,L,A		1975	Vic	+	++	Goodwin & Schicha 1979; Ridland et al. 1986; Waite 1988a,b; Gough 1991; J.L Readshaw pers. comm.
Typhlodromus pyri (#)	E,L,A	NZ	1975–77	ACT, NSW	+	+	Williams 1978; Readshaw 1979; Readshaw et al. 1982
			1976–78	Tas	+	+	
(#) introduced against *Panonychus ulmi*							

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Table 1. (cont'd) Target, including incidental target (†), pests and natural enemies released etc.
(for explanation of abbreviations and symbols, see pp. 26–27).

Target Biological control agent	H.S.	Origin of agent	Liberated		Est.	Eff.	Host(s) References
98. *Ommatoiulus moreleti* Diplopoda: Julidae							house intruder
DIPTERA							
SCIOMYZIDAE							
Pelidnoptera nigripennis	L	Portugal	1988	SA	–		Bailey 1989

Details of biological control projects

1

Sminthurus viridis (Linnæus) Collembola: Sminthuridae clover springtail, lucerne flea

PRECIS

Sminthurus viridis has been known as a pest in Australia since 1884 and occurs widely in southern States. It is a pest of legume pastures.

In 1931 the European bdellid mite, *Bdellodes lapidaria*, was found to be a predator of lucerne flea in Western Australia. The mite was then distributed throughout southern Australia until it was found to be already established there. Clover springtail numbers have diminished where the predatory mite is present.

Because *B. lapidaria* does not occur in the drier portion of the range of the clover springtail, another predaceous mite, *Neomolgus capillatus*, which could tolerate these dry conditions, was introduced from Morocco and France and became established in 1969. The clover springtail is now seldom a problem where adequate numbers of predatory mites occur.

BIOLOGY

Sminthurus viridis, of European origin, was first recorded as a pest in 1884 in South Australia (Molineaux 1896; Summers 1900). Later, it was recorded in Western Australia (1910: Newman 1927, 1934a,b), Victoria (Pescott 1937) and Tasmania (Nicholls 1930). It now occurs in Australia throughout regions where there is a Mediterranean-type climate with its winter rainfall (Wallace and Mahon 1971).

The greenish-yellow adult has a globular body and is up to 2.5 mm long. It normally moves by walking but, when disturbed, is able to jump about 30 cm by releasing a ventral, rear-attached organ called the spring or furca — hence the insect's common name.

The male attaches a spermatophore by a stalk to the soil or low vegetation. The female later straddles the spermatophore to pick it up into her genital opening. The lucerne flea is active during the cool moist period of the year, with females laying batches of about 40 winter eggs on the soil. These proceed to develop through three to nine instars; three generations are produced each winter

(Wallace 1968; Ridsdill-Smith 1991a). In spring, drought and temperature-resistant diapause eggs are produced. These do not hatch until the following autumn after exposure to low temperatures and adequate soil moisture (Wallace 1967, 1968). Populations build up in autumn and there is a winter trough, followed by a second peak in spring (Wallace 1967).

PEST STATUS

S. viridis is not generally considered as a pest in its native Europe but, for many years, it was regarded as a major pest in Victoria, Tasmania, South Australia and Western Australia (Allen 1987). It has a preference for leguminous plants such as clovers and lucerne and rapidly increased in abundance when subterranean clover (*Trifolium subterraneum*) was sown widely in improved pastures from the 1940s onwards. It can cause high mortality of annual pastures if the diapausing eggs hatch at the time of seed germination. *S. viridis* is abundant on cape weed (*Arctotheca calendula*) and damages other soft-leaved plants. It sometimes attacks vegetable seedlings and young barley, oats and wheat (Swan 1940).

S. viridis has biting mouthparts. Young individuals eat out small, isolated patches from host-plant leaves, resulting in a speckled appearance. Older insects remove much of the upper cuticle of the leaf and the cell contents, leaving only the veins.

BIOLOGICAL CONTROL

Together with two other pasture pests that are often associated with it (the redlegged earth mite, *Halotydeus destructor*, and the blue oat mite, *Penthaleus major*), *S. viridis* lives in an environment where there are mites and many other insects. Although no parasitoids are known, a number of predators, especially mites, attack it (Swan 1940). Before 1970, one predator in particular was significant for the clover springtail — the European bdellid mite *Bdellodes lapidaria*. Other predatory mites often present include *B. affinis, B. australica, B. harpax, B. hessei* and *B. symmetricus* (Wallace 1967). *B. symmetricus* has since been recognised to be a mixture of three species, *B. hospita, B. koloseta* and *B. tasmanicus* (Wallace and Mahon 1976). Nothing is recorded about infection in the field by entomopathogenic nematodes, although laboratory trials indicated that the clover springtail is susceptible to *Heterorhabditis heliothidis* and *Steinernema feltiae* (Ireson and Miller 1983).

Womersley (1933) first reported *B. lapidaria* feeding on clover springtail in 1931 in pastures in Western Australia and Currie (1934) noted that the mite exerted a considerable effect on springtail numbers in local patches. In 1932, large numbers of these mites were distributed to farms in Western Australia and sent to infested areas in eastern Australia. However, soon after in 1933, *B. lapidaria* was collected from localities in Victoria far removed from the release sites. Further

distribution was then discontinued, because the mite was evidently already widespread (Wallace 1974), although Ireson (1982) later showed it had a restricted distribution in Tasmania. Norris (1938) made an intensive study in Western Australia over 2 years of the population changes of *Sminthurus* and *Bdellodes* and stated,

> The impression was gained in the field that *Sminthurus* diminished in numbers at the end of the season long before the meterological conditions were sufficiently adverse to account for the fall. It seems possible that the Bdellid mite was at least partly responsible for this early decline.

Wallace (1954, 1967) found that, if *B. lapidaria* numbers in autumn and early winter exceeded 20 per m^2, no severe outbreak of *S. viridis* would develop.

In Western Australia there was thus evidence that the mite reduced clover springtail numbers (Jenkins 1935; Norris 1938). In Victoria there was a reduction in clover springtail numbers where the mite occurred (Pescott 1937) and numbers were believed to be reduced in Tasmania where *B. lapidaria* was present (Evans 1937a, 1939a). At that time, only in South Australia, where mite numbers were generally low, was there no definite evidence of the predatory mite affecting numbers of the springtail, any influence being overshadowed by that of meteorological factors (Swan 1940).

The impact of insecticides on biological control was investigated by Wallace (1954) who top-dressed subterranean clover-dominated pastures in Western Australia with superphosphate mixed either with benzene hexachloride (BHC) or dichlorodiphenyltrichloroethane (DDT). The dominant mite was *B. australica* but a few '*B. symmetricus*' were present. BHC was only moderately toxic to the clover springtail and had no harmful effect on the bdellid mites. By contrast, springtail populations in DDT-treated areas increased over controls due to the elimination of the bdellid mites, which are susceptible to DDT.

Wallace (1967) found that *B. lapidaria* had a more restricted distribution than *S. viridis* in Western Australia and that *S. viridis* extended further into dry regions. Surveys were therefore carried out in western Europe and Morocco to locate any predator(s) that would cover the drier regions. The bdellid mite, *Neomolgus capillatus*, which showed a distinct feeding preference for the clover springtail but would also attack redlegged earth mite, was chosen. A collection from the Netherlands was liberated in Western Australia in 1965, but failed to become established, probably because of mismatching of climates. In 1969, *N. capillatus* collected from Morocco and southern France were liberated in southern Western Australia and there was soon evidence of establishment (Wallace 1974). It was then distributed to other southern States.

Studies by Ireson (1982, 1984) revealed a complex of introduced European predatory mites in Tasmanian pastures. The most important were bdellid mites (particularly *B. lapidaria*), the parasitid mites *Pergamasus longicornis* and

P. quisquiliarum, and the anystid mite *Anystis baccarum*. However, none of these species, either singly or in combination, was able to exert significant control of the clover springtail.

N. capillatus was, therefore, introduced during 1985 to 1990 from the homoclimatic Brittany region of north-western France and released at eight locations in north-western Tasmania, resulting in permanent establishment (Ireson and Paterson 1991). Studies by Ireson and Webb (1994, 1995) showed that *N. capillatus* was soon reducing autumn populations of *S. viridis* by over 90%. However, spread of the predator was very slow. It averaged about 70 m per year under the most favourable conditions in Western Australia, so Michael et al. (1991b) carried out a major redistribution program to over 45 sites from 1988 to 1990. An even more extensive redistribution program was carried out in Tasmania, involving 494 dairy pastures. The predator was established in about 90% of these sites (Ireson and Webb 1996). Excellent control was obtained in autumn, but low activity of *N. capillatus* in spring allowed *S. viridis* numbers to build up. *Anystis wallacei*, which had been established in Western Australia in 1965 primarily against the redlegged earth mite, *H. destructor*, was therefore introduced to north-western Tasmania in 1993. It was predicted that the addition of this predator to that region should result in effective control of *S. viridis* in both spring and autumn (Ireson and Webb 1995).

In south-western Australia, *S. viridis* numbers have been reduced by predatory mites by 60% and vegetative growth and seed yields have more than doubled (Michael 1995). There seems little doubt then that when adequate numbers of predatory mites are present, clover springtail numbers can be suppressed to non-damaging levels.

COMMENTS

The interaction between *S. viridis, H. destructor* (target pest no. 95) and their three major mite predators (*A. wallacei, B. lapidaria* and *N. capillatus*) is a complex one, with a number of obscure features. The two hosts may interfere with each other, and can compete for the same resources. Thus, a reduction in the numbers of one often allows the other to increase. For example, the number of eggs laid by the clover springtail decreases with increasing density of either clover springtail or redlegged earth mite (Walters 1964). Moreover, when the numbers of either clover springtail or redlegged earth mite were suppressed by a selective insecticide, the other pest increased in numbers (Michael 1991), an effect not due to suppression in *B. lapidaria* numbers.

It has been shown that clover springtail numbers may be increased by the presence of the redlegged earth mite predator, *A. wallacei* (hence a reduction in earth mite numbers) and, in the absence of this predator, redlegged earth mite numbers were increased by the presence of *N. capillatus* (hence a reduction in clover springtail numbers) (Michael 1991).

Where the predators *A. wallacei* and *B. lapidaria* are present together, the situation is even more complex. During high clover springtail populations many individuals die due to the massive accumulation of toxic nitrogenous wastes in their body and a further large number by consuming the recently dead bodies of their own species (Wallace 1967). *A. wallacei* also consume recently dead clover springtails, thereby making these less available to being consumed and thus stopping them from contributing to the death of other clover springtails. In some situations, high populations of *A. wallacei* have reduced numbers of *B. lapidaria* (Michael et al. 1991b), possibly by predation or by removing alternative, scarce prey. In other situations, large numbers of both predators have coexisted (Michael et al. 1991a).

MAJOR NATURAL ENEMIES

Bdellodes lapidaria Acari: Bdellidae

An unintentionally introduced species, probably from Europe, this predatory mite was first observed in Western Australia in 1931 (Womersley 1933). It may have been introduced many years earlier, perhaps with its principal host *S. viridis*, because it was discovered in the early thirties to be widely spread in south-western Australia, coastal South Australia, southern Victoria and eastern Tasmania. It is restricted almost entirely to modified habitats and is especially abundant in improved pastures. It often shelters in large numbers under pieces of stick, dead leaves or dry grass. When catching its prey it often attaches a series of silk threads to hold the prey to the substrate whilst it inserts its proboscis and sucks out the juices (Wallace and Mahon 1976).

Eggs of *B. lapidaria* are always in diapause to some extent, with incubation periods at 16°C ranging from 4 to 30 weeks. Diapause development proceeds in both dry and moist eggs at constant temperatures ranging from 16°C to 38°C, but most rapidly at 30°C (Wallace 1971). The effect of this predator is to limit *S. viridis* in the area where it has the potential for major annual outbreaks, to minor and local outbreaks at 3 to 5 year intervals. Even so, local outbreaks can occasionally reach levels where insecticides may be necessary, but only on a very minor scale (Wallace 1967, 1974).

Neomolgus capillatus Acari: Bdellidae

A native of Europe and North Africa, *N. capillatus* favours moist, lush habitats with dense ground covers of clovers, grasses and weeds. It shows a strong feeding preference for Collembola, with a special liking for *S. viridis*. Evidence from its native range suggests that it can tolerate a wide range of climatic zones and should eventually extend into relatively low rainfall areas (< 150 mm) (Wallace 1974; Wallace and Mahon 1976).

2

Acyrthosiphon kondoi Shinji Hemiptera: Aphididae bluegreen aphid

PRECIS

The bluegreen aphid, *Acyrthosiphon kondoi*, probably of eastern Asian origin, was first detected in Australia in 1977. Two parasitoid species of Palaearctic origin (*Aphidius ervi* and *Ephedrus plagiator*) and a third exotic species (*Aphelinus abdominalis*, of European origin, but previously know as a parasitoid of *A. kondoi* in the field in Tasmania) were liberated in New South Wales. *A. ervi* was recovered from *A. kondoi* and became widespread. It is now producing a major reduction in bluegreen aphid numbers in higher rainfall areas. However, it is less effective in drier areas where the bluegreen aphid is still regarded as a major pest of pasture legumes.

BIOLOGY

Acyrthosiphon kondoi is bluegreen from birth and has a life cycle typical of an aphid in which no sexual forms are produced in the field (although males have appeared in cultures). It develops from nymph to 3 mm long adult in 6.4 days at 25°C and in 12 days at 15°C. Its threshold of development lies between 6 and 7°C, it has an optimum development temperature of 20°C (Milne 1978a) and is usually most numerous in autumn and spring.

Before 1975, when it became a serious pest of lucerne in California and New Zealand, *A. kondoi* was known only as a rare aphid in Manchuria (its possible area of origin) and Japan. It was first detected in Australia (Queensland) in May 1977, a few weeks after the discovery of the spotted alfalfa aphid, *Therioaphis trifolii* forma maculata (Carver 1989). It was recorded in Tasmania in October 1977, South Australia in April 1978 and Western Australia in June 1979. It also occurs on Norfolk Island (M. Carver, pers. comm.).

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Pest status

A. kondoi causes young lucerne leaves to become distorted and plants to be stunted and it can transmit alfalfa mosaic virus (Garran and Gibbs 1982). The aphids suck sap mainly from the terminal buds, giving the tops of infested lucerne stems a bunched appearance, with small, stunted leaves and shortened internodes. The leaves turn yellow and die, after which the plants may die from the top downwards. Infestation of lucerne seedlings may result in their death (Goodyer and Walters 1980). In addition to lucerne and clover, hosts of *A. kondoi* include peas, lentils, soybeans, Sturt's desert pea and lupins. It transmits cucumber mosaic virus, a serious disease of narrow-leafed lupins (*Lupinus angustifolius*) (Thackray et al. 1998).

Biological control

A number of the parasitoids, hyperparasitoids and predators of *A. kondoi* (listed in Tables 2, 3 and 4, respectively) also attack other species of aphids.

Overseas searches by American entomologists for effective natural enemies of *A. kondoi* revealed only *Aphidius ervi* and *Ephedrus plagiator* (identified as *Ephedrus nacheri*), both widespread polyphagous braconids of palaearctic origin (González et al. 1978, 1979; M. Carver, pers. comm.). The program against *A. kondoi* in Australia commenced in October 1977 when two parasitoid species were imported, cultured and liberated in New South Wales between 1977 and 1979. These were *A. ervi* (from Japan via USA and New Zealand and cultures also directly from Italy, France and Greece) and *E. plagiator* (from Japan via USA via New Zealand). A population of *A. ervi* was also obtained from Tasmania where it was colonising *Acyrthosiphon pisum spartii*, an innocuous subspecies of *A. pisum* (present well before the arrival of *A. kondoi* or *A. pisum, sensu stricto*) on leguminous shrubs, but not known from aphids on lucerne or clovers. The European (France, Italy, Greece) and/or the Tasmanian introductions became established. The Japanese introductions did not. The Greek consignment proved to belong to *Aphidius urticae* (species group: M. Carver, pers. comm.). *A. ervi* was also supplied to other States (e.g. Tasmania, Anon. 1978; Western Australia, Sandow 1981). A third exotic species, *Aphelinus abdominalis*, was introduced from Tasmania, where it had been found attacking *A. kondoi* in the field (Milne 1986a). *E. plagiator* did not become established. There is no information on the fate of the *A. abdominalis* introduction, although this species is now widespread, but uncommon, in eastern Australia, parasitising aphid species other than *A. kondoi.* It was common, however, as a laboratory contaminant of cultures of *A. kondoi* in 1979 and of other species in 1981 (Carver and Woolcock 1981; M. Carver, pers.comm.).

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Table 2. Parasitoids of pest aphids in Australia (Carver 1984, 2000)

Species	*Acyrthosiphon kondoi*	*Acyrthosiphon pisum*	*Aphis craccivora*	*Aphis gossypii*	*Brevicoryne brassicae*	*Cavariella aegopodii*	*Eriosoma lanigerum*	*Hyperomyzus lactucae*	*Macrosiphum rosae*	*Metopolophium dirhodum*	*Myzus persicae*	*Pentalonia nigronervosa*	*Pineus boerneri*	*Pineus pini*	*Rhopalosiphum maidis*	*Rhopalosiphum padi*	*Therioaphis trifolii*	*Toxoptera aurantii*	*Toxoptera citricidus*	*Tuberculatus annulatus*
HYMENOPTERA																				
APHELINIDAE																				
Aphelinus abdominalis	+	+																		
Aphelinus asychis																	+			
Aphelinus gossypii			+	+					+		+							+		
Aphelinus humilis				+																
Aphelinus mali							+													
Aphelinus subflavescens																				
Aphelinus varipes										+					+	+				
BRACONIDAE																				
Aphidius colemani			+	+							+	+			+	+		+		+
Aphidius ervi	+	+							+	+	+									
Aphidius rhopalosiphi										+						+				
Aphidius rosae									+											
Aphidius salicis						+														
Aphidius similis											+					+				
Aphidius sonchi								+												
Diaeretiella rapae					+						+					+				
Ephedrus persicae											+									
Lysiphlebus fabarum			+																	
Lysiphlebus testaceipes			+												+	+		+		

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Table 2. (cont'd) Parasitoids of pest aphids in Australia (Carver 1984, 2000)

Species	*Acyrthosiphon kondoi*	*Acyrthosiphon pisum*	*Aphis craccivora*	*Aphis gossypii*	*Brevicoryne brassicae*	*Cavariella aegopodii*	*Eriosoma lanigerum*	*Hyperomyzus lactucae*	*Macrosiphum rosae*	*Metopolophium dirhodum*	*Myzus persicae*	*Pentalonia nigronervosa*	*Pineus boerneri*	*Pineus pini*	*Rhopalosiphum maidis*	*Rhopalosiphum padi*	*Therioaphis trifolii*	*Toxoptera aurantii*	*Toxoptera citricidus*	*Tuberculatus annulatus*
Praon exsoletum																	+			
Praon volucre								+												
Tioxys complanatus																	+			

Table 3. Hyperparasitoids of aphid parasitoids (Carver 2000)

Species	*Acyrthosiphon kondoi*	*Acyrthosiphon pisum*	*Aphis craccivora*	*Aphis gossypii*	*Brevicoryne brassicae*	*Cavariella aegopodii*	*Eriosoma lanigerum*	*Hyperomyzus lactucae*	*Macrosiphum rosae*	*Metopolophium dirhodum*	*Myzus persicae*	*Pentalonia nigronervosa*	*Pineus boerneri*	*Pineus pini*	*Rhopalosiphum maidis*	*Rhopalosiphum padi*	*Therioaphis trifolii*	*Toxoptera aurantii*	*Toxoptera citricidus*	*Tuberculatus annulatus*
HYMENOPTERA																				
APHELINIDAE																				
Euryischomyia flavithorax							+				+						+			
CHARIPIDAE																				
Alloxysta australiae			+	+												+				
Alloxysta darci			+								+				+					
Alloxysta fuscicornis			+	+	+	+		+			+				+	+				
Phaenoglyphis villosa	+	+	+	+	+	+		+	+		+					+			+	
ENCYRTIDAE																				

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Table 3. (cont'd) Hyperparasitoids of aphid parasitoids (Carver 2000)

Species	*Acyrthosiphon kondoi*	*Acyrthosiphon pisum*	*Aphis craccivora*	*Aphis gossypii*	*Brevicoryne brassicae*	*Cavariella aegopodii*	*Eriosoma lanigerum*	*Hyperomyzus lactucae*	*Macrosiphum rosae*	*Metopolophium dirhodum*	*Myzus persicae*	*Pentalonia nigronervosa*	*Pineus boerneri*	*Pineus pini*	*Rhopalosiphum maidis*	*Rhopalosiphum padi*	*Therioaphis trifolii*	*Toxoptera aurantii*	*Toxoptera citricidus*	*Tuberculatus annulatus*
Aphidencyrtus sp.															+				+	
MEGASPILIDAE																				
Dendrocerus aphidum	+	+				+		+	+		+						+			
Dendrocerus carpenteri	+	+				+		+	+		+									
PTEROMALIDAE																				
Asaphes vulgaris																				+
Moranila comperei					+	+	+				+						+			
Pachyneuron aphidis	+	+	+		+	+	+	+	+	+	+				+		+			

Table 4. Aphid predators recorded in the aphid data base (aphid data base: Milne 1978b; Carver 2000)

Species	*Acyrthosiphon kondoi*	*Acyrthosiphon pisum*	*Aphis craccivora*	*Aphis gossypii*	*Brevicoryne brassicae*	*Cavariella aegopodii*	*Eriosoma lanigerum*	*Hyperomyzus lactucae*	*Macrosiphum rosae*	*Metopolophium dirhodum*	*Myzus persicae*	*Pentalonia nigronervosa*	*Pineus boerneri*	*Pineus pini*	*Rhopalosiphum maidis*	*Rhopalosiphum padi*	*Therioaphis trifolii*	*Toxoptera aurantii*	*Toxoptera citricidus*	*Tuberculatus annulatus*
HEMIPTERA																				
NABIDAE																				
Nabis kinbergii	+																+			
PENTATOMIDAE																				
Cermatulus nasalis																	+			
Oechalia schellenbergii																	+			
NEUROPTERA																				

Table 4. (cont'd) Aphid predators recorded in the aphid data base (aphid data base: Milne 1978b; Carver 2000)

Species	*Acyrthosiphon kondoi*	*Acyrthosiphon pisum*	*Aphis craccivora*	*Aphis gossypii*	*Brevicoryne brassicae*	*Cavariella aegopodii*	*Eriosoma lanigerum*	*Hyperomyzus lactucae*	*Macrosiphum rosae*	*Metopolophium dirhodum*	*Myzus persicae*	*Pentalonia nigronervosa*	*Pineus boerneri*	*Pineus pini*	*Rhopalosiphum maidis*	*Rhopalosiphum padi*	*Therioaphis trifolii*	*Toxoptera aurantii*	*Toxoptera citricidus*	*Tuberculatus annulatus*
HEMEROBIIDAE																				
Drepanacra binocula														+				+		+
Micromus tasmaniae	+	+		+				+	+	+	+	+					+			
CHRYSOPIDAE																				
Mallada signata				+							+						+		+	
Mallada tripunctata														+						
Plesiochrysa ramburi											+		+							
COLEOPTERA																				
CANTHARIDAE																				
Chauliognathus lugubris																	+			
MELYRIDAE																				
Dicranolaius bellulus	+	+															+			
COCCINELLIDAE																				
Cleobora mellyi	+																			
Coccinella transversalis	+	+	+	+	+		+		+		+						+	+		
Coccinella undecimpunctata	+																			
Coelophora inaequalis			+									+				+			+	
Coelophora sp.				+																
Diomus notescens	+	+	+	+			+	+			+						+			
Diomus pumilio													+							
Harmonia conformis	+		+	+	+		+	+	+		+		+				+		+	+
Menochilus sexmaculatus							+													

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Table 4. (cont'd) Aphid predators recorded in the aphid data base (aphid data base: Milne 1978b; Carver 2000)

Species	*Acyrthosiphon kondoi*	*Acyrthosiphon pisum*	*Aphis craccivora*	*Aphis gossypii*	*Brevicoryne brassicae*	*Cavariella aegopodii*	*Eriosoma lanigerum*	*Hyperomyzus lactucae*	*Macrosiphum rosae*	*Metopolophium dirhodum*	*Myzus persicae*	*Pentalonia nigronervosa*	*Pineus boerneri*	*Pineus pini*	*Rhopalosiphum maidis*	*Rhopalosiphum padi*	*Therioaphis trifolii*	*Toxoptera aurantii*	*Toxoptera citricidus*	*Tuberculatus annulatus*
Micraspis frenata	+						+													
Parapriasus australasiae	+						+													
Rhyzobius sp.							+													
Scymnodes lividigaster			+	+							+							+		
Scymnus sp.												+								
DIPTERA																				
CHAMAEMYIIDAE																				
Leucopis formosana	+		+	+					+		+				+				+	
SYRPHIDAE																				
Melangyna viridiceps	+		+	+	+	+	+	+	+	+	+					+	+			
Simosyrphus grandicornis	+	+	+	+	+	+	+	+	+		+		+		+		+	+	+	
Sphaerophoria macrogaster					+												+			

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A. ervi is a polyphagous species (or species complex), parasitising *Acyrthosiphon* spp., especially in legume crops; *Sitobion* spp., especially in cereal crops; and, occasionally, *Macrosiphum rosae* on roses. When, by September 1979 after an 18-month release program, no evidence was obtained of establishment of *A. ervi* in New South Wales, a second program of releases was initiated which continued until June 1982. However, in May 1980, *A. ervi* was found parasitising *A. kondoi* in 5 of 12 original release sites surveyed: establishment had clearly occurred from the first set of releases. Fifteen of the 19 sites at which *A. ervi* had been released during the second set of releases in 1980 were surveyed in 1981. It was found at all sites sampled, with a rate of parasitisation varying between 3.2% and 95.2%. *A. ervi* is now widely distributed in Queensland, New South Wales, Victoria and Western Australia (up to 70% parasitisation there) and there is good evidence of spread of up to 300 km in a year (Sandow 1981; Milne 1986a,b; M. Carver, pers. comm.).

A. ervi frequently became established in areas before the introduced pea aphid appeared. It is also widespread in areas where the pea aphid has remained at a low level (Milne 1986a). In Australia, it is attacked by hyperparasitoids — *Dendrocerus aphidum* in particular, but also by *Dendrocerus carpenteri*, *Pachyneuron aphidis* and *Phaenoglyphis villosa* (Milne 1999).

The polyphagous braconid, *Praon volucre*, introduced to control *Hyperomyzus lactucae*, parasitised *A. kondoi* in the laboratory (Carver 1984), but has not been found in the bluegreen aphid in the field (W. Milne, pers.comm. 1998). The exotic aphelinid, *Aphelinus asychis*, introduced against *A. pisum* and *Hyperomyzus lactucae*, oviposits in *A. kondoi* but the eggs are often encapsulated (Carver and Woolcock 1985).

The exotic fungus *Pandora kondoiensis*, whose arrival in Australia is undocumented, caused (early after arrival) significant mortality of crowded *A. kondoi* under prolonged humid conditions, although in recent years the disease has become uncommon (Milner et al. 1983). Other fungi isolated from *A. kondoi*, but not introduced intentionally (Table 5 page 113), include *Conidiobolus obscurus, C. thromboides, Entomophthora planchoniana, Pandora neoaphidis, Zoophthora phalloides* and *Z. radicans* (Milner 1978; Milner et al. 1980; Sandow 1981; Lawrence and Milner 1996).

Surveys in 1982 and 1983 demonstrated the successful establishment and dispersal of *A. ervi* in *A. kondoi* and *A. pisum* in the major lucerne-growing areas of New South Wales and also the ability of the parasitoid to build up populations rapidly again after a severe and widespread drought. Sampling in the southern half of New South Wales and in coastal areas from 1994 to 1996 revealed that populations of *A. kondoi* and *A pisum* were almost invariably parasitised by *A. ervi.* This parasitoid has been very effective in reducing aphid populations in the high rainfall areas of eastern Australia. In drier inland areas, *A. ervi* is less effective and,

in many areas, *A. kondoi* remains a serious pest of lucerne and clover pastures (W.M. Milne, pers. comm.).

Importations from California in 1980 against *A. pisum* contained mummies of both *A. pisum* and *A. kondoi*. From the latter, *Aphidius pisivorus* emerged and, after its liberation, was recovered briefly in the field, but has not become established in Australia. It has been recorded overseas from both *A. pisum* and *A. kondoi* (M. Carver, pers. comm.).

Many of the exotic parasitoids attacking pest aphids in Australia are attacked in turn by hyperparasitoids (Table 3 page 108). Thus, *A. ervi* attacking *A. kondoi* is host to *Phaenoglyphis villosa*. These charipids (subfamily Alloxystinae) are solitary endoparasitic in Aphidiinae and *Aphelinus* spp. and may influence the effectiveness of their parasitoid hosts (Carver 1992).

Table 5. Fungi (Phycomycetes: Entomophthoraceae) attacking pest aphids in Australia[a]

Species	*Conidiobolus coronatus*	*Conidiobolus obscurus*	*Conidiobolus thromboides*	*Entomophthora planchoniana*	*Pandora kondoiensis*	*Pandora neoaphidis*	*Neozygites fresenii*	*Verticillium lecanii*	*Zoophthora phalloides*	*Zoophthora radicans*	*Not identified*
Acyrthosiphon kondoi	*	**	*	*	**	***		*	*	*	
Acyrthosiphon pisum				*	*	***		*	*		
Aphis craccivora						*					
Aphis gossypii							*				
Brevicoryne brassicae		*				*					
Hyperomyzus lactucae						***	*				
Macrosiphum rosae		*		*		*					
Metopolophium dirhodum											*
Myzus persicae		*	*	*			*	*	*		
Pentalonia nigronervosa											
Pineus boerneri											
Rhopalosiphum maidis								*			
Therioaphis trifolii	*	*		*						*	
Therioaphis trifolii f. maculata	*	*	*	*		*				*	
Toxoptera aurantii											*
Toxoptera citricidus											*

[a]drawn from Milner et al. 1980, 1983; Glare et al. 1986; Milner and Holdom 1986; Lawrence and Milner 1996
Note: * recorded; ** common; *** epizootics recorded.

3

Acyrthosiphon pisum (Harris) Hemiptera: Aphididae pea aphid

PRECIS

The European pea aphid, *Acyrthosiphon pisum*, was first detected on mainland Australia in lucerne fields in Victoria in January 1980 and, within 18 months, had spread into Queensland and South Australia.

The braconid *Aphidius ervi*, which had recently (1981) become established on the bluegreen aphid, *Acyrthosiphon kondoi*, also attacked *A. pisum* and has contributed to preventing the pea aphid from becoming a serious pest in Australia.

BIOLOGY

Acyrthosiphon pisum is parthenogenetic in the field, although oviparous females have been found once in the field and sexual forms can be produced in the laboratory. It is green, up to 4 mm long and can develop high populations in Victoria and southern New South Wales, but is usually a relatively minor pest in warmer regions of New South Wales.

The pea aphid is a European species, which has been known in North America since the late 1800s as a serious pest of lucerne and peas. It is also present in South America, Africa and parts of Asia. It was first recorded in New Zealand in 1976 and on mainland Australia (Victoria) in January 1980 (Ridland and Berg 1981), although it has subsequently been found in earlier trap catches of September 1979 (M. Carver, pers. comm.). A non-pest, shrub-infesting form, *Acyrthosiphon pisum spartii,* has been present in Tasmania for many years (Carver 1989).

PEST STATUS

Heavy infestations by the pea aphid on the stems and foliage of peas cause stunting and reduce the yield and quality of the crop. The pea aphid also attacks many other legumes including lucerne, clover and broad beans. It is an effective

transmitter of many viruses, including alfalfa mosaic virus (Garran and Gibbs 1982) and clover yellow vein virus.

BIOLOGICAL CONTROL

Many of the predators listed for the spotted alfalfa aphid (Table 4 page 109) also attack the pea aphid.

Aphidius eadyi, A. pisivorus, A. smithi and *A. urticae* group were introduced specifically for control of *A. pisum. A. smithi* has become established, but only in Tasmania where it is less numerous in the pea aphid than is *Aphidius ervi* (Carver 1989). *Aphelinus abdominalis* was transferred from Tasmania to the mainland, where it was already present and is now widespread in hosts other than *A. pisum* and *Acyrthosiphon kondoi* (M. Carver, pers.comm.). On the other hand, *A. ervi*, which was released in 1977 to control the bluegreen aphid, *A. kondoi,* well before *A. pisum* arrived in Australia in 1979 (and which was subsequently released again in 1980 and 1981), attacked both *A. pisum* and *A. kondoi* in the major lucerne-growing areas of New South Wales. Widespread surveys demonstrated that *A. pisum* was almost always less abundant than *A. kondoi*, although the latter was considered to be generally under excellent biological control (Hughes 1989). It appears thus that, due partly at least to the presence of *A. ervi, A. pisum* has never had an opportunity in Australia to demonstrate its potential destructiveness.

Aphelinus asychis (from France), which parasitises *A. pisum* overseas, was liberated and became established on the spotted alfalfa aphid, *Therioaphis trifolii* forma maculata (SAA), in Australia, before the arrival of pea aphid. It is a species complex attacking certain groups of aphid species, e.g. SAA (Drepanosiphinae) and a range of Aphidinae. However, *A. asychis* bred from SAA is not known to parasitise Aphidinae and vice versa (M. Carver, pers. comm.). *A. asychis* was again introduced in very small numbers from USA in 1980, descendants released in the Australian Capital Territory and starter cultures sent to Hobart. It was introduced yet again (from South Africa) in 1981 against the sowthistle aphid, *Hyperomyzus lactucae* (Carver 2000). Only small numbers were imported and 2300 specimens were later released in New South Wales in 1981, but their fate has not been investigated (Carver and Woolcock 1986). *A. asychis* has not become established on the pea aphid. Indeed, although *A. asychis* is known in the field from the spotted alfalfa aphid, it has not appeared in sampling of the pea aphid (W. Milne, pers.comm.). Also *Praon volucre* (Braconidae), imported for control of *Hyperomyzus lactucae,* parasitises *A. pisum* in the laboratory (Carver 1984), but has not been recorded from it in the field.

From shortly after its arrival in Australia, the pea aphid was subjected to frequent widespread epizootics of the fungus *Pandora neoaphidis* (Milner 1982). However, field populations of pea aphid were found to contain two biotypes; one susceptible, and the other resistant to most strains of the fungus (Hughes and

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Bryce 1984). In the laboratory, fungal dosages which killed an average of 94% of susceptible aphids did not kill a single resistant biotype. However, 2 of 11 isolates of *E. neoaphidis* were found to attack the resistant biotype as readily as they attacked the susceptible biotype (Milner 1982; Milner et al. 1983). When activated by dew periods, *E. neoaphidis* can achieve high levels of transmission, even during rainless periods (Milner et al. 1983).

Pandora kondoiensis, which causes epizootics of the bluegreen aphid *A. kondoi* under conditions of prolonged high moisture levels, is rarely found on *A. pisum* and in recent years has become less common on *A. kondoi* (Milner et al. 1983). Other fungi recorded from *A. kondoi* and other aphid species of concern to this publication are shown in Table 5 on page 113.

4

Aleurodicus dispersus Russell Hemiptera: Aleyrodidae spiralling whitefly

PRECIS

The widely polyphagous *Aleurodicus dispersus* is native to the Caribbean region and Central America, but has spread so rapidly in the past 20 years that it is now almost pantropical in distribution. It arrived in Torres Strait in February 1991 and on mainland Australia in 1995.

Following substantial control of *A. dispersus* in the Pacific by *Encarsia* sp., this parasitoid was released on Boigu Island, Torres Strait in 1992 and soon controlled spiralling whitefly on this and many other inhabited islands. When *A. dispersus* appeared on Cape York Peninsula in 1995, further releases were made there and later in Cairns where it appeared in 1998. Populations of the pest have been substantially reduced by the parasitoid, aided by native predators.

BIOLOGY

Aleurodicus dispersus attaches its eggs at right angles to leaf veins by means of a short stalk inserted into a stomate on the lower surface of a host-plant leaf. Eggs are associated with irregularly spiralling deposits of waxy, white flocculence, from which the whitefly derives its common name. There are four instars and development from egg to adult takes a little over a month. Although immature stages are mobile, only adults disperse beyond the leaf on which the egg was laid. The wings of newly emerged adults (body length 2.28 mm in males and 1.74 mm in females) are clear on emergence, but develop a covering of white waxy powder over the next few days. Heavy rains or cool temperatures may result in a temporary reduction in *A. dispersus* populations which, however, rise rapidly again in warm, dry weather (Waterhouse and Norris 1989).

A. dispersus is native to the Caribbean and Central America and was first observed in Florida in 1957. Once it had arrived in Hawaii in 1978 it started to spread rapidly to most tropical regions of the world, reaching Papua New Guinea in 1987 (Waterhouse and Norris 1989). It first reached Australia on the Torres

Strait island of Boigu, lying less than 10 km from the southern Papua New Guinea coast. By 1998 it had spread to 14 of the 17 inhabited Torres Strait islands and, meanwhile, it was recorded in March 1995 at Seisia (near the tip of Cape York Peninsula) and has since spread to Bamaga and surrounding communities and to the Weipa area. It was discovered in Cairns in 1998 (Lambkin 1998) and in Townsville in 1999 (AQIS 1999a; Lambkin 1999).

PEST STATUS

A. dispersus is widely known as a pest of vegetables, fruit trees, ornamentals and shade trees. Its extensive host range covers 41 plant families and more than 104 species. In Torres Strait, numbers are always high on guava (*Psidium guajava*), acalypha (*Acalypha* spp.), sea almond (*Terminalia catappa*) and poinsettia (*Euphorbia pulcherrima*). Other preferred hosts in Torres Strait and Cape York include sugar apple (*Annona squamosa*), capsicum (*Capsicum annuum*), papaw (*Carica papaya*), coconut (*Cocos nucifera*), tomato (*Lycopersicon esculentum*), cassava (*Manihot esculenta*), banana (*Musa sapientum*), frangipani (*Plumeria* spp.) and eggplant (*Solanum melongena*) (Grimshaw 1995; Lambkin 1996, 1997, 1998, 1999).

Nymphs and adults suck sap from these host plants and can cause premature leaf drop, but seldom death. Copious white, waxy, flocculent material secreted by the nymphs is spread widely by the wind and creates a very unsightly nuisance. Copious, sticky honeydew serves as a substrate for dense growths of sooty moulds which interfere with photosynthesis (Waterhouse and Norris 1989).

A. dispersus is not known to be a virus vector.

BIOLOGICAL CONTROL

Progress with biological control in the Pacific up to 1988 has been dealt with in some detail by Waterhouse and Norris (1989). A very substantial reduction in spiralling whitefly populations was brought about in the Pacific by the introduction of natural enemies, in particular a parasitoid referred to as *Encarsia* ? *haitiensis.* However, Pacific island voucher specimens do not match Dozier's original description of *E. haitiensis* (D.P.A. Sands, unpublished). This is recorded from Cuba and Haiti, where it parasitises *Aleuroglandulus* spp. (Aleyrodidae) (De Santis 1979). It is, therefore, referred to here as *Encarsia* sp.

Following the discovery of *A. dispersus* on Boigu Island in 1991, some 70 adults of *Encarsia* sp. from Fiji (originally from Trinidad, via Hawaii) were released, supplementing earlier releases on nearby southern Papua New Guinea. Possibly because of the small number of parasitoids released, complete control required about 2 years in Boigu. During this period, the pest spread rapidly to Sabai, Dauan, Thursday, Horn, Yam, Prince of Wales and Hammond Islands (1993), Yorke and Murray Islands (1994), Coconut Island (1995) and Darnley

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Island (1996). By April 1996, control of *A. dispersus* was brought about by the parasitoid on all of these islands except Darnley Island, where parasitoids were first released in April 1996 (Lambkin 1996). Parasitoids from Torres Strait were released at Seisia on Cape York Peninsula when the pest appeared in 1995, although these were discovered to be already present. Within 5 months, and before release of parasitoids, pest numbers on guava had increased to a mean value of 25 third and fourth instar nymphs per leaf, or some 100,000 nymphs per plant. Establishment of *Encarsia* sp. was confirmed there and later in the Weipa area in March 1998. The latter population served as the source of subsequent releases made in Cairns in 1998 (Lambkin 1998). It is confidently expected that excellent control will be achieved.

The control of *A. dispersus* in Torres Strait and Cape York has been aided by two native predators, *Acletoxenus* sp. (Drosophilidae) and *Cryptolaemus affinis* (Coccinellidae). Although they do not usually control whitefly populations, these predators were recorded as having an impact on pest numbers on eggplant prior to release of *Encarsia* sp. (Lambkin 1998).

5

Aonidiella aurantii (Maskell) Hemiptera: Diaspididae red scale

6

Aonidiella citrina (Coquillett) yellow scale

PRECIS

Red scale, *Aonidiella aurantii* and yellow scale, *Aonidiella citrina*, originated in Southeast Asia. Both species are now widespread in all countries where citrus is cultivated. *A. aurantii* ranks as one of the most important citrus pests, whereas *A. citrina* is far less important and is not as destructive. *A. aurantii* is also a major pest of passionfruit in Queensland.

Most parasitoids and predators of *A. aurantii* also attack *A. citrina*. Important parasitoids of *A. aurantii* include *Aphytis lingnanensis*, *A. melinus* and the red scale biotype of *Comperiella bifasciata*, whereas the yellow scale biotype of *C. bifasciata* is an important parasitoid of *A. citrina*. Native Coccinellidae and larvae of Chrysopidae are important predators of *A. aurantii* and *A. citrina*. Biological control of *A. aurantii* and *A. citrina* is effectively achieved by a combination of these natural enemies in most Australian States.

BIOLOGY

Aonidiella aurantii originated in Southeast Asia, but now occurs throughout most temperate and subtropical countries where citrus is grown. *A. aurantii* has a wide host range on other plants. *Aonidiella citrina* has a similar distribution but also occurs in Russia, India and Iran. Based on the distribution of host-specific biotypes of the parasitoid *Comperiella bifasciata* (Smith 1942), *A. aurantii*

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probably originated in China and *A. citrina* in Japan. Infestations of *A. aurantii* develop mostly in the dry, warmer areas of Australia, whereas *A. citrina* is more frequent in temperate regions. On citrus, *A. aurantii* infests leaves, fruit and stems in the outer canopy, whereas *A. citrina* infests leaves and fruit in the shady, inner canopy.

A. aurantii and *A. citrina* are similar in appearance and biology, and are easily confused. Both species are ovoviviparous and, depending on temperatures, each female scale produces from 50 to 300 crawlers which emerge from beneath the parent scale and move to settle on plant tissues, or are dispersed to other trees by wind (Rosen and DeBach 1978; Smith et al. 1997a). Adult males commence emerging in early September and crawlers emerge from beneath the female scales in September and October before moving to settle on the developing fruit and other plant tissues. After settling, they remain at one site until mature. When feeding commences, the crawlers secrete a small, dome-shaped, white covering which is later extended during subsequent instars into a somewhat flat, red or yellow scale covering the soft ,reddish body, which is circular in females and oval in males. Females have two larval instars before moulting to the adult stage, whereas in males the two larval instars are followed by pre-pupa, pupa and winged adult stages. Unlike most other diaspine scale insects, in mature females the scale covering is attached to the soft body of the insect (Rosen and DeBach 1978).

A. aurantii is particularly well adapted to the hot, dry summers of inland Victoria, South Australia and New South Wales and develops very slowly during winter months. In the southern States, *A. aurantii* and *A. citrina* complete two to five generations and in the northern States, five to six generations per year. During warmer months the scales develop several overlapping generations.

Pest status

A. aurantii was reported from Western Australia in 1895 (Jenkins 1946). It subsequently became a major pest in the citrus-growing areas of eastern Australia, ranging from the Atherton Tablelands through northern New South Wales, the Murray River irrigation areas of New South Wales and to northern Victoria. It is also a pest in south-western and central Western Australia (Smith et al. 1997a). *A. aurantii* is only an occasional pest in central New South Wales and the Northern Territory. *A. citrina* is not as widely distributed, occurring in coastal southern and central New South Wales and in the Murray River irrigation areas. *A. citrina* also occurs in northern New South Wales but it is less abundant than *A. aurantii* and is only a minor pest in the south-eastern States. *A. citrina* is uncommon in Queensland and the Northern Territory.

A. aurantii infests citrus, passionfruit (Murray 1976) and ornamentals, including roses, and occurs on a wide range of other plants, whereas *A. citrina* occurs mainly on citrus and ornamentals including palms, ivy and privet (Smith

et al. 1997a). All parts of a citrus plant may become infested with *A. aurantii*, particularly the outer canopy, whereas *A. citrina* occurs mainly on the leaves and fruit within the canopy and infrequently on the bark. Both species secrete phytotoxins in their saliva causing chlorosis of leaves and immature fruit, and leaf drop. Yellow chlorotic areas surrounding each scale are characteristic features of both species. Heavy infestations of *A. aurantii* and *A. citrina* may result in dieback of branches or death of whole plants.

BIOLOGICAL CONTROL

A range of indigenous predators, parasitoids, predators and a fungal pathogen attack *A. aurantii* and *A. citrina*, but they failed to prevent destructive infestations developing on citrus. Many native Coccinellidae and Chrysopidae prey on the immature stages and some also attack the adult scales. Several predatory Coccinellidae were introduced into Australia but their identities are not known except for *Chilocorus bipustulatus*, introduced from Israel, which is not known to have become established (Rosen and DeBach 1978). The impact by this beetle on *A. aurantii* and *A. citrina* overseas has not been determined.

The most important native predators are *Halmus chalybeus*, *Rhyzobius lophanthae* (Coccinellidae), *Mallada* spp. (Chrysopidae) and *Batrachedra arenosella* (Batrachedridae) (Snowball and Sands 1970; Smith et al. 1997a) (Table 6 page 124). The identities of some parasitoids reported attacking *A. aurantii* remain in doubt. For example, Wilson (1960) lists the native *Tomocera californica* as a parasitoid, but the records from *A. aurantii* seem unlikely since, although soft scale hosts of *T. californica* are known, they do not include diaspid scales. The pathogen, *Fusarium coccophilum* and the predatory mites, *Eupalopsis jamesi*, *Euseius elinae* and *E. victoriensis* are reported to prey on *A. aurantii* (Smith et al. 1997a).

Most parasitoids introduced to control *A. aurantii* also attack *A. citrina* but the impacts by each parasitoid vary according to the species of host, especially when different host biotypes have been introduced. The most widely distributed and important parasitoids introduced to control *A. aurantii* are *C. bifasciata* (red scale biotype), *Aphytis lingnanensis* and *A. melinus.* Also abundant, but not as effective as control agents, are *A. chrysomphali*, *Encarsia citrina* and *E. perniciosi* (red scale biotype) (Furness et al. 1983; Smith et al. 1997a). *C. bifasciata* (yellow scale biotype) is the most important parasitoid of *A. citrina*, but *A. chrysomphali* and biotypes of *E. citrina* and *E. perniciosi* are also common parasitoids of this scale.

Two biotypes of *C. bifasciata* are established in Australia; one adapted to *A. aurantii* (red scale race) and the other adapted to *A. citrina* (yellow scale race) (Smith et al. 1997a). The origin of these biotypes has not been fully resolved. The biotype of *C. bifasciata* from Japan, introduced into Western Australia in 1909,

was said to have failed to have become established (Jenkins 1946). Jenkins (1946) also reported that *C. bifasciata* had

> …long been known to be a parasite of yellow scale…and that development of *C. bifasciata* on *A. aurantii* only commenced in…recent years...

Smith et al. (1997a) suggested that *C. bifasciata* may have been accidentally introduced before the 1940s, and Jenkins (1946) indicated that a biotype adapted to *A. citrina* was present before the first release of *C. bifasciata* for *A. aurantii* (Wilson 1960). Jenkins (1946) was probably referring to two biotypes of *C. bifasciata*: one adapted to *A. citrina* (yellow scale strain), imported from Japan in 1909 that did establish, and another adapted to *A. aurantii* ('Chinese race' of Wilson 1960), imported from China (via California) and released between 1943 and 1944. Subsequent releases of *C. bifasciata* from California from 1947 to 1949 (Wilson 1960) were probably also the red scale biotype. The origins of these biotypes of *C. bifasciata* introduced into Australia agree with findings by Smith (1942) in the USA, that the Japanese race of *C. bifasciata* developed only on *A. citrina* and the Chinese race developed only on *A. aurantii*.

A. lingnanensis and *A. melinus* together supplement the activity of *C. bifasciata* and achieve effective control of *A. aurantii*, but each is adapted to different climates. *A. lingnanensis* is more effective where temperatures are not so extreme, in the coastal regions of eastern New South Wales and Queensland (Papacek and Smith 1985), whereas *A. melinus* is more effective in the inland, dry areas of Victoria and South Australia. By comparison, the indigenous and other exotic parasitoids are relatively unimportant in achieving effective biological control of *A. aurantii* in Australia.

A. melinus has also been recorded attacking black parlatoria scale, *Parlatoria pergandii* (Malipatil et al. 2000).

MAJOR PARASITOID SPECIES

Comperiella bifasciata Hymenoptera: Encyrtidae

C. bifasciata is an internal, solitary, bi-parental parasitoid of *A. aurantii* and *A. citrina*. Single eggs are deposited in all stages of the female scales but development only takes place in the advanced 2nd instars and adult scales. If the yellow scale biotype of *C. bifasciata* oviposits in *A. aurantii*, many of the eggs and some larvae become encapsulated and parasitoids fail to develop (Brewer 1971; Snowball and Sands 1971b). By contrast, the red scale biotype of *C. bifasciata* successfully parasitises up to 80% of adult female scales (Smith et al. 1997a) without significant encapsulation.

Aphytis spp. Hymenoptera: Aphelinidae

When *A. lingnanensis* was first introduced into Western Australia in 1906, probably from China, its identity was confused with *A. chrysomphali* (Wilson 1960). *A. lingnanensis* is a solitary, biparental, parasitoid of late 2nd instar and adult females of *A. aurantii*, whereas *A. melinus* is a gregarious ectoparasitoid of late 2nd instar and adult females of *A. aurantii* (Smith et al. 1997a). The life cycle of *Aphytis* spp. occupies about 17 days at 25°C and the adult females may live for several weeks. In addition to differences in biology, these *Aphytis* spp. are distinguished by the colour of the pupae and the shape of the crenulae on the propodium of adults. Up to 80% of susceptible stages of the hosts are parasitised and 50% of the scale insects are also killed by host feeding (Smith et al. 1997a).

Several *Aphytis* spp. have been introduced into Australia for the biological control of *A. aurantii* (Wilson 1960), although their times of introductions are not at all clear. *A. chrysomphali* is thought to have been introduced to Western Australia from China in 1905. It is a solitary, uniparental parasitoid of 2nd instar scales, and it is not considered to be a very effective control agent for *A. aurantii.*

Table 6. Indigenous natural enemies of *Aonidiella aurantii* and *A. citrina*

Species	Stage of host	References
NEUROPTERA		
CHRYSOPIDAE		
Mallada sp.	L 1, 2	Smith et al. 1997a
unidentified sp.	L 1, 2	Furness et al. 1983
unidentified spp.		Wilson 1960
COLEOPTERA		
COCCINELLIDAE		
Halmus chalybeus	L 1, 2	Wilson 1960
Harmonia conformis	L 1, 2	Wilson 1960
Menochilus sexmaculatus	L 1, 2	Wilson 1960
Orcus sp.[a]	L 1, 2	Snowball & Sands 1972
Parapriasus australasiae	L 1, 2	Wilson 1960
Rhyzobius debilis	L 1, 2	Wilson 1960
Rhyzobius ? lindi	L 1, 2	Milne 1974
Rhyzobius lophanthae	L 1, 2	Wilson 1960; Furness et al. 1983
Rhyzobius ventralis		Smith et al. 1997a
Serangium sp.[a]	L 1, 2	Snowball & Sands 1972
LEPIDOPTERA		
BATRACHEDRIDAE		
Batrachedra arenosella	L 1, 2, A	Wilson 1960

[a] from *A. citrina*; [b] hyperparasitoid

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Table 6. (cont'd) Indigenous natural enemies of *Aonidiella aurantii* and *A. citrina*

Species	Stage of host	References
NOCTUIDAE		
Mataeomera dubia	L 1, 2, A	Wilson 1960
HYMENOPTERA		
APHELINIDAE		
Ablerus sp.[b]	L 2, A	Malipatil et al. 2000
Aphytis chilensis	L 2	Snowball & Sands 1970; Noyes 1998
Aphytis columbi	L 2, A	Malipatil et al. 2000
Coccophagus scutellaris	L 2, A	Noyes 1998
Coccophagus gurneyi		Noyes 1998
Encarsia aurantii		Noyes 1998
Encarsia iris		Wilson 1960
Marietta carnesi[b]	L 2, A	Noyes 1998
ENCYRTIDAE		
Rhopalencyrtoidea dubius		Summerville 1934
ARACHNIDA		
Eupalopsis jamesi		Smith et al. 1997a
Euseius elinae		Smith et al. 1997a
Euseius victoriensis		Smith et al. 1997a

[a] from *A. citrina*; [b] hyperparasitoid

7

Aonidiella orientalis (Newstead) Hemiptera: Diaspididae oriental scale

PRECIS

Aonidiella orientalis originated in the Oriental region and it is now widely distributed in tropical countries. Although the scale insect is polyphagous, its economic host in Australia is pawpaw, on which it disfigures the fruit and infests the trunk, causing leaf drop and killing the trees when infestations are heavy.

A. orientalis is effectively controlled in eastern Queensland by the parasitoid *Comperiella lemniscata*, imported into Australia from China and Torres Strait.

BIOLOGY

Aonidiella orientalis is a native of the Oriental region and is also known from Israel, Hong Kong, Hawaii, the Philippines, Papua New Guinea, Australia, and the Middle East (Ben-Dov 1985). *A. orientalis* has up to six generations each year in Queensland. At 25°C development takes 44 days for female scales and 19.5 days for males (Elder and Smith 1995). About 200 eggs are deposited by the female. After hatching, crawlers migrate to settle on the leaves, fruit and stems of pawpaws where they remain until maturity. Crawlers are carried to neighbouring plants by wind. The circular female scale covering (ca 2.5 mm) is similar to that of red scale, although pale orange to greyish yellow in colour, whereas the scales of males are smaller (ca 0.6 mm) and oval in shape. There are two larval instars in females preceding the adult stage, whereas in males the larval instars are followed by pre-pupa, pupa and winged adult stages.

PEST STATUS

A. orientalis was recorded in Australia from pawpaws in Darwin in 1915, Torres Strait in 1954, and subsequently Mount Isa (Brimblecombe 1961). In eastern Queensland, *A. orientalis* is distributed from Cape York to south-eastern Queensland. It became a serious pest of pawpaws in 1985 in eastern Queensland from near Yarwin. to Mareeba, on the Atherton Tablelands. Infestations affected

the leaves, stems and fruit, sometimes causing death of the plants, spoiling the appearance of fruit and rendering fruit unmarketable due to legal restrictions (Elder and Smith 1995).

BIOLOGICAL CONTROL

Indigenous natural enemies of *A. orientalis* are shown in Table 7on page 128. *Aphytis melinus* was first introduced into Australia from Pakistan to control red scale, *A. aurantii*, but the parasitoid was not recognised as having established in Queensland until it was recovered from *A. orientalis* on pawpaws at Mount Isa. Subsequent attempts to establish *A. melinus* at Yarwin and Innisfail for control of *A. orientalis* were only partially successful; levels of parasitisation reaching 40% after inundative releases of cultured parasitoids. However, high levels of parasitisation were not sustained the following spring, and the decline in abundance of the parasitoid was attributed to winter stress (Smith and Elder 1993). Another parasitoid of red scale, *Encarsia citrina*, maintained high levels of activity following inundative releases into pawpaw orchards, but was subjected to marked seasonal effects.

Comperiella lemniscata, was introduced into south-eastern Queensland from China and Torres Strait, Queensland. After it became established in 1991, levels of parasitisation by this parasitoid reached 80% and it persisted at all the release sites (Elder et al. 1998). *C. lemniscata* spread rapidly and controlled most infestations in the pawpaw-growing areas of eastern Queensland. *C. lemniscata* is a parthenogenetic parasitoid (males are rare) of 2nd and 3rd instar female and male *A. orientalis* (Elder et al. 1997). It has also been recorded as a parasitoid of *Chrysomphalus dictyospermum* (Malipatil et al. 2000).

The coccinellid *Chilocorus circumdatus* is recorded as a predator of *A. orientalis* in Queensland (Elder et al. 1998). This beetle was introduced into Australia from Hong Kong in 1902 for biological control of *Comstockaspis perniciosi*, but it was not known to have become established until it appeared unaided in 1990 in Queensland (Houston 1991). *C. circumdatus* and the native *Chilocorus baileyi* (Blackburn) have been released in pawpaw orchards in Queensland to control *A. orientalis* (Elder and Bell 1998).

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Table 7. Indigenous natural enemies of *Aonidiella orientalis*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Chilocorus baileyi	L 1, 2, A	Smith & Elder 1993
Lindorus sp.	L 1, 2	Smith & Elder 1993
Telsimia sp.		Smith & Elder 1993
LEPIDOPTERA		
BATRACHEDRIDAE		
Batrachedra arenosella	L 1, 2, A	Smith & Elder 1993
HYMENOPTERA		
APHELINIDAE		
Encarsia sp.	L 2	Smith & Elder 1993
Marietta carnesi[a]	A	Elder et al. 1998

[a]hyperparasitoid of *Comperiella lemniscata*

8

Aphis craccivora Koch Hemiptera: Aphididae
cowpea aphid

An account of worldwide natural enemies of *A. craccivora* is provided by Waterhouse (1998).

PRECIS

Aphis craccivora is of 'Old World' (possibly Mediterranean or East African) origin, although it is now virtually cosmopolitan in warmer regions of the world. It is capable of causing considerable production losses, in particular as a vector of important legume viruses. It consists of a complex of strains exhibiting differing host preferences. *A. craccivora* and the cotton aphid *A. gossypii* are often found on the same hosts and share at least 11 parasitoid species and many predator species (Waterhouse 1998).

A. craccivora is very sporadic in occurrence in Australia. It was hoped that, in its unpredictable absence, introduced parasitoids would continue to survive in other hosts, such as *A. gossypii*. Nine exotic parasitoid species (five not introduced intentionally) now attack *A. craccivora* in Australia. While no doubt reducing its abundance on many occasions, *A. craccivora* is still a troublesome pest from time to time.

BIOLOGY

The origin of *Aphis craccivora* within the 'Old World' is unclear, with views of authors ranging from the Mediterranean or East African area to south-eastern Europe and adjoining areas (Waterhouse 1998).

A. craccivora has wingless, 2 mm long, black, parthenogenetic females producing young nymphs, which become wingless parthenogenetic females. This process is repeated until colony crowding, host-plant wilting or senescence triggers the production of winged parthenogenetic females which depart to found new colonies. Because of its sensitivity to crowding, *A. craccivora* colonies seldom build up as high numbers as do those of many other aphids. Nymphs pass through four moults. A generation takes 6 to 8 days under favourable conditions. Wingless

females produce about 100 nymphs in 30 days in the field. *A. craccivora* colonies are often tended by ants, which leads to larger body size and lower aphid mortality (Waterhouse 1998).

PEST STATUS

A. craccivora is polyphagous, but shows a distinct preference for legumes. It builds up high populations on cowpeas, pigeon peas, beans, lucerne, lupins, subterranean clover and other legume pastures. It is also known from citrus, okra and many other crops (Waterhouse 1998).

A. craccivora is most active in early spring and late autumn and feeds on young terminal shoots and, as the plant matures, on flowers and pods. Heavy attacks on young seedlings can cause death and on older plants stunting, distortion of leaves and delay in flowering. After flowering, pod infestation leads to shrivelling and reduction in seed yield. However, its very considerable importance is mainly due to its role as a vector of legume viruses (e.g. subclover stunt virus, cucumber mosaic virus and bean yellow mosaic virus: Grylls and Butler 1959; Grylls 1972; Thackray et al. 1998). On citrus it is capable of transmitting tristeza virus (Waterhouse 1998).

BIOLOGICAL CONTROL

Five coccinellid species have been found attacking *A. craccivora* (*Coccinella transversalis, Coelophora inaequalis, Diomus notescens, Harmonia conformis* and *Scymnodes lividigaster*), one chamaemyiid fly predator (*Leucopis formosana*) and two syrphid species (*Melangyna viridiceps* and *Simosyrphus grandicornis*) (Table 4 page 109) (Grylls 1972; Carver 2000).

Exotic parasitoids known to attack *A. craccivora* are listed in Table 1on page 29. Native species are not known to cause high levels of parasitisation. Mohammad (1979a,b) states that parasitisation by *Aphidius colemani* of *A. craccivora*, in laboratory colonies in Adelaide, frequently eliminated the colony soon after establishment.

Six hyperparasitoids of *A. craccivora* parasitoids have been recorded, the charipids *Alloxysta australiae, A. darci, A. fuscicornis* and *Phaenoglyphis villosa,* the megaspilid *Dendrocerus aphidum* and the pteromalid *Pachyneuron aphidis* (Carver 1992; Table 3 page 108).

Four exotic parasitoids, whose time and method of arrival in Australia are not known (*Aphelinus gossypii, A. mariscusae, Aphidius colemani* and *A. similis*) attack *A. craccivora* in Australia. Of these, *A. colemani* is a very common, widely distributed aphid parasitoid in Australia. It is believed to be of Indian origin and is now widely distributed in the warmer parts of the world (Carver and Stary 1974). In 1982 and 1983, the polyphagous parasitoids *Lysiphlebus fabarum* (from France, Greece and Turkey) and *Lysiphlebus testaceipes* (from the oleander aphid,

Aphis nerii, and one of the black citrus aphids *Toxoptera aurantii*, in California) were mass-reared and released in New South Wales and Victoria. Both parasitised *A. craccivora* and some other aphid species in the laboratory. *L. testaceipes* became established as a parasitoid of the oleander aphid, *A. nerii*, in Victoria. Since 1997 it has been reared from the black citrus aphid, *Toxoptera aurantii*, the wheat aphid, *Rhopalosiphum padi*, and the corn aphid, *Rhopalosiphum maidis*, as well as *A. craccivora*. *L. fabarum* has been reared from *Aphis oenotherae* (Carver and Franzmann 2001). It is interesting that *L. testaceipes* was recorded from Australia (from the native *Aphis acaenovinae* in New South Wales) (Stary and Carver 1979) well before its introduction as a biological control agent in 1981.

A third species, *Lysiphlebus confusus*, was introduced from Greece and Turkey, but Carver (1984) subsequently declared this to be a junior synonym of *L. fabarum*. In 1986, *Trioxys indicus*, an Indian parasitoid of *Aphis* and its allies, was imported to control *A. craccivora* on lupins, and released in Western Australia, Victoria and New South Wales, but there is no indication of establishment (Carver 1989).

The braconid *Praon volucre*, imported into Australia from the Mediterranean area and liberated from 1981 to 1983 for the control of the sowthistle aphid, *Hyperomyzus lactucae*, is reported to have become established in Tasmania on this aphid, and it also parasitised *A. craccivora* in the laboratory (Carver 1984), but is not known from it in the field. The fungus *Pandora neoaphidis* has been reported from *A. craccivora* (Table 5on page 113).

9

Aphis gossypii Glover Hemiptera: Aphididae † cotton aphid, melon aphid

PRECIS

Aphis gossypii probably originated in south-eastern Europe, but is now cosmopolitan. It consists of a number of biotypes. It is a widely polyphagous species and is attacked in Australia by many different predators and a few parasitoids, most of which it shares with other pest aphids. Although its numbers are undoubtedly reduced by these natural enemies, it remains one of the major pest aphids in Australia.

BIOLOGY

Aphis gossypii probably originated in south-eastern Europe and adjoining regions. Its taxonomic status is complex and there are a number of biotypes. It is very widely polyphagous. Cotton, in particular, can carry heavy infestations, but so too can various cucurbits, especially melons, pumpkins and cucumbers. It also infests eggplant, potato, beans, mango, and many other crops and numerous ornamentals.

A. gossypii varies in colour from light green to almost black and, at high temperatures, may be yellow to almost white. Its rate of development is influenced by the host plant, for example, from birth to adult it takes an average of 4.5 days on cotton and 6 to 7 days on squash at about 27°C. Females on cotton produced an average of 27 nymphs (range 9 to 43) and on squash an average of 14 (2 to 35) (Khalifa and Sharaf 1964). The rate of reproduction is reduced as crowding occurs and it may be only then that the rate of parasitoid increase can exceed that of the aphid (Hussey and Bravenboer 1971).

PEST STATUS

A. gossypii can be a major problem on cotton and even cause the death of young plants. At later stages of growth, abundant populations lead to copious production of honeydew which contaminates the cotton lint.

On all of its many hosts, severely attacked leaves curl and young growth is stunted. The honeydew produced adheres to upper surfaces of leaves and fruit and provides a substrate for sooty moulds which are both unsightly and interfere with photosynthesis. *A. gossypii* is also an important vector of a very wide range of plant diseases including bean yellow mosaic virus, subclover stunt virus (Grylls 1972) and the bacterium that causes the devastating citrus greening disease (Kiritani and Su 1999).

BIOLOGICAL CONTROL

As with other exotic aphids that build up substantial populations in Australia, *A. gossypii* is attacked by a wide range of generalist predators, such as those listed for *Aphis craccivora* (Carver 2000). In addition, *Dicranolaius formosana* (Melyridae), *Eupeodes confrater* (Syrphidae) and *Micromus tasmaniae* (Hemerobiidae) are known to be predators. In northern New South Wales on cotton, the coccinellids *Coccinella transversalis* and *Harmonia octomaculata*, the chrysopid *Mallada signata* and syrphid larvae are recorded (Room and Wardhaugh 1977). These, together with the parasitoid *Aphidius colemani*, are capable of producing rapid decreases in populations of *A. gossypii* on cotton and of carrying this to extinction.

Higher numbers of *A. gossypii* occurred in cotton in New South Wales sprayed five times with thiodicarb than in unsprayed cotton and lower numbers of aphid predators were recorded in the sprayed areas. The predators involved were adults and larvae of the coccinellids *Adalia bipunctata, C. transversalis, Coelophora inaequalis, Harmonia conformis, H. octomaculata* and adults and nymphs of the hemipterans *Deraeocoris signatus, Geocoris* sp., *Orius* spp. and *Nabis* sp. (Wilson et al. 1998, 1999).

In view of the number of introductions of parasitoids against aphids, it is surprising that *A. gossypii* does not appear to have been the principal target of any project. It was hoped that polyphagous species introduced for other aphid pests would also attack *A. gossypii* ('collective control': Carver 1989). Thus, *Lysiphlebus testaceipes* (from *Aphis nerii* and *Toxoptera aurantii* in California) and *L. fabarum* (from Greece and Turkey) were introduced primarily against *Aphis craccivora.* Both attacked *A. craccivora* and *A. gossypii* (and some other aphid species) in the laboratory, but have not been recovered from either species in the field. However, *L. testaceipes* became established on the oleander aphid, *Aphis nerii,* one of the black citrus aphids, *Toxoptera aurantii*, and on the wheat aphid, *Rhopalosiphum padi* (Carver and Franzmann 2001). *L. fabarum* has been recovered in New South Wales from *Aphis oenotherae* on *Epilobium* sp. (Carver and Franzmann 2001). *Trioxys indicus*, which is known from *A. gossypii* in China and India (Waterhouse 1998) was introduced against *A. craccivora* but apparently failed to become established (Carver 1989).

The fungal pathogen *Neozygites fresenii* has been recorded from *A. gossypii* on *Hibiscus* sp. in south-eastern Queensland and has been shown to attack *Hyperomyzus lactucae* and *Myzus persicae* in the laboratory (Milner and Holdom 1986).

10

Asterodiaspis variolosa (Ratzeburg)
Hemiptera: Asterolecaniidae
golden oak scale

PRECIS

Asterodiaspis variolosa, of European origin, became a pest of oaks in the early 1930s in New South Wales, Victoria, South Australia and Tasmania.

An endoparasitoid previously established in the USA, *Habrolepis dalmanni*, was introduced from New Zealand to Tasmania and established in 1933. In 1937, it was transferred from Tasmania to the Australian Capital Territory and, in turn, from there to New South Wales and Victoria. Scale abundance declined in Tasmania, where biological control of both the scale and the associated oak aphid, *Tuberculatus annulatus*, has led to an improvement in the health of oak trees. Assessments are not available from the mainland, but these two pests are now unimportant in Tasmania.

BIOLOGY

Asterodiaspis variolosa is native to Europe where its life cycle has been described by Podsiadlo (1975). It occurs also in North America, South Africa, New Zealand (since 1881) and Australia (Gourlay 1935).

A. variolosa occurs on oaks (*Quercus* spp.) in New South Wales, Victoria and South Australia, but in Tasmania is reported only from *Q. pedunculata*, some individual trees of which appear to be resistant to attack. In California it has been recorded also from olives.

The golden oak scale is oval, dark greenish-brown and forms pits in the bark where it settles. The cover ('tent') it produces for its body to shelter under is a transparent honey-yellow, presumably the origin of its common name. Females produce about 50 eggs, which start to hatch in early summer to produce crawlers which settle on the current season's growth. Males are formed by a second generation in autumn (Evans 1939b).

TARGET PEST NO. 10

PEST STATUS

Infestations of *A. variolosa* restrict the growth of oak trees and contribute, together with the oak aphid, *Tuberculatus annulatus*, to the death not only of large branches, but also of whole trees. The scale is somewhat more important than the aphid (Evans 1939b). It was reported by Nicholls (1933) to be

> very widely spread in Tasmania and there is probably no oak tree that is not infested to a greater or lesser degree. In some localities it has done very serious injury to these beautiful trees.

BIOLOGICAL CONTROL

An encyrtid endoparasitoid *Habrolepis dalmanni*, obtained from the USA but said to have come originally from Europe where it has been studied by Podsiadlo (1986), had been successfully established on *A. variolosa* in New Zealand from liberations in 1924 and 1925. Stocks from New Zealand were liberated in Tasmania in 1931 and 1932. In the absence of field recoveries, it was again introduced in 1933 and it then established readily in both Hobart and Launceston. Up to 50% parasitisation of scales was reported in the summer of 1935/36 and a large oak tree in Hobart that had been heavily infested in 1934 was almost free of the scale a few years later (Evans 1939b).

In 1937, *A. variolosa* developed heavy infestations on *Quercus robur* in Canberra, Australian Capital Territory. *H. dalmanni* was obtained from both Tasmania and New Zealand and released. It established rapidly and, in 1938, parasitoids were sent to New South Wales and Victoria (Wilson 1960).

In the material sent from Tasmania (Launceston) there was an unidentified chalcidoid hyperparasitoid (Wilson 1960). It is not clear whether this was the 'yellow pteromalid' from Launceston referred to by Evans (1939b) and which is probably *Moranila comperei* (D.P.A. Sands, unpublished).

H. dalmanni is credited with providing a useful measure of control of the golden oak scale in Tasmania, where there has been an improvement in the health of the oak trees (Evans 1939b; Wilson 1960). The situation has not been assessed elsewhere, but the scale is no longer regarded as more than a minor pest.

MAJOR NATURAL ENEMY

Habrolepis dalmanni Hymenoptera: Encyrtidae

Although now widespread in Europe, USSR, northern and southern Africa, North and South America and New Zealand, this internal parasitoid is thought to be native either to Europe or Japan. Its reported hosts are *Asterolecanium variolosa* and *A. quercicola*.

Females are small, metallic blue and green and have dusky wings. They reproduce parthogenetically, although males have been seen rarely. They oviposit in the nearly fully-grown scale. Winter is spent as larva within the host (Bartlett 1978a; Ferguson 1989).

11

Brevicoryne brassicae (Linnæus) Hemiptera: Aphididae cabbage aphid

PRECIS

This aphid of European origin now occurs throughout the world and can be a serious pest of brassicas wherever they are grown. Warm dry conditions, as in late summer or autumn, are favourable for the development of colonies which are commonly attacked by the native coccinellid *Harmonia conformis*.

Whether introduced unintentionally or intentionally, the parasitoid *Diaeretiella rapae* became established and is common. It is considered that native enemies do not usually exert much influence on cabbage aphid populations in New South Wales until after a good deal of damage has been done (Hely et al. 1982).

BIOLOGY

Brevicoryne brassicae is cosmopolitan and occurs wherever cabbages and other brassicaceous crops are grown in Australia.

Adult cabbage aphids are slate grey, globular and covered with a waxy bloom. Infestation usually commences on the upper surface of a leaf in the form of a winged female surrounded by wingless nymphs which are produced alive. In cool areas, wingless forms overwinter and their young develop wings in spring. In warmer conditions a generation takes about 2 weeks.

PEST STATUS

Many brassicas serve as hosts of the cabbage aphid in Australia. Warm, dry conditions suit it and, as colonies build up, infested leaves curl in and protect the colonies. Infested plants stop growing and leaves become mottled and distorted. If populations become large, the plants, particularly if young, become smothered with insects and may wilt suddenly and die. Lower populations and the honeydew they produce may still render plants unfit to market.

BIOLOGICAL CONTROL

In Western Australia, natural enemies of the cabbage aphid from 1895 to 1897 included an ichneumonid, syrphids and three coccinellids (*Coccinella transversalis, Menochilus sexmaculatus* and *Scymnus australasiae*). Parasitisation by the ichneumonid was heavy and syrphids were numerous, but the cabbage aphid was reported to be an extremely serious pest (Wilson 1960). *Diaeretiella rapae* (Ichneumonoidea:Braconidae) was already present in Western Australia before its introduction from eastern Australia in 1902 (see below).

The first introduction into Western Australia against cabbage aphid was *Harmonia conformis*, unsuccessfully from New South Wales in 1896, but successfully from Tasmania in 1901 to 1902. It is possible that, from among the early introductions resulting from G. Compere's overseas collections, *Coccinella undecimpunctata* and *Adalia bipunctata*, may have survived (Pope 1988). Then followed, in 1902, introduction of two unidentified species thought to be Ichneumonidae from New South Wales and Queensland, one of which was probably *D. rapae* (a braconid, not an ichneumonid). This parasitoid was first recorded in Australia in 1900 (Wilson 1960) and was probably accompanied to the west by the hyperparasitoid *Alloxysta fuscicornis* (Cynipoidea). *Coccinella septempunctata* was introduced unsuccessfully from the Mediterranean area in 1903. Then followed the introduction of an unidentified parasitoid from India and one from Sri Lanka (both in 1907) and a third from the 'Orient' (in 1909). All are variously said to have become established (Newman 1934b; Jenkins 1946; Wilson 1960; M. Carver, pers. comm.). The hyperparasitoid *A. fuscicornis* parasitises *D. rapae* heavily within *B. brassicae*, often to 100% at the end of the season (Carver 1989). Since *D. rapae* is the only hymenopterous parasitoid of *B. brassicae*, all of the other Hymenoptera introduced were almost certainly hyperparasitoids of *D. rapae* (M. Carver, pers. comm.).

The established natural enemies have clearly had an important effect on cabbage aphid populations. *D. rapae* has become abundant in Western Australia and Jenkins (1946) quotes the opinion of Newman (1934b) that the position in Western Australia had substantially improved. In the Australian Capital Territory, natural enemies provide a high degree of cabbage aphid control, but in Queensland an unidentified 'disease' is more important than parasitoids (Wilson 1960). The population dynamics of the cabbage aphid are discussed by Hughes (1963). Two unidentified braconids attack *B. brassicae* in Tasmania, but little is known of their habits or status (Miller and Hudson 1953). *D. rapae* disperses rapidly and may be present in the bodies of alate *B. brassicae* alighting on a crop (Gilbert and Hughes 1971; Carver 1989). The fungi *Conidiobolus obscurus* and *Pandora neoaphidis* have been reported attacking *B. brassicae*.

12

Cavariella aegopodii (Scopoli) Hemiptera: Aphididae carrot aphid

PRECIS

The hosts of the European carrot aphid, *Cavariella aegopodii*, include willow and carrot. Until 1962 its main economic importance in Australia was through its role as a vector of the carrot motley dwarf virus complex.

A parasitoid, *Aphidius salicis,* from California, was established in Australia in 1962. Coincidentally, the abundance of carrot aphid dropped dramatically and so did the incidence of carrot motley dwarf disease. It is postulated that this greatly improved situation is due, in major part, to the change in the early 1960s from virus- and aphid-susceptible carrot cultivars to virus-tolerant, less aphid-susceptible ones.

BIOLOGY

The carrot aphid, *Cavariella aegopodii*, is native to Europe, but now occurs in North America, Hawaii, Australia and New Zealand.

Females produce living nymphs, which may become adult in as little as 10 days. Winged adults, which disperse, may be produced at any time of the year, but most frequently in late spring or in autumn. Adults vary in colour from green or yellow to brown. Carrot aphid is uncommon in Queensland, but common in the southern States.

PEST STATUS

Carrot aphids can cause severe injury as a result of their feeding, which results in copious honeydew, poor growth of the carrot root and curling, buckling and yellowing of the leaves. The aphids congregate on the underside of the leaves and may almost completely cover them. Some carrot varieties are considerably more resistant than others. Celery, fennel, parsley and parsnip are also hosts.

Often, far more serious than effects of sap removal is the transmission of the virus complex, carrot motley dwarf, which can cause severe losses.

BIOLOGICAL CONTROL

C. aegopodii is attacked by a range of native natural enemies, especially coccinellids, but also syrphids (*Melangyna viridiceps* and *Simosyrphus grandicornis*) and chrysopids. However, these were often unable to maintain carrot aphid populations below economic injury levels.

In 1962, 10 adults of an *Aphidius* sp. were introduced from California and their descendants became established (Stubbs 1966; Stubbs et al. 1983). Although the imports were not identified to species (Carver and Stary 1974), pre-release descendants have since been identified as *Aphidius salicis* (M. Carver, pers. comm.), which now occurs in south-eastern Australia wherever *C. aegopodii* is present.

Coinciding with the 1962 introduction, the abundance of *C. aegopodii* has dropped dramatically and the incidence of carrot motley dwarf disease has also declined to such an extent that the disease is now extremely rare. Five hyperparasitoids have been reported: *Alloxysta fuscicornis, Phaenoglyphis villosa* (Charipidae), *Dendrocerus aphidum, D. carpenteri* (Megaspilidae) and *Pachyneuron aphidis* (Pteromalidae) (Table 3 page 108).

Although *C. aegopodii* is now rare on carrot in Australia, it is still common on other umbellifers, such as fennel, celery and parsley, and on *Salix*, its primary host. *A. salicis* also attacks the carrot aphids on these hosts.

Evidence has been assembled that this unusual situation may be due, not to biological control alone, but rather to the replacement in the 1950s and 1960s of virus- and aphid-susceptible carrot cultivars (principally Chantenay) by virus-tolerant, less aphid-susceptible ones (e.g. Topweight, All Seasons, Western Red) (Carver 1989; M. Carver, pers. comm.).

13

Ceroplastes ceriferus (Fabricius) Hemiptera: Coccidae † Indian wax scale

PRECIS

Ceroplastes ceriferus was earlier thought to be native to India, but its origin is probably South America. *C. ceriferus* was long confused with *Ceroplastes destructor* and heavy mixed infestations on citrus in eastern Australia prevented separate assessment of the economic significance of each species. In Australia, *C. ceriferus* is effectively controlled on economically important plants by a number of indigenous natural enemies. It is occasionally abundant on ornamental and native plants, resulting in disfigurement and accompanying growth of sooty moulds. The scale is effectively controlled by the introduced egg predator *Scutellista caerulea*, and by the native parasitoid *Microterys australicus*.

BIOLOGY

Ceroplastes ceriferus is considered to be a pest in North America and Japan but is not a pest in Australia. It was first described from India in 1791 and was subsequently recorded from Australia in 1893 (Zeck 1932). For many years it was thought to have originated in India, but recently Qin and Gullan (1998) predicted the native region to be South America, based on its phylogenetic relationships. *C. ceriferus* is recorded from Australia, India, Sri Lanka, Southeast Asia, China, North and Central America, England, Japan, Micronesia, Papua New Guinea, Vanuatu, New Caledonia, Fiji, Cook Islands and Tonga (Williams and Watson 1990; Ben-Dov 1993).

The life history of *C. ceriferus* was outlined by Zeck (1932) and hosts were listed by Brimblecombe (1956b) and Ben-Dov (1993). Adult *C. ceriferus* are similar in size (up to 9 mm) and appearance to those of *Ceroplastes destructor*, and secrete a white, pale grey or cream wax which covers the soft body of the insect. However, the wax of mature females of *C. ceriferus* is much firmer in texture than that of *C. destructor*, and can be distinguished from the latter by the downwardly pointed, anterior 'horn' of wax, instead of the anteriorly rounded wax of

C. destructor. There are three larval instars. Instars 1 and 2 secrete a white wax dorsal coating with pointed, lateral white wax projections, differing from those of *C. destructor* which are truncated when viewed from above. The wax coating develops first a peak, then a dome, and in heavy aggregations the wax of individuals may eventually coalesce. Adult females of *C. ceriferus* are orange, red or brown and have an upwardly-directed caudal process, which differs in shape from that of *C. destructor* in which the longer process lies parallel to the plant host. Females of *C. ceriferus* reproduce parthenogenetically and, although males are recorded from India, they are not known to occur in Australia.

In central and south-eastern New South Wales, *C. ceriferus* is univoltine, whereas in Queensland and northern New South Wales, it is multivoltine. Oviposition occurs mainly from December to January, but may occur at other times during the warmer months. Adult *C. ceriferus* deposit up to 900 pink eggs in a mass beneath their concave ventral surface. After hatching, crawlers settle mainly on the stems of their host and rarely on the leaves or leaf petioles. The four instars usually complete development without migration from the original feeding site.

PEST STATUS

In Australia, *C. ceriferus* is common from New South Wales to Queensland where it is sometimes abundant on plants of little or no economic importance. However, at times it is a pest of avocado (D. Smith, pers. comm.). It has been recorded from citrus, coffee and red cedar, as well as a range of native plants, particularly *Pittosporum undulatum* (Brimblecombe 1956b), *Monotoca elliptica*, *Pararistolochia praevenosa* (D.P.A. Sands, unpublished) and *Pandorea pandorana* (Ben-Dov 1993). *C. ceriferus* is occasionally seen on exotic plants including various fruit trees, e.g. persimmon and citrus, but is much more abundant in moist, subtropical forests on native plants, especially vines and the exposed roots of shrubs. It is always heavily parasitised.

BIOLOGICAL CONTROL

Due to the relatively low incidence of *C. ceriferus* on exotic crops, biological control agents have not been introduced specifically for it into Australia. One egg predator, *Scutellista caerulea*, introduced from South Africa to control *Saisettia oleae*, is an important natural enemy of *C. ceriferus*. Several indigenous parasitoids associated with the immature stages and adults of *C. ceriferus* undoubtedly contribute to maintaining this species under control (Table 8 on page 143). In northern New South Wales and Queensland, the most abundant of these is *Microterys australicus*.

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Table 8. Indigenous natural enemies of *Ceroplastes ceriferus*

Species	Stage of host	References
NEUROPTERA		
CHRYSOPIDAE		
Mallada spp.	L 1, 2	D.P.A. Sands unpubl.
HYMENOPTERA		
ENCYRTIDAE		
Coccidoctonus dubius[a]	L 3, A	D.P.A. Sands unpubl.
Metaphycus sp.	A	Sands 1984
Microterys australicus	A	Sands 1984
PTEROMALIDAE		
Moranila californica	A	Sands 1984
Moranila comperei[a]	A	D.P.A. Sands unpubl.

[a]hyperparasitoid

14

Ceroplastes destructor Newstead Hemiptera: Coccidae white wax scale

PRECIS

Ceroplastes destructor, a white wax scale of African origin, was introduced into Australia in the late 1800s. The insect excretes honeydew which accumulates on the leaves and fruit, providing a substrate for the growth of sooty moulds. Before its biological control in the 1970s, *C. destructor* was a major pest of citrus and ornamental plants in south-eastern Australia, and in the south-west of Western Australia.

Of the six species of parasitoid and one predator introduced from South Africa as biological control agents for *C. destructor* between 1968 and 1974, five parasitoids became established. Effective biological control has been achieved in northern, central and southern New South Wales, Norfolk Island and in Queensland, mainly by *Anicetus communis* and *A. nyasicus*.

BIOLOGY

Ceroplastes destructor is one of several similar, wax-secreting scale insects originally from South Africa (DeLotto 1956) that are now established in Australia, Norfolk Island, New Zealand, Papua New Guinea and the Solomon Islands. *C. destructor* was established in Australia during the late 1800s and, before its biological control in the early 1970s (Milne 1981), it was a major pest of citrus from Kuranda, northern Queensland to Moruya, southern New South Wales and also in southern Western Australia. It is also recorded from near Griffith in south-western NSW (Smith et al. 1997a).

Female *C. destructor* produce eggs parthenogenetically and males have not been recorded in Australia. In Queensland (Smith and Ironside 1974) and northern New South Wales, *C. destructor* may be bivoltine or multivoltine, whereas in central and southern New South Wales and Western Australia the scale is univoltine (Milne 1981). Univoltine populations reproduce from November to December, whereas bivoltine adults reproduce from mid-October to February and

April to early October (Smith 1970). However, adults may oviposit at any time of the year following the death of the host plant.

C. destructor secretes a soft, white wax which covers the body of the insect. Unlike other *Ceroplastes* spp. occurring in Australia, including the similar *C. ceriferus*, the dome-shaped wax secretion (ca 8 mm) of *C. destructor* is soft and very moist. When aggregations are dense, the wax from individuals merges to form a continuous, undifferentiated mass on the stem of the host plant. The body of the adult is pink, red or brown. There are four instars of *C. destructor*. Depending on size, each adult female deposits up to 3000 pink eggs in a concave cavity beneath its ventral surface. First instars (crawlers) hatch from the egg mass, migrate to the upperside of leaves and commence feeding at the veins. Crawlers may fall or be dispersed by the wind to other plants. After settling, crawlers penetrate the tissues with their stylets and secrete a coating of white wax with lateral projections (rosette stage). Ecdysis of 2nd instars occurs on leaves and 3rd instars transfer from leaves to settle permanently on stems. Occasionally scales reach maturity on the leaves or petioles of the host plant.

PEST STATUS

C. destructor was a major pest of citrus and ornamental plants in south-eastern and south-western Australia before its biological control in the 1970s. Honeydew excreted from heavy infestations of *C. destructor* provides the substrate for the growth of sooty moulds on the host plant. The moulds reduce photosynthesis, discolour fruit and require removal before marketing. Heavy infestations are believed to reduce plant vigour and fruit set, but these impacts have not been quantified.

On the coast from Byfield, Queensland to southern New South Wales, *C. destructor* infested a wide range of plants, particularly guava (*Psidium guajava*), gardenia (*Gardenia augusta*) and oleander (*Nerium oleander)*, and the indigenous *Bursaria spinosa*, *Dodonaea triquetra*, *Pittosporum undulatum* and *Syzygium* spp. Heavy infestations of *C. destructor* were mainly coastal and the scale was uncommon west of the The Great Dividing Range. The level of infestation varied locally on plants, with plant variety and with plant phenology. For example, oleander was infested mainly in the subtropics, and lemons (*Citrus limon*) were not as seriously affected as Valencia or Washington navel oranges (*Citrus sinensis*). Small citrus plants (< 0.5 m) carried no more than a few scales and stems of greater diameter than 2.5 mm were rarely infested.

BIOLOGICAL CONTROL

Several indigenous insect predators and parasitoids attacked *C. destructor* before the introduction of exotic parasitoids (Table 9 page 150), but they failed to prevent heavy infestations from developing (Snowball 1969b). Coccinellidae

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preyed mainly on the immature stages of the scale since the wax coating inhibited access to the soft bodies of the more advanced stages. Indigenous *Microterys* spp. (Encyrtidae) were usually rare and had no noticeable impact on populations of *C. destructor*. Two species, *M. nietneri* and *M. newcombi,* were only reared once from scale infested stems (D.P.A. Sands, unpublished) and have not been recovered from individual *C. destructor*. The host records referred to by Prinsloo (1976) must therefore remain in doubt since the stems carried other scale insects that may have been host to these parasitoid species. *M. australicus* has occasionally been reared from *C. destructor* and *C. ceriferus* from south-eastern Queensland and northern NSW (D.P.A. Sands, unpublished).

Metaphycus helvolus was introduced as a biological control agent for *Saissetia oleae* (Wilson 1960). It also attacks other soft scales, is uncommon and has little impact on populations of *C. destructor* (Sands et al. 1986). It has also been recorded parasitising *Ceroplastes sinensis* and *C. rubens* (Sands 1984). Birds occasionally fed on *C. destructor*, including the silvereye (*Zosterops lateralis*), the red-browed finch (*Neochmia temporalis*), the superb fairy wren (*Malurus cyaneus*) and the double-barred finch (*Taeniopygia bichenovii*) (W.M. Milne, pers. comm.; D.P.A. Sands, unpublished).

Natural enemies of *C. destructor* were introduced into Australia between 1935 and 1938 (Wilson 1960) and between 1968 and 1974 (Sands et al. 1986). Initially 25 species of parasitoid from Uganda and Kenya were reared but only two species, *Scutellista caerulea* and *Diversinervis elegans*, were released. It is likely that some of the parasitised scales introduced were not *C. destructor*, since the plants from which they were collected included coffee in Kenya, where it is not recorded as a host plant for *C. destructor* (DeLotto 1956). The early attempts at biological control probably failed because the parasitoids were reared from scale insects other than *C. destructor* (Sands et al. 1986). Many parasitoids of wax scale insects are relatively host-specific and not able to utilise as hosts other closely-related scale insects. Biological control investigations in the 1960s placed emphasis on obtaining, from South Africa, parasitoids developing on *C. destructor* (Snowball 1969b). One parasitoid, *Euxanthellus philippiae*, was obtained parasitising *C. sinensis* in New Zealand, where it was known to be an important parasitoid of both *C. destructor* and *C. sinensis* (Cumber 1972; R.A. Cumber, pers. comm.).

Anicetus communis is abundant in South Africa (Snowball 1969b) and has became the most important parasitoid of this scale insect in central and southern New South Wales since its first release in 1968. *A. communis* has become established in coastal New South Wales, in south-eastern Queensland and in Western Australia, although it is not abundant in north-eastern New South Wales and Queensland.

Anicetus nyasicus is an abundant parasitoid of *C. destructor* in South Africa (Annecke 1967) and it has become the most important biological control agent for *C. destructor* from Queensland to northern New South Wales since its release

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in 1968 (Sands et al. 1986). *A. nyasicus* is uncommon in the cooler climatic regions of central New South Wales and on the Border Ranges of Queensland where *C. destructor* is mostly parasitised by *A. communis*. Populations in Queensland have become so low that it is difficult to find even solitary *C. destructor* in orchards, whereas densities before introduction of the parasitoid often exceeded 20 scales per 10 mm of stem. On Norfolk Island, *C. destructor* declined in abundance within 12 months of the release of *A. nyasicus*, and was completely controlled throughout the island within the following 7 months (D.P.A. Sands, unpublished).

Aprostocetus ceroplastae is indigenous throughout Africa and the Mediterranean countries, parasitising at least seven species of *Ceroplastes* (Ben-Dov 1972), and was found by Snowball (1969b) to commonly attack *C. destructor* in South Africa. *A. ceroplastae* has become established and is abundant in coastal New South Wales and Queensland. However, it is not considered to contribute significantly to the control of *C. destructor* in the presence of *A. communis* and *A. nyasicus*. *A. ceroplastae* has also been recorded parasitising *C. sinensis* in New South Wales (Smith et al. 1997a).

A biotype of *S. caerulea* became established in Australia before 1969, but did not parasitise *C. destructor*—although it was commonly reared from *C. ceriferus, C. floridensis, C. rubens* and *C. sinensis* (Sands 1984) in addition to several other soft scales. This biotype is believed to have been from South Africa, introduced via California for control of *Saisettia oleae* (Wilson 1960). Between 1969 and 1970, a biotype from South Africa adapted to *C. destructor* was released but recoveries in eastern Australia were not made until 1984. By 1989, this biotype of *S. caerulea* had become established on *C. destructor* and spread throughout coastal New South Wales and south-eastern Queensland, sometimes parasitising up to 60% of the scales (Smith et al. 1997a). *S. caerulea* is considered to be of minor importance as an agent for *C. destructor* in the presence of the highly-effective parasitoids *A. communis* and *A. nyasicus*.

D. elegans is also represented by different biotypes, adapted to parasitising different species of scale insects. *D. elegans* was said to be an important parasitoid of *Ceroplastes* from Kenya, but it failed to become established following early releases (Wilson 1960). Releases of *D. elegans* reared from *C. destructor* from South Africa were made in 1971 but it was not known to have become established until March 1988, when it was recovered at Alstonville, northern New South Wales (Malipatil et al. 2000; D.P.A. Sands, unpublished). *D. elegans* then outnumbered all other species of parasitoids parasitising *C. destructor*, including *A. nyasicus*. These *D. elegans* were presumably descendants that had spread from releases made in northern New South Wales in 1971 (Sands et al. 1986).

AGENTS RELEASED THAT FAILED TO ESTABLISH

Euxanthellus philippiae was considered to be a most important parasitoid of *C. sinensis* in New Zealand (Cumber 1972) and frequently also parasitised *C. destructor* (G.J. Snowball, pers. comm.). There has been no evidence for it parasitising *C. destructor* or *C. sinensis* following the release of 132 male and 791 female parasitoids near Sydney, New South Wales in 1971.

In South Africa, *Trichomasthus ingens* is a parasitoid of *C. destructor, C. mimosae* and *C. brevicauda* (Annecke 1964; Cilliers 1967). Up to 700 *T. ingens* were released at 10 localities in central and northern New South Wales between 1969 and 1970 but the parasitoid failed to establish. One female was recovered 16 weeks after a release at Elizabeth Beach, central New South Wales.

The noctuid moths *Coccidiphaga scitula* and *C. costimacula* were considered for introduction into Australia (Snowball 1969b) but only *C. scitula* was successfully reared and released (Sands et al. 1986). At seven liberation sites of *C. scitula* in central New South Wales there was no evidence for its establishment following the release of 28 gravid females and 2500 eggs between 1969 and 1970.

MAJOR NATURAL ENEMIES

Anicetus communis Hymenoptera: Encyrtidae

A. communis is a biparental, solitary, internal parasitoid of 3rd instar nymphs and small, adult *C. destructor*. The development period ranges from 29 to 154 days at 24°C, depending on the stage of the host. In nymphs and in adults approaching oviposition, *A. communis* develops without interruption, but in immature adults, the 1st instar parasitoids enter diapause. This suspended development is seasonal and, in univoltine adults of *C. destructor*, parasitoid larvae enter diapause in autumn and re-commence development in late spring when oocyte development of the host takes place. Occasionally *A. communis* develops at other times of the year following a break in diapause, when death of the plant on which the scale insect is feeding stimulates oocyte development in the parasitised adult scale insects. *A. communis* is the most effective biological control agent for *C. destructor* in temperate climates.

Anicetus nyasicus Hymenoptera: Encyrtidae

A. nyasicus is an internal, solitary parasitoid of adults, but sometimes 3rd instars are also attacked. The parasitoids are mostly uniparental in Australia with males being only occasionally recovered. However, in South Africa, the parasitoid is biparental (Annecke 1967). The development period for *A. nyasicus* ranges from 31 to 49 days, and adults survive for up to 67 days at 24°C. *A. nyasicus* is the most effective biological control agent for *C. destructor* in tropical and subtropical climates.

Diversinervis elegans Hymenoptera: Encyrtidae

D. elegans is a solitary, or occasionally gregarious, biparental, internal parasitoid of medium to large adult *C. destructor*. The development period for *D. elegans* ranges from 26 to 46 days at 24°C, and adults survive for up to 83 days at ca 20°C. The biotype parasitising *C. destructor* has not been morphologically distinguished from the biotype reared from other soft scales in Australia.

Aprostocetus ceroplastae Hymenoptera: Eulophidae

A. ceroplastae is known to parasitise a number of *Ceroplastes* spp. in Africa and Europe. *A. ceroplastae* is an internal solitary parasitoid, mainly of 3rd instars and small (1.5 mm) adults, but it has also been reported developing in 2nd instars in South Africa (Cilliers 1967). Males outnumber females when reared in the laboratory. The development period for *A. ceroplastae* ranges from 20 to 116 days, and adults survive for up to 70 days (Ben-Dov 1972).

Scutellista caerulea Hymenoptera: Pteromalidae

Larvae of *S. caerulea* are biparental predators on the eggs of *C. destructor*. Eggs are deposited singly or in pairs beneath the adult scale insect, either among eggs of the scale or beneath the ventral body wall of the adult scale prior to oviposition. The biotype of *S. caerulea* adapted to *C. destructor* appeared to complete development only if eggs of its host were present. Otherwise, newly-hatched parasitoid larvae survived beneath the scale for up 89 days without feeding. However, in South Africa the parasitoid larvae were also recorded feeding on the body tissues of the scale insect (Cilliers 1967). The biotype of *S. caerulea* adapted to *C. destructor* can be distinguished from the biotype established earlier in other scales by slight differences in the antennae and wings. It is not known if the *C. destructor* biotype attacks other species of soft scale.

COMMENTS

It is likely that early attempts to establish African natural enemies of white wax scales in Australia failed when host-specific parasitoids were reared from hosts other than *C. destructor*, the target species in Australia (Sands et al. 1986). Where biological control of *C. destructor* has been achieved in the tropical and subtropical environments of northern New South Wales, Queensland, Norfolk Island and Papua New Guinea, *A. nyasicus* has proved to be an effective agent. However, *A. nyasicus* is not effective in temperate regions where *C. destructor* is univoltine. By contrast, *A. communis* is a very effective agent for temperate localities since its diapausing larvae are able to synchronise with the univoltine, overwintering development of its host. The other parasitoids from South Africa now established in Australia have little importance in controlling populations of *C. destructor* when either *A. nyasicus* or *A. communis* are present.

An economic assessment of the benefit–cost ratio of biological control of *C. destructor* (2.6:1 at 5% discount rate) by Marsden et al. (1980), was very conservatively based on calculations for a reduction of insecticide use (from two applications to one per year), rather than complete suspension of insecticide for control of this pest which occurred since the mid-1970s. As well as commercial citrus, benefits have accrued to plant nurseries and growers of ornamental plants throughout eastern Australia ever since biological control of *C. destructor* was achieved in the 1970s. In addition, it was not possible to evaluate the benefits to natural enemies of other pests by withholding insecticide applications in citrus orchards. On Norfolk Island, where all fruit was locally produced to avoid the introduction of exotic pests, biological control of *C. destructor* by *A. nyasicus* in the late 1980s was followed by a marked increase in yields of citrus fruit (N. Tavener, pers. comm.).

Table 9. Indigenous natural enemies of *Ceroplastes destructor*

Species	Stage of host	References
NEUROPTERA		
CHRYSOPIDAE		
Mallada spp.		Smith et al. 1997a
Plesiochrysa ramburi	L 1, 2, 3	D.P.A. Sands & G.J. Snowball unpubl.
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzieri	L 2, 3	D.P.A. Sands & G.J. Snowball unpubl.
Halmus chalybeus	L 1, 2, 3	Wilson 1960
Parapriasus australasiae	L 1, 2, 3	D.P.A. Sands & G.J. Snowball unpubl.
Rhyzobius lindi	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
Rhyzobius ventralis	E, L 1, 2	Wilson 1960
Scymnodes lividigaster	L 1, 2	Smith et al. 1997a
Scymnus pumilis	L 1	D.P.A. Sands & G.J. Snowball unpubl.
Serangium bicolor	L 1, 2	Smith et al. 1997a
Serangium maculigerum	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
HYMENOPTERA		
APHELINIDAE		
Coccophagus sp.[a]	L 3	Sands 1984
ENCYRTIDAE		
Cheiloneurus sp.[a]	L 3	Sands 1984; Malipatil 2000
Coccidoctonus dubius[a]	L 3, A	D.P.A. Sands unpubl.
Microterys australicus	A	Prinsloo 1976
Microterys newcombi		Prinsloo 1976
PTEROMALIDAE		
Moranila comperei[a]	A	D.P.A. Sands & M. Schotz unpubl.

[a]hyperparasitoid

15

Ceroplastes floridensis Comstock Hemiptera: Coccidae † Florida wax scale

PRECIS

The origin of Florida wax scale, *Ceroplastes floridensis*, is probably Central or South America but is not known with certainty. In eastern Australia the scale insect occurs from north-eastern New South Wales to northern Queensland. It is occasionally an important pest on citrus and seedling *Pinus* spp. in Queensland and is a minor pest of many ornamental and native plants. Honeydew secreted by the scale accumulates on leaves and fruit of host plants, providing a substrate for sooty moulds. No agents have been imported specifically for the biological control of *C. floridensis*, but it is attacked by a number of predators and exotic parasitoids introduced against other species of scale.

BIOLOGY

Ceroplastes floridensis was first described from Florida (Brimblecombe 1956b) but its native range is unknown, and it probably did not originate in the USA as its specific name implies (Qin and Gullan 1998). *C. floridensis* is recorded from central and tropical South America, Irian Jaya, Hawaii, Hong Kong, northern Africa, Madagascar, India, China, Southeast Asia, Egypt, Cyprus, France, Israel, Italy, Lebanon, Madeira, Turkey, Mariana Islands, Palau and Australia (Ben-Dov 1993). It is a serious pest of citrus in Israel and a minor pest in North America. In eastern Australia, *C. floridensis* occurs from northern New South Wales (where it is uncommon) to Cairns, northern Queensland. It is most abundant in south-eastern Queensland but is also common on the Atherton Tablelands.

The life history of *C. floridensis* was discussed by Smith et al. (1997a) and some hosts were listed by Brimblecombe (1956b) and Ben-Dov (1993). Adult *C. floridensis* are similar in size (up to 5 mm) and appearance to *Ceroplastes rubens*, although adults are paler in colour. The insect secretes a firm, pale pink or grey wax covering the soft body of the insect. There are three larval instars. Instars 1 and 2 secrete a white wax dorsal coating with short lateral white wax projections.

The majority of nymphs move from the leaves after instar 3 to settle on the stems of the host plant, unlike those of *C. rubens* which remain mostly on the leaves and petioles. Females of *C. floridensis* reproduce parthenogenetically and deposit up to 1400 red eggs in a mass beneath their concave ventral surface (Smith et al. 1997a).

In north-eastern New South Wales and south-eastern Queensland, *C. floridensis* is bivoltine, whereas in northern Queensland several over-lapping generations occur. Most oviposition, followed by hatch of crawlers, occurs between mid-September and December and from February until April.

PEST STATUS

C. floridensis produces copious secretions of honeydew, followed by heavy growth of sooty moulds. In central Queensland, it sometimes develops moderate infestations on citrus (particularly Meyer lemons and Valencia oranges). *C. floridensis* is also a pest on nursery seedlings of *Pinus caribaea* and is common on several species of native plants, particularly *Ficus* sp., *Melaleuca quinquenervia* and other *Melaleuca* spp. (Brimblecombe 1956b). Until recently, *C. floridensis* was not considered to be a pest (Brimblecombe 1956b) but it is now occasionally important and may be gaining significance as a pest of citrus in Queensland (Smith et al. 1997a).

BIOLOGICAL CONTROL

Several indigenous parasitoids and predators are associated with the immature stages and adults of *C. floridensis* and most are well known as natural enemies of other wax scales (Table 10 page 153). The egg predators *Scutellista caerulea* and *Moranila californica*, and the parasitoids *Coccophagus ceroplastae*, *Diversinervis elegans* and *Microterys neitneri*, are the most important parasitoids. The South African parasitoid *Aprostocetus ceroplastae* attacks mainly small adults of *C. floridensis* in northern New South Wales and the ladybird *Cryptolaemus montrouzeieri* and larvae of the moth *Mataeomera dubia* are common predators on crawlers and the mature stages of the scale, respectively. The fungus *Verticillum lecanii* sometimes infects immature scales during humid conditions (Smith et al. 1997a).

Although *Anicetus beneficus* is recorded as a parasitoid of *C. floridensis* (Noyes 1998), it has not been associated with this scale insect in Australia.

The combined effects of natural enemies appear to be limiting the importance of *C. floridensis,* except in south-eastern Queensland, where attempts are being made to establish *A. ceroplastae* to reduce the importance of this scale (Smith et al. 1997a).

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Table 10. Indigenous natural enemies of *Ceroplastes floridensis*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzeri	L 1, 2	Smith et al. 1997a
LEPIDOPTERA		
NOCTUIDAE		
Mataeomera dubia	L 2, 3, A	Smith et al. 1997a
HYMENOPTERA		
ENCYRTIDAE		
Metaphycus sp.	L 3	D.P.A. Sands unpubl.
PTEROMALIDAE		
Moranila californica[a]	E	Smith et al. 1997a

[a]egg predator

16

Ceroplastes rubens Maskell Hemiptera: Coccidae pink wax scale

PRECIS

The origin of pink wax scale, *Ceroplastes rubens*, was once thought to be Sri Lanka, but it is now predicted to be Africa. In eastern Australia, *C. rubens* develops heavy infestations on citrus (especially mandarins), mango, custard apple, avocado and seedling *Pinus caribaea*, in addition to a wide range of ornamental and native plants. As with other *Ceroplastes* spp., honeydew accumulates on the leaves and fruit of host plants, providing a substrate for sooty moulds which then reduce photosynthesis. Several parasitoids of *C. rubens* were introduced into Australia many years ago, including some for biological control of other scale insects, but they failed to control the scale. However, following the introduction of *Anicetus beneficus* from Japan in 1977, *C. rubens* has decreased in importance. The scale is now considered to be under effective biological control by *A. beneficus* on most plants, including citrus.

BIOLOGY

Ceroplastes rubens was first described from Queensland in the late 1800s and is thought to have been introduced from Sri Lanka (Wilson 1960). However, Qin and Gullan (1998) recently constructed cladograms for the genus and predicted the native region for *C. rubens* to be Africa. *C. rubens* is recorded from Australia, China, Southeast Asia, Micronesia, Kiribati, Niue, Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia, Fiji, Samoa, French Polynesia, Cook Islands, Norfolk Island (Williams and Watson 1990), Hawaii and Japan.

The life history of *C. rubens* was described by Summerville (1935a). Adult *C. rubens* secrete a firm grey, pink or red wax which covers the soft body of the insect. Earlier instars secrete a wax coating, first white and then dark pink with small, lateral white wax projections. Third instar larvae secrete lateral bands of white wax on the dorsal surface. Females reproduce parthenogenetically and winged males are rarely recorded. In central and southern New South Wales,

C. rubens is univoltine, whereas in Queensland and northern New South Wales, it is bivoltine (Smith 1997b). Univoltine populations oviposit in October and 1st instars emerge from November to December, whereas bivoltine adults oviposit in early September and crawlers emerge from mid-September until early December. The second generation emerges from February to April (Smith 1997b).

Adult *C. rubens* vary in size depending on the nitrogen content of their food plant. They deposit up to 900 red eggs in a mass beneath their concave ventral surface. Crawlers hatch from the egg mass and move to the leaves of the host plant or are dispersed by wind to other plants. They usually settle at or near the leaf veins, particularly on the midrib, where they penetrate the tissues with their stylets. The four instars are normally completed without migration from the original feeding site on the leaves. Occasionally crawlers settle and develop to adults on young stems or fruit of host plants.

PEST STATUS

In Australia, *C. rubens* is a pest in the Northern Territory, from north-eastern Queensland to southern New South Wales and in Western Australia. It has also been recorded from South Australia and Victoria, but is absent from Tasmania (Qin and Gullan 1994). In eastern Australia, infestations are common in coastal regions but are uncommon west of the main Dividing Range.

C. rubens is a serious pest of fruit trees, particularly citrus, mango, longan, guava, avocado and custard apple, and is a nursery pest on seedlings of *Pinus taeda* and *P. caribaea* (Merrifield and Howcroft 1975; R. Wylie, pers. comm.). It is also infests a wide range of other fruit trees and crops, ornamental plants and indigenous plants including lillypilly (*Syzygium* spp.), fig (*Ficus* spp.), umbrella tree (*Shefflera actinophylla*) and pittosporum (*Pittosporum undulatum*) (Summerville 1935a; Brimblecombe 1956; Ben-Dov 1993). Heavy infestations of *C. rubens*, in common with other *Ceroplastes* spp., produce copious honeydew which encourages the growth of sooty moulds, thus reducing plant photosynthesis, disfiguring fruit and requiring removal before marketing.

BIOLOGICAL CONTROL

Indigenous predators and parasitoids are commonly associated with the immature stages of *C. rubens* (Table 11 page 157) but alone are not effective in reducing scale infestations to acceptable levels. Crawlers and 2nd instars are preyed upon by Coccinellidae and predatory larvae of the moth *Mataeomera dubia* (Noctuidae), and parasitoids, particularly *Coccophagus ceroplastae*, are often abundant (Loch 1996, 1997). A number of unsuccessful attempts were made between 1896 and 1901 to control *C. rubens* by introducing natural enemies from Hawaii, Japan and China (Wilson 1960).

In 1955, *Anicetus beneficus* was imported from Japan, but a culture was not established and the parasitoid was not released. Following favourable reports on its effectiveness in Japan (Yasumatsu 1968), *A. beneficus* was again imported in 1976 and released in Queensland in 1977, achieving effective control in citrus orchards within about 2.5 years of its establishment (Smith 1986). In 1990, *A. beneficus* was introduced into Norfolk Island where infestations of *C. rubens* and *Ceroplastes destructor* were previously reducing yields of citrus fruit, particularly grapefruit. *A. beneficus* began to spread 18 months after its establishment in Norfolk Island, and this was followed by a decline in the abundance of *C. rubens*, with parasitisation reaching 30% of adults and nymphs of the scale within 24 months.

COMMENTS

In addition to the indigenous parasitoids that develop in *C. rubens*, several exotic parasitoids that were introduced to control other scale insects also attacked *C. rubens*. For example, the biotypes of *Scutellista caerulea* and *Metaphycus helvolus* that parasitise *C. rubens* (Sands 1984; Sands et al. 1986), appear to be the same as those introduced to control *Saissetia oleae*, whereas the biotype of *Diversinervis elegans* may be the same as that introduced to control *C. destructor* (Loch 1997).

C. rubens was first reported in Japan in 1897 infesting a wide range of plants including citrus, persimmon and tea. Between 1942 and 1946, a decline in the abundance of the scale was attributed to parasitism by the previously unknown *A. beneficus* (Yasumatsu 1968). The origin of *A. beneficus*, which has since effectively controlled *C. rubens* in Japan, Australia and Norfolk Island, has not been determined (DeBach 1964), but it may be Africa where *C. rubens* is now believed to have originated. Alternatively, *A. beneficus* may be native to southern China and was introduced from there to Japan during World War II (Hirose et al. 1990). On Norfolk Island *A. beneficus* dispersed slowly after establishment and in Queensland does not always control infestations of *C. rubens* on umbrella trees (*Schefflera actinophylla*), although the reasons for this are not clear (Loch 1998).

Hyperparasitisation of *C. rubens* by *Coccidoctonus dubius* exceeding 40% has been recorded (Loch 1998), but it is not known whether it develops on *A. beneficus* in addition to other primary parasitoids (Loch 1997). Hyperparasitisation of *A. beneficus* by *C. dubius* on Norfolk Island increased to more than 20% during establishment of the primary parasitoid (D.P.A. Sands, unpublished).

To date, parasitoids have not been recorded attacking *Ceroplastes rusci* (L.) in the Northern Territory, where the scale insect was recently discovered for the first time in Australia (E.S.C. Smith, pers. comm.). Previously known in the region from West Papua (Williams and Watson 1990), *C. rusci* may prove to be a host for several species of parasitoids that also attack *C. rubens*.

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Table 11. Indigenous natural enemies of *Ceroplastes rubens*

Species	Stage of host	References
NEUROPTERA		
CHRYSOPIDAE		
Mallada signata	L 1, 2, 3	Wilson 1960
Mallada spp.		Smith et al. 1997a
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzieri	L 2, 3	Wilson 1960
Diomus sp.		Smith et al. 1997a
Diomus notescens		Wilson 1960; Smith et al. 1997a
Halmus chalybeus	L 1, 2, 3	D.P.A. Sands & G.J. Snowball unpubl.
Harmonia conformis	L 1, 2	Wilson 1960; Smith et al. 1997a
Rhyzobius ventralis	E, L 1, 2	Wilson 1960
Scymnus sp.	L 1	Wilson 1960
Serangium bicolor	L 1, 2	Smith et al. 1997a
Serangium maculigerum	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
LEPIDOPTERA		
NOCTUIDAE		
Mataeomera dubia	L 2, 3, A	Wilson 1960
HYMENOPTERA		
APHELINIDAE		
Coccobius atrithorax	L 3	Smith et al. 1997a
Coccophagus ceroplastae[a]	L 3	Noyes 1998
Encarsia citrina	L 3	Wilson 1960; Smith 1974
Euryischomyia flavithorax		Carver 1995
Myiocnema sp.[a]	L 3, A	Loch 1997
ENCYRTIDAE		
Cheiloneurus sp.[a]	L 3, A	Sands 1984; Loch 1997
Coccidoctonus dubius[a]	L 3, A	Sands 1984; Smith 1986; Loch 1997
Metaphycus sp.	A	Sands 1984
Metaphycus varius	L 3, A	Smith 1974, 1986; Loch 1997
Microterys sp.? *australicus*	A	Loch 1997
Rhopalencyrtoidea dubia	A	Loch 1997

[a]hyperparasitoid

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Table 11. (cont'd) Indigenous natural enemies of *Ceroplastes rubens*

Species	Stage of host	References
EULOPHIDAE		
Aprostocetus sp.	L 3, A	Sands 1984; Loch 1997
Coccobius atrithorax	L 2, 3	Wilson 1960
PTEROMALIDAE		
Moranila californica	A	Loch 1997
Moranila comperei[a]	A	D.P.A. Sands unpubl.

[a]hyperparasitoid

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Ceroplastes sinensis Del Guercio Hemiptera: Coccidae † Chinese wax scale

PRECIS

Chinese wax scale, *Ceroplastes sinensis*, is now thought to have originated in South America. In eastern and south-western Australia, *C. sinensis* develops heavy infestations on citrus (especially oranges and lemons), as well as on a wide range of ornamental and native plants. As with other *Ceroplastes* spp., honeydew from *C. sinensis* accumulates on leaves, twigs and fruit of its host plants, providing a substrate for sooty moulds which then reduce photosynthesis. Several parasitoids and predators attack *C. sinensis* but they are not effective in controlling outbreaks of the scale. No natural enemies of *C. sinensis* have been intentionally introduced into Australia, but several parasitoids that attack the scale in its native range of Argentina may be potentially valuable as biological control agents for Australia.

BIOLOGY

Ceroplastes sinensis was first described from Italy (Del Guercio 1900) but is also recorded from Sicily, France, Spain, Algeria, Morocco, Jamaica, Madeira, China, Hong Kong, North America, New Zealand, Norfolk Island, Solomon Islands, Australia (Snowball 1970; Williams and Watson 1990) and South America (Qin et al. 1994). Some of these locality records, including those from China, are thought to be incorrect (Qin et al. 1994). Cottier (1939) considered *C. sinensis* to be a native of South America, the country of origin later suggested by Qin et al. (1994), based on its phylogenetic relationships to other scales.

The life history of *C. sinensis* was discussed by Del Guercio (1900) and Snowball (1970). Most females reproduce parthenogenetically, but low numbers (2.5%) of winged males also occur. In New South Wales and Western Australia, *C. sinensis* is univoltine. Oviposition occurs from November and crawlers emerge from November to March, and occasionally also in April, June and July. In Queensland *C. sinensis* is bivoltine with most oviposition occurring in October and March.

Female *C. sinensis* secrete a firm wax covering the soft body of the insect. Adult females vary in size but their wax (ca 5 mm) is usually larger than that of *Ceroplastes rubens* (ca 3 to 4 mm) and smaller than that of *Ceroplastes destructor* (ca 7 to 9 mm). Up to 3800 eggs are deposited in a mass beneath their ventral surface and, after hatching, the crawlers are dispersed by wind before settling at leaf veins to penetrate the tissues of host plants with their stylets.

There are four instars in the female and six in males of *C. sinensis*. In instars 1 to 3 the body wax is overlaid by long, white wax projections (rosettes) which persist until the 4th instar when red or pink body wax predominates. Females usually transfer from leaves to stems from March until May during the 4th instar (rarely 3rd), but male scales remain on the leaves where they complete development. However, on some plants (e.g. *Ficus virens*) females complete development on the leaves. In 3rd instars and adults, the red or bright pink body wax of females changes until the anterior portion becomes distinctly pale pink and posterior becomes white. Adult scales retain this colour or become almost white when gravid. In males, development from the 3rd instar to pupa takes place without further enlargement of the scale covering.

PEST STATUS

In Australia, *C. sinensis* was first observed in the Botanical Gardens, Sydney in 1966. Later it spread to central New South Wales, Victoria, southern Western Australia and southern Queensland. *C. sinensis* became a pest of citrus in 1967 near Sydney and was subsequently observed infesting more than 50 other plants, especially native *Melaleuca* spp., *Syzygium* spp., *Callistemon* spp. and *Ficus* spp. This scale is an important pest of citrus in central New South Wales, especially in the Gosford region and in southern Western Australia. In common with other *Ceroplastes* spp., honeydew excreted from heavy infestations of *C. sinensis* provides a substrate for growth of sooty moulds on leaves of the host plant, reducing photosynthesis and vigour of the plant host.

BIOLOGICAL CONTROL

A number of native generalist parasitoids and predators are commonly associated with the immature stages of *Ceroplastes sinensis* (Table 12 page 161) but none are effective in controlling the scale. No natural enemies have been specifically introduced for its biological control, although several exotic species attack it. *Metaphycus helvolus*, introduced from the USA for biological control of *Saissetia oleae*, has adapted to parasitise 2nd, 3rd and early 4th instar females of *C. sinensis*, and *Aprostocetus ceroplastae*, introduced against *C. destructor*, has become an uncommon parasitoid of late 3rd and early 4th instar female *C. sinensis*. *Euxanthellus philippiae*, an important parasitoid of *C. sinensis* in New Zealand (Cumber 1972), was introduced into Australia for biological control of *C.*

destructor. However, it failed to establish either on *C. destructor* or on *C. sinensis* (Sands et al. 1986).

Although *Anicetus beneficus* is recorded as a parasitoid of *C. sinensis* (Noyes 1998), it has not been associated with this scale insect in Australia.

Predators of early instar scales include several ladybirds and the larvae of Lepidoptera and Thysanoptera. Larvae of the egg predator *Scutellista caerulea* may attack up to 70% of gravid *C. sinensis*. This predator was known to attack *C. sinensis* in Australia before introduction from South Africa of the biotype adapted to *C. destructor*. Based on its morphology, *S. caerulea* attacking *C. sinensis* appears to be the same biotype as that associated with *Saissetia oleae* and other *Ceroplastes* spp.

Larvae of the moth *Stathmopoda melanochra* are common predators on all stages of *C. sinensis* when the scales reach high densities, for example, on species of *Ficus* spp. (D.P.A. Sands, unpublished). The fungi *Fusarium moniliforme* var. *subglutinans* and *Verticillium lecanii* are reported to cause high levels of mortality of *C. sinensis* (Smith et al. 1997a).

In May 1993, brief surveys of *C. sinensis* were carried out in Argentina (D.P.A. Sands, unpublished). Individual, heavily parasitised scales at La Plata were collected from holly, supporting the predictions by Qin et al. (1994) that Argentina is likely to be the origin of *C. sinensis*.

Table 12. Indigenous natural enemies of *Ceroplastes sinensis*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Halmus chalybeus	L 1, 2, 3	Smith et al. 1997a
Micraspis frenata	L 1, 2	Smith et al. 1997a
Scymnodes lividigaster	L 1, 2	Smith et al. 1997a
Serangium bicolor	L 1, 2	Smith et al. 1997a
Serangium maculigerum	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
LEPIDOPTERA		
STATHMOPODINAE		
Stathmopoda melanochra	L, A	Common 1990; D.P.A. Sands unpubl.
HYMENOPTERA		
APHELINIDAE		
Coccophagus ochraceus	L 2, 3	Snowball 1970

[a]hyperparasitoid

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Table 12. (cont'd) Indigenous natural enemies of *Ceroplastes sinensis*

Species	Stage of host	References
ENCYRTIDAE		
Cheiloneurus sp.[a]	L 3	Snowball 1970
Coccidoctonus dubius[a]	L 3, A	Sands 1984
unidentified[a]	L 3	Snowball 1970
PTEROMALIDAE		
Moranila californica	A	D.P.A. Sands unpubl.
Moranila comperei[a]	A	Snowball 1970

[a]hyperparasitoid

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Chrysomphalus aonidum (Linnæus) Hemiptera: Diaspididae circular black scale, Florida red scale

PRECIS

Chrysomphalus aonidum is probably originally from Asia, but has become widely distributed in subtropical countries. Its main economic host is citrus but it is also known to attack bananas, palms, camellias and a range of ornamental and native plants. On citrus, *C. aonidum* disfigures fruit and causes leaf drop when infestations are heavy.

C. aonidum is effectively controlled by the parasitoid, *Aphytis holoxanthus*, originally from Hong Kong, and it is now uncommon.

BIOLOGY

In Australia *Chrysomphalus aonidum* occurs in the Northern Territory and from Cooktown, north-eastern Queensland, to Sydney, New South Wales. *C. aonidum* has two to four generations each year in New South Wales and up to six generations in the Northern Territory.

The life history of *C. aonidum* was discussed by Smith et al. (1997a). Up to 300 eggs are deposited beneath its hard scale coating. After hatching, crawlers migrate to settle on both surfaces of leaves and on fruit where they remain until mature. Crawlers may be dispersed to neighbouring plants by wind. The adult scale covering is dark purple or almost black with a dark reddish-brown central apex, covering the yellow, soft body beneath. The oval scales of males are smaller (ca 0.6 mm) than the circular coverings of female scales (ca 2.5 mm). There are two larval instars in females before the adult stage, whereas in males there are two larval instars, followed by pre-pupae and pupae before the winged adults eclose.

PEST STATUS

Unlike red scale (*Aonidiella aurantii*), *C. aonidum* does not produce a phytotoxin in its saliva but heavy infestations of *C. aonidum* on the leaves and fruit of citrus result in disfigurement and leaf drop. Before the introduction of *Aphytis*

holoxanthus from Israel and its establishment in 1974, *C. aonidum* was a serious pest of citrus from Grafton, northern New South Wales to Rockhampton, south-eastern Queensland. *C. aonidum* also attacks other horticultural crops and a range of ornamental and native plants including banana, camellia, acacia, avocado, oleander, custard apple and palms.

BIOLOGICAL CONTROL

Before the introduction of *A. holoxanthus*, a number of generalist predators and four other species of *Aphytis*, including the common *A. columbi*, were known to attack *C. aonidum* over most of its range, but they had little influence on the abundance of the scale (Table 13 page 165). In central and south-eastern Queensland, an internal parasitoid, *Comperiella pia*, was recovered from adult females of this scale. *C. pia* usually reproduces parthenogenetically, but occasional males were reared in laboratory cultures (Sands and Snowball 1980). *Pteroptrix chinensis* is commonly found parasitising *C. aonidum*, but it does not appear to influence the abundance of the scale.

A. holoxanthus was originally collected from *C. aonidum* in Hong Kong and introduced into USA in 1956. Following outstanding control of *C. aonidum* there, the parasitoid was introduced into Israel where its effect was equally spectacular. In Australia it was released in New South Wales and south-eastern Queensland in 1974. It spread throughout the citrus orchards and, since 1977, *C. aonidum* has become extremely uncommon and difficult to find in the field. Chemical control is no longer required.

MAJOR PARASITOID SPECIES

Aphytis holoxanthus Hymenoptera: Aphelinidae

A. holoxanthus is a bi-parental, external parasitoid of adult female *C. aonidum*. After boring through the hard scale covering with its ovipositor, the parasitoid deposits an egg on the soft tissues of the host scale. After hatching, parasitisoid larvae become attached to the scale, where they feed on the body fluids of the host. Pupation by the parasitoid occurs on the host remains beneath the scale cover. Adult parasitoids cut an irregular-shaped hole in the scale cover to emerge.

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Table 13. Indigenous natural enemies of *Chrysomphalus aonidum*

Species	Stage of host	References
NEUROPTERA		
CHRYSOPIDAE		
Mallada spp.	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
COLEOPTERA		
COCCINELLIDAE		
Halmus chalybeus	L 1, 2	Smith et al. 1997a
Harmonia conformis	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
Parapriasus australasiae	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
Rhyzobius lindi	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
Rhyzobius lophanthae	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
Rhyzobius ventralis		Smith et al. 1997a
HYMENOPTERA		
ENCYRTIDAE		
Comperiella pia	A	Sands & Snowball 1980
APHELINIDAE		
Aphytis ? *chilensis*[a]	A	Snowball 1969a
Aphytis columbi	L 2, A	Smith 1978b
Aphytis hispanicus[a]	A	Snowball & Sands 1970
Encarsia sp.[a]	L 2	Lukins & Snowball 1977a

[a]indigenous status not certain

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Coccus hesperidum Linnæus Hemiptera: Coccidae soft brown scale

PRECIS

The country of origin of *Coccus hesperidum* has not been confirmed but it is thought to be South Africa. *C. hesperidum* has spread to most countries of the world. It was recorded in Australia in the late 1800s and became a serious pest in the early 1900s. *C. hesperidum* is now an occasional pest of citrus and other plants in Western Australia and south-eastern Australia.

More than 20 hymenopterous parasitoids have been introduced into Australia to control *C. hesperidum*. Many failed to become established and a number that were introduced to control other scales have also attacked *C. hesperidum*. Native natural enemies include coccinellids, a chrysopid and larvae of a predatory noctuid.

Biological control of *C. hesperidum* has been achieved by several introduced parasitoids assisted by native natural enemies.

BIOLOGY

Female *Coccus hesperidum* are viviparous and reproduce parthenogenetically. Males are rare. Larvae are green to yellow and similar to those of *Coccus pseudomagnoliarum*. There are three larval instars. Second instars have a dorsal longitudinal ridge that does not extend to the posterior, enabling this species to be distinguished from those of *C. pseudomagnoliarum* in which the ridge is longer (Smith et al. 1997a). Adult females are flat and oval, about 4 mm in length, green to yellowish brown and darken with age.

Leaves, young green twigs and fruit are preferred by all stages of *C. hesperidum*. Crawlers do not settle permanently and, until maturity, all stages are capable of movement (Bartlett 1978a). Each adult *C. hesperidum* produces about 200 crawlers. There are two to four generations in the southern States and four to five overlapping generations in Queensland and the Northern Territory. In warm climates a generation may be completed in 40 to 60 days.

TARGET PEST NO. 19

PEST STATUS

C. hesperidum was first recorded in Western Australia in 1894 (Jenkins 1946) and it later became a very serious pest in Western Australia. However, its importance has since been substantially reduced by a complex of introduced parasitoids and native natural enemies. *C. hesperidum* is currently a minor or occasional pest in southern Western Australia, south-eastern Queensland, central New South Wales, Victoria, and south-eastern South Australia, especially the Murray Valley (Smith et al. 1997a; D. Smith, pers. comm.). It occurs on citrus, passionfruit, figs, ornamentals, and many species of native plants. *C. hesperidum* produces honeydew which accumulates on the leaves and fruit. This attracts growth of sooty moulds which reduces photosynthesis and disfigures fruit. Copious honeydew also attracts ants which interfere with natural enemies of the scales, especially parasitoids, sometimes allowing heavy infestations to develop (Smith et al. 1997a). Heavy infestations lead to dieback of twigs and leaf drop.

BIOLOGICAL CONTROL

Predators of immature stages include the coccinellids *Cryptolaemus montrouzieri, Diomus notescens, Harmonia conformis, Parapriasus australasiae, Rhyzobius lophanthae* and *R. ventralis*, and the chrysopid *Micromus tasmaniae* (Table 14 page 168). Larvae of the noctuid moth *Mataeomera dubia* prey on all stages of *C. hesperidum*.

More than 20 species of hymenopterous parasitoid have been introduced into Australia specifically to control *C. hesperidum* and, of these, about six have become established (Table 1page 29). Several parasitoids introduced as agents for other scale insect species have adapted to attack *C. hesperidum*.

Aphytis proclia is recorded as a parasitoid of *C. hesperidum* by Wilson (1960), but it is unlikely to be a valid host record, since the genus *Aphytis* is known to parasitise only diaspidid scales. Similarly, an *Aphelinus* sp. recorded as a parasitoid of *C. hesperidum* by Wilson (1960) is unlikely to parasitise Coccidae.

Several of the parasitoids introduced between 1901 and 1938 are believed to have controlled *C. hesperidum* in Australia. The most abundant parasitoids are *Coccophagus ceroplastae, C. lycimna, Encyrtus infelix, Diversinervis elegans, Microterys nietneri* and *Metaphycus anneckei*.

Table 14. Indigenous natural enemies of *Coccus hesperidum*

Species	Stage of host	References
NEUROPTERA		
CHRYSOPIDAE		
Mallada sp.	L 1, 2	D.P.A. Sands unpubl.
Micromus tasmaniae		Smith et al. 1997a
Plesiochrysa ramburi	L 1-2	Smith et al. 1997a
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzeri	L 1, 2	Wilson 1960
Diomus notescens		Smith et al. 1997a
Harmonia conformis	L 1-2	Smith et al. 1997a
Parapriasus australasiae	L 1, 2	Wilson 1960
Rhyzobius lophanthae		Smith et al. 1997a
Rhyzobius sp. nr *lophanthae*		Smith et al. 1997a
Rhyzobius ventralis		Wilson 1960
LEPIDOPTERA		
BATRACHEDRIDAE		
Batrachedra arenosella	L 1, 2, 3	D.P.A. Sands & G.J. Snowball unpubl.
OECOPHORIDAE		
Stathmopoda melanochra	E, L	D.P.A. Sands & G.J. Snowball unpubl.
NOCTUIDAE		
Mataeomera dubia	L 1, 2, A	Wilson 1960; Smith et al. 1997a
Mataeomera sp.		Wilson 1960
HYMENOPTERA		
APHELINIDAE		
Aphelinus sp.		Wilson 1960
Coccophagus gurneyi		Malipatil et al. 2000
Coccophagus scutellaris	L 2	Wilson 1960
Euryischomyia flavithorax		Malipatil et al. 2000
Myiocnema comperei [a]	L 2, 3	Wilson 1960; Malipatil et al. 2000

[a]hyperparasitoid

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Table 14. (cont'd) Indigenous natural enemies of *Coccus hesperidum*

Species	Stage of host	References
ENCYRTIDAE		
Cheiloneurus 2 spp.[a]		Malipatil et al. 2000
Coccidoctonus dubius[a]		Malipatil et al. 2000
Cristatithorax sp.		Wilson 1960
Diversinervis cervantesi		Rosen and Alon 1983
Encyrtus sp.		Wilson 1960
Epitetracnemus sp.		Malipatil et al. 2000
Metaphycus alberti	L 2, 3	Wilson 1960
Metaphycus verdini		Wilson 1960
Microterys triguttatus		Smith et al. 1997a
MYMARIDAE		
Erythmelus schilleri		Wilson 1960
PTEROMALIDAE		
Moranila californica	E	Malipatil et al. 2000

[a]hyperparasitoid

20

Coccus longulus (Douglas) Hemiptera: Coccidae † long soft scale

PRECIS

Coccus longulus is a cosmopolitan tropical pest and its origin is not known. In eastern Australia, *C. longulus* occurs from northern Queensland to central New South Wales, where it is sometimes a pest of citrus, leucaena, custard apple, lychee, carambola, fig and ornamental plants.

Natural enemies include the parasitoid *Coccophagus ceroplastae*, the coccinellid *Cryptolaemus montrouzeri*, and a fungus, *Verticillium lecanii*.

BIOLOGY

The origin of *Coccus longulus* is not known. The scale is a cosmopolitan tropical pest on a wide range of plants, particularly citrus, leucaena, custard apple, fig, lychee and carambola. In Australia, *C. longulus* occurs from northern Queensland to central New South Wales, and is occasionally an important pest of citrus and leucaena in northern New South Wales and Queensland (Johnson 1994; Smith et al. 1997a).

When compared with other *Coccus* spp., adults of *C. longulus* are relatively long and narrow, each fully grown scale measuring about 4 to 6 mm in length. Female *C. longulus* reproduce parthenogenetically and are ovoviviparous, each producing more than 200 crawlers which are dispersed by wind. Adult scales are green to brown, darkening with age and the immature stages are similar to other *Coccus* spp., somewhat translucent and yellowish-green. In the female there are three larval instars (Johnson 1994) and males are unknown (Ben-Dov 1977). There are three to four generations per year on citrus (Smith et al. 1997a) and overlapping generations on leucaena (*Leucaena leucocephala*), with two main generations and a peak of abundance occurring on young growth during the early summer wet season (Johnson 1994).

After settling, crawlers usually remain at one site on the plant but sometimes move when the tissues become unsuitable. On citrus, green twigs,

leaves and fruit stalks are infested (Smith et al. 1997a) while on leucaena the scales develop on the leaves, stems and branches (Johnson 1994).

PEST STATUS

On citrus, *C. longulus* produces large amounts of honeydew that support the growth of sooty moulds and affect photosynthesis. Heavy infestations of the scale may cause stem death. On leucaena, an important fodder for cattle in northern Queensland (Bray et al. 1984), infestations of *C. longulus* reduce the stem growth and branching, biomass and the growing period, especially during the early summer wet season when the plant is growing most actively (Johnson 1994). Development of sooty moulds on plants and surrounding grass may follow heavy infestations (Elder et al. 1998).

BIOLOGICAL CONTROL

The coccinellid *Cryptolaemus montrouzieri* preys on the immature stages of *C. longulus*, and the fungus *Verticillium lecanii* causes heavy mortality of scales during prolonged wet weather (Smith et al. 1997a). *Coccophagus ceroplastae* is a common parasitoid of *C. longulus* in New South Wales. *Anicetus communis* was recorded from *C. longulus* by Noyes (1998), but this species has only been found to parasitise *Ceroplastes destructor* in Australia (D.P.A. Sands, unpublished). An unidentified parasitoid, *Metaphycus* sp., has been reared from *C. longulus* in central New South Wales.

COMMENTS

C. longulus is not effectively controlled by natural enemies in Australia, and there is a potential to improve biological control by the introduction of further species of natural enemies.

21

Coccus pseudomagnoliarum (Kuwana) Hemiptera: Coccidae † citricola scale

PRECIS

Coccus pseudomagnoliarum is originally from Asia and now occurs in Japan, USA, Mexico, Australia and parts of Europe. *C. pseudomagnoliarum* is an important pest, mainly of irrigated citrus in the drier regions of southern Australia and it is present, but not important, in southern Western Australia.

Several native chrysopids and coccinellids, larvae of the noctuid moth *Mataeomera dubia,* and two introduced parasitoids, *Coccophagus lycimnia* and *C. semicircularis*, are important natural enemies of *C. pseudomagnoliarum.*

BIOLOGY

Coccus pseudomagnoliarum originated in Asia but it has spread to Japan, USA, Mexico, parts of Russia and Iran and southern Australia (Bartlett 1978a). In Australia, it is associated mainly with cooler, dry climates where it is a pest of citrus. Overseas, *C. pseudomagnoliarum* also occurs on other Rutaceae (Bartlett 1978a).

Adult females of *C. pseudomagnoliarum* are broadly oval, convex and measure about 3 to 4 mm in length. The immature stages are almost transparent, yellowish and darken with mottled brown as they develop. *C. pseudomagnoliarum* is distinctly greyish brown and superficially similar to *Saissetia oleae* but can be distinguished by its paler colour and absence of the 'H' dorsal pattern on *S. oleae.* The early immature stages are very similar to those of *Coccus hesperidum.*

Female *C. pseudomagnoliarum* reproduce parthenogenetically and are oviparous, producing up to 1500 eggs which hatch soon after being laid (Bartlett 1978a) or after 2 to 3 days (Smith et al. 1997a). Males are unknown in Australia. Crawlers settle on leaves and twigs of citrus but later instars move to the older twigs and stems as they mature. There are three larval instars (or two, Smith et al. 1997a) with one generation per year occurring in southern Australia.

TARGET PEST NO. 21

PEST STATUS

C. pseudomagnoliarum is a serious pest in the citrus-growing areas of the Lachlan, Murrumbidgee and Murray Rivers in southern New South Wales and Victoria. It is occasionally important or a minor pest in South Australia and southern Western Australia (Smith et al. 1997a). *C. pseudomagnoliarum* produces quantities of honeydew which support growth of sooty moulds, causing disfigurement and reducing photosynthesis, and attracts ants which then reduce the effectiveness of natural enemies of the scale.

BIOLOGICAL CONTROL

C. pseudomagnoliarum is attacked by a number of native natural enemies, especially chrysopids, coccinellids and predatory larvae of the moth *Mataeomera dubia* (Smith et al. 1997a) (Table 15). Two parasitoids, *Coccophagus lycimnia* and *C. semicircularis,* introduced for biological control of *Coccus hesperidum*, are also important parasitoids of *C. pseudomagnoliarum.*

Table 15. Indigenous natural enemies of *Coccus pseudomagnoliarum*

Species	Stage of host	References
NEUROPTERA		
Mallada spp.	L 1, 2	Smith et al. 1997a
Micromus tasmaniae		Smith et al. 1997a
Plesiochrysa ramburi	L 1, 2	Smith et al. 1997a
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzeri	L 1, 2	Smith et al. 1997a
Diomus notescens	L	Smith et al. 1997a
Harmonia conformis	L 1, 2	Smith et al. 1997a
Parapriasus australasiae	L 1, 2	Smith et al. 1997a
Rhyzobius lophanthae	L 1, 2	Smith et al. 1997a
LEPIDOPTERA		
NOCTUIDAE		
Mataeomera dubia	L 1, 2, A	Smith et al. 1997a
HYMENOPTERA		
APHELINIDAE		
Coccophagus scutellaris		Noyes 1998
ENCYRTIDAE		
Epitetracnemus sp.	L	Malipatil et al. 2000
PTEROMALIDAE		
Moranila californica	E	Malipatil et al. 2000

22

Coccus viridis (Green) Hemiptera: Coccidae
green coffee scale

PRECIS

The origin of *Coccus viridis* is not known, but is probably Africa. It is now cosmopolitan and occurs throughout eastern Queensland and northern New South Wales. Since 1960, *C. viridis* has been a pest of citrus, coffee and ornamental plants in subtropical and tropical Australia.

Important natural enemies include parasitoids, the coccinellid *Cryptolaemus montrouzeri*, and a fungus, *Verticillium lecanii*. In 1999, a parasitoid, *Diversinervis* nr *stramineus*, was introduced from Kenya. It has become established in Queensland with promising results.

BIOLOGY

The origin of *Coccus viridis* is not certain but it may be Africa (D. Smith, pers. comm.). The type specimen was from Sri Lanka. *C. viridis* occurs in the Americas, Africa, Southeast Asia, Philippines, Papua New Guinea, Pacific islands (Williams and Watson 1990) and eastern Australia (Smith et al. 1997a) from Mareeba, Queensland to about Grafton, New South Wales.

Adult females of *C. viridis* are broadly oval, somewhat flattened and measure about 3 to 4 mm in length. The immature stages are yellowish-green and have four slender pairs of latero-ventral, rod-like white wax processes on each side and a single pair near the anus. All are visible through the dorsal surface. *C. viridis* is superficially similar to some other species of *Coccus*, and is sometimes confused with them. However, adult females of *C. viridis* may be distinguished by their shape, green colour, black eye spots, and dark brown gut which is visible through the translucent body of the scale.

Female *C. viridis* reproduce parthenogenetically and are ovoviviparous, producing up to 200 crawlers. Males are rare and only occur at high scale densities (Ben-Dov 1993). Green twigs and the ventral surface of young leaves are preferred by *C. viridis*, but it also occurs on fruit when infestations are heavy. There are three

to four generations per year in Queensland (Smith et al. 1997a) and each generation may be completed in about 50 to 70 days (Ben-Dov 1993), depending on temperatures. The three larval instars and adults of *C. viridis* are capable of movement.

PEST STATUS

In some countries, *C. viridis* is a serious pest of coffee, citrus and other crops (Ben-Dov 1993). In Queensland it is at times an important pest of coffee and citrus, and may infest tea (*Camellia sinensis*) and a range of ornamentals including gardenia, *Ixora*, frangipani and native plants.

Honeydew secreted by *C. viridis* accumulates on leaves and attracts ants, and the resulting growth of sooty moulds reduces photosynthesis. Ants enhance infestations by lowering crawler mortality, by reducing attack on the scales by parasitoids (Smith et al. 1997a), and by transporting scales to new locations (Zimmerman 1948). Heavy infestations of *C. viridis* weaken plants by loss of sap from feeding and they cause defoliation, death of stems and downgrading of fruit.

BIOLOGICAL CONTROL

The coccinellid *Cryptolaemus montrouzieri* is an important predator of the immature stages of *C. viridis*. The fungus *Verticillium lecanii* is reported to cause high levels of scale mortality of heavy infestations in late summer and autumn, during wet weather (Smith et al. 1997a).

Several native parasitoids parasitise *C. viridis,* in addition to several parasitoids introduced for biological control of other scale insects (Table 16 page 176). Of these, *Coccophagus ceroplastae* and an *Encarsia* sp. sometimes cause significant mortality of *C. viridis* (Smith et al. 1997a; D. Smith, pers. comm.) and contribute to partial control of the scale.

MAJOR PARASITOID SPECIES

Diversinervis nr *stramineus* Hymenoptera: Encyrtidae

D. nr *stramineus* was introduced from Kenya and released in Queensland in 1999. Recent observations indicate that it has become established with promising results (D. Smith, pers. comm.). One or two parasitoids develop in each host and the development from egg to adult occurs in about 21 days (D. Smith, pers. comm.). In Africa, *D. stramineus, sensu strictu,* is known to parasitise other species of *Coccus* and *Saissetia* (Noyes 1998).

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Table 16. Indigenous natural enemies of *Coccus viridis*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzeri	L 1, 2	Smith et al. 1997a
HYMENOPTERA		
APHELINIDAE		
Encarsia sp.[a]	L 2	Smith et al. 1997a
Myiocnema comperei[b]	L 2, 3	Noyes 1998
ENCYRTIDAE		
Cheiloneurus sp.[b]	L 2, 3	Malipatil et al. 2000
PTEROMALIDAE		
Moranila californica	E	Malipatil et al. 2000

[a]indigenous status uncertain; [b]hyperparasitoid

23

Comstockaspis perniciosus (Comstock)
Hemiptera: Diaspididae
San José scale

PRECIS

Comstockaspis perniciosus is thought to have originated in China and has been present in Australia since the late 1800s. *C. perniciosus* is a serious pest of stone fruit in the southern States and the apple-growing areas of Queensland. Infested fruit is unacceptable for export, and a roughened appearance on infested stems is accompanied by the exudation of gum. Heavy infestations may reduce tree vigour and lead to tree death.

A strain of the parasitoid *Encarsia perniciosi,* adapted to *C. perniciosus* was introduced from Germany from 1977 to 1978, but it has not proved to be more effective than the red scale strain of *E. perniciosi* that was already established. Several coccinellids, particularly *Rhyzobius lindi* and *Chilocorus circumdatus*, are important predators of *C. perniciosus*.

BIOLOGY

Comstockaspis perniciosus is a polyphagous scale insect of Oriental origin, probably China. It has been present in southern Australia and Western Australia since 1897 (Jenkins 1946), Queensland since 1895 (Bengston 1961b) and South Australia since 1958 (Baker 1977). In addition to infesting stone fruit, *C. perniciosus* has a wide host range, including pawpaw and grape (Brimblecombe 1962).

C. perniciosus is ovoviviparous and bi-parental. Each female produces from 200 to 400 crawlers and the females reach maturity in 35 to 60 days, depending on temperature (Rosen and DeBach 1978). Crawlers settle mainly on the twigs, but also on the fruit or the older stems of the host. After feeding, crawlers secrete a dome-shaped grey or greyish-brown scale covering the soft yellow body, which is almost circular in females and oval in males. Males are paler than females or purplish-brown and are more abundant than females on leaves of the host trees.

C. perniciosus is well adapted to the climates suitable for the cultivation of stone fruit in Australia. On apples in Australia, up to five generations have been reported (Rosen and DeBach 1978) and two generations with a partial third are reported from southern New South Wales (Bower 1989). In most countries, 1st and 2nd instar larvae overwinter in diapause.

PEST STATUS

C. perniciosus is a serious pest of deciduous fruit trees wherever they are grown in Australia (Bower 1989). The scale infests deciduous fruit trees including apricot, pear, apple, plum, cherry and peach. *C. perniciosus* primarily infests the woody parts of trees, especially the twigs and stems, and it also infests the leaves, calyx and fruit. Red spots develop on fruit surrounding each individual scale. When *C. perniciosus* is detected on fruit, quarantine regulations require rejection of whole consignments (Bower 1989).

On the stems of apple and stone fruit trees, a rough and wrinkled appearance induced by infestation is accompanied by lifting of the bark and exudation of gum. Infection by fungi may follow and the cambium layer becomes discoloured red or purple. In heavy infestations of *C. perniciosus*, reduced tree vigour and defoliation may be followed by the death of branches or even of the whole tree. Dieback of trees occurs about 12 months after the onset of heavy scale infestations (W.M. Milne, pers. comm.). *C. perniciosus* continues from time to time, to be a serious pest of stone fruit in the southern States and the apple-growing areas of Queensland, requiring insecticide intervention.

BIOLOGICAL CONTROL

Several native coccinellids, particularly *Rhyzobius lindi*, are important predators on the immature stages of *C. perniciosus* (Table 17 page 179). On its own, *R. lindi* often controls infestations of the scale unless its survival is disrupted by insecticide use. *R. lindi* prefer to oviposit in scales through an emergence hole after they have been parasitised by *Aphytis* spp. Larvae of *R. lindi* often become cannibals on their own immature stages when the density of *C. perniciosus* has declined following predation (W.M. Milne, pers. comm.).

The parasitoid *Encarsia perniciosi*, introduced into Australia in the early 1900s and between 1970 and 1973 to control red scale, *Aonidiella aurantii*, and two species of *Aphytis* (*A. aonidiae* and *A. diaspidis*, both apparently accidentally introduced) were recovered from apple orchards between 1977 and 1978 from parasitised *C. perniciosus*. Although abundant, these three parasitoids failed to effectively control *C. perniciosus* (CSIRO, unpublished).

In an attempt to improve biological control of San José scale, a strain of *E. perniciosi* adapted to *C. perniciosus* was introduced from Germany and released between 1977 and 1978. A second strain from France was reared in quarantine at

the same time, but its reproductive rate was lower than that of the German strain and a decision was made not to release it. The German *E. perniciosi* became established, but it did not prove to be any more effective in controlling *C. perniciosus* than the strain that was already parasitising it in Australia. It is interesting that, in the USA, the strains of *E. perniciosi* are specific to their hosts; the red scale strain does not develop in San José scale and the San José strain does not develop in red scale (Rosen and DeBach 1978).

When *R. lindi* was abundant in an orchard near Armidale, New South Wales, attempts to establish the German *E. perniciosi* were not successful—thought to be due to competition from the coccinellid for prey (CSIRO, unpublished). *Chilocorus circumdatus* is also reported to be an important predator of *C. perniciosus* (D. Smith, pers. comm.).

Native birds also contribute to predation of *C. perniciosus* (W.M. Milne, pers. comm.).

Table 17. Indigenous natural enemies of *Comstockaspis perniciosus*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Coccinella transversalis		Wilson 1960
Halmus chalybeus	L 1, 2	Wilson 1960
Parapriasus australasiae	L 1, 2	Wilson 1960
Rhyzobius debilis		Wilson 1960
Rhyzobius hirtellus		Wilson 1960
Rhyzobius lindi	L 1, 2	Milne & Snowball 1977
LEPIDOPTERA		
ADELIDAE		
Nemophora chrysolamprella sparsella		Wilson 1960
BATRACHEDRIDAE		
Batrachedra sp.	L, A	Wilson 1960
HYMENOPTERA		
APHELINIDAE		
Coccophagus clariscutellum		Wilson 1960
ARACHNIDA		
CHEYLETIDAE		
unidentified sp.		Wilson 1960

24

Diaspis bromeliae (Kerner) Hemiptera: Diaspididae † pineapple scale

PRECIS

Diaspis bromeliae was described from Europe and is now distributed in many subtropical countries. In northern New South Wales and Queensland, the scale insect is an occasional pest of pineapples and ornamental Bromeliaceae.

D. bromeliae is attacked in eastern Queensland by the parasitoids *Encarsia citrina* and an unidentified *Aphytis* sp., and native Coccinellidae. These species maintain control of *D. bromeliae* unless insecticides disrupt their activity. It is now a minor pest.

BIOLOGY

Diaspis bromeliae was described from Europe, but may have originated from the Americas since it is adapted mainly to hosts in the family Bromeliaceae. *D. bromeliae* is a bi-parental, oviparous scale and males greatly outnumber females. Each female deposits up to 100 yellow eggs. Crawlers hatch in about 7 days and disperse before settling on the fruit and leaves, particularly on the suckers when shaded by foliage (Brimblecombe 1956a). After settling, crawlers remain at one site until mature. Colonies of the scale develop mainly on the leaf bases of pineapple plants and then spread along the leaves to infest suckers and the lower parts of fruit.

The life cycle of *D. bromeliae* is completed in about 60 days during warm weather and several generations may develop annually. In Queensland, reproduction takes place throughout the year, with peaks of oviposition in summer, early winter (Brimblecombe 1955) and also in spring (Murray 1982a). The female scales have two larval instars before moulting to the adult stage. Mature scale coverings are greyish-white, somewhat flattened and circular, each measuring about 3 mm in diameter. Mature male scale coverings are white, narrow and slightly ribbed longitudinally, measuring about 0.8 mm in length. The two larval instars of males are followed by pre-pupae, pupae and winged adults.

PEST STATUS

The scale insect was first reported as a pest of pineapples in Queensland in 1942 (Jarvis 1944), although earlier known from near Brisbane from pineapples and related plants (Tryon 1928). *D. bromeliae* is known mainly from south-eastern Queensland, from Gympie to south of Brisbane (Murray 1982a). It is also recorded in New South Wales from pineapples (Turner 1891). On pineapples, heavy infestations produce a roughened grey appearance on fruit, chlorosis of leaves and suckers, reduce plant vigour and cause stunted growth and dieback. Although not a major pest, this scale is thought to pose a risk should it expand its range to other pineapple-growing areas of Australia. Crawlers are dispersed over short distances by wind but the spread of *D. bromeliae* is slow. Its dispersal and new infestations result mainly from relocating infested planting material (Murray 1982a).

All varieties of pineapples (including smooth and rough leaved) are affected by the scale. *D. bromeliae* also attacks other Bromeliaceae including the ornamentals *Agave*, *Billbergia* and *Bromelia* spp. (Murray 1980b).

BIOLOGICAL CONTROL

The minor significance of *D. bromeliae* as a pest of pineapples is undoubtedly a result of high levels of parasitisation and predation (Table 18). Several native coccinellids prey on *D. bromeliae*, including *Orcus* sp. *Rhyzobius sp.* and *Rhyzobius lophanthae,* destroying up to 27.7% of mature female scales (Murray 1982a).

The identities of parasitoids of *D. bromeliae* in Australia remain uncertain. Adult female scales were parasitised by an *Aphytis* sp. while immature females and males were parasitised by an *Encarsia* sp. (= *Aspidiotiphagus* sp.) (Murray 1982a). It is likely that this *Encarsia* sp. was *Encarsia citrina,* and the *Aphytis* sp. may prove to be *A. chilensis*, but the identities of both parasitoids of *D. bromeliae* require confirmation.

Table 18. Indigenous natural enemies of *Diaspis bromeliae*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Orcus sp.		Brimblecombe 1955
Rhyzobius lophanthae		Murray 1982a
Rhyzobius sp.		Brimblecombe 1955
HYMENOPTERA		
APHELINIDAE		
Aphytis sp.[a]	A	Brimblecombe 1955; Murray 1982a

[a]indigenous status not known with certainty

25

Edwardsiana froggatti (Baker) Hemiptera: Cicadellidae apple leafhopper

Edwardsiana froggatti has been long known in Australia as *Typhlocyba australis* or *T. froggatti*. It and *Edwardsiana crataegi* are very similar European species, which crossing experiments demonstrate to be substantially isolated genetically (Day and Fletcher 1994; M. Fletcher, pers. comm.).

PRECIS

Edwardsiana froggatti became established in New South Wales some time before 1918 and had spread to all States by 1942. In 1935, the North American mymarid parasitoid *Anagrus armatus* was introduced to Tasmania, where it soon built up to high levels of egg parasitisation. It was sent to South Australia in 1940 and Western Australia in 1943, but is not recorded as established on the mainland.

A. armatus clearly had a major impact on apple leafhopper populations in Tasmania, but there and elsewhere *E. froggatti* has, for some years, been effectively controlled by pesticides applied against other apple pests.

BIOLOGY

Edwardsiana froggatti was first recorded in 1918 in Australia by Froggatt (1918), who stated that it had been known for some years in southern New South Wales. The closely related *E. crataegi* reached New Zealand about the same time (Charles 1989a).

E. froggatti spread to Tasmania about 1929 and also to South Australia. The first serious outbreaks in Victoria occurred in 1935 to 1936, in Queensland (Stanthorpe district) in 1937 to 1938 and in Western Australia in 1938 (Ward 1936; Jenkins 1943b; Wilson 1960).

The apple leafhopper overwinters as eggs laid in the bark of last season's twigs. It has two generations and a partial third each year. After hatching in spring, nymphs feed on the underside of leaves to become 4 mm long, canary yellow adults. The resulting females oviposit in the midribs or veins of the leaves leading,

by late summer, to adults whose overwintering eggs are laid under the bark of new growth twigs.

PEST STATUS

E. froggatti occurs mainly on apple trees and hawthorn hedges and less frequently on prunes. Adults have also been recorded on pears, cherries, plums, crataegus, blackberry, raspberry and roses, but breeding is not known to take place on hosts other than apple (Noble 1929; Evans 1935, 1940a,b; Jenkins 1943a).

Apple leaves become spotted following sap-feeding activities of the leafhopper. Large numbers of nymphs and adults cause leaves to turn yellow and drop early. Nursery stock may lose all their leaves, with a consequent reduction in vigour. The apple leafhopper does not feed on the fruit. However, it deposits difficult-to-remove faecal spots which disfigure the fruit and require washing if it is to be marketed.

Damage is greater in years of high temperatures and low rainfall in summer. In earlier years, the apple leafhopper was regarded as a moderately serious pest, but the widespread use of broad-spectrum sprays in recent years against other apple pests has reduced its status to that of a minor pest (Noble 1929; Miller 1949a).

BIOLOGICAL CONTROL

In New Zealand, the overwintering eggs of *E. crataegi* were found to be parasitised to the extent of 78% to 93% and summer eggs up to 100% by the mymarid *Anagrus armatus*. This parasitoid is native to North America and is known to attack the eggs of other leafhopper hosts (Dumbleton 1934, 1937; Clausen 1978b; Charles 1989a).

A. armatus from New Zealand was liberated in Tasmania in 1935 and was reported to be well established in 1937 (Evans 1937b). Within a few years, in some orchards 80% to 90% of overwintering eggs were parasitised (Evans 1943). By 1947, the apple leafhopper had not been a serious problem in these areas for several years (Wilson 1960). *A. armatus* was sent to South Australia in 1940 and to Western Australia in both 1943 and 1947 to 1948, but is not known to have become established on the mainland (Jenkins 1943b; Wilson 1960).

26

Eriococcus araucariae Maskell Hemiptera: Eriococcidae felted pine coccid

PRECIS

The eastern Australian coccinellid *Cryptolaemus montrouzieri*, which was introduced to Western Australia in 1902 against mealybugs, proved to be effective also in controlling the felted pine coccid, *Eriococcus araucariae*, a minor pest on Norfolk Island pines.

BIOLOGY

The felted pine coccid, *Eriococcus araucariae*, occurs widely on *Araucaria* spp., including the Norfolk Island pine (*Araucaria heterophylla*). Bartlett (1978b) suggested that it was native to Norfolk Island, but Hoy (1962) stated that it did not occur there and was most likely from Australia where its original host was probably hoop pine, *Araucaria cunninghamii*. *E. araucariae* occurs in many overseas countries, including Egypt and Israel (Ben-Dov 1985), Italy (Tranfaglia et al. 1985), South Africa (Tribe 1991) and Brazil (Vernalha and Da Rocha 1971).

Adult males are active in August. Newly moulted adult females are brownish yellow with a pair of dorsal, purple stripes: older females are purple. The oval ovisac is white, felted and covers the female. The eggs are yellow (Williams and Watson 1990). There are two generations per year.

PEST STATUS

E. araucariae seldom attains pest status in Australia, although it appears to have done so in Western Australia on Norfolk Island pine in the early 1900s. It is more important in nurseries. The large amounts of honeydew produced provide an excellent medium for the growth of sooty moulds which blacken host foliage.

BIOLOGICAL CONTROL

At the very beginning of the 1900s, two mealybugs (now known as *Planococcus citri* and *Pseudococcus longispinus*) were very destructive pests of citrus in Western Australia. In 1902, the coccinellid *Cryptolaemus montrouzieri* was introduced from New South Wales. It established readily and became an important factor in the control of mealybugs and related scales in Western Australia. One of several species attacked was the felted pine coccid, *E. araucariae*, on Norfolk Island pine against which it also proved effective (Wilson 1960).

A 'number of years' before 1909, the scale was successfully controlled in Auckland, New Zealand by the introduction of three Australian coccinellids, *C. montrouzieri, Halmus chalybeus* and *Rhyzobius ventralis* (Kirk and Cockayne 1909; Bartlett 1978b).

27

Eriosoma lanigerum (Hausmann) Hemiptera: Aphididae woolly aphid, woolly apple aphid

PRECIS

Eriosoma lanigerum is native to eastern USA, but now has a worldwide distribution. Its main economic host is apple.

The greatest injury results from feeding by the aphids on the roots, although large numbers are also found on aerial parts of the tree. The use of aphid-resistant rootstocks is an effective way of controlling underground infestation. Although a range of native coccinellid, syrphid and chrysopid predators attack aerial infestations, they are unable to gain access to subterranean infestations.

The introduction of the North American parasitoid *Aphelinus mali* in 1923 caused a dramatic reduction in aerial infestations. *E. lanigerum* is now generally under excellent biological control in warmer apple-growing areas, although stem infestations may require treatment in cool seasons or in climatically cool areas.

BIOLOGY

Eriosoma lanigerum is native to eastern USA and has been present in Western Australia since before 1895, where it was recorded as widely distributed and one of the most serious pests of apple (Jenkins 1946).

The common name of the woolly apple aphid refers to the body covering of multiple, tangled strands of white, waxy material. On apple, the wingless nymphs overwinter on the roots or in protected places on the trunk or branches of the tree.

Wingless, dark purple females each produce about 100 nymphs, which repeat the cycle until autumn, when some winged females and males are produced, but these are apparently unimportant in survival over winter. Movement from infested to clean trees is slow and is mostly due to nymphs which move readily. Low humidity and temperatures above 27°C are unfavourable; low temperatures have little adverse effect except for slowing rate of development.

TARGET PEST NO. 27

PEST STATUS

The woolly aphid was, for many years, an extremely important pest of apple trees in Australia. It occurs on branches and especially on roots. The use of resistant root stocks was developed in Victoria in 1868 to 1870. Of the resistant varieties selected, Northern Spy was the most effective and has been widely used. This has largely prevented the development of subterranean colonies, although infestation of the branches continued to be important until controlled by parasitoid introduction.

E. lanigerum is a pest of apples and may also infest other hosts, such as crab apple and hawthorn. On apple, the greatest injury results from the aphids feeding on the roots where they produce galls, although large numbers may also occur on aerial parts of the tree. Favoured sites are new bark at pruning or wound scars and their presence facilitates the entry of fungi at these locations. As young lateral shoots are produced during summer they are infested and become cracked and distorted, with destruction of the buds, so that there is little development of fruit-bearing wood. The woolly aphid may reduce cropping, lower the quality of the fruit and, because of wax and honeydew, be a nuisance to pickers. It thrives in cool, moist apple districts and is generally most serious in seasons when growing conditions are favourable. It is most abundant in thick, vigorous trees with shady interiors, or in trees shaded by windbreaks (Hely et al. 1982).

BIOLOGICAL CONTROL

Native predators of *E. lanigerum* include six coccinellids *(Menochilus sexmaculatus, Coccinella transversalis, Diomus notescens, Harmonia conformis, Micraspis frenata* and *Rhyzobius* sp.), two syrphids (*Melangyna viridiceps* and *Simosyrphus grandicornis*) and chrysopids (Carver 2000). The most important is possibly *H. conformis* which was introduced into Western Australia unsuccessfully from New South Wales in 1896 and successfully from Tasmania in 1901 to 1902. It assists greatly in the control of above-ground woolly aphid infestations.

The coccinellid, *Exochomus melanocephalus*, from South Africa was introduced to New South Wales in 1900, but did not become established. A coccinellid, possibly *M. sexmaculatus*, was introduced to Victoria from Western Australia in 1911, but did not become established. It was, for a time, mass-produced and distributed in Western Australia for the control of *E. lanigerum* and red scale, *Aonidiella aurantii* (Wilson 1960).

In 1923, the parasitoid *Aphelinus mali* was introduced from New Zealand, which had earlier acquired stocks from USA (Connecticut and Arkansas). This parasitoid was widely liberated in apple-growing areas until 1926 and established readily everywhere, except for initial difficulties in South Australia (Wilson 1960). At least one later consignment of *A. mali* was received, namely from England in

November 1938 (CSIR files). Since the parasitoid is unable to gain access to underground *E. lanigerum*, the use of resistant root stocks remains highly important.

Three hyperparasitoids of *A. mali* have been recorded: *Euryischomyia flavithorax* (Aphelinidae), and *Moranila comperei* and *Pachyneuron aphidis* (Pteromalidae) (Carver 1995, 2000). Within a few years of the establishment of *A. mali*, woolly apple aphid was reduced to the status of a minor pest (Wilson 1960; Sproul 1981a; Hely et al. 1982), although in cool seasons or in cooler areas (such as the northern New South Wales tablelands and some parts of Victoria and Tasmania), parasitoid activity may lag behind that of its host and infestations may require chemical control (Asante and Danthanarayana 1992, 1993a,b). Overall, this is widely regarded as an example of extremely valuable biological control.

MAJOR NATURAL ENEMY

Aphelinus mali Hymenoptera: Aphelinidae

This aphelinid parasitoid has been introduced from eastern USA to more than 50 countries and, in most, has brought about excellent control of aerial infestations of *E. lanigerum*. It is unable to reach infestations on the roots (Clausen 1978a).

A. mali may lay more than one egg in each host aphid, although only one parasitoid survives. Parthenogenesis occurs and unfertilised eggs produce males, whereas females arise from fertilised eggs. The parasitoid oviposits into all nymphal instars and adults, but the host aphid continues to develop until shortly before the parasitoid is about to pupate, when the aphid host is either in the 3rd instar or is an adult. Parasitised aphids become inflated, lose the power of secreting their woolly covering of wax and turn black on becoming mummies. The adult wasp emerges from the mummy through a large, irregular hole cut in the back of the aphid abdomen (Asante and Danthanarayana 1993a).

The developmental threshold is 8.3°C (compared with 5.2°C for *E. lanigerum*) and at temperatures from 13°C to 30°C mean development times ranged from 11.7 to 53.3 days for males and 11.8 to 55.4 days for females (Asante and Danthanarayana 1992).

28

Hyperomyzus lactucae (Linnæus) Hemiptera: Aphididae sowthistle aphid

PRECIS

Hyperomyzus lactucae is European in origin and now almost cosmopolitan in distribution. Its main host in southern Australia is the widespread sowthistle, *Sonchus oleraceus. H. lactucae* is of major economic importance as the only known vector of lettuce necrotic yellows virus. The aphid transmits the virus from infested, but symptomless, sowthistle to lettuce, on which it lands and probes, but which it does not colonise.

Three parasitoid species were introduced from Europe, Japan and South Africa and two of these, the braconids *Aphidius sonchi* and *Praon volucre*, have become established. No evaluation is available of their impact in eastern Australia, although the virus is reportedly far less important than formerly. In Western Australia there has been a documented, dramatic reduction in virus transmission.

BIOLOGY

Hyperomyzus lactucae is palaearctic in origin, but is now present in all temperate and cool temperate regions of the world. It occurs in all Australian States.

H. lactucae has a typical aphid life cycle. In warmer areas (Queensland and South Australia) it reproduces parthenogenetically, without sexual forms, although these occur in cooler areas, such as the Australian Capital Territory and Tasmania. In cooler areas it infests and alternates between species of primary hosts, *Ribes* (Saxifragaceae) (such as blackcurrant and gooseberry), and species of secondary hosts, *Sonchus* (Asteraceae) and, more rarely, related genera. In warmer areas where *Ribes* are not extensively grown, the sowthistle, *Sonchus oleraceus*, is the common host (Carver and Woolcock 1986).

PEST STATUS

H. lactucae is a minor pest of blackcurrant in Tasmania. However, it is of major economic importance as the only known vector of lettuce necrotic yellows

rhabdovirus, a serious disease of lettuce known only from Australia and New Zealand. The sowthistle aphid transmits the disease from infected, but symptomless, sowthistle to lettuce, on which it lands and probes, but which it does not colonise (Carver and Woolcock 1986).

BIOLOGICAL CONTROL

The common natural enemies attacking *H. lactucae* on *Sonchus* in Australia are larvae of the syrphid *Simosyrphus grandicornis* (a native insect) and the exotic fungi *Pandora neoaphidis* and *Neozygites fresenii*. Before 1981 it was not attacked by any hymenopterous parasitoids. Less common are *Harmonia conformis* (Coccinellidae) and *Micromus tasmaniae* (Hemerobiidae) (Carver 2000).

In 1981, 2300 second generation descendants of 14 specimens of *Aphelinus asychis* from South Africa were released in New South Wales, but there is no evidence of establishment (Carver and Woolcock 1986).

Two stocks of *Aphidius sonchi* (a specific parasitoid of *Hyperomyzus* spp.) were obtained from Japan and France. Establishment from releases from 1981 to 1983 has been recorded wherever the French strain was released in the Australian Capital Territory and all States, although it is not recorded from the Northern Territory. However, it appears that releases of the Japanese strain (which came from a mismatched climatic zone) were unsuccessful. Limited observations have shown a high percentage of sowthistle plants bearing parasitised mummies, but a low percentage of mummies per plant. Recoveries included parasitoids in diapause and five species of hymenopterous hyperparasitoid (*Alloxysta fuscicornis, Dendrocerus aphidum, D. carpenteri, Pachyneuron aphidis* and *Phaenoglyphis villosa*) (Carver 1992, 2000). However, the level of hyperparasitism was low (0 to 10%) (Liu and Carver 1985). In the laboratory, *A. sonchi* oviposited in, but did not develop in, *Macrosiphum euphorbiae,* another common aphid species on sowthistle (Liu and Carver 1985).

Three consignments of *A. sonchi* were sent from Canberra, Australian Capital Territory to Perth, Western Australia, where descendants were liberated late in 1981 and early in 1982, at a time when *H. lactucae* populations were undergoing a natural seasonal decline as thistle hosts senesced. In 1984, the parasitoid was found to have dispersed up to 55 km and, at that time, a marked decrease in lettuce necrotic yellows virus in lettuce was noted, although there was no indication of any changes in lettuce varieties or horticultural practice over this 3-year period. Previously, the virus had been common in metropolitan market gardens until the early 1980s, when losses of up to 90% were recorded. The results have been described as dramatic (Sandow 1993). Anecdotal information indicates that the transmission of lettuce necrotic yellows virus has also diminished in eastern Australia.

Stocks of *Praon volucre* were obtained from *H. lactucae* from Mediterranean areas of Greece and Turkey and from France, and mass-produced progeny were liberated in Canberra and all States in 1981 and 1982. It is surprising that this widely polyphagous species has not been recovered on the mainland, although it has become established in Tasmania (Carver and Woolcock 1986).

MAJOR PARASITOID SPECIES

Aphidius sonchi Hymenoptera: Braconidae

Usually a single egg is laid at a time by *A. sonchi*. The parasitoid larva lives in the aphid body cavity, eventually consuming all but the exoskeleton of the aphid, the stylets of which remain inserted in the plant tissue. With one of its mandibles, the mature larva cuts a slit in the underside of the aphid abdomen and attaches the latter to the plant with a silk-like secretion. The internal surface of the aphid is also lined with this secretion to produce a bloated, parchment-like mummy. The larva then voids the meconium and pupates. When the adult is ready to emerge, it cuts a circular hole in the cuticle of the mummy, usually between the siphunculi. At 20°C the time taken from egg to adult is 12 to 13 days. Females lay an average of 215 eggs. Even if more than one egg is laid in an aphid, only one parasitoid survives. Females oviposit in all nymphal instars and in both apterous and alate adults of the host (Liu and Carver 1985).

29

Lepidosaphes beckii (Newman) Hemiptera: Diaspididae † mussel scale, purple scale

PRECIS

Lepidosaphes beckii is believed to have originated in the Oriental region, and is now widespread in many countries where citrus is cultivated. In Australia, *L. beckii* is sometimes an important pest of citrus, causing fruit disfigurement, chlorosis, leaf curl and occasionally defoliation, and death of stems.

Occasional outbreaks of *L. beckii* are controlled by the Chinese parasitoid *Aphytis lepidosaphes* and native predatory coccinellids, especially *Rhyzobius lophanthae.*

BIOLOGY

Lepidosaphes beckii is bi-parental and oviparous and males outnumber females. Each female produces from 40 to 100 white eggs, deposited under the scale in two rows between the ventral surface of the scale and the plant substrate. Crawlers settle on leaves, especially when shaded or curled, on twigs and on fruit near the calyx and when in contact with other fruit or a leaf. They are dispersed to other trees by wind and the scale is often introduced into orchards on infested buds and grafts. In New South Wales there are two to five generations of *L. beckii* each year and five to six in Queensland and the Northern Territory (Smith et al. 1997a). The life cycle of *L. beckii* is completed in about 65 days during warm weather.

Eggs of *L. beckii* hatch in about 14 days and, after settling, crawlers remain at one site until mature, often forming aggregations of overlying scales. Crawlers secrete an oval, light-brown covering, extended during subsequent instars into a convex, mussel-shaped, brown or purple scale, covering the soft, white body. The brown scale of males is smaller and narrower than that of females, and apically darker. Mature females are 3 to 4 mm in length and have two larval instars before moulting to the adult stage. Mature male scale coverings are about 2 mm in length, and the two larval instars are followed by pre-pupa, pupa and winged adult.

TARGET PEST NO. 29

PEST STATUS

Before the 1960s, *L. beckii* was a serious pest of citrus in parts of Australia (Rosen and DeBach 1978). Currently, the scale is an occasional pest only of citrus from southern New South Wales to the Atherton Tablelands and is a minor pest in the Northern Territory (Smith et al. 1997a). *L. beckii* is most abundant in the humid, coastal regions of eastern Australia on lemons and mandarins, and on nursery stocks of all citrus. The scale induces leaf curl and leaf distortion and heavy infestations of scales cause leaf chlorosis, leaf drop, and death of stems and branches. On fruit, aggregations of *L. beckii* result in the development of chlorotic blemishes, especially on the rind where fruit have been in contact with each other.

BIOLOGICAL CONTROL

Important native natural enemies of *L. beckii* include the parasitoid *Aphytis chilensis* and coccinellids *Halmus chalybeus* and *Rhyzobius lophanthae*. Other natural enemies of the scale, including *Encarsia citrina*, are relatively unimportant (Table 19 page 194).

The most important parasitoid of *L. beckii* worldwide is *Aphytis lepidosaphes*. *A. lepidosaphes* was introduced from China into California in 1948 (Rosen and DeBach 1978) and was first recorded in Australia as a parasitoid of *L. beckii* in 1967 (Snowball 1968), although not intentionally introduced. It is possible that *A. lepidosaphes* became established accidentally in Australia in the 1960s, at a time when the parasitoid was being considered for introduction from the USA (Snowball 1966b). This is supported by observations made between 1967 and 1969, when *A. lepidosaphes* appeared to be increasing in abundance and displacing the related native parasitoid *Aphytis chilensis* (Snowball 1969a).

Although *Aphytis lingnanensis* is recorded as a parasitoid of *L. beckii* (Noyes 1998), it is rarely associated with *L. beckii* in Australia.

MAJOR PARASITOID SPECIES

Aphytis lepidosaphes Hymenoptera: Aphelinidae

A. lepidosaphes is a bi-parental, gregarious ectoparasitoid, specific to *Lepidosaphes* species. Adult females are preferred as hosts but nymphs and male pre-pupae may also be attacked. From one to eight individual parasitoids may develop in one parasitised scale host. Adult females of *A. lepidosaphes* outnumber males and feed from wounds caused by oviposition and probing, leading to considerable mortality of scales in addition to those killed by parasitisation.

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Table 19. Indigenous natural enemies of *Lepidosaphes beckii*

Species	Stage of host	References
NEUROPTERA		
CHRYSOPIDAE		
Mallada sp.	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
COLEOPTERA		
COCCINELLIDAE		
Halmus chalybeus	L 1, 2	Smith et al. 1997a
Rhyzobius lophanthae	L 1, 2	Rosen & DeBach 1978; D.P.A. Sands & G.J. Snowball unpubl.
HYMENOPTERA		
APHELINIDAE		
Aphytis sp.	L 2	Snowball & Sands 1970
Aphytis chilensis	L 2	Snowball 1967
Aphytis columbi	L 2, A	Malipatil et al. 2000
Encarsia aurantii		Noyes 1998
Marietta carnesi[a]	L 2, A	Noyes 1998
[a]hyperparasitoid		

30

Lepidosaphes gloverii (Packard) Hemiptera: Diaspididae † Glover's scale

PRECIS

Lepidosaphes gloverii probably originated from Southeast Asia but it now occurs worldwide. In eastern Australia, it is a minor pest of citrus and also occurs on coconut, macadamia, mango and palms.

L. gloverii is usually controlled by the coccinellid *Chilocorus circumdatus* and the parasitoids *Aphytis lingnanensis* and *A. chrysomphali*, introduced to control other coccid species. Unidentified species of *Encarsia* and *Aphytis* are also important natural enemies of *L. gloverii.*

BIOLOGY

The biology of *Lepidosaphes gloverii* is very similar to that of *L beckii.* The scale is bi-parental and oviparous and males outnumber females. Adult females are pale brown and much narrower than *L. beckii*, measuring up to 6 mm with sub-parallel margins. The male scale is much smaller. Each female produces 30 to 80 white eggs in two rafts between the body of the scale and plant surface. Eggs hatch in about 14 days and crawlers disperse to settle beneath the leaves, on fruit and often near the outer leaf margins, or at the apex of petioles, especially when heavily shaded.

There are two larval instars in females of *L. gloverii* and two larval instars in males are followed by a pre-pupa, pupa and winged adult. There are two to four generations of *L. gloverii* in New South Wales and up to six in Queensland, the life cycle taking about 6 to 8 weeks during the warmer months (Rosen and DeBach 1978; Smith et al. 1997a).

PEST STATUS

L. gloverii probably originated in Southeast Asia. The scale occurs in eastern Australia from Mareeba and Cairns, northern Queensland to Woolongong, New South Wales. In Australia, *L. gloverii* is a minor pest of citrus, coconut,

macadamia, mango and palms in humid locations. Infestations occur on fruit, leaves and branches but most often beneath the leaves. They induce leaf-curl and the development of chlorotic patches on leaves and fruit.

BIOLOGICAL CONTROL

In the absence of insecticide applications, *L. gloverii* is controlled by the coccinellid *Chilocorus circumdatus* and the parasitoids *Aphytis lingnanensis* and *A. chrysomphali*, species introduced to control other coccid species.

Unidentified species of *Encarsia* from New South Wales (D.P.A. Sands, unpublished) and a species of *Aphytis* are important natural enemies (Smith et al. 1997a). Several parasitoids known to occur in Australia were listed by Noyes (1998), and these include *Encarsia aurantii* and *E. citrina*.

31

Macrosiphum rosae (Linnæus) Hemiptera: Aphididae
rose aphid

PRECIS

Macrosiphum rosae is probably native to Eurasia, but is now a cosmopolitan pest of roses. G. Compere sent unspecified species of syrphids from the Philippines in 1907 to Western Australia for the control of the rose aphid, but they failed to become established.

Aphidius rosae from Italy was liberated in South Australia in 1990 and rapidly became established. It has since spread to New South Wales and the Australian Capital Territory where aphid mummies are now a familiar sight on rose buds in spring and rose aphid abundance has diminished markedly.

BIOLOGY

Macrosiphum rosae reproduces parthenogenetically and viviparously all year round on roses, if temperature and host conditions permit. Sexual forms and eggs are not produced. There are two common colour forms: green and pink. Populations build up on young shoots and emerging buds but, when the bud sepals start to fold back, aphids tend to move to younger buds or shoots.

PEST STATUS

M. rosae occurs widely on roses in Australia and it has also been recorded on *Centranthus ruber* (Valerianaceae) (Carver 2000).

Populations build up, especially in spring, on tender rose shoots and flowering buds. If dense enough, these can cause the shoots to wilt. The moulted skins, mummies and the honeydew produced detract greatly from the appearance of blooms and render them unmarketable. Heavy rainfall may cause nearly 100% aphid mortality.

BIOLOGICAL CONTROL

G. Compere sent some unspecified species of syrphids from the Philippines in 1907, but the predators failed to establish (Jenkins 1946).

Until recently, the only Australian record of *M. rosae* being attacked in the field by a parasitoid was in Adelaide, South Australia in 1975, when 0.04% of aphids were parasitised by *Aphelinus gossypii* (Maelzer 1977). This is a widespread, polyphagous species which presumably arrived unaided years ago.

M. rosae is preyed upon in Adelaide by a number of native species (ranked in order of decreasing effectiveness): the hemerobiid *Micromus tasmaniae*, the syrphid *Melangyna viridiceps*, the coccinellid *Harmonia conformis*, the syrphid *Simosyrphus grandicornis*, the coccinellid *Coccinella transversalis*, and the chamaemyiid *Leucopis formosana*. *Micromus*, the most abundant predator, is effective because it can locate and eat adult aphids in small, recently-founded colonies (Maelzer 1977, 1978, 1981; Carver 2000). *M. rosae* is also attacked by the fungi *Conidiobolus obscurus, Entomophthora planchoniana* and *Pandora neoaphidis* (Table 5 page 113).

The numbers of aphids on hybrid tea roses in Adelaide have three peaks (coinciding with the three flushes of growth of the rose): highest in spring, followed by two lower peaks, brought about mainly by the attack of native predators (Maelzer 1977).

The particular strains of *Lysiphlebus testaceipes* and *L. fabarum* imported into Australia for the biological control of *Aphis craccivora* did not develop on the rose aphid in the laboratory, although *Praon volucre* imported to control *Hyperomyzus lactucae* was able to do so (Carver 1984).

Aphidius ervi (which was first liberated in 1978 against *Acyrthosiphon kondoi*) oviposited readily in the rose aphid in the laboratory. However, the level of parasitisation in the Parliamentary rose gardens in Canberra, Australian Capital Territory, was very low. This was possibly due to the remoteness of the rose gardens from major sources of *A. ervi*, such as lucerne fields and cereal paddocks (Milne 1991).

Aphidius rosae from Italy was liberated in South Australia in 1990 (Kitt and Keller 1998) and soon became established. It has since spread at least to New South Wales and to the Australian Capital Territory where mummies are common on rose buds in spring (M. Carver, pers. comm. 1999). Aphids no longer reach the same damaging levels in spring and disappear earlier. However, they may reappear in numbers in autumn.

Hyperparasitoids bred from *M. rosae* mummies include *Dendrocerus aphidum, D. carpenteri, Pachyneuron aphidis* and *Phaenoglyphis villosa* (Carver 2000).

32

Metopolophium dirhodum (Walker) Hemiptera: Aphididae rose-grain aphid

PRECIS

Metopolophium dirhodum, of European origin, occurs widely in eastern Australia on barley and oats and is also known from wheat, sorghum and a number of grasses. Although it was parasitised by the exotic *Aphidius ervi*, the level of attack was insufficient to prevent the rose-grain aphid from building up damaging populations from time to time.

After several unsuccessful attempts to colonise *Aphidius rhopalosiphi* in Australia, a strain obtained from New Zealand (originating in England and France) was established. It now occurs widely on *M. dirhodum* and there are seldom reports of the rose-grain aphid attaining damaging populations.

BIOLOGY

From its area of origin in Europe *Metopolophium dirhodum* has spread to the Middle East, North and South America (1966), northern and South Africa (1967), Central Asia, India, China, New Zealand (1981) and Australia (1984).

The rose-grain aphid derives its common name from Europe, where its primary host is the rose and its alternative hosts are cereals and grasses. In Australia, it is not known from roses. In south-eastern Australia it is common on the underside of leaves of barley and oats and less common on wheat, triticale and forage sorghum. It also occurs on several grass species, especially prairie grass (*Bromus catharticus*), but also phalaris (*Phalaris aquatica*), cocksfoot (*Dactylis glomerata*) and *Lolium* sp. Although apterous and alate viviparous females reproduce parthenogenetically, males do occur and are commonly found in laboratory cultures.

PEST STATUS

Although no information is available on losses caused by *M. dirhodum* in Australia, trials in New Zealand showed significant yield increases of spring oats

and barley following insecticide application to crops infested with up to 115 aphids per tiller (Stufkens and Farrell 1985). In addition to the damage caused by sap removal and honeydew production, the aphid has been shown to be an effective vector of an Australian isolate of barley yellow dwarf virus (Waterhouse and Helms 1985).

BIOLOGICAL CONTROL

Surveys in the early months after the arrival of *M. dirhodum* in Australia in 1984 showed that it was already being attacked by the parasitoid *Aphidius ervi* in south-eastern Australia and Tasmania (Carver 2000). This parasitoid had been established in Australia at an earlier stage as a result of introductions between 1977 and 1981 against *Acyrthosiphon kondoi* (Milne 1986a), although it was present in Tasmania before these introductions (Carver 2000). The rose-grain aphid was also infected with an unidentified fungus. It was suggested that *Aphidius* sp. nr *uzbekistanicus*, which had been reared from another cereal aphid, *Sitobion* sp. nr *fragariae*, would also be a useful parasitoid (Carver 1984). It is not clear whether or not *Aphidius uzbekistanicus* is a distinct species from *Aphidius rhopalosiphi* (the preferred name) or whether there is a complex of species, perhaps better represented by the term *A. rhopalosiphi* group.

The first introductions of *A. rhopalosiphi* group were from England in March 1985. Although wasps of this introduction attacked *M. dirhodum* readily in quarantine, the culture was destroyed in favour of obtaining one from an area with climate similar to Australia. Later that year, mummies of *M. dirhodum* parasitised by *A. rhopalosiphi* were obtained from Chile (which had obtained its stock from the Drôme area of France). In late 1985 and early 1986, some 91,000 laboratory-reared adults were liberated in the Australian Capital Territory, New South Wales and Victoria, but recoveries were made only for a short period. Later consignments from Chile did not alter this picture.

A. rhopalosiphi from *Sitobion avenae* mummies obtained directly from the south of France did not respond to *M. dirhodum* in quarantine in Australia. It seems that this was a parasitoid strain closely adapted to *S. avenae*, an aphid that does not occur in Australia.

A. rhopalosiphi had been established at an earlier stage in New Zealand in *M. dirhodum* from stocks obtained from England and France. Mummies were imported from New Zealand in 1986 and 1988 and *A. rhopalosiphi* mass-produced in *M. dirhodum* developing on barley seedlings. Releases were made in 1987 in the Australian Capital Territory, New South Wales, Victoria and Tasmania and again in August 1988. At the latter time, *M. dirhodum* was present in moderate numbers at release sites and, in Victoria at least, appeared to be increasing in abundance. *A. rhopalosiphi* is now widely established on *M. dirhodum* and there are now few reports of the latter attaining damaging populations (CSIRO files; L.T. Woolcock, pers. comm. 1998).

33

mirid bugs Hemiptera: Miridae

In 1994, Australian quarantine authorities gave permission for the introduction and release of a commercial strain of *Beauveria bassiana* for the control of the mirid bug *Pseudatomoscelis seriatus*. This bug can be a serious pest in the USA cotton belt. Although a number of mirids attack cotton in Australia and may cause important damage, in particular the widespread native green mirid, *Creontiades dilutus*, the North American *P. seriatus* is not one of them. It is assumed here that the main intended target of the introduction was *C. dilutus*. In Queensland, another mirid, *Campylomma liebknechti*, is capable of damaging cotton (Bishop 1980).

PRECIS

The application of a commercial preparation of the fungus, *Beauveria bassiana*, against mirid bugs and other pest insects in cotton failed to live up to expectations. There is no evidence that this strain of the fungus has persisted in the field.

BIOLOGY

Adults of the green mirid, *Creontiades dilutus*, are slender, pale green to yellowish green and about 6 mm long. The female inserts her eggs into the soft tissue of a leaf. Eggs hatch in 10 to 12 days and the young bugs become adults in about 3 weeks (Hely et al. 1982).

PEST STATUS

The green mirid attacks not only cotton (of which it is an important pest), but a wide range of fruit (e.g. passionfruit, peaches, nectarines) and vegetables (e.g. beans, carrots, potatoes, cucurbits). It has a strong preference for succulent young bud tissue, causing buds to wither and fall, leaving only the bracts. On cotton, adults and nymphs feed on the growing points of young plants, destroying the vegetative buds and causing abscission of the flower buds (Bishop 1980; Foley and Pyke 1985).

BIOLOGICAL CONTROL

The predatory bug *Nabis capsiformis* is believed to be important in limiting the numbers of the green mirid in Australia (Hely et al. 1982). Spiders are also common predators. There are brief reports that a commercial preparation (ATCC74040) of the fungus *Beauveria bassiana*, introduced to Australia in 1994 provided control of a number of cotton insects (including mirids) (Knauf and Wright 1994; Wright and Knauf 1994). However, disappointing results (a maximum of 35% mortality) were obtained against *C. dilutus* in New South Wales (R.K. Mensah, pers. comm.). No continuing effects of the fungus have been observed in following pest generations.

34

Myzus persicae (Sulzer) Hemiptera: Aphididae † green peach aphid

PRECIS

The polyphagous, cosmopolitan aphid *Myzus persicae* is widespread in Australia. It is capable of damaging, both directly and through virus transmission, a wide range of host plants, but it has not been the specific target of a biological control project.

M. persicae is attacked by several native coccinellids and the larvae of syrphid flies and lacewings. These are capable of eliminating infestations once predator populations build up. It is also attacked by a range of exotic parasitoids, but these are of less importance. With the assistance of winter sprays, it is now one of the aphid pests of secondary importance in Australia.

BIOLOGY

In cooler regions of Australia, *Myzus persicae* overwinters as eggs on its primary host, the peach. These eggs hatch in early spring to produce yellowish-green, wingless, viviparous females. After several generations, when the weather warms up and the peach foliage hardens, dark green to black winged females are produced. These move to other host plants to produce mainly wingless females, throughout summer and autumn. As the weather cools, winged males and females are produced which return to peach trees. Mating occurs and eggs are deposited behind the buds. In milder climates there is no egg stage and breeding occurs throughout the year on secondary hosts. When these senesce, winged forms are produced which leave to infest other vigorously growing secondary hosts (Hely et al. 1982).

Young nymphs develop in about 6 days to adult females which are capable of producing about 50 nymphs per week. Dry, warm conditions favour multiplication but this ceases above about 29°C. There are many biotypes that vary greatly in their ability to colonise particular host plant species or even varieties.

M. persicae has a worldwide distribution. It was first recorded in New South Wales in 1910 (Zeck 1928). In the early days it threatened to cripple the peach-growing industry, but natural enemies and winter sprays have reduced it to a pest of secondary importance.

PEST STATUS

M. persicae develops on peach, nectarine, plum and almond trees and on a wide range of secondary hosts. These include vegetables such as cabbage, peas, potatoes, tomatoes, garden plants such as lupins, poppies and roses, and weeds including capeweed, dock and sowthistle (Hely et al. 1982).

Cool, moist conditions, with vigorous growth of secondary hosts and late leaf fall from peach trees followed by a cool, moist spring favour the build-up of damaging green peach aphid populations in spring. The cool, moist conditions delay both hardening of the peach growth and the build-up of natural enemies.

Infestation of buds and flowers reduces fruit set and feeding on leaves produces distortion followed by dropping off. Large amounts of honeydew are produced which lead to heavy growth of sooty moulds and inhibition of photo-synthesis. *M. persicae* is reported to transmit more than 100 virus diseases worldwide and a number of these occur in Australia (Stubbs 1955; Kennedy et al. 1962). For example, on lupins in Western Australia, it transmits cucumber mosaic virus in a non-persistent manner. Plants infected through the seed provide the source from which aphids acquire and spread the virus within the crop (Thackray et al. 1998).

BIOLOGICAL CONTROL

In other countries, at least 100 species of predator, 50 of parasitoid and 10 of fungi have been reported attacking *M. persicae*. On field crops the attack by parasitoids is disappointingly small (0.5% to 6.4%) (van Emden et al. 1969). Upwards of 30 of these species of natural enemy occur in Australia, although not all have been recorded attacking the aphid here (Carver 2000). Many Australian native predators attack colonies as they build up in spring and may even suppress infestations. Most effective are coccinellids, especially *Coccinella transversalis* and *Harmonia conformis*. Larvae of syrphid flies and of lacewings are also valuable predators (Hely et al. 1982). Six species of fungi have also been reported (Table 5 page 113).

Several exotic parasitoids have been recorded from *M. persicae* in Australia (Carver 2000), but they do not appear to play a major role in regulating its population density. The hyperparasitoid *Euryischomyia flavithorax* has been bred from *Aphidius colemani* attacking *M. persicae* (Carver 1995).

35

Nezara viridula (Linnæus) Hemiptera: Pentatomidae green vegetable bug

PRECIS

Nezara viridula is native to Ethiopia, southern Europe and parts of the Mediterranean region, but is now cosmopolitan. It is a common pest of agricultural and horticultural crops, particularly legumes and some nut crops, in most temperate and tropical countries. Several exotic hymenopterous parasitoids of eggs and four tachinid parasitoids of nymphs and adults have been released in Australia, but only the egg parasitoid *Trissolcus basalis* has been effective in coastal and southern parts of Australia. A dipteran parasitoid of adults and nymphs, *Trichopoda giacomellii* from Argentina, has recently become established in New South Wales and southern Queensland, but its impact on *N. viridula* has yet to be evaluated.

BIOLOGY

The native geographical range of *Nezara viridula* is thought to be Ethiopia, southern Europe and parts of the Mediterranean region (Hokkanen 1986; Jones 1988). Other species in the genus occur in Africa and Asia (Freeman 1940) and closely related genera occur in South America, Asia and Australia, indicating that the extent of the native range of *N. viridula* may never be known. In Australia, *N. viridula* is present in all States, but it is now uncommon or rare in southern Australia and Tasmania (Clarke 1992). Nymphs and adults of *N. viridula* feed on a wide range of plants, particularly legumes, causing damage to the plant tissues by piercing fruiting bodies, stems and petioles with their stylets to withdraw fluids.

From 40 to 80 cylindrical, yellow eggs are deposited by *N. viridula* in rafts cemented beneath the leaves of the host plant. First instar nymphs are orange and brown, whereas the 2nd instars are darker brown with four yellow spots on the abdomen. Third and 4th instars are brightly-coloured, green or black with yellow and white spots. Fifth instars are green with six pale cream spots on a central dark

brown area of the abdominal segments. In Australia, adults are mostly green (known as form *smaragdula*) but develop a mottled appearance or become brown when entering diapause in autumn months. Occasionally yellow or black forms of the adult occur.

Eggs hatch occurs in 4 to 9 days, depending on temperature, and newly-hatched nymphs remain close to the old egg raft without feeding. After moulting, 2nd instar nymphs move onto the soft petioles and fruiting bodies to feed. Instars 2 and 3 feed gregariously, but instars 4 and 5 disperse to feed on the soft plant tissues. The five nymphal stages take from 24 to 60 days to develop to the adult stage. Adults of *N. viridula* live for about 3 weeks in the warmer months, but survive for much longer periods in the cooler months and in diapause. When overwintering in southern States they may live for 5 months or more under bark, in crevices in trees and in buildings. In spring, females resume reproduction within 7 to 14 days after the termination of diapause. In warmer regions, adults remain green in the field but may become reproductively inactive.

PEST STATUS

N. viridula is a pest of a wide range of agricultural and horticultural crops throughout the temperate and tropical regions of the world (Todd 1989). Damage is caused by adults and nymphs feeding and from saliva released. The result is discoloration, malformation, stunting and shrivelling of the plant tissues, and abortion of fruiting bodies (Waterhouse and Norris 1987). *N. viridula* attacks most legume crops, particularly beans, broad beans, navy beans, snake beans and soybeans, as well as citrus, corn, crucifers, cucurbits, grapes, macadamia nuts, passionfruit, pecans, potatoes, sorghum, spinach, sunflower, tobacco, tomatoes and rice (Hely et al. 1982; Waterhouse and Norris 1987; Seymour and Sands 1993).

In southern Australia, *N. viridula* was formerly a serious pest but it is now important only in the inland regions of Queensland, New South Wales and Victoria. In Queensland, *N. viridula* has recently increased its significance in cotton crops following changes to insecticide applications for the control of *Helicoverpa* spp. (D.A.H. Murray, pers. comm.). *N. viridula* also breeds commonly on leguminous and other weeds, particularly *Solanum* spp., crucifers (*Rapistrum rugosum*, *Raphanus raphanistrum*), variegated thistle (*Silybum marianum*), marshmallow (*Malva parviflora*) and castor oil (*Ricinus communis*) (Velasco and Walter 1992).

BIOLOGICAL CONTROL

Native parasitoids including *Xenoencyrtus niger*, *X. hemipterus* and *X. rubricatus* are uncommonly found attacking eggs of *N. viridula* (Noyes 1998) but do not have a significant influence on the abundance of the pest. Clarke and Seymour (1992)

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indicated that two native hyperparasitoids, *Acrolisoides* spp., utilise *Trissolcus basalis* as hosts and that care should be exercised not to include them when exporting *T. basalis* as a biological control agent for *N. viridula.* It is not known if these hyperparasitoids are sufficiently abundant to reduce the effectiveness of biological control of *N. viridula* by *T. basalis.* In Australia, a number of native natural enemies attack the nymphs and adults of *N. viridula* (Table 20 page 209).

Before the establishment of *Trichopoda giacomellii*, only a native tachinid parasitoid, *Cylindromyia rufifemur*, was recorded in Australia from *N. viridula* (Cantrell 1986). However, this and other species of native parasitoid attacking adults or nymphs have not been recovered in recent times (Seymour and Sands 1993). An unidentified disease accompanied by discoloration of the ventral surface of the bug was shown to contribute to significant levels of mortality, mainly of adults, both in the field and laboratory (D.P. A. Sands and M. Coombs, unpublished). This disease is an important mortality factor during periods of high humidity, making sustained culture of *N. viridula* difficult during autumn months.

The damage to crops by *N. viridula* has declined greatly since effective biological control was achieved in most of coastal, southern Australia by the egg parasitoid *T. basalis* (Jenkins 1946; Waterhouse and Norris 1987; Waterhouse 1998). However, *T. basalis* is not effective throughout Australia and *N. viridula* continues to be a pest of legumes and pecans in the inland regions of northern Victoria, central New South Wales and southern Queensland (Clarke 1992; Seymour and Sands 1993). *T. basalis* was introduced into Australia initially from Egypt in 1933 (Wilson 1960) and later from several other countries (Waterhouse and Norris 1987). Subsequently *T. basalis* has been distributed internationally wherever *N. viridula* caused problems, including Fiji, Hawaii and New Zealand in the Pacific Region (Clausen 1978a).

In many parts of Australia, *T. basalis* has greatly reduced the abundance of *N. viridula* (Waterhouse 1998). However, in certain areas, particularly those that produce grain legume and nut crops, *T. basalis* is not always an effective biological control agent. This prompted Clarke and Walter (1993) to question the effectiveness of biological control of *N. viridula* in Australia, and similarly in Hawaii, Jones (1995) discussed problems caused by *N. viridula* despite the presence of *T. basalis.* Introductions of strains of *T. basalis* into Australia from various countries and their effectiveness in controlling populations of *N. viridula* were discussed by Waterhouse (1998, but see Clarke 1990, 1993a page 452). An egg parasitoid from Japan, *Trissolcus mitsukurii*, became established in 1962 but its effect on *N. viridula* appears to be negligible. *Telenomus chloropus* (= *Telenomus nakagawai*, Clarke [1990]) was released between 1962 and 1981, but it is not known to have become established (Waterhouse and Norris 1987).

Attempts to establish in Australia *Trichopoda pilipes,* originally from the Caribbean, and *T. pennipes* from the United States, have not succeeded

(Waterhouse and Norris 1987), despite the initial recoveries of parasitoids at field release sites in Western Australia (Michael 1981). Bennett (1990) discussed several potential agents for *N. viridula.* In Argentina, the polymorphic *Trichopoda giacomellii* is an important, relatively specific parasitoid of adults and later instar nymphs of *N. viridula* and, with *T. basalis,* contributes to biological control of the pest (Liljesthrom and Bernstein 1990; Liljesthrom 1992). *T. giacomellii* is also an important parasitoid of *N. viridula* in Brazil (Ferreira et al. 1991). Based on its performance in Argentina (Liljesthrom 1991), *T. giacomellii* was identified as a promising agent to supplement biological control of *N. viridula* in Australia (Seymour and Sands 1993). After laboratory evaluation to determine its host range, *T. giacomellii* was released in south-eastern Queensland and New South Wales between 1996 and 1998 (Sands and Coombs 1999). *T. giacomellii* has become established near Moree, New South Wales, where between 9% and 72% of adult *N. viridula* were parasitised during summer months, and 42% of diapausing adults were parasitised. In the field, the proportion of male *N. viridula* parasitised by *T. giacomellii* was greater than females. This parasitoid has been released in south-eastern Queensland and its establishment is confirmed (Coombs and Sands 2000). The dispersal and longer term impact of *T. giacomellii* on *N. viridula* in Australia awaits evaluation.

The exotic ant *Pheidole megacephala* has been recorded as an important predator of the eggs of *N. viridula* in weeds near pecan orchards (Seymour and Sands 1993).

COMMENTS

The published identities of egg parasitoids introduced into Australia and thought to be *T. basalis* were doubted by Clarke (1990), who subsequently (Clarke 1993a) described specimens from Pakistan as *Trissolcus crypticus* and recognised a second, undescribed species from Italy. Neither species became established in Australia after their release (Clarke 1990, 1993b). Specimens of a *Trissolcus* species recently collected in southern France and thought to be *T. basalis* (J.-L. Sagliocco, pers. comm.) are morphologically different from Australian *T. basalis* and may be the same as the undescribed taxon from Italy (D.P.A. Sands, unpublished). Strains of *T. basalis* established in Australia were shown to have a higher fecundity than strains from the United States, possibly resulting from the development of ecotypes or strains in different locations (Powell and Shepard 1982). The identities of populations of *Trissolcus* spp., currently all considered to be *T. basalis,* have not been resolved, and further material from their countries of origin may help in determining their taxonomic status.

In Hawaii, the impact on *N. viridula* by *T. basalis* is supplemented by that of two tachinid parasitoids, *Trichopoda pilipes* and *T. pennipes* (Davis 1964; Jones 1988; Todd 1989). *T. pennipes* is also an important natural enemy of *N. viridula*

in Italy, although it was not intentionally introduced (Colazza et al. 1996). Small releases of a tachinid parasitoid, *Bogosia antinorii*, from Kenya were made in Australia in 1958 but this species also failed to become established (Greathead 1971). *T. pilipes* and *T. pennipes* contribute to effective control of *N. viridula* in Hawaii, but attempts to establish both species in Australia failed despite several introductions between 1941 and 1980. One or both *Trichopoda* species introduced into Antigua, Papua New Guinea, Fiji and Solomon Islands failed to become established (Waterhouse and Norris 1987).

Table 20. Indigenous natural enemies of *Nezara viridula*

Species	Stage of host	References
ORTHOPTERA		
TETTIGONIIDAE		
unidentified	E	Seymour & Sands 1993
DIPTERA		
TACHINIDAE		
Cylindromyia rufifemur	A	Cantrell 1986
HYMENOPTERA		
CERAPHRONIDAE		
Ceraphron sp.[a]	E	J.E. Seymour & D.P.A. Sands unpubl.
ENCYRTIDAE		
Anastatus sp. [a]	E	Seymour & Sands 1993
Xenoencyrtus hemipterus	E	Seymour & Sands 1993; Noyes 1998
Xenoencyrtus niger	E	Waterhouse & Norris 1987
Xenoencyrtus rubricatus	E	Riek 1962; Noyes 1998
PTEROMALIDAE		
Acrolisoides spp.[a]	E	Clarke & Seymour 1992
SCELIONIDAE		
Psix lacunatus[b]	E	Jones 1988
Trissolcus oenone	E	Johnson 1991
Trissolcus ogyges	E	Johnson 1991; Seymour & Sands 1993
Telenomus sp.	E	Waterhouse & Norris 1987

[a]hyperparasitoid; [b]from *N. viridula* in Pakistan. Reared from other hosts in Australia

36

Parasaissetia nigra (Nietner) Hemiptera: Coccidae † nigra scale

PRECIS

Parasaissetia nigra is believed to have originated in Southeast Asia or possibly Africa. This scale insect is a minor pest of citrus, custard apple, avocado and ornamental hibiscus in subtropical eastern Australia.

P. nigra is controlled by a complex of native predators and parasitoids, as well as several parasitoids introduced for the biological control of other Coccidae, the most important being *Coccophagus ceroplastae, Metaphycus helvolus* and the egg predator *Scutellista caerulea.*

BIOLOGY

Parasaissetia nigra mainly occurs in the citrus-growing areas of south-eastern Queensland and northern New South Wales (Smith et al. 1997a).

The adult, elongate, smooth, oval females of *P. nigra* measure about 3 to 4 mm in length and reproduce parthenogenetically. Males have not been reported from Australia. Mature scales are dark brown to black and the immature stages are at first translucent, becoming light brown with darker markings. About 800 eggs are deposited and retained beneath the parent scale for 1 to 3 weeks before they hatch (Bartlett 1978a). Crawlers settle on the twigs, young stems and petioles where they remain or may transfer to older stems as they develop, passing through three larval instars until the adult stage.

There are several overlapping generations (four to six) each year, the life cycle taking about 60 days to complete (Smith et al. 1997a).

PEST STATUS

In Australia, *P. nigra* is a minor pest, mainly of citrus and avocado, but also occasionally custard apples and ornamental hibiscus in the humid regions of eastern Australia. Overseas the scale also attacks more than 200 species, mostly ornamentals and coffee (Bartlett 1978a). Infestations of *P. nigra* are accompanied

by heavy secretions of honeydew which accumulates on the leaves and fruit, attracting growth of sooty moulds. Ants are frequently attracted by the honeydew and these interfere with the activity of natural enemies.

BIOLOGICAL CONTROL

P. nigra is usually controlled by a complex of native predators and parasitoids, especially the coccinellid *Cryptolaemus montrouzeri,* the pteromalid egg predator *Scutellista caerulea,* and larvae of the noctuid moth, *Mataeomera dubia* (Table 21). Several parasitoids introduced for biological control of other Coccidae attack *P. nigra*, the most important of these being *Coccophagus ceroplastae* and *Metaphycus helvolus*. The fungus *Verticillum lecanii* is a common pathogen of *P. nigra* during warm, wet weather (Smith et al. 1997a).

Table 21. Indigenous natural enemies of *Parasaissetia nigra*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzeri	L 1, 2	Smith et al. 1997a
LEPIDOPTERA		
NOCTUIDAE		
Mataeomera dubia	L 1, 2, A	Smith et al. 1997a
HYMENOPTERA		
ENCYRTIDAE		
Coccidoctonus dubius[a]	A	D.P.A. Sands unpubl.
PTEROMALIDAE		
Moranila californica	E	Malipatil et al. 2000

[a]hyperparasitoid

37

Parthenolecanium persicae (Fabricius) Hemiptera: Coccidae grapevine scale

PRECIS

The cosmopolitan *Parthenolecanium persicae* was first observed in Western Australia, later spreading in the 1920s to other southern States, where it became a serious pest of grapevines, plums and other plants. *P. persicae* is now of less importance, mostly due to biological control by the exotic parasitoid, *Metaphycus maculipennis*.

A native coccinellid, *Cryptolaemus montrouzierei,* and predatory larvae of the moth *Mataeomera dubia* contribute to the effective biological control of *P. persicae.*

BIOLOGY

Parthenolecanium persicae is a cosmopolitan coccid. Its native range is not known but it may be Southeast Asia. In Australia, *P. persicae* occurs in south-western Western Australia, South Australia and New South Wales.

Adult scales are large (6 mm), elongate-oval and dark brown and, in heavy infestations, they form clusters on grapevine stems. The scales are univoltine and overwinter as adults on older stems amongst rough bark. Each female *P. persicae* produces several hundred eggs parthenogenetically in spring. Males have not been recorded in Australia. The yellow crawlers emerge in late spring in New South Wales (Hely 1957) or early summer in Queensland (Bengston 1961a) and disperse to settle on leaves or young stems of the vines. There are three larval instars. In autumn the larvae migrate to settle on the stems and later on the older wood of the vines, where they develop to the adult stage (Hely 1957).

PEST STATUS

P. persicae was first observed in Western Australia in 1901 and in the 1920s it spread to become a serious pest of grapevines, plums and some other plants in southern Western Australia, Victoria, New South Wales and Queensland. However, *P. persicae* has since decreased in importance and, although common in

vineyards, infestations are usually confined to a few plants and only occasionally cause serious damage (Hely 1957).

Sooty moulds, which accumulate on leaves and fruit, develop on honeydew secreted by the scale. In heavy infestations, affected vines are weakened by loss of sap and by the sooty moulds which reduce photosynthesis. Sooty moulds blacken the stems and may result in the death of affected vines (Bengston 1961a).

BIOLOGICAL CONTROL

Several native predators of *P. persicae* are important, particularly when infestation levels are high (Table 22). These include larvae of the moth *Mataeomera dubia*, and the coccinellid *Cryptolaemus montrouzieri* (Hely 1957). Little is known of the indigenous parasitic wasps but at least two, *Aphobetus lecanii* and the hyperparasitoid, *Myiocnema comperei*, are recorded from the scale.

The history of introduction into Australia of *Metaphycus maculipennis,* is not clear. It may have been introduced from Japan via the USA in 1907, but it is also possibly one of three parasitoids introduced from the Philippines in 1909 (Wilson 1960). *M. maculipennis* is responsible for maintaining effective biological control of *P. persicae* throughout the grape-growing areas of southern Australia.

MAJOR PARASITOID SPECIES

Metaphycus maculipennis Hymenoptera: Encyrtidae

M. maculipennis is an internal, gregarious, bi-parental parasitoid of *P. persicae.* Up to 172 eggs are deposited by the parasitoid in the host, with development to adult taking as little as 27 days. Third instar nymphs and adult scales are attacked by the parasitoid, and from 1 to 26 individuals may be produced from each host depending on its size and stage of development.

Table 22. Indigenous natural enemies of *Parthenolecanium persicae*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzierei	L 1, 2, A	Wilson 1960
LEPIDOPTERA		
NOCTUIDAE		
Mataeomera dubia	L 1, 2, A	Wilson 1960
HYMENOPTERA		
APHELINIDAE		
Myiocnema comperei [a]		Jenkins 1946
PTEROMALIDAE		
Aphobetus lecanii		Wilson 1960

[a]hyperparasitoid

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Pentalonia nigronervosa (Coquerel) Hemiptera: Aphididae † banana aphid

PRECIS

Pentalonia nigronervosa is probably native to Southeast Asia, although it now occurs in most banana-growing areas of the world.

Direct damage caused by feeding is generally regarded as minor. Its considerable importance is due to the fact that it is a transmitter of banana bunchy top virus. This virus was far more important in the 1920s and 1930s than it is now, due partly to the program of destruction of diseased plants. However, it appears that *P. nigronervosa* populations have also declined. Although no detailed studies of natural enemies have been made in Australia, it is known that *Aphidius colemani* attacks it occasionally. No information is available on the time or mode of arrival in Australia of this parasitoid.

BIOLOGY

Pentalonia nigronervosa is widespread in Australia and is common on bananas in the warmer parts of eastern Australia. It occurs in colonies at the base of the banana pseudostem, down to 8 cm below soil level, and also on young suckers and between the sheath of the outer leaf and the pseudostem. Honeydew produced in considerable quantities by this phloem feeder attracts ants which tend to ward off natural enemies. They may transport aphids from plant to plant.

Females are parthenogenetic and young are produced viviparously. Most females are wingless but, from time to time, winged forms are produced. There may be more than 30 generations per year (Waterhouse and Norris 1987).

PEST STATUS

Colonies of virus-free aphids can check the growth of young banana plants and produce blemishes on young fruit. The honeydew collecting around the base of leaves and fermenting there may cause petioles to rot and plants to die. However, it is the role of *P. nigronervosa* as a transmitter of banana bunchy top virus that

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makes it a truly formidable pest. Virus-infected banana aphids do not pass the bunchy top virus to their young, which have to acquire their own infection. Nymphs are more effective vectors than adults. Plants infected as young suckers are severely stunted and never bear edible fruit. A rigorous campaign, involving the destruction of diseased plants and their replacement with disease-free stock, has saved the banana industry in Australia and a number of other countries (Waterhouse and Norris 1987).

BIOLOGICAL CONTROL

No specific attempts at biological control of *P. nigronervosa* have been made in Australia. However, two exotic aphidiid parasitoids have been recorded attacking it. There are no published records of the origin of either *Aphidius colemani* or *Aphidius* sp. (probably also *Aphidius colemani*: M. Carver, pers. comm.) which have become established in Australia, their time or manner of arrival. However, *A. colemani* is believed to be native to India. Hely et al. (1982) comment that parasitisation by *Aphidius* sp. in New South Wales is hindered by the presence of ants attracted by honeydew. Although *A. colemani* has been recorded from banana aphid in northern New South Wales (M. Carver, pers. comm. 1986), a careful search several years later failed to find it attacking *P. nigronervosa* (P. Wellings, pers. comm. 1989).

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Pineus boerneri Annand Hemiptera: Adelgidae

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Pineus pini Koch
pine adelgids

Two species of *Pineus* attack *Pinus* spp. in Australia and New Zealand: *P. boerneri* described from *Pinus radiata* in California, but possibly from East Asia in origin and which has often been recorded as *Pineus laevis*; and *Pineus pini* (= *P. laevis*) from Western and Central Europe, recorded in Australia from *Pinus sylvestris* and other pines (Blackman and Eastop 1994). These two species are difficult to separate and, because of the absence of voucher specimens, it is not possible to be certain of the identity of the target species.

PRECIS

After a period of concern in the 1930s, *Pineus boerneri* and *P. pini* are now only minor pests of *Pinus radiata* in eastern mainland Australia and Tasmania.

Two chamaemyiids, a coccinellid and a hemerobiid, which were found attacking *Pineus pini* in England, were introduced and liberated, but failed to become established. A chamaemyiid fly, *Leucopis atrifacies* from *Pineus boerneri* in California, was introduced in 1938, but did not become established. Native predators assist in controlling pine adelgid abundance in Australia.

BIOLOGY

Pineus spp. females are parthenogenetic, usually wingless, and about 1 mm long. They are purplish-brown, covered with waxy, thread-like filaments and lay eggs on pine twigs in abundant, greyish-white wax wool. Males are not produced. Spread occurs by crawlers being blown by wind or carried by animals or plants. There are

several generations per year (Zondag 1977; Blackman and Eastop 1994). *Pineus boerneri* is also present in New Zealand, Hawaii, Chile, Malaysia, Taiwan, Europe, South Africa and possibly Taiwan (Zondag 1977; Blackman and Eastop 1994).

PEST STATUS

Pineus spp. are of little significance in established plantations, but can be a problem on trees in nurseries and young plantations. Infestation can result in shortening of needles, malformation, defoliation and even death. Dry conditions favour infestations, as do trees under stress (Tanton and Alder 1977). Before its biological control there by *Leucopis tapiae* and other predators, *P. boerneri* was an important pest of *Pinus* spp. in New Zealand (Zondag 1977; Zondag and Nuttall 1989).

BIOLOGICAL CONTROL

Native coccinellids and a chrysopid attack *Pineus* spp. in Australia. Of these, the coccinellid *Diomus pumilio* is reported to be of considerable value in controlling them in the Australian Capital Territory and also in Queensland. *D. pumilio* from Canberra, Australian Capital Territory was liberated in 1936 and 1937 in Queensland because it was not thought to be present, although subsequent information indicates that it was already there (Wilson 1960).

The importance of accurate taxonomy is well illustrated by the work in the early 1930s on *P. boerneri* (then known as *Chermes boerneri*). This pine adelgid was first identified as *Chermes pini* (or as it is now known, *Pineus pini*), a species of European origin and one that occurs on *Pinus sylvestris* and some other *Pinus* spp. in Australia. A search in England for natural enemies revealed no parasitoids, but many predators, ten species of which were introduced and four liberated in the Australian Capital Territory and New South Wales: *Leucopis obscura* (1932 to 1936, 1938 to 1939) and *Leucopis praecox* (1933) (both Chamaemyiidae), *Wesmaelius concinnus* (1936 to 1937) (Hemerobiidae) and *Exochomus quadripustulatus* (1934 to 1935, 1937 to 1939) (Coccinellidae) (Wilson 1938, 1960). Nothing is known of *E. quadripustulatus* in the liberation areas, but it has been common around Perth, Western Australia since 1935 and was found in 1981 on non-native conifers near Melbourne, Victoria (Pope 1988).

When an alternative identification of the pine adelgid as *P. boerneri* was announced, a brief survey of its native enemies was made in California. As a result, *Leucopis atrifacies* (Chamaemyiidae) was introduced and about 20 individuals liberated in 1938.

With one exception, none of the above species that were liberated is known to have become established although, on two occasions, *L. obscura* was recovered in the field (Wilson 1960). Of the English predators, failure of all except *E. quadripustulatus* to establish was variously attributed to mortality during

shipment, failure of adults to develop to sexual maturity, inability to establish cultures in the insectary and lack of synchronisation of life cycles of northern and Southern Hemisphere species. It is also possible that *E. quadripustulatus* became established as a result of some other (accidental) introduction.

The two pine adelgids are seldom regarded now as more than very minor pests of *Pinus radiata*.

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Planococcus citri (Risso) Hemiptera: Pseudococcidae citrus mealybug

Four mealybug species are found on commercial citrus in south-eastern Australia: *Planococcus citri, Pseudococcus longispinus, P. calceolariae* and *P. viburni*. Only the first two species present serious problems to citrus production across a relatively wide area. By contrast, *P. calceolariae* is a pest only in Riverland, South Australia (Smith et al. 1997a; Baker and Keller 1998, 1999; Ceballo et al. 1998). *P. viburni* occurs in the Murray Valley, the Riverina and the Narromine region of New South Wales.

This account draws heavily on Waterhouse (1998).

PRECIS

The citrus mealybug, *Planococcus citri*, occurs very widely wherever citrus is grown in tropical, subtropical and temperate areas. It also attacks a very wide range of other plants, including passionfruit and custard apple in Queensland. It has been in Australia for more than a century.

Like other mealybugs, *P. citri* is attacked by a number of non-specific predators, especially Coccinellidae, but also Chrysopidae. Although these predators consume vast quantities of prey when mealybugs are abundant, they often do not reduce host numbers to a level at which economic injury no longer occurs. Nevertheless, the introduction of the predatory coccinellid *Cryptolaemus montrouzieri* from New South Wales to Western Australia in 1902 is credited with producing effective control of *P. citri* there.

Four exotic parasitoids — *Anagyrus* sp., *Coccidoxenoides peregrinus, Leptomastidea abnormis* and *Ophelosia crawfordi* — were found attacking the citrus mealybug in Queensland before biological control was initiated. These parasitoids and the native predators often did not maintain *P. citri* below economic levels.

The Brazilian encyrtid *Leptomastix dactylopii* was introduced from California and liberated in Queensland between 1980 and 1987. It established readily, soon became a widespread and abundant parasitoid of the citrus mealybug, and brought about a considerable measure of control. Augmentative

releases in early summer have been shown to be a valuable supplement if overwintering mealybug populations are substantial.

BIOLOGY

The citrus mealybug is extremely widespread, being present in almost all tropical, subtropical and temperate regions of the world and in glasshouses in cooler parts. Doubts have been raised about its reputed origin, south China (Bartlett 1978b), because it is a reasonably important and widespread pest there (Li Li-ying et al. 1997). It has been present in Australia for more than a century.

Adult female *Planococcus citri* are wingless, oval, flat, and yellow to yellowish-brown, with a barely visible dorsal line under a waxy covering. Around the edge of the wax cover there are short waxy protuberances, with somewhat longer protuberances at the posterior end. Yellow eggs are laid in a waxy ovisac and from these hatch young lemon-yellow larvae or crawlers.

Depending upon the temperature and host plant, development takes from 20 to 40 days. The pre-oviposition period is 7 to 10 days, eggs hatch in 3 to 6 days and 300 to 500 eggs are laid per female. All stages are capable of overwintering. There are three instars for females and four for males. In warm areas, there are typically four or five overlapping generations. *P. citri* shows considerable morphological variation when reared under different conditions — small specimens, caused by high temperature (32°C), having smaller appendages and lower numbers of cuticular structures than those reared between 17°C and 25°C (Cox 1981). *P. citri* can be readily reared in the laboratory on potato sprouts (Fisher 1963). Virgin females secrete a pheromone continuously to attract males, (IR-*cis*) (3-isopropenyl-2-2-dimethylcyclobutyl) methyl acetate (Dunkelbaum et al. 1986), which repels males of *Pseudococcus calceolariae* and *P. viburni* (Rotundo and Tremblay 1973).

PEST STATUS

P. citri occurs on an extremely wide range of plants, but is most frequently reported from citrus. In Queensland, before biological control, it was a serious pest on citrus and custard apple, an important pest on passionfruit and occurred on guava and starfruit. Mealybug crawlers infest young citrus fruit in early November in Queensland and settle under the calyx. Later, they move either to the navel of navel oranges or between adjoining surfaces of clustered fruit. Large amounts of honeydew are produced, leading to abundant growth of sooty moulds, which may render fruit unmarketable. Dry conditions are favourable for a build-up of *P. citri* populations. Heavy infestations in navel oranges can cause end rot and fruit drop. Infestation levels up to about 5% of fruit harvested are acceptable for local markets (Smith et al. 1988). In general, *P. citri* is now a minor pest in Australia, although augmentative early releases of the parasitoid *Leptomastix*

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dactylopii may be desirable in Queensland to avoid damage to citrus if overwintering populations have not been reduced to very low levels.

P. citri is also a serious pest of custard apple (*Annona* spp.) in Queensland and north-eastern New South Wales. Crawlers infest young fruit in late December and by harvest (April to June) over 50% of the crop may be heavily infested and disfigured by the growth of sooty mould on the honeydew produced by the mealybug (Smith 1991).

P. citri is reported to be a pest in glasshouses and shade houses in South Australia (Brookes 1957).

BIOLOGICAL CONTROL

At the beginning of the twentieth century, mealybugs were very destructive pests of citrus in Western Australia. Although the species involved cannot be reliably identified, they are likely to have included *P. citri* and *Pseudococcus longispinus* (Wilson 1960). Two coccinellid predators were introduced into Western Australia, *Cryptolaemus montrouzieri* from New South Wales in 1902 and an unidentified species from Spain in 1903. Both species were liberated but, as far as is known, only *C. montrouzieri* became established. It rapidly brought about a major reduction in mealybug populations and Wilson (1960) reported that its introduction was regarded as an outstanding biological control success.

Before biological control was initiated in Queensland in 1980 as part of an integrated pest management package for citrus pests, 12 natural enemies were recorded attacking *P. citri*. They were the coccinellids *Cryptolaemus montrouzieri* and *Harmonia octomaculata*, the syrphid *Syrphus* sp., the midge *Diadiplosis koebelei,* the neuropterans *Chrysopa* sp., *Mallada signata, Micromus* sp. and *Oligochrysa lutea* (all eight native) and four encyrtids — *Anagyrus pseudococci*, *Coccidoxenoides peregrinus, Leptomastidea abnormis* and *Ophelosia crawfordi* (Murray 1978, 1982b; Smith et al. 1988, 1997b; Ceballo et al. 1998; Malipatil et al. 2000). The introduction of the last three species, which are exotic, does not appear to have been recorded, although *L. abnormis* at least is known to have been attacking *P. citri* before 1960 (Wilson 1960). A fungus, similar to *Entomophthora fumosa*, caused up to 58.1% mortality of both 3rd instar nymphs and adults on passionfruit during wet periods (Murray 1978). However, these natural enemies were unable to maintain infestations consistently at acceptable commercial levels.

A more recent survey (Ceballo et al. 1998) added five additional parasitoids: the aphelinids *Coccophagus* sp., *Euryischia* sp., *Myiocnema comperei*; an unidentified encyrtid; and a signiphorid hyperparasitoid, *Chartocerus* sp.

The Brazilian encyrtid *Leptomastix dactylopii* was imported from California and some 2.5 million adults released between 1980 and 1987. It rapidly established and soon became the most important natural enemy of citrus mealybug throughout south-eastern Queensland. Infestations averaging 38% of

fruit in early December were reduced to a commercially acceptable level of 5% or less at harvest in April. Parasitoid numbers were greatly reduced during winter and spring and augmentative releases of 5000 to 10,000 parasitoids per hectare in spring to early summer brought forward substantial parasitoid activity by some 6 weeks (Smith et al. 1988).

If no releases were made, *L. dactylopii* was first recorded in early February and, by mid-March, was present in an average of 55% of mealybug-infested fruit. The mealybug infestation peaked at an average of 47% of fruit in mid-December but, by late April, only dropped to 10%. The presence of the mealybug on 25% or more fruit from December to March generally resulted in excessive amounts of sooty mould at harvest. *C. montrouzieri* was recorded on a maximum of 5% of mealybug-infested fruit and augmentative releases failed to increase this level. On the other hand, augmentative releases of *L. dactylopii* were found to be as cheap as pesticides and far more compatible with integrated pest management of other citrus pests. This parasitoid is commercially available in Queensland (Smith et al. 1988, 1997a,b).

Once established, *L. dactylopii* was able to bring potentially serious mealybug populations on custard apple under control, with the parasitoid present on 90% or more of infested fruit. Often all of the third instars and mature females on heavily infested fruit were parasitised. The coccinellid *O. lutea* was able to reduce to low levels young stages not parasitised by *L. dactylopii. C. montrouzieri* was also a valuable predator, with the potential to rapidly reduce heavy infestations; but it did not occur as consistently as *O. lutea*. Unless *L. dactylopii* is released annually, the level of control on custard apple is not as good as that on citrus (Smith 1991).

When ants (mainly *Pheidole megacephala*, but also *Iridomyrmex glaber*) were present, tending colonies of the mealybug for their honeydew, numbers of both mealybug and ant increased greatly. When sticky bands were placed around the trunks of custard apple trees to prevent ant access, numbers of *P. citri* were lowered. Parasitisation of the mealybug by *L. abnormis* was low and not increased by banding, although there were then more predators, especially *C. montrouzieri, O. lutea* and *Syrphus* sp. Nevertheless, in pre-*L. dactylopii* times, these natural enemies were unable to maintain *P. citri* at acceptable levels (Murray 1982b).

A recent assessment of the situation comes from the studies of Ceballo et al. (1998) carried out in 1994 and 1995. A total of 1147 adults of 10 parasitoid species were reared from *P. citri* infesting mandarins, oranges and grapefruit at Mundubbera, Queensland. Of this total, *C. peregrinus, Chartocerus* sp., *L. abnormis* and *Anagyrus* sp. were present in relatively high numbers, although their proportional contribution to overall parasitoid abundance (Table 23 page 225) was not regular. Furthermore, their relative abundance varied according to the citrus host bearing *P. citri*. Thus, *Anagyrus* sp., *L. abnormis* and *L. dactylopii* were not present in *P. citri* from grapefruit. Only *C. peregrinus* was recorded from

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all citrus varieties sampled. It achieves high levels of parasitisation in *P. citri* mass-rearing facilities.

The following parasitoids, which are present in Australia on other hosts, are recorded overseas as attacking *P. citri* (Malipatil et al. 2000), however they do not appear to have been recorded yet from *P. citri* in Australia: *Allotropa* nr *citri, Anagyrus agraensis, A. fusciventris, Coccophagus lycimnia, Coccophagus gurneyi* and *Encyrtus aurantii*.

MAJOR NATURAL ENEMIES

Cryptolaemus montrouzieri Coleoptera: Coccinellidae

This general predator of mealybugs, which also feeds on some other scales (*Eriococcus* sp., *Pulvinaria* spp.) and aphids, is native to eastern Australia. It is the most widely distributed of all natural enemies of mealybugs, according to a count in 1978, covering the past 80 years, and listing more than 40 countries, geographical areas or islands into which it has been imported. In many instances it was introduced against mealybugs other than *P. citri* and sometimes against coccids such as *Pulvinaria* spp., which produce egg masses similar to those of mealybugs (Bartlett 1978b).

Both larvae and adults feed voraciously on all mealybug stages, for example, a larva is recorded as consuming an average of 3331 host eggs (Oncuer and Bayhan 1982) and females need to consume at least eight adult *P. citri* for normal egg production (Reddy et al. 1991). *C. montrouzieri* does not distinguish between unparasitised *P. citri* and mealybugs parasitised by *L. dactylopii* (Prakasan and Bhat 1985). Adults mate 1 or 2 days after emergence and, 5 to 6 days later, females begin ovipositing in or near host egg masses. About 100 eggs are deposited in 1 month. These hatch in 4 to 8 days, and wax-covered larvae develop in 12 to 20 days, so that the life cycle can be completed in slightly less than a month (27.7 days at 25.5°C ± 1°C: Oncuer and Bayhan 1982), although there are usually only four generations per year. Development stops below 10°C and freezing temperatures are lethal. Pupae, and occasionally adults, are capable of hibernating. Hot, dry climates are tolerated, but high humidities are said to be detrimental. *C. montrouzieri* thrives when host density is high and, under these conditions, is capable of providing spectacular control. However, its searching ability and natural spread is poor, so it often dies out locally when hosts become scarce (Cole 1933; Mineo 1967).

Methods have been developed for the production of mealybugs and *C. montrouzieri* that permit the production and release of large numbers of the predators at low cost (Fisher 1963).

Coccidoxenoides peregrinus Hymenoptera: Encyrtidae

This parasitoid, earlier widely known as *Pauridia peregrina*, is probably native to southern China (Bartlett 1978b), although Meyerdirk et al. (1978) suggest that it is indigenous to Texas. It has been reported, inter alia, from India, Japan, Philippines, Fiji, Hawaii and Uganda. It is a solitary endoparasitoid of 1st, second and third instar female *P. citri* and *Planococcus kenyae* and first and second instar males. It is normally parthenogenetic, but there are rare males. Females commence oviposition shortly after emergence, and continue for about 2 days. At 27°C, larval development takes 11 to 12 days and the pupal stage 16 to 18 days (Fisher 1963).

Leptomastidea abnormis Hymenoptera: Encyrtidae

This solitary endoparasite is possibly native to the Mediterranean, although it is now widespread, occurring in eastern USA, Canada, Brazil (Compere 1939) and many other countries.

L. abnormis strongly prefers small second instar mealybugs for oviposition, but also attacks first and third instars. Females begin to search for hosts soon after emergence. The number of eggs laid varies from 57 to over 300, although it is reported that only about 33 offspring survive to the adult stage. Fertilised eggs give rise to females and unfertilised eggs to males. The inconspicuously stalked eggs are laid free in the haemolymph and hatch in 36 to 72 hours. The larvae consume haemolymph at first but, in the last instar, consume the entire body contents. The tailed larvae complete development in about 8 days and the life cycle may be as short as 17 days in the laboratory at 26°C. In the field, a generation in summer takes about 1 month. There may be five or six generations per year, with adults living 11 days if provided with honey and water.

Leptomastix dactylopii Hymenoptera: Encyrtidae

This solitary endoparasitoid prefers third instar larvae and young (but not egg-laying) females, but occasionally attacks first and second instar larvae (Bartlett 1978b; Meyerdirk et al. 1978). It is presumed to be native to Brazil, although found also in the West Indies and parts of southern USA (Compere 1939). In the field, it appears to be specific to *P. citri* (Bartlett 1978b; Nagarkatti et al. 1992). It has also been used in suppression of *P. citri* in USA, Procida island and mainland Italy, Cyprus and India (Waterhouse 1998).

Adults live up to 35 days. Parasitised hosts are generally rejected after simple antennal contact but, if not then, also following defensive behaviour of the host or possibly after detection of the egg stalk emerging from the surface of the host. If not rejected earlier, they may be rejected after insertion of the ovipositor (Baaren and Nenon 1994). About 18 eggs are laid each day, up to a total of 300 per female. These hatch in 1.5 to 2 days at 28°C and there are four larval instars, each of about 2 days. The pupal stage lasts 7 to 8 days. In Italy there are six (and a partial

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seventh) generations per year (Zinna 1959). Additional information on the biology of *L. dactylopii* is given by Lloyd (1958).

The original introduction of *L. dactylopii* from Brazil to California in 1934 was based on a single pair (Compere 1939). The extent to which the progeny of this pair may have had genes from later introductions added to the gene pool is quite unclear. There may thus be good justification for obtaining fresh stock from matching climatic zones in Brazil if new introduction are to be made.

Table 23. Hymenopterous parasitoids of *Planococcus citri* on citrus at Mundubbera, Queensland (after Ceballo et al. 1998)

Species	Type	% Parasitised
ENCYRTIDAE		
Anagyrus sp.	endoparasitoid	17.4
Coccidoxenoides peregrinus	endoparasitoid	23.4
Leptomastidea abnormis	endoparasitoid	17.8
Leptomastix dactylopii	endoparasitoid	3.7
Unidentified		3.7
SIGNIPHORIDAE		
Chartocerus sp.	ectoparasitoid, hyperparasitoid	20.8
PTEROMALIDAE		
Ophelosia bifasciata	endoparasitoid	8.2
APHELINIDAE		
Myiocnema comperei	? hyperparasitoid	
Euryischia sp.	hyperparasitoid	
Coccophagus sp.	endoparasitoid	

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Pseudococcus calceolariae (Maskell)
Hemiptera: Pseudococcidae †
citrophilous mealybug

This species has also been referred to in earlier literature as *Pseudococcus citrophilus, P. fragilis* or *P. gahani*. Recent work by Charles et al. (2000) has synonymised *P. similans* with *P. calceolariae*, extending the distribution and host range of the latter in Australia and including more records on roots.

PRECIS

This polyphagous, eastern Australian mealybug appeared in California in 1913 and by 1928 had become a serious pest. Two parasitoids, *Coccophagus gurneyi* and *Tetracnemoidea brevicornis*, were introduced from the Sydney area in 1928 and soon brought about such a dramatic reduction in citrophilus mealybug numbers that it was reported to be a rare insect. Similar success was reported in several other countries where the mealybug had become established.

When *Pseudococcus calceolariae* was recorded in 1986 in inland, southern Australian citrus-producing areas, both parasitoids were introduced from the Sydney area. *T. brevicornis* became established, but did not bring about adequate control. A second introduction of *C. gurneyi* has since led to establishment, but it is too early to assess overall effectiveness.

BIOLOGY

The slow-moving, adult *Pseudococcus calceolariae* female is 3 to 4 mm long, oval and covered with a thin coat of white mealy wax. Waxy processes project from around the margin of the body and, of these, the posterior set of four are longer than the rest, the central pair being about one third of the length of the body. Where the dorsal waxy covering is thinner, four longitudinal dark-claret lines are visible and these are characteristic of the citrophilus mealybug.

Females go through three and the delicate, winged males four moults. Up to 500 eggs are laid in a waxy, filamentous egg sac. These hatch within a few days to

disclose tiny, pink, mobile crawlers. The life cycle takes about 2 months in midsummer and 3 to 4 months in winter. In southern Australia there are three to four generations per year (Smith et al. 1997a).

Most overwintering mealybugs are immature and develop into adults in spring. These lay eggs which produce crawlers that migrate to young fruit in early summer. They seek sheltered sites, such as under the fruit calyx, in the navel of navel oranges, between leaves touching fruit, in leaves curled by the citrus leafminer and in crevices in the bark. A number of later stages migrate down the trunk and reproduce on various broadleaf weeds.

P. calceolariae is believed to be native to the Sydney area of eastern Australia (Williams 1985), although it is usually an uncommon insect. It is known from Queensland by only a few specimens collected in the Stanthorpe and Applethorpe districts (Ceballo et al. 1998). It is occasionally the dominant mealybug species in south-eastern Australia, although generally *Pseudococcus longispinus* is more abundant (Baker and Keller 1998). It now occurs also in New Zealand, California, South America, South Africa and south-western Europe (Smith et al. 1997a).

PEST STATUS

P. calceolariae occurs on a very wide range of hosts, including all citrus varieties, although mandarins are less affected, possibly because of their smaller calyx (Smith et al. 1997a). The mealybug is also found on stone, pome and berry fruits, ornamentals (such as roses, acacias and grevilleas) and on a range of broadleaf weeds, including blackberry nightshade (*Solanum nigrum*), three corner jack (*Emex australis*), bridal creeper (*Myrisphyllum asparagoides*) and caltrop (*Tribulus terrestris*).

Damage is caused by the honeydew produced which, with resulting sooty moulds, accumulates under and around the calyx, inside the navel and on the fruit surface where this touches leaves or other fruit. Other rot-producing fungi may grow on the honeydew. After harvest, colonies of insects may continue to infest the fruit and may survive to the marketplace, together with unsightly sooty moulds which are difficult to remove and greatly reduce value.

BIOLOGICAL CONTROL

Table 24 page 230 lists eight common parasitoids of *P. calceolariae* in citrus-growing areas in south-eastern Australia. These and the many predators that now attack it are, unless exposed to pesticides, capable of maintaining numbers of the mealybug there at very low levels.

A search in the Sydney area in 1927 and 1928, after *P. calceolariae* had become a major pest in California, revealed its presence there but in very low numbers, suggesting that it was under the effective control of natural enemies (Compere 1928). Two parasitoids (*Coccophagus gurneyi* and *Tetracnemoidea*

brevicornis) and several predators (*Midus pygmaeus, Diomus* sp.: Coccinellidae; *Pleisochrysa ramburi*: Chrysopidae; *Diadiplosis koebelei*: Cecidomyiidae) were introduced to California, but only the two parasitoids became established. They rapidly produced such a high level of control that the mealybug was soon regarded as a rare insect (Smith 1931; Clausen 1978a). Either parasitoid was shown to be capable of reducing the pest, but a combination of the two was able to hold it at a lower density (Smith and Compere 1928; Compere and Smith 1932). *C. gurneyi* was generally dominant, especially in spring, although *T. brevicornis* gained in importance during summer. When the citrophilous mealybug appeared in other countries, *C. gurneyi* and *T. brevicornis* were sent to New Zealand (Charles 1989b), and the former to Chile, the Black Sea area and South Africa, and excellent control was reported from each area (Bartlett 1978b).

P. calceolariae was first recorded in the Riverland area of South Australia in 1987 and, in the absence of its two primary parasitoids, rapidly increased to become the major mealybug pest in the region. It is the major honeydew-producing pest of citrus and now extends to neighbouring citrus areas in inland Victoria and New South Wales.

In view of the overseas successes, both *C. gurneyi* from Sydney, New South Wales and *T. brevicornis* from Nangiloc, Victoria were introduced into the Riverland in 1990, but only *T. brevicornis* became established. A second introduction into the Riverland of *C. gurneyi* in 1996 and 1997 resulted in its establishment at seven sites in 1997, but *P. calceolariae* is not yet suppressed to an acceptable level (Baker 1993; Baker and Keller 1999). An additional population of inland *Coccophagus* from the Riverina, New South Wales, possibly better adapted to the climatic conditions in South Australia, is in culture for later release (Baker and Keller 1998, 1999). Curiously, there was only limited retrieval of *C. gurneyi* from *P. calceolariae* in the Sydney region, although the citrophilous mealybug was as abundant there as in Riverland, calling into question the significance of *C. gurneyi* and *T. brevicornis* in the dynamics of Australian citrophilous mealybug populations (Baker and Keller 1998, 1999). *T. brevicornis* was reported to be capable of parasitising 20% to 40% of mealybug hosts and to be well established (Altmann and Green 1992). Two predators were also liberated and established in the South Australian citrus areas, the cecidomyiid fly *Diadiplosis koebelei* and the coccinellid beetle *Cryptolaemus montrouzieri* (Altmann and Green 1992).

In Riverland, South Australia, in addition to species listed in Table 24 page 230, the following were recovered during 1994 to 1997: *Coccidoxenoides peregrinus* (Encyrtidae), *Cryptanusia* nr *comperei* (Encyrtidae), *Ophelosia bifasciata* (Pteromalidae) and the hyperparasitoid *Cheiloneurus* sp. (Encyrtidae). The most commonly encountered predator was *Rhyzobius ruficollis*, but *Cryptolaemus montrouzieri* and *Diomus* sp. (all three Coccinellidae) were also present (Baker and Keller 1998).

The following parasitoids, which are present in Australia on other hosts, are recorded overseas as attacking *P. calceolariae* (Malipatil et al. 2000), however they do not appear to have been recorded from this host in Australia: *Anagyrus pseudococci, Leptomastidea abnormis, Leptomastix dactylopii, Ophelosia charlesi* and *Tetracnemoidea peregrina*.

MAJOR NATURAL ENEMIES

Coccophagus gurneyi Hymenoptera: Aphelinidae

This Australian species is a solitary internal parasitoid of second, third and fourth instar mealybugs, with a preference for the second instar. It is known from a number of *Pseudococcus* species including *P. calceolariae* and *P. longispinus*. It kills many of its very small and some of its larger hosts during oviposition and frequently deposits eggs in host species in which it cannot develop. Females predominate in a ratio of about 10:1, they lay about 125 eggs, have about two generations to each one of *P. calceolariae* and are more tolerant to cold than this host.

Both *C. gurneyi* and *T. brevicornis* are attacked by the hyperparasitoid *Chartocerus* sp. (Altmann and Green 1992).

The female is a primary parasite of the mealybug, whereas the male develops only in or on a female of its own or another species (Flanders 1936, 1937, 1964). Female-producing eggs hatch in about 4 days at 27°C, larvae develop in a minimum of 2 days, prepupae 2 days and pupae 11 days. The male-producing egg is deposited either in the developing larva of a female parasite or in an unparasitised mealybug. In the latter instance, it may hatch up to 85 days later when a mature female parasitoid develops within the mealybug. In this event, the male larva develops as a parasitoid external to the female (Cendana 1937). In California *C. gurneyi* is active during winter, although *T. brevicornis* is very scarce (Compere and Smith 1932).

Tetracnemoidea brevicornis Hymenoptera: Encyrtidae

This species is native to Australia and is a solitary internal parasitoid, principally of second instar mealybugs, although it will occasionally attack first and third instars. Most of its 100 to 200 eggs per female are laid during the first day of adult life. Oviposition is rapid and the egg is inserted into the body cavity of the host.

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Eggs develop in 6 to 7 days and larvae in about 17 days. The sex ratio is about 1:1 and two generations may be produced to each one of the host (Compere and Smith 1932; Clancy 1934; Bartlett 1978b).

Table 24. Hymenopterous parasitoids of *Pseudococcus calceolariae*

Species	References
APHELINIDAE	
Coccophagus gurneyi	Compere & Smith 1932
Coccophagus sp.	Malipatil et al. 2000
ENCYRTIDAE	
Anagyrus fusciventris	Smith et al. 1997a
Cryptanusia comperei	Timberlake 1929; Noyes & Hayat 1984
Tetracnemoidea brevicornis	Timberlake 1929
Tetracnemoidea sydneyensis	Compere & Flanders 1934
PLATYGASTERIDAE	
Allotropa sp. nr *citri*	Smith et al. 1997a; Malipatil et al. 2000
PTEROMALIDAE	
Ophelosia sp.	Smith et al. 1997a

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Pseudococcus longispinus Targioni-Tozzetti
Hemiptera: Pseudococcidae
longtailed mealybug

This species has been confused in much early Australian literature with *Pseudococcus adonidum* (D. Williams, pers. comm.). On the basis of its low density and high rate of parasitisation in eastern Australia *P. longispinus* is probably native to that region (Flanders 1940).

PRECIS

Pseudococcus longispinus was first recorded on grapevines in Western Australia in 1898. The establishment in 1902 in Western Australia of *Cryptolaemus montrouzieri* from New South Wales, and the subsequent decline of the longtailed mealybug is regarded as providing very successful control. Although *P. longispinus* was recorded in earlier days as a pest of irrigated citrus, grapes and pears in southern Australia, it is less important now and is regarded as generally of minor importance elsewhere in Australia. It is attacked by a number of native parasitoids and predators.

BIOLOGY

The adult female *Pseudococcus longispinus* is elongate oval in shape, covered with a white mealy (waxy) secretion and is capable of moving quite actively around the host plant. A fringe of wax filaments projects from the sides of the body. Two of these at the posterior end are longer than the body. Instead of laying eggs, 200 or so living, young 1st instar 'crawlers' are produced which resemble tiny adults. First and 2nd instar nymphs are readily dispersed by wind. First instar crawlers disperse over the whole tree. Some 2nd instars are found in exposed situations, but most 2nd and all 3rd instar larvae seek sheltered sites and adults reproduce in protected sites. The three immature stages of females each take a few weeks to develop. Immature males are initially similar to females, but later form cottony cocoons about 3 mm long in which they develop. They pass through five instars. Adult

males have a pair of wings, but aborted mouthparts. There are several generations per year (three in South Australia, three or four in Victoria), with highest populations in spring and autumn (Clausen 1915; Browning 1959; Furness 1976; Barrass 1993). Hot dry conditions are unfavourable for population increase (Hely 1968; Hely et al. 1982).

PEST STATUS

The mealybug attacks citrus, grapevines and many ornamental and other plants (Clausen 1915; Williams 1985). All citrus varieties are attacked, but mature trees with dense foliage suit *P. longispinus* best.

P. longispinus was reported in 1898 to be an important pest in Western Australia of grapes and, somewhat later, of citrus. In the early 1950s it was recorded as a serious pest of citrus, pears and grapes in commercial orchards in Murray River irrigation areas and is still of some concern. It is also a pest of fresh and stored pears, reducing the value of the fruit through uneven ripening and the unsightly signs of its presence (Barrass 1993). Although reasonably widespread in New South Wales, it only occasionally builds up to pest abundance. In Queensland it is not a pest and has been recorded only from the Brisbane area (Ceballo et al. 1998).

All stages suck sap from foliage, young twigs and fruit, but more important damage is caused by the production of copious amounts of honeydew on which sooty moulds develop, giving a dirty appearance to both the tree and fruit. On oranges, longtailed mealybugs commonly gather under the calyx and particularly in the navel of navel oranges. Sooty moulds are difficult to remove by washing from these areas before marketing.

Grapevines with heavy foliage are most susceptible to infestation. During spring and early summer the mealybugs are present along the veins on the backs of the leaves. They move to the grapes in mid-summer. Here the honeydew and associated sooty moulds, together with waxy residues and other debris, give the branches a very unattractive appearance and make them unpleasant to harvest (Hely et al. 1982).

In general, mealybug numbers increase under warm, humid conditions, such as in irrigated orchards with dense foliage and in glasshouses.

In Europe and North America, *P. longispinus* is known to transmit grapevine viruses (Rosciglione and Gugerli 1986; Minafra and Hadidi 1994; La Notte et al. 1997).

BIOLOGICAL CONTROL

Compere and Flanders (1934) recorded three parasitoids from *P. longispinus* from Sydney: *Anagyrus fusciventris, Tetracnemoidea sydneyensis* and *Ophelosia crawfordi.* Wilson (1960) lists seven native natural enemies of *P. longispinus* in Australia, the

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parasitoids ? *Anagyrus* sp., *Tetracnemoidea sydneyensis*, *Leptomastix* sp. (all Encyrtidae) and *Coccophagus gurneyi* (Aphelinidae), and the predators *Cryptolaemus montrouzieri*, *Callineda testudinaria* (both Coccinellidae) and *Pleisochrysa ramburi* (Chrysopidae). These are credited with keeping the mealybug under adequate control in most areas for most of the time.

When *P. longispinus* was found to be a serious pest of grapes and citrus in Western Australia, the coccinellid predator *C. montrouzieri* was introduced from New South Wales and Queensland and liberated in 1902, after which mealybug numbers were reduced to a level regarded as satisfactory control (Jenkins 1946). An unidentified coccinellid was introduced from Spain and liberated in 1903, but failed to establish (Wilson 1960).

The most abundant natural enemy of *P. longispinus* on citrus and grapes along the Murray River region of Victoria and South Australia was the parasitoid *A. fusciventris*, which was introduced to the Riverland area in the 1970s (Baker and Keller 1998). The species is attacked by the native hyperparasitoid *Ophelosia bifasciata* when present in either *P. longispinus* or *P. calceolariae* (Berry 1995). In 1972, the native *T. sydneyensis* was introduced from the Sydney area and *Tetracnemoidea peregrina* from Israel. Both were released widely until 1974, but in 1977 appeared not to have become established (Furness 1977a). However, *T. sydneyensis* was recorded in the Riverland by Altmann and Green (1992), and both species, particularly *T. sydneyensis*, were found attacking *P. longispinus*, although only in small numbers (Barrass 1993; Smith et al. 1997b; Baker and Keller 1998). An insecticide check experiment on grapevines failed to demonstrate that natural enemies significantly reduced populations of *P. longispinus* (Furness 1977b). *Tetracnemoidea brevicornis* was introduced around 1990 and, together with *A. fusciventris*, contributed between 62.2% and 68.1% of parasitisation of *P. longispinus* and *P. calceolariae* (Baker and Keller 1998).

Browning (1959) recorded that the only predator with a life cycle in tune with *P. longispinus* in South Australia was *Rhyzobius ruficollis*.

In Riverland samplings in 1971 and 1972 Furness (1976) recorded *A. fusciventris* (most abundant), *Moranila* sp. and *T. peregrina* as primary parasitoids and *Procheiloneurus oviductus* and *Thysanus* sp. as hyperparasitoids. *R. ruficollis* was the most abundant predator, followed by *Chrysopa* sp. Other predators were *Micromus tasmaniae* and *Scymnus* sp.

Three parasitoids which are present in Australia on other hosts are recorded overseas from *P. longispinus* (Malipatil et al. 2000), however they (*Leptomastidea abnormis, Leptomastix dactylopii* and *Ophelosia charlesi*) do not appear to have been recorded yet from this host in Australia.

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Pseudococcus viburni Maskell Hemiptera: Pseudococcidae tuber mealybug

Pseudococcus viburni has also been referred to as *Pseudococcus affinis, Dactylopius affinis* or *Pseudococcus obscurus* and for many years was confused with the North American *P. maritimus* (Miller et al. 1984). Most recently, *P. affinis* was stated to be a synonym of *P. viburni* (Ben-Dov and Matile-Ferrero 1995).

PRECIS

This widespread, polyphagous mealybug, of North American origin, is the most important underground mealybug in Australia. Although long known from eastern Australia, *Pseudococcus viburni* was not regarded as being of much economic importance until it appeared in the Loxton citrus-growing area of South Australia and the pome fruit area of Applethorpe, Queensland. It has attained minor pest status in South Australia, although attacked by a number of natural enemies, including *Anagyrus fusciventris*. In Queensland it is somewhat more important. In 1997, *Pseudaphycus maculipennis* from the United Kingdom was liberated in Queensland but, although it has become established, has had little effect on the tuber mealybug problem in pome fruits.

BIOLOGY

In California the tuber mealybug, *Pseudococcus viburni*, has four to five generations per year on citrus. Females produce up to 500 eggs over a period of 1 to 2 weeks. These hatch in about 8 days and mature about 42 days later (Clausen 1924; Bartlett 1978b). In Bangladesh, development at 30°C took 37 days and 93 days at 18°C (Islam et al. 1995). In 1995, a survey of commercial citrus in New South Wales, Victoria and South Australia revealed low levels of *P. viburni* in the Murray Valley, Riverina and Narromine regions. However, it formed no more than 1% to 2% of the total mealybug population, which comprised mainly *Pseudococcus calceolariae* or *P. longispinus* (Baker and Keller 1998).

Williams (1985) presumed that *P. viburni* originated in Australia, where it was collected in 1893 from potato and dahlia tubers. However, Cox (1987) considered that it was almost certainly native to North America. It is now cosmopolitan (Miller et al. 1984; Gimpel and Miller 1996).

PEST STATUS

P. viburni is regarded as the most important of the underground mealybugs in Australia. It is known for the damage it can cause to lawns and also to potato and dahlia tubers and gladioli corms in storage. It also infests above-ground parts of citrus, apples, pears, grape and passionfruit vines, beetroot, lucerne and melons. It is widely polyphagous (Williams 1985). Although of minor importance on the fruit of table grapes and citrus in South Australia, it is of greater significance in infesting the calyx of apples and pears in Queensland (J.A. Altman and F.D. Page, pers. comm. 1999). In Italy, it is known to transmit grape trichoviruses (Garau et al. 1995).

BIOLOGICAL CONTROL

P. viburni is known in eastern Australia to be attacked by native parasitoids, an aphelinid, *Coccophagus gurneyi*, and the encyrtids *Anagyrus pseudococci* and *Tetracnemoidea peregrina*. The latter was imported from Israel and liberated from 1972 to 1974 against *P. longispinus* (Bartlett 1978b). *P. viburni* is also attacked by *Ophelosia keatsi* (Malipatil et al. 2000).

In the field in Georgia (formerly USSR) and Italy and in glasshouses in France, the European encyrtid *Pseudaphycus maculipennis* gives valuable control (Panis and Brun 1971). It was introduced from the United Kingdom and liberated in Applethorpe, Queensland in 1987. It has become established, but has not had a marked effect on tuber mealybug infestation. Ants appear to interfere with its activities. In Applethorpe, *P. viburni* is attacked by the coccinellid *Cryptolaemus montrouzieri*, by two wasps and by a strepsipteran (F.D. Page, pers. comm. 1999).

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Pulvinaria polygonata Cockerell Hemiptera: Coccidae † cottony citrus scale

PRECIS

Pulvinaria polygonata probably originated in Southeast Asia. It is a common and sometimes important pest in south-eastern Queensland.

The coccinellids *Cryptolaemus montrouzieri* and *Halmus chalybeus* are abundant native predators. *Coccophagus ceroplastae* and *C. lycimnia,* introduced against other Coccidae, are occasional parasitoids of *P. polygonata.*

BIOLOGY

Pulvinaria polygonata occurs in throughout South Asia, Sri Lanka, Philippines, Cook Islands (Williams and Watson 1990), and eastern Australia. The only known hosts are species of *Citrus* (Smith et al. 1997a). In Australia it is limited in distribution, from Rockhampton, Queensland to central, coastal New South Wales.

The immature stages of *P. polygonata* are similar in appearance to species of *Saissetia* and *Coccus,* being translucent green and later yellow-brown with brown spots. However, unlike both these genera, a white cottony ovisac develops beneath the posterior body as the adult female *P. polygonata* matures. Female scales are elongate, 3 to 5 mm in length and oval, with a somewhat glossy and roughened appearance. Each female deposits 200 to 300 bright orange eggs in the ovisac which increases in size during oviposition (Smith et al. 1997a). There are about four generations each year. Females commence oviposition in late spring and, after hatching, crawlers disperse and settle on leaves and twigs where they remain, completing two instars before the adult stage.

PEST STATUS

P. polygonata is occasionally an important pest of citrus, particularly Meyer lemon, in subtropical eastern Australia. Heavy infestations on leaves, petioles and twigs in

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spring, accompanied by the growth of sooty moulds on honeydew, reduce photosynthesis and lead to leaf drop.

In the Cook Islands, the scale has been recorded on *Plumeria rubra* (Williams and Watson 1990).

BIOLOGICAL CONTROL

Two native coccinellids, *Cryptolaemus montrouzieri* and *Halmus chalybeus,* usually control *P. polygonata*, but infestations occasionally build up before the predators have developed sufficient numbers to control the scale (Smith et al. 1997a). Eggs of *H. chalybeus* are deposited in the ovisac of the host, among the eggs of the scale (Smith et al. 1997a).

The parasitoids *Coccophagus ceroplastae* and *C. lycimnia,* introduced for biological control of other soft scales, are occasional parasitoids of *P. polygonata.* In the Cook Islands, parasitoids of *P. polygonata* include *Microterys nietneri* (Williams and Watson 1990), but this species has not been associated with this scale in Australia.

A fungus, *Verticillium lecanii*, is an important cause of mortality of *P. polygonata* during prolonged wet weather (Smith et al. 1997a).

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Rhopalosiphum maidis (Fitch) Hemiptera: Aphididae † corn aphid

PRECIS

Rhopalosiphum maidis develops on corn, sorghum and a range of grasses and would be a minor pest except for its role in transmitting viral diseases. It is attacked by a range of native predators and by the exotic parasitoid *Aphelinus varipes* which arrived unaided. *A. varipes* is known to attack the Russian wheat aphid *Diuraphis noxia* (not yet present in Australia) and other cereal aphids in Europe. However, since the Australian strain of *A. varipes* may not be preadapted to the Russian wheat aphid, a strain of *A. varipes* from *D. noxia* in Ukraine was introduced in 1990. There is no evidence of the establishment of this strain.

BIOLOGY

Rhopalosiphum maidis is green in colour, occurs on corn, barley, sorghum and a number of grasses throughout tropical areas of the world and has a large number of biotypes worldwide. It has no sexual cycle in Australia. It is probably Asiatic in origin.

PEST STATUS

R. maidis is possibly the most important pest of cereals in tropical and warm-temperate climates (Kröber and Carl 1991). On corn, the aphids live initially in the furled leaves, but move to, and develop rapidly on, male and female infloresences. Pollination is interfered with, leading to reduction in yield, and leaf sheaths become yellow and dry out. On sorghum and sugarcane, the aphids feed mainly in the furled leaves. Direct damage is generally unimportant, but *R. maidis* is a vector of virus diseases, such as cucumber mosaic, which is a serious disease of lupins (Thackray et al. 1998) and of sugarcane mosaic virus (Noone et al. 1994).

BIOLOGICAL CONTROL

R. maidis colonies are preyed upon by many of the native species — coccinellids, syrphids, chrysopids and hemerobiids — listed for other pest aphids in Australia (Table 4 page 109) (Carver 1992, 2000) and also by the fungus *Verticillium lecanii*.

Of relevance to this compilation is that *R. maidis* could be an alternative host on which to establish a strain of the parasitoid *Aphelinus varipes*, capable of attacking the Russian wheat aphid, *Diuraphis noxia*, should it appear in Australia. *A. varipes* (of unknown origin) is already present in Australia attacking *R. maidis* and, to a lesser extent, the three other cereal aphids in Australia, namely *Rhopalosiphum padi, Metopolophium dirhodum* and *Sitobion* nr *fragariae*. Regrettably, the strain of *A. varipes* from *D. noxia*, introduced from Ukraine in 1990, does not appear to have become established, at least not on the three cereal aphids listed above (Hughes et al. 1994).

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Rhopalosiphum padi (Linnæus) Hemiptera: Aphididae † wheat aphid

PRECIS

Rhopalosiphum padi, of eastern European origin, is a major pest of wheat and other cereals in Australia and is regarded as a possible host on which to establish parasitoids that might immediately attack the Russian wheat aphid, *Diuraphis noxia*, likely to be devastating should it become established in Australia.

Three unintentionally introduced exotic species of parasitoids of *R. padi*— *Aphidius colemani, A. similis* and *Diaeretiella rapae*— occur in New South Wales. A strain of *Aphelinus varipes*, from *D. noxia* in Ukraine, was liberated in 1990 in south-eastern Australia, but no sign of its establishment has been reported.

BIOLOGY

Rhopalosiphum padi originated in the Palaearctic region, but now occurs virtually worldwide.

R. padi attacks all cereals, but prefers barley. It also colonises a range of grasses. It feeds mainly on leaves, and to a lesser extent on the ear. It overwinters as viviparous apterae or alatae on grasses.

PEST STATUS

R. padi is an important pest of cereals and damaging populations develop occasionally. Its main importance is due to its transmission of viruses such as barley yellow dwarf and cucumber mosaic, which can result in serious losses in grains and lupins.

BIOLOGICAL CONTROL

Before any intentional introduction of parasitoids against *R. padi*, two species of presumed Indian origin, *Aphidius colemani* and *A. similis*, were found attacking

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the wheat aphid in eastern Australia, with *A. similis* the more important species (Milne 1995).

Lysiphlebus testaceipes parasitising *Toxoptera aurantii* and *Aphis nerii* in California was introduced and liberated in 1982. It is now recorded from *R. padi* and *Rhopalosiphum maidis* in the field (Carver and Franzmann 2001).

Surveys were carried out in eastern Europe for parasitoids that might establish on *R. padi* in Australia and be ready to attack the destructive Russian wheat aphid *Diuraphis noxia*, should it appear. Other possible 'reservoir' aphids present in cereals in Australia are the corn aphid, *R. maidis*, the rose-grain aphid, *Metopolophium dirhodum*, and the grain aphid, *Sitobion* nr *fragariae* (Hughes et al. 1994).

In eastern Europe, dense aphid infestations on spring barley and wheat consisted of *D. noxia, R. padi, Schizaphis graminum* and *Sitobion avenae*. Of these, only *R. padi* occurs in Australia. Host-specific natural enemies of *D. noxia* have not been recorded and most species reported from its native range are polyphagous. Table 25 page 242 summarises information on parasitoids of *D. noxia* in south-eastern Europe (Aeschlimann and Hughes 1992). Of these, only *Aphidius matricariae* and *A. uzbekistanicus* have not yet been recorded in Australia. However, these two species are morphologically very similar to *Aphidius similis* and *A. rhopalosiphi*, respectively (M. Carver, pers. comm.).

Few natural enemies of *D. noxia* are able to penetrate the tight leaf rolls on cereal seedlings caused by the aphids and within which they are protected. However, this behaviour has been recorded for the oligophagous *Aphelinus varipes*. Furthermore, aphelinids are reported to be the most important natural enemies of *D. noxia* in areas close to its probable centre of origin (Berest 1980). Although a strain of *A. varipes* was already known to parasitise *R. maidis* on corn in Australia, it did not appear in Milne's (1995) survey of *R. padi* on barley and wheat. A strain of *A. varipes* parasitising *D. noxia* on barley in Ukraine was introduced and liberated in eastern Australia in 1990. Under laboratory conditions, it was shown to be able to parasitise all four species of cereal aphids present in Australia and listed above. However, no evidence of its establishment in the field has been found (Hughes et al. 1994). Surveys for parasitoids of *R. padi* revealed very large numbers of *A. colemani*, as well as *A. similis* and *Diaeretiella rapae*, together with the hyperparasitoid *Phaenoglyphis villosa* (Hughes et al. 1994). *D. rapae* is regarded primarily as a parasitoid of the cabbage aphid, *Brevicoryne brassicae* (see target pest no. 11 page 137), but may attack other species on crops adjacent to infested brassicas (Carver 1992).

Table 25. Hymenopterous parasitoids of *Diuraphis noxia* in Ukraine, southern Russia and Georgia (after Aeschlimann and Hughes 1992)

Species	% Mummies
APHELINIDAE	
Aphelinus ? asychis *Aphelinus varipes*	0.5
BRACONIDAE	
Aphidius ervi *Aphidius matricariae* *Aphidius rhopalosiphi* *Aphidius uzbekistanicus* total *Aphidius* spp.	44.8
Diaeretiella rapae	2.0
Ephedrus plagiator	0.2
Praon volucre	52.5

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Saccharicoccus sacchari (Cockerell)
Hemiptera: Pseudococcidae
pink sugarcane mealybug

PRECIS

Saccharicoccus sacchari is believed to be Australasian in origin, but has been reported from every sugarcane-growing nation of the world.

It has generally been considered only a minor pest of sugarcane in Australia. However, damaging outbreaks are occasionally reported elsewhere and it was considered threatening when it appeared in Hawaii in 1896. The striking reduction in abundance that followed the introduction to Hawaii in 1930 of the Philippine encyrtid *Anagyrus saccharicola* stimulated Australian interest and the parasitoid was released in Queensland in 1953, but was believed not to have become established. However, in 1987, the parasitoid was reported to be widespread in the main sugarcane-growing areas of Queensland and New South Wales. It, together with several native predators, and particularly an entomopathogenic fungus, *Aspergillus parasiticus*—which is the most important of all—suppresses populations to such a low level that control of the mealybug is not required.

BIOLOGY

Saccharicoccus sacchari is believed to be Australasian in origin, but is now coextensive with its principal host, sugarcane (Carver et al. 1987).

The 5 mm long, adult female *S. sacchari* is oval, pink, soft, wrinkled and covered with a dusting of powdery wax. In Australia, the usual number of instars is four in the female and five in the male. Males cease feeding after the second instar and pass the third (pre-pupal) and fourth (pupal) stages within a loose cover of fine wax filaments. Females do not appear to be parthenogenetic and commence laying up to 1100 eggs 7 to 12 days after becoming adult and continue for some 3 weeks. Egg to adult development takes about 4 weeks. The eggs hatch shortly after deposition. Females usually cease feeding about the time that egg-

laying commences. Adult males are small (1.25 mm long) and may be winged or wingless. Wingless males lack not only all traces of wings, but also the large dorsal and ventral eyes possessed by winged males (Beardsley 1962; Rae 1993; Agnew 1997).

Cultural practices undoubtedly influence the occurrence of pink sugarcane mealybugs in cane fields. The harvesting of sugarcane customarily follows burning, which destroys many mealybugs. Studies revealed that young nymphs (crawlers) deep within the leaf sheaths near the top of the cane stalks were the principal survivors, their numbers depending upon the fire intensity. Even in a hot burn, not all of the cane around the edges of the field is badly burnt, so that some mealybugs survive. During subsequent mechanical harvesting operations, the blower disperses tops and other extraneous matter over the harvested area where it is left to dry for several days, during which time surviving mealybugs move underground, sometimes assisted by ants. First and 2nd instar nymphs are then found underground, feeding on plant tissue, whereas they were not detected below ground before harvesting. Colonies develop around the base of new shoots and sometimes on the roots. Most of these mealybugs return above ground where they migrate down inside the leaf sheaths to the nearest node (Inkerman et al. 1986).

PEST STATUS

S. sacchari was the only species of mealybug found in a survey of commercial crops of sugarcane in Australia from 1982 to 1985, although the pseudococcids *Dysmicoccus boninsis, Dysmicoccus brevipes* and *Ripersia* sp. have been previously reported (Inkerman et al. 1986).

S. sacchari is a minor pest of cultivated sugarcane. In Australia, its only other host is nutgrass, *Cyperus rotundus*, in suburban gardens, although it is not found on this weed in cane fields. Its economic importance is as a sap-feeder and a copious producer of honeydew, which attracts ants and serves as a substrate for sooty moulds. It carries acetobacter-like bacteria (Franke et al. 1999) affecting the quality of the sugar (Ashbolt and Inkerman 1990). The overall losses of sugar have not been quantified, although significant amounts of honeydew are produced by the mealybugs at certain times of the year. The pink sugarcane mealybug infests the stalks of sugarcane, developing deep within the leaf sheath, and it is also found at times on the roots (Inkerman et al. 1986).

BIOLOGICAL CONTROL

The striking success claimed for the introduction of *Anagyrus saccharicola* from the Philippines to Hawaii in 1930 against the pink sugarcane mealybug stimulated interest in this parasitoid for introduction into Australia. It was, therefore, imported twice from Hawaii in 1935. The first introduction 'failed

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because only females were present' (Wilson 1960): presumably because the females were unfertilised. The second introduction in 1935 was also not successful.

A. saccharicola was again introduced from Hawaii in 1953 and liberated near Brisbane. It was believed not to have become established, which was attributed to the fact that most of the larger mealybugs were eaten by a plague of field mice shortly after the parasitoids were liberated (Wilson 1960). However, surveys in the mid-1980s showed that it was both widespread and abundant in the principal cane-growing areas of Queensland and New South Wales. Whether or not these are the descendants of the 1953 liberations is not known (Inkerman et al. 1986; Carver et al. 1987). *A. saccharicola* parasitises only late instar nymphs and adults, with up to 18 wasps emerging from a single mealybug mummy (De Barro 1990).

Other natural enemies were common (Table 26 page 246). Included in the list is *Domomyza (= Cacoxenus) perspicax* (Drosophilidae), whose larvae are predators of the pink sugarcane mealybug (Carver et al. 1987). Moreover, observations showed that they actually feed on contaminated honeydew, and produce a microbial broth that drowns the mealybugs and renders the habitat unfit for them. *D. perspicax* thus serves both as a habitat destroyer and as a predator. Puparia of *D. perspicax* were parasitised by *Chartocerus* sp. (Signiphoridae), peaking at 40.3% parasitisation and producing an average of 15 parasitoids per host (De Barro 1990). *Pachycrepoideus vindemmiae* has also been reported from a drosophilid fly associated with the sugarcane mealybug (Boucek 1988).

Five fungal pathogens of *S. sacchari* have been recorded (Table 26). Of these, *Aspergillus parasiticus* is by far the most significant and is more important than all other natural enemies in Australia (Drummond et al. 1991). The wet 1987 season favoured this pathogen so that it accounted for 59.3% to 93.9% of the natural enemy activity on infested nodes whereas, during the corresponding dry period in 1988, it fell to 0.5% to 31.1% (De Barro 1990). It was found to produce aflatoxins, although these were not essential to the entomopathogenic activity of the fungus against *S. sacchari* (Inkerman et al. 1986; Drummond and Pinnock 1990). High temperatures (28°C) favoured its activity and it was absent in winter months, during which infestation of sugarcane nodes with *S. sacchari* increased (Drummond et al. 1991).

Seven species of ants, *Camponotus* sp., *Iridomyrmex* sp., *Paratrechina* probably *bourbonica, P. obscura, P.* probably *vaga, Pheidole megacephala* and *Tetramorium bicarinatum*, are involved in attending the pink sugarcane mealybug (Carver et al. 1987). Some of these have been observed carrying nymphs underground following cane harvesting and, on occasion, *P. obscura* was observed to remove mealybug mummies and *Chartocerus* puparia from sugarcane nodes containing live mealybugs (De Barro 1990).

The fact that control of the pink sugarcane mealybug is not currently required is ascribed to the presence of three major enemies: the pathogenic fungus *A. parasiticus*, the parasitoid *A. saccharicola* and the predator and habitat destroyer *D. perspicax* (Inkerman et al. 1986; De Barro 1990; Agnew 1997).

Table 26. Natural enemies of *Saccharicoccus sacchari*

Species	Predator stage	References
HEMIPTERA		
ANTHOCORIDAE		
Oplobates woodwardi		Carver et al. 1987
DERMAPTERA		
FORFICULIDAE		
Elaunon bipartitus	L, A	De Barro 1990
LABIDURIDAE		
Nala lividipes	A	De Barro 1990
NEUROPTERA		
CHRYSOPIDAE		
Mallada innotata	L	De Barro 1990
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzieri	L, A	Carver et al. 1987
Halmus ovalis	L, A	De Barro 1990
LEPIDOPTERA		
PYRALIDAE		
Dipha aphidovora	L	De Barro 1990
DIPTERA		
CECIDOMYIIDAE		
Coccodiplosis sp.	L	Carver et al. 1987
DROSOPHILIDAE		
Domomyza perspicax	L	Carver et al. 1987; De Barro 1990
FUNGI		
Aspergillus flavus		Drummond & Pinnock 1990; Drummond et al. 1991
Aspergillus parasiticus		Inkerman et al. 1986; De Barro 1990; Drummond et al. 1991
Cordyceps sp.		De Barro 1990
Metarhizium anisopliae		De Barro 1990; Drummond et al. 1991
Penicillium sp.		De Barro 1990; Drummond et al. 1991

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Saissetia coffeae (Walker) Hemiptera: Coccidae † hemispherical scale

PRECIS

Saissetia coffeae is originally from Africa, but it is now distributed worldwide. The scale is occasionally an important pest of avocado, citrus, coffee and ornamentals in subtropical and tropical eastern Australia.

Abundant native predators include the coccinellid *Cryptolaemus montrouzieri* and larvae of the noctuid *Mataeomera dubia*. The parasitoids *Encyrtus infelix* and *Metaphycus* sp., and the egg predator *Scutellista caerulea,* introduced against *Saissetia oleae*, are important natural enemies of *S. coffeae*.

BIOLOGY

Saissetia coffeae originated from Africa but it now occurs worldwide. In eastern Australia, *S. coffeae* occurs in coastal, humid regions from Mareeba, northern Queensland to Grafton, northern New South Wales. *S. coffeae* undergoes two to four generations per year in New South Wales during the warmer months and up to six generations in Queensland. Reproduction may occur at any time of time of the year, especially when death of twigs induces oviposition in attached scales.

The life history of *S. coffeae* was summarised in Smith et al. (1997a). The immature stages of *S. coffeae* are very similar to those of *Saissetia oleae,* the larvae of both species having a raised pattern of ridges, resembling an 'H'. However, adults of *S. coffeae* are much more convex than similar species. The scale covering of adult females is smooth, hard and hemispherical, edged with a narrow flange where it adheres to the plant substrate. Males of *S. coffeae* have not been reported from Australia. When mature, females are medium to dark brown, with a somewhat glossy surface. Each female deposits up to 1200 eggs in a concavity beneath its ventral surface. After hatching, crawlers migrate to settle on leaves, petioles and green stems where they usually remain, developing three larval instars (two in Smith et al. 1997a) until reaching the adult stage.

PEST STATUS

S. coffeae is usually a minor pest in Australia but outbreaks sometimes follow insecticide applications targetting other insect pests. *S. coffeae* is occasionally an important pest of avocado, citrus, coffee and ornamentals, particularly ferns and palms. Navel oranges are particularly susceptible to attack (Smith et al. 1997a). Loss of plant vigour and death of twigs may follow heavy infestations. The excretion of honeydew by scales supports growth of sooty moulds, reduces photosynthesis, and attracts ants which ward off natural enemies.

BIOLOGICAL CONTROL

A number of native natural enemies attack the early stages of *S. coffeae*, usually maintaining its levels of abundance below economic thresholds (Table 27). Coccinellids, in particular, *Cryptolaemus montrouzieri*, prey on crawlers and the young larvae. Larva of the noctuid *Mataeomera dubia* prey on all stages of *S. coffeae*, building a protective covering from the scales.

No agents have been specifically introduced against *S. coffeae,* although it has been recognised as an important pest (Wilson 1960). However, the parasitoids *Encyrtus infelix* and *Metaphycus* sp. and the egg predator *Scutellista caerulea*, introduced for biological control of *S. oleae,* have contributed to control of *S. coffeae,* regulating abundance of the scale unless disrupted by ants or insecticide applications. The fungus *Verticillium lecanii* is reported to kill many scales during prolonged wet weather (Smith et al. 1997a).

Table 27. Indigenous natural enemies of *Saissetia coffeae*

Species	Stage of host	References
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzeri	L 1, 2	Smith et al. 1997a
LEPIDOPTERA		
Mataeomera dubia	L 1, 2, 3, A	Smith et al. 1997a
HYMENOPTERA		
APHELINIDAE		
Euryischomyia flavthorax		Malipatil et al. 2000
PTEROMALIDAE		
Moranila californica	E	Malipatil et al. 2000

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Saissetia oleae (Olivier) Hemiptera: Coccidae black scale

PRECIS

Saissetia oleae, originally from Africa, spread to most countries of the world including Australia in the late 1800s. *S. oleae* is now a minor pest but, before biological control in the early 1900s, it was a major pest of citrus, olives and ornamental plants.

Between 1902 and 1947, 22 species of parasitoid and 2 predators were introduced into Australia against *Saissetia oleae*, reducing its importance to that of to a minor pest. Of the introduced parasitoids, 13 have become established. Control of *S. oleae* has been attributed mainly to the parasitoid *Metaphycus anneckei* and the egg predator *Scutellista caerulea.* Their effects are complemented by a native pteromalid egg predator, *Moranila californica*, several species of coccinellids including *Rhyzobius ventralis*, and lacewings, *Mallada* spp.

BIOLOGY

The mature, domed-shaped females of *Saissetia oleae* reproduce parthenogenetically, but smaller, elongate males also occasionally occur. The larvae are green to yellow with a distinctive, raised pattern of ridges, resembling an 'H'. Young adult females are mottled grey and become glossy black or very dark brown as they mature. The raised ridges on *S. oleae* distinguish this species from the immature stages of similar *Coccus* species.

There are usually two generations in the southern States and up to four in the subtropical regions of Australia. Each female produces from 1000 to 4000 eggs. Eggs hatch from December to January and, in the autumn months in southern States, where the life cycle takes from 4 to 8 months (Smith et al. 1997a). In Queensland, eggs hatch throughout the warmer months and the life cycle may be completed within 3 months. There are three larval instars, occupying about 60 days (Bartlett 1978a). When crawlers hatch they are dispersed by wind and settle

on leaves of the host plant until the early 3rd instar when they migrate to the young twigs or fruit and there remain until maturity.

PEST STATUS

In the late 1880s, *S. oleae* was one of the most destructive pests of citrus and olives in Western Australia (Bartlett 1978a). After biological control, its importance has been reduced to that of a minor pest in Western Australia and in south-eastern Queensland, and to an occasional pest in central New South Wales, Victoria, and southern South Australia. *S. oleae* is polyphagous and causes damage mainly to citrus, olive, custard apple, ornamentals, and many species of native plants including *Syzygium* species and *Duboisia* species (D. Smith, pers. comm.). Infestations of *S. oleae* produce honeydew which accumulates on the leaves and fruit, permitting growth of sooty moulds, which reduces photosynthesis and disfigures fruit, leading to downgrading. Ants attracted by the honeydew interfere with natural enemies of the scale, allowing heavy infestations to develop (Snowball and Milne 1973).

BIOLOGICAL CONTROL

The significance of *S. oleae* as a pest declined in Australia following the importation of natural enemies from overseas in the early 1900s (Bartlett 1978a). Native natural enemies, including some introduced from other States, contributed to the impact on the pest and complemented the effects of the introduced agents. Important predators of immature stages are the coccinellids *Cryptolaemus montrouzieri, Diomus* spp., *Halmus chalybeus, Parapriasus australasiae, Rhyzobius ventralis* and *R.* nr *lophanthae*, and Chrysopidae, especially *Mallada* spp. and *Plesiochrysa ramburi* (Table 28 page 252).

Several species of ants that feed on the honeydew produced by *S. oleae* stop predators from attacking the scales. For example, when the ant *Iridomyrmex rufoniger* was prevented from attending *S. oleae,* the scale decreased in abundance, as a result of an increase in predation by the coccinellid *Rhyzobius* sp. and larvae of Chrysopidae (Snowball and Milne 1973; Milne 1974). The stout larvae of the noctuid moth *Mataeomera dubia* attack all stages of *S. oleae*, moving from one scale to another beneath an oval shelter constructed from the hard scale coverings of their prey.

A fungal pathogen, *Verticillum lecanii*, destroys high densities of *S. oleae* in late summer and autumn when conditions are humid (Smith et al. 1997a).

MAJOR PARASITOID SPECIES

Scutellista caerulea Hymenoptera: Pteromalidae

Larvae of *S. caerulea* are a bi-parental, gregarious predators of the eggs of several species of Coccidae, including *S. oleae*. Adults are large, stout, beetle-like black wasps with bluish reflections. Female wasps oviposit among eggs of the scale or, occasionally, between the ventral surface of the scale and the plant substrate, before it has become gravid. The larvae of *S. caerulea* hatch in 4 to 5 days and then prey on the eggs of the scale. About 200 eggs of *S. oleae* are required for a larvae to complete development which takes from 15 to 20 days, or longer if eggs of the scale are not already present. Pupation takes place beneath the parent scale among the egg remnants. After 14 to 21 days, the adult emerges through a large hole cut through the dorsal surface of the scale. The biotype of *S. caerulea*, introduced from the USA in 1903 to attack *S. oleae*, is of African origin. It is an important natural enemy of *S. oleae* and several other soft scales including most *Ceroplastes* species, but its host range does not include *C. destructor*, which is attacked by a different biotype of *S. caerulea* (see target pest no. 14, *Ceroplastes destructor* page 144).

Moranila californica Hymenoptera: Pteromalidae

The biology of the native *M. californica* is somewhat similar to that of *S. caerulea,* since the larvae of both are predatory on the eggs of soft scales including *Saissetia oleae. M. californica* is frequently attacked by the hyperparasitoid *Coccidoctonus dubius*, which develops on mature larvae and, after emergence, leaves behind a brown, cocoon-like remnant of the larval skin of *M. californica* in the parasitised scale.

Metaphycus anneckei Hymenoptera: Encyrtidae

M. anneckei is one of the most important parasitoids of *S. oleae*. It is a gregarious, bi-parental, internal parasitoid of 2nd instar nymphs and immature adults of *S. oleae*. It has also been recorded attacking other Coccidae including *Coccus hesperidum* and *Saissetia coffeae* (Malipatil et al. 2000).

The identity of *M. anneckei* has been subject to misidentification. It was first introduced into Australia in 1902 as *M. lounsburyi* from South Africa, but has recently been found to be a different species and the correct identity of *M. lounsburyi* has only recently been established (Guerrieri and Noyes 2000; Malipatil et al. 2000). Since Timberlake (1916), all authors when referring to *M. lounsburyi* (e.g. Wilson 1960) were actually referring to *M. anneckei*.

Metaphycus lounsburyi Hymenoptera: Encyrtidae

M. lounsburyi has also been incorrectly identified in the past. *M. lounsburyi* was not one of the parasitoids introduced into Australia, although referred to as such by Wilson (1960). *M. lounsburyi* was first introduced in 1998 as *M. bartletti*, a name shown recently to be a synonym of *M. lounsburyi* (Guerrieri and Noyes

2000). The valid name for the parasitoid referred to by Smith et al. (1997a) as *M. bartletti* is therefore *M. lounsburyi.* The effectiveness of *M. lounsburyi* as a biological control agent for *S. oleae* has yet to be determined (Malipatil et al. 2000).

COMMENTS

The most abundant natural enemies of *S. oleae* are *Metaphycus*, *S. caerulea, M. californica,* and several native species of Coccinellidae and Chrysopidae. The parasitoids *Encyrtus infelix, Diversinervis elegans, Metaphycus inviscus* and *Microterys nietneri* are also commonly associated with of *S. oleae*. It seems likely that *M. nietneri* is the species referred to as *Microterys* sp. by Hooper (1902) and Wilson (1960).

Metaphycus helvolus was introduced to control *S. oleae*, but it is an uncommon parasitoid of this scale. However, it is commonly reared as an internal, solitary parasitoid of other soft scales. The stages it attacks are limited to the nymphs and occasionally the immature adults.

Several native predators of *S. oleae* are important, particularly when infestation levels are high. For example, larvae of the moth *M. dubia* require high densities of the scale infestations to complete development. They appear unaffected by the presence of ants, whereas many parasitoids are susceptible to ants (D.P.A. Sands, unpublished).

Table 28. Indigenous natural enemies of *Saissetia oleae*

Species	Stage of host	References
NEUROPTERA		
CHRYSOPIDAE		
Mallada sp.	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
Micromus tasmaniae		Smith et al. 1997a
Plesiochrysa ramburi	L 1, 2	Smith et al. 1997a
COLEOPTERA		
COCCINELLIDAE		
Cryptolaemus montrouzeri	L 1	Smith et al. 1997a.
Diomus sp.	L	Smith et al. 1997a
Halmus chalybeus	L 1, 2	Wilson 1960
Harmonia conformis	L 1, 2	D.P.A. Sands & G.J. Snowball unpubl.
Orcus sp.	L 1, 2	Wilson 1960
Menochilus sexmaculatus		Wilson 1960
Parapriasus australasiae	L 1, 2	Wilson 1960
Rhyzobius ventralis	L 1, 2	Wilson 1960

[a]hyperparasitoid

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Table 28. (cont'd) Indigenous natural enemies of *Saissetia oleae*

Species	Stage of host	References
Rhyzobius sp. nr *lophanthae*	L 1, 2	Smith et al. 1997a
LEPIDOPTERA		
BATRACHEDRIDAE		
Batrachedra arenosella	L 1, 2, A	Wilson 1960
OECOPHORIDAE		
Stathmopoda melanochra	E, L 1	D.P.A. Sands & G.J. Snowball unpubl.
NOCTUIDAE		
Mataeomera dubia	L 1, 2, A	Wilson 1960
Mataeomera cocciphaga	L 1, 2, A	Wilson 1960
HYMENOPTERA		
APHELINIDAE		
Coccophagus scutellaris	L 2	Wilson 1960
Myiocnema comperei [a]	L 2, A	Wilson 1960
ENCYRTIDAE		
Cheiloneurus 2 spp.[a]		Malipatil et al. 2000
Coccidoctonus dubius [a]	L 3, A	Wilson 1960; Smith 1986
Metaphycus alberti	L 2, A	D.P.A. Sands & G.J. Snowball unpubl.
PTEROMALIDAE		
Moranila californica	E	Wilson 1960
Moranila comperei[a]	L 2, 3	Wilson 1960

[a]hyperparasitoid

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Therioaphis trifolii Monell forma clover Hemiptera: Aphididae † spotted clover aphid

PRECIS

A new form of the western Palaearctic *Therioaphis trifolii* appeared on clover in 1989 in Western Australia. It is distinct from forma maculata, the spotted alfalfa aphid (SAA), which feeds almost exclusively on lucerne (see target pest no. 52 page 256, *Therioaphis trifolii* forma maculata).

The braconid parasitoid *Trioxys complanatus*, which is mainly responsible for the control of the spotted alfalfa aphid, seldom attacks the clover aphid, which remains an important pest.

BIOLOGY

Spotted clover aphids which feed on clovers, lucerne and annual medics, are yellow-brown, 1.5 mm long when fully grown, and usually feed on the underside of clover leaves. They are very similar morphogically to spotted alfalfa aphids, but are genetically different (Sunnucks et al. 1997). In addition, the spotted clover aphid has a wider host-plant range than the spotted alfalfa aphid (Milne 1998).

The spotted clover aphid (forma clover) and the spotted alfalfa aphid (forma maculata) are only morphologically distinguishable from each other as populations, but both are distinguishable from the yellow clover aphid, another form of *T. trifolii* which occurs in eastern North America, but not in Australia, and is largely restricted to clovers.

Spotted clover aphid can survive and develop over a wide range of temperatures, from 9°C to 35°C. At 9°C, the life cycle takes about 43 days, whereas at higher temperatures it may be as short as 6 days. At about 19°C, aphids take about 8 days from birth to adult and can produce more than 100 offspring (W.M. Milne, pers. comm. 1998). In drier areas, where clover is not a component of summer pastures, spotted clover aphids may survive on susceptible varieties of lucerne or other medics.

TARGET PEST NO. 51

The spotted clover aphid was first discovered in 1989 in Albany, Western Australia and, by 1990, had appeared in the Murrumbidgee Irrigation Area of New South Wales. It is probable that the males of the spotted alfalfa aphid recorded in New South Wales near Sydney in November 1986 and the males and females recorded in 1987 (Milne and Wellings 1991) were actually the spotted clover aphid (M. Carver, pers. comm.).

PEST STATUS

The spotted clover aphid poses a threat to irrigated clover pastures in New South Wales and Victoria and dryland pastures in Western Australia. It attacks many cultivars of clover and has caused yield losses of up to 90% in some pastures in autumn. This is particularly so if there are early autumn rains in dryland pasture areas or an early start to the irrigation season.

Large aphid populations produce yellowing of clover leaves, which become very sticky due to honeydew excreted by the aphids. Populations in New South Wales of 800 aphids per m^2 have caused yield losses and reduction in percentage of clover in the pasture of 42%. Heavy infestations cause stunting and even death of plants unless suitable insecticides are applied.

BIOLOGICAL CONTROL

Although the spotted clover aphid is attacked by the same range of predators as the other aphids attacking lucerne and clover (Table 4 page 109), only two parasitoid species have been recorded from it. *Aphelinus asychis*, of French origin, which was liberated from 1978 to 1979 and established against the spotted alfalfa aphid, attacks the clover aphid and there are very occasional attacks by *Trioxys complanatus*. The latter is a particularly striking situation in view of the effective control of spotted alfalfa aphid on lucerne by this braconid. It is yet to be established whether *T. complanatus* is simply not adapted to searching in clover and/or whether it is reluctant to attack the spotted clover aphid in the field, although it will do so readily in the laboratory (W.M. Milne, pers. comm. 1997).

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Therioaphis trifolii Monell forma maculata
Hemiptera: Aphididae
spotted alfalfa aphid

PRECIS

Therioaphis trifolii forma maculata was found in Queensland in April 1977 and soon afterwards it started devastating stands of lucerne in eastern and southern Australia. A very rapid response by agricultural authorities led, later that year, to the introduction of the exotic parasitoid *Trioxys complanatus* from USA (and from Iran in 1978) and its liberation in all States. It established rapidly and within 6 years the spotted alfalfa aphid (SAA) ceased to be an economic problem. The planting of varieties of lucerne resistant to the aphid contributed to the reduction of the pest.

The parasitoid *Praon exsoletum* was introduced from Cyprus in 1977, from Iran in 1978 and from Pakistan in 1979. It was liberated in all States. *Aphelinus asychis* was introduced from France and liberated in 1978. Both of these parasitoids became established, but have made only small contributions to the overall very high rate of parasitisation of *T. trifolii* forma maculata.

BIOLOGY

The spotted alfalfa aphid (forma maculata) is one of two forms of *Therioaphis trifolii* occurring in Australia. The other is the spotted clover aphid (see that entry page 254), first recognised in Western Australia in 1989 due to its very heavy attack on subclover, which is not a host of spotted alfalfa aphid.

T. trifolii forma maculata is of Palaearctic origin. It appeared in western USA in 1954 and in Australia (Queensland) in March 1977. It rapidly dispersed very widely throughout eastern (New South Wales, April 1977) and southern Australia and not long afterwards in Western Australia.

The adult is about 2 mm long, brownish-yellow and has transverse rows of dark spots on its abdomen. Both apterous and alate adults of spotted alfalfa aphid occur throughout the year, although all stages are uncommon in colder months.

Each female is capable of producing about 100 young parthenogenetically. Nymphal development (four instars) may be completed in less than 1 week at optimum temperatures (around 21°C) and adults may live for 3 weeks. Small numbers of sexual forms have been recorded in winter and spring in New South Wales, although overwintering eggs were not found (Milne and Wellings 1991). It is possible that these sexuales may actually have been spotted clover aphid (M. Carver, pers. comm.).

PEST STATUS

T. trifolii forma maculata attacks a limited range of legume pastures, particularly *Medicago* spp., including lucerne. The lucerne variety Hunter River is particularly susceptible to attack.

The aphid feeds mainly on the underside of both young and mature lucerne leaves and can build up huge populations. Young leaves show yellow veining and older leaves turn white and papery before dropping. The stems soften and die back to the root crown. Although the crown will shoot again, repeated infestation and die-back depletes root reserves, resulting eventually in the death of the plant or, if not, effects that carry over for at least two subsequent crops (Kain et al. 1977). Large amounts of honeydew are produced which foul harvesting machinery and lead to the growth of sooty moulds which spoil the crop for sale as lucerne hay (Hughes et al. 1987). The spotted alfalfa aphid is a vector of alfalfa mosaic virus (Garran and Gibbs 1982).

Within 2 months of its arrival in the Hunter River Valley in New South Wales, it was estimated that 95% of the lucerne there had been defoliated and, not long after, it was devastating lucerne stands throughout eastern Australia. It was soon joined by another exotic, the bluegreen aphid, *Acyrthosiphon kondoi.* Together they attacked lucerne and annual medics and, in these first 2 years, cost the grazing and hay-growing industries about $200 million (Lehane 1982).

BIOLOGICAL CONTROL

Before 1977, lucerne in Australia was virtually free of pest aphids. As soon as they arrived in eastern Australia, *T. trifolii* forma maculata and *A. kondoi* were attacked by a range of predators, including those listed in Table 4 page 109 (Brieze-Stegeman 1978; Forrester 1978; Milne 1978b; Ridland and Berg 1978; Ting et al. 1978; Allen 1986; Bishop and Milne 1986; Milne and Bishop 1987). The most important of these were *Coccinella transversalis, Diomus notescens, Harmonia conformis, Micromus tasmaniae* and *Simosyrphus grandicornis*, although their effectiveness varied greatly from place to place and according to season. Whereas predators often consumed large numbers of aphids, the peak of predator activity often occurred after aphid populations had begun to decline. Thus, although they provided a valuable impact, they are not credited with being able to maintain

aphid numbers below economic injury levels. Because of promising reports of biological control of spotted alfalfa aphid from California (Clausen 1978a), exotic parasitoids were sought for introduction.

Six fungal pathogens, presumed to be exotic, were also recorded from *T. trifolii*, although rarely, in the early days of its appearance in Australia (Table 5 page 113): *Conidiobolus coronatus, C. obscurus, C. thromboides, Entomophthora planchoniana, Pandora neoaphidis* and *Zoophthora radicans* (Milner 1978; Teakle 1978). However, in surveys from 1980 to 1982 in New South Wales, no evidence of disease was found in *T. trifolii* (Milne and Bishop 1987), so the incidence of attack by these fungi must have been low.

Following the first appearance of *T. trifolii*, seed of aphid-resistant lucerne cultivars was imported from USA and a program of breeding for resistance was rapidly commenced in Australia. As a result, several resistant lucerne biotypes are now grown widely and have undoubtedly played a role in reducing the economic importance of the spotted alfalfa aphid. However, evidence has been presented by Hughes et al. (1987) that introduced parasitoids have played the major role in reducing the pest status of the spotted alfalfa aphid.

Three parasitoids were introduced and established in eastern Australia: *Trioxys complanatus* from USA in 1977 (and from Iran in 1978); *Praon exsoletum* from Cyprus and Iran in 1978; and *Aphelinus asychis* from southern France in late 1978. Each of the three forms a characteristic mummy in *T. trifolii*: that of *T. complanatus* produces a bloated aphid, with skin straw-coloured and papery; *P. exsoletum* is transparent, with the parasitoid cocoon beneath the dead aphid skin; and *A. asychis* has a black and non-bloated aphid skin with pale legs.

Up to 1980, 85% to 93% of parasitoids emerging from *T. trifolii* mummies in the field in New South Wales were *T. complanatus*. In 1981, *T. complanatus* was firmly established also over a wide area in Western Australia and, by 1983, it was generally agreed that *T. trifolii* had ceased to be an economic pest, except in summer in South Australia (Sandow 1981; Walters and Dominiak 1984). This occurred in spite of the fact that only a small proportion of lucerne stands consisted of aphid-resistant cultivars, indicating the key role of exotic parasitoids, particularly *T. complanatus*. The lack of synchronisation of harvesting lucerne crops appears to favour the effectiveness of the parasitoids, which can move readily from a harvested field to a nearby standing crop at an earlier growth stage. It was estimated that successful biological control was saving New South Wales alone about $1 million per year (Hughes et al. 1987).

Six hyperparasitoid species have been reared from spotted alfalfa aphid mummies: *Dendrocerus aphidum, D. carpenteri* (Megaspilidae), *Euryischomyia flavithorax* (Aphelinidae), *Moranila comperei, Pachyneuron aphidis* (Pteromalidae) and *Phaenoglyphis villosa* (Charipidae) (Table 3 page 108) (Carver 1995, 2000).

T. complanatus was highly efficient in spite of the fact that, within a year of establishment, two hyperparasitoids, *Dendrocerus aphidum* and *Phaenoglyphis*

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villosa, were recorded attacking it in Victoria (Berg et al. 1978). In South Australia, levels of up to 20% parasitisation were produced by these and two additional species, *Pachyneuron aphidis* and *Euryischomyia flavithorax* (Wilson et al. 1978).

When the incidence of fungal pathogens of *T. trifolii* was found to be extremely low in the field in Australia, a number of overseas isolates of various entomopathogenic species were screened for pathogenicity to spotted alfalfa aphid. The only effective pathogen found was *Zoophthora radicans* and a virulent Israeli strain from this aphid was selected. This was released in 1979 and a local outbreak was initiated, with up to 88% infection being recorded at one site. *Z. radicans* produces resting spores, which enable the disease to persist from year to year. Before release of this strain which is pathogenic to spotted alfalfa aphid, another strain had been found to occur in Australia infesting the lucerne leafroller *Merophyas divulsana* (Tortricidae). However, this latter strain had not been recorded attacking spotted alfalfa aphid (Milner et al. 1980, 1982).

MAJOR PARASITOID SPECIES

Trioxys complanatus. Hymenoptera: Braconidae

T. complanatus is native to southern Europe and the Middle East and is restricted to hosts of the genus *Therioaphis*. It has a preference for the first three nymphal instars which, when parasitised, rarely reach maturity. It seldom parasitises adults. Its host-finding ability has been studied in lucerne and clover (Milne 1997). The life cycle takes about 12 days and females lay up to 570 eggs at 18°C (Roberts 1978). There is no diapause. Very few parasitised aphids develop into winged adults before death and there is little transport of the parasitoid by this means from one area to another (Clausen 1978a).

53

Toxoptera aurantii Boyer de Fonscolombe
Hemiptera: Aphididae

54

Toxoptera citricidus (Kirkaldy)
black citrus aphids

Toxoptera aurantii and *T. citricidus* are very similar in appearance and habits, both are known as the black citrus aphid and both are attacked by much the same predators and parasitoids (Stary 1967a). Other aphid species found on citrus include *Aphis gossypii, Macrosiphum euphorbiae* and *Myzus persicae* (Carver 1978b).

PRECIS

Toxoptera aurantii and *T. citricidus* occur wherever citrus is grown in Australia. *T. citricidus* causes distortion of young leaves, flower drop and reduced fruit set and lead to sooty mould development on the honeydew they produce. Both species transmit citrus tristeza virus. Both species are attacked by several species of *Aphelinus* and *Aphidius* parasitoids (of unknown origin) and by a large number of native predators. Only *T. citricidus* is regarded as a pest.

BIOLOGY

Toxoptera citricidus is oriental in origin and widespread in citrus-growing areas of eastern Asia northwards to Japan, India, Africa (south of the Sahara), and South America. It is absent from the Mediterranean region (Carver 1978b).

Young black citrus aphids are produced alive and can develop to adults in as little as 1 week. There may be as many as 25 to 30 generations per year. They feed in colonies on citrus flowers, fruit and particularly on young leaves and stems.

Winged forms develop and disperse as food quality declines, or as crowding increases. Colonies are most abundant in spring and autumn. Overwintering occurs on young shoots and in leaves curled by the citrus leafminer, *Phyllocnistis citrella*. These aphids move onto new shoots as they appear in early spring.

T. citricidus has a fairly restricted host range, covering some members of the Rutaceae (in particular *Citrus* spp.) and a few other families including the Rosaceae. It may have been introduced in the early days to Australia on *Citrus* hosts and was possibly the 'black aphis' on citrus referred to in 1890 (Hely 1968). It is now common in Australia in spring and autumn wherever citrus is grown.

Toxoptera aurantii is highly polyphagous, with a very much wider host range than *T. citricidus*. It is known from at least 190 plant genera in 80 families, which include, in particular, the Rutaceae, Rosaceae, Apocynaceae and Rubiaceae. *T. aurantii* was possibly present in the subtropical areas of northern Australia before European settlement, but was also almost certainly introduced again on imported hosts. It is common on young citrus growth, often on the same tree as *T. citricidus*, but seldom in large, massed colonies. It is also known from many introduced and native plants. *T. aurantii* occurs more widely in the world than *T. citricidus*, covering not only the distribution of the latter, but also the Mediterranean region and Central and North America (Carver 1978b).

PEST STATUS

Both *Toxoptera* species develop on *Citrus* spp. and *T. aurantii* is also known from tea and related *Camellia* species, macadamia and coffee. Large colonies of *T. citricidus* cause leaf and twig deformation and flower drop, they reduce fruit set, and copious honeydew production leads to heavy growth of sooty moulds. *T. aurantii* is a vector, second in importance to *T. citricidus*, of tristeza virus (Stubbs 1964) and is generally regarded as a minor pest. *T. citricidus* is a far more important pest of citrus and in New South Wales may severely restrict growth and adversely affect fruit set (Hely 1968). With the widespread use in Australia of tristeza-resistant rootstock, transmission of tristeza virus is no longer a serious threat (Carver 1978b). In China and Southeast Asia, *T. citricidus* is an important vector of the devastating citrus disease, citrus greening (Kiritani and Su 1999).

BIOLOGICAL CONTROL

A 'black orange aphis' and an 'orange aphis' recorded as pests in Western Australia before 1900 were both presumed to be *T. aurantii* (Jenkins 1946; Wilson 1960). However, they might equally have been two separate species, *T. citricidus* and either *Aphis craccivora* or *Macrosiphum euphorbiae*, respectively (Carver 1978b; M. Carver, pers. comm. 1998). Natural enemies there included two coccinellids (*Menochilus sexmaculatus* and *Coccinella transversalis*), two syrphids, the pteromalid hyperparasitoid *Moranila comperei*, and an ichneumonid parasitoid.

Native natural enemies of *T. aurantii* include larvae of the dipteran *Leucopis* sp., five coccinellids *(Callineda testudinaria, Coccinella transversalis, Coelophora inaequalis, Harmonia conformis* and *Scymnodes lividigaster*), three chrysopids (*Chrysopa* sp., *Mallada signata* and *Oligochrysa lutea)* and three syrphids (*Melangyna viridiceps, Simosyrphus grandicornis* and *Xanthandris agrolas)*. The syrphids are usually heavily parasitised by the cosmopolitan ichneumonid *Diplazon laetatorius* and by *Leucopis formosana* (Chamaemyiidae) (Wilson 1960; Carver 1978b, 2000; Smith et al. 1997a).

The coccinellid *H. conformis* was introduced to Western Australia from New South Wales in 1896 and from Tasmania in 1901 and 1902. It only became established from the Tasmanian material (Wilson 1960).

Unspecified parasitoids were introduced into Western Australia from France in 1903, but their fate is unknown (Wilson 1960). Parasitoids were also introduced from Algeria in 1906 and Sri Lanka in 1907 and 1909, but failed to establish (Jenkins 1946). Stary (1967a) reviewed the hymenopterous parasitoids of citrus pest aphids of the world.

The polyphagous *Aphelinus gossypii* is a common parasitoid of both *T. citricidus* and *T. aurantii* in South Australia, especially in autumn. The polyphagous *Aphidius colemani* is also a very common parasitoid of *T. aurantii* and other Aphidinae on a range of host plants in South Australia, but was rarely found attacking *T. citricidus* (Carver 1978b). Neither parasitoid was introduced intentionally.

Aphelinus mali, which was introduced to Australia in 1923 for control of the woolly apple aphid, *Eriosoma lanigerum*, has been recorded from *T. aurantii* in Western Australia and Queensland, but is believed to have little effect (Jenkins 1946; Smith et al. 1997a). Since *A. mali* is host-specific to *E. lanigerum*, it is concluded that the parasitoid involved was actually *A. gossypii* (M. Carver, pers. comm. 1998).

Both *Lysiphlebus fabarum* and *L. testaceipes* (the latter obtained from mummies of both *T. aurantii* and *Aphis nerii*), liberated in Australia from 1981 to 1983, developed successfully on *T. aurantii* in the laboratory. *L. testaceipes* became established on *Aphis nerii* on oleander in Victoria. Since 1997, it has been reared from *Rhopalosiphum padi*, *T. aurantii* on camellias, *R. maidis* on *Sorghum* spp. and *Aphis craccivora* on mung bean. *L. fabarum* is uncommon, but has been bred (in 1997) from *Aphis oenotherae* on *Epilobium* (Carver and Franzmann 2001).

It has been reported from Taiwan that consumption of *T. citricidus* was lethal to 5 out of 13 species of Coccinellidae (including *Coccinella transversalis*) and to two species of *Chrysopa*, but not to several species of Syrphidae (Tao and Chiu 1971). The black citrus aphid is attacked by the fungus *Entomophthora* sp.

55

Trialeurodes vaporariorum (Westwood)
Hemiptera: Aleyrodidae
greenhouse whitefly

PRECIS

Trialeurodes vaporariorum is probably of tropical American origin as is its principal parasitoid, *Encarsia formosa*. It was a pest of field-grown tomatoes, potatoes, cucumbers and other vegetables and became a serious pest when glasshouse culture expanded in southern Australia.

E. formosa was introduced from New Zealand and established in Canberra, Australian Capital Territory in 1934. Over the next 2 years, vigorous colonies were established in New South Wales, Victoria, Tasmania and South Australia, such that, wherever the parasitoid became established, the greenhouse whitefly was (and is) no longer a pest.

BIOLOGY

Trialeurodes vaporariorum occurs in Europe, the Americas and many other countries, including Australia and New Zealand. It is believed to be native to Central America (Tonnoir 1937).

Adults are very small (1.25 mm in length), mealy white and gregarious. They congregate on the underside of leaves. When disturbed, they leave the plants as a cloud, only to settle again rapidly under nearby leaves. Eggs (up to 500 per female) are laid on the underside of very young foliage. Soon after hatching, the young settle, insert their mouthparts into young leaf tissue and remain in the one position through four larval stages. A generation takes about 5 weeks and there are a number of overlapping generations each year. The optimal temperature for development is about 30°C (Tonnoir 1937; Noble 1938; Pescott 1940; Burnett 1948; Clausen 1978a).

PEST STATUS

Before the proliferation of glasshouses for growing tomatoes in southern Australia, the greenhouse whitefly was a minor pest of field-grown tomatoes, beans, potatoes, cucumbers and a wide range of weeds, including sowthistle (*Sonchus oleraceous*). With the progressive development of glasshouse culture, excellent breeding conditions were provided for the pest for much of the year. Glasshouses also provided a source of early reinfestation of field crops in spring (Noble 1938).

Sap is extracted from host plants by the greenhouse whitefly's sucking mouthparts and considerable quantities of sugary excretion are produced, on which there is heavy growth of sooty moulds (Miller 1945).

BIOLOGICAL CONTROL

The exotic aphelinid parasitoid *Encarsia formosa* was discovered in glasshouses in England in 1926 to be causing a high mortality of *T. vaporariorum*. In the next few years, cultures of the parasitoid were sent to North America and New Zealand. After failed attempts to obtain viable parasitoids from England in 1933, a culture was established in 1934 in Canberra, Australian Capital Territory from a colony established in New Zealand (Martin 1989). The parasitoid bred up rapidly and consignments were sent in 1935 and 1936 to New South Wales, Victoria, Tasmania and South Australia. Rapid establishment and population increase followed in each State and, since then, the greenhouse whitefly has not been reported to be of importance anywhere that *E. formosa* is present (Tonnoir 1937; Wilson 1960).

Because a related parasitoid, *Encarsia pergandiella*, was observed on the azalea whitefly, *Aleurodes azaleae*, in California (Mackie 1936), it was hoped that *E. formosa* would also attack this azalea pest in Victoria. However, *E. formosa* did not attack *A. azaleae* (Pescott 1943).

MAJOR PARASITOID SPECIES

Encarsia formosa Hymenoptera: Aphelinidae

This endoparasitoid, probably of central American origin (Tonnoir 1937; Clausen 1978a), is parthenogenetic although, in cool conditions, small numbers of males may be developed. The female lays a single egg in a fourth instar host larva and the adult wasp later emerges from a black host pupa. Male wasp larvae are hyperparasitic on female wasp larvae. *E. formosa* has a slightly higher oviposition threshold (between 12°C and 15°C) than that of its host (between 9°C and 12°C) (Burnett 1948) and temperatures above 24°C are required for effective control of the greenhouse whitefly. Its life cycle occupies at least 28 days and each female wasp is capable of parasitising at least 50 whitefly larvae (Speyer 1927; Tonnoir 1937; Gerling 1966).

56

Tuberculatus annulatus (Hartig) Hemiptera: Aphididae
oak aphid

PRECIS

The oak aphid, *Tuberculatus annulatus*, a native of Europe, is a common insect on oaks (*Quercus* spp.) in New South Wales and the Australian Capital Territory and used to be damaging in both Victoria and Tasmania.

Four species of parasitoid were sent from England between 1936 and 1938, but only one species was eventually liberated in 1939. This was because two others of the four species were found to be already present in the field in Tasmania and the Australian Capital Territory. These two, *Aphelinus subflavescens* and *Trioxys tenuicaudus (*as *T. cirsii)*, were cultured from field material and distributed widely in Tasmania, leading to heavy parasitisation of the aphid and a gradual improvement in the health of the oaks. No assessment of the impact of the parasitoids elsewhere is available.

BIOLOGY

The oak aphid, *Tuberculatus annulatus*, is native to Europe, where it is found on oaks (*Quercus* spp.) and chestnuts (*Castanea* spp.). It also occurs in North Africa, Asia, the Americas, New Zealand and Australia.

The small, yellowish-green aphids occur in abundance on the underside of the leaves throughout the summer months and produce copious honeydew. In late summer, alate males appear and fertilised females lay overwintering eggs around the buds, to hatch in early spring.

PEST STATUS

T. annulatus was a common insect on oaks in New South Wales and the Australian Capital Territory and held to be responsible for some defoliation and growth of dense sooty moulds on oak trees in Victoria and Tasmania.

Oak insects in Tasmania, which include the golden oak scale, *Asterodiaspis variolosa*, in addition to *T. annulatus*, restrict the growth of oaks and may cause the

death of larger branches and even of whole trees. In Tasmania, only *Quercus pedunculata* appeared to be infested and, even then, certain trees were free from attack (Evans 1939b).

BIOLOGICAL CONTROL

Coccinellid predators, of which *Harmonia conformis* was the most abundant, and lacewing larvae were frequently found feeding on the oak aphid in Tasmania (Evans 1939b). The hemerobiid *Drepanacra binocula* has also been recorded as a predator (Carver 2000).

Shortly before a parasitoid, *Aphelinus subflavescens* (introduced as *A. flavus*) from England, was due to be liberated, it was discovered in the field in both the Australian Capital Territory (where it was considered to have appeared very recently, introduced by accident) and in Launceston, northern Tasmania. *A. subflavescens* was, nevertheless, liberated in Hobart, southern Tasmania, in 1939 (Evans 1939b; Wilson 1960). Three other parasitoids were also introduced from England during 1936 to 1938, but not released: *Praon flavinode, P. volucre* and one said to be *Trioxys cirsii*. However, the latter is a specific parasitoid of *Drepanosiphum* spp., so it was probably *Trioxys tenuicaudus*, a common European parasitoid of *T. annulatus* (Carver and Stary 1974). At that stage, *Trioxys tenuicaudus* was found to be already established at Hobart, where it was attacked by the hyperparasitoid *Asaphes vulgaris* (Pteromalidae).

Further introductions were not made, but *A. subflavescens* and *T. tenuicaudus* were distributed widely in Tasmania from 1939 to 1941, thereby supplementing their natural rate of spread (Carver and Stary 1974). It was reported that the oak aphid soon became parasitised by one or other of the two parasitoids in many areas of Tasmania, following which the health of the oaks in these areas gradually improved (Evans 1939b; Miller 1947; Wilson 1960). No assessments in other States are available, although the oak aphid is no longer regarded as a pest in the Australian Capital Territory. The hyperparasitoid *A. vulgaris* is recorded from oak aphid mummies (Carver 2000).

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Unaspis citri (Comstock) Hemiptera: Diaspididae white louse scale, citrus snow scale

PRECIS

Unaspis citri is of southern China or Southeast Asian origin and is now widespread in the warmer parts of the world citrus belt. Before successful control, it was a serious pest in eastern Australia and in Florida.

The scale infests all parts of the citrus tree, but most commonly the trunk and limbs. When abundant, the white scale covering of males gives the bark a white-washed appearance. Control by natural enemies, especially the parasitoid *Encarsia ? citrina*, and the predator *Batrachedra arenosella*, was only partial, so three strains of the parasitoid *Aphytis lingnanensis* were introduced. The first (HKI) originating from Hong Kong was introduced in 1977, the second (HKJ) from Japan in 1980 and the third from Thailand in 1988. Of these, the Thai strain was the most effective, but combined control was still often inadequate.

The predatory oriental coccinellid *Chilocorus circumdatus* appeared in Queensland in 1990. It was mass-produced and released widely in Queensland and New South Wales and has given excellent control of *U. citri* in many areas. It is susceptible to interference from insecticides.

BIOLOGY

Unaspis citri occurs mainly on the trunk and larger branches of citrus trees, but heavy infestations spread to smaller branches, outer twigs, leaves and fruit. About 80 eggs on average are laid which hatch soon after, producing active, orange crawlers. These disperse to find a suitable place to settle (usually a depression), where they begin to produce a covering scale. Development is completed without moving from the site. The female crawler moults twice to produce an orange, sac-like, sedentary adult, devoid of appendages. The male moults four times to produce a short-lived, winged adult without mouthparts. The female scale is 2 mm long and grey in colour, whereas that of the male is 1 mm long and white. Heavy infestations of male scales give the tree trunks a white-washed appearance

and lighter infestations the appearance of being sprinkled with flakes of desiccated coconut.

A generation takes 2 to 3 months and there are several overlapping generations in a year, with highest populations in late autumn. Infestations develop best in humid regions although, in New South Wales coastal districts, population increase is favoured by dry, warm conditions in late summer and autumn (Summerville 1934b, 1935b; Hely 1944; Hely et al. 1982; Waterhouse and Norris 1987).

U. citri is of southern China or Southeast Asian origin and has a worldwide distribution in the warmer parts of the citrus belt. It occurs in all citrus areas of Queensland and in coastal New South Wales.

PEST STATUS

The host plants of *U. citri* are mainly in the genus *Citrus*, although it is also recorded from some ornamentals (Hely 1944). It is less usual for young trees to be infested. Typical infestation is on the trunk and main limbs of citrus, with large populations spreading to twigs, leaves and fruit. Heavily infested leaves become yellow where the scales are feeding and heavily spotted leaves fall early. Infested fruit are stunted, have a pitted appearance and, even if the scales are removed by washing, the fruit may be seriously disfigured. Twigs and smaller branches may die and even larger limbs, particularly those in the top centre of the tree, may be killed. Normal expansion of the bark of the trunk and main limbs is prevented by heavy white louse infestations, causing the bark to split. Limbs thus weakened become susceptible to wood borers and fungi (Hely 1944).

BIOLOGICAL CONTROL

Before *U. citri* became the target of a specific biological control campaign (which only commenced as recently as 1987), a number of natural enemies (both parasitoids and predators) had been recorded attacking it (Table 29 page 271). In addition, three fungi have been reported — *Aschersonia* sp., *Fusarium coccophilum* and *Nectria* sp. (Hely 1944; Hely et al. 1982).

Aphytis chrysomphali from China was established in 1905 in Western Australia for the control of red scale, *Aonidiella aurantii* (Wilson 1960). In 1925 and 1926 it was sent from there to attack a series of scales (including *U. citri*) in New South Wales and, somewhat later, it was reported attacking *U. citri* in Queensland (Summerville 1934).

Aphytis lingnanensis from California (but originally from China) was liberated against *A. aurantii* during 1965 to 1969 in the Murray River citrus areas of South Australia and Victoria. In 1970, it was found attacking white louse scale in south-eastern Queensland, some 1000 km distant (Snowball and Sands 1971a). Its method of arrival in Queensland is uncertain, but it may have been mixed with

stocks of *A. chrysomphali* from China released in 1905 (Wilson 1960), since the two species were not differentiated at that time (D. Smith, pers. comm.). In spite of the presence of these two parasitoids, in the late 1970s the main natural enemies of *U. citri* in Queensland were *Encarsia ? citrina* (which causes up to 50% mortality of 2nd instar scales and has been present since before 1900 (Smith et al. 1997a)) and the scale-eating caterpillar *Batrachedra arenosella*. Coastal *U. citri* populations never reached the very serious levels of subcoastal populations because of the competing presence of lichen and moss on the trunk and main limbs. Overall, the level of control achieved was inadequate (Smith and Papacek 1993).

With the rapid development of integrated pest management in Queensland orchards, improved biological control of *U. citri* became a priority. In view of the effectiveness of *A. lingnanensis* against white louse scale in Florida, the HKI strain (originating from Hong Kong) was introduced from Florida in 1977 and 1978 and some 50,000 adults reared and released. However, if established, this strain made no difference to scale populations. In 1981 and 1982, the HKJ strain (originating from Japan) was introduced from Florida. It soon became established, resulting in up to 30% parasitisation of *U. citri* on leaves, but less on the stems. It, therefore, scarcely reduced the status of the pest. Further reports of the continuing success of the HKI strain against *U. citri* in Florida (Browning 1994) led to the reintroduction of this strain in 1985 (D. Smith, pers. comm. 1985), but without producing significant change.

Next, a strain from Thailand was liberated in 1989 and 1990 and proved to be the most successful of the three, although still inadequate because it was not effective on the scales on the trunk and main limbs. Nevertheless, its contribution and that of other *A. lingnanensis* strains cannot be ignored, since parasitisation levels up to 50% were observed of scales on the fruit and leaves. Similarly, the effect of *Encarsia ? citrina*, which causes up to 50% mortality of second instar scales, cannot be discounted (Smith and Papacek 1993). Meanwhile, two parasitoids, *Aphytis gordoni* and *Encarsia inquirenda*, from southern China were liberated in small numbers in 1986 and 1988. *A. gordoni* was recovered for one or two generations from a caged tree, but neither became established (Smith and Papacek 1993). *E. inquirenda* is a prominent parasitoid of female *U. citri* on trunks and limbs in southern China.

The coccinellid predator *Chilocorus circumdatus* was first observed in Queensland in 1990 feeding on *U. citri* (Houston 1991). Earlier attempts made to establish it in Western Australia in 1902 and from 1960 to 1963 for control of red scale, *A. aurantii*, and San José scale, *Comstockaspis perniciosus*, were thought to have been unsuccessful. However, it may have established and remained undetected until it was discovered in Queensland. Of oriental origin, it is known to attack *Aspidiotus destructor* and other diaspid scales, but not previously *U. citri*. *C. circumdatus* was field-collected in Queensland, mass-reared on oleander scale, *Aspidiotus nerii*, and released during 1990 and 1991 throughout citrus areas of

Queensland. Beetles were also sent to coastal New South Wales (Smith and Papacek 1993). Within 2 years, severe infestations of *U. citri* were reduced to sub-economic levels. *U. citri* numbers averaged about 5 per tree in coastal (lower) scale infestations, 20 per tree in subcoastal areas and up to 1000 per tree further inland. Even when scales were reduced to a very low level, a few coccinellids usually remained in the tree. This predator does not eliminate the scale infestation and if it is adversely affected by pesticide application, the scale resurges.

Other natural enemies present were the small encyrtid *Encarsia ? citrina*, the predatory moth larva *Batrachedra arenosella*, the coccinellids *Telsimia* sp. and *Rhyzobius* sp., and the nitidulid *Cybocephalus* sp *arenosella* (Table 29 page 271). Often associated with *C. circumdatus* near the coast, the predatory mite *Hemisarcoptes* sp. and, during wet weather, the fungi *Aschersonia* sp. and *Fusarium coccophilum* are common natural enemies of *U. citri* (Smith et al. 1997a).

MAJOR NATURAL ENEMY

Chilocorus circumdatus Coleoptera: Coccinellidae

This predator is known from south China, India, Sri Lanka, Indonesia and Hawaii (where it was introduced from China in 1895). Liberations failed to establish it in Australia (in 1902), California and South Africa, where it was introduced to control diaspid scales, such as *A. aurantii* and *Comstockaspis perniciosus* (Houston 1991). It was re-introduced to south-western Western Australia with three other *Chilocorus* species from India in 1960 to 1963 to control *A. aurantii* on citrus (Rimes 1962; Sproul 1981b) but was not known to have become established (Anon. 1981; Pope 1988). It seems, therefore, that the appearance in Queensland in 1990 may have been the result of a separate (accidental) introduction (Houston 1991). It was collected from the field in 1991 and mass-reared on *A. nerii* on pumpkins for widespread release in Queensland and New South Wales.

In Queensland, *C. circumdatus* has been observed feeding on *U. citri* and *A. aurantii* on citrus, on *C. perniciosus* on peaches, and on *Asterolecanium* sp. on bamboo (D. Smith, pers. comm. 1998). Overseas, it is known from a wide variety of diaspid scales (including *A. destructor*) and a few Coccidae. Although present in south China, it was not seen there attacking *U. citri* (Smith and Papacek 1993). Both *U. citri* and *A. nerii* are new host records (Houston 1991).

In eastern Australia, *C. circumdatus* extends as far south as about Gosford (a little north of Sydney, New South Wales). *C. circumdatus* usually lays its eggs singly under the eaten-out scale cover of *U. citri*. There are four larval instars and the time from egg to adult is about 25 days at 25°C. Individual adults have been observed to prey on up to 10 adult female scales, 10 1st and 2nd instar scales and 33 newly hatched crawlers per day. This compares with the production of up to 150 crawlers per female *U. citri* over a period of 2 to 3 months. Adults are capable

of dispersing widely, with distances up to 100 km over open, dry sclerophyll forest and grazing land having been recorded (Smith and Papacek 1993).

COMMENTS

The biological control in Queensland of *U. citri*, largely by *C. circumdatus*, is an example of excellent control by a predator. It is fortunate that this predator appeared without assistance in Queensland, since current procedures controlling approval by quarantine authorities for the introduction of biological control agents to Australia would probably have resulted in permission being refused. Although it is not a narrowly specific predator, it has not yet been recorded as attacking any other than species of pest scales.

Table 29. Indigenous natural enemies of *Unaspis citri*

Species	References
COLEOPTERA	
COCCINELLIDAE	
Rhyzobius sp.	Smith & Papacek 1993; Smith et al. 1995
Telsimia sp.	Smith & Papacek 1993; Smith et al. 1995
NITIDULIDAE	
Cybocephalus sp.	Smith & Papacek 1993; Smith et al. 1995
LEPIDOPTERA	
BATRACHEDRIDAE	
Batrachedra arenosella	Smith & Papacek 1993; Smith et al. 1995
Batrachedra sp.	Hely et al. 1982
OECOPHORIDAE	
Stathmopoda sp.	Hely 1944
NOCTUIDAE	
Mataeomera dubia	Summerville 1934; 1935b
HYMENOPTERA	
APHELINIDAE	
Aphelinus sp.	Hely 1944
Aphytis sp.	
Coccophagus sp.	Hely 1944
Encarsia australiensis	Summerville 1934; 1935b
Encarsia sp.	Hely et al. 1982
ACARI	
HEMISCARCOPTIDAE	
Hemisarcoptes sp.	Smith & Papacek 1993

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Heliothrips haemorrhoidalis Bouché
Thysanoptera: Thripidae
greenhouse thrips

PRECIS

The cosmopolitan European greenhouse thrips, *Heliothrips haemorrhoidalis*, occurs on many cultivated shrubs and fruit trees and is capable of disfiguring leaves and fruit, especially late-hanging oranges.

Although it was already present, at least in Queensland, the eulophid larval parasitoid *Goetheana shakespearei* was introduced from California to New South Wales, but it has not been recovered. Another widespread eulophid, *Thripobius semiluteus*, was found attacking *H. haemorrhoidalis* in coastal districts of New South Wales and it has been noted that the thrips were scarce in years following those when this parasitoid was numerous (Hely et al. 1982).

BIOLOGY

The European greenhouse thrips, *Heliothrips haemorrhoidalis*, thrives in tropical and subtropical conditions as well as in greenhouses. It became an important pest of late-hanging Valencia oranges in coastal New South Wales during the mild summers and autumns from 1985 to 1988. Its main economic damage resulted from its feeding on immature and mature citrus fruits and on leaves, usually between leaves and fruit when in contact.

The black adult females insert one or two eggs per day singly into leaf or fruit tissue just under the surface. The newly hatched nymph is about 0.5 mm long. It moults to a 2nd instar nymph, followed by non-feeding prepupal and pupal stages. Egg incubation takes from 7 to 20 days under favourable conditions and the complete life cycle 33 to 38 days. There are no males.

TARGET PEST NO. 58

PEST STATUS

The feeding activities of *H. haemorrhoidalis* can cause severe blemishes on the foliage of citrus and on many garden shrubs and trees including mango, persimmon, fuchsia, magnolia, rhododendron, hibiscus, lily of the valley, and liquidamber. Scarred citrus fruit with grey patches on the rind and black spots of excreta is downgraded (Beattie and Jiang 1990). Greenhouse thrips is recorded as a minor pest of macadamia nuts (Ironside 1979).

BIOLOGICAL CONTROL

The pathenogenetic eulophid, *Thripobius semiluteus*, described originally from Africa and India, was found parasitising thrips larvae in 1986 in coastal New South Wales. However, even at high levels of parasitisation, it did not prevent serious blemishing of the thrips' hosts (Beattie and Jiang 1990). The parasitoid attacks 1st instar and, to a lesser extent, 2nd instar *H. haemorrhoidalis*.

A trichogrammatid egg parasitoid, *Megaphragma mymaripenne*, was introduced from California to New South Wales in 1986, but did not survive quarantine and hence was not released. However, an unidentified species of *Megaphragma* was bred from *H. haemorrhoidalis* eggs on mango leaves in Sydney in 1988 and from eggs on *Viburnum tinus* from the mid-north coast (Beattie and Jiang 1990).

The biparental, eulophid larval parasitoid *Goetheana shakespearei* was introduced from California and released from June 1987 to May 1988 in mid-coastal New South Wales. This species had been recorded near Cairns, Queensland before 1920, so it already occurred, at least in northern Australia. It has not been reared from field-collected eulophid pupae in the release areas in New South Wales, from which *T. semiluteus* always emerged (Beattie and Jiang 1990). Hely et al. (1982) record another eulophid, *Ceranisus* sp., as an abundant parasitoid, referring to specimens identified in 1968, but it is probably *T. semiluteus* (Beattie and Jiang 1990). It was noted that the thrips were scarce in years following those in which this parasitoid was numerous.

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Phaulacridium vittatum (Sjöstedt) Orthoptera: Acrididae wingless grasshopper

PRECIS

The widespread, native, wingless grasshopper *Phaulacridium vittatum* is often a serious pest of pastures and crops in Australia. Its native natural enemies appear not to play much part in effective population regulation.

A pathotype of the well-known fungal pathogen of grasshoppers, *Entomophaga grylli* from USA, was field tested in the Australian Capital Territory in 1984 to 1985. Although up to 30% of grasshoppers exposed became infected, the disease did not spread from the release sites.

BIOLOGY

Phaulacridium vittatum is widely distributed in pastures in eastern and southern Australia, including Tasmania, and also occurs in the south-western districts of Western Australia (Key 1939).

Despite its name, *P. vittatum* is not entirely wingless, although the majority of individuals have short to very short wings. Females are 12 to 18 mm in length and males 12 mm or less. Eggs are laid in up to nine pods of about 15 eggs. There are five nymphal instars of average total duration 6 to 7 weeks, and there is a single generation per year (Hely et al. 1982).

PEST STATUS

P. vittatum is omnivorous, attacking pastures and forage crops, most fruit trees, vegetables, garden plants and native vegetation. Heavy grazing of improved pastures, notably those involving subterranean clover, favour the survival of 1st instar nymphs in spring. Most damage occurs in dry summers when nymphs move into orchards as their natural food of pasture and broadleaf plants dries out.

BIOLOGICAL CONTROL

Parasitoids of locusts and grasshoppers in eastern Australia include: a nemistrinid fly, *Trichopsidea oestracea*; two sarcophagid flies, *Blaesoxipha pachytyli* and *Helicobia australis*; a scelionid wasp, *Scelio improcerus*; and a mermethid nematode. However, these do not appear to play a significant role in population regulation (Noble 1936; Hely et al. 1982). The microsporidian *Nosema locustae*, which occurs in Australia, has been field-tested against *P. vittatum*, but with limited success (Moulden 1981; Moulden and D'Antuono 1984).

It is probable that the well-known pathogen of grasshoppers and locusts *Entomophaga grylli* has been in Australia for a long time, although it was first reliably identified in New South Wales only in 1907 (McAlpine 1910). This fungus had already attracted much attention in South Africa a decade or more earlier. It was responsible for killing locusts there and arrangements were thus made to send cultures to Australia. However, it was discovered much later that the fungus that was actually cultured and sent to Australia was the non-pathogenic, saprophytic *Mucor racemosus*, obtained from the bodies of dead locusts (McAlpine 1899, 1900, 1910).

M. racemosus was thus imported on a number of occasions from South Africa and released over a span of years: between 1898 and 1904 in Queensland, from 1900 to 1903 in New South Wales, in 1899 in Victoria and 1902 in Western Australia. It was spread by dipping living individuals in a fungus suspension and releasing them back in the field. Claims were made initially that the fungus was effective, especially in the cooler, higher, wetter areas. It is now believed that whatever mortality resulted was almost certainly due to the widespread presence, already, of *E. grylli* in the field. After some years it was concluded that the fungal liberations had been generally ineffective and much too inconsistent in their results (Anon. 1898, 1903a,b, 1904; Froggatt 1900, 1902a, 1903, 1907; French 1902, 1903; Despeissis and Compere 1903; Wilson 1960).

In more recent times, the pathogenicity of Australian *E. grylli* to *P. vittatum* has been re-examined and found to be very low. However, it was highly susceptible to the imported USA pathotype 1. Pathotype 1 was liberated in the Australian Capital Territory from 1984 to 1985. Up to 30% of *P. vittatum* exposed became infected and the disease caused a local population decline. However, the fungus did not spread from the release areas and it was concluded that it was unlikely that this strain of *E. grylli* would provide effective, ongoing classical biological control of *P. vittatum* (Milner 1985).

Arrangements were mentioned (Anon. 1903a) for the introduction from USA of the cinch bug fungus, *Beauveria globulifera*, which was reported as having great success against locusts, but there is no report of its liberation. It had already been introduced in 1901 to New South Wales for use against the Rutherglen bug,

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Nysius vinitor, but again there appears to be no record of its actual release in the field (Anon. 1901).

Comments

Although the more recent trials with *E. grylli* from USA were specifically against *P. vittatum*, the much earlier experiments with it and *M. racemosus* also involved other species, including the Australian plague locust, *Chortoicetes terminifera*, and the yellow-wing locust, *Gastrimargus musicus*, but details of all species involved are not available.

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Teleogryllus commodus (Walker) Orthoptera: Gryllidae
black field cricket

PRECIS

Teleogryllus commodus is regarded as an occasionally important native pest in eastern Australia. It attacks many young crops, especially Brassicaceae and, when abundant, it may damage young trees.

Natural mortality is caused by a native egg parasitoid, widespread natural infection by a virus and infection by the fungus *Metarhizium anisopliae*. However, this is inadequate to prevent serious outbreaks when conditions are favourable.

A strain of the fungus *Nosema locustae* was introduced from the USA, found to infect *T. commodus* in the laboratory and liberated in the field, but its impact on cricket populations has not been evaluated.

BIOLOGY

Adult *Teleogryllus commodus* are black or brown, about 2.5 cm long and are strong fliers. Their hindlegs are adapted for jumping. Males produce a chirping sound to attract females for mating. This they do by rubbing together rows of teeth on their forewings. Adults are active in summer and autumn and oviposition occurs (up to 300 eggs per female) after the first autumn rains. These eggs hatch late in the following spring (Hogan 1966; Hely et al. 1982).

Clay soils which crack on drying, such as river flats and irrigation areas, are favoured. Wet seasons also favour cricket abundance, as do conditions following floods (Hely et al. 1982).

PEST STATUS

Both nymphs and adults eat out the central part of young brassicaceous crops and may graze them to the ground. Young plants of all sorts may be attacked, including young trees. Domestic nuisance results when the crickets swarm to lights and into houses, where they have been known to damage clothes and other fabrics (Hely et al. 1982).

BIOLOGICAL CONTROL

The scelionid wasp *Probaryconus dubius* is recorded as attacking a high proportion of *T. commodus* eggs in one district of Victoria and 'may be an important factor in keeping down cricket populations in some years' (Anon. 1960). Larvae of the trombidiid mite *Trombella alpha* are known as parasites of *T. commodus* in northern New South Wales (Southcott 1986a,b). The hypomycete fungus *Metarhizium anisopliae* is a natural pathogen of *T. commodus* (Williams 1987; Milner et al. 1996). A 1979 survey in western Victorian showed that it was present in 5.2% of 232 sites sampled and that a cricket paralysis virus was present in 42.7% (Reinganum et al. 1970, 1981).

A strain of the locust fungus *Nosema locustae* was introduced from the USA and, after proving to attack *T. commodus* in the laboratory, was released in the field. However, its impact on field populations of cricket has not been evaluated (T.W. Hogan, pers. comm. 1999).

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Brontispa longissima (Gestro) Coleoptera: Chrysomelidae palm leaf beetle

This account draws heavily on Fenner (1992) and Waterhouse and Norris (1987).

PRECIS

Brontispa longissima is native to Indonesia and possibly also to Papua New Guinea. It was recorded on the Australian Torres Strait island of Moa in 1911, in Cooktown in 1977, in Darwin in 1979 and in Broome in the early 1980s.

The attack of both larvae and adults of *B. longissima* on the surface tissue of the leaves of many palms leads to brown, shrivelled feeding scars, which give the leaves a characteristic scorched, ragged appearance.

The Javanese eulophid parasitoid *Tetrastichus brontispae* was introduced from New Caledonia and established in the Northern Territory in 1984 but died out in the late 1980s. It was reintroduced from Guam via Queensland in 1994 and survives in low numbers. It was established in Queensland in 1994 from Guam and has produced notable control there.

BIOLOGY

Brontispa longissima is native to western Indonesia and possibly also to West Papua (Irian Jaya) and Papua New Guinea. Its main damage in Pacific island nations is to coconut (*Cocos nucifera*).

It was recorded from the Torres Strait island of Moa (Australian territory) as early as 1911, from Cooktown (Queensland) in 1977 and has since spread to Cairns and Innisfail. After its discovery in Darwin (Northern Territory) in 1979 eradication was attempted. However, by early 1981, it was clear that the pest was firmly established in the metropolitan area (Fenner 1984). *B. longissima* has since spread some 30 to 40 km south of Darwin (D. Chin, pers.comm. 1998). The palm leaf beetle has been present in the Broome area (Western Australia) since the early 1980s.

B. longissima lays its eggs in groups of up to four, end to end, in a furrow chewed by the female in the leaf between or inside the tightly folded leaflets. The

eggs are covered with excreta by the female. Eggs hatch after about 5 days and newly hatched larvae feed between and inside unopened leaflets, causing browning and death of the surrounding tissues. There are five or six larval instars during a period of 30 to 40 days, followed by a prepupal period of 3 days and a pupal period of 6 days.

The long, slender adults (8 to 10 mm long, 2 mm wide) feed among the young, unopened leaflets, grazing the leaf tissue in narrow lines parallel to the midrib. Since they may live up to 220 days, their cumulative damage greatly exceeds that of the larvae. There is a preoviposition period of 1 to 2 months and 100 or more eggs may be laid. There are about three overlapping generations per year.

PEST STATUS

B. longissima attacks a wide range of palm species of all ages, although it is most damaging to young palms in nurseries and for the first few years after planting out in the field, especially in dry areas. In northern Australia, royal palms (*Roystonea regia*) are sometimes severely attacked and moderate damage may be caused to areca or betel nut palms (*Areca catechu*), nicobar palms (*Bentinckia nicobarica*), Carpentaria palms (*Carpentaria acuminata*), fishtail palms (*Caryota mitis*) and *Hyophorbe lagenicaulis*. A number of other palms are attacked to a minor degree (Fenner 1984).

Both adults and larvae of *B. longissima* damage the leaflets of young, unopened fronds. They graze the inner surface in streaks, which typically lie parallel to the midrib. As the frond opens, the underlying cells die and the scars enlarge to form irregular, elongate brown areas, which shrivel and curl, giving the leaf a characteristic scorched, ragged appearance. Destruction of young leaf spike tissue restricts growth and heavy attacks may cause death. In any event, palms weakened by attack are more susceptible to drought and disease.

The ragged fronds of avenues of palms or of individual trees planted for aesthetic purposes detract greatly from their appearance.

BIOLOGICAL CONTROL

In the Darwin area, large numbers of torn, empty eggshells of *B. longissima* were found in the nest of an ant, *Tetramorium simillimum*, but the importance of this ant in influencing abundance of the pest is unknown (Fenner 1984). The green muscardine fungus, *Metarhizium anisopliae*, infests all stages and causes death of the beetle, especially during wet spells.

Large samples of larvae, pupae and adults of *B. longissima* were collected in the early 1980s in Cooktown, where *B. longissima* had been present for several years, but no parasitoids were recovered (Fenner 1984). In 1982, the eulophid parasitoid *Tetrastichus brontispae*, of Javanese origin, was introduced from Western Samoa for quarantine screening and specificity testing in Brisbane, Queensland.

Over 4000 adults were subsequently released in infested coconut palms in the Darwin area, however the parasitoid became established only temporarily there (Fenner 1984). Establishment of the parasitoid also failed in Cooktown which received 200 parasitised pupae. Since this parasitoid stock was known to have been bred for some 20 generations in the laboratory and hence may have lost field adaptation, a consignment of 20 parasitised *B. longissima* pupae was obtained from the field in New Caledonia. After one generation in quarantine, 220 adult *T. brontispae* were released in Darwin in June 1984. Subsequent releases brought numbers up to about 2300 adults. Field recoveries of parasitised hosts followed soon afterwards and coconut palms in Darwin were reported in 1987 to suffer, on average, less damage than they did before *T. brontispae* was established. On mature palms, a sequence of several palm fronds was heavily attacked, followed by a similar or longer sequence of predominantly healthy fronds, but the trees were neither particularly debilitated nor unsightly and produced reasonable quantities of nuts. Control of *B. longissima* on mature coconut palms was thus considered satisfactory. Younger palms, up to 4 m, are much less tolerant of damage and the cyclical pattern of damage resulted in retarded growth and sometimes severe stunting or even death (Fenner 1992). However, by 1992, the extent of *Brontispa* damage had increased noticeably and several searches for pupae parasitised by *Tetrastichus* proved negative. It is suggested that an unusually cool dry period in 1988 and 1989 may have eliminated the wasp (T.L. Fenner, pers.comm.1998).

In 1984, a fresh stock of *T. brontispae* was introduced from Guam and liberated in Cairns and Cooktown in Queensland, in Darwin, Northern Territory and in Broome, Western Australia. It established in Queensland and has produced excellent control in a number of locations, although some damage is occurring in others. The parasitoid is occasionally recovered in well-watered areas in Darwin (D.Chin, pers.comm.), but no information is available on the Broome release. *B. longissima* appears to cause little damage to palms in Queensland when nests are present of the predatory ant *Oecophylla smaragdina* (K. Halfpapp, pers. comm.1998).

MAJOR PARASITOID SPECIES

Tetrastichus brontispae Hymenoptera: Eulophidae

This parasitoid is native to Indonesia and Papua New Guinea and has been recorded from several species of *Brontispa* (O'Connor 1940; Clausen 1978a). It attacks the very late larval and also the prepupal and pupal stages of the beetle and many eggs may be laid in each host. Parasitised larvae may die before pupation, but parasitoids still emerge. From 8 to 20 individuals develop in each host pupa.

The life cycle of *T. brontispae* is short (16 to 21 days), so at least two generations may be produced to each one of *B. longissima* (Lever 1936a,b; Doutt 1950; Lange 1950, 1953). *T. brontispae* was found not to attack the hispid *Uroplata girardi* (Bourke 1981), an important biological control agent of *Lantana camara*.

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Bruchus pisorum (Linnæus) Coleoptera: Chrysomelidae pea weevil

PRECIS

The European pea weevil, *Brushus pisorum*, is an important pest of field peas in southern Australia.

A braconid larval parasitoid, *Triaspis thoracicus*, introduced from France in 1939 and from USA in 1942, was recovered briefly after liberation, but did not become established.

BIOLOGY

Bruchus pisorum first appeared in 1931 in Western Australia, where it became an important pest of peas (Newman 1932). After more than 30 years, it spread to other southern mainland States. This was at a time when the growing of field peas as a winter crop in rotation with cereals expanded more than ten-fold to reach a production of almost half a million tonnes by 1987 (New 1994).

Adults of this European pest hibernate and migrate into crops in spring. Eggs are laid on young pods and larvae bore through the pod wall and into the seed. There is one generation per year.

PEST STATUS

More than 70% of field pea seeds may be infested by *B. pisorum* in high rainfall areas, leading to substantial yield losses. Crops grown for storage and dry feed purposes are damaged, but green peas for human consumption are generally not seriously affected. Although *B. pisorum* does not continue to breed in stored, dried peas, it can be a significant contaminant of export grain even if all stages are killed by fumigation (Newman 1932). *B. pisorum* is also recorded attacking beans.

BIOLOGICAL CONTROL

In 1939, the larval parasitoid *Triaspis thoracicus* (Braconidae) was imported from France and liberated in Western Australia. Although field recoveries were made, it did not survive the winter of 1940. It was again imported without success in 1942 from USA, where attempts were also being made to establish it (Jenkins 1946; Wilson 1960). Wilson (1960) postulated that the failure to establish may have been due to the absence of a suitable alternative host in which the parasite can pass the months when suitable stages of *B. pisorum* are not present in the field.

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canegrubs Coleoptera: Scarabaeidae

Antitrogus spp., *Dermolepida albohirtum* (Waterhouse), *Lepidiota* spp., *Rhopaea magnicornis* Blackburn

Larvae of some 19 native species of scarabaeid larvae damage sugarcane in Australia, including *Dermolepida albohirtum* which is the most serious canegrub pest. Other damaging species are *Antitrogus consanguineus*, *A. parvulus, A. planiceps, A. rugulosus, Lepidiota caudata, L. consobrina, L. crinita, L. frenchi, L. froggatti, L. grata, L. grisea, L. negatoria, L. noxia, L. picticollis, L. rothei, L. sororia, L. squamulata* and *Rhopaea magnicornis* (Agnew 1997).

PRECIS

The larvae of native species of canegrub are pests of sugarcane in Queensland and northern New South Wales. Two scoliid predators and a tachinid parasitoid were introduced, but both failed to become established. *Bacillus popilliae* from Japan is considered to be an important cause of milky disease in canegrubs. *Adelina* sp., a protozoan, and *Metarhizium anisopliae*, a native fungus and also introduced from Samoa, have some impact on canegrub abundance. The toad, *Bufo marinus*, imported from South America via Hawaii to prey on the adult beetles has had no influence on canegrub abundance.

BIOLOGY

Adult beetles are medium to large, light to dark brown, sometimes with a covering of white scales or fine hairs. The distribution and keys to the species of adults were given by Miller and Allsopp (2000). The larvae of most can be identified by the pattern and number of rows of hairs on the anal segment. However, some species cannot be identified by morphology and molecular methods are available to separate these species (Miller et al. 1999). The life histories of pest species of canegrub were summarised by Agnew (1997).

The most abundant pest species, the greyback canegrub, *Dermolepida albohirtum*, occurs in northern Queensland and has a 1-year life cycle. Adult beetles emerge from the soil after periods of rain between October and February and disperse to feed at night on the foliage of trees, especially *Ficus* spp., *Acacia* spp., *Eucalyptus* spp., palms and bananas. After feeding for 10 to 14 days, females

enter the sugarcane crops at night and burrow into the soil to depths of 22 to 45 cm, to oviposit. Up to three batches of about 28 oval, cream eggs are deposited in soil chambers by each female. Eggs hatch after 14 days and the 1st instar larvae feed for about 4 weeks on organic matter and small roots. Second and 3rd instar larvae feed for a further 5 weeks on the roots of sugarcane at the base of the stools, feeding heavily and growing rapidly from February to May, before burrowing deeply to form chambers in which to pupate from July to October.

The other important canegrubs are *Lepidiota frenchi* in northern Queensland and *Antitrogus parvulus* in the Bundaberg district of central Queensland (D. Logan, pers. comm.). Some species have a 1-year life cycle, whereas others have a 2-year cycle which influences the nature and timing of damage to sugarcane crops. Third instar larvae of those with a 1-year life cycle occur mainly in advanced sugarcane, whereas those species with a 2-year life cycle feed mainly on the recently ratooned plants. The depth at which feeding occurs is influenced by soil moisture. Larvae remain near the surface during periods of wet weather but disperse to varying depths when the soil is dry. After about 1 month as pupae, adult beetles develop but remain in the soil chambers until rainfall induces them to emerge. Adult beetles are frequently attracted to lights.

PEST STATUS

Larvae of the 3rd instar canegrubs prune or destroy the roots of sugacane, preventing the uptake of moisture and nutrients by the plant. Damage reduces growth and sugar levels of the canes, causes chlorosis and mature canes to fall or pull out of the ground, and sometimes death of the plants. Heavy damage results in the death of plants, or the removal of plants during mechanical harvesting, forming gaps in subsequent ratoons. In species with a 2-year cycle, most damage occurs in spring when large larvae begin feeding on the roots, whereas in species with a 1-year cycle, damage to roots occurs in late summer and autumn. The levels of damage to sugarcane varies according to the species of canegrub and the number of larvae, sugarcane variety, age and growing conditions of the crop.

Each species of canegrub is adapted to particular soil types and climatic regions. Some are important pests and their damage varies according to the developmental stage of the sugarcane crop. Most, for example *L. frenchi*, usually prefer young ratoon cane and replanted crops, while others, including *D. albohirtum*, cause plants to fall over and stools to pull out of the ground following root pruning by the larvae. The most serious pest species, *D. albohirtum,* occurs in Queensland north of Sarina in a range of soil types. Other species are adapted to volcanic loams, clays or sandy soils, occurring from the Clarence River, New South Wales to Mossman, Queensland. Larvae of different species of *Lepidiota* sometimes occur together in sugarcane and one species, *Lepidiota squamulata,* is also a common pest of lawns in northern Queensland. *Lepidiota caudata* is a pest of pastures as well as of sugarcane.

BIOLOGICAL CONTROL

Canegrubs are preyed upon by native digger wasps (Scoliidae, Naumann 1991), including *Campsomeris tasmaniensis* and *Dielis formosus* (Wilson 1960), and also by robber flies (Asilidae) (Agnew 1997). The larvae of some elaterid beetles (Cardiophorinae) prey on the eggs and larvae of canegrubs but do not give effective control. Nematodes are sometimes important natural enemies of canegrubs but the cost of producing them limits their use as living insecticides.

A bacterium, *Bacillus popilliae*, probably a native, was also imported from Japan and initially not thought to be effective (Wilson 1960). However, it is now considered to be a very important cause of milky disease in canegrubs (Agnew 1997). It produces long-lasting spores but has proved difficult to culture for use as an insecticide. *Bacillus euloomarahae*, *B. lentimorbus* and *B.* nr *sphaericus*, are also recorded from canegrubs, leading to mortality reaching 66% (Dall et al. 1995). Several fungi, including the little-known *Paraisaria* sp. attack canegrubs, and a coccidian protozoan, *Adelina* sp., has been associated with 27% mortality of larvae of *D. albohirtum in* northern areas (Dall et al. 1995). The green soil fungus, *Metarhizium anisopliae*, known from Australia but also imported from Samoa in 1914, may sometimes be an important disease of canegrubs (Agnew 1997; Lai-Fook et al. 1997). It has recently been developed into a biological insecticide, Biolane™ (Samson et al. 1999).

Two species of digger wasps, *Campsomeris* spp., from the Philippines, and a tachinid parasitoid, *Microphthalma michiganensis*, from Canada were released, but both failed to become established. The fungus *Botrytis tenella*, from France, became established but it has not been recently observed and has had no impact on the abundance of canegrubs (P.J. Allsopp, pers. comm.).

The cane toad, *Bufo marinus*, was introduced in March 1935 into Queensland from South America via Hawaii for control of canegrubs. By 1999, the toads had spread throughout Queensland, northern New South Wales and into eastern Northern Territory (Caneris and Oliver 1999). *B. marinus* has not been effective against canegrubs or other beetle pests, and it has had a detrimental environmental impact, particularly on native vertebrates that prey on frogs and toads. Poisoning of predators feeding on the toads occurs when toxins from glands in the skin of toads are absorbed. Poisoning of snakes, lizards, some birds and native rats has been recorded (Freeland 1987), and the toad is implicated in the extinction of quolls (*Dasyurus* sp.) from parts of Australia and for declines in the abundance of frogs (Caneris and Oliver 1999). Cane toads are sometimes responsible for poisoning domestic animals and they have been implicated in reducing the effectiveness of the introduced dung beetle *Onthophagus gazella* (Bornemissza 1973). When attracted by moisture, they frequently cause problems in plant nurseries by burrowing into pots and seedling boxes, disturbing or uprooting the seedlings.

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Cosmopolites sordidus (Germar) Coleoptera: Curculionidae banana weevil borer

PRECIS

Cosmopolites sordidus is native to the Indo-Malaysian region, but is now present in virtually all banana-growing areas of the world. It is believed to have come to Queensland at about the end of the nineteenth century, possibly from Papua New Guinea, and to New South Wales in 1914 or 1915 from Fiji.

Larvae of the weevil damage bananas by tunnelling into the rhizome. Rotting occurs in riddled areas and leaves die prematurely. When boring is extensive, the pseudostems are easily knocked or blown over.

A predatory hydrophilid beetle, *Dactylosternum hydrophiloides*, from Malaysia has been established in Queensland and New South Wales, but it appears to have little effect on weevil populations.

C. sordidus is reported to be of minor importance in some areas (e.g. southern China) and, if this is confirmed, it would be desirable to evaluate what part is played there by resistant cultivars, cultural methods and natural enemies. Two predatory beetles, *Dactylosternum abdominale* and *Thyreocephalus interocularis*, are capable in Kenya of reducing the abundance of *C. sordidus* larvae by 40% to 90% and these may be worth considering if further work on biological control of the banana weevil borer is contemplated.

BIOLOGY

Cosmopolites sordidus is considered to be of Indo-Malaysian origin, but is now present in virtually all banana-growing regions of the world. Surprisingly, it is considered unimportant in southern China (Li Li-ying et al. 1997), but no explanation is available for this situation. It is believed that *C. sordidus* from Papua New Guinea probably established itself in Queensland at about the end of the nineteenth century. Somewhat later, in 1914 or 1915, it was accidentally introduced from Fiji to New South Wales.

C. sordidus eggs are laid singly in small cavities chewed by the female into the crown of the banana rhizome, usually beneath the leaf scars, just above ground surface. The larvae tunnel deep into the tissues, turning back when they become mature to near the surface to form a chamber in which they pupate. The period from egg to adult varies from about 1 month in summer to 6 months or so in the cooler parts of the year. The heavily sclerotised adults may live as long as 2 years and up to 100 eggs a year are laid throughout the year at a rate varying with temperature. The nocturnal adults tunnel in banana tissue. Male *C. sordidus* produce in the hindgut an aggregation pheromone, sordidin, which attracts both males and females (Waterhouse 1998).

PEST STATUS

C. sordidus attacks all banana cultivars, although some exhibit a degree of resistance. Larvae tunnel in the banana rhizome and the base of the pseudostem that arises from it, but do not attack the roots. The tunnelling may kill young plants and greatly increases the susceptibility of mature stems to wind damage. Injury by larvae introduces rotting fungi and interferes with root initiation and sap flow within the plant, which delays the maturation of the fruit. Grossly infested plants may bear only small bunches of undersized fruit. Adults cause little damage and feed mainly on rotting banana tissue.

It is possible that much of the damage attributed to *C. sordidus* is actually caused by rhizome rot or nematodes (Ostmark 1974). Although *C. sordidus* has occasionally been held responsible for heavy losses of newly planted rhizomes, it has also been claimed that damage is not as important as frequently asserted (Wallace 1937; Smith 1993b). In New South Wales, Braithwaite (1958, 1963) concluded that the importance of *C. sordidus* infestation was aggravated by poor culture methods, although benefit could be derived from almost complete control with insecticides. Furthermore, Lobel (1975) believed that heavy weevil infestation is a symptom, not a cause, of a deteriorating plantation, because 2 years of effective use of chemicals failed to improve growth or yield in his experimental plots. Nevertheless, *C. sordidus* is always likely to be important in areas that experience strong winds and, in spite of the foregoing reservations, there continues to be a widespread view in many countries that it is a major pest.

BIOLOGICAL CONTROL

Froggatt (1928a,b) reported unidentified elaterid larvae attacking *C. sordidus* and Braithwaite (1958) likewise reported a blue planarian worm, *Caenoplana coerulea*, which lives in moist sheltered situations. It sucks out the body fluids of its prey. It is interesting that no parasitoids of *C. sordidus* are known, but far less surprising that the heavily sclerotised adult weevil has very few enemies.

Target Pest No. 64

Following the successful establishment of the predatory histerid *Plaesius javanus* from Java in Fiji in 1918, it was introduced directly from Java and liberated in Queensland on a number of occasions from 1921 to 1928. However, it became established only briefly. It was introduced into New South Wales from Java in 1922 and again in 1934 from Fiji, but it still did not establish. In Southeast Asia, both adults and larvae of this beetle are predators of the larvae and pupae of *C. sordidus* and other weevils attacking bananas and palms (Wilson 1960; Clausen 1978a). In 1934, *Hololepta quadridentata* was liberated in New South Wales, but failed to become established (CSIRO files).

Larvae of the rhagionid fly, *Chrysopilus ferruginosus*, attack larvae and pupae of *C. sordidus*. This species was introduced to Queensland from Java in 1928, but failed to become established. The predaceous hydrophilid beetle *Dactylosternum hydrophiloides* from Malaysia was liberated in 1939 in Queensland where it rapidly became established in coastal areas. It was also liberated in New South Wales, but it has not had a significant effect on banana weevil populations (Wilson 1960), although in 1940 and 1941 growers reported that it was already reducing beetle numbers.

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Ips grandicollis (Eichhoff) Coleoptera: Curculionidae fivespined bark beetle

PRECIS

The North American *Ips grandicollis* was first recorded in Australia in 1943 and spread throughout the mainland by 1983. It tunnels in the inner bark of living trees and logs of *Pinus* spp., introducing fungi which discolour the outer sapwood and contribute to tree death. Attack on trees stressed by drought or other causes leads, from time to time, to significant losses, especially of *Pinus radiata*. Seven natural enemies — two beetle predators and two wasp parasitoids — were introduced from eastern USA, commencing in 1982, and two of the parasitoids have become established. One of them, *Roptrocerus xylophagorum*, is now widespread and causes up to 70% parasitisation. This attack, combined with much improved silvicultural management (including removal of bark from slash and logs), has greatly reduced the damage caused by the fivespined bark beetle.

BIOLOGY

Ips grandicollis is native to eastern North America and is the most important of the three exotic bark beetles attacking *Pinus radiata* in Australia. The other two are *Hylastes ater* and *Hylurgus ligniperda*, both of European origin (Neumann and Morey 1984a). *I. grandicollis* was first recorded in South Australia in 1943 in recently milled logs of *Pinus nigra* var. *calabrica*. Later, in 1952 it appeared in Western Australia (Rimes 1959), then in Victoria and Queensland, in 1982, and New South Wales in 1983 (Morgan 1967; Neumann and Morey 1984a; Neumann 1987; New 1994). The South Australian and Western Australian introductions may have been due to two different importations of pine timber with bark from North America.

Adults are 3 to 4 mm in length and are active from about 9 a.m. into the evening hours of suitable days. They are capable of flying upwards of 1 km in 1 or 2 days and of spreading up to 16 km in a year. The posterior ends of the elytra are bent sharply downwards and bear five projections or teeth, leading to the beetle's

common name (Morgan 1967). Adults emerge from hibernation in the bark of dead trees and logs in spring and pass through three to four warm weather and one winter generation. Males construct a nuptial chamber in the inner bark which the females enter for mating. Females then construct galleries leading from the chamber and from these galleries lateral niches into which, together with other females, they deposit eggs to form clutches of about 18 eggs. Each female produces, on average, about three eggs a day to a total of about 100. In addition to oviposition behaviour, there is feeding behaviour in which tunnels are produced in the phloem, cambium and outer sapwood, but no nuptial chamber is formed. The density in individual trees may be very high, often exceeding 3700 per 900 cm^2. Egg incubation takes 7 to 12 days, depending upon temperature. There are four larval instars, all of which are legless. A generation time from egg to adult takes about 45 days (Morgan 1967).

I. grandicollis males produce an aggregation pheromone, ipsenol (2-methyl-6-methylene-7-octen-4-ol) (Silverstein et al. 1966; Vité and Renwick 1971) and both sexes are attracted by trans-verbenol (Neumann and Morey 1984a).

PEST STATUS

I. grandicollis is capable of developing in the inner bark of living trees and logs of many of the species of *Pinus* that occur in Australia (Morgan 1967; Neumann 1987). A number of fungi are introduced during tunnelling. These cause discolouration of the sapwood, and constitute a significant factor in the death of infected trees. The fungus *Ceratocystis ips*, in particular, may play an important role in tree death (Mathre 1964). *Diplodea pinea* and certain yeasts are also always associated with *I. grandicollis* (Vaartaja 1963).

Oviposition tunnelling by *I. grandicollis* causes less damage than feeding behaviour, in which the phloem, cambium and outer sapwood are extensively damaged.

For some years after it became established in South Australia and Western Australia, *I. grandicollis* was a minor pest, causing low mortality, mainly in stressed pines. However, it is now a far more important pest wherever it occurs. In Victoria, Neumann and Morey (1984a) report that, following the build-up by mid-summer of large, adult populations in fresh logging slash, substantial numbers of adults may carry out lethal, massed feeding attacks on nearby living trees, leading to extensive tree deaths ranging from 15% to 100% of certain sites in some stands (Morgan 1989).

BIOLOGICAL CONTROL

In his studies of *I. grandicollis* in South Australia, Morgan (1967) reported no insect parasitoids or predators, nor any other insects which seriously compete with it for food or breeding sites. However, attack by fungi (Entomophthoraceae) may

reduce numbers. The effect of the parasitic nematode *Contortylenchus grandicolli* is obscure, although Stone (1990) recorded that 90% of overwintering beetle populations carried infestations of this internal obligate parasite. Natural control of *I. grandicollis* populations in South Australia appears to include intraspecific competition for food and space, due to larvae being apparently unable to pass through the mines of other larvae (Morgan 1967). In the absence of parasitisation, *I. grandicollis* broods suffered a density-dependent mortality which increased greatly as densities exceeded 400 per 1000 cm^2 of bark.

Seven oligophagous natural enemies of *I. grandicollis* and other bark beetles in eastern USA were selected for rearing in quarantine in Adelaide, South Australia. These were five hymenopterous parasitoids and two coleopterous predators. There were difficulties in rearing three of the parasitoids (*Coeloides sympitus, Dinotiscus dendroctoni* and *Rhopalicus pulcheripennis* (Table 1 page 29) and only small numbers were released in South Australia. They have not become established. Considerable attention was, however, paid to the remaining four species. The two beetle predators *Thanasimus dubius* (Cleridae) and *Temnoscheila virescens* (Trogossitidae) were released in considerable numbers in all mainland States (Lawson and Morgan 1992).

T. dubius adults were first released in South Australia in 1983. The species survived in the field for at least a year but, by 1990, appeared not to have become established. The same fate followed releases of larvae of this species in logs in other mainland States from 1984 to 1985 (Ips Committee 1990). Between 1984 and 1990, larvae of *T. virescens* in logs were released in all States. Although an adult was observed much later on the bark of an infested tree at Casino, New South Wales and *T. virescens* larvae were recorded in logs, there is no clear evidence yet that it has become established.

Several months after the parasitoid *Roptrocerus xylophagorum* was first released in South Australia in 1982, it was found more than 2 km away from the release point. It has since established readily in all States. The reduction it is causing of host populations in late instars averages more than 25% and has reached 70% (Samson and Smibert 1986; Ips Committee 1990).

The parasitoid *Dendrosoter sulcatus*, which was first released in South Australia in 1984, was found in the field in 1986 and again in 1990. In the latter year its establishment near Casino, New South Wales was confirmed and cultured material was sent to all mainland States (Ips Committee 1990).

Lawson (1993) studied the mortality of the overwintering generation of both *I. grandicollis* (71%) and *R. xylophagorum* (86%) in South Australia. Mortality of *I. grandicollis* was highest in larval (95%) and pupal stages (86%), which are attacked by *R. xylophagorum*, and lowest in adults (41%), which are not. The significance of these results to the long-term impact of *R. xylophagorum* on *I. grandicollis* is unclear.

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MAJOR PARASITOID SPECIES

Roptrocerus xylophagorum Hymenoptera: Pteromalidae

This species is a common ectoparasitoid of bark beetles in the genera *Ips* and *Dendroctonus* in eastern North America. Adult arrival at host-infected trees and logs peaks at about 19 to 24 days after infestation begins and attack is concentrated on late larval instars, prepupae and pupae. Attraction and attack is stimulated by bark beetle pheromones in the frass, host-tree terpenes and other volatile materials (Ips Committee 1990). Samson (1984) found that females would only parasitise a larva of *I. grandicollis* if it was contained in pine bark. Its biology and behaviour under both field and laboratory conditions are described by Dix and Franklin (1981).

R. xylophagorum is an unusual parasitoid of bark beetles in that it searches within the beetle galleries and parasitises those host larvae that can be reached with its ovipositor. Each female is able to parasitise up to 70 hosts (Samson and Smibert 1986). Females live up to 24 days at 24°C and can parasitise up to 11 hosts per day. Usually only one egg is laid per host larva, prepupa or pupa. There are about two parasitoid generations to every one of *I. grandicollis* (Samson 1984).

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Listroderes difficilis Germain Coleoptera: Curculionidae vegetable weevil

This species has long been incorrectly known as *Listroderes costirostris* or *L. obliquus* (Zimmerman 1994). A related species, *L. delaiguei*, is a minor pest of subterranean clover and vegetables in Western Australia where is has been known since 1899.

PRECIS

Listroderes difficilis, a South American species, is widespread in all States and is an intermittently important, highly polyphagous pest. Four parasitoids (three ichneumonid wasps and one tachinid fly) from Argentina and Uruguay were liberated widely in eastern Australia. It is believed that at least one ichneumonid parasitoid has become widely established and exerts a reasonable level of control.

BIOLOGY

Listroderes difficilis, a native of Argentina and Uruguay, was first recorded in Victoria in 1905 and now occurs in all States. Adult females, which are parthenogenetic, start emerging in September, enter diapause during summer and commence feeding and oviposition in March. Eggs are laid in damp situations on surface litter or low-growing leaves. Adults and larvae are nocturnal, although there is some daytime feeding by the larvae. The fully-fed larva pupates in a cell 2 to 5 cm deep in the soil. At about 25°C, development from egg to adult takes 5 to 6 weeks, but in the cooler weather up to 20 weeks. The adult summer diapause is broken by cooler weather after a period at a higher temperature (Wilson and Wearne 1962).

PEST STATUS

L. difficilis is highly polyphagous, attacking many vegetables and garden plants, with tomato, potato, turnip and carrots as favoured hosts. Many weeds are also attacked, including cape weed (*Arctotheca calendula*), chickweed (*Stellaria media*),

plantain (*Plantago lanceolata*) and Paterson's curse (*Echium plantagineum*). Adults and larvae both damage foliage, and adults are generally more damaging. Adults also attack the roots of root crops and the buds of fruit trees (Wilson and Wearne 1962). *L. difficilis* is intermittently troublesome in all States, but generally only in rather limited areas.

BIOLOGICAL CONTROL

The only natural enemy of vegetable weevil recorded in Australia is a nematode. Dead adult weevils collected in the field in Canberra, Australian Capital Territory each contained 15 to 20 nematodes and nematode-infected larvae were found later (Wilson and Wearne 1962).

Four parasitoid species from Uruguay and Argentina were imported and liberated in mainland States. These were the tachinid *Epiplagiops littoralis* and three species of Ichneumonidae, *Stethantyx argentinensis, S. parkeri* and *Stethantyx* sp.

Epiplagiops littoralis, a polyphagous, solitary larval parasitoid, was liberated in Canberra in 1957, but no recoveries have been made. This may be because an alternative host is necessary in summer when *L. difficilis* is aestivating. The three *Stethantyx* species oviposit in larvae of *L. difficilis* of any size. The fully grown parasitoid larva breaks out of the host larvae when the latter prepares to pupate. The adult *Stethantyx* usually oversummers in diapause within its pupal cocoon and emerges when host larvae are available in the field. Liberations of parasitoid adults were made in 1958 in the Australian Capital Territory, New South Wales and Queensland, and in 1959 in the Australian Capital Territory. Liberations of parasitised *Listroderes* larvae and of *Stethantyx* adults were made in all five mainland States in 1961 to 1962, in New South Wales in 1963 to 1964 (when the first parasitoid recoveries were made in Queanbeyan, New South Wales), and in Canberra, New South Wales and Victoria in 1964 to 1965 (CSIRO 1960–1965, unpublished; Wilson and Wearne 1962).

There appears to be no published record of the outcome of these releases, although in a CSIRO file note in July 1978 attributed to G.R. Wearne, the opinion is expressed that at least one parasitoid species is widely established on *L. difficilis* in eastern Australia and exerts a reasonable level of control (J.M. Cullen, pers. comm.). It is probable that *S. parkeri* is the species involved.

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Pyrrhalta luteola (Müller) Coleoptera: Chrysomelidae elm leaf beetle

PRECIS

The European elm leaf beetle, *Pyrrhalta luteola*, is capable of causing serious damage to the leaves of elm trees. It was discovered in 1989 in Victoria and an egg parasitoid, *Oomyzus gallerucae*, was liberated from 1990 to 1992. Although it became established briefly, it did not persist.

In spite of important insecticidal and other measures, the elm leaf beetle continues to cause important damage.

BIOLOGY

The 6 mm long elm leaf beetle, *Pyrrhalta luteola* is native to Europe, North Africa and Eurasia. It was first recorded on the Mornington Peninsula, Victoria in 1989. Because of the high density it attained at some localities, it is postulated that, when discovered, the beetle had already been present in Victoria for at least 14 years. Until the late 1990s, it was only known to be present in an area within 100 km of Melbourne, Victoria (Osmalek 1990; Field and Kwong 1994). However, in 2000, it is known to be present in Sale and Benalla, indicating a considerably greater area of infestation (G. Lafoe, pers. comm. 2000).

PEST STATUS

Adults and larvae of *P. luteola* feed on the leaves of several elm species. Adults pass the winter in sheltered places, leaving in spring to deposit eggs on fresh elm foliage. A batch of some 25 or more yellowish eggs are laid in a double row on the underside of the elm leaf. They hatch in 7 to 10 days to produce slug-like larvae which feed for 3 to 4 weeks, after which pupation occurs at the base of the trunk or in nearby trash. The pupal stage lasts from 7 to 10 days. In Victoria there is generally only one generation per year (Osmelak 1990; Field and Kwong 1994; Kwong and Field 1994).

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P. luteola attacks the leaves of English and Golden elms, often causing extensive skeletonisation, followed by premature dropping and sometimes defoliation.

BIOLOGICAL CONTROL

A European egg parasitoid, *Oomyzus gallerucae*, is now well established in California where it is credited with being important in regulating *P. luteola* numbers. It was liberated in Victoria, commencing in 1990, and became established briefly, but has not been recovered in recent years (G. Lafoe, pers. comm.).

In 1994, the European tachinid *Erynniopsis antennata* was introduced from California but, although approved for release, this was prevented by rearing problems. There are plans to import it again and release it in 2000 (G. Lafoe, pers. comm.).

Substantial control of the elm leaf beetle has been reported following the application of a commercial preparation of *Bacillus thuringiensis* ssp. *tenebrionis* (Wells et al. 1994). Natural epizootics have not been reported in the field.

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Rhabdoscelus obscurus (Boisduval)
Coleoptera: Curculionidae
sugarcane weevil borer

PRECIS

Larvae of the sugarcane weevil borer, *Rhabdoscelus obscurus,* tunnel into the stems of sugarcane in northern Queensland, causing major damage. A tachinid parasitoid of larvae, *Lixophaga sphenophori*, introduced from Papua New Guinea and Fiji, has become established but has had no significant impact on the abundance of the weevil. A fungus, *Metarhizium anisopliae*, introduced from Samoa to control canegrubs, attacks the larvae of *R. obscurus* but its effects are not known.

BIOLOGY

Rhabdoscelus obscurus is originally from New Guinea and gained entry to northern Queensland in about 1893. *R. obscurus* is also native in the Maluku Islands, Indonesia and it has also become a pest of sugarcane on several other Pacific islands including Hawaii.

Adult *R. obscurus* are dark brown weevils with dark red patches on the elytra, measure 12 to 15 mm in length, and have a long, curved rostrum. They are nocturnal and shelter by day in trash or leaf sheaths of the sugarcane. Adults live for 10 to 12 months and females deposit about 1500 elongate eggs, singly through splits or small incisions made above the node in semi-mature and mature canes. Four to eight eggs are deposited per day and these hatch in about 6 days. The cream larvae bore into the soft tissues, forming tunnels in canes, and feed for 50 to 90 days before pupation (Clausen 1978a). Before pupating, larvae construct a tightly bound, fibrous cocoon and chew an exit hole in the rind of the cane to allow emergence of the adult. Pupal development occupies 8 to 10 days. In tropical areas, all stages of the weevil are present throughout the year (Muir and Swezey 1916).

PEST STATUS

In Queensland, *R. obscurus* occurs north from Mackay but it is only a serious pest of sugarcane in the high rainfall areas between Tully and Cairns (Agnew 1997). *R. obscurus* also damages a number of other plants including banana and palms.

Larvae mainly cause damage by tunnelling into the mature and semi-mature canes or sometimes into the stools in ratoon crops (Agnew 1997). The damage leads to red rot and other diseases that reduce the sugar content in the canes. When compared with undamaged sugarcane, damaged canes are lighter in weight, have a higher fibre content, and the dextran content is higher in extracted juice. Damage from tunnelling by larvae leads to lodging of canes following strong winds, especially during autumn months. Twisted or split canes resulting from cyclone damage, and canes damaged by rats or moth larvae, are especially prone to attack.

Widespread burning of cane immediately before harvest in northern Queensland formerly controlled *R. obscurus,* but this practice has been largely discontinued and, when conducted only on individual blocks, is no longer effective due to immigration of weevils from unburnt areas (Agnew 1997).

BIOLOGICAL CONTROL

Very few natural enemies of *R. obscurus* are recorded from Australia. The tachinid parasitoid *Lixophaga sphenophori*, introduced into Queensland from Papua New Guinea and Fiji, was reported to attack about 90% of larvae and to control the pest (Illingworth 1919). Biological control was claimed to have been achieved wherever climatic and other conditions were favourable (Mungomery 1934). However, in recent years *L. sphenophori* has been considered to be an uncommon parasitoid and *R. obscurus* continues to cause serious damage in the wet regions of northern Queensland (Agnew 1997).

The green soil fungus, *Metarhizium anisopliae*, known from Australia and also imported from Samoa in 1914, attacks *R. obscurus* in Queensland, but it is not considered to be important. The cane toad, *Bufo marinus*, introduced into Queensland from South America via Hawaii for control of canegrubs, was once reported to control sugarcane weevil borer (Wilson 1960), but it is not now considered to be effective against *R. obscurus.*

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Sitona discoideus Gyllenhal Coleoptera: Curculionidae sitona weevil

PRECIS

Sitona discoideus is of Mediterranean region origin. It has been a major pest of annual medic pastures in South Australia since it became widespread in the 1960s.

The braconid wasp *Microctonus aethiopoides* from Morocco, a parasitoid of adults, was liberated from 1977 to 1979 in the Australian Capital Territory, New South Wales and South Australia and is now widely established. Another biotype, from Greece, was also liberated and recovered in south-eastern Australia. In South Australia, 60% to 90% parasitisation of adult *S. discoideus* is recorded. However, this level of attack is not credited with lowering weevil abundance. This is because it is held to simply replace high larval mortality caused by a severe shortage of suitable food (legume root nodules) required to sustain the successful development of all larvae from all of the eggs produced.

The mymarid egg parasitoid *Anaphes diana*, from France and Greece, was liberated from 1976 to 1978 and biotypes from hot, dry areas of France and Syria were introduced from 1982 to 1984. *A. diana* was recovered for a few years, but has not survived.

Field trials of a strain of the nematode *Heterorhabditis heliothidis* (a pathotype from New Zealand) and of the fungus *Beauveria bassiana* (from France) on sitona weevil larvae were disappointing, although both pathogens were effective in laboratory trials.

BIOLOGY

Sitona discoideus has one generation a year. The dark greyish-brown adults, which are 4 to 5 mm long, aestivate during summer, usually in aggregations, and especially in surface litter under trees. In autumn, they undertake migratory flights and can invade medic pastures many kilometres distant. Indeed, masses of weevils have been observed floating on the ocean more than 20 km off the coast of South Australia (Aeschlimann 1983a). About 1000 eggs are laid per female on the soil

surface and, on hatching, larvae burrow into the soil to a depth of 5 to 15 cm to find legume roots and root nodules on which to feed. Larval development takes 3 to 4 months during which time they consume many nodules. Adults feed on the leaves, usually during early morning or late afternoon and shelter under surface debris during the hottest parts of the day.

S. discoideus was formerly misidentified as *Sitona humeralis*, also a southern European species with which it occurs in south-western Europe. *S. discoideus* occurs from Portugal to Italy and, alone of its species group, in North Africa (Aeschlimann 1984). It was first recorded in Australia in November 1958 in New South Wales (Chadwick 1960). It was first noted in Victoria in 1964, not long after in South Australia (rising to major pest proportions in the early 1970s) and in Western Australia in 1974. It reached New Zealand in the mid-1970s.

PEST STATUS

S. discoideus is a major pest of annual medic pastures and also attacks lucerne in New South Wales, Victoria and particularly South Australia, where large areas of pasture are based on annual *Medicago* spp., mainly in the 300 mm and above rainfall areas (Cullen and Hopkins 1982) where *M. minima, M. polymorpha* and *M. trunculata* are important species. Larvae cause most damage by feeding on the roots and particularly the root nodules, thereby reducing the nitrogen-fixing capacity of the plants, resulting in lower yields (Hopkins 1982). The number of eggs laid, and young larvae produced, greatly exceeds the availability of nodules in most years. This leads to considerable competition for food and high mortality of young larvae, which may attain densities in excess of 2000 per m^2.

Adults feed on the foliage and can defoliate large areas of pasture, both after aestivation in autumn when annual pastures are becoming established and again as newly emerged adults in spring, thereby restricting plant growth and leading to poor seed set (Cullen and Hopkins 1982). Densities in excess of 800 per m^2 were recorded in the early 1970s, with accumulations of adults several centimetres deep in road gutters and washed up on the sea shore. Adults have also been recorded landing on ships 12 km offshore.

On lucerne, the feeding of adult weevils produces U-shaped holes in the leaf margins and they chew into the stems. Heavy infestations can defoliate established stands and kill seedlings and young plants. Damage is usually most serious in spring and autumn, although adults may feed actively during warm weather periods in winter.

BIOLOGICAL CONTROL

Before any attempt was made at biological control, *S. discoideus* was found to be attacked in Australia by the fungi *Beauveria bassiana* and *Metarhizium anisopliae*, although at a low incidence. It was thought that a strain of *B. bassiana* from

France, within the area of origin of *S. discoideus*, might be more pathogenic than the South Australian strain already present. The French strain is reported to be the major natural enemy of *S. discoideus* larvae and pupae, but seldom of adults, in the Mediterranean region, although it is not present in North Africa, Cyprus, Syria or Iraq (Aeschlimann et al. 1985). Although the French strain was effective in the laboratory, neither it nor the Australian strain was effective in controlling sitona weevil in the field (Bailey and Milner 1985).

A strain of *Heterorhabditis heliothidis* from New Zealand, that was particularly pathogenic for sitona weevil in the laboratory, was field-tested in South Australia in 1982, but there was no evidence of any infection by the nematodes or of any population decline (Bailey and Milner 1985).

It was pointed out that farming practices create problems of survival for the resting stages of pathogens. Medic pastures in South Australia are usually grown as annuals in a 2-year rotation with cereals, which are unsuitable for survival of sitona weevil. Thus, *S. discoideus* larvae are only in the soil for 3 to 4 out of every 24 months. Hence, for continuing biological control, unless there are suitable alternative hosts, the pathogen resting stages have to survive (a) without a host for about 20 months, and (b) cultivation practices associated with the cereal crop (Bailey and Milner 1985).

A study of the natural enemies of *Sitona* spp. in southern Europe and northern Africa revealed 16 species. Of these, the braconid *Microctonus aethiopoides* and the tachinid *Microsoma exigua* were important mortality factors of adults in high *S. humeralis* populations and the mymarid *Anaphes diana* was the most important egg parasitoid. Mites of the genus *Allothrombium* were important egg predators (Aeschlimann 1978, 1979, 1980, 1990).

M. aethiopoides was introduced from Morocco to Australia, mass-reared and released in New South Wales and South Australia in 1977 and 1978 (Cullen and Hopkins 1982) and soon became widely established (Hopkins 1982). A second biotype from central Greece was introduced and released from 1979 to 1981. It became established, but had limited impact and dispersal (Aeschlimann 1995). In spite of the fact that 60% to 90% of adult sitona weevils may be parasitised (Bailey and Milner 1985), Hopkins (1984) concluded 'the numbers of larvae, pupae and emerging adults were maintained at pre-parasite levels' and 'the parasite, by itself, is not an efficient control agent of sitona weevil in annual medic pastures in South Australia'. The same view applied several years later (Hopkins 1989). This situation results from the fact that the number of sitona larvae produced from eggs in most years greatly exceeds the availability of root nodules. The resulting competition for food results in very high mortality of young larvae (Bailey and Milner 1985). Thus, for a lowering of adult populations, the number of sitona eggs laid must be reduced below a level at which there is adequate food for all resulting larvae.

The Australian situation contrasts sharply with that in New Zealand, where it has been clearly demonstrated that *M. aethiopoides* from South Australia has suppressed *S. discoideus* to below damage thresholds. This striking result is ascribed to two factors. Firstly, *Sitona* larvae appear later in spring in New Zealand, giving the parasitoid time to suppress much of the weevil population before egg laying. Secondly, and more importantly, 3% of the parasitoid population does not aestivate, but continues to attack pre-aestivatory weevils. Such weevils are unable to migrate out to aestivation sites and the resulting adult wasps produced from these weevils remain in the lucerne ready to attack post-aestivating weevils returning to the pasture. This striking departure from the wasp's usual behaviour results in an increase in parasitisation to levels up to 10 times greater than the maximum of 6.5% observed in New South Wales. Parasitisation after aestivation, but before the bulk of egg-laying, was found to average 60% in the Canterbury region of New Zealand (Goldson et al. 1993).

Concern that *M. aethiopoides* might compromise the effectiveness of the weevil *Rhinocyllus conicus* introduced to New Zealand to assist in the biological control of nodding thistle, *Carduus nutans*, was at least partly allayed by its significantly lower attack on *R. conicus* (Ferguson et al. 1998).

The tachinid fly *Microsoma exigua* was introduced in 1979 to quarantine in Canberra, Australian Capital Territory, but rearing difficulties led to it not being released (Aeschlimann 1990).

As indicated earlier, the mymarid wasp *A. diana* was found to be the major parasitoid of *Sitona* spp. eggs throughout the Mediterranean regions of Spain, France, Italy, Greece, Bulgaria, Romania, Turkey and Syria. The mean parasitisation of eggs over this range fluctuated between 1.9% and 23.9% and increased from autumn to spring. French and Greek biotypes were first released in Australia from 1976 to 1978. However, since these might not have been well adapted to the very hot and dry Australian summer (particularly of South Australia), surveys were carried out in hot, dry climatic areas in southern Europe, the Middle East and North Africa. Although *A. diana* was recovered from the European countries listed above, it was not found in Iraq nor in North Africa (Morocco, Algeria, Tunisia). In a second phase, additional parasitoids were imported from Syria and France during 1982 to 1984 (Aeschlimann 1986).

A. diana was recovered in low numbers in 1979 from the first group of eggs field-collected in New South Wales. There it initially reached a maximum of 14.8% parasitisation, but declined in subsequent samples. During the next 5 years (1980 to 1984), no further recoveries were made at one site and recoveries declined to zero at another. It appears that *A. diana* is better adapted to parasitising sitona weevil eggs under a temperate climate in perennial lucerne than in annual *Medicago* species in hot, dry conditions. It was concluded that, although the parasitoid was able to maintain itself in low numbers for several seasons at

some localities, it has probably not become established in Australia (Aeschlimann 1989; Aeschlimann et al. 1989).

MAJOR NATURAL ENEMIES

Microctonus aethiopoides Hymenoptera: Braconidae

The adult female parasitoid follows an active adult weevil for a period before laying a single egg into the abdomen of the weevil. Immobile weevils are ignored. Female *S. discoideus* cease oviposition 1 to 2 days after parasitisation. The parasitoid egg hatches and the larva develops inside the adult weevil until it reaches the fifth instar. At that stage it leaves its host and spins a cocoon amongst surface litter. Unfertilised females only produce male offspring.

When young, non-reproductive weevils are parasitised in late spring or early summer, the 1st instar parasitoids are arrested in development until after aestivation, when the adult weevils resume feeding and become sexually mature in autumn. Four or five wasp generations then take place during one generation of *S. discoideus* over the autumn–spring period (Cullen and Hopkins 1982).

Aeschlimann (1983b, 1995) showed that there were many biotypes of *M. aethipoides* associated with different *Sitona* spp. hosts and adapted to different climatic conditions. Most of its incidence on *S. discoideus* in Australia is attributed to the Moroccan biotype.

Anaphes diana Hymenoptera: Mymaridae

Adult females oviposit up to 35 eggs, singly into *S. discoideus* eggs, in which all further development occurs. At 22° ± 2°C, development takes 14 to 15 days. *S. discoideus* aestivates from late spring to the first rains of early autumn, during which time no eggs are laid. During this time, *A. diana* also undergoes an obligatory summer diapause within the host eggs. Two biotypes of *A. diana* coexist at all sites investigated in the Mediterranean region — one is bisexual, the other consists of parthenogenetic females. The latter biotype has provided most material for releases from 1982 onwards. It was pointed out that the obligatory diapause within host eggs considerably increases the difficulty of establishment of the parasitoid in annual Medicago pastures, particularly where a 2-year cereal pasture rotation occurs (Aeschlimann 1986). Specificity tests indicated that it would not parasitise the eggs of the beneficial weevil *Apion antiquum* imported into Australia for biological control of *Emex* spp.

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Bactrocera tryoni (Froggatt) Diptera: Tephritidae Queensland fruit fly

PRECIS

Many species of the genus to which the native Queensland fruit fly *Bactrocera tryoni* belongs are major pests of fruits and vegetables in tropical and subtropical regions of Australia, Asia, Africa and the Pacific islands. *Bactrocera tryoni*, which is as damaging as any, occurs throughout eastern Australia and has been accidentally established in Lord Howe Island, New Caledonia and French Polynesia. Its presence in any of a very wide range of fruits and vegetables renders infested produce (unless it is treated to kill all stages) unmarketable in Australia and banned by importing countries. The difficulties in effectively protecting hosts from fly infestation deter many individual growers from growing certain crops and add significantly to the costs (and losses) of commercial and backyard growers.

Although there have been a number of failures in attempts at classical biological control of fruit flies, there has also been a significant reduction in fruit fly numbers in Hawaii of two exotic fruit flies — the oriental fruit fly *Bactrocera dorsalis* and the medfly *Ceratitis capitata* — following the introduction and establishment of four wasp parasitoids, *Fopius arisanus*, *F. vandenboschi*, *Diachasmimorpha longicaudata* and *Psyttalia incisi*. However, when these species were introduced into eastern Australia, only *F. arisanus* and *D. longicaudata* became established, but they are having little impact on fruit fly abundance. *D. longicaudata* also became established on Lord Howe Island, where it was recovered in low numbers at the last sampling in 1962, but its fate since then is unknown.

BIOLOGY

Bactrocera tryoni occurs in eastern Australia from the top of Cape York Peninsula, Queensland in the north, to East Gippsland,Victoria in the south. Away from the coastal strip, it is generally present year-round in towns up to about 300 km inland, except those in cooler, highland areas. However, winter breeding is

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possible only in the northern half of this range, although adult flies (the most cold-hardy stage of the life cycle) can survive winter in most of the entire region. There have been outbreaks in other than coastal areas of Victoria, in South Australia and in Western Australia, but these have all been eradicated when detected. A few males have been trapped in Papua New Guinea, but it is not established there. It has been accidentally established on Lord Howe Island, New Caledonia and French Polynesia and has twice been eradicated from Easter Island (White and Elson-Harris 1992). The closely-related *Bactrocera neohumeralis* is a less important, but still major, pest in Queensland, attacking many of the same crops as *B. tryoni*. It mates in the middle of the day, whereas *B. tryoni* mates at dusk.

Females of *B. tryoni* insert several eggs at a time directly into the host fruit or vegetable. They do not produce a marking pheromone and multiple ovipositions by the same or different females may occur in the same fruit and often into the same oviposition puncture. Once larvae start to feed, an unidentified change occurs in the fruit, which generally causes females to avoid it. A female fruit fly is capable of laying up to 500 eggs in her lifetime, which may last several months. There are three larval instars and a prepupal stage is followed by pupation near the surface of the ground beneath the host plant. Adults require a regular supply of water and carbohydrate to survive and of protein to attain sexual maturity and develop eggs. Bacteria on the surface of the plant form an important source of nutrients (Drew and Lloyd 1989). Mating is necessary for the production of fertile eggs.

When the cuticle of the newly emerged adults has fully hardened and darkened, they enter a dispersive phase. The presence of hosts during this period appears to have little influence on their behaviour, so that most adults leave the area where they emerged and disperse, sometimes for many kilometres, throughout the surrounding area, regardless of whether or not host fruits are available. After several days, as these mobile adults approach maturity, they start to seek ripening fruits in which to oviposit. When they find a suitable host plant their behaviour changes. They remain near it and mate at dusk, usually on the western side of a bush or fruit tree. *B. tryoni* passes through successive generations throughout the year, as long as hosts are available and the temperature does not fall below the developmental threshold. When it does, adults seek out shelter areas where they remain relatively inactive until temperatures rise again in spring. There does not appear to be a true diapause.

Male *B. tryoni* are strongly attracted to cue lure (4-(p-acetoxyphenyl) butan-2-one) and Willison's lure, its hydroxy derivative (4-(p-hydroxyphenyl) butan-2-one) — compounds that are also attractive to a number of other *Bactrocera* species.

PEST STATUS

B. tryoni is the most destructive pest of fruits and vegetables in tropical, subtropical and temperate eastern Australia and infests all commercial fruit crops in the field except pineapple, strawberry (Drew 1982) and lychee (R.A.I. Drew, pers. comm.). In addition to commercial crops, it has been bred from at least 60 wild hosts from 25 plant families, enabling it in forest areas to build up large populations which act as reservoirs of adults which then invade crops. The overall costs attributed due to fruit fly in eastern Australia (the majority due to *B. tryoni*) were estimated for 1988/89 (Anon. 1991). At that time, Commonwealth and State Governments spent at least $6 million a year on control, the horticultural industry more than $18 million and consumers incurred losses of more than $100 million.

The presence of fly larvae (maggots) in a piece of fruit or vegetable rapidly renders it inedible although, in early stages of larval development, home growers may use sound parts after trimming. Infested produce is unacceptable for marketing in Australia and is rigorously banned by most importing countries. Losses are thus due not only to crop damage and the cost of control measures, but also to the restriction or loss of export markets. For many years, almost all importing countries have required produce to be free of living fruit fly eggs or larvae. Until recently, this was achieved by fumigation with methyl bromide or ethylene dibromide. However, these fumigants have been banned because of possible health risks from bromide residues in treated produce. Other methods, mostly involving heat or cold, have been adopted or are under investigation, although there are difficulties in achieving disinfestation without damage to some commodities.

To add to exporting difficulties, New Zealand, which is free from fruit flies, has considered increasing its import restrictions such that produce cannot contain even dead fruit fly eggs or larvae above a specified, very low level. This would mean, in effect, that export produce must be uninfested when exposed in an exporting country to an effective commodity treatment. This requirement would provide a very strong incentive for exporting countries to maintain populations of pest fruit flies at as low a level as possible.

BIOLOGICAL CONTROL

Fullaway (1951) listed a number of natural enemies of fruit flies in Australia: the parasitoids *Aganaspis daci*, *Dirhinus* sp. *Psilus* sp. *Pachycrepoideus vindemmiae* and *Spalangia* sp. and the predator *Thyreocephalus albertisi*, but nothing is known of their effectiveness.

Three native braconid parasitoids were reared from *B. tryoni* in many samples of mainly commercial fruits in eastern Australia north of Sydney collected

from 1960 to 1962. These were *Diachasmimorpha tryoni*, *Fopius deeralensis* and *Opius perkinsi* (Snowball and Lukins 1964). Two further species were added a little later, *Diachasmimorpha kraussi* and *Psyttalia fijiensis* (Snowball 1966a). The incidence of native parasitoids in the 1960 to 1962 rearings generally averaged between 5% and 12% of the insects emerging from all samples at any one site, with a maximum of 80% in one individual sample. It was concluded that native parasitoids were of little importance in regulating *B. tryoni* numbers (Snowball et al. 1962b). No native parasitoids of *B. tryoni* were found on Lord Howe Island (Snowball 1966a).

Intensive studies over a 7-year period some 90 km south of Sydney (Bateman 1968) also produced very few parasitoids of *B. tryoni*, the majority being *D. tryoni*. When a grass carpet developed in an orchard, ant colonies increased greatly in abundance and ants were responsible for at least 10% mortality of fruit fly prepupae and puparia in the soil. Predaceous beetles and a millipede also caused some mortality. *D. tryoni* was introduced to French Polynesia to control *B. tryoni*, but failed to become established (Waterhouse 1993a).

Fruit-eating birds and rodents were shown by Drew (1987) to consume large quantities of infested and uninfested rainforest fruits. They were postulated to be the major causes of reduction in fruit fly populations and far more important than parasitoids in this habitat. Since these natural enemies were clearly unable to prevent *B. tryoni* causing serious, widespread damage, several thousand *Tetrastichus giffardianus* and small numbers of *Psyttalia concolor* (= *P. humilis*) and *Biosteres fullawayi* from Hawaii were released in New South Wales between 1932 and 1933. During 1937 and 1938, some 205,000 *Aceratoneuromyia indica* from India were liberated in New South Wales and a further number in Queensland. However, none of these species became established (Noble 1942).

Following encouraging success in 1950 in Hawaii against the oriental fruit fly *Bactrocera dorsalis*, and after it had been shown that *Fopius arisanus*, *F. vandenboschi* and *Diachasmimorpha longicaudata* would parasitise, in the laboratory, both the Queensland fruit fly and the solanum fruit fly, *Bactrocera cacuminata*, these three parasitoids were introduced in 1956 from Hawaii. The two *Fopius* species have behaviours that are unknown in Australian fruit fly parasitoids: *F. arisanus* oviposits in the host egg or recently hatched larva and *F. vandenboschi* in the 1st instar larva (van den Bosch and Haramoto 1951). Eggs and young larvae of *B. tryoni* occur close to the skin of the host fruit, but older larvae are deeper in the tissues and are less accessible, particularly in the larger commercial fruits. These two species are thus more likely to be able to locate hosts than are those, like *D. longicaudata*, that oviposit only in older larvae (Snowball et al. 1962b).

In 1956 and 1957, 1700 *F. arisanus* and 21,000 *D. longicaudata*, bred in Sydney from parents introduced from Hawaii, were liberated at Coffs Harbour in

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northern New South Wales, but did not become established (Snowball et al. 1962b). In 1958 and 1959, in addition to 46,000 parasitoids reared in Sydney (Snowball et al. 1962a) the following numbers of foreign parasitoids were reared in Hawaii, carefully screened in Sydney to exclude all other organisms, and liberated in the field: *A. indica* 3200; *D. longicaudata* complex 198,700; *Dirhinus anthracia* 2500; *F. arisanus* 229,200; *F. vandenboschi* 28,100; *Psyttalia incisi* 27,100; and *T. giffardianus* 2500. The liberations were made at 25 locations in New South Wales, 59 in Queensland and 6 on Lord Howe Island against *B. tryoni* and 12 liberations of four of the species were made in Western Australia against the Mediterranean fruit fly, *Ceratitis capitata* (Snowball et al. 1962b).

Fruit, extensively sampled in eastern Australia between 1960 and 1962, revealed that *F. arisanus* was established and that, at places, it had dispersed up to about 8 km in the 4 years since liberation. It was present on Lord Howe Island from late 1959 to early 1961, but then died out. *D. longicaudata* was not recovered on the mainland but was still present in low numbers on Lord Howe Island up to 1962. No other introduced parasitoids were recovered.

Further samplings, from 1962 to 1965 from Cairns to Sydney, confirmed the establishment of *F. arisanus* (but of no other exotic parasitoids) at a number of locations in Queensland, and one in northern New South Wales. *D. longicaudata* (but not *F. arisanus*) was again recovered in low numbers from Lord Howe Island. On the mainland, *F. arisanus* was bred from fruit infested with *B. tryoni* and six other tephritid species, namely *B. cacuminata*, *B. jarvisi*, *B. kraussi*, *B. musae*, *B. neohumeralis* and *Rioxa confusa* (Snowball 1966a). It thus seemed to be well established. Its ability to disperse (up to some 40 km in 5 years), the frequency of its recovery from fruit samples and the level of parasitisation were greater at the northen than the southern end of its distribution (Snowball 1966a). The sampling of fruits on trees did not provide information on *D. anthracina*, which is a pupal parasitoid and hence would only have been found by sampling puparia in the soil. More recently (R.A. Wharton, pers. comm. 1992), limited material was examined from Queensland, which may be either *D. longicaudata* or a closely related native species, intermediate between it and the native *D. kraussi*.

A ratio of 1.5 female *F. arisanus* per male in parasitoids emerging from fruit samples indicated that it was mating satisfactorily in the field. The parasitoid exhibited a marked preference for some fruits, but this varied in different years and different localities. The most consistent preference was for infested star fruit, *Averrhoa carambola*, in north Queensland. It showed no preference for utilising more heavily, rather than less heavily, infested fruit. In Hawaii, *F. arisanus* displaced both *F. vandenboschi* and *D. longicaudata*, which had been established before it (van den Bosch et al. 1951). However, there is no indication that any native Australian parasitoids were displaced by it. In Hawaii, parasitisation by *F. arisanus* ranged up to 70% in infested guava. In Australia, it reached 78% for the most favoured fruits but, for others, ranged between 0 and 35%. The high levels

in favoured fruits in northern Australia were often offset by the production of large numbers of flies from fruits that were not favoured by the parasitoid. The data obtained by Snowball and Lukins (1964) and Snowball (1966a) indicated that, following the establishment of *F. arisanus*, the number of flies produced per fruit was reduced, but that there was little change in the percentage of fruit infested.

The most recent information comes from 30 samples of commercial and wild fruits from over 5000 km^2 in the Cairns area from 1997 to 1998, following the discovery in 1995 of the exotic papaya fruitfly, *Bactrocera papayae*. *B. tryoni* adults emerged on 17 and parasitoids on 29 occasions. Of the latter, *D. longicaudata* was recovered on 20 and *F. arisanus* on 15 occasions, with levels of parasitisation ranging from 0 (once) to 100% (thrice) and commonly between 12% and 50%. It was not possible to determine the actual level of parasitisation of *B. tryoni*, because five other fruit fly species also emerged from some samples. However, there can be little doubt that *B. tryoni* suffered considerable mortality of both eggs (*F. arisanus*) and larvae (*D. longicaudata*) (data from D. Hancock and D.P.A. Sands, pers. comm. 1998). It is not known how far south that these parasitoids occur. Nevertheless *B. tryoni* remains a major widespread pest.

MAJOR PARASITOIDS

There have been many changes in the nomenclature of the fruit fly parasitoids liberated in Australia and generic changes are listed below in the brief accounts of each species based on Waterhouse (1993a). Irrespective of whether oviposition occurs into the egg or the early, middle, or later instar larva or the pupa, all of the parasitoids complete their development in, and emerge from, the puparium (Clausen et al. 1965).

Aceratoneuromyia indica (Synonyms: *Melittobia*, *Syntomosphyrum*)
Hymenoptera: Eulophidae

This species is known to occur naturally in southern India, Sri Lanka, Malaysia, Sabah, Indonesia and the Philippines. Native hosts include the *B. dorsalis* complex in the laboratory. *A. indica* can be reared on *C. capitata* and *B. tryoni*. From the day of adult emergence, eggs are laid in mature host larvae. Females enter the infested fruit through breaks in the skin to search for fruit fly larvae, depositing a number of eggs in the posterior end of the body, often being dragged into the fruit pulp during this process by the burrowing host larva. Up to 35 individuals may mature in a single host. Adult females are short lived (not more than 27 days) and may lay 100 or so eggs. Under optimal conditions, the period from egg to adult is 15 to 16 days, and the progeny are predominantly (75%) female. Noble (1942) provided details of the biology of this parasitoid.

Biosteres fullawayi (Synonyms: *Diachasma*, *Opius*) Hymenoptera: Braconidae

This species is native to Cameroon, Guinea, Nigeria, Senegal and Zaire. Native hosts include *C. capitata*. It was introduced into Hawaii and became established, but has been recovered rarely since 1949 (Bess 1953; Bess et al. 1961). It was introduced unsuccessfully to Spain, Puerto Rico and Australia. This species has a diapause.

Diachasmimorpha longicaudata (Synonyms: *Biosteres* or *Opius*) Hymenoptera: Braconidae

This parasitoid is native to Southeast Asia. It has been established in Hawaii under several varietal and specific names and also in Australia, Fiji, Mexico, Costa Rica, Florida and Trinidad. It has also been introduced into north-western USA and Guam, but is not established there. It was also introduced to Greece, but the outcome is unknown.

Its native hosts include the *B. dorsalis* complex and in the laboratory it will breed amongst other species on *C. capitata*, *Bactrocera frauenfeldi*, *B. curvipennis*, *B. psidii* and *B. tryoni*.

D. longicaudata oviposits in the nearly fully-grown host larvae, puncturing the fruit skin to so do. Its fully-grown larvae are capable of diapausing. The parasitoid visits fruit on the tree and also on the ground where breaks in the fruit skin often give good access to older fruit fly larvae (Bess and Haramoto 1961). Fruit size and volatiles, but not colour, are probably responsible for its greater attraction to some fruit (e.g. grapefruit) than others (e.g. mango, orange, peach), although greater percentage parasitisation of larvae was mostly recorded in the latter group. This may be due to length of ovipositor in relation to fruit diameter, depth of the fruit pulp and behaviour of the host larvae (Leyva et al. 1991). Mass-rearing is possible in the laboratory and rearing and life history studies are reported by Bess and Haramoto (1961) and Greaney et al. (1976). The following (mostly colour) varieties, although they may be sibling species, are mentioned in the literature: var. *longicaudata* (prob. = *chocki*), Philippines; var. *comperei* (prob. = *compensans*), South India; var. *formosanus*, Taiwan; var. *malaiaensis*, Malaysia; var *novocaledonicus*, New Caledonia; and var. *taiensis*, Thailand.

Dirhinus anthracia Hymenoptera: Chalcididae

This species occurs naturally in East and West Africa. It was established in Hawaii against *C. capitata*, but was also found to parasitise *Bactrocera cucurbitae* (up to 17%) and *B. dorsalis* (Nishida 1955). It was introduced to Fiji, but not established. It was recorded amongst parasitoids reared in 1949 to 1950 from Australian fruit flies (Clausen et al. 1965), although not reported in the 1960 to 1962 surveys of Snowball and Lukins (1964) which did not sample field puparia. For rearing of this pupal parasitoid see Chong (1962) page 452.

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Fopius arisanus (Synonym: *Biosteres* (or *Opius*) *oophilus*) Hymenoptera: Braconidae

This species extends naturally from southern India to Taiwan. *F. arisanus* has been reared from many hosts including *B. dorsalis*. It has been established (as *Opius oophilus*) in Australia, Costa Rica, Fiji, Hawaii and Mauritius and was also introduced to north-western USA, Guam, Mexico and Italy, but not recovered (Wharton and Gilstrap 1983). This species is believed to be the major factor in the reduction of oriental fruit fly in Hawaii and probably has also reduced populations of Mediterranean fruit fly. Attempts to obtain similar results in other countries or on other hosts have not been as successful.

F. arisanus is the only fruit fly parasitoid so far known that oviposits in the eggs of its host (van den Bosch and Haramoto 1951). The female inserts her ovipositor through the oviposition puncture made by the host fruit fly and may spend an hour or more probing to reach as many eggs or freshly hatched larvae as possible. Host eggs that are probed suffer high mortality, even without receiving a parasitoid egg. After the 1st instar parasitoid larva has hatched from the egg, it ceases development until the host pupates, whereupon development proceeds rapidly. Superparasitism is common, with up to three eggs being deposited in a single host egg. At optimum temperatures, the life cycle occupies 18 to 20 days: 28 to 35 hours for egg incubation, 5 to 8 days for the pupal stage and a variable period for larval life depending upon the rate of development of the host larvae. *F. arisanus* larvae prevent the development of *F. vandenboschi* and *D. longicaudata* larvae when they occur together in the same larva of *B. dorsalis* (van den Bosch and Haramoto 1953). There is a premating period for the male of 5 to 6 days. Adults reared from field-collected material show a ratio male:female of 1:1.8. Females are rarely seen on fallen fruit (van den Bosch et al. 1951). *F. arisanus* can be mass-reared in the laboratory and details are given by Chong (1962), Ramadan et al. (1992) and Wong and Ramadan (1992). Behaviour is dealt with by van den Bosch and Haramoto (1951) and biology by Bess and Haramoto (1961).

Fopius vandenboschi (Synonyms: Biosteres or Opius vandenboschi)
Hymenoptera: Braconidae

The native range of this species includes northern India, Thailand, Malaysia, the Philippines and Taiwan. It has been introduced and established in Hawaii and introduced but not established in Australia, Costa Rica, Guam, Fiji and Mexico. Native hosts include *B. dorsalis*, but it has been bred in the laboratory on, amongst other species, *C. capitata* and *B. tryoni*. It can be readily mass-reared in the laboratory.

Oviposition occurs through the fruit fly oviposition puncture into the newly hatched fruit fly larvae rather than into the eggs. After hatching, the 1st instar larva does not moult again until the host larva pupates. Adult females are rarely seen on fruit on the ground and appear to concentrate their attention on

mature green and ripe fruit on the tree. The proportion of males to females in field collected material was 1:1.8.

Psyttalia concolor (Synonym: *Opius humilis*) Hymenoptera: Braconidae

This is an African species which has been established in Hawaii and Bermuda. It has been introduced to Australia, Algeria, Egypt, Fiji, New Caledonia, Costa Rica, Puerto Rico, Spain, Italy and Greece, but is apparently not established. Native hosts include *C. capitata* and it has been bred in the laboratory on other hosts including *Bactrocera passiflorae*. Oviposition generally takes place into the fully-grown fruit fly larva, although younger larvae may be successfully parasitised. Oviposition can start on the day that the female emerges and 250 eggs or more may be laid in the next 3 weeks. The female may live for 3 or more months. The period from egg to adult is 15 to 17 days at optimal summer temperatures and there is no larval diapause (Pemberton and Willard 1918). In the Mediterranean, the life cycle details are somewhat different with adult survival only 15 to 20 days and a pre-oviposition period of 4 to 5 days (Biliotti and Delanoue 1959).

Psyttalia incisi (Synonym: *Opius incisi*) Hymenoptera: Braconidae

This species occurs naturally in India, Thailand, Malaysia, Borneo and the Philippines and has been established in Hawaii. It was released in Australia and Mexico, but has not been recovered. Native hosts in Southeast Asia include the *B. dorsalis* complex and it can be mass-reared in the laboratory. It could not be bred successfully in *B. cucurbitae*. The female has a moderately short ovipositor and this species is recovered mainly from small host fruits.

Tetrastichus giffardianus Hymenoptera: Eulophidae

A native of South Africa, *T. giffardianas* was introduced and established in Hawaii to combat *C. capitata*. It also attacks *B. dorsalis*. If *T. giffardianus* oviposits in larvae of *B. cucurbitae*, the parasite is unable to develop. However, if *Psyttalia fletcheri* oviposits in larvae of *B. cucurbitae* before *T. giffardianus*, the latter is able to develop normally (Pemberton and Willard 1918). Information on its biology in Hawaii is provided by Ramadan and Wong (1990).

COMMENTS

Although there are some 80 species of fruit fly in Australia, only 7 have any significant effect on horticulture. Two of these, the native *B. tryoni* in eastern Australia and the introduced *C. capitata* in Western Australia (see separate account), far surpass the others in number of hosts and the extent of damage they cause.

It is legitimate to raise the question of whether biological control is relevant for largely unseen quarantine pests which infest the saleable portion of a plant. For nearly 100 years biological control programs have been mounted against some 10 species of tephritids, but adequate control, even in relation to the home market,

has never been achieved. Why then persist? Biological control, at best, can only lead to a substantial lowering of the pest population (which happened in Hawaii for both oriental fruit fly and medfly) and not to eradication, which is really required for export. In spite of this limitation, the benefits of even a modest level of control should not be casually dismissed. This is because a lowering of fly populations can lead to less-preferred hosts completely escaping attack and to a lower level of attack even on preferred hosts (Clausen et al. 1965). Both effects will decrease the probability that dead eggs or larvae will occur in produce treated for export, a highly desirable outcome (Baker et al. 1990). Furthermore, the home grower will benefit by the need for less trimming or discarding. Nevertheless, it must be recognised that the chances are likely to be far more remote for substantial biological control of a native pest (such as *B. tryoni*) than for an exotic species if it is controlled by natural enemies in its native range.

Concern has been expressed by opponents of classical biological control that the introduction of exotic natural enemies may threaten the survival of non-target, native species related to the target pest. Although this is a valid concern, there is, as yet, no single confirmed example of the eradication of an arthropod species as a result of classical biological control. This is despite the very large number of species introduced and minimal consideration given to specificity until quite recent times. There is no doubt, of course, that populations of a few non-target species have been reduced by non-specific introductions, but opinions clearly differ on the importance of this reduction compared with the major benefits that frequently result from the reduction of the pest population.

With the exception of possible interference with the effectiveness of biological control agents that are already proving valuable, it appears that the theoretical disadvantages to the environment as a whole through classical biological control may well have been overstressed, compared with the actual advantages.

Opinions will, nevertheless, continue to differ, at least until solid evidence is obtained on the effects on non-target species. A recent study deals with the effects of the biological control of fruit flies program in Hawaii (Messing and Duan 1998). In this, during the past 100 years over 100,000 parasitoids of 40 different parasitoid species were reared (Clancy 1952a,b), many released, and some 10 species have become abundant. Yet, not a single, deliberately-introduced fruit fly parasitioid has been recovered from any of the 26 endemic Hawaiian tephritids, most of which are seed feeders living in flowerbuds, and the rest stem miners or gall formers. Only one of the five exotic, beneficial tephritids introduced over the years for weed control is regularly attacked by the introduced parasitoids. This is the lantana gall fly, *Eutreta xanthochaeta*, which is not a significant biological control agent of its target weed, *Lantana camara* (Perkins and Swezey 1924).

A significant factor in this failed Australian attempt at biological control may be that *B. tryoni* is native to Australia, whereas the exotic parasitoids introduced were not adapted to parasitising it effectively in the field. Another possibility is that the parasitoids are unable to locate or reach immature stages of *B. tryoni* in cultivated fruits because of their size. It should be noted that the attempt at control does not fall into the category of classical biological control, where the pest is exotic and natural enemies are introduced from its native range. By contrast, the species of parasitoid that became established in Hawaii came from a region where *B. dorsalis* occurs naturally and thus were presumably already pre-adapted to that host.

It seems probable that neither the native parasitoids already present in Australia, of which there are several, nor any so far known overseas, have characteristics that would enable them to maintain *B. tryoni* populations substantially below those that exist today.

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Ceratitis capitata (Wiedemann) Diptera: Tephritidae
Mediterranean fruit fly, medfly

PRECIS

Ceratitis capitata is probably native to equatorial Africa, but has spread to many countries including Australia, where it has been present continuously in Western Australia since 1895. It was present in eastern Australia from 1898 to 1941, when it disappeared. The attempts at biological control of *C. capitata* and *Bactrocera tryoni* are closely linked and many relevant aspects are covered in the account dealing with the latter species (target pest no. 70). There is a very extensive literature on the (moderately successful) biological control of *C. capitata* in Hawaii, where it and the oriental fruit fly, *Bactrocera dorsalis* have been subjected to lengthy and major biological control campaigns.

After failures of several introduced parasitoids to maintain themselves on *C. capitata* in Hawaii, these same species did so following their establishment on *B. dorsalis* when this species arrived some years later. None of these parasitoids are believed to have become established on *C. capitata* when introduced to Australia. If further biological control of *C. capitata* in Western Australia is to be attempted, as yet untried parasitoids attacking it in its native home in Africa would appear to be worthy of investigation.

BIOLOGY

Adult *Ceratitis capitata* live a maximum of 52 days at 35°C (mean 16 days) and up to 566 days at 18°C (mean 177 days) (Bodenheimer 1951). Males are able to mate the day after emergence, but the pre-ovipositional period of females is 2 to 3 days (compared with 7 to 8 days for *Bactrocera tryoni* at 25°C). However, wild flies may take 1 to 2 weeks after emergence to mature, during which time they must find a source of protein and carbohydrate. They are comparatively weak fliers and, if adequate food is available, seldom travel more than a few hundred metres unless carried by wind, although movements over 20 km have been reported (Fletcher 1989).

One to 10 eggs are deposited at a time in an oviposition puncture, which may heal over and become invisible, especially in immature hosts. Several females (or the same female again) may oviposit into the same puncture. A female may lay 300 or more eggs in a lifetime. The tunnelling by larvae into the host fruit leads to decay, which may cause premature drop of the infested fruit. Larvae usually pupate in the soil at depths of 5 to 15 cm. Male *C. capitata* are attracted to trimedlure: t-butyl trans 4 (or 5) -chloro-2-methyl cyclohexane carboxylate.

C. capitata is the most widespread and thus possibly the world's most economically important fruit fly pest. It is thought to have originated in equatorial Africa, and from there it spread to countries around the Mediterranean. Later, it spread to all other continental regions except for most parts of Asia and North America, although from time to time there have been outbreaks in California, but these have been eradicated (or reduced to undetectable levels) (Carey 1991a,b). In the Pacific, it occurs in Hawaii. It is well established on a number of islands in the Atlantic and Indian Oceans (White and Elson-Harris 1992). *C. capitata* is often cited as one of the ablest colonisers of any tephritid. However, it may actually not be a good coloniser, because it has not established generally in the Pacific or in Asia, but rather a tenacious and persistent competitor once rare colonisation does occur (Carey 1991a,b).

Possibly due in part to the strong competition posed by the 80 or so species of native Australian fruit flies, only three exotic pest species have managed to establish themselves in Australia. These are the Mediterranean fruit fly, *C. capitata* (in Western Australia since 1895), the mango fruit fly, *Bactrocera frauenfeldi* (in Cape York, Queensland since 1972), and the papaya fruit fly, *Bactrocera papayae* (near Cairns, Queensland since 1995, but probably eradicated). Of these three species, biological control has been attempted only against *C. capitata*. Permanent populations of *C. capitata* now only occur in Western Australia, where it remains a serious pest. In 1898, not long after it had appeared in the west, it was recognised in Sydney and rapidly became the dominant pest of orchards and domestic fruit, both there and further south. It continued to be a very common species up to the mid-1930s when its numbers started to dwindle and it finally disappeared in 1941 through, as yet, unconfirmed causes (see comments page 319). It has been recorded in Adelaide, South Australia in 19 of the years from 1948/49 to 1986/89 (and *B. tryoni* in 34 of these years). All the infestations were tackled vigorously and eradicated or reduced to undetectable levels (Maelzer 1990 a,b; Carey 1991a,b). Spatial outbreaks in one year bear no relationships with outbreaks in the following year, and numbers of flies trapped each year are strongly correlated with weather in that year (D.A. Maelzer, pers. comm.). Unsuccessful attempts have been made since 1901 to eradicate *C. capitata* from Western Australia and these continue to the present time.

PEST STATUS

C. capitata attacks a very wide range of commercial and wild fruits, but a more limited range of vegetables (White and Elson-Harris 1992). It does not attack pineapple nor, up to harvesting stage, the varieties of banana and avocado grown in Hawaii (Armstrong 1983; Armstrong et al. 1983).

It is of major economic importance in Western Australia where, until the appearance of *B. tryoni* in 1988 (eradicated in 1990), it has been the only fruit fly attacking commercially-grown fruits. For the 40 years or so from 1898, when it appeared in eastern Australia, it also caused extensive economic damage there until it disappeared in 1941.

Many of the comments concerning the pest status of *B. tryoni* apply equally to *C. capitata.*

BIOLOGICAL CONTROL

World overviews of classical biological control of medfly have been published by Wharton (1989a,b) and there have been many papers dealing with the situation in Hawaii. Following the emergence of *C. capitata* as a serious pest in Western Australia about the turn of the century, several fruit fly parasitoids were shipped in 1903 from India, but they arrived dead, following pre-departure fumigation. Unsuccessful introductions and liberations in the west from Brazil followed in 1904 and 1905 of several predaceous staphylinid beetles (one possibly *Belonuchus rufipennis*) and three parasitic wasps (*Doryctobracon aerolatus, Opius bellus, Trybliographa braziliensis*) (Wilson 1960; Clausen 1978a).

Aceratoneuromyia indica was introduced from India in 1907 and 250,000 liberated in Western Australia between 1908 and 1910. It, and an unidentified braconid, also from India, were recovered in the field, but did not become established (Wilson 1960).

Following the detection of medfly in Hawaii in 1910, an expedition lasting many months to find natural enemies was mounted along the west coast of Africa on behalf of the Hawaii Department of Forestry and Agriculture (Silvestri 1914). Only two adults and four Mediterranean fruit fly puparia were collected (Carey 1991b), although 16 parasitoid species were bred from 18 species of tephritid. If the very low numbers of Mediterranean fruit fly in this part of its native range was due to natural enemies, it would clearly be desirable to investigate their use; a number of species were subsequently introduced to Hawaii.

In Australia, the next attempt at biological control was when three shipments of parasitised Mediterranean fruit fly puparia were obtained from Hawaii. In addition to abundant *Diachasmimorpha tryoni,* a native species previously shipped from Australia to Hawaii where it parasitised *C. capitata* (Ramadan et al. 1989), there were three exotic species. From these shipments,

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several thousand *Tetrastichus giffardianus* were released near Sydney in 1932 and 1933, together with small numbers of *Biosteres fullawayi* and *Psyttalia concolor* but these did not become established. In 1937, *A. indica* was received from India and mass-cultured. Some 205,000 were liberated in New South Wales and an unspecified number in Queensland. At the time of the foregoing liberations *C. capitata* was present in eastern Australia and also, of course, *B. tryoni*, but none of these parasitoids became established on either target host (Noble 1942).

During 1948 to 1950, a major program of parasitoid introductions took place into Hawaii against, in particular, the oriental fruit fly, *Bactrocera dorsalis*, but also against *C. capitata*. Populations of both (and particularly *B. dorsalis*) were considerably reduced. About that time (and before *Fopius arisanus* was established) the most effective parasitoid on *C. capitata* in Hawaii was the Australian *D. tryoni* (Clausen 1956).

It was demonstrated, by exposing artificially-infested fruit, that *C. capitata* was parasitised in the field in Hawaii by *Diachasmimorpha longicaudata*, *F. arisanus*, *Fopius vandenboschi* and *Psyttalia incisi* (Clancy 1952a,b). However, *F. arisanus* showed a strong preference for fruit infested with eggs of *B. dorsalis* over eggs of *C. capitata* (Harris et al. 1991). Large numbers of the above parasites, at first reared in Sydney and later mainly in Hawaii, were rigorously screened in quarantine in Sydney to exclude any fellow travellers and a portion of the rearings were liberated between 1956 and 1959 in 12 locations in Western Australia that were heavily infested with *C. capitata*. The numbers liberated were 16,700 *D. longicaudata*, 20,400 *F. arisanus*, 2100 *F. vandenboschi* and 5800 *P. incisi*. In spite of the relatively large numbers liberated, there is no evidence that any became established (Snowball et al. 1962b).

Some further information on the above parasitoids is provided in the account dealing with *B. tryoni*.

Comments

It is clear that the interactions between medfly, its natural enemies and tephritid competitors are far from simple and that a number of aspects are worthy of further investigation.

Several introduced parasitoids that are now attacking *C. capitata* in Hawaii have failed to establish on it when liberated in Australia. These include not only three Southeast Asian species — *F. arisanus*, *F. vandenboschi* and *D. longicaudata* —from well outside its native range, but also *B. fullawayi* and *P. concolor*, which come from its presumed native range in Africa. To what extent they parasitise medfly in its native range, however, is not known.

It is interesting to note that the parasitoid species that have given greatest control of the oriental fruit fly in Hawaii, *F. arisanus*, *F. vandenboschi*, *P. incisi* and *D. longicaudata* (in descending order of effectiveness) have also provided the

greatest control there of *C. capitata* (Bess et al. 1961). Some years before oriental fruit fly was accidentally introduced, all of these had been released in Hawaii against medfly, but apparently did not become established. After oriental fruit fly became established they were again released in considerable numbers, whereupon they all became established. Wharton (1989a,b) has raised the possibility that the parasitoids might have established during the first introductions, but remained at very low levels, to increase greatly when a better host, the oriental fruit fly, became available. Whether or not this is so, there is a distinct possibility that, in the absence of suitable alternative hosts, these parasitoids are unable to maintain effective numbers on medfly. If this is so, any further attention should, perhaps, be directed to species that attack medfly within its native range in Africa but are as yet untested. Several possibilities are listed by Wharton (1989a).

In relation to tephritid competitors, it would appear that *C. capitata* has suffered greatly from the presence of *B. tryoni* in Australia and *B. dorsalis* in Hawaii. When *C. capitata* appeared in Sydney in 1898 and rapidly built up to pest numbers, *B. tryoni* (primarily a rainforest species) was not regarded as a pest as far south as this. Indeed, for the next 20 years or so, the majority of records of fruit flies in New South Wales refer to *C. capitata*, not *B. tryoni*. Mediterranean fruit fly spread rapidly into country districts west of the Dividing Range, south-west to the Murrumbidgee Irrigation Area and Albury and was even recorded from Melbourne and Tasmania. Then the picture changed: *C. capitata* began to disappear and its place was increasingly taken by *B. tryoni*. By the mid-1930s, the latter was clearly the dominant species. *C. capitata* numbers continued to dwindle until the last seen in eastern Australia was collected in 1941 (Bateman 1971). This is the only example of medfly disappearing due to 'natural' causes from an area where it had become established. Thus took place a truly spectacular elimination of a well-established, polyhagous pest from a vast area containing an abundance of suitable hosts — a highly unusual occurrence not closely paralleled before.

Support for the theory that *C. capitata* was eliminated from eastern Australia due to competition with *B. tryoni* is supported by the adverse interaction between *C. capitata* and oriental fruit fly in Hawaii. *C. capitata* was introduced there in 1911 and soon became a widespread and serious pest. When *B. dorsalis* appeared much later (in 1946), it rapidly displaced *C. capitata* as the major pest at low altitudes. Indeed, by 1949 *C. capitata* was reduced to occurring in less than 5% of lowland guava samples, although it was more abundant in some fruits at higher altitudes, where it continued to be an important pest. Epidemic densities were reached by *B. dorsalis* during 1948 to 1951, with 100% of guava and other fruits being infested and up to 200 eggs per fruit being common.

Keiser et al. (1974) showed that the survival of *C. capitata* larvae in guava was greatly reduced (sometimes to zero) when *B. dorsalis* larvae were present, although both species developed together normally on artificial medium. Explanations for the effect in guavas range from a lethal factor, or growth

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suppressant, for *C. capitata* produced by *B. dorsalis* larvae, to the bacterial symbionts associated with *B. dorsalis* larvae producing chemicals toxic to *C. capitata*, and to the exhaustion of available food by the faster-developing *B. dorsalis* larvae (Fitt 1989).

In the case of *B. tryoni* (and presumably the same applies to *B. dorsalis*), females are extremely aggressive when ovipositing and will not tolerate the presence of other females of whatever species. This behaviour may also play a role as it might often prevent *C. capitata* from laying in suitable hosts.

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Haematobia exigua de Meijere Diptera: Muscidae buffalo fly

This species has also been referred to as *Siphona exigua* or *Lyperosia exigua*. It is very closely related to the European and American *Haematobia irritans* (Mackerras 1933) and some authors use *Haematobia irritans exigua*, thereby reducing the status of the Australian material to that of a subspecies (Pont 1973).

PRECIS

The dung-breeding buffalo fly, *Haematobia exigua*, is a pest in northern Australia because it sucks blood from cattle and horses. Native natural enemies attack the larvae, but are unable to maintain adult numbers low enough to prevent considerable irritation, blood loss, skin lesions and reduction of live weight gain. The introduction of the parasitoid *Spalangia nigroaenea* from Indonesia failed to improve the situation.

More recently, significant alleviation is reported from some inland areas where introduced dung-dispersing beetles are well established. However, the buffalo fly remains a pest in higher rainfall areas, where there are niches which currently-established dung beetles do not occupy effectively.

BIOLOGY

Adult *Haematobia exigua* females leave their host animals briefly to deposit all their mature eggs, a few at a time, on the dung of cattle as soon as it is excreted. Eggs usually hatch within 18 hours of being laid and larvae feed within the dung for 3 to 5 days, moving to drier parts to pupate (Roberts 1931, 1941). They can also develop in the dung of wallabies, pigs, rabbits and guinea pigs, although adult flies have not been observed to feed on such animals (Windred 1933). The pupal period is 3 to 5 days, leading to an oviposition to adult period varying from 7 to 11 days under summer conditions (Roberts 1941).

High temperature and humidity are necessary for development, 22°C being the lowest temperature for effective reproduction (Pont 1973), and 85% to 88% moisture content of the dung being optimal.

The buffalo fly is native to Southeast Asia. It is believed to have arrived in Darwin with early herds of buffalo, probably about 1838, from Indonesia. For a time, it was restricted to the Northern Territory, but about 1910, during favourable seasons, it gradually extended its distribution first to the Kimberley region of Western Australia and later in 1928 to Queensland (Pont 1973) where it is now a problem as far south as Brisbane. In more recent times (mid-1970s) it has also invaded northern New South Wales.

PEST STATUS

The adult *H. exigua* is the only stage to cause damage to stock. Damage results from adults sucking blood repeatedly from the cattle or horses on which they rest, only leaving them to oviposit on faeces as soon as these are voided. It has also been recorded biting humans, sheep, pigs and dogs, usually when those are near cattle. Large numbers, into the thousands, cause considerable irritation, mainly through their bites. Irritation causes reduction in weight gain by reducing food intake, particularly on poor pasture (Roberts 1941). Substantial loss of blood may lead to weight loss and the sores, resulting from licking and rubbing to alleviate the discomfort from the bites, reduce the suitability of the hides for tanning.

In Malaysia, the volume of blood ingested per fly averaged 1.4 ¨µL per day and buffalos averaged 5525 flies per head (Fadzil and Ragavan 1985).

Bovine stephanofilariasis caused by *Stephanofilaria* spp. is transmitted in Queensland by *H. exigua* (Anon. 1984; Johnson et al. 1986) and many other diseases are believed to be transmitted (Pont 1973).

BIOLOGICAL CONTROL

Table 30 page 327 lists native enemies of buffalo fly larvae recorded in the early 1930s (Mackerras 1932). Earlier, Hill (1917) recorded that eggs are preyed upon by the ants *Solenopsis geminata* var. *rufa, Iridomyrmex purpureus* and *Odontomachus ruficeps*. He also found that adults were preyed upon by birds, such as the northern fantail, *Rhipidura rufiventris*, and by insects, such as the fossorial wasp *Sericophorus relucens*. Handschin (1932) found that the staphylinid beetle *Anotylus ocularis* rapidly destroyed fresh dung pads at the end of the wet season, working mainly in horse dung. The pupa is parasitised by the diapriid wasp *Phaenopria fimicola* and the staphylinid beetle *Aleochara windredi* (Handschin 1934). At that time, their combined activity was inadequate to prevent the buffalo fly being regarded as a serious pest. Since it was not considered a pest of any significance in most parts of Indonesia, from which it came, investigations were undertaken of its natural enemies there (Anon. 1928; Tillyard 1931; Handschin 1932; Krijgsman and Windred 1933). These led to the introduction to the Northern Territory in 1932 and 1933 of the most promising natural enemy, the pupal parasitoid *Spalangia nigroaenea*. This interbred readily with the native *S.*

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endius, which was already parasitising buffalo fly puparia (Mackerras 1932; Handschin 1933). Both species and their hybrid were released in the Northern Territory and Western Australia in 1932 and 1933. However, there was no observable effect on buffalo fly abundance and the parasitisation of buffalo fly puparia remained at a low level (Campbell 1938). It is not known whether *S. nigroaenea* failed to become established or whether its identity has been submerged by hybridisation with *S. endius* (Wilson 1960).

Additional studies in Java by Windred (1933) led to the conclusion that the often low density there was mainly because the dung was frequently rendered unsuitable for breeding by high rainfall either directly, or because its consistency, as produced, was too liquid. Nevertheless, buffalo fly eggs are far less susceptible to drowning either due to rainfall or in bovine dung fluids, than those of the bush fly. The latter may be one reason why dung beetles have had less effect on buffalo fly abundance than on bushfly abundance in coastal Queensland (Walker and Doube 1984). Another mortality factor is the presence in this area of the coastal brown ant, *Pheidole megacephala*, which is a ubiquitous predator of soil organisms and may well exert an effect on the abundance of buffalo flies and bushflies through destruction of their larvae and puparia (K.R. Norris, pers. comm.).

Larvae of the muscid flies, *Hydrotaea* spp., are predatory on other dipterous larvae in dung and adults cause no obvious inconvenience to cattle. *Hydrotaea dentipes* was introduced from England in 1928, but a culture could not be established, so it was not liberated. It was not introduced again because larvae of the native *H. australis* were found to be already attacking buffalo fly larvae in dung in Australia and doubts were cast on the value of liberating a closely-related species less well adapted to the Australian climate (Mackerras 1932; Wilson 1960). Puparia of *H. australis* are attacked by the native parasitoids *Spalangia endius* and *Phaenopria* sp., but apparently not as readily as those of the buffalo fly (Mackerras 1932).

Myers (1938) found that parasitoids were unimportant in the control of *Haematobia irritans* in Haiti, but was more impressed with the histerid predator *Hister coenosus*. Some were sent to Australia in 1939, but arrived dead.

Pactolinus chinensis (Histeridae), which had been successfully introduced to Fiji from Java in 1938 for housefly control (Lever 1945), was liberated near Cairns, Queensland from 1944 to 1946 and is firmly established (Legner 1978). Both adults and larvae are recorded attacking buffalo fly larvae.

Two South African species, *Hister nomas* and *Pactolinus caffer*, were introduced from Hawaii in the 1960s. Both are established and the former is widespread (Tyndale-Biscoe 1996).

A second phase of attempts to control buffalo fly commenced in the 1970s, with the introduction of dung-burying beetles, mainly from southern Africa. The principal reason for the introductions was to disperse bovine dung pads to reduce their smothering effects on pasture. It was also hoped that they would greatly

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reduce the availability of dung as a breeding ground for pest flies, including the buffalo fly, the bush fly (*Musca vetustissima*) and the stable fly (*Stomoxys calcitrans*). The beetle introductions are dealt with under *Musca vetustissima* (target pest no. 75). Those liberated in the warmer areas of Australia, where *H. exigua* occurs, are listed in Table 1 page 29. Of the early liberations, *Onthophagus gazella* was the most successful species, spreading rapidly, building up to large numbers under suitable conditions and burying cow-pats in 2 to 3 days. It was estimated at the time that the buffalo fly population was reduced by 80% to 100% (Bornemissza 1976), although the suppression has been less than this in more recent times. Thus, at Rockhampton, Queensland fauna-induced mortality of *H. exigua* was estimated at 66.7 ± 9.8% (Doube et al. 1988).

Large predatory mites of the *Macrocheles glaber* group that are phoretic on (carried on the surface of) dung beetles attack the eggs and very young larvae of dung-inhabiting Diptera, including those of *H. exigua* and the bush fly, *M. vetustissima*. Although *M. glaber* and *M. perglaber* are widespread and abundant in south-eastern Australia, no large mites of this group have been found in northern and western parts of the continent (Wallace and Holm 1983; Wallace et al. 1979).

Large mites are more effective predators of fly eggs and young larvae than smaller species. Buffalo fly eggs have a comparatively thick chorion, much thicker than that of bush fly eggs, and only large mites are able to attack them successfully (Halliday and Holm 1987).

A large phoretic, predatory mite, *Macrocheles peregrinus*, was selected for introduction because of its wide distribution in southern Africa, its relatively high abundance there and the large number of dung beetle species on which it is phoretic. These include most of the African species established in northern Australia. Individual mites are able to kill 8 to 10 fly eggs per day at high egg densities, many more than they consume. *M. peregrinus* attacks eggs at any stage of development and also newly hatched larvae. Its effectiveness as a predator thus extends to about 24 hours after fly oviposition, most of which occurs soon after, and all within 3 hours of, dung pad production (Doube et al. 1986). *M. peregrinus* from South Africa was released in 1980 at Rockhampton, Queensland and in 1981 at Adelaide River, Northern Territory. Establishment was achieved immediately and the mite soon became very widespread. This is probably because of its ability to use dung beetles to carry it from one dung pad to another and also because it is able to complete its life cycle within 3 days at 27°C (Wallace and Holm 1983). Mites acting alone caused an average of 33% suppression of *H. exigua* breeding in field pads. However, they showed a strong preference for eggs of other muscid fly species with softer chorions (e.g. *Neomyia lauta*). *M. peregrinus* was judged to be a relatively ineffective buffalo fly predator (Roth et al. 1988a). Doube et al. (1986) were unable to demonstrate that *M. peregrinus* caused a reduction in buffalo fly abundance, although it is clear that, when present

in considerable numbers in a dung pad, as it often is, it must be causing considerable buffalo fly mortality, although part or all of this might be substitute mortality. By contrast, the activity of the introduced dung beetles, in particular, and other predators periodically caused significant reductions in the numbers of flies emerging from dung pads (Roth et al. 1988b). Fauna-induced mortality at Rockhampton, Queensland averaged 79% (Fay et al. 1990) and 66.7% (Doube et al. 1988) in two different trials.

Queensland graziers in some drier, inland regions reported, in January 1999, that buffalo fly numbers were reduced to such an extent that control measures were no longer required (J. Feehan, pers. comm.). This was attributed mainly to the rapid destruction of dung pads by dung beetles, but *M. peregrinus* may also be contributing valuable predation. Graziers in higher rainfall areas still reported problems.

COMMENTS

Comparisons were made between the fauna-induced mortality in southern Africa (of *Haematobia thirouxi potans*) and in Queensland (of *H. exigua*). In the Transvaal, where dung removal by dung beetles was considerable and rapid, the mean fauna-induced mortality was 97.6%. In Natal, fauna-induced mortality was 92.8% in grassveld and 84.3% in bushveld and much of this mortality was attributed to the activity of predators or parasitoids.

In Queensland, the fauna-induced mortality (66.7%) was significantly lower and more variable than in southern Africa. It was postulated that the African fauna may contain species of dung beetles, predators or parasitoids that, if introduced to Australia, would help to increase and stabilise the level of fauna-induced mortality of immature stages of *H. exigua* (Doube 1986; Doube et al. 1988).

The majority of dung beetles so far introduced favour dung in open pastures and are far less abundant in dung in lightly wooded situations. The dispersal of dung dropped in open pastures is thus far greater than elsewhere, although seldom sufficiently complete to prevent some buffalo flies from being produced. Nevertheless it is in lightly wooded situations that largely undisturbed dung pads still remain available in quantity for fly breeding. Since buffalo flies remain on hosts which enter wooded situations, they are available to deposit eggs on any dung produced there by day or by night. There is good reason, therefore, to suggest that the introduction of additional beetle species adapted to lightly wooded environments might significantly reduce the buffalo fly problem in the vast areas which are lightly wooded.

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Table 30. Indigenous natural enemies of *Haematobia exigua*

Species	Stage attacked	Reference
HYMENOPTERA		
DIAPRIIDAE		
Phaenopria sp.	puparia	Mackerras 1932
PTEROMALIDAE		
Spalangia endius	puparia	Mackerras 1932
DIPTERA		
MUSCIDAE		
Hydrotaea australis	larvae	Mackerras 1932
COLEOPTERA		
HISTERIDAE spp.	larvae, puparia	Fullaway 1922
SILPHIDAE sp.	larvae, puparia	Fullaway 1922
STAPHYLINIDAE spp.	larvae, puparia	Fullaway 1922
? *Oxytelus* sp.		Mackerras 1932
Philonthus minutus	eggs	Fincher & Summerlin 1994

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Lucilia cuprina (Wiedemann) Diptera: Calliphoridae
Australian sheep blowfly

Lucilia cuprina is responsible for initiating most sheep blowfly strike in Australia (Mackerras and Fuller 1937; Waterhouse and Paramonov 1950). Since biological control was aimed at reducing blowfly strike, *L. cuprina* was its principal target. However, other species are also involved in blowfly strike, in particular four native brown blowflies — *Calliphora augur* and *C. stygia* in eastern Australia and *C. dubia* and *C. albifrontalis* in Western Australia. Two other native species are important as secondary invaders of strike wounds, *Chrysomya rufifacies* and *C. saffronea*. Their larvae compete strongly and effectively against those of the primary species and those of *C. rufifacies* prey voraciously on them.

PRECIS

The Australian sheep blowfly, *Lucilia cuprina*, is the principal species attacking sheep in Australia. Although its larvae are attacked by a number of parasitoids and predators, these have a negligible effect on sheep blowfly population density, even when mass-reared and released. Since *L. cuprina* seldom breeds successfully in carrion, its numbers are regulated mainly by the availability of susceptible living sheep on which to breed and on the effectiveness of control measures to prevent this. Fierce inter-specific competition for food in carcasses and the high temperatures generated by the massed activity of maggots lead to very few *L. cuprina* being produced from dead sheep (Waterhouse 1947). It is concluded that *L. cuprina* is not a suitable target for biological control.

BIOLOGY

The gravid female *Lucilia cuprina* is attracted to lay its eggs on susceptible living sheep. In most instances, this occurs many hours before other species are attracted to do so. Sheep become susceptible because of skin irritation due to continuous moistness from urine and faeces in the crutch area; or elsewhere on the body because of bacterial or fungal-produced fleece rot, with underlying skin irritation. Each female *L. cuprina* lays a batch of 200 to 250 eggs at a time. On hatching

about 24 hours later, the young larvae move to the skin surface. This they abrade with their sharp mouth hooks, causing serum to exude, which they ingest. Further abrasion invades skin tissues and a progressively deepening wound is produced, in which a seething mass of maggots develops. After about 3 days, fully grown 3rd instar larvae drop to the ground and bury themselves in the soil. There they pupate and, after some 12 to 15 days depending upon the temperature, emerge as adults. Females normally need to obtain protein-rich food before maturing eggs. Then, 2 or 3 days later and after mating, they are able to begin oviposition. The life cycle takes about 3 weeks in warm weather.

L. cuprina occurs as two subspecies, which are morphologically indistinguishable: a dull olive-bronze *L. cuprina cuprina* and a brilliant coppery or blue-green *L. cuprina dorsalis*. Only the latter attacks sheep. *L. cuprina dorsalis* is also known from South Africa and it was probably introduced from there in the late 1800s. There are no records of strikes in Australia before 1883 (JBC 1933; Mackerras 1936; Waterhouse and Paramonov 1950) and, as recently as the 1930s, *L. cuprina dorsalis* was still gradually spreading up the coast of Western Australia (Mackerras and Fuller 1937; Jenkins 1945).

PEST STATUS

The attack of blowfly larvae on the skin of a sheep soon leads to an increase in its body temperature and a reduction or cessation in wool growth. When larval development from a single batch of eggs is completed, or when the strike is treated, growth of wool resumes, but a thinner region is left in the wool fibre. This breaking point not only reduces the effective length of the fibre but also its value. If the strike is not treated and further egg batches are added, septicaemia sets in, often resulting in the death of the sheep. For years, blowfly strike has caused losses running into many millions of dollars. In more recent times, a range of measures, involving reducing skin wrinkles and application of persistent chemicals (Levot and Sales 1998) has greatly reduced losses. However, chemical residues in meat and fleece remain matters of concern, particularly with regard to exports.

L. cuprina dorsalis also breeds in carrion, but is far less successful there. This is mainly because of intense competition for food with other blowfly species which arrive at the same time, or even earlier than it does (Waterhouse 1947). *L. cuprina* seldom enters houses. This is in stark contrast with the native brown blowflies which, particularly in spring and autumn, may enter in large numbers unless prevented from doing so by screening.

BIOLOGICAL CONTROL

The first introduction of a natural enemy was in 1911, when a Japanese sarcophagid fly was brought from Hawaii. This fly was also intended by the

Western Australian Department of Agriculture for use against the housefly, *Musca domestica*, but it did not become established (Jenkins 1946; Wilson 1960).

In 1913 the cosmopolitan pupal parasitoid *Nasonia vitripennis* (Pteromalidae) was discovered in New South Wales and Queensland. For some years from 1914 onwards it was mass-cultured and released in both States, but with no observable effect on sheep blowfly populations. *N. vitripennis* oviposits only in exposed blowfly puparia and it has been estimated that, at most, only 4% are accessible (Wilson 1960). The remaining 96% of larvae bury themselves before pupating, thus making the puparia inaccessible to the parasitoid. *N. vitripennis* was established in Western Australia in 1915, and mass-reared and distributed there until 1925 (Newman and Andrewartha 1930) with no observable effect (Wilson 1960).

The native encyrtid *Tachinaephagus zealandicus*, which is attracted to larvae, was found in Western Australia and was mass-reared and distributed there from 1928 to 1931 (Newman and Andrewartha 1930), but again without effect (Wilson 1960). The exotic braconid larval parasitoid, *Alysia manducator*, was introduced on several occasions, both directly from England and via New Zealand. It was liberated in eastern and Western Australia (Newman 1928) between 1928 and 1930, but failed to become established. Reasons for this failure are discussed by Wilson (1960). The braconid *Aphaereta aotea*, which was introduced to control the bush fly *Musca vetustissima*, is also known to parasitise calliphorid larvae in New Zealand (Heath and Bishop 1989), but it is not known to do so in Australia.

On living sheep, *L. cuprina* larvae are seldom attacked by natural enemies, but face competition from the maggots of other flies and particularly those of the secondary flies. However, when they drop off the living sheep, or when in carrion, they are exposed to attack by a number of parasitoids and predators until they burrow into the soil. Of those listed (Table 31 page 332) the pupal parasitoid *N. vitripennis* and the predators *Creophilus erythrocephalus* (Staphylinidae), and *Saprinus cyaneus* (Histeridae) kill many pre-imaginal *L. cuprina*. Nevertheless they appear to have little overall effect on fly abundance. The predators are native species but it is probable that many of the parasitoids are exotic, although their present widespread occurrence often makes their origin difficult to determine.

Laboratory trials were carried out with the microsporidian pathogen *Octosporea muscaedomesticae*, previously known to infect *Lucilia sericata*. Both adult and larval *L. cuprina* were susceptible and infected females failed to produce offspring. However there is no report of field liberation (Cooper et al. 1983; Smallridge et al. 1990, 1995).

COMMENTS

Although sheep blowflies are attacked by a number of parasitoids and predators, there is no evidence that fly numbers are thereby greatly influenced. On the contrary, there is abundant evidence that both inter- and intra-specific competition between larvae of several blowfly species in carrion for food is the significant factor limiting populations from that source (Fuller 1934; Waterhouse 1947).

On the living, susceptible sheep, adult female *L. cuprina* generally arrive well in advance of other species. *L. cuprina* larvae hatching from their eggs are thus able to develop successfully until other species (and especially the secondary *Chrysomya* flies) add their eggs. Even then, until the death of the sheep, food is not limiting. On the other hand, on carrion, *L. cuprina* does not have the advantage of arriving before other species. Its larvae suffer seriously, from the beginning, from competition for food and are adversely affected by the high temperatures (up to 50°C) generated by the active metabolism of the seething mass of maggots. Few *L. cuprina* survive to maturity. As a result, most of the *L. cuprina* population in sheep-raising country is produced from strikes on living sheep (Waterhouse 1947).

No natural enemies (except humans!) are known that can influence the number of larvae developing successfully in a strike wound. Natural enemy attack on survivors from larval competition would seem to be the only real option for reducing abundance and both *N. vitripennis* and *Brachymeria ucalegon* operate at this time (Fuller 1934). Unlike *N. vitripennis* which oviposits only in puparia, *B. ucalegon* attacks the larvae and is capable of digging and burrowing into carrion and soil in search of them (Fuller 1934). Unfortunately, the rapid burying in the soil by most mature *L. cuprina* larvae once they drop from the struck sheep at night (Smith et al. 1981) means that there is only a very limited time available for predators and parasites to attack them. Very few remain exposed and vulnerable to attack and *B. ucalegon* is only able to find a small proportion of those that are buried. The prospects for successful biological control thus appear to be extremely remote.

The occurrence of covert (or inapparent) strikes, which may persist for periods of months at a time, is known to be common, particularly in dry areas. These may explain the persistence of *L. cuprina* populations during times when overt strike is absent (Wardhaugh and Dallwitz 1984).

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Table 31. Natural enemies of *Lucilia cuprina* and other sheep and carrion-feeding Calliphoridae (Tillyard and Seddon 1933; Fuller 1934; Kitching 1981)

Parasitoids	Predators
HYMENOPTERA	**COLEOPTERA**
BETHYLIDAE	HISTERIDAE
Goniozus sp.	*Carcinops pumilio*
	Saprinus cyaneus
CHALCIDIDAE	*Tomagenius ripicola*
Bephratella sarcophagae	
Brachymeria podagrica	SILPHIDAE
Brachymeria ucalegon	*Ptomaphila lachrymosa*
Dirhinus anthracia	
	STAPHYLINIDAE
DIAPRIIDAE	*Aleochara guerini*
Hemilexomyia abrupta	*Aleochara speculifera*
Paraspilomicrus froggatti	*Creophilus erythrocephalus*
Spilomicrus sp.	*Homalota sordida*
Trichopria quadrata	*Philonthus nigritulus*
	Philonthus politus
ENCYRTIDAE	*Philonthus subcingulatus*
Tachinaephagus zealandicus	
	HYMENOPTERA
PTEROMALIDAE	FORMICIDAE
Nasonia vitripennis	many species
Pachycrepoideus vindemmiae	
Spalangia nigroaenea	**BIRDS**
	Rhipidura leucophrys
	insectivorous species

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mosquitoes Diptera: Culicidae

All species of mosquito that attack humans and livestock have been targets of attempts at biological control. With the exception of three introduced species — *Aedes aegypti, Culex quinquefasciatus* and *Culex pipiens molestus* — all are native to Australia and Kay et al. (1981) list 14 species as major pests.

Vectors of diseases have been of particular concern, e.g. of malaria (*Anopheles farauti* and *Anopheles amictus hilli* in northern Australia; *Anopheles annulipes* in cooler regions), of filariasis (*Culex quinquefasciatus*), of Australian encephalitis, Ross River, Sindbis and Barmah Forest viruses (*Culex annulirostris*) and of Ross River virus (*Aedes vigilax*). Dengue fever is transmitted by the cosmopolitan *Aedes aegypti*, which breeds in containers and is closely associated with human dwellings.

PRECIS

A number of mosquito species are significant pests of humans in Australia because of irritation from their bites and because they transmit diseases. The introduction of exotic mosquito-eating fish has supplemented important predation by native fish species but, in spite of these and other control measures which have reduced or eliminated some problems, mosquitoes continue to be important in many areas.

BIOLOGY

Eggs are laid singly or in batches on the surface of water or on moist substrates which are likely to be flooded. Larvae are aquatic and most species need to come to the surface for air from time to time. This they do by breaking through the surface film of water with their caudal breathing siphon. There are four larval instars. Only females of the pest species suck blood. Males of these species and both sexes of some non-pest species suck plant juices. Larvae are found in still or slowly flowing fresh or polluted water and may colonise temporary pools.

PEST STATUS

The piercing mouth stylets of the female mosquito produce a brief sting as they are inserted into the human skin to obtain blood. Anti-coagulant saliva, which accompanies feeding, induces an immediate or delayed allergic response (itching and swelling), which may last for some days. In most of Australia, the irritation from mosquito bites was (and still is) the major concern. Up until the mid-1940s dengue fever and malaria and, to a lesser extent, filariasis, were still being transmitted in northern Australia, although control of the vector species has led to these occurring only very occasionally, mainly when infected overseas travellers temporarily reintroduce the causal organisms to the mosquito population. Nowadays the mosquito-transmitted diseases that are still endemic are the arboviruses. The most serious, and occasionally fatal, disease is Australian (formerly Murray Valley) encephalitis. Epidemic polyarthritis is caused by Ross River virus and there are also Japanese B encephalitis and Sindbis viruses (Waterhouse 1991).

BIOLOGICAL CONTROL

Mosquito larvae and pupae are preyed upon by a wide variety of invertebrate and vertebrate predators that share their breeding grounds. These include: the predatory larvae of three species of mosquitoes belonging to the genus *Toxorhynchites*; many Hemiptera belonging to the families Corixidae, Gerridae and Notonectidae; Coleoptera belonging to the Drytiscidae; frogs; and fish (Table 32 page 336).

In the early decades of the twentieth century, valuable reductions in the abundance of mosquito larvae were reported in a number of countries, following the introduction of *Gambusia affinis* or other fish species (Bay 1978). In Australia, Stead (1907) suggested the introduction of native *Galaxias* spp. into ponds and tanks and Bancroft (1908) of *Eleotris*, gobies or gold carp. Wilson (1960) has brought together published and unpublished records on a number of species (Table 1 page 29), although the names he used of some species are no longer valid and have been replaced. In addition, *Macropodus opercularis*, reported by Wilson (1960) to have been used is not known to have been released, although it is not an uncommon aquarium fish (M. McGrowther, pers. comm.). The exotic *Gambusia holbrooki* (*G. affinis* does not occur in Australia) has proved to be by far of greatest importance. Although it had already been an aquarium fish for some years, stocks were imported from Italy in 1926 and distributed widely until the 1930s in streams and swamps in New South Wales, Queensland and probably other mainland States (Wilson 1960). During World War II it was again widely distributed by army malaria control units. The general opinion of those concerned with mosquito control at that time was that the establishment of *G. holbrooki*

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reduced mosquito abundance. On the other hand, the use of *G. holbrooki* and the native *Hypseleotris galii* in Newcastle and the north coast of New South Wales was held to be unsuccessful (Wilson 1960). The exotic *Poecilia reticulata*, which had long been an aquarium fish in Australia, was successfully employed against mosquitoes around Brisbane (Hamlyn-Harris 1929), although it was unable to survive the winter in Sydney or Adelaide (Wilson 1960).

The use of *G. holbrooki* for control of mosquitoes in ponds (Bancroft 1908) and of *Perca fluviatilis* in dams in South Australia has been strongly criticised following their spread to some Australian rivers (Whitley 1951). *Heterandria formosa* was found in 1925 to be unsuitable for controlling mosquitoes in Sydney (Wilson 1960).

The possibility of biological control of mosquitoes by the alga *Nitella phauloteles* was investigated in Queensland, based on the reputed inhibition of oviposition caused by the film produced by the alga on the water surface (Buhôt 1926). However, investigations on *N. phauloteles* and other Queensland Characeae failed to find any beneficial effect (Hamlyn Harris 1927, 1930).

In recent years a good deal of attention has been paid to the possibility of using naturally-occurring pathogenic microorganisms for long-term control of mosquito larvae. Species that infect mosquitoes in Australia include the fungi *Culicinomyces clavisporus, C. bisporalis* and *Crypticola clavulifera* (Sweeney 1985; Frances 1990, 1991) and the microsporidia *Amblyospora dyxenoides, A. indicola, A. trinus* and *Duboscgia dengihilli* (Sweeney et al. 1988, 1990, 1993; Becnel and Sweeney 1990; Sweeney and Becnel 1991). Although high mortality can be initiated by inoculating breeding places, there is no evidence yet that this can produce self-sustaining control.

Comments

No quantitative studies have been published on the effects of exotic fish in control of mosquito larvae in Australia. However, there is little doubt of their significant attack on larvae when they inhabit the same body of water (Wilson 1960). Periodic restocking may be necessary, especially following flushing by storms. Mosquito-eating fish can have no influence on breeding in tree holes or in temporary sites, such as tins or sagging roof gutters. Other measures continue to be required, such as reducing the number of breeding sites by draining; making those that remain less favourable by means such as removing emergent vegetation; and by application of insecticides.

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Table 32. Some Australian mosquito-eating fish (Wilson 1960; Merrick & Schmida 1984; Paxton et al. 1989; McDowall 1996)

Species	Common name
ATHERINIDAE	
Craterocephalus eyresii	Murray hardyhead or freshwater silverside
Melanotaenia nigrans	black-banded rainbow fish
Pseudomugil signifer	southern blue-eye
CENTROPOMIDAE	
Ambassis agassizii	olive perchlet
Ambassis spp.	perchlets
ELEOTRIDAE	
Hypseleotris galii	fire tailed gudgeon
GALAXIIDAE	
Galaxias maculatus	common jolly tail
RETROPINNIDAE	
Retropinna semoni	Australian smelt

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Musca vetustissima Walker Diptera: Muscidae
bush fly

The bush fly, *Musca vetustissima*, was recorded in the journals of the Europeans who first set foot on the coast of Western Australia (Pelsaert 1629; Dampier 1688; Waterhouse 1971). Its ancestors may have travelled into northern Australia with the aborigines migrating from Southeast Asia. *M. vetustissima* is closely related to one form of the African *M. sorbens*, but difficulties in hybridisation indicate long isolation and that specific status for *M. vetustissima* is appropriate (Paterson and Norris 1970). In Australia, the bush fly is a member of an extensive fauna of dung-breeding flies (Ferrar 1979).

PRECIS

The bush fly, *Musca vetustissima*, occurs throughout Australia in summer, but in eastern Australia dies out over the southern third of the continent during winter. In Western Australia, it persists except in the south-western corner. It repopulates southern Australia each year chiefly by long-distance flight on mild northerly winds. Bush flies can be a source of great annoyance as they seek moisture and nutrients by feeding on sweat and protein-containing fluids, such as tears, saliva and serum or blood from wounds. They breed in fresh animal faeces, notably now the dung of cattle. Their eggs and larvae are attacked by native natural enemies, but even in the pre-cattle situation these were unable to reduce populations below nuisance levels.

The introduction and release, between 1967 and 1984, of 49 species of exotic dung beetle has led to the burying and dispersal of much of the cattle dung dropped in many parts of Australia. This has correspondingly reduced the main breeding ground of *M. vetustissima*. Introduced dung beetles have been major factors in the very large reduction in bush fly numbers (and nuisance), now permitting more pleasant outdoor eating and untroubled other activities for much of the warmer weather, in marked contrast with the situation prevailing decades ago.

BIOLOGY

Bush flies (*Musca vetustissima*) are attracted upwind by the odour of freshly-produced dung and, after feeding on dung fluids, gravid females search the surface of the dung for crevices or overhanging edges. There, or between the pad and the earth, each lays a batch of some 10 to 40 eggs at a time. Other females are probably attracted by an egg-laying pheromone (Hughes et al. 1972), so that egg masses may become quite large. The eggs hatch in as short a time as 7 hours at higher temperatures (28°C), extending to 17 hours at lower temperatures (16°C) (Vogt et al. 1990).

If a freshly deposited pad is not disturbed, a crust is soon formed by the drying out of the surface layer. An air gap forms beneath the crust and fly larvae live on the moist surface of the underlying dung. As this dries out, larvae penetrate the body of the pad to form a network of air-filled tunnels (Branch and Nicholas 1971). There are three larval instars which, for 3 days or longer, imbibe the fluids and soft-slurry parts of the dung, leaving a loose, dry, fibrous remnant. If the dung pad is exposed to heavy rain, eggs and larvae drown (Hughes 1979). The pupal period lasts from 3 to 18 days according to temperature and, depending upon conditions, adults live for a month or more. The mean egg to adult development time ranges from 7 to 26 days at constant temperatures of 39°C and 18°C, respectively (Vogt et al. 1990).

Before European settlement, the main breeding grounds were probably faeces of humans, emus and dingoes (the last for the past 4,000 or so years only) and, since then, those of cattle, sheep, horses and camels. In the laboratory, eggs have been deposited on marsupial dung and have developed there, but there appear to be no field records of this behaviour.

In summer, bush flies occur widely throughout mainland Australia, Tasmania, southern Papua New Guinea and the larger inshore islands, although they are absent from the wetter, coastal subtropical and tropical areas during summer. They are capable of long-distance flight, assisted by moderate northerly to north-easterly winds and this is the principal way in which they recolonise south-eastern areas each summer (Hughes and Nicholas 1974). Here and elsewhere their ability to move with the wind enables them to invade even inhospitable areas, such as deserts and towns. Except at high temperatures, bush flies avoid shade and they become sluggish at air temperatures below 15°C. They are active in the open on warm to hot sunny days, characteristic of long periods of the year in many parts of Australia.

PEST STATUS

The bush fly is a widely known nuisance pest of humans and domestic animals. It causes great irritation by its persistence in seeking body fluids from the eyes, nose,

mouth and wounds. It is specially attracted in the early stages of ovarian development (Tyndale-Biscoe 1989). When numbers exceed 1000 flies per hectare (Vogt 1992), as they once did in many areas of Australia in summer, they become a significant source of annoyance. To a large degree this can be alleviated by the use of repellents containing di-N-propyl isocinchomeronate (Waterhouse and Norris 1966).

In Central Australia, the bush fly is implicated in spreading the agents causing the human eye disease, trachoma, and elsewhere is an important vector of eye diseases of stock. It is a vector of the nematode *Habronema* sp. which infects horses (Hughes 1981). It is also suspected of transmitting gonococcal conjunctivitis in aboriginal communities (Weinstein 1991).

In the inland tropics, flies are rare in the late spring and during periods of heavy summer rainfall. They reappear in late summer and increase to peak numbers in autumn, then decline in winter. In the south, flies appear in spring and populations build up to peak numbers in late spring or summer. They decline during summer, but in early autumn numbers may recover before cooler, wetter weather causes their disappearance (Norris 1966; Hughes 1970).

BIOLOGICAL CONTROL

When the first English colonists arrived in Sydney in 1788, they brought with them five cows and two bulls. These produced large, moist dung pads, quite unlike the dry, golfball-sized, fibrous pellets of the largest marsupial herbivores surviving in the Australian fauna.

The cattle dung pads (dropped at the rate of 10 or so a day) and the organisms associated with them have formed a complex ecosystem that varies significantly and often erratically throughout the year. Climatic factors (especially rainfall and temperature), the highly variable quality and consistency of the dung, the nature of the soil on which it rests (sand, loam, clay etc.), and the terrain (whether in open pasture or in partly shaded areas) all influence the arthropods in an intricate web of interrelationships. Before the intentional introduction of exotic dung beetles, the pads served as the breeding grounds of at least 20 native species of Diptera (Hughes et al. 1974). Their eggs, larvae and sometimes puparia were preyed upon by staphylinid, histerid and hydrophilid beetles (Wallace and Tyndale-Biscoe 1983). They were also attacked by predatory mites, *Macrocheles glaber* sens. lat. (includes *M. perglaber*) (Tyndale-Biscoe et al. 1981), *M. merdarius* and *Parasitus* sp. (Ridsdill-Smith and Hall 1984; Matthiessen et al. 1986). In south-western Australia immunological tests were carried out on 612 arthropods from 11 families collected in and around cattle dung. Positive results for predation on bush fly were found in Staphylinidae (65%), Histeridae (64%) Carabidae (12%), Dermaptera (21%) and lycosid spiders (27%). Three staphylinids, *Leptacinus socius, Philonthus longicornis* and *P. subcingulatus*, and one histerid,

Saprinus sp., were numerous and widespread and consistently showed a high proportion of positive results (Calver et al. 1986).

In south-eastern Australia, near Canberra, Australian Capital Territory, arthropods were tested against bush fly eggs and larvae over two seasons in the laboratory in the numbers in which they were attracted to dung pads. The mite *M. glaber*, the hydrophilid *Cercyon* sp. and the histerid *Saprinus* sp. were all very effective predators. The native dung beetles *Onthophagus granulatus* and *O. australis* exerted only a marginal controlling effect and staphylinid and aphodiine beetles were largely ineffective (Tyndale-Biscoe et al. 1981).

Wallace et al. (1979) showed that complete destruction of bush fly eggs could be achieved by as few as 50 *M. glaber* mites in a 1 litre pad on which 300–400 eggs had been laid. This mite is brought to the pad by *O. granulatus* adults, which carry them in great numbers on their body surface. To achieve maximum predation this must happen as soon as possible after oviposition. Wallace et al. (1979) and Tyndale-Biscoe et al. (1981) showed that, when *O. granulatus* was allowed to carry naturally occurring numbers of the mite, fly survival was reduced to a much greater extent than was achieved by the beetles alone.

The bush fly is commonly parasitised (Branch and Nicholas 1971; Matthiessen 1985) by a nematode belonging to the genus *Heterotylenchus*, which prevents the full development of eggs in the female fly and kills puparia. Levels up to 30% parasitisation are recorded. These nematodes are added to fresh dung pads by infected female flies, which deposit them in mock oviposition. Bush fly larvae are infected, and adult flies possibly pick up nematodes during feeding or ovipositing on the dung. In arid regions, *Heterotylenchus* appeared to control the numbers of bush fly larvae (Matthiessen 1985). In the laboratory, the parasite has also been shown to lower the survival rate of pupae (Nicholas and Hughes 1970; Branch and Nicholas 1971). Massive populations of the horse-infesting nematode *Habronema* sp. in the haemocoele of the head and thorax can also cause bush fly mortality (Minter 1951).

Adult bush flies are the casual prey of several species of birds, of asilid flies (e.g. *Bathypogon* sp.) and of dragonflies (e.g. *Hemicordulia* sp.). They have also been found as provisioning in the nests of sphecid wasps (e.g. *Sericophorus* sp., *Bembix atrifrons, B. littoralis, B. variabilis* and *B. wangoola*) (Hughes 1981). Froggatt (1917) records the wasp *Gorytes* sp., and Evans and Matthews (1973) *Bembix wangoola*, taking bushflies from among those resting on the body of the observer. Several polyphagous wasps (*Spalangia* sp., *Eucoila* sp.) have been found to oviposit in larvae and to emerge from the puparia (Hughes 1981).

Only a handful of the 320 or so species of native Australian dung beetles, in particular *Onthophagus australis, O. granulatus* and *O. pentacanthus* in south-eastern Australia (Tyndale-Biscoe 1994), *O. sloanei, O. consentaneus* and *O. murchisoni* in Central Australia (Matthiessen et al. 1986) and *O. ferox* in south-western Australia (Ridsdill-Smith et al. 1989) have adapted to utilising bovine

dung. Two of these in the east, *O. australis* and *O. granulatus*, when newly emerged sometimes build up sufficiently large local populations in late spring and early summer to shred pads to such an extent that fly breeding is greatly reduced (Hughes 1975) and the same applies to *O. ferox* in the west. If largely undisturbed, dung pads smothered, for a year or more, the pasture where they were deposited.

In spite of all the adverse factors influencing the breeding of bush fly larvae, before the introduction of exotic dung beetles, very large numbers often survived to produce highly troublesome populations of adults (Waterhouse 1973). By contrast, in regions with large native herbivores which produce large dung pads (Africa, southern Europe), pads are dispersed rapidly by a range of co-evolved dung beetles, which interfere significantly with fly breeding. Successful introductions of several dung beetle species were made to Hawaii in the early 1920s (Fullaway 1922). Bornemissza (1960) suggested that dung beetles be introduced to Australia to aid in the dispersal of bovine dung and to contribute towards the control of dung-breeding flies, including the bush fly. He also suggested that, to achieve dispersal in the various situations in which dung is deposited, a substantial array of beetles with different patterns of activity would be required. Additional information was provided in later years (Bornemissza 1970, 1976). Hughes (1975) provides an assessment of the burial of cattle dung by Australian dung beetles.

Dung beetles affect the survival of bush fly eggs and larvae in two ways: by newly emerged beetles in the maturation feeding phase churning up the dung pad, causing eggs either to become engulfed and drowned or exposed and desiccated; and by depriving larvae of food by removing dung for beetle feeding or oviposition (Walker and Doube 1984). Bornemissza (1970, 1976) and Hughes et al. (1978) showed that the egg stage was particularly susceptible to dung beetle activity and Feehan et al. (1985) found that high exotic dung beetle activity on the south coast of New South Wales substantially reduced the survival of bush flies.

After developing safe methods of surface-sterilising beetle eggs to remove the chance of accidental introduction of animal diseases (Bornemissza 1976), 50 species of dung beetles and 5 species of predaceous histerids were brought to Australia mainly from southern Africa (Tyndale-Biscoe 1996) commencing in 1967. The first species to be field released was *Onthophagus gazella* on 30 January 1968 at Townsville, Queensland. It bred rapidly and spread at some 60 to 80 km a year, even colonising two islands (Magnetic and Palm) that were offshore 10 and 30 km, respectively (Bornemissza 1976). At a much later stage, a wider range of options for introducing valuable species became available when it became possible to receive adult dung beetles from Spain for processing through the top security Australian Animal Health Laboratory in Victoria (Steinbauer and Wardhaugh 1994). The species chosen for introduction were those showing a preference for ruminant-type dung in open pastures. Of these, 49 species of dung beetle and 5 histerids were reared successfully and released (Table 1 page 29). *Onitis ion*,

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recorded as introduced by Tyndale-Biscoe (1996), could not be reared in quarantine and was not, in fact, released (J. Feehan, pers. comm.). By 1989, at least 27 species of dung beetle (including two earlier, unintentional introductions) and three histerids were recorded as established and a few have built up large populations (Doube et al. 1991; Tyndale-Biscoe 1996). The month of first release in each State and subsequent establishment, where known, is shown in Table 33 page 346.

In south-western Western Australia, 19 exotic species of dung beetle were released between 1972 and 1986 (Table 33). By 1987, nine species were known to have become established, seven of which were common. In addition, the cosmopolitan *Aphodius lividus*, whose arrival years earlier is undocumented, was also common. Twenty-six native species also occur in the general region, but only *O. ferox* is at all common. The native dung beetles are active in winter and early spring, but their numbers fall before bush fly numbers increase. The first three exotic introductions, *Euoniticellus intermedius, Onitis alexis* and *Onthophagus binodis*, are most active in summer as are native predatory staphylinids and histerids. The gap between spring and summer active species has since been substantially filled by additional importations (Ridsdill-Smith and Kirk 1985; Ridsdill-Smith et al. 1989) and 13 introduced species are now known to be established (Table 33).

Overall, the present tally of well established, intentionally introduced species is 25 dung beetles and 3 histerids (Table 1 page 29), although many of these species still do not occur in many areas climatically suitable for them. Of course, it is possible that additional species will be recovered, since many of the release areas have not been surveyed in recent years.

There is no comprehensive, consolidated account available of the impact of the introduced dung beetles on bush fly numbers, so several individual examples have been selected to illustrate the overall impact.

Following the establishment of *Euoniticellus fulvus* and *Onthophagus taurus* in the Australian Capital Territory, fly populations were shown to be much older than before, indicated by reduced levels of newly-emerged flies, and thus local fly breeding, and by a higher proportion of older immigrants. The mean annoyance index for humans was also significantly lowered. Survival of immature bush flies in the dung pads fell below the replacement level of 3% throughout one year, and exceeded it on only two occasions the next. In dung pads in the Australian Capital Territory containing only the two native species, *O. granulatus* and *O. australis*, bush fly survival ranged from 0.3% to 12.5%. The addition of the two exotic species *E. fulvus* and *O. taurus* led to maximum survival of 4.4%. This was low enough to keep mean bush fly recruitment below replacement level for most of the season. Bush fly mortality caused by the native fauna averaged 85% of eggs that survived abiotic effects and, when exotic beetles were added, the mortality reached 97%. This supplementation of the native dung fauna with exotic dung beetles

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significantly lowered emergence of adult bush flies (Tyndale-Biscoe and Vogt 1991). Rainfall variation from year to year had a significant effect on both beetle and fly populations. In addition to its direct effect on fly eggs and larvae, the abundance of univoltine (one generation a year) native dung beetles is determined by rainfall, with short periods of drought depressing numbers and breeding activity for the remainder of the season and even longer. By contrast, a multivoltine species, such as *E. fulvus*, was able to recover quickly after a period of drought (Vogt 1992; Tyndale-Biscoe and Vogt 1996), although not as quickly as the bush fly.

In recent times, *O. binodis* has become well established in the Australian Capital Territory and *Geotrupes spiniger* is present, although its numbers are seriously affected by foxes breaking into dung pads in search of adults (J. Feehan, pers. comm. 1999).

In Western Australia, the rainfall is much more regular in its seasonal occurrence (wet winters, dry summers) than in the east and bush fly population events are remarkably consistent each year. In far south-western areas, populations typically decline from about February. The introduction of summer-active dung beetles, however, advanced that decline to December (Ridsdill-Smith and Matthiessen 1988).

In central Australia, near Alice Springs, Northern Territory, bush fly numbers were suppressed in summer by *E. intermedius, O. gazella* and by mites, especially following favourable rains (Matthiessen et al. 1986). *O. alexis* is also established (J. Feehan, pers. comm.).

Dung burial is positively correlated with the biomass of dung beetles in a pad, which is governed, inter alia, by moisture levels and by soil type. Beetles bury dung or shred it (up to 70% of a pad), dependent upon their physiological state and their numbers (Tyndale-Biscoe 1994). In Spain, 60% to 90% of dung pads were found to be buried during substantial periods of the year (Ridsdill-Smith and Kirk 1982; Lobo 1991).

Single species dung beetle populations appeared to be as effective as multiple species populations, although a benefit could be derived from a combination of day and night flying species (Wallace and Tyndale-Biscoe 1983).

Hughes et al. (1978) reported that 50 *E. intermedius* adults in a 1 litre pad in the laboratory were able to destroy half of the 300 bush fly eggs that had been added and that 140 beetles lowered survival to only 10%.

In Western Australia, *O. binodis* and *O. ferox* caused a very high level of mortality of bush fly eggs and larvae (Ridsdill-Smith and Hayles 1990). In laboratory tests, the smaller *O. binodis*, at densities of 120 beetles per pad, caused mortality of 12% of fly eggs and 11% of young larvae, but did not affect older larvae. On the other hand, the larger species, *O. ferox*, at densities of 48 beetles per pad, caused no extra mortality of eggs, but did cause an increased mortality of 47% of young fly larvae and 61% of older larvae (Ridsdill-Smith et al. 1987).

OTHER INTRODUCTIONS

In the summer of 1973/74 the New Zealand larval parasitoid *Aphaereta aotea* was released on the south coast of New South Wales. There, cattle dung was mainly producing *M. vetustissima* and the sarcophagid fly, *Tricharaea brevicornis*. The latter fly deposits progeny as newly-hatched larvae and, unlike the bush fly, overwinters in the south. There are at least 15 other fly species that breed in cattle dung, the larvae of which could serve as hosts for *A. aotea* (Hughes et al. 1974). One of these, *Neomyia australis* is recorded as a host in the field (Hughes and Woolcock 1976). *A. aotea* established readily on *T. brevicornis* and spread rapidly, but was rarely recovered from the bush fly (Hughes and Woolcock 1978), so it is clearly unable to have much impact on nuisance populations.

The contribution of macrochelid mites has been discussed in relation to their predation on the eggs and very young larvae of the buffalo fly (see target pest no. 72, *Haematobia exigua* page 322). Although the duration of the egg stage of *M. vetustissima* is only 8 hours at 27°C, compared with 16 hours for buffalo fly eggs, the mites are probably more effective predators of bush fly eggs because of the far thinner shell of the latter (Walker and Doube 1984).

Seven native and two exotic mite species were tested in the laboratory as predators of both fly species. The smaller mite species, *Macrocheles merdarius* and *M. robustulus*, killed 24% of bush fly eggs offered, whereas larger species, such as *M. glaber, M. limue, M. perglaber, M. peniculatus* and *Glyptholaspis confusa* killed 64 to 92%. In parallel experiments with buffalo fly eggs, only the largest mites killed a significant number of eggs. Although species such as *M. glaber* and *M. perglaber* occur widely in southern Australia and must be taking a toll of the early stages of the bush fly, they were not recorded from northern and Western Australia (Halliday 1986; Halliday and Holm 1987).

Macrocheles peregrinus, which is a relatively large, widespread, and abundant predatory species in warmer areas of southern Africa, was introduced to Queensland in 1980 and the Northern Territory in 1981. It established very readily, spread widely and is expected to colonise the whole of the summer rainfall area of mainland Australia, except perhaps for the cooler areas of the northern tablelands and south-eastern New South Wales. Its distribution in Namibia suggests that it should be able also to colonise most of the arid zone of central Australia, although it may be restricted there to somewhat moister local habitats (Doube et al. 1986). It is hoped that *M. peregrinus* will provide a useful additional agent of mortality of bush fly eggs and young larvae.

There can be little doubt that a major factor in the widespread reduction in the abundance of bush flies has been the extensive destruction of cattle dung pads following the establishment of exotic dung beetles. However, fly abundance has also been influenced — to an undocumented degree — by the widespread administration of anthelmitics and synthetic pyrethroids to cattle for endo- and

ecto-parasite control, respectively. Most of these compounds prevent fly and dung beetle breeding for a period after administration (Roncalli 1989). Dung from animals treated against worms with ivermectin attracted more beetles than dung from untreated animals. This enhancement of attraction lasted for 25 days, but produced 100% mortality of newly hatched larvae of *M. vetustissima* and 93% mortality at day 35 (Wardhaugh and Mahon 1991). This useful effect, however, is partially offset by the fact that the dung has adverse effects also on the exotic dung beetles visiting it (see later).

A further change in recent years, which may reduce bush fly populations to some degree near cities, is that the majority of dairy herds are now located far away from major centres of human population.

COMMENTS

The continued use of pesticides on crops or animals that are also being protected by biological control generally causes problems for biological control agents. In the case of cattle, the pesticides implicated are the macrocyclic lactones (administered for control of internal parasites) and the synthetic pyrethroids (administered for control of ectoparasites). The macrocyclic lactones comprise several commercially-available avermectins and a single milbemycin, moxidectin. The avermectins are only partially metabolised during their passage through the body and are excreted in the faeces. Tests showed that dung was toxic to dung beetles for 2 to 4 weeks after treatment and lethal to dung breeding flies for at least 5 weeks. Fortunately, the milbemycins appear to have little or no effect on non-target beetles or flies.

Synthetic pyrethroids, such as deltamethrin, are persistent and effective against animal ectoparasites. They are widely used, particularly in areas where ticks and biting flies are a problem (Wardhaugh et al. 1998). Development of bush fly larvae was severely inhibited in dung collected during the first week after treatment but, by the 14th day, dung dropped was relatively harmless. Residues present in dung voided one week after treatment were also sufficiently toxic to kill adults of *O. binodis* (Ridsdill-Smith 1993; Wardhaugh and Beckman 1996; Wardhaugh et al. 1998; Wardhaugh and Ridsdill-Smith 1999). In Western Australia, dung pads collected from cattle treated 7 and 10 days earlier with ivermectin were dispersed significantly less by *O. taurus* then untreated dung pads (Dadour et al. 1999).

Many papers have been published on the biology, behaviour and interactions of the bush fly, the buffalo fly, their native natural enemies and native and introduced dung beetles, but it is not feasible to do them proper justice in this summary account. An attempt, however, has been made to list the first recorded liberation of each exotic species of dung beetle in Australia (Table 1 page 29). These liberations have been followed by a succession of redistributions in different

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locations to increase the chances of establishment (Tyndale-Biscoe 1996). In addition, grazier enthusiasm for the project has led to many undocumented redistributions to other areas. Detection of successful colonists has usually taken in excess of 2 or 3 years after first release. A few of the introduced species with more than one generation per year (e.g. *O. gazella, E. intermedius*) have spread rapidly. Many others, especially those having only one generation per year, build up their numbers slowly unless exceptionally good pasture seasons prevail, and thus many spread only a few kilometres a year. Therefore there are very good reasons for increasing, by redistribution, the rate at which natural spread occurs.

There are also very good reasons for seriously resuming the introduction of additional dung beetle species with special qualities for filling the niches in the pastoral map for which those species already introduced are unsuitable.

Table 33. Month of first release in each State and the establishment, where known (*), of exotic dung beetles

Species	Qld	NSW	Vic	Tas	SA	WA	NT
COLEOPTERA							
HISTERIDAE							
Hister calidus	Dec 71	Sept 72				Jan 72	Mar 72
Hister cruentus		72					
Hister nomas	Dec 67 *	Nov 68 *	Mar 70	Feb 83		Mar 71	
Pactolinus caffer	May 68 *					Jan 70	Dec 69
Pactolinus chinensis	Apr 67 *						
SCARABAEIDAE							
Allogymnopleurus thalassinus	Mar 79						
Aphodius lividus	*	*	*	*	*	*	
Bubas bison		*	*			Apr 83 *	
Canthon humectus		Apr 69					
Chironitis scabrosus		Oct 72					
Copris bornemisszai	Jan 77						
Copris diversus	Oct 76					Jan 77	Nov 76
Copris elphenor	Jan 77 *						
Copris fallaciosus	Jan 77	Jan 78					
Copris hispanus						83 *	
Copris incertus	Apr 69					Jan 70	Dec 69
Copris lunaris	Dec 83						
Euoniticellus africanus	*	Oct 71 *	Dec 71	Nov 75	May 73	May 73 *	
Euoniticellus fulvus		Mar 78 *	Nov 79 *	Nov 79 *	Jan 81 *	May 80 *	
Euoniticellus intermedius	Dec 71 *	Dec 71 *	Mar 74		Feb 74 *	May 73 *	Oct 72 *
Euoniticellus pallipes		Apr 77 *			June 77	Mar 73 *	
Geotrupes spiniger		May 79 *	*	Feb 80 *			

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Table 33. (cont'd) Month of first release in each State and the establishment, where known (*), of exotic dung beetles

Species	Qld	NSW	Vic	Tas	SA	WA	NT
Liatongus militaris	Jan 68 *	Feb 77 *					Dec 69 *
Onitis alexis	Aug 72 *	Oct 72	Sept 72	Oct 72	May 73	May 73	Nov 73
Onitis aygulus		Apr 77 *			June 77 *	May 77 *	
Onitis caffer	late 80s	Oct 79 *				May 82 *	
Onitis deceptor	Dec 79						
Onitis pecuarius	Nov 76 *	Oct 77 *					
Onitis tortuosus	Nov 76	Nov 79					
Onitis uncinatus	Dec 79						
Onitis vanderkelleni	Oct 74 *	Dec 76 *					
Onitis viridulus	Sept 76 *	Nov 76 *					Nov 76 *
Onitis westermanni	Jan 77						
Onthophagus binodis	Aug 72 *	Oct 71 *	Oct 71 *	Oct 72 *	Aug 72 *	June 72 *	Oct 73
Onthophagus bubalus		Oct 72					
Onthophagus cameloides						Dec 80	
Onthophagus depressus (U)		pre 1900 *					
Onthophagus foliaceus	Sept 75						
Onthophagus gazella	Jan 68 *	Aug 72 *	Sept 72	Sept 72	Aug 72 *	Feb 70 *	Dec 69 *
Onthophagus nigriventris	Sept 74 *	Dec 78 *	Feb 82				
Onthophagus obliquus	Jan 76 *						Nov 76
Onthophagus opacicollis						Apr 82	
Onthophagus sagittarius	Jan 68 *	Feb 77 *				Jan 70 *	Dec 69 *
Onthophagus taurus		Feb 75 *	Jan 76 *	Jan 77 *	Nov 75 *	Oct 75 *	
Onthophagus vacca		Sept 80					
Sisyphus fortuitus	Dec 76						
Sisyphus infuscatus	Mar 76 *						
Sisyphus mirabilis	Apr 72						
Sisyphus rubrus	Nov 73 *	Mar 73				Sept 73	
Sisyphus spinipes	Mar 72 *	Sept 72 *				Feb 74	Jan 73

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Stomoxys calcitrans (Linnæus) Diptera: Muscidae
stable fly

PRECIS

This cosmopolitan, blood-sucking fly causes misery to cattle, horses, dogs and other animals and occasionally bites humans. It breeds in stable or yard refuse of dung, urine, straw or other vegetable material and also in rotting vegetable matter. In such situations it is exposed to non-specific predatory insects and to limited parasitisation.

A pteromalid parasitoid, *Spalangia nigroaenea*, known to attack stable fly in Indonesia, was liberated in 1932 and 1933, primarily against buffalo fly, in the Northern Territory. There is no evidence that it survived, although it may have hybridised with the closely-related, native *Spalangia endius*. The dung beetles introduced later against the bush fly, *Musca vetustissima*, devote their attention almost entirely to single cattle dung pads in open pastures and are not adapted to the same breeding medium as the stable fly.

BIOLOGY

Stomoxys calcitrans is a cosmopolitan species of Afro-tropical (or possibly Palaearctic) origin. It is common throughout subtropical and temperate Australia and is known from all States, generally in association with human settlement (Ferrar 1979). It is absent from the very dry areas of Australia and is most common in coastal areas, especially in autumn, although adults are rare in winter (Pont 1973).

Both sexes are biting flies and obligate blood feeders, mainly of cattle and horses. They are rarely encountered in open pastures any distance away from yards, but can be very abundant around stables, dairies and stock yards. They breed mainly in stable refuse of dung mixed with urine, straw or other vegetable material, but also in rotting vegetable matter, such as heaps of grass clippings. They do not normally breed in individual cattle dung pads in pastures. Indeed, animal faeces as deposited do not attract flies to oviposit (Ferrar 1979).

At each oviposition, up to 20 or so eggs are laid in loose clusters in crevices amongst the stable refuse. Under favourable field conditions, eggs hatch in 1 to 5 days and development of larvae takes 7 to 8 days and of pupae 3 days (Zumpt 1973). Pupation occurs 2 to 3 cm below the surface in the drier part of the food medium, under it or nearby.

Third instar larvae show an escape reaction not seen in other dung breeding Muscidae. They flex the body rapidly from s-shape to reverse s-shape. At other times, they may go into a cataleptic state of immobility (Ferrar 1979).

PEST STATUS

The obligate, blood-sucking stable fly is common throughout Australia around stables, holding yards and milking sheds, where it causes considerable nuisance by biting stock. Its buzzing makes animals nervous and difficult to manage. It attacks horses and cattle in particular, but also dogs, pigs, humans and other animals (Seddon 1967; Ferrar 1979). In USA, average populations of *S. calcitrans* (some 50 per beast) were found to depress the weight gains of calves (Campbell et al. 1977) and possibly the amount of milk produced by dairy cows (Miller et al. 1973). In the Philippines, it was found that each fly consumed 25.8 mg of blood twice a day (Mitzmain 1913).

The stable fly acts as an intermediate host of the spirurid worm, *Habronema microstoma*, which causes habronemiasis in horses (Seddon 1958) and it is suspected of transmitting a number of other diseases (Pont 1973).

BIOLOGICAL CONTROL

Six cosmopolitan parasitoids of *S. calcitrans* have been recorded from eastern Australia (Johnston and Bancroft 1920; Legner and Olton 1968) (Table 34 page 350). All are habitat specific rather than host specific, since they can be readily reared on a wide variety of hosts in the laboratory. Of these parasitoids, *Tachinaephagus zealandicus* oviposits in larvae (a niche that few other species occupy) and the remainder attack the puparia. Legner and Olton (1968) comment that there are several strains of *T. zealandicus* and *Spalangia* spp., which offer the possibility of introducing forms that are more effective than those already present. Ferrar (1979) has listed a number of dung-inhabiting muscid species, whose larvae have predaceous habits. However, no observations are recorded of actual attack on *S. calcitrans* larvae. These species include *Brontaea obliterata, B. ruficornis, B. subtilis, Helinomydaea fuscoflava, Hennigiola setulifera* and *Hydrotaea australis*.

The pteromalid pupal parasitoid *Spalangia nigroaenea* was introduced from Indonesia, where it caused 6% to 46% parasitisation of *S. calcitrans* (Handschin 1933). It was released in the Northern Territory from 1932 to 1933 against the buffalo fly, *Haematobia exigua*. It was, however, known to be most active in

Indonesia on house and stable fly puparia. It interbred in the laboratory with the very closely-related, native *Spalangia endius*. It is not known whether its genes have merged with those of *S. endius*, but there is no record of any change in stable fly numbers.

The exotic dung beetles introduced against the bush fly, *Musca vetustissima*, were selected for their adaptation to utilise single bovine dung pads in open pasture country. There is no reason to believe that they have had any influence on fly larvae in the breeding grounds of *S. calcitrans*.

Table 34. Parasitoids of *Stomoxys calcitrans* in eastern Australia

Species	% Parasitisation	References
COLEOPTERA		
STAPHYLINIDAE		
Aleochara sp.	1.7%	Legner & Olton 1968
HYMENOPTERA		
ENCYRTIDAE		
Tachinaephagus zealandicus	53.6%	Legner & Olton 1968
PTEROMALIDAE		
Muscidifurax raptor	0.8%	Legner & Olton 1968
Spalangia cameroni	1.7 – 8.9%	Legner & Olton 1968
Spalangia endius	5.4 – 37.5%	Legner & Olton 1968
Spalangia nigroaenea		Johnston & Bancroft 1920; Johnston & Tiegs 1921

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Agrotis spp., *Anadevidia peponis, Chrysodeixis* spp., *Diarsia intermixta, Leucania* spp., *Mythimna* spp., *Persectania* spp., *Spodoptera* spp. Lepidoptera: Noctuidae armyworms, cutworms and semi-loopers

Biological control of armyworms, cutworms, a cluster caterpillar and semi-loopers has been attempted by introducing parasitoids adapted to these noctuid moths (as well as budworms, Heliothinae). The important pest species are: armyworms, *Leucania loreyi, L. stenographa, Mythimna convecta, M. separata, Persectania dyscrita, P. ewingii, Spodoptera exempta, S. exigua, S. mauritia*; the cluster caterpillar, *S. litura;* cutworms, *Agrotis infusa, A. ipsilon, A. munda, A. porphyricollis, Diarsia intermixta*, and semi-loopers, *Anadevidia peponis, Chrysodeixis argentifera, C. eriosoma, C. subsidens* and *Thysanoplusia orichalcea.*

PRECIS

Many cosmopolitan and native cutworms, armyworms, the cluster caterpillar and semi-loopers are serious pests of a wide range of crops, turf, pastures or pine seedlings, especially in southern Australia and Norfolk Island. A native ichneumonid, *Campoletis* sp., is sometimes an important parasitoid of *Mythimna convecta.* Agents introduced against the range of noctuids include the braconid *Cotesia marginiventris* and the ichneumonids *Campoletes chlorideae* and *Hyposoter didymator*, but they have had little impact on populations of the pests. A strain of the braconid *Cotesia ruficrus*, from Pakistan, may have had some impact on the abundance of *Mythimna separata* in northern Western Australia.

BIOLOGY

Armyworms and cluster caterpillars (subfamilies Amphipyrinae and Hadeninae), cutworms (subfamily Noctuinae), and semi-loopers (subfamily Plusiinae) comprise groups of noctuid moths with some species known as pests of crops, turf, pastures and forestry. The taxonomy of the moths was reviewed by Common

(1954a, 1958) and recently by Edwards (1996). The reproductive biology of *Spodoptera litura* was described by Etman and Hooper (1979).

Adult cutworms, armyworms and some semi-loopers are renowned for their ability to migrate, often over considerable distances within the continent of Australia, or to offshore islands. For example, the cutworm *Agrotis ipsilon* and the armyworm *Persectania ewingii* have been collected after migrating to Macquarie Island, where they fail to breed (Greenslade et al. 1999), and windborne seasonal migrations of *P. ewingii* are known to precede outbreaks of the moths (Helm 1975). Migrations of *A. ipsilon* in autumn from New Zealand and *P. ewingii* in spring from Australia, are aided by strong winds associated with cold fronts and depressions. Low level winds may transport the moths at speeds in excess of 100 km per hour (Drake 1984). Moths return northwards in early autumn, following a southerly migration in late spring. Adult *Chrysodeixis argentifera* also migrate large distances in south-eastern Australia, especially during the spring (Common 1990). Adult bogong moths, *Agrotis infusa*, form dense aggregations and aestivate in rock shelters at high altitudes in the mountainous regions of south-eastern Australia (Common 1954b, 1958).

The larvae of major pest species of armyworms, cutworms and semi-loopers damage a range of crops, pastures and pine seedlings (see Table 35 page 355). Larvae can be identified by their colour, mandibles and arrangement of their setae. The pupae are various shades of brown or black with lighter markings, and can be distinguished by the spiracles, cremaster, abdominal sculpturing and setae. Keys for some larvae and pupae were provided by Cantrell (1980).

The distribution, biology and common host plants for the armyworms *Mythimna convecta* and *P. ewingii* were discussed by McDonald et al. (1995). In their surveys, *M. convecta, P. ewingii* and *Leucania stenographa* were the most abundant armyworms in eastern Australia. More than 29 plant species, mainly grasses, were hosts of *M. convecta*, the most common being *Dichanthium sericeum*, *Chloris* spp. and wild oats, *Avena fatua*. Similarly, larval hosts of *Spodoptera mauritia* in south-eastern Queensland were mainly grasses and sedges (Grant 1982).

S. litura ecloses from pupae at night and adults live for 8 to 10 days. They feed on the nectar of flowering plants, particularly Myrtaceae, and are attracted to fermenting fruit. Fermentation traps and light traps have been used to monitor their populations (McDonald and Farrow 1990). Eggs of *S. litura* are deposited on the underside of leaves of their plant hosts (Waterhouse and Norris 1987). More than 2600 eggs may be deposited by each female in the laboratory (Etman and Hooper 1979). In the field, masses of 200–300 eggs are covered by a layer of hair scales from the abdomen of the female moth. Eggs hatch in 4 to 8 days in the field, or 76 hours at 28°C. Larval development occupies 13 to 30 days in the field or 12 days at 28°C. Pupae develop in 7 to 18 days depending on temperatures and at 28°C, adults eclose after 11 days (Etman and Hooper 1979).

The immature development rates and survival of *M. convecta* and *P. ewingii* may be influenced also by the species of plant host (McDonald 1991) and immature development, especially variation in the number of larval instars of *M. convecta*, was discussed by Smith (1984). *M. convecta* was predicted to have more generations per year than *P. ewingii*.

The larvae of cutworms, *Agrotis* spp., are nocturnal and live in shallow burrows in the soil by day. They cut the stem of seedlings near the base before carrying the plants into burrows where they are consumed.

The larvae of most armyworms are very variable in colour. For example, larvae of *Spodoptera exempta* are usually pale green with dark green stripes when their densities are low, or black with yellowish stripes when their densities are high. They sometimes occur in dense populations and exhibit gregarious behaviour, destroying all green leaf material as they feed and move over pastures. Whereas larvae of *S. exempta* feed openly on foliage by day and pupate in small chambers made in the soil or in leaf litter at the base of the food plants, *S. litura* are nocturnal feeders and remain on the crops, except when feeding on rice, when they shelter by day at the base of the plant. *Leucania* spp. and *Mythimna* spp. shelter by day in the root mass, rolled leaves or litter at the base of the food plants, and emerge at night to feed on the foliage. The larvae of *M. convecta* and *P. ewingii* defoliate cereal crops before leaf senescence or by lopping of grain (Broadley 1979).

The larvae of semi-loopers, *Chrysodeixis* spp., prefer low-growing plants but *C. eriosoma* occasionally damages citrus. *Anadevidia peponis* is a pest of Cucurbitaceae, when larvae feed on the foliage and flowers.

PEST STATUS

The extensive range of crops, pastures and seedlings damaged by cutworms, armyworms and semi-loopers is summarised in Table 35 page 355.

Damage by all species of cutworms, armyworms and semi-loopers varies considerably from year to year. Infestations develop when climatic conditions favour migrations and outbreaks of larvae. Outbreaks appear to be related to periods of heavy autumn rains (McDonald et al. 1995). The synchronisation between larval maturation and the ripening of crops and pastures influences the extent of damage by several species, especially *M. convecta* and *Persectania* spp. (McDonald and Smith 1986). Droughts may reduce the effectiveness of parasitoids and predispose armyworm populations to outbreaks in seasons that follow (Marcovitch 1957).

Many armyworms predominate in southern Australia, whereas *L. stenographa*, *S. litura* and *S. exempta* are mainly pests in eastern and northern Australia. *M. convecta* is the most important pest species in northern Victoria, and *P. ewingii* is important in the southern regions of Victoria, South Australia,

Western Australia and Tasmania (McDonald and Smith 1986). *Mythimna separata* is the major pest of pastures on Norfolk Island (N. Tavener, pers. comm.). *S. exempta* and other armyworms build up in numbers in the summer rainfall areas of north-eastern New South Wales and south-eastern Queensland, producing outbreaks of damage to crops and pastures. In Queensland, *S. litura* is a very serious pest of strawberries (Murray 1980a), and in north-western Australia, it is a major pest mainly of tobacco and vegetable crops but has also caused problems in cotton (Common 1990).

BIOLOGICAL CONTROL

Many indigenous natural enemies attack the immature stages of cutworms, armyworms and semi-loopers, but they are not always able to prevent outbreaks of the pests. Several species of birds, especially crows, *Corvus* sp. (Mungomery 1934), Australian magpie, *Gymnorhina tibicen* and pied butcherbird, *Cracticus nigrogularis* (D.P.A. Sands, unpublished) take a heavy toll of larvae. Overseas, many insect and spider predators have been recorded attacking *S. litura* (Waterhouse and Norris 1987) and relatives of these are likely to attack *S. litura* in Australia.

An ichneumonid, *Campoletis* sp., is sometimes an important parasitoid of *M. convecta* in Victoria, preventing the build-up of damaging populations (McDonald and Smith 1986). Other abundant parasitoids of this species are two ichneumonids, *Lissopimpla excelsa* and *Netelia* sp., the braconids *Apanteles* sp. and *Rogas* sp., and tachinids *Ceromya* sp. and *Palexorista* sp. Tachinids are also significant parasitoids of cutworms, armyworms, semi-loopers and *Helicoverpa* spp. (Table 36 page 355). Keys to most of the species attacking these groups of noctuids were provided by Cantrell (1984).

Parasitoids introduced against cutworms, armyworms and semi-loopers were intended to control simultaneously a suite of noctuid hosts to which they were broadly adapted. Although several species became established, their levels of attack varied according to the host species and none has proved to be particularly effective. The indigenous strain of *Cotesia ruficrus*, although widely distributed, was not effective, but a strain introduced from Pakistan was reported to be partially effective against *M. separata* when it became established in the Ord River area, Western Australia (Learmonth 1981). However, the two species of introduced braconids *C. ruficrus* and *C. kazak* were not able to successfully parasitise *S. litura*. *C. marginiventris* introduced from the USA was recovered from *S. litura* in Western Australia but its continuing presence has not been confirmed (Michael et al. 1984). Many of the parasitoids of *M. convecta* in south-eastern Queensland were discussed by Broadley (1986).

Little is known of the effectiveness of egg parasitoids introduced against the pest species of noctuids. *Telenomus remus* was introduced from Southeast Asia and

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the Dominican Republic. This parasitoid showed a preference for eggs of *Spodoptera* spp. in the laboratory and it is not known to have become established (Michael et al. 1984).

Table 35. Common Australian cutworms, armyworms and semi-loopers

Species	Economic host plants
Cutworms *Agrotis infusa, A. ipsilon, A. munda, A. porphyricollis, Diarsia intermixta*	cereals, citrus, cotton, grains, legumes, lucerne, maize, pastures, pine seedlings, potato, sugar beet, strawberry, tobacco, tomato, turf, vegetables
Armyworms *Leucania loreyi, L. stenographa, Mythimna convecta, M. separata, Persectania ewingii, P. dyscrita, Spodoptera exempta, S. mauritia, S. litura, S. exigua*	cereals,citrus, cotton, grains, legumes, lucerne, maize, ornamentals, pastures, peanuts, rice, sesame, sugarcane, strawberry, sweet potato, tobacco, tomato, turf, vegetables
Semi-loopers *Anadevidia peponis, Chrysodeixis argentifera, C. subsidens, C. eriosoma, Thysanoplusia orichalcea*	citrus, corn, cotton, cucurbits, grains, legumes, maize, ornamentals, sorghum, tobacco, vegetables

Table 36. Indigenous arthropod natural enemies of armyworms, cutworms and semi-loopers

Species	Stage and species of host[a]	References
DIPTERA		
TACHINIDAE		
Carcelia cosmophilae	L (SE, SL)	Cantrell 1986
Carcelia illota	L (CA)	Cantrell 1986
Ceromya sp.	L (CA, MC)	Cantrell 1986; McDonald & Smith 1986
Chaetophthalmus bicolor	P (AI)	Cantrell 1986
Chaetophthalmus dorsalis	P (PD)	Cantrell 1986
Compsilura concinnata	L (SL)	Cantrell 1986
Cuphocera varia	L (MC)	Broadley 1986
Eurygastropsis tasmaniae	(CE, CS)	Cantrell 1986
Exorista curriei	L (SL)	Cantrell 1986
Exorista psychidivora	L (CA)	Cantrell 1986
Goniophthalmus australis	L / P (MC, SL)	Broadley 1986; Cantrell 1986
Linnaemya sp.	L (MC)	Broadley 1986
Microtropesia flaviventris	? P	McDonald & Smith 1986
Palexorista sp.	L (CA, MC, PD, SM)	Michael et al. 1984; Cantrell 1986; McDonald & Smith 1986
Peribaea orbata	L / P (MC, SL)	Broadley 1986; CSIRO unpubl.
Peribaea sp.	L / P (SI)	Cantrell 1986
Stomatomyia tricholygoides	(SM)	Cantrell 1986

[a](AI) *Agrotis infusa*, (CA) *Chrysodeixis argentifera*, (CE) *C. eriosoma*, (CS) *C. subsidens*, (MC) *Mythimna convecta*, (PD) *Persectania dyscrita*, (SE) *Spodopotera exempta*, (SI) *S. exigua*, (SL) *S. litura*, (SM) *S. mauritia*
[b]hyperparasitoid

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Table 36. (cont'd) Indigenous arthropod natural enemies of armyworms, cutworms and semi-loopers

Species	Stage and species of host[a]	References
Tritaxys heterocera	L (PD, SL)	Cantrell 1986
Tritaxys scutellata	L	McDonald & Smith 1986
Tritaxys sp.	L (SL)	Cantrell 1986
Winthemia neowinthemioides	(CE)	Cantrell 1986
HYMENOPTERA		
BRACONIDAE		
Apanteles sp.	L (MC)	McDonald & Smith 1986
Homolobus ophioninus	L	McDonald & Smith 1986
Microgaster sp.	L	McDonald & Smith 1986
Microplitis demolitor	L	CSIRO unpubl.
Rogas sp.	L (MC)	McDonald & Smith 1986
ENCYRTIDAE		
Litomastix sp.	L	Michael et al. 1984, McDonald & Smith 1986
EULOPHIDAE		
Euplectrus sp.	L	McDonald & Smith 1986
ICHNEUMONIDAE		
Campoletis sp.	L (MC)	McDonald & Smith 1986
Diadegma sp.	L / P (MC)	Broadley 1986
Eutanyacra licitatorius	P	McDonald & Smith 1986
Ichneumon promissorius	P	McDonald & Smith 1986
Lissopimpla excelsa	L / P (MC)	McDonald & Smith 1986
Lissopimpla semipunctata	L / P (SE)	CSIRO unpubl.
Netelia producta	P (SL)	CSIRO unpubl.
Netelia sp.	P (MC)	Broadley 1986; McDonald & Smith 1986
PTEROMALIDAE		
Trichomalopsis sp.[b]	L	McDonald & Smith 1986

[a](AI) *Agrotis infusa*, (CA) *Chrysodeixis argentifera*, (CE) *C. eriosoma*, (CS) *C. subsidens*, (MC) *Mythimna convecta*, (PD) *Persectania dyscrita*, (SE) *Spodopotera exempta*, (SI) *S. exigua*, (SL) *S. litura*, (SM) *S. mauritia*
[b]hyperparasitoid

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Cryptophlebia ombrodelta (Lower) Lepidoptera: Tortricidae macadamia nutborer

PRECIS

Cryptophlebia ombrodelta is a native, widespread pest of macadamia nuts in warm, coastal eastern and northern Australia. Although it is attacked by a number of native parasitoids, these are unable to prevent commercially important damage.

A eulophid parasitoid of Chinese origin, *Elachertus* nr *lateralis*, was liberated in Queensland from 1993 to 1994 and has become established. Its impact on nutborer populations has not been assessed.

BIOLOGY

Cryptophlebia ombrodelta is native to Australia (mainly coastal Queensland, Northern Territory and New South Wales) and is best known for its attack upon the developing nuts of *Macadamia integrifolia* and *M. tetraphylla*. It was recorded as early in 1897 on *Acacia farnesiana* in northern New South Wales (Ironside 1974). Eggs are laid singly on, or near, developing nut husks. In warm weather they hatch in 4 to 6 days, young larvae enter the husk and tunnel into the kernel while the shell in still soft. As the shell hardens, feeding is usually confined to the husk. The period from oviposition to adult emergence is about 5 weeks. Populations of the moth appear to be rather sedentary, since new macadamia plantations not adjacent to established infestations have remained free of the pest for some years.

Males are attracted by the commercial pheromone Orfamone II (containing (z)-9-dodecenylacetate and 1-dodecanol) (Sinclair and Sinclair 1980; Vickers et al. 1998).

PEST STATUS

The macadamia nutborer is active throughout the year, but the most severe damage occurs from December to February. Varieties differ in their susceptibility to damage and crop loss can be minimised by growing varieties that mature early

(Ironside 1974). The tunnelling by larvae into macadamia nuts reduces both the yield and quality of kernels and losses of more than 60% of the crop can occur (Ironside 1978, 1982). Damaged nuts fall prematurely. With ripe fruit the larvae may die in the plant tissues.

Froggatt (1897) recorded *A. farnesiana* pods to be heavily infected. Thirty-three host plants from Australia and overseas are listed by Ironside (1974). Hosts include the pods of many exotic plants grown for fruit or as ornamentals, including lychee, longan, tamarind, *Bauhinia, Cassia* and *Poinciana* (Hely et al. 1982).

BIOLOGICAL CONTROL

A number of parasitoids are known to be enemies of *C. ombrodelta* larvae in Australia (Table 37). Six of these, in order of decreasing abundance (Sinclair 1979), are *Apanteles briareus, Bracon* sp., *Gotra bimaculata, Brachymeria pomonae*, *Thelairosoma* sp. and *Euderus* sp.. The hyperparasitoid *Eupelmus* sp. (Encyrtidae) emerged from *A. briareus*. No egg parasitoids were found Sinclair (1979). Ironside (1974, 1978) also listed *Apanteles* sp. (? *ater* group), *Apanteles* sp. (*myoecenta* group) (Braconidae) and *Echtromorpha insidiator* (Ichneumonidae). Galloway (in Sinclair 1979) stated that *Apanteles* sp. (*myoecenta* group) is now included with *A. briareus* in the *merula* group.

The level of *C. ombrodelta* control was considered commercially inadequate, so the Chinese eulophid parasitoid *Elachertus* sp. nr *lateralis* was released in Queensland from 1993 to 1994 into unsprayed nutborer hosts such as *Poinciana* and *Bauhinia*. It has been recovered from the field, but no evaluation of its impact is yet available (Waite and Elder 1996; G. Waite, pers. comm. 1999).

Table 37. Natural enemies of *Cryptophlebia ombrodelta* in Australia

Species	References
DIPTERA	
TACHINIDAE	
? *Thelairosoma* sp.	Sinclair 1979
Unidentified	Ironside 1978
HYMENOPTERA	
BRACONIDAE	
Apanteles briareus	Ironside 1978; Sinclair 1979
Apanteles sp. *(ater* group*)*	Ironside 1974
Apanteles sp. *(myoecenta* group*)*	Ironside 1974
Apanteles sp. *(merula* group*)*	Sinclair 1979
Bracon sp.	Ironside 1978; Sinclair 1979

[a]emerged from *Apanteles briareus*

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Table 37. (cont'd) Natural enemies of *Cryptophlebia ombrodelta* in Australia

CHALCIDIDAE	
Brachymeria pomonae	Sinclair 1979
ENCYRTIDAE	
Eupelmus sp.[a]	Sinclair 1979
EULOPHIDAE	
Euderus sp.	Sinclair 1979
ICHNEUMONIDAE	
Echtromorpha insidiator	Ironside 1974
Gotra bimaculata	Ironside 1974, 1978; Sinclair 1979

[a]emerged from *Apanteles briareus*

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Cydia pomonella (Linnæus) Lepidoptera: Tortricidae
codling moth

This species has also been referred to as *Carpocapsa pomonella* or *Grapholita pomonella*.

PRECIS

The codling moth, *Cydia pomonella*, is of Eurasian origin, and now occurs in most regions of the world where apples are grown. It has been in Australia at least since 1857 and has long been the most important pest of pome fruits. Because it feeds in the fruit itself, very little attack can be tolerated.

Although *C. pomonella* is the host of many predators and parasitoids which, at times, can cause considerable mortality, there is no evidence that these have a significant effect upon the amount of fruit damage. This is because, in the absence of insecticides, the residual codling moth population continues to be capable of exhausting each year its supply of larval food.

Two exotic parasitoids were liberated, but, although they have become established, have not influenced the pest status of the moth.

BIOLOGY

The first serious outbreak of codling moth, *Cydia pomonella*, was recorded in 1857 in Tasmania (Oliff 1890; Froggatt 1902b), in 1885 in Victoria and South Australia, in 1887 in New South Wales, and in 1889 in Queensland. It is not established in Western Australia although, since its first report there in 1903, brief incursions had been eradicated on 19 documented occasions up to 1980 (Geier 1970, 1981).

Females lay eggs (some 50) singly on or near host fruit, whose presence attracts females and stimulates oviposition (Wildbolz 1958). Within hours of hatching, larvae enter a fruit via the calyx, or by chewing through the skin and excavating a cavity in the flesh. After the first of five instars, the larva bores to the centre of the fruit, where it completes its development by feeding on and around the seeds. Fully-fed larvae drop to the ground and tend to crawl back to the tree

trunk where they spin a tough, closely woven cocoon. There are generally two main generations per year and a partial third, except in southern Tasmania where there is usually only one.

A few individuals of the first generation, most of the second and all survivors of the third generation diapause as fully-fed 5th instar larvae within their cocoons. These pupate and emerge in the next season.

PEST STATUS

Codling moth occurs most commonly on apples, pears, quinces and crab apples and is essentially a pest of pome fruit, although it occasionally attacks a range of other fruits (Hely et al. 1982). It does not develop on native plants (Geier 1963).

Codling moth has caused enormous commercial losses in apples and pears, being most damaging in warmer and drier pome fruit districts. Until the introduction of synthetic insecticides in the 1940s, it could destroy almost an entire crop on untreated trees and up to 30% on trees sprayed with pre-war insecticides. Orchard hygiene and modern selective pesticides have done much to control this key pest (Hely et al. 1982).

BIOLOGICAL CONTROL

Adult codling moths are taken by birds and spiders. Eggs and newly hatched larvae are attacked by mirid bugs and larvae of the green lacewing, *Chrysopa* sp. (Allman 1928). Once larvae tunnel into the fruit they are well protected against predators and parasitoids. However, when mature larvae leave the fruit they are attacked by earwigs (including *Labidura riparia*), ants (including *Iridomyrmex purpureus* by day and *Camponotus consubrinus* at night) and spiders, often greatly reducing the number of fully-fed larvae that manage to spin a cocoon. Larvae of a melyrid beetle, *Carphurus elongatus*, and of the dermestid beetle *Trogoderma froggatti* are occasionally predators on larvae and pupae in cocoons (Froggatt 1906; Allman 1928, Wilson 1960; Geier 1964).

A number of parasitoids have been recorded from *C. pomonella* (Table 38 page 363). Eggs are attacked by *Trichogramma australicum* and *T. minutum*, usually at a low level in spring, rising to a maximum of 30% in autumn (Allman 1928; Wilson 1960; Geier 1964; Hely et al. 1982).

Larval and pupal parasitoids were often reared from cocoons spun in trap bands placed around the mainstem of the tree. The native chalcid *Antrocephalus stokesi* attacks pupae in their cocoons and, in Canberra, Australian Capital Territory, formed 78% of all parasites recovered from trap bands. *C. pomonella* is thought to overwinter as adults (Geier 1964). The native ichneumonid, *Glabridorsum stokesii*, which attacks pupae in their cocoons, accounted for 12% of the total and 7 other hymenopterous parasitoids and a tachinid fly accounted for the remaining 10%. Of these, the pteromalid *Dibrachys pacificus* is believed to be

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hyperparasitic on *A. stokesi*. At least 50% of larvae and pupae in cocoons in trap bands were parasitised, but individuals in natural shelter were rarely found to be parasitised (Geier 1964).

Death from diseases was common in the Australian Capital Territory, involving a granulosis virus that was particularly effective amongst crowded, overwintering larvae (Geier 1964). The fungus *Isaria farinosa* has been reported to kill 90% of *C. pomonella* larvae in one area of Victoria and large numbers in most seasons in Tasmania (McAlpine 1903).

A predatory neuropteran, *Raphidia* sp., was imported from California to New Zealand in 1891. It is reported that the farmer involved 'may have sent a few of them to Australia for acclimatisation' (Wearing and Charles 1989).

When *C. pomonella* first arrived in Western Australia in 1903 it was planned to introduce from California *Liotryphon caudatus* (under the name of *Calliephialtes messor*), originally from Spain. Although there is a report of its introduction from 1904 to 1905 (Johnston 1928), Wilson (1960) raised doubts that this actually took place.

T. minutum, from California, was liberated in 1928 in both Queensland and New South Wales. Some recoveries were made from codling moth eggs shortly after in 1929, but without any apparent change in moth abundance. Stocks from England were also imported in 1929 and 1930, but no liberations were made because investigations indicated that neither it nor *Trichogramma evanescens* would be able to control *C. pomonella*. This species was already known from the eggs of other hosts in four mainland States of Australia (Wilson 1960).

In 1964, the braconid parasitoid *Ascogaster quadridentatus* was introduced from Canada, but details are not available concerning its liberation (Clausen 1978c) and there appear to be no records of its recovery from the field.

The fact that codling moth inflicts unacceptable economic damage, even at very low population densities, makes it an unattractive target for effective classical biological control. Based on his extensive studies, Geier (1963) concluded that the population dynamics of codling moth would not be seriously affected either by the disappearance of existing natural enemies in Australia, or by the introduction of others from overseas.

No successes have been reported in attempts at biological control of *C. pomonella* in other countries to which it has been introduced.

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Table 38. Parasitoids attacking *Cydia pomonella* in Australia

Species	Stage attacked	References
DIPTERA		
TACHINIDAE		
Unidentified	P	Geier 1964; Wilson 1960
HYMENOPTERA		
BETHYLIDAE		
Bethylus sp.	C [a]	Wilson 1960
Goniozus antipodum	C	Wilson 1960
Goniozus sp.	C	Allman 1928; Geier 1964; Wilson 1960
CHALCIDIDAE		
Antrocephalus carcocapsae	P	Boucek 1988
Antrocephalus stokesi	C	Miller 1938; Wilson 1960; Boucek 1988
Brachymeria phya	C	Geier 1964
Brachymeria pomonae	C	Geier 1964
EURYTOMIDAE		
Eurytoma pyrrhocera	C	Geier 1964; Boucek 1988
ICHNEUMONIDAE		
Glabridorsum stokesii	C	Miller 1938; Wilson 1960; Geier 1964
Unidentified spp.	C	Wilson 1960
PTEROMALIDAE		
Dibrachys boarmiae	C	Wilson 1960; Geier 1964; Boucek 1988
Pseudanogmus australia	C	Boucek 1988
Pteromalus sp.	C	Wilson 1960
TRICHOGRAMMATIDAE	E	
Trichogramma australicum	E	Allman 1928; Wilson 1960
Trichogramma ivelae	E	McLaren & Rye 1981
Trichogramma minutum	E	Wilson 1960
Trichogramma sp.	E	Geier 1964

C[a] = fully fed larva or pupa in cocoon

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Grapholita molesta (Busck) Lepidoptera: Tortricidae
oriental fruit moth

This species has also been referred to as *Cydia molesta, Laspeyresia molesta* or *Grapolitha molesta.*

PRECIS

From its introduction in about 1910 until the 1970s, the oriental fruit moth, *Grapholita molesta*, was an important pest in many years in Victoria and southern New South Wales. Larvae tunnel into the growing tips of the host fruit tree, leading to their death and disruption of tree growth; and they also bore into, and damage, up to 80% of the fruit.

Before attempts at biological control, nine hymenopterous parasitoids were recorded and, since then, two additional species, but their combined activity was insufficient to prevent serious damage. Six of what were considered to be its major exotic parasitoids were introduced from eastern USA where an extensive, but unsuccessful, biological control program was in progress. None of these have survived, although three became established briefly. There are no reports of successful ongoing biological control of *G. molesta* in other countries.

BIOLOGY

On average, 85 eggs are laid singly, over about 15 days, on the undersurface of leaves or on smooth stems. The newly-hatched larva tunnels into the tip of a twig, often through a petiole. Older larvae may leave a twig once or twice during development to attack another twig or to enter a fruit, generally at the stem end. These larvae tunnel to the stone of the fruit. When fully grown, the larva leaves the twig or fruit and seeks a place to spin its cocoon, which incorporates bark or other debris. Larvae of the three early and mid-season generations spin cocoons high up in the tree, whereas most of those of the fourth and fifth generations do so under the rough bark on the tree trunk. Up to 37% descend to spin their cocoons under debris on the soil surface.

Development times (egg to adult) in the field for the first four generations range from 33 to 47 days and of the overwintering fifth generation 202 to 224 days. In the first four generations egg incubation takes 5 to 10 days, larval development 12 to 24 days, prepupal period 4 to 6 days, pupal period 10 to 12 days and pre-oviposition period 3 to 6 days (Gay 1935; Helson 1939).

Grapholita molesta was first reported about 1910 attacking peaches in the Sydney district (Froggatt 1914) and since then it has spread throughout the State. It is of special importance in the coastal region north of Sydney as a pest of desert peaches and in the canning peach industry in the Murrumbidgee Irrigation Area, where it was first reported in 1936. Pescott (1931) reported that infestations of peaches, which had occurred for many years in the Goulburn Valley, Victoria and had been attributed to the codling moth (*Cydia pomonella*), were actually due to the oriental peach moth. *G. molesta* also occurs in the Australian Capital Territory and in Queensland. In 1952, it was identified from quinces and pears in Western Australia and a very similar larva was found attacking citrus there (I.F.B. Common, CSIRO files). It appeared in South Australia in 1959 (Wishart 1960).

Clausen (1978a) suggests that *G. molesta* is probably native to China, Korea and Japan and states that it now occurs in most peach-growing areas of the world. However, its origin is more probably continental Asia since it is a major pest of peaches in Japan.

PEST STATUS

Damage by *G. molesta* larvae is of two types:

(1) newly hatched larvae tunnel up to a length of 15 cm into the young growing tips, particularly those of young trees. This causes wilting and death of the tips, which leads to secondary shoots below the damaged tips and interferes with the proper shaping of the trees;

(2) far more serious, however, is the tunnelling into the fruit, encouraging brown rot and destroying its market value. This is particularly serious in late canning peaches. During a bad season, such as 1933–1934, 40% to 80% of the canning crop in Victoria was destroyed (Gay 1935).

All peach and nectarine varieties may be attacked and occasionally quinces, apples, plums, cherries and pears. Overseas it is also recorded from apricots. In the 5 years following the disastrous 1933–1934 season, the percentage damage was 25, 50, 30, 10, 10 (CSIRO files). It then remained at modest levels for some years, and *G. molesta* is now substantially controlled in many orchards by the continuous release of its female sex pheromone to produce male confusion. This is now a valuable component of the control of the oriental peach moth (Vickers et al. 1985).

BIOLOGICAL CONTROL

The late summer and overwintering generations of *G. molesta* are attacked by two egg, four larval, two prepupal and three pupal, hymenopterous parasitoids (Table 39 page 368).

Helson (1939) claimed that, of these, *Dibrachys boarmiae*, a cosmopolitan ectoparasitoid with a very wide host range, was the most important parasitoid of the oriental peach moth in the Goulburn Valley. This was because its attack, which occurs in the autumn and winter months, may result in as many as 90% of overwintering prepupae producing *D. boarmiae* adults. He also reported that *D. boarmiae* is a hyperparasitoid of *Chromocryptus antipodialis*, second in abundance in the region. Later, when the exotic *Macrocentrus ancylivora* was briefly established, it was also hyperparasitised by *D. boarmiae* (Helson 1939).

Antrocephalus stokesi is the most important species in the Sydney district and is abundant in February and March. *Glabridorsum stokesii* is second in importance in New South Wales, but less important in Victoria. It is a mid-season ectoparasitoid, attacking host pupae from December to March. *Goniozus* sp. is the third most important species in the Sydney district and attacks prepupae late in the season. The remaining species are uncommon (Helson 1939).

Two species of *Trichogramma* have been reported to attack the eggs of *G. molesta: T. funiculatum* (also from the eggs of *Epiphyas postvittana*) in South Australia (Carver 1978a) and *Trichogramma* sp. nr *ivelae* from Victoria (McLaren and Rye 1981).

The activity of what were considered to be the more important parasitoids already present is restricted to the latter part of the growing season and, in any event, they were unable to reduce the abundance of *G. molesta* to a satisfactory level. Parasitoids active in spring and summer were, therefore, sought from eastern North America where a major biological control program was in progress. There, 57 primary parasitoids and 8 hyperparasitoids had been recorded by Haeussler (1930). Of these, two native species attacking *G. molesta*, namely *M. ancylivora* and *Glypta rufiscutellaris*, were regarded as the most important of the parasitoids. Six species, including these two, were introduced from eastern USA and released in the Goulburn Valley between 1935 and 1941 (Table 1 page 29). Most attention was paid to *M. ancylivora* whose preferred host is the strawberry leaf roller, *Ancylis comptana fragariae* (Clausen 1978a). Upwards of 12,000 adults were released in 18 locations, followed by about 1,000 *G. rufiscutellaris* at 7 locations.

Three of the species (*M. ancylivora, G. rufiscutellaris* and *Agathis diversus*) were recovered from the field during 1936 to 1938, but no further recoveries were made after 1938, except for a very small number of *M. ancylivora* over the next 2 years. Small numbers of *M. ancylivora* were liberated near Sydney and also in the Murrumbidgee Irrigation Area of New South Wales, but there were no recoveries (CSIRO files; Wilson 1960).

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It was postulated that the comparatively long warm autumns and early winters in Victoria cause a high proportion of *M. ancylivora* to emerge in May and June each year, when no hosts are available (as native hosts are in USA) to provide it with an overwintering host. *G. rufiscutellaris* also requires an alternative host which is not available in Australia (Helson 1947). It is interesting that, when *G. molesta* appeared in California in 1942, *M. ancylivora* was mass-produced on the potato moth, *Phthorimaea operculella*, to aid in an eradication program (Finney et al. 1947). This was unsuccessful, but *M. ancylivora* became established there on oriental fruit moth and other native species (Clausen 1978a). It has not been established outside North America (Bailey 1979).

No attempts have been made since 1941 to introduce further natural enemies to south-eastern Australia. This is, in part, due to the lessened importance of this pest due to the effective use of the female sex pheromone, cis-8-dodecenyl acetate, as a means of male confusion. This is as effective as the use of insecticides (Rothschild 1975, 1979; Vickers et al. 1985). *M. ancylivora* was again introduced from USA, reared and released in 1977 and 1978 at rates of up to 60 females per tree in five peach orchards in the Loxton area of South Australia. An average of only 4% of *G. molesta* larvae were parasitised, possibly because hosts were scarce, about one per tree. Parasitoids were bred only from larvae of the generation in which the release was made (Bailey 1979). Most peach orchards in the Riverland area have not been sprayed for some years and it has been assumed that *G. molesta* has come under effective natural control (G.O. Furness, pers. comm. 1979).

COMMENTS

Helson (1939) concluded that, although *D. boarmiae* was a hyperparasitoid of the next most abundant species (namely the primary parasitoid *C. antipodalis*), this hyperparasitoid was the most important natural enemy of *G. molesta* in the Goulburn Valley of Victoria. It can also act as a primary parasitoid but, unless a substantial proportion of its progeny are primary parasitoids of oriental fruit moth larvae, his conclusion may require reviewing, since the number of adult *C. antipodalis* may be seriously reduced by its activity.

Most attention has been paid to native North America parasitoids (*M. ancylivora* and *G. rufisculellaris*) which included *G. molesta* in their host range when it became established there. Clearly, however, parasitoids that co-evolved with it in China and neighbouring countries are likely to be better adapted to reducing its abundance. Although two of the parasitoid species introduced to Australia came from that region, it can be questioned whether, if further biological control is desired, enough consideration has been given to other oriental parasitoids.

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Table 39. Parasitoids attacking *Grapholita molesta* in Australia (Helson 1939; Carver 1978a; Bailey 1979; McLaren and Rye 1981; Boucek 1988)

Species	Stage attacked	Ecto- or endo-parasitoid	State from which recorded
HYMENOPTERA			
BETHYLIDAE			
Goniozus angulata	prepupa	ecto	NSW, Vic
Goniozus sp.			
BRACONIDAE			
Bassus sp.	larva	endo	Vic
unidentified	larva	endo	Vic
CHALCIDIDAE			
Antrocephalus stokesi	pupa	endo	NSW, VIC
EULOPHIDAE			
unidentified	pupa	endo	NSW, Vic
ICHNEUMONIDAE			
Chromocryptus antipodialis	larva	ecto	NSW, Vic, SA
Glabridorsum stokesi	pupa	ecto	NSW, Vic
Diadegma sp.	larva	endo	Vic
PTEROMALIDAE			
Dibrachys boarmiae	overwintering prepupa	ecto	NSW, Vic
Dibrachys nr *cavus*	overwintering prepupa		SA
TRICHOGRAMMATIDAE			
Trichogramma funiculatum	eggs	endo	SA
Trichogramma ivelae	eggs	endo	Vic

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Helicoverpa armigera (Hübner) Lepidoptera: Noctuidae
cotton bollworm, corn earworm

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Helicoverpa punctigera (Wallengren)
native budworm, tobacco budworm

PRECIS

Helicoverpa armigera may be native to southern Europe and the Mediterranean region, but now has a cosmopolitan distribution including much of eastern Australia. *Helicoverpa punctigera* is an indigenous Australian moth, occurring in all States and on Cocos Island. The larvae of *H. armigera* and *H. punctigera* are major pests in Australia, and feed on a wide range of the leaves, flowers and fruiting bodies of field and horticultural crops.

Natural enemies do not achieve effective biological control of *Helicoverpa* spp. in crops, but a range of parasitic flies, wasps, predatory ants, beetles and spiders attack the immature stages. Insecticides are widely used to control *Helicoverpa* spp., and inundative releases of *Trichogramma* spp. and applications of *Bacillus thuringiensis* have been made with mixed success in cotton, sorghum and tomatoes. Several exotic natural enemies have been introduced into Australia with limited benefits. In particular, the egg parasitoid *Trichogramma pretiosum* has had some effect on *Helicoverpa* populations in south-eastern Queensland since it was introduced in 1995.

BIOLOGY

Helicoverpa armigera occurs from the Canary Islands in the west, to the Pacific islands in the east (Matthews 1999) and, in Australia, it occurs mainly in the

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eastern half of the mainland. In Queensland, it occurs mostly in the coastal region up to 160 km inland between Cairns and Brisbane, and also further inland. In New South Wales, it extends its distribution to the Victorian border (Zalucki et al. 1986) and into Victoria, South Australia and sporadically, Northern Territory and Western Australia (Matthews 1999). *Helicoverpa punctigera* is a native Australian moth and occurs throughout all States and on Cocos Island (Common 1953). It was thought to be absent from the eastern coast of Queensland north of Brisbane (Zalucki et al. 1986) but has been shown to also occur near Cairns (Matthews 1999).

Helicoverpa species were reported causing damage to fruit in New South Wales from 1923 to 1924 (Common 1953) and were subsequently recorded as pests of a wide range of crops in Australia. The relative importance of *H. armigera* and *H. punctigera*, and their seasonality and distribution, were confused by misidentification of the two species before 1953. Each is now known to predominate in certain crops and to migrate long distances from breeding sites.

The taxonomy of *Helicoverpa* spp. was recently reviewed by Matthews (1999). The adults of *H. armigera* and *H. punctigera* are very similar in appearance but may be readily distinguished by their genitalia (Zalucki et al. 1986; Matthews 1999). In fresh specimens, both sexes of *H. armigera* have a pale patch on the otherwise black terminal band of the hind wing, between veins M_3 and CuA. There is no similar patch on the hind wing of *H. punctigera.* Larvae of the two species can be distinguished by examining the hairs and markings on the abdominal segments (Pyke and Brown 1996). Differences in colour of the first abdominal segments and legs have been used to separate the larger larvae (Stanley 1978), but these have been shown to be unreliable (Daly and Gregg 1985). The pupae can be easily distinguished, in that the cremaster spines of *H. armigera* are more widely spaced at their bases than those of *H. punctigera* (Cantrell 1980). The two species can now be readily distinguished by deoxyribonucleic acid (DNA) tests.

The eggs of *H. armigera* and *H. punctigera* are deposited beneath the leaves, or on buds, flowers and young fruit of the host plants. They are almost spherical, about 0.5 mm in diameter and vary from white to yellow or brown depending on the stage of development. Eggs hatch in 3 to 17 days depending on temperature and, after consuming the egg shell, the 1st instar larvae commence feeding on young growth of the food plants. Larvae feed for 14 to 18 days externally on the plant tissues or tunnel into fruiting bodies, often moving from one fruit to another. After completing five to six instars, larvae drop to the ground and tunnel into the soil to a depth of about 10 cm where they construct an earthen cell before pupating. Pupal development varies in duration depending on the season. Adults emerge after 12 to 14 days in warm, humid weather, but eclosion may be delayed if they enter a facultative diapause — pupal development then taking 69 to 318 days (Kay 1982). Cannibalism by larvae in laboratory cultures, and of eggs and

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larvae in the field on corn, is a major mortality factor when the density of larvae of *Helicoverpa* spp. is high, and may also be important on sorghum and sunflower.

PEST STATUS

The larvae of both *Helicoverpa* spp. are polyphagous and cause serious damage to a wide range of agricultural crops by feeding on the leaves, flowers and fruiting bodies. *H. armigera* occurs on monocotyledons as well as dicotyledons, whereas *H. punctigera*, with a wider host range, occurs mainly on dicotyledons. At least 160 plants representing 49 plant families are recorded as hosts for larvae of the two species of moths. The principal hosts of both species are cotton, legumes, corn, linseed, sunflower, sorghum, tobacco, tomato and deciduous fruit (Zalucki et al. 1986). Ornamental plants are also frequently attacked by both species. Damage to fruit trees sometimes results when larvae move from alternative hosts that have become unsuitable for larval development (Common 1953). Asparagus and pecan nuts are also recorded as hosts for *H. armigera* (Seymour and Sands 1993; Kay and Hardy 1999). Two other species of *Helicoverpa*— *H. assulta* and *H. rubrescens*— damage crops in Australia; and in Sumatra, *H. assulta* is a major pest of tobacco (Common 1953). *H. propodes* is very rare and its life history is unrecorded. *H. hardwicki* has recently been described from northern Western Australia and the Northern Territory, where its larvae feed on leguminous plants (Matthews 1999).

BIOLOGICAL CONTROL

Due to difficulties in identifying to species the eggs and larvae of *Helicoverpa* spp., the effects of most natural enemies on *H. armigera* and *H. punctigera* have not been differentiated. Viruses, fungi, protozoa, nematodes, predators and parasitoids have been identified as natural enemies of both *Helicoverpa* spp. (Zalucki et al. 1986). Arthropod predators, identified by field observations and radio-tracer techniques, are mainly Arachnida, Coleoptera and Hemiptera (Table 40 page 373), but a much wider range of potential predators has been demonstrated by exposing immature stages of *Helicoverpa* to them in the laboratory (Room 1979).

Indigenous hymenopterous and dipterous parasitoids are important natural enemies except when insecticides are extensively used. The levels of parasitisation of *H. armigera* and *H. punctigera* vary with season, host plant and geographic location. An indigenous *Telenomus* sp. nr *triptus*, contributes most to parasitisation of eggs of *H. armigera*, although three *Trichogramma* spp. are also important (Zalucki et al. 1986). *Trichogramma* sp. nr *ivelae* is recorded parasitising up to 69% of eggs of *H. punctigera* (Ridland et al. 1993). This parasitoid has a wide host range, including eggs of other, unrelated Lepidoptera. *Trichogramma* sp. nr *ivelae* and other *Trichogramma* spp. have been considered suitable for inundative releases in certain crops (Ridland et al. 1993).

Microgaster sp. is an important braconid larval parasitoid of *Helicoverpa* spp. in cotton (Wilson and Greenup 1977) and *M. demolitor* is the predominant parasitoid of small larvae (Michael 1989). *Microplitis* sp. is considered to be an effective parasitoid in sunflower crops (Broadley 1984). Of the ichneumonids, *Heteropelma scaposum* has a wide geographical range and parasitises *Helicoverpa* spp. on many different plants (Zalucki et al. 1986), but the ichneumonid *Netelia producta*, a common pupal parasitoid, is not considered to have sufficient impact on *Helicoverpa* spp. to reduce damage (Ridland et al. 1993). *Ichneumon promissorius* may be an important species and has probably been overlooked since it does not attack larvae and only develops in pupae (Fitt and Mares 1992). Many other indigenous parasitoids of eggs, larvae and pupae cause mortality, but their impact on populations of the hosts does not appear to be sufficient to achieve control in most cropping systems. *Chaetophthalmus* sp. and *C. dorsalis* are considered to be some of the more effective tachinid parasitoids of *Helicoverpa* spp. in sunflower and cotton crops in south-eastern Queensland (Broadley 1984; Walker 1998). However, *C. dorsalis* and *Tritaxys* sp., although common pupal parasitoids, do not prevent the build-up of damaging numbers of *Helicoverpa* spp. (Ridland et al. 1993).

Ants are important predators of the eggs of *Helicoverpa* spp. in cotton in Queensland. Predatory beetles, bugs and spiders also contribute to mortality (Scholz et al. 2000).

Eight hymenopterous parasitoids have been introduced into Australia for biological control of *Helicoverpa* spp. (Table 1page 29). The egg parasitoid *Trichogramma pretiosum* has had a significant impact on the abundance of the pest species since it was introduced into Queensland (B.C.G. Scholz, pers. comm.). In Western Australia, levels of egg parasitism by *T. pretiosum* sometimes reach 93% and it is considered to be the most important beneficial natural enemy of *Helicoverpa* spp. (Strickland and Lacey 1996). Other exotic parasitoids of eggs or larvae have not proved to be effective.

A native fungal pathogen, *Beauveria bassiana*, may kill up to 20% of overwintering pupae (Wilson and Greenup 1977). A commercial strain (ATCC 74040) of *B. bassiana* was introduced from California and released in 1994 (AQIS 1999b), against *H. armigera* and other cotton insects. Although a brief report indicated promising results (Wright and Knauf 1994), there are no reports of its commercial use, or of the continuing presence of the fungus in the field.

COMMENTS

Despite the considerable economic importance of *Helicoverpa* spp., relatively few biological control agents have been introduced into Australia in attempts to control these serious pests. Several promising agents are known to attack

Helicoverpa spp. overseas, but very little is known of their host specificity. Several Old World egg and larval parasitoids of *H. armigera* and New World parasitoids of *H. zea* may prove suitable for introduction, one of which is *Microplitis croceipes,* which is specific to *Heliothis* spp. and *Helicoverpa* spp. Since its establishment in New Zealand, *M. croceipes* is recognised as a potentially valuable candidate for introduction into Australia (Ridland et al. 1993).

Table 40. Indigenous arthropod natural enemies of *Helicoverpa armigera* and *H. punctigera*

Species	Stage of host	References
DERMAPTERA		
LABIDURIDAE		
Labidura truncata	P	Room 1979
Nala lividipes	E	Lytton-Hitchins 1999
HEMIPTERA		
LYGAEIDAE		
Geocoris ? lubrus	E, L	Room 1979
MIRIDAE		
Campylomma liebknechti	E	Scholz et al. 2000
NABIDAE		
Nabis capsiformis	E, L	Room 1979; Lytton-Hitchins 1999
Nabis kinbergii	E	Scholz et al. 2000
ANTHOCORIDAE		
Orius sp.	E	Scholz et al. 2000
PENTATOMIDAE		
Cermatulus nasalis	L	Room 1979
Oechalia schellenbergii	L	Room 1979
COLEOPTERA		
CARABIDAE		
Calosoma schayeri	L, P	Room 1979; Lytton-Hitchins 1999
Geoscaptus laevissimus	L, P	Lytton-Hitchins 1999
COCCINELLIDAE		
Diomus notescens	E, L	Room 1979
Coccinella transversalis	E	Scholz et al. 2000
Micraspis frenata	E	Scholz et al. 2000
NEUROPTERA		
CHRYSOPIDAE		
Mallada ? signata	E, L	Room 1979

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Table 40. (cont'd) Indigenous arthropod natural enemies of *Helicoverpa armigera* and *H. punctigera*

Species	Stage of host	References
DIPTERA		
TACHINIDAE		
Actia sp.	L	Cantrell 1984
Anamastax braueri	L	Broadley 1980
Anamastax sp.	L	Titmarsh 1980
Carcelia cosmophilae	L	Cantrell 1986; Michael 1989
Carcelia illota	L / P	Room 1979; Michael 1989
Carcelia sp.	L / P	Kay 1982; Titmarsh 1980
Chaetophthalmus bicolor	L / P	Cantrell 1984
Chaetophthalmus biseriatus	L / P	Bishop & Blood 1977; Michael 1989; Ridland et al. 1993
Chaetophthalmus ? biseriatus	L / P	Room 1979; Broadley 1984
Chaetophthalmus dorsalis	L	Walker 1998
Chaetophthalmus sp.	L / P	Broadley 1980
Compsilura concinnata	L	Broadley 1984
Cuphocera sp.	L	Broadley 1984
Exorista curriei	L	Teakle et al. 1983
Exorista psychidivora	L	Cantrell 1984
Exorista sp.	L	Titmarsh 1980; Broadley 1984
Goniophthalmus australis	L / P	Broadley 1984
Goniophthalmus sp.	L / P	Titmarsh 1980
Linnaemya sp.	L	Cantrell 1984
Microtropesa sp.	L	Cantrell 1984
Palexorista sp.	L	Bishop 1984
Paradreno laevicula	L	Cantrell 1984
Peribaea orbata	L / P	Crosskey 1973
Peribaea sp.	L / P	Bishop & Blood 1977
Sisyropa sp.	L	Bishop 1984
Tritaxys heterocera	L	Broadley 1980
Tritaxys sp.	P	Ridland et al. 1993
unidentified 2 spp.	L / P	Room 1979
Winthemia lateralis	L	Cantrell 1986
Winthemia neowinthemoides	L	Cantrell 1984
Winthemia sp.	L	Crosskey 1973

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Table 40. (cont'd) Indigenous arthropod natural enemies of *Helicoverpa armigera* and *H. punctigera*

Species	Stage of host	References
HYMENOPTERA		
BRACONIDAE		
Cardiochiles sp.	L	Room 1979
Chelonis sp.	E / L	Broadley 1984
Microgaster sp.	L	Michael 1973; Broadley 1984
Microplitis sp.	L	Kay 1982; Michael et al. 1984
Microplitis demolitor	L	Michael 1989; Ridland et al. 1993
Pristomerus sp.	L	Broadley 1984
Rogas sp.	L	Bishop 1984
unidentified 3 spp.	L	Room 1979
FORMICIDAE		
Iridomyrmex vicinus (group)	E	Lytton-Hitchins 1999; 2000
Iridomyrmex sp.	E	Scholz et al. 2000
Pheidole spp.	E	Lytton-Hitchins 1999; 2000
ICHNEUMONIDAE		
Campoletis sp.	L	Michael et al. 1984
Heteropelma scaposum	L / P	Room 1979; Broadley 1984
Ichneumon promissorius	P	Fitt and Mares 1992; Murray & Zalucki 1994
Lissopimpla excelsa	L / P	Room 1979
Netelia producta	L / P	Room 1979; Ridland et al. 1993
PTEROMALIDAE		
unidentified sp.	L	Room 1979
SCELIONIDAE		
Telenomus sp. nr *triptus*	E	Twine 1973
Telenomus sp.	E	Room 1979; Scholz 1990
TRICHOGRAMMATIDAE		
Paratrichogramma heliothidis		Michael 1989
Trichogramma australicum	E	Twine 1973; Scholz 1990
Trichogramma nr *brassicae*	E	McLaren & Rye 1981; Scholz pers. comm.
Trichogramma carverae	E	Scholz 1990
Trichogramma funiculatum	E	Michael 1989
Trichogramma sp. nr *ivelae*	E	Ridland et al. 1993
Trichogramma sp.	E	Room 1979; Scholz 1990
Trichogrammatoidea bactrae	E	Scholz 1990
Trichogrammatoidea flava	E	Twine 1973
Trichogrammatoidea nana	E	Michael 1989
Trichogrammatoidea sp.	E	Scholz 1990

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Table 40. (cont'd) Indigenous arthropod natural enemies of *Helicoverpa armigera* and *H. punctigera*

Species	Stage of host	References
ARACHNIDA		
CLUBIONIDAE		
Cheracanthium diversum	E, L, A	Room 1979
Cheracanthium sp.	E	Scholz et al. 2000
LYCOSIDAE		
Lycosa godeffroyi	L	Lytton-Hitchins 1999
Lycosa sp.	L	Room 1979
OXYOPIDAE		
Oxyopes elegans	L	Room 1979
THERIDIIDAE		
Achaearanea veruculata	L	Room 1979

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Hellula undalis (Fabricius) Lepidoptera: Pyralidae
cabbage-centre grub

Hellula undalis is native to Europe, Africa and most of Asia. A related species of minor economic importance, *H. hydralis*, is confined to Australia. The prospects for biological control of four pest *Hellula* species are discussed by Waterhouse and Norris (1989).

PRECIS

Hellula undalis is a widespread pest of cabbage and other Brassicaceae, but does not occur in the Americas.

Overseas it is attacked by a range of non-specific ichneumonids and braconids, but these do not appear to control its abundance. A single attempt in 1907 to establish an unidentified Indian braconid in Western Australia was a failure. On the basis of existing knowledge, *H. undalis* is not an attractive target for biological control.

BIOLOGY

Hellula undalis eggs are laid singly or in groups on cabbage leaves and hatch in 2 to 3 days at 28°C. The 5th (usually host) instar grows to 14 mm in length and the entire larval development takes about 2 weeks at 28°C. Young larvae mine a leaf or graze on its surface under a protective silken web. Older larvae bore into the compact head of cabbages and cauliflowers. Cocoon spinning and pupation occur in the feeding tunnels or in an earthern cell just below the soil surface. The greyish brown adults are nocturnal and females produce a sex pheromone (Waterhouse and Norris 1989).

H. undalis occurs in north and north-eastern Australia. It has spread also to a number of Pacific Nations (Cook Islands, Fiji, Hawaii, Guam, New Caledonia, Solomon Islands, but apparently not to Papua New Guinea) (Waterhouse and Norris 1989).

PEST STATUS

The main hosts of *H. undalis* are Brassicaceae, but it also attacks Amaranthaceae and eggplant (Solanaceae). Losses are serious at the seedling stage and boring by advanced larvae ruins cabbage and cauliflower heads. Radish and turnip also suffer severe damage (Waterhouse and Norris 1989).

BIOLOGICAL CONTROL

No studies of the natural enemies of *H. undalis* or *H. hydralis* in Australia appear to be available. Five non-specific parasitoids are known in Egypt and several from elsewhere, but they do not prevent the cabbage-centre grub from becoming an economic problem (Waterhouse and Norris 1989).

An unidentified braconid was introduced to Western Australia from India in 1907, but this parasitoid failed to become established (Jenkins 1946; Wilson 1960). It may have been *Chelonus blackburni* which is known from *H. undalis* in India (Rawat et al. 1968). There do not appear to have been any attempts at biological control of *Hellula* spp. elsewhere in the world.

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Oncopera spp. Lepidoptera: Hepialidae underground grass grubs

There are 12 species of the genus *Oncopera* in eastern Australia and many of them are known as occasional pasture pests. These include *O. intricata* in Tasmania (Martyn 1960), *O. fasciculata* in western Victoria and South Australia (Madge 1954), *O. rufobrunnea* in Tasmania, Victoria and on the northern tablelands of New South Wales, *O. alboguttata* and *O. tindalei* on the northern tablelands of New South Wales, and *O. brachyphylla* and *O. mitocera* on the Atherton tablelands of Queensland (Barton Browne et al. 1969; Elder 1970; Common 1990). The biological control investigations were aimed primarily at the Tasmanian and Victorian species.

PRECIS

The larvae of several native species of *Oncopera* are occasional pests of grassy pastures in eastern Australia. They are heavily preyed upon by birds and other native enemies and occasionally parasitised by tachinids and ichneumonids. The liberation in Victoria over the years 1932 to 1939 of two native New Zealand tachinids (*Hexamera* spp.) that parasitise the New Zealand grass grubs (*Wiseana* spp.) did not lead to their establishment.

The prospects for improved biological control appear to be remote.

BIOLOGY

The broad features of the biology of the pest species appear to be similar. In spring, adults fly and mate for a brief period (less than 1 hour) at dusk. Shortly after mating, 500 to 2000 eggs are laid on the ground under pasture, where the female shelters by day, or are scattered during low flight over the pasture.

The incubation period is 3 to 5 weeks or longer. For 2 or 3 days, newly hatched larvae live in communities under webbing before dispersing to build individual, vertical tunnels in the soil. Some species spin a narrow, silken strip up one side of the tunnel to aid movement. This strip is extended horizontally to form one or more runways along the ground surface to assist accessing food. A

silken cover incorporating vegetation, debris and soil is built over much of the runways to provide shelter and concealment. Tunnels of mature larvae may be as long as 25 cm. After a prepupal stage of about 14 days, the pupa advances to the mouth of the tunnel and the adult emerges in the late afternoon. There is one generation a year (Hill 1928; Evans 1941; Madge 1954; Martyn 1960; Barton Browne et al. 1969).

PEST STATUS

All grasses and herbaceous plants sown for pastures are attacked including clovers. Rye grass (*Lolium* spp.) is generally attacked first and, together with cocksfoot (*Dactylis glomerata*), may be eliminated during the second or third year after sowing. Grasses are preferred to clovers (Hill 1928). Lawns may also be damaged. Larvae feed by night and, as daylight approaches, may carry pieces of vegetation to the entrance of their tunnels to be eaten during the day. When abundant, the pasture can be eaten bare as larvae mature in early winter. Outbreaks occur rather intermittently and most of the time *Oncopera* populations appear to be under good natural control.

BIOLOGICAL CONTROL

There do not appear to be any detailed studies of the natural enemies of *Oncopera* spp. In relation to parasitoids, there are in Tasmania two tachinids which deposit their microeggs on grass near possible hosts. The eggs are later swallowed by host larvae during feeding. These tachinids are *Tritaxys heterocera*, which is also reported from Queensland and also attacks cutworm larvae; and a *Sturmia* sp. which is very abundant at times on *Oncopera*. Also in Tasmania, Thompson (1895) reported that, in 1891, a green ichneumonid wasp (possibly *Theronia viridicans*: Evans 1941) was extensively parasitising *Oncopera* larvae and J.W. Evans (unpublished, in the 1930s) obtained 16 unidentified wasp larvae from one *Oncopera* larva.

Predation is almost certainly a far more important source of mortality. The carabid beetle, *Promecoderus ovicollis*, occurs in northern Tasmania and spiders and ants are also mentioned as predators. Birds undoubtedly consume an immense number of larvae, especially in showery or dull weather when larvae are often found under the covered ways near the entrance to the tunnel. Magpies, crows and spur-winged plovers are amongst those involved, but the introduced starling is said to be particularly important (Martyn 1960). Lea (1908) placed the bandicoot first in importance amongst the natural enemies (Hill 1928).

Two fungi, *Cordyceps gunnii* and *Isaria oncopterae*, together with a third, undescribed species from Victoria, have been recorded, with infestations of up to 15% in *Oncopera* larvae (Hill 1928). Steinhaus (1951) lists *Beauvaria* sp. from *O. fasciculata* in South Australia. *Cephalosporium* sp. is widespread in Tasmania

but, except in wet seasons when mortality may be high, is generally at low incidence.

Hexamera alcis and *Protohystrichia orientalis* (earlier known as *Hexamera signata*) parasitise native hepialid larvae (*Wiseana* spp.) in New Zealand. Females deposit living larvae, or eggs that hatch immediately, on grass in the vicinity of hosts. These larvae seek out young larvae and bore into them, often killing newly hatched hosts. Similar behaviour was observed towards 1st, 2nd and 3rd instar *Oncopera* larvae, although there is apparently no record of the parasitoids completing their life cycle in *Oncopera* larvae. Somewhat surprisingly, a prolonged campaign of introductions of adult *Hexamera* from New Zealand commenced in 1931 (Anon. 1931). Liberations were made in Victoria (at Moe and Leongatha) in the years 1932, 1934 to 1939 and in the Australian Capital Territory in 1935. Some adults were used for laboratory experiments in Canberra. Never more than 61 adults were liberated at any one time — and mostly far fewer — and often the adults were in poor condition. No establishment occurred, ascribed at the time to be, at least in part, due to lack of effective synchronisation of the New Zealand parasitoids, which generally emerged as adults earlier than young *Oncopera* larvae were available in Australia (CSIR 1932–1939; Wilson 1960).

Ichneumon suspiciosus (wrongly known at the time as *Allomya debellator*) was known from the English underground grass grub *Hepialis humili*. It was imported between 1939 and 1942, but no evidence was obtained that it would parasitise *Oncopera* larvae, so it was not liberated. Tests in Canberra, Australian Capital Territory with two consignments of the common European toad (*Bufo bufo*) showed that they readily consumed larvae, pupae and adults of *Oncopera*, but that they were unable to extract larvae from their tunnels. The frogs were destroyed (Wilson 1960).

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Phthorimaea operculella (Zeller) Lepidoptera: Gelechiidae
potato moth

This species was earlier referred to as *Gnorimischema operculella.*

PRECIS

The potato moth, *Phthorimaea operculella*, of South American origin, has been in Australia at least since 1854 and occurs in all major potato-growing areas. It is also a pest of tobacco and other solanaceous crops.

Ten exotic species of wasp have been liberated in Australia and three have assumed importance (up to about 80% parasitisation). *Apanteles subandinus* is dominant in the cooler, southern and inland areas, *Orgilus lepidus* in the warmer coastal regions of eastern Australia, and *Copidosoma desantisi* in the warmer, drier areas of eastern and Western Australia. These, and a granulosis virus, greatly reduce potato moth populations, although crop sanitation and other measures are necessary from time to time to avoid economic loss.

BIOLOGY

The potato moth, *Phthorimaea operculella*, is native to South America, and is now cosmopolitan where solanaceous crops are grown. It was recorded as early as 1854 in Australia (French 1913), 1884 in Tasmania (Berthon 1885) and 1895 in Western Australia (Lea 1895b).

Adults have a wingspan of about 12 mm and rest among host plants by day, becoming active towards dusk. Eggs (up to about 200) are laid singly on the leaf undersurface, in groups around the eyes of potato tubers or on the soil near tubers. The newly hatched larva becomes a miner, eating its way either into the tuber or into the leaf, then into the leaf stalk and finally into the stem. After about 2 weeks in warm weather, the larva spins a flimsy cocoon, generally amongst plant refuse on the ground. The life cycle takes about a month and there are several generations per year.

Females produce a sex pheromone consisting of a mixture with two main components: trans 4, cis 7-tridecadienyl acetate and trans 4, cis-7, cis-10 tridecatrienyl acetate (Voerman and Rothschild 1978; Rothschild 1986).

PEST STATUS

The potato moth can be a serious pest of potatoes and also attacks tobacco, tomatoes, eggplant and other Solanaceae (French 1913, 1915; Atherton 1936; Lloyd 1943, 1944, 1950; Cannon 1948; Franzmann 1980; Hely et al. 1982). Tunnelling into a host-plant stem usually kills its terminal portion. In the potato tuber or the fruit of tomatoes and eggplant, the larvae at first tunnel just under the surface, but later penetrate more deeply and render them unfit for sale. Plants may die prematurely. Field infestation of potato tubers occurs when the soil cracks under dry conditions to allow larvae or egg-laying adults easy access (Lloyd 1950). Serious infestations can develop in stored potatoes.

BIOLOGICAL CONTROL

Native parasitoids have been recorded from potato moth larvae in Australia, but their effect on host populations is insignificant. There are about six species of Ichneumonidae belonging to the genera *Campoplex, Nythobia* and *Temelucha* and at least two species of Braconidae belonging to the genus *Microchelonus* (CSIRO 1972; Callan 1974). Atherton (1936) records three or four braconids from larvae attacking tobacco in northern Queensland. Gauld (1980) lists an undescribed species of *Temelucha* from Queensland, New South Wales and Western Australia, and Franzmann (1980) *Chelonus curvimaculatus* and *Elasmus funerus* (Elasmidae) from Queensland. Boucek (1988) and Galloway and Franzmann (1983) describe *Perilampus franzmanni* as a hyperparasitoid of the introduced *Orgilus lepidus* in Queensland and the Australian Capital Territory and Briese (1981) lists the exotic *Cotesia melanoscelus* in the Australian Capital Territory. Horne et al. (2000) demonstrated that the melyrid beetle *Dicranolaius bellulus* was a predator of eggs and 1st instar larvae of the potato moth in carrot and potato crops in northern Victoria.

In 1964, a granulosis virus appeared in potato moth cultures in Canberra, Australian Capital Territory (Reed 1969) and one is also known from New Zealand, Sri Lanka and South Africa (Briese 1981). When a suspension of the virus was applied to potato plants in the field, over 90% of larvae became diseased, although no virus-infected larvae had been found in pre-treatment samples (Reed 1969). Larvae infected naturally in the field have been reported from only six locations: single larvae on three occasions, once each in northern Queensland, near Sydney and in south-western Western Australia; and a number of larvae at three locations in Victoria — this suggesting a recent epizootic (Reed 1971; Briese 1981). Virus infection rates of 100% were achieved following field application in

Western Australia, with spread occurring some kilometres distant. Spread was attributed in part to the frequent predation on larvae by the silvereye, *Zosterops lateralis*, in whose faeces virus particles were detected (Reed and Springett 1971; Mathiessen and Springett 1973; Springett and Mathiessen 1975). Resistance in some potato moth populations to this granulosis virus has been reported by Briese (1982).

In relation to importations, in a first brief phase, *Bracon gelechiae* (Braconidae) was imported in 1921 from California to Western Australia, but arrived dead (Wilson 1960).

In the second phase, seven parasitoid species were introduced in the 1940s from California, but only four were liberated, because of difficulties in establishing cultures of *Agathis gibbosus, Illidops scutellaris* and *Macrocentrus ancylivora*. Those liberated were *Bracon gelechiae* and *Chelonus phthorimaeae* (both Braconidae) from 1944 to 1949 in all States — except that only *B. gelechiae* was liberated in Western Australia — and both *Copidosoma desantisi* (Encyrtidae: native to Chile: Annecke and Mynhardt 1974) from 1946 to 1949 and *Campoplex phthorimaeae* (Ichneumonidae) from 1947 to 1949 in mainland eastern Australia. In 1944 to 1945, *Chelonus phthorimaeae* was recovered in the Australian Capital Territory and *B. gelechiae* in New South Wales, but neither became established. However, *C. desantisi* was recovered in South Australia, New South Wales, Australian Capital Territory and especially in Queensland and was clearly established (Wilson 1960).

The third, much larger, but poorly documented, phase commenced with introductions in 1964 and liberations in 1965. Six species of Hymenoptera, all native to South America were introduced to Australia via California or India, but *I. scutellaris* was not released (CSIRO 1965). *Agathis unicolorata* (Braconidae) was introduced from India and liberated in eastern Australia from 1967 to 1970, but has not been recovered (CSIRO 1967–1970). *Apanteles subandinus* (Braconidae) from California was liberated in New South Wales, Australian Capital Territory and South Australia in 1965 and recovered in the Australian Capital Territory shortly after (CSIRO 1965). It was again introduced from California in 1965 and from India in 1967 and liberated widely in eastern Australia until 1969. Liberations were then discontinued because the species had become widely established (CSIRO 1966–1970). *O. lepidus* (Braconidae) from India was liberated in all States except South Australia and Tasmania from 1965 to 1969, when liberations ceased because it had become established (CSIRO 1966–1970).

The earlier (1946 to 1949) introductions of the encyrtid *Copidosoma desantisi* (then wrongly identified as *C. koehleri*) originated in the dry upland areas of central Chile. A closely related species, *C. koehleri*, native to the humid, coastal areas of Uruguay, was introduced via California and first liberated in 1964 in New South Wales, Victoria, South Australia and Western Australia (CSIRO 1965). Since cultures of the two *Copidosoma* species (not recognised at that stage as distinct) were mixed, unknown proportions of the two species (if, indeed, both

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species survived in culture) were released widely until 1968. Widespread recoveries were made but, up to 1978, only the Chilean *C. desantisi* had been identified in Queensland (Franzmann 1980). Later, Horne (1990) found only *C. koehleri* in Victoria in 1989.

Campoplex haywardi (Ichneumonidae) from India was liberated in Queensland, New South Wales and Victoria in 1968/69 and from 1969 to 1971. Although it was recovered briefly in New South Wales, it did not become established (CSIRO 1969–1971). *Temelucha minuta* (Ichneumonidae) from India was liberated in eastern Australia from 1968 to 1970, but it has not been recovered (CSIRO 1968–1970).

The changing status of the exotic parasitoids in Australia has been reviewed on four occasions since 1970 (Callan 1974; Franzmann 1980; Briese 1981; Horne 1990). Callan (1974) recorded the widespread occurrence of three species (*A. subandinus, C. desantisi* and *O. lepidus*); also the possible establishment of *C. haywardi* in the 1970/71 season in New South Wales, although there have been no reports of the latter species since then. *A. subandinus*, which occurred from Tasmania to Queensland, was the most effective species and the outstanding parasitoid in Victoria. In the 1969 to 1970 season, there was an explosive increase in the second most important species, *O. lepidus*, which became the dominant species in some coastal areas of New South Wales, displacing *A. subandinus*. *C. desantisi* occurred from Victoria, where it was uncommon, to Queensland, where it was better suited to the warmer north.

Franzmann (1980) recorded that, in Queensland from 1975 to 1978, parasitisation of larvae in potato foliage frequently exceeded 50%. *C. desantisi* and *O. lepidus* together accounted for 92.6% of the parasitoid numbers recorded. In more northerly areas of Queensland, however, the dominant species was *A. subandinus*. *Copidosoma koehleri* was not recorded in Queensland.

Briese (1981) found in 1980 that *A. subandinus* was dominant in the cooler southern and inland parts of Australia, and also in far northern Australia. *C. desantisi* was abundant in the warmer, drier areas of eastern and Western Australia, producing up to 80% parasitisation (Map 2 page 387). A granulosis virus was also recorded causing significant mortality.

The most encouraging report is that of Horne (1990) who studied potato leaf infestations in 1989 in Victoria. *A. subandinus* and *O. lepidus* were the most abundant, but *C. koehleri* was also present at several sites. In an area free from insecticides, parasitoids were found, on detailed analysis of the data, to be a major factor in controlling potato moth. Even more recently, *O. lepidus* abundance has again increased markedly (Glenn and Clissold 1999).

Currently used insecticides were shown from laboratory testing to be far more toxic to *O. lepidus* and *C. desantisi* than to potato moth larvae, these two species being responsible for more than 90% of the heavy parasitisation of the larvae in southern Queensland (Keeratikasikorn and Hooper 1981).

Planting nectar-bearing plants close to potatoes in Victoria increased the rate of parasitisation by *C. koehleri* but, at the same time, increased potato moth abundance and crop damage (Baggen and Gurr 1998).

MAJOR PARASITOID SPECIES

Apanteles subandinus Hymenoptera: Braconidae

This species is a primary, solitary endoparasitoid of larvae, known only from the potato moth. The culture sent from California to Australia was a mixture of stock from Argentina and Peru.

The egg (up to a production of about 350 per female) is deposited singly into the body cavity of the host and the females prefer to oviposit in larvae only a few days old. When mature, the 3rd instar parasitoid larva emerges by cutting its way out along the lateral line, resulting in the death of the host larva. The developmental period from egg to adult is about 15 days at 27°C. After leaving the host larva, the larva of *A. subandinus* spins a silvery white cocoon (Cardona and Oatman 1975).

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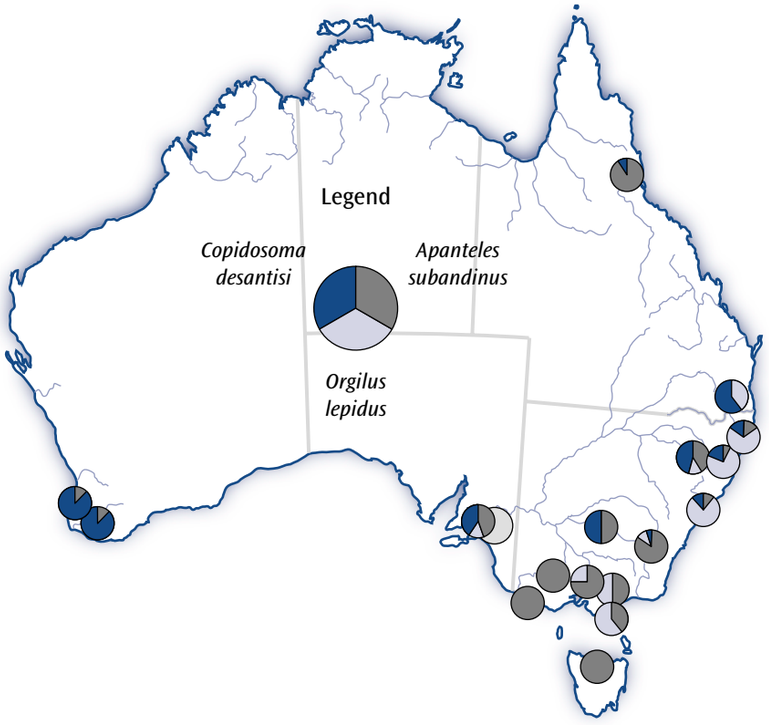

Map 2. Relative contribution of the three major introduced parasitoids to total parasitisation in field samples of *Phthorimaea operculella* collected throughout the major potato-growing areas in Australia (Briese 1981).

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Phyllocnistis citrella Stainton Lepidoptera: Gracillariidae citrus leafminer

PRECIS

Phyllocnistis citrella is of southern Asian (possibly southern China) origin and now occurs in most regions of the world where citrus is grown. It has been present in northern Australia since 1912 and has since greatly extended its range, first eastwards to coastal Queensland and New South Wales and then, in the last decade, southwards to Victoria and South Australia and finally westwards to coastal Western Australia.

It is an important pest in citrus nurseries and young plantings and causes unsightly damage to new flushes of growth on mature trees.

Before biological control was first attempted in Australia in 1983, *P. citrella* was already being attacked (sometimes reasonably heavily) by a number of non-specific parasitoids that are adapted to leafmining Lepidoptera.

The eulophid parasitoids *Ageniaspis citricola* from Thailand and *Cirrospilus ingenuus* from Southern China have been established in Queensland since 1992 and the former has achieved parasitisation rates ranging up to 100%. These introductions are contributing importantly to citrus leafminer control in Queensland. In southern Australia, in spite of attempts to do so, exotic parasitoids have not yet been established. A native eulophid parasitoid, *Semielacher petiolatus*, attacks the leafminer wherever it occurs and is the most important natural enemy in southern States.

BIOLOGY

Phyllocnistis citrella larvae are legless and sapfeeding. On hatching, the larva bores into the leaf and forms a mine directly under the epidermis. The long serpentine mine, produced by ingestion of sap, fills with air to give it a silvery white appearance. Mines have a characteristic narrow, dark, central line of faecal material. Both upper and lower surfaces of the same leaf may be mined by different larvae. When moth populations are very high, the young stems may also

be mined. Larvae pupate in a silken chamber within the mine. Adult females have a wing span of 4 mm, lay up to 50 eggs and survive up to 164 days under cool conditions. They mate soon after emergence and start laying the next day. Depending upon the temperature, there may be up to 15 overlapping generations in a year. Females produce a sex pheromone (Z, Z) 7, 11-hexadecadienal (Sabine 1971; Tough 1975; Beattie and Smith 1993; Smith et al. 1997a; Waterhouse 1998).

In a study in Darwin (Wilson 1991), a mean of 5.9 eggs per leaf was recorded with 32.7% on the upper surface. More than half of all new leaves were affected. Only 5.2% of larvae pupated, most of the remainder succumbing to overcrowding. Usually one or two larvae completely mine a leaf and, when more than two are present, it is rare for any to survive, although eight pupae were once counted in a single leaf. Mines were not observed to intercept one another.

P. citrella was first recorded in Australia in 1912 in the Northern Territory (Hill 1918). It was not regarded as of much importance until, in the early 1970s, it started to extend its distribution, first eastwards to coastal Queensland and then southwards into New South Wales. By the early 1990s, it had reached first Victoria, then South Australia and, by 1995, Western Australia. Newly invaded areas generally experienced severe attacks which diminished after a few years, probably due to an increased attack on it by local parasitoids.

In Queensland, leafminer activity begins in late spring (late October to early November) and peaks when about 80% of susceptible leaves are being mined in January to February, with up to five mines per leaf. Infestation usually declines rapidly after March and there is little activity between May and late October. At least two thirds of the main (crop dependent) flush of growth occurs between late July and September, but there is almost no leafminer activity at this time (Smith et al. 1997a).

PEST STATUS

Most species and cultivars of *Citrus* are attacked by *P. citrella*. It lays its eggs only on young leaves, making its first appearance, often with little damage, when new growth appears in spring. With each flush of new growth it increases in abundance until autumn. Leaves in the 1 to 3 cm length range are preferred and are extensively mined immediately below the epidermis. The mesophyll is not attacked. The mined leaves cease to grow, curl and become distorted. Many remain on the tree and provide shelter for other pests. Where it occurs, secondary infections by the citrus canker fungus, *Xanthomonas citri*, take place frequently. The subdermal damage from mining in young twigs when populations are high is serious, as it often leads to the new growth dying back to the old wood.

Damage is heaviest in citrus nurseries and in young, transplanted trees, in which leaf loss may result in death. Even if this does not occur, the continuous

infestation of new leaves retards normal, vigorous growth of the tree which is necessary for satisfactory development.

The growth flush that has the greatest effect on yield of citrus occurs in early spring when leafminer populations are low. Although the later infestations of subsequent flushes are severely disfiguring, it seems that they have relatively little impact on yield. Of course, the damaged shoots may require pruning.

BIOLOGICAL CONTROL

Lepidopterous leafminers are attacked in Australia by several eulophid parasitoids that are not specific to a host species, but rather to the microhabitat. Three native species, *Cirrospilus ingenuus, Semielacher petiolatus* and *Sympiesis* sp., as well as predatory lacewings, were reported to attack *P. citrella* (Beattie and Smith 1993; Neale et al. 1995). *S. petiolatus* is the most abundant, causing up to 40% parasitisation, with an average of about 8%. It travelled with the leafminer into the Murrumbidgee Irrigation Area of New South Wales. It was also sent from Queensland and established in Victoria and South Australia in 1994 and was later recovered in Western Australia in 1996. It is well adapted to southern regions and parasitisation levels up to 50% have been recorded (Smith et al. 1997a). In Darwin, *Cirrospilus* sp. parasitised 10.5% of 475 *P. citrella* larvae in spring, with up to four parasitoid larvae feeding externally on a single host larva. An unidentified eulophid pupal parasitoid also emerged from 2 of 300 field-collected leafminer pupae (Wilson 1991).

Sabine (1971) reported that *P. citrella* was sometimes parasitised by a small wasp in Queensland, but there is no evidence that it had much influence on population density (Tough 1975). Boucek (1988) recorded from south-eastern Queensland a single male of a *Kratoysma* sp. which may be the same as a species reared from the citrus leafminer in India. He also listed the eulophid *Ascotolinx funeralis* (which also occurs in Papua New Guinea) and the pteromalid *Asaphoideus niger*.

Three parasitoids *Ageniaspis citricola* (Encyrtidae, from Thailand), *C. ingenuus* and *Citrostichus phyllocnistoides* (both Eulophidae, from southern China) were released in 1990 and 1991 in Queensland, New South Wales, Victoria and South Australia. *A. citricola* and *C. ingenuus* rapidly established throughout Queensland and parasitisation, especially by the former, now reaches up to 100% between February and April and results in significantly reduced attack on summer and autumn flushes. Cool winters and springs delay the onset of leafminer activity, but there is usually heavy attack on December to January flushes. A few recoveries were made of *A. citricola* in New South Wales, Victoria and South Australia, but is appears not to have become established. *C. ingenuus* appears not to be established in the southern States where the native *S. petiolatus* is the key parasitoid (Smith 1997a). One recovery was made of *C. phyllocnistoides*

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in Queensland, but it is not established there (Smith et al. 1997b). A *Quadrastichus* sp. from Thailand is being studied in quarantine for host specificity (Neale et al. 1995).

Waterhouse (1998) has published an account dealing with worldwide attempts at biological control of *P. citrella*.

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Pieris rapae (Linnæus) Lepidoptera: Pieridae cabbage white butterfly

PRECIS

The European *Pieris rapae* became established in Victoria in 1937 and spread rapidly to all States. Although many non-specific parasitoids and predators soon attacked it, they were unable to prevent serious damage to cabbage and related crops. Three parasitoids were introduced, two of which (*Cotesia glomerata, C. rubecula*) oviposit in host larvae and the third (*Pteromalus puparum*) in the recently-formed pupa. Together with native natural enemies and a granulosis virus, these parasitoids have greatly reduced cabbage white butterfly populations for much of the time in many areas. Nevertheless, damaging populations do occur from time to time.

BIOLOGY

Well before *Pieris rapae* became established in Australia in 1937, an individual was reared in 1929 in Melbourne and an adult was caught in 1933. Gooding (1968) reared a long series from 1937 to 1938 at Moe, Victoria and it became abundant in Melbourne in 1939. By 1940, it was recorded in Tasmania, South Australia and New South Wales, by 1942 in Western Australia (Jenkins 1943a), and by 1943 in Queensland (Peters 1970; Common and Waterhouse 1981; Braby 2000). It is probably not permanently established in the Northern Territory. Its current widespread distribution is given by Braby (2000). It is thought that the Australian infestation came from New Zealand where it appeared in 1930 (Wilson 1960; Gooding 1968).

Its pale yellow eggs are laid singly and usually on the underside of food plant leaves. Host plants are generally members of the family Brassicaceae (e.g. cabbage, cauliflower, brussel sprouts, mustard, canola), although they may also be garden plants from other families, such as nasturtium, mignonette, and stock. The mature larva is velvety green and about 5 cm long. Pupation may occur on the food plant, but more frequently takes place on neighbouring objects. Pupae

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assume, to some extent, the colouration of the objects to which they attach themselves by a cremaster and a central silk girdle. In warm weather, eggs hatch in a few days, larvae feed for 2 to 3 weeks and the pupal stage lasts about 2 weeks. There are up to five continuous generations throughout the warmer months. Overwintering occurs in the pupal stage. Adults fly erratically and are highly mobile.

PEST STATUS

P. rapae larvae eat ragged holes in the leaves of the host plant. When attack is heavy, only the veins are left, resulting in considerable losses to commercial growers. Less heavily infested plants become stunted and fouled with dark green faecal pellets. No webbing is produced.

BIOLOGICAL CONTROL

P. rapae was attacked by a wide range of non-specific predators and parasitoids from the time of its establishment in Australia. In Victoria, immunological tests gave positive results for some 40 predator species of Hemiptera, Dermaptera, Coleoptera, Neuroptera, Diptera and Arachnida (Table 41 page 396). No indication, however, is available on the percentage of available hosts destroyed (Kapuge et al. 1987). These authors indicated that the main predators were the earwigs *Nala lividipes* and *Labidura truncata*, the staphylinid beetle *Thyreocephalus cyanopterus* and the spider *Olios diana*, although other species were shown in their records to be equally effective. Ants were not listed. Bird predation of larvae or pupae has received little attention in Australia, although it is known to be important in Britain (Jones 1981).

In south-eastern Queensland, the parasitoids *Brachymeria lasus* (Chalcididae), with up to 56% parasitisation, and *Compsilura concinnata* (Tachinidae) were the most important of five species bred from *P. rapae* pupae (Hassan 1976). Although the tachinid *Exorista flaviceps* is also known from Tasmania, New South Wales and Queensland, it is only in South Australia that it has been reared from *P. rapae* larvae. Up to 20.5% (average 12%) were parasitised by this species (Rahman 1970a).

In the Australian Capital Territory, eggs were attacked by an unidentified mite and *P. rapae* larvae consumed their own eggs along with the cabbage leaf. However, unless cannibalism was high, egg mortality was low (Jones and Ives 1979). Spiders also ate larvae, but the major source of mortality was ant predation by *Iridomyrmex purpureus* and *Iridomyrmex* sp. Ant predation alone more than accounted for all the unexplained losses of larvae in instars 3 to 5 (Jones et al. 1987). It is, perhaps, strange that none of the many predator species recorded in Victoria was recorded playing a similar role in Canberra, Australian Capital Territory.

Death from a granulosis virus (*Bergoldiavirus virulentum*) often occurred in instars 3 to 5 in Canberra and south-eastern Queensland, particularly late in the season. Mortality of 20% or so was observed and localised epizootics, with up to 100% mortality, also took place. Infections from *Bacillus thuringiensis, Metarhizium anisopliae* and a microsporidian, *Nosema mesnili*, have also been reported (Lokkers and Jones 1999). However, Jones et al. (1987) regarded mortality from disease as generally of minor importance.

The pupal parasitoid *Pteromalus puparum* was introduced from New Zealand and liberated in Victoria from 1941 to 1944. It was found to be widely established by 1944, when up to 95% parasitisation of pupae was recorded (Wilson 1960). *P. puparum* was again introduced from New Zealand in 1942 and released in Tasmania in 1943 (Miller 1947). A culture from Tasmania was sent to Western Australia in 1943 (Jenkins 1946; Wilson 1960). It soon became established in these States and also appeared unaided in the Australian Capital Territory in 1943, from where it was sent to South Australia in 1945. *P. puparum* was already well known as a parasitoid of a range of other butterfly hosts in Australia before its introduction from New Zealand, which may explain the speed with which it was reported established on *P. rapae* (Wilson 1960). In south-eastern Queensland, the highest parasitisation of *P. rapae* recorded for *P. puparum* was approximately 63% (Hassan 1976).

The larval parasitoid *Cotesia glomerata* was introduced from Canada in 1942 and from England in 1943 to 1944. Progeny from both sources were liberated in the Australian Capital Territory. From there, it was sent to Queensland and Victoria (1944), South Australia (1944 to 1946), Tasmania (1949) and Western Australia (1950). It became established rapidly in all States (Miller and Hudson 1953; Wilson 1960). *C. glomerata* does not kill host larvae until late in the final instar and thus does not prevent crop damage (Hamilton 1979a,b). It was recorded parasitising 67% of *P. rapae* larvae in south-eastern Queensland (Hassan 1976).

The larval parasitoid *Cotesia rubecula* was imported from England from 1941 to 1942 and from 1943 to 1944, but was not released. In 1949, it was imported from Switzerland and liberated from 1949 to 1951 in the Australian Capital Territory and New South Wales; and in all other States from 1950 to 1951. Wilson (1960) reports its establishment in the Australian Capital Territory, New South Wales and possibly South Australia. It is not recorded as established in Tasmania, although it was released in four locations in 1951 (Miller and Hudson 1953). *C. rubecula* kills larvae in the 4th instar and thus helps to reduce crop damage in the current crop, in addition to reducing the population of *P. rapae* in the next generation (Hamilton 1979b).

Field parasitisation rates may vary considerably from place to place. Larvae of *P. rapae* on honey mustard near Canberra in 1977 to 1978 were parasitised

mainly by *C. rubecula* whereas, on cabbages in Canberra, *C. rubecula* was rare, but both *C. glomerata* and *P. puparum* were abundant (Jones 1981).

No detailed evaluation has been made of the impact of the parasitoids on *P. rapae* abundance, but Jones (1981) considers that they are likely to be most effective after the spring build-up of *P. rapae* has occurred and that their effect will probably be to reduce both the maximum density achieved by the butterfly and also the numbers of overwintering pupae.

At Richmond, near Sydney, New South Wales, no *P. rapae* egg parasitoids were found in 1972 or 1973, but the tachinid *C. conncinata* was bred from pupae. Larvae were parasitised by *C. glomerata* (10% to 70%, average 38%) and pupae by *P. puparum* (usually low, but up to 81%). More important was a granulosis virus, which resulted in three epizootics, in November 1972, April and November 1973, reducing the number of larvae to one or less per two cabbage plants. Up to 81% of larvae sampled were diseased. Overcast and wet weather during the epizootics assisted the spread of the virus (Hamilton 1979b). A polyhedrosis virus was reported to kill many larvae in New South Wales, but not enough to make other control measures unnecessary (Hely et al. 1982).

In the Australian Capital Territory, parasitisation by *C. glomerata* killed a large number (up to 100%, average 45%) of larvae which had survived to the 5th instar, but *C. rubecula* was generally uncommon. Parasitised larvae were more susceptible to ant predation than unparasitised larvae (Jones 1987). Jones et al. (1987) concluded that the major factor determining *P. rapae* abundance was the action of general and specific natural enemies acting, at least in part and patchily, in a density-dependent way.

MAJOR PARASITOID SPECIES

Pteromalus puparum Hymenoptera: Pteromalidae

This European species is a cosmopolitan, gregarious endoparasitoid of pupae of various pierid and nymphalid butterflies and less frequently of other Lepidoptera. It is occasionally reported to be a secondary parasitoid (Boucek 1988). It was already present in Australia well before being intentionally introduced from New Zealand in 1941 (Wilson 1960). This no doubt accounts for reports of its widespread attack on *P. rapae* so soon after liberation. Adults are known to follow (even ride upon) fully grown *P. rapae* larvae as they leave their host plant and to wait until these have pupated before ovipositing. Many eggs are laid. Both larval and pupal development occur within the host pupa and 30 to 50 adults emerge through a hole neatly bored in its cuticle (Jones 1981).

Cotesia glomerata Hymenoptera: Braconidae

Many eggs of this European species are laid in 1st, 2nd or 3rd instar *P. rapae* larvae. These hatch in 3 to 4 days to produce larvae which lie free in the host haemocoele.

They reach maturity when the host larva is ready to pupate. At this stage they all emerge within a short period through the host body wall. Each larva spins a yellow cocoon close to its neighbour to form a cocoon mass. The duration of pupal development is a week or so, depending upon the temperature. *C. glomerata* overwinters as a pupa. Mating occurs soon after emergence and females immediately begin searching for suitable host larvae (Miller and Hudson 1953; Jones 1981). Parasitised *Pieris* larvae cause additional damage to the host plant since they take longer to develop to maturity and eat about 30% more than unparasitised larvae (Rahman 1970b).

Cotesia rubecula Hymenoptera: Braconidae

C. rubecula oviposits in 1st and 2nd instar host larvae. Unlike *C. glomerata*, it is a solitary parasitoid and only a single mature larva emerges from the half-grown 4th instar *P. rapae* larva (Miller and Hudson 1953). The host larva consequently eats only about half as much as an unparasitised larva (Rahman 1970a). *C. rubecula* may kill many (up to 70%) of the 1st instar larvae, but less than 10% of 7-day-old larvae into which they attempt to oviposit (Rahman 1970c). *C. rubecula* is hyperparasitised at a low level by *Trichomalopsis braconophagus*.

COMMENTS

No parasitoids of *P. rapae* eggs have been recorded in Australia (Hamilton 1979b). However the polyphagous, European *Trichogramma evanescens* produced 20% to 75% parasitisation of eggs per host generation after release in Missouri, USA (Parker 1970; Parker et al. 1971). This species has not yet been recorded in Australia. Another polyphagous species, *Trichogramma pretiosum*, was introduced to Australia against pest noctuids (see target pests no. 81 and 82, *Helicoverpa armigera* and *H. punctigera* page 369) and is known to be well established in Queensland and northern Western Australia, but it is not yet recorded from *P. rapae*.

Table 41. Natural enemies of *Pieris rapae*

Species	References
HEMIPTERA	
LYGAEIDAE	
Dieuches notatus	Kapuge et al. 1987
NABIDAE	
Nabis nr *kinbergii*	Kapuge et al. 1987
DERMAPTERA	
LABIDURIDAE	
Labidura truncata	Kapuge et al. 1987

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Table 41. (cont'd) Natural enemies of *Pieris rapae*

Species	References
Nala lividipes	Kapuge et al. 1987
Parisopalis nr *spryi*	Kapuge et al. 1987
Unidentified spp.	Kapuge et al. 1987
FORFICULIDAE	
Forficula auricularia	Kapuge et al. 1987
COLEOPTERA	
CARABIDAE	
Anomotaris crudelis	Kapuge et al. 1987
Geoscaptus nr *laevissimus*	Kapuge et al. 1987
Gnathaphanus nr *melbournensis*	Kapuge et al. 1987
Mecyclothorax ambiguus	Kapuge et al. 1987
Notonomus gravis	Kapuge et al. 1987
Rhytisternus liopleurus	Kapuge et al. 1987
Rhytisternus miser	Kapuge et al. 1987
COCCINELLIDAE	
Coccinella transversalis	Kapuge et al. 1987
ELATERIDAE	
Agrypnus sp.1	Kapuge et al. 1987
Agrypnus sp.2	Kapuge et al. 1987
STAPHYLINIDAE	
Thyreocephalus cyanopterus	Kapuge et al. 1987
TENEBRIONIDAE	
Adelium sp.	Kapuge et al. 1987
Isopteron trivialis	Kapuge et al. 1987
DIPTERA	
SYRPHIDAE	
Simosyrphus nr *grandicornis*	Kapuge et al. 1987
Syrphus damaster	Kkapuge et al. 1987
TACHINIDAE	
Compsilura concinnata	Hasssan 1976; Cantrell 1986
Compsilura sp.	Hassan 1976
Exorista flaviceps	Rahman 1970a
Paradrino laevicula	Cantrell 1986
Winthemia lateralis	Cantrell 1986
NEUROPTERA	
HEMEROBIIDAE	
Micromus sp.	Kapuge et al. 1987

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Table 41. (cont'd) Natural enemies of *Pieris rapae*

Species	References
HYMENOPTERA	
CHALCIDIDAE	
Brachymeria hyalaretae	CSIRO file B14/13
Brachymeria lasus	Hassan 1976
Brachymeria sp.	Hassan 1976
EURYTOMIDAE	
Unidentified sp. (hyperparasitoid)	Hassan 1976
FORMICIDAE	
Iridomyrmex purpureus	Jones 1987
Iridomyrmex sp.	Jones 1987
ICHNEUMONIDAE	
Goryphus turneri	Hassan 1976
Goryphus spp.	Hassan 1976
PTEROMALIDAE	
Megadicylus dubius (hyperparasitoid)	Boucek 1988
Trichomalopsis braconophaga (hyperparasitoid of *Cotesia rubecula)*	Nealis 1985; Boucek 1988
ACARINA	
Unidentified	Jones et al. 1987
ARACHNIDA	
AMAUROBIIDAE	Kapuge et al. 1987
ARGIOPIDAE	Kapuge et al. 1987
CLUBIONIDAE	Kapuge et al. 1987
Clubiona 3 spp.	Kapuge et al. 1987
DYSDERIDAE	
Dysdera crocata	Kapuge et al. 1987
EUSPARASSIDAE	
Olios diana	Kapuge et al. 1987
GNAPHOSIDAE I sp.	Kapuge et al. 1987
LYCOSIDAE 3 spp.	Kapuge et al. 1987
THERIDIIDAE	
Steatoda 4 spp.	Kapuge et al. 1987
PHALANGIIDAE 2 spp.	Kapuge et al. 1987

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Plutella xylostella (Linnæus) Lepidoptera: Plutellidae diamondback cabbage moth

In early literature, this species was often referred to as *Plutella maculipennis*. Prospects for its biological control were reviewed by Waterhouse and Norris (1987). There have been three important international workshops dealing with the biology and control of the diamondback moth (Talekar 1986, 1992; Sivapragasam et al. 1997).

PRECIS

The diamondback cabbage moth, *Plutella xylostella*, is believed to have originated in the Mediterranean area and has been in Australia at least since 1889. It is attacked by a number of native natural enemies which, however, are unable to prevent it from being a troublesome pest of brassicas for human consumption or as forage crops. It has been the target of several attempts at biological control and three major parasitoids have been established — *Cotesia plutellae, Diadegma semiclausum* and *Diadromus collaris*. As a result, there has been a marked reduction in damage to host plants in many areas. The use of insecticides for other pests attacking brassicas can seriously interfere with the biological control of *P. xylostella*.

BIOLOGY

The now cosmopolitan *Plutella xylostella*, considered to be of Mediterranean origin, is widespread in Australia where it was first reported in 1889 in Queensland (Tryon 1889; French 1893; Fuller 1896), although Tryon indicated that it was probably present some years earlier.

Eggs are laid singly, or in groups of up to eight, mainly on the upper surface of the leaf. They hatch in 4 to 8 days and the young larvae mine leaf tissues from the lower surface. Later instars chew irregular patches in the leaves, consuming all except the veins and upper epidermis, producing a characteristic window effect. The mature larva usually spins a fine, open network cocoon, generally on the host plant. The larva completes development in 9 to 30 days, followed by prepupal and

pupal stages of 5 to 15 days. At high temperatures, the life cycle may be as short as 16 days. Young larvae are very susceptible to drowning during periods of rainy weather. At rest, the folded wings of the adult show a creamy-yellow dorsal band with three constrictions, the resulting diamond shapes giving the moth its common name.

Adults are inactive during the day unless disturbed, but become active just before dusk. Females mate only once and lay about 160 eggs over a 10-day period. There are many overlapping generations in a year. The female produces a sex pheromone which is a mixture of Z-11-hexadecanal and Z-11-hexadecenyl acetate and perhaps other minor constituents (Waterhouse and Norris 1987).

PEST STATUS

P. xylostella is a widespread pest of cultivated and wild Brassicaceae. These include cabbage, cauliflower, broccoli, brussel sprouts, radish and field crops such as turnip, mustard and rape. It is also known from garden plants, including alyssum, candytuft, stock and wallflower.

BIOLOGICAL CONTROL

Unrelated to any intentional biological control introductions, some 20 species of parasitoid (most of which are native) have been reported attacking *P. xylostella* in Australia (Table 42 page 404). However, their combined effects are inadequate to suppress damaging populations. Two species (one of which was probably *Diadegma rapi* (Wilson 1960)), were successfully transferred in 1902 from New South Wales to Western Australia. This species, which was described from New South Wales, is widespread and believed to be native, and is now common in Western Australia.

Between 1903 and 1909, five unnamed parasitoid species were introduced from overseas and liberated in Western Australia (Table 1 page 29). Of these, two species from Spain and one from India are reported to be established (Wilson 1960).

The egg parasitoid *Trichogramma minutum*, which was introduced in 1927 and 1928 to Queensland against the codling moth, *Cydia pomonella*, was found to attack *P. xylostella* eggs in the laboratory. It was liberated in cabbage plantings heavily infested with *P. xylostella*, but was not recovered (Veitch 1928, 1931; Wilson 1960).

Commencing in 1936, and continuing to 1951, five additional parasitoids, originally of European origin, were introduced and liberated. These were the braconid *Cotesia plutellae* (from Italy, liberated 1951 to 1955) and the ichneumonids *Diadegma fenestrale* (from the United Kingdom in 1936, but not liberated, and from New Zealand and liberated in 1938 to 1939), *Diadegma semiclausum* (from New Zealand in 1947 to 1951), *Diadromus collaris* (from New

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Zealand in 1947 to 1951 and from Italy in 1951 to 1952) and *Nythobia tibialis* (from Italy in 1951 to 1952). *C. plutellae*, *D. semiclausum* and *D. collaris* have become widely established and together have had a very significant effect in lowering *P. xylostella* populations in much of Australia. There is some doubt about the identity of the insects introduced as *D. fenestrale* and *N. tibialis* and both may have actually been *D. semiclausum*. *D. fenestrale* was liberated in New South Wales, Victoria and South Australia and the other species were liberated on a large scale in all States, but neither species was recovered (Wilson 1960).

In Queensland, *D. semiclausum*, which was released in 1947, is the most important parasitoid (22.4% to 35.7% parasitisation, average 29.0%), followed by *D. collaris*, which was also released in 1947 (1.2% to 4.6%, average 2.4%). Parasitoids of lesser importance are *Brachymeria phya, B. sidnica* and *Apanteles ippeus*, together causing about 2.5% mortality. Three hyperparasitoids are also present, *Ceraphron fijiensis, Trichomalopsis* sp. and *Lienella* sp. (Yarrow 1970).

In New South Wales *P. xylostella* flourishes in hot, dry districts and is generally more important inland than on the coast. Numbers decline markedly in winter and generally peak in late summer. Parasitisation over a 2-year period averaged 20%. *D. semiclausum* and *Diadegma* sp. were bred from 41% of pupae, *D. collaris* from 25% and the native *A. ippeus* from 8% to 16%. Small numbers of the native *B. phya* and an unidentified chalcid were also reared. Total parasitisation by all species ranged between 65% and 85% (average 72%) per annum from 1971 to 1975. The parasitoids do not prevent significant plant damage during periods of high *P. xylostella* activity, since they do not kill the host until the pupal stage. However, they do exert the important effect of reducing the subsequent adult population (Hamilton 1979b).

In Victoria, 10 species of parasitoid were reared from *P. xylostella* in successive cabbage crops between 1972 and 1974. Parasitisation fluctuated in each crop, averaging 49% (range 41% to 57%). *D. semiclausum* was the most numerous and, in three separate crops, its attack constituted 86.9%, 74.8% and 83.6% of the total crop parasitisation. Parasitisation by *D. collaris* was 7.7%, 9.3% and 11.7% of the total and by the native *D. rapi* 2.0%, 5.0% and 0.0003%, respectively. Although *Apanteles* sp. (which parasitised 2.5% of the *Plutella* population) and *Mesochorus* sp. (1.4%) were important on some occasions, neither these nor the remaining five species of native parasitoid (Table 42 page 404) were major contributors to larval mortality. The effect of the hyperparasitoid *Trichomalopsis* sp. on *D. semiclausum* and *D. rapi* was low at 3.8% parasitisation (Goodwin 1979).

In Tasmania, *D. semiclausum* and *D. rapi* together cause 48% parasitisation. *D. collaris, C. plutellae* and *Diplazon laetatorius* (well known as a parasitoid of syrphid pupae) were also recorded (Azif Alishah, pers. comm. 1984). Earlier, *D. semiclausum* and *D. collaris* were reported to be widespread (Miller and Hudson 1953). In South Australia, parasitisation of Plutella reached 87% in the

late 1970s, with *D. semiclausum*, *D. collaris* and *Apanteles* sp. being the major species (Hamilton 1979b.

In Western Australia, Lea (1895a, 1897) recorded unnamed ichneumon and chalcid parasitoids, syrphid and reduviid predators and a bacterial disease, together causing a low level of mortality. As indicated earlier, two unidentified parasitoids from New South Wales (one of which may have been *D. rapi*) were introduced and established in 1902. Five unidentified parasitoid species from Spain, Sri Lanka, India and China were introduced between 1903 and 1909. All except the species from China, which may not have been liberated, are reported to have become established (Wilson 1960). In the period between 1907 and 1926, there were several reports that parasitoids had had a considerable effect on the abundance of *P. xylostella*, although it continued to be a pest of some importance (Wilson 1960).

The exotic *D. semiclausum* was more successful than the native *D. rapi* in avoiding superparasitisation by exercising discrimination in distributing eggs among available hosts. It also laid about three times as many eggs. When eggs of both species were laid in the same host, *D. semiclausum* was always the sole survivor. Furthermore, *D. semiclausum* females also avoided laying eggs in host larvae already containing older larvae of *D. collaris*, although they were not able to distinguish hosts containing eggs or 1st instar larvae (Venkatraman 1964; Waterhouse and Norris 1987; Waterhouse 1992).

Trichogramma pretiosum, which was introduced to Queensland from USA in the 1970s, is now well established and is credited with contributing significantly to mortality of diamondback moth eggs. Field sampling of eggs in south-eastern Queensland between 1995 and 1997 revealed that *T. pretiosum* was present for most of the crop-growing season. Rates of parasitisation were mostly below 10%, but reached 30% to 50% on many occasions. As an indicator of potential effectiveness, in a 4-hour laboratory test *T. pretiosum* and two strains of *Trichogrammatoidea bactrae*, all collected from the field, parasitised an average of 20.5%, 19.7% and 20.5% *P. xylostella* eggs per female wasp, respectively (Liu Shu-Sheng 1998; Liu Shu-Sheng, pers. comm. 1998).

MAJOR PARASITOID SPECIES

Cotesia plutellae Hymenoptera: Braconidae

C. plutellae is native to Europe and attacks the first three larval instars of *P. xylostella*. Many eggs may be laid in each host, but only one larva develops. The mature host larva dies soon after the parasitoid larva emerges to pupate. At 25°C the total development period ranges from 11 to 16 days (average 13.5) (Oatman 1978b; Waterhouse and Norris 1987).

Diadegma semiclausum Hymenoptera: Ichneumonidae

D. semiclausum is native to Europe, but is now virtually worldwide. It is widely polyphagous, but *P. xylostella* is a preferred host. Females oviposit in all larval instars and occasionally in host prepupae in cocoons. Parasitised larvae develop normally until their cocoons are completed, after which the parasitoid larva emerges and spins its own cocoon inside that of the host. Both larval and pupal stages last some 8 to 10 days and the life cycle takes 18 to 20 days (Oatman 1978b; Waterhouse and Norris 1987).

Diadromus collaris Hymenoptera: Ichneumonidae

D. collaris is native to Europe, but has been introduced into many countries. The female deposits a single egg in *P. xylostella* prepupae or pupae and then feeds at the oviposition puncture. The larval period is about 15 days, the pupal period 6 to 8 days and there may be 4 or 5 generations per year (Oatman 1978b; Waterhouse and Norris 1987).

COMMENTS

It is clear from the records from each State that the indigenous parasitoid complex, of which *D. rapi* is outstanding, is dominated by the introduced parasitoids, in particular by *D. semiclausum* (which is widely established and is abundant in many areas), but also by *D. collaris* and *C. plutellae*. There has been a very marked reduction in abundance of *P. xylostella* in many areas as a result of these introductions and it is heavily parasitised in the Australian Capital Territory, New South Wales, Tasmania and Western Australia. In South Australia and the Australian Capital Territory, brassicas can now be grown with little or no use of pesticides (Wilson 1960; Waterhouse and Norris 1987). More than 90 parasitoids of *P. xylostella* have been recorded from various parts of the world and a number of species that are dominant in other regions (e.g. North America) do not occur in Australia (Waterhouse and Norris 1987). Additional options are thus available should the generally satisfactory level of control be regarded as inadequate.

Any major improvement in biological control of *P. xylostella* will depend to a large extent on further reduction in the application of broad-spectrum insecticides to brassicaceous crops. Many other pests are associated with these crops — several of which have been targets of biological control projects in Australia — including (major pests) the cabbage white butterfly (target pest no. 87, *Pieris rapae*), the cabbage-centre grub (target pest no. 83, *Hellula hydralis*), the cabbage cluster caterpillar (*Crocidolomia pavonana*), the cluster caterpillar (*Spodoptera litura*), the cotton bollworm (target pest no. 81, *Helicoverpa armigera*) and (minor pests) cutworms (*Agrotis* spp.), loopers (*Chrysodeixis* spp.), the cabbage aphid (target pest no. 11, *Brevicoryne brassicae*), the green peach aphid (target pest no. 34, *Myzus persicae*) and the vegetable weevil (target pest no. 66, *Listroderes difficilis*).

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Table 42. Natural enemies of *Plutella xylostella*

Species	References
HYMENOPTERA	
BRACONIDAE	
Apanteles ippeus	Yarrow 1970; Hamilton 1979b
Apanteles sp.	Goodwin 1979
Dolichogenidea laevigata	Goodwin 1979
CHALCIDIDAE	
Antrocephalus sp.	Goodwin 1979
Brachymeria phya	Yarrow 1970; Cordingly & Danthanarayana 1976; Hamilton 1979b
Brachymeria plutellophaga	Girault 1922; Boucek 1988
Brachymeria sidnica	Yarrow 1970
Brachymeria sp.	Goodwin 1979
unidentified spp.	Hamilton 1979b
ICHNEUMONIDAE	
Diadegma rapi	Miller & Hudson 1953; Yarrow 1970; Goodwin 1979; A. Asif pers. comm.
Diadegma sp.	Hamilton 1979b
Diplazon laetatorius	Yarrow 1970; A. Asif pers. comm.
Lienella sp.	Yarrow 1970
Mesochorus sp.	Goodwin 1979
Paraphylax sp.	Goodwin 1979
Spinolia sp.	Goodwin 1979
PTEROMALIDAE	
Megadicylus sp.	Boucek 1988
Pteromalus sp.	Yarrow 1970
Trichomalopsis sp.	Goodwin 1979

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Sitotroga cerealella (Olivier) Lepidoptera: Gelechiidae
Angoumois grain moth

PRECIS

The cosmopolitan *Sitotroga cerealella* is a minor pest of sorghum in Queensland. Two unidentified species of ichneumonid parasitoids of Spanish origin were liberated in Western Australia in 1903, but there is no information on the outcome.

BIOLOGY

Although primarily a pest in the past of loosely-stored grain, this situation no longer exists. The moth is now a minor pest in Queensland of sorghum and also of corn in the field.

Sitrotroga cerealella adults (wingspan about 15 mm) are nocturnal and, when disturbed, settle quickly. Eggs are laid singly or in batches of up to 12 on cereal grains. Newly hatched larvae penetrate via the kernel in which the fully grown larva (6 mm) pupates. After about 7 days the adult emerges, leaving a characteristic trap door hinged to one side of the emergence hole.

PEST STATUS

Minor damage can be caused to a mature grain crop in the field under warm conditions. Infestations are now rare in grain stores. In the past, loose stacks of grain tended to be infested to a depth of 20 to 30 cm. High humidity and high grain moisture content favours infestation and drying harvested grain prevents it.

BIOLOGICAL CONTROL

The hay itch mite, *Pyemotes ventricosus*, is a common ectoparasitoid of *S. cerealella* larvae, but appears to do little to control its numbers. The eggs of the moth are widely used for the mass-rearing of various *Trichogramma* species. It is probable,

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therefore, that its eggs are attacked, both in the field and the storage situation, whenever encountered by any of these wasps.

Two unidentified ichneumonid parasitoids were introduced from Spain and released in Western Australia in 1903, but there is no report of the outcome (Compere 1903; Despeissis and Compere 1903). A comment was made by Compere (1903) in relation to the consignment of grain moth parasitoids: 'I am not sure but there are some parasites of the grain weevil in this lot.'

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Caliroa cerasi (Linnæus) Hymenoptera: Tenthredinidae pear and cherry slug

This species has also been referred to as *Caliroa limacina.*

PRECIS

Caliroa cerasi is a pest of minor importance in all States of Australia, except Queensland where it is uncommon. Only one early, unsuccessful attempt has been made at biological control, presumably because it is easily controlled by insecticides.

BIOLOGY

Caliroa cerasi is a cosmopolitan pest, presumed to be of European origin.

The olive green to black larvae are slug-like, grow to 12 mm in length and are covered with a greenish slime. They graze on the upper surface of leaves leading to a skeletonised appearance. Adults are small (8 mm long), black sawfly wasps which emerge during spring. Females have a saw-like ovipositor with which they slit the leaf tissue to deposit small, oval, flattened eggs which hatch in about 2 weeks. There are two generations per year. In autumn, larvae make small earthen cells in the soil in which to overwinter before pupating in early spring.

PEST STATUS

Cherries are the main hosts of the pear and cherry slug, but pears in particular and apples, quinces and plums are also attacked. Hawthorn and other related ornamental plants may become heavily infested. In coastal and tableland areas of New South Wales, cherry and pear trees may be severely damaged by the larvae grazing away the upper surface of the leaves. These turn brown, curl in from the edges, shrivel and appear as if they had been scorched. Heavy attack may reduce leaves to a network of veins. Populations build up readily in higher, cooler districts, but in cool moist springs, they can cause problems in normally hotter and drier areas (Hely et al. 1982).

BIOLOGICAL CONTROL

There appear to be no parasitoids in New South Wales that are adapted to *C. cerasi* (Hely et al. 1982).

In 1928 cocoons of *C. cerasi*, believed to be parasitised by four species of Ichneumonidae — *Polyblastus phygadeuontoides, Mesoleius caninae, M. dorsalis* and *Perilissus luteolator* — were introduced to New South Wales from northern France and possibly England. Adult wasps emerged during the Australian winter when no suitable hosts were available. It is not clear whether any liberations were made, but it is possible that *P. phygadeuontoides* may have been. In any event no parasitoids survived (Wilson 1960). A second consignment of cocoons collected in northern France was imported in 1931, but no parasites emerged (Wilson 1960).

In more recent times eight parasitoids, one hyperparasitoid, one predatory pentatomid bug and a pathogenic flagellate have been recorded in Europe. Their attack on larvae and pupae of *C. cerasi* is considered to be effective in population control (Carl 1972, 1976). The flagellate *Blastocrithidia caliroae* was originally discovered attacking *C. cerasi* in New Zealand. Massive infections were responsible for high larval mortality and appeared to control outbreaks of *C. cerasi* on at least two occasions in Europe (Lipa et al. 1977). The flagellate does not appear to have been looked for in Australia.

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Sirex noctilio Fabricius Hymenoptera: Siricidae
sirex wood wasp

PRECIS

In the Northern Hemisphere, siricid woodwasps infest a range of softwoods and hardwoods, but are regarded as secondary pests, attacking dying or dead trees. One of these species, *Sirex noctilio*, which is native to Europe and reaches its greatest density in the Mediterranean zone, has been unintentionally introduced into Australia and several other Southern Hemisphere countries. Uncontrolled, it is capable of causing (and has caused) extensive deaths of relatively healthy *Pinus radiata*, a softwood of Californian origin, which has proved particularly susceptible to *S. noctilio* attack. Thus, there developed in Australia a combination of the most virulent siricid, a highly susceptible host tree, absence of natural enemies and a climate often disposed to make the tree susceptible to attack.

The serious damage caused in recently established infestations as *S. noctilio* has progressively invaded *P. radiata* plantations in eastern Australia has been largely reduced to low levels by a combination of classical biological control and silvicultural methods. By far the most important biological control agent, of 15 species introduced and released, is the European nematode *Beddingia* (formerly *Deladenus) siricidicola*, with the parasitoid wasps *Ibalia leucospoides, Megarhyssa nortoni* and *Rhyssa persuasoria* playing a subordinate role. Silvicultural methods include selection of relatively resistant planting material, site selection for vigorous growth, and programmed pruning and thinning.

BIOLOGY

In Tasmania, most *Sirex noctilio* adults emerge from January to May, with peaks in late January and late March (the larger peak). Males start emerging before females and form swarms around the tops of the tallest pine trees. Females enter these swarms and mating occurs on the upper foliage. Female offspring result from fertilised and males from unfertilised eggs. Adults do not feed.

A few days after emergence and after some flight activity, the females begin to oviposit in susceptible trees by drilling holes through the bark and into the sapwood. Several tunnels are commonly drilled at each oviposition site, introducing a phytotoxic mucus (produced in a special gland), a fungus and one or more eggs. Even minute quantities of the mucus produce a severe, temporary, physiological setback to the tree, reducing its capacity to wall off *Sirex* eggs and the associated fungus, *Amylostereum areolatum*. This is known only from trees into which the female has inoculated it during oviposition. Its metabolites are capable of killing the pine tree.

If conditions in the wood are suitable (neither too moist nor too dry) the rapidly growing fungus produces the trigger necessary for the hatching of the *Sirex* egg. The resulting 1st and 2nd instar larvae depend mainly on the fungus for their nutrition. In later instars, larvae tunnel more deeply into the wood, turning back towards the bark before becoming prepupae, usually within about 5 cm of the bark surface. Many individuals do not pupate until the second or even the third year of larval life, to emerge about 3 weeks after pupation as adults via circular holes chewed through the bark. The continuity of transmission of the fungus is ensured by the female taking up a fungal culture into a special pouch, the mycangium, when she casts off the pupal skin.

If fungal growth is impeded either by excess or scarcity of water, egg hatching may be delayed for up to 12 months. When conditions for fungal growth are optimal, larvae may pass through 12 instars and produce large adults. When conditions are less suitable, there may be as few as 7 instars, resulting in smaller adults.

PEST STATUS

Pinus radiata, a native of the Monterey region of California, is the most important plantation softwood in Australia and is also grown extensively in New Zealand, Chile and South Africa. It is believed that a consignment in the middle forties of infested pine logs from New Zealand (where *S. noctilio* had been present at least since 1900 (Nuttall 1989)) led to its establishment in plantations of this pine in Tasmania and Victoria. *S. noctilio* occurs naturally throughout Europe, reaching its highest density around the Mediterranean, and is the only siricid, of some 40 species worldwide, able to kill relatively healthy pine trees which are its principal hosts. Although *Sirex* wasps are of minor significance, except when pines are stressed, unthrifty or damaged, this wasp killed up to 33% of trees in some plantations in New Zealand, up to 40% in some compartments in the early years after its establishment in Tasmania and up to 80% on the Australian mainland (Bedding 1993). In recent years, *S. noctilio* entered Uruguay and Argentina (Aguilar and Lanfranco 1988), then into some of the large *Pinus taeda* and *P. elliottii* plantations in Brazil, and is already close to the border of Chile where

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there are several million hectares of *P. radiata* (Bedding 1993). More recently it has appeared in South Africa (Tribe 1995). Losses result from tree death and also from damage to the timber as a result not only of the tunnels bored by the larvae but of staining by fungal growth.

S. noctilio was first discovered in Tasmania in 1952, in Victoria in 1961 (Irvine 1962) and has since spread into both South Australia (Haugen and Underdown 1990a) and New South Wales (Eldridge and Taylor 1989).

Female *S. noctilio* do not attack trees indiscriminately, but are attracted to susceptible trees which are releasing monoterpene hydrocarbons through their bark, following changes in its permeability. These changes occur in parts of physiologically stressed trees where there is a lowering of osmotic pressure and where growth had ceased temporarily (Madden 1968, 1977). Small trees are sometimes killed as a result of the *Sirex* mucus and fungus introduced by a single ovipositing female, whereas as many as 50 females can be observed attacking, and sometimes killing, dominant trees (Madden and Coutts 1979). Many trees become chlorotic in the apical region 10 to 14 days after attack and this can be induced in healthy trees by injection of the *Sirex* mucus.

Healthy, vigorous trees can resist attack by *Sirex* by either or both of two mechanisms: flooding the oviposition drills with resin, which results in egg or larval mortality (a process which is partially dependent upon the genetic constitution of the tree); and isolation of the symbiotic fungus by secretion of a barrier around it of polyphenols.

It is clear that the host trees have a major influence on *Sirex* populations and there are a number of factors affecting their ability to do so. These include the planting of progeny from dominant trees that have survived *Sirex* attack, the selection of plantation sites that encourage vigorous growth, and both programmed thinning and pruning, also to encourage growth. When such silvicultural methods are combined with the use of nematodes and wasp parasitoids, damage can be reduced to very low levels.

BIOLOGICAL CONTROL

A native ichneumonid *Certonotus nitidulus* was reared from *P. radiata* logs from many localities in Tasmania and Victoria. Weevils (mainly *Orthorrhinus cylindrirostris* and *Poropterus* spp.) generally emerged from the same logs and, it is assumed, were among the natural hosts of *C. nitidulus*. However, this parasitoid also attacks *S. noctilio* and, in 1973, was found to have attained a 15% level of parasitisation of *Sirex* larvae in a plantation in north-eastern Tasmania. Several bird species were observed in Tasmania consuming quantities of *S. noctilio* (from mating swarms at the tops of trees) and also its parasitoids, especially *Ibalia leucospoides, Rhyssa persuasoria* and *Megarhyssa nortoni* (Madden 1982). In Europe, woodpeckers are predators on siricid larvae in tree trunks (Spradbery 1990).

The biological control of *S. noctilio* in Australia can be conveniently divided into three phases.

The first phase commenced a few years after *Sirex* was discovered in Tasmania in 1952. Following unsuccessful attempts at eradication, two parasitoids originating from England were introduced from New Zealand. One was *R. persuasoria*, which was liberated near Hobart in 1958, and the other *I. leucospoides*, which was liberated in both 1959 and 1960. Both became established, with *I. leucospoides* spreading well from liberation points, but *R. persuasoria* remaining close to them (Taylor 1967a).

The second phase started following the discovery of *Sirex* in Victoria in 1962. Stocks of *R. persuasoria* and *I. leucospoides* were imported from New Zealand and liberated both east of Melbourne and in East Gippsland. *I. leucospoides* established in the former, but not the latter area, and *R. persuasoria* in neither (Taylor 1967a). Since it appeared that these two parasitoids would not, unaided, bring about adequate control, a major investigation was undertaken by the CSIRO Division of Entomology. Collections of pine logs containing parasitoids and entomopathogenic nematodes from *S. noctilio* and other siricids were made from many countries in Europe, Asia and North America (Spradbery and Kirk 1978).

Since a number of Northern Hemisphere siricids are dependent upon the same symbiotic fungus (*Amylostereum areolatum*) as *S. noctilio* and because its volatile metabolites are the main host-locating stimuli for their parasitoids, it was relevant to collect, for testing, as many species as possible, wherever they occurred in relevant climates and host trees. Twenty-one species or subspecies of insect parasitoid were introduced to Tasmania up to 1973 for culturing and nine of these with four subspecies and geographic races were released in Tasmania and Victoria (see Table 1 page 29). Five species up to 1975 became established (Taylor 1976). In addition, and most importantly, an entomopathogenic neotylenchid nematode, *Beddingia siricidicola*, was introduced and established widely (see later).

In the first series of importations and releases in Tasmania, which occurred between 1962 and 1967, liberations were made between 1963 and 1965 of fresh stocks of *I. leucospoides* and *R. persuasoria* from Europe. There, *I. leucospoides* is the dominant parasitoid in dry areas (e.g. the typical Mediterranean climate), whereas *R. persuasoria* tends to increase in relative abundance in northern Europe. In addition to these two species, ten other species or subspecies were imported and five of these liberated: *Rhyssa hoferi* from the drier part of USA (Arizona), *Rhyssa persuasoria himalayensis* from India, *Rhyssa lineolata* from North America via New Zealand, and *Megarhyssa nortoni nortoni* and *Ibalia leucospoides ensiger* from USA. *I. leucospoides ensiger, I. leucospoides leucospoides, R. hoferi* and *M. nortoni nortoni* were also liberated in Victoria between 1962 and 1967. The five species not liberated in Tasmania at that time were *Ibalia rufipes drewseni* and *Megarhyssa emarginatoria* from Europe, *Rhyssa alaskensis* from USA, *R. amoena* from Europe

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and *Schlettererius cinctipes* from USA. The first and last of these were later liberated and established in Tasmania and *Megarhyssa praecellens* liberated, but not established. Other species imported into Tasmania and either never bred or, if so, in insufficient numbers and not liberated, were *Ibalia aprilina, I. montana, Megischus* sp. (Stephanidae), *Pristaulacus niger* (Aulacidae), *Rhyssa crevieri, R. howdenorum, R. jozana* (Taylor 1976) and *Pseudorhyssa maculicoxis* (Ichneumonidae) (Kirk 1974). Because it is cleptoparasitic on siricids by first destroying the rhyssine larva already present on the host, *P. maculicoxis* was not suitable for release (Spradbery 1969; Nuttall 1989).

Rhyssa persuasoria persuasoria was collected over a wider range in the Northern Hemisphere than any other species, with material being received from most European countries, Morocco, Turkey, Japan, Canada and USA. Individuals from all these areas appeared to be conspecific, although differences in colour and maculation are apparent and minor differences in behaviour were observed in the insectary, especially in the Moroccan strain (Spradbery and Ratkowski 1974; Taylor 1976).

Megarhyssa nortoni nortoni and *Megarhyssa nortoni quebecensis* were the easiest of all species to culture and establish in the field. *I. leucospoides leucospoides* was found to disperse rapidly and over quite long distances. Its numbers build up rapidly and it often moves along with the advancing front of *Sirex* infestation. *M. nortoni* disperses more rapidly than *R. persuasoria*, although both do so far more slowly than *I. leucospoides*. Methods used for rearing the parasitoids and details relating to the biology and behaviour of individual species are described by Spradbery (1970a,b, 1973c) and by Taylor (1967a, 1976), from which much of the foregoing account is drawn.

The first group of parasitoids to attack siricids after winter are the ibaliids. These oviposit down the *Sirex* drill hole. They are endoparasitic until the 3rd instar, which emerges from the host larva to become ectoparasitic. *Ibalia* spp. emerge in spring to attack *Sirex* eggs, about to hatch, and young larvae in trees where egg hatching has been delayed. The remaining parasitoids attack later and, except for *Odontocolon geniculatus*, have longer ovipositors, up to 4 cm or more (especially *M. nortoni* and *Schletterius cinctipes*). These can be inserted far into the wood to reach larvae deep in the tree. Host location, at least in *R. persuasoria* and *M. nortoni*, depends upon the volatiles produced by the renewed growth of symbiotic fungus and other microorganisms in the moist area immediately behind the feeding siricid larva. The host larva is paralysed by stinging and an egg laid on the body surface. Adult parasitoids feed on honeydew. In this group of species, most individuals of each generation enter diapause as fully-fed larvae and pupate during the following spring to emerge at the time (late spring, early summer) when *Sirex* larvae are boring outwards towards the bark to pupate. Those parasitoids that do not enter diapause soon pupate and emerge shortly after (Taylor 1976).

Members of the family Stephanidae, to which *S. cinctipes* belongs, are reported to be primary parasitoids of wood-boring beetles. A single, fertilised female, collected in California in an area of *Pinus jeffreyi* and *Abies* spp. infested by the siricids *Xeris morrisoni* and *X. spectrum*, enabled a culture to be established on *S. noctilio* larvae in Tasmania. *S. cinctipes* was later found to be one of the dominant parasitoids emerging from siricid-infested logs collected in Arizona and New Mexico (Kirk 1975). Females live an average of 30 days in an insectary and produce 32% parasitisation. *S. cinctipes* was liberated in Tasmania in the late 1960s but, by 1974, was still causing only 1% or 2% parasitisation in the field (Taylor 1967b, 1978, 1981). The importance of evaluating attempts at biological control was emphasised by Taylor (1980).

The nematode *B. siricidicola*, which was first recognised in New Zealand (Zondag 1962), is now regarded as the main controlling agent of *S. noctilio* in Australia. Only this species, of seven of *Beddingia* which were found parasitising 31 siricid and parasitoid hosts from 31 tree species and 29 countries, was found to be suitable for the control of *S. noctilio* in Australia (Akhurst 1975; Bedding and Akhurst 1978; Bedding 1984, 1993). Because of its importance and of its complex life cycle, its biology is described in somewhat greater detail than usual.

Many strains of *B. siricidicola* parasitise, but do not fully sterilise *S. noctilio* females. However four strains (Corsican, Greek, Hungarian and New Zealand) parasitised nearly 100% of emerging *Sirex*. Female *Sirex* infected with a Hungarian strain were found to fly further, produce more eggs and more nematodes than the others. Therefore, although some releases were made of the other three strains, the bulk of releases in Australia (and also those in Brazil from 1989 on) have been of strain 198 from Sopron, Hungary (Bedding 1993).

When a parasitised adult *Sirex* emerges from a nematode-infested tree it may contain, in its haemocoel, up to 100 adult female nematodes each measuring from 0.5 to 2.5 cm long. These adults have usually already released into the host haemocoel most of their juveniles, which have migrated into the host reproductive organs. Male *Sirex* are not sterilised, but females are. Ovarian development is retarded and every egg produced is either penetrated by up to 200 juvenile nematodes or is too small to develop. Parasitised female *Sirex* oviposit readily and, in doing so, introduce egg shells packed with nematode juveniles into the tree. Unparasitised *Sirex* oviposit in the same susceptible trees and the resulting healthy larvae are exposed to nematode parasitisation.

The symbiotic fungus inoculated with each *Sirex* oviposition grows rapidly and extensively in susceptible trees. Juvenile nematodes migrate to the growing front of the fungus, feed there and develop into adult, egg-laying females, quite unlike their parents. Juveniles hatching from these eggs feed on the fungus and produce further egg-laying adults, this cycle continuing for many generations, leading to hundreds of millions of offspring. Juveniles that arrive in the vicinity of *Sirex* larva transform into adult males or females. After fertilisation, females

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penetrate a *Sirex* larva and soon grow enormously in size. Triggered in due course by the pupation of the host larva, many thousands of juvenile nematodes are soon thereafter produced by the female. The cycle is completed with the deposition by the *Sirex* female of eggs packed with juveniles (Bedding 1993).

Between 1979 and 1984, the interactions between *S. noctilio* and its natural enemies were studied in north-eastern Victoria in trap trees killed with 20% dicamba herbicide. *B. siricidicola* did not affect the activity of the two most abundant parasitoids (*I. leucospoides* and *M. nortoni nortoni*), nor restrict the fungal food supply to *S. noctilio* larvae. Of these three biological control agents *B. siricidicola* was by far the most effective, causing almost 100% sterility of *S. noctilio* females. Of the two wasps, only *I. leucospoides* showed any promise as a control agent. The other wasps released in the region, *R. persuasoria* and *R. hoferi*, played no significant role (Neumann and Morey 1984b).

Although nematodes can be spread from plantation to plantation by infected *Sirex* females, this is an unreliable method of dispersion and may occur too late in a new infestation to prevent a serious outbreak. Nematodes are, therefore, introduced as early as possible by inoculating accessible trees infested by *Sirex*. The methods for doing this are described by Bedding (1993 and papers quoted therein).

The final phase of the biological control program commenced in 1987 as a result of the spectacular death in that year of 1.8 million *P. radiata* trees in south-western Victoria and south-eastern South Australia. This massive mortality was followed during the next 2 years by a further three million tree deaths (Bedding 1993).

After *S. noctilio* became established on mainland Australia in 1961, it spread from the Melbourne area at a rate of about 20 to 30 km per year, taking nearly 20 years to reach the borders of Victoria. During this time, nematode liberations and other control measures were undertaken and there were relatively few *Sirex* outbreaks. This situation led to complacency so that, when *Sirex* arrived during 1979 in the valuable, extensive pine plantations spanning the Victorian–South Australian border, no serious attempt was made to introduce nematodes until 1987, by which time widespread deaths were occurring (Bedding 1993). This experience shows that, in the absence of effective control agents, *Sirex* can kill up to 80% of pine trees in some areas.

Fortunately, as a result of a major program mounted in 1987 to inoculate highly infective nematodes into 140,000 trees in the region (Haugen and Underdown 1990a,b), very high levels of nematode parasitisation were achieved within 2 years and the *Sirex* population crashed. On the basis of this outbreak, it was calculated that, in the absence of control agents, *Sirex* has the potential to cause a A$1 billion to $4 billion loss of timber in each rotation (every 30 years) of the total pine plantations in Australia (Bedding 1993).

The reason for the catastrophic outbreak was traced to a gradual, and until then undetected, loss in parasitic ability of the strain of nematode being liberated. Whereas 20 years earlier, inoculation of trees invariably resulted in nearly 100% parasitisation (Bedding and Akhurst 1974), the recent inoculations produced less than 25%. It was then shown that continuous subculturing of *B. siricidicola* in the free-living form for over 20 years without intervention of the parasitic life cycle had led to the selection of a strain that rarely formed the parasitic stage. A highly infective strain was, therefore, recovered from the Tasmanian forest where the nematode was first liberated in 1970. This strain has since been cultured and liberated over some 500,000 hectares of pine forest in southern Australia. Many hundreds of vials of this highly infective strain have now been stored under liquid nitrogen, so that, each year, the starter cultures used for releases can be re-initiated from this stock (Bedding 1993).

COMMENTS

This successful classical biological control of a major exotic pest (*S. noctilio*) by an exotic entomopathogenic nematode (*B. siricidicola*) is a spectacular world first for entomopathogenic nematodes. Although, at times, *B. siricidicola* can achieve nearly 100% parasitisation in some pine stands, it is desirable to establish several parasitoids which can also achieve useful levels of parasitisation.

If repeated inoculations of any of these organisms into new *Sirex* infestations are required, careful attention is needed to culture techniques to ensure that parasitisation ability of released material is not impaired.

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Vespula germanica (Fabricius) Hymenoptera: Vespidae
European wasp

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Vespula vulgaris (Linnæus)
English wasp

PRECIS

These two Northern Hemisphere species of *Vespula* were discovered in Australia in the late 1950s. *V. germanica* is now widespread, although it does not occur in northern Australia; *V. vulgaris* is still limited to south-eastern Victoria and Tasmania. Both wasps can inflict painful stings. They prey upon native and exotic insects and also seek honeydew and sugary fluids from overripe fruit.

A European parasitoid of prepupae and pupae, *Sphecophaga vesparum*, was obtained from New Zealand and liberated in Melbourne, Victoria in December 1989 and later more widely, but there are no reports of the outcome.

BIOLOGY

The European wasp, *Vespula germanica* is native to the western Palaearctic and the English wasp *Vespula vulgaris* to the Holarctic (Donovan 1989). Both species have now become established in many other countries (Matthews et al. 2000).

V. germanica was first recorded in Tasmania in 1959 (Anon 1962a,b) and in Melbourne in 1961 (Anon. 1962b; Goodman and Darby 1995). It was first collected in Sydney, New South Wales in 1975 (Smithers and Holloway 1977, 1978), in Freemantle, Western Australia in 1977 (Anon. 1977) and in South Australia during the summer of 1977/78 (Edwards 1980). It is now widespread,

although it has not been reported further north than Maryborough in Queensland (Spradbery and Maywald 1992).

V. vulgaris was first found in Melbourne in 1958 and, in 1991, was reported to have spread only a few hundred kilometres into south-eastern Victoria (Crawford 1985; Field and Darby 1991), although common where it occurred (Crosland 1991). It has recently been found near Hobart and it appears that this species has been established in Tasmania, but gone undetected for years. Gullen (1999) suggests that *V. vulgaris* prefers cooler climates than *V. germanica* and that rainfall and other biotic factors may limit its distribution in Australia.

In spring, hibernating queens of both species found new nests which attain a peak in size in late summer. Males appear in January and new queens about March (Spradbery 1973a). The nests of English wasps are usually abandoned each winter, but some of those of the European wasp survive (Spradbery 1973b; Donovan 1989).

PEST STATUS

When abundant, both wasp species can become a public nuisance through their stings which are occasionally fatal to humans and domestic animals. A dangerous situation arises when adult wasps enter drink cans or bottles in search of sweetened cordials and are inadvertently swallowed, sometimes leading to asphyxiation (Spradbery 1989). However, adults are seldom aggressive, unless a nest is disturbed.

Adult wasps are reported to destroy or damage colonies of honeybees. The juices of ripening fruit, including grapes, plums, peaches and nectarines, are commonly sought. The wasps are sometimes considered to be useful predators of pest insects, particularly of lepidopterous larvae and flies. However, their general foraging behaviour in invaded countries almost certainly results in many non-target native insects being taken in addition to exotic pest species.

BIOLOGICAL CONTROL

Many non-specific and a few more specific natural enemies of vespid wasps have been recorded overseas (Spradbery 1973a; Edwards 1980). However, there appear to be no published reports from Australia.

After specificity tests indicated that there would be little risk to native wasps, the European ichneumonid wasp *Sphecophaga vesparum* was obtained from New Zealand and releases made in Melbourne in December 1989 (Field and Darby 1991). Later, large numbers were released throughout Victoria, Tasmania, and to a lesser extent in South Australia (Goodman and Darby 1995). This culture was derived from a single European female (Donovan 1991; Beggs et al. 1996; Donovan and Read 1987). There have been no reports of its establishment (S. Darby, pers. comm. 1999).

MAJOR PARASITOID SPECIES

Sphecophaga vesparum Hymenoptera: Ichneumonidae

S. vesparum is an ectoparasitoid of prepupae and young pupae in capped cells of species of Vespinae. It is multivoltine and facultatively parthenogenetic, each generation producing diapausing and non-diapausing progeny. Diapause may last up to 3 years. Adults usually enter vespid nests in spring and deposit each egg on the inhabitant of a capped cell. Larval development takes about 12 days at 30°C and adult, non-diapausing parasitoids then parasitise neighbouring capped cells. Parasitoids that enter a nest early in the season can destroy it before the autumn production of vespid queens (Donovan and Reed 1987; Donovan 1991; Field and Darby 1991).

94

Boophilus microplus (Canestrini) Acari: Ixodidae
cattle tick

PRECIS

The cattle tick, *Boophilus microplus*, probably arrived in Darwin in 1872 from Java. It now occurs in the northern third of Australia, where it is capable of causing significant losses to beef and dairy production.

The cattle egret, with has been observed to pick living ticks from the skin of cattle was introduced unsuccessfully in 1933 and on at least one subsequent occasion. However, it has more recently become well established in Northern Australia, without human assistance. It has had no observable effect on cattle tick abundance.

BIOLOGY

The cattle tick, *Boophilus microplus*, occurs from India through Southeast Asia to Australia and is present also in the Americas south from Mexico. It was probably introduced to Australia at Darwin in 1872 with Brahman cattle brought from Java. Later, the tick spread with travelling cattle to Queensland, New South Wales and Western Australia.

The fully-fed (engorged) and fertilised female ticks drop from their animal host and seek shelter at ground level for a few days before producing a single batch of about 2000 eggs and dying shortly afterwards. The six-legged young larvae, or seed ticks, hatch after some 2 weeks and they soon become extremely active and congregate at the tips of grass stalks. There they assume a questing pose, front legs outstretched waiting to transfer to a passing animal. Once this is achieved, they attach themselves to the skin of the host and feed for several days before moulting to eight-legged nymphs. These in turn, after about 2 weeks, moult to adults, the males fertilising the females shortly after moulting has occurred.

PEST STATUS

Although cattle are favoured hosts, the cattle tick also occurs on horses and has, at times, been found to infest sheep, deer and, more rarely, pigs, dogs, rabbits and kangaroos (Seddon 1958). Blood loss, due to large numbers of ticks feeding and the associated irritation, lowers production on dairy farms and beef cattle properties over large areas of tropical and subtropical Australia. Deaths may occur through transmission by the tick of protozoa that cause redwater fever. In addition, there are significant costs associated with dipping in acaracide to reduce infestations, there is interference with cattle trading due to quarantine restrictions and, in heavy infestations, there can be important damage to hides.

BIOLOGICAL CONTROL

A number of non-specific predators of engorged females of the cattle tick have been recorded in central and southern Queensland (Sutherst et al. 2000). Ants (19 species) and the house mouse, *Mus musculus*, were the only significant predators, although birds, anystid mites, a spider, a centipede and a bandicoot were also listed. Mouse predation was higher in winter and ant predation more frequent in summer. It was concluded that the predators usually occur in sufficiently high densities to influence the size of tick populations in pastures, but a less than proportional reduction in tick numbers on cattle could be expected. It was unlikely that the numbers of non-specific predators could be manipulated as a means of tick control.

In 1933, 18 specimens of the cattle egret (*Ardea ibis*) from London were released at Kimberley Downs Station, Western Australia for the control of cattle tick. However, the birds fell easy prey to hawks and other enemies and survived scarcely more than a week (Jenkins 1946; Wilson 1960). Serventy and Whittell (1948) record that cattle egrets were also unsuccessfully introduced from Calcutta. Nevertheless, the species has become well established in northern Australia, probably without human assistance (Wilson 1960). The cattle egret is not known to have any impact on cattle tick populations.

The introduction of the starling, *Sturnus vulgaris*, into northern Western Australia was proposed, but not implemented (Jenkins 1946).

95

Halotydeus destructor (Tucker) Acari: Penthaleidae redlegged earth mite

PRECIS

The South African redlegged earth mite, *Halotydeus destructor*, first recorded in Australia in 1917, now occurs in pastures where there is a Mediterranean climate. It is capable of causing serious damage to pasture legumes and to crops and vegetables. It is considered the most important pasture pest in southern mainland States.

A European predatory mite, *Anystis wallacei*, was introduced from France to Western Australia in 1965. It has a slow rate of spread and has been greatly assisted by redistribution in Western Australia and Victoria. Wherever it has built up numbers it is capable of reducing earth mite populations and the damage they cause. Earth mite control is intimately involved with that of the lucerne flea, *Sminthurus viridus* (target pest no. 1).

BIOLOGY

The redlegged earth mite, *Halotydeus destructor*, of South African origin now, occurs also in Australia and New Zealand. The Australian population originated from the Cape Town area (Qin and Gullan 1998). It was first reported in Western Australia in 1917 (Newman 1934a), Victoria in 1921, South Australia in 1925 and New South Wales in 1930 (Swan 1934). It occurs in pastures where there is a Mediterranean climate with winter rainfall and dry, warm to hot summers. It is a major pest in the four southern mainland States (Allen 1987).

H. destructor is essentially a soil mite, spending 90% of its time on or near the soil surface and only moves up onto plants to feed. Its eggs are orange to pink and hatch to a larval stage, followed by proto-, deuto- and trito-nymphal instars before becoming adult, each stage lasting 1 to 2 weeks. There are three generations per year with spring and autumn peaks. Winter eggs, which develop without diapause, are laid singly on the surface of leaves close to the ground or on the soil surface. Drought-resistant, diapausing summer eggs are produced in spring and

these do not hatch until the following autumn. They are retained within the body of the female when it dies (Norris 1950; Wallace 1968, 1970a,b).

Males spin webs on the soil surface and sometimes on plants. On these they deposit spermatophores which the females later pick up and transfer to their genital opening.

PEST STATUS

The redlegged earth mite causes damage to pasture legumes, crops and vegetables and feeds extensively on broadleaf weeds, in particular on capeweed, *Arctotheca calendula* (Solomon 1937; Wallace 1967). It uses its sharp chelicerae to pierce the upper leaf epidermis down to the palisade layer and then imbibes the exuded droplet of cell contents. This leads to silvering of the leaf as a result of air replacing fluids in the damaged cells (Swan 1934). Wallace and Mahon (1963) estimated that, if earth mite and lucerne flea were controlled, 0.8 extra sheep per ha could be carried. Ridsdill-Smith (1991b, 1997) has reviewed the information relating to the economic impact of redlegged earth mite and has estimated the annual loss to pasture production as A$145 to $238 million, making it the most important pasture pest over the southern mainland States of Australia.

BIOLOGICAL CONTROL

Predatory mites and the fungus *Neozygites acaridis* are the most commonly encountered natural enemies of redlegged earth mite in Australia. In spring, over a 3-week period, 15% of adult females showed symptoms of the fungus and contained 47% less diapausing eggs than healthy females (Ridsdill-Smith and Annells 1997).

In early years, natural enemies were reported to have little impact on *H. destructor* populations (Swan 1934; Norris 1938). More recently, James (1995) recorded 19 species of mite and insect predators of redlegged earth mite in southern New South Wales (Table 43 page 426). He reported that predators constituted 36% of vacuum-sampled biomass and comprised 8% to 76% of all organisms collected. Furthermore, earth mite populations were smaller in unsprayed than in sprayed fields. It appeared then that native natural enemies may be important in some situations. Wallace and Mahon (1972, 1976) had already recorded a surprisingly large fauna of bdellid mites in Australia, including a number that occur in the regions occupied by redlegged earth mite and lucerne flea. However, their relative contributions to reducing pest populations has not been assessed.

Womersley (1933) believed that *H. destructor* had been introduced to South Africa, and suggested a search for natural enemies in Mediterranean France. Although no redlegged earth mites were found, a species of *Anystis* was seen to be feeding on another pest, the blue oat mite, *Penthaleus major*. In 1938, large

numbers of this *Anystis* sp. were collected for shipment to Australia. However, when this predator was (wrongly) identified as *Anystis baccarum*, Womersley pointed out that there was no point in introducing this species as this species was already recorded to be widespread in southern Australia. The introduction was then abandoned (Otto and Halliday 1991).

In the course of searching for natural enemies of the lucerne flea in Europe, Wallace (1981) realised that the mite earlier identified there as *A. baccarum* was quite different from the species known by this name in Australia. Initially again wrongly identified as *Anystis salicinus*, it proved to be a new species, known for a time as *Anystis* species A. It was later described as *Anystis wallacei*. It was a general predator attacking *P. major*, other mites (but not *H. destructor*, which does not occur in Europe) and Collembola (Wallace 1981; Michael 1995; Ridsdill-Smith 1997). Valuable features were that it inhabited pastures in Europe and occurred in areas where the climate is similar to that where *H. destructor* is present in Australia. It was predicted that it should become established wherever the earth mite occurs in Australia (Otto and Halliday 1991).

The outcome was that *A. wallacei* was liberated at four sites in Western Australia in 1964. It became established at two of these and spread very slowly until 1976 (Waterhouse 1978; Wallace 1981). Steps were then taken to accelerate its spread by a program of collection and distribution (Otto and Halliday 1991).

In Australia, *A. wallacei* exhibits a preference for *H. destructor* over other prey, although it also consumes lucerne fleas. Feeding tests showed that 100 *Anystis wallacei* per m^2 could kill 16,000 redlegged earth mites in one mite generation (Michael 1995). Field evidence has been reported that the predator can reduce pest numbers. In plots in south-western Australia *A. wallacei* was shown to reduce redlegged earth mite populations by up to 80% and, in ungrazed plots, both vegetative material and seed yields were more than doubled (Michael et al. 1991a,b,c; Michael 1995).

In 1976, and again in 1991, consignments of *A. wallacei* were sent from Western Australia to Victoria (Berg 1991), but evidence of establishment was only obtained following consignments commencing in 1993 (Gardner and Gardner 1994). Because of the slow rate of success with *A. wallacei*, possibly because it came from France and not from the native range of redlegged earth mite, recent surveys were carried out in South Africa. These have revealed several species of predatory mites associated with *H. destructor* populations. The most notable of these, *Chaussieria capensis*, can kill significant numbers of *H. destructor* without attacking many Collembola or aphids. However, both the geographical and the seasonal range of *C. capensis* are greater than those of *H. destructor*, so its full range of prey is not yet known. It is a serious contender for introduction to Australia (R.B. Halliday, pers. comm. 1999).

Strains of the entomopathogenic fungi *Metarhizium anisopliae* and *Beauvaria bassiana* have been isolated that are pathogenic to the earth mite, but

not to its predators. However, there is no report of its field release (Ireson and Rath 1991; Say et al. 1995).

MAJOR NATURAL ENEMY

Anystis wallacei Acari: Anystidae

A. wallacei is native to Mediterranean France, Spain and western North Africa. It attacks a wide array of mites and Collembola and, in the laboratory, has a special preference for juvenile Sminthuridae (Wallace 1981). It will suck dry redlegged earth mite eggs, although they are not a preferred food (Otto and Halliday 1991). This apparently aberrant laboratory behaviour does not match its field performance, in which it has been found to reduce earth mite populations by up to 80% (Michael 1995).

Eggs are laid in batches of 13 to 47, covered with fine silk. Development from larva to adult takes about 28 days at 22°C. If eggs in winter are held at 93% relative humidity until fully developed they are, thereafter, able to withstand dryness. The fully developed prelarval stage then emerges when triggered to do so by rain or dew (Otto and Halliday 1991). Thus, the predator can appear in the field before the pest species has hatched and it also lives long after they have died at the end of the season (Michael 1995).

COMMENTS

The trials conducted by Michael (1995) indicate that predators (especially *A. wallacei*) may provide up to 80% control of redlegged earth mite, leading to a reduction in losses of up to 30%, depending on the situation. Although chemical control may be desirable at times, it is clear that any pest management situation, including the use of mite-resistant cultivars, should take into consideration the major role that natural enemies can play in control if not prevented from doing so by acaricides. Assisted, widespread establishment of *A. wallacei* is highly desirable, although this may take some years to achieve. Meanwhile there remains the possibility of introduction of other, better-adapted, predatory mites from South Africa.

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Table 43. Natural enemies of *Halotydeus destructor* in southern New South Wales, 1987–1993 (James 1995)

NEUROPTERA	**ACARI**
CHRYSOPIDAE	PHYTOSEIIDAE
Mallada spp.	*Amblyseius dieteri*
	Galendromus occidentalis
HEMEROBIIDAE	*Neoseiulus barkeri*
Hemerobius spp.	*Proprioseiopsis messor*
	Typhlodromus victoriensis
COLEOPTERA	
COCCINELLIDAE	ANYSTIDAE
Coccinella transversalis	*Erythracarus* sp.
Diomus notescens	*Walzia australica*
Harmonia conformis	
	BDELLIDAE
FUNGI	*Bdellodes affinis*
ENTOMOPHTHARALES	*Bdellodes lapidaria*
Neozygites acaracida	*Cyta latirostris*
	CUNAXIDAE
	Cunaxa sp.
	ERYTHRAEIDAE
	Balaustium murorum

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Panonychus ulmi (Koch) Acari: Tetranychidae
European red mite

PRECIS

Panonychus ulmi has a similar distribution, biology and pest status to the twospotted mite, *Tetranychus urticae* (target pest no. 97), although it prefers cooler, temperate climates and is an important pest only of apples and pears. Pesticide resistance in *P. ulmi* is widespread and, if its natural enemies are reduced or eliminated by pesticides, numbers can increase dramatically during summer.

When the pesticide-resistant predatory mite *Galendromus occidentalis*, introduced from USA, failed to reduce numbers of *P. ulmi* sufficiently, a pesticide-resistant strain of another predatory mite, *Typhlodromus pyri*, was introduced from New Zealand. This established readily and has reduced *P. ulmi* numbers to subeconomic levels in eastern Australia, wherever integrated pest management is practised.

BIOLOGY

Panonychus ulmi is widespread on deciduous fruits, shade trees and shrubs in Europe and North America. It was first recorded in New South Wales in 1954, in Queensland in 1957 (Hely et al. 1982) and has spread throughout southern Australia. It overwinters as red, onion-shaped eggs, which are laid in autumn on twigs and smaller branches and hatch in spring. Females are brownish red, oval and about 0.3 mm long. Males are smaller and paler. Females may lay up to 20 summer eggs and they live for up to 3 weeks. Eggs develop to adults in 1 to 2 weeks and there are three generations per year in New South Wales (Bower 1977). Feeding and egg laying occur on the underside of leaves. No webbing is produced (Hely et al. 1982).

PEST STATUS

P. ulmi is a cosmopolitan pest of pome and stone fruits and occurs in Australia mainly on apples, pears and plums. Low populations cause speckling of leaves, where sap has been withdrawn from cells, and can generally be tolerated. When

high populations are present, serious leaf bronzing and defoliation may occur, fruit may be small and poor in quality and fruit buds prevented from forming. *P. ulmi* outbreaks occur in cooler districts where broad-spectrum pesticides are used to control codling moth and other pests. Thus, it is reported as a serious pest of apples in Tasmania, in the Batlow area of New South Wales and second in importance to *Tetranychus urticae* in the tableland of Queensland (Bengston 1965; Readshaw 1975b; Bower 1977; Hely et al. 1982).

BIOLOGICAL CONTROL

P. ulmi is attacked by many of the same predators recorded for the twospotted mite, *T. urticae*, and in particular by *Stethorus* spp. and some of the predacious mites (see target pest entry no. 97 page 429, Table 44 page 432) (Readshaw 1975a,b; Schicha 1975b,c; Thwaite 1980).

It is tolerant, or resistant, to many orchard chemicals. These are, however, highly toxic to the predators and, when the latter are killed, it is able to increase to damaging populations. Pesticide-resistant *Galendromus occidentalis*, which was introduced to control *T. urticae*, also attacked *P. ulmi*, but did not provide adequate control (Bower 1984).

Pesticide-susceptible *Typhlodromus pyri* already occurred in Australia, but a strain resistant to many orchard pesticides was introduced from New Zealand and liberated in the Australian Capital Territory in 1974 (Readshaw et al. 1982). *T. pyri* was probably introduced accidentally to New Zealand from Europe in the early days of European settlement (Wearing and Ashley 1982). In 1977, it was liberated in the Batlow and Bilpin apple-growing districts of New South Wales. It soon became established and flourished in tableland districts in mild and normal seasons, but has been unable to increase adequately in numbers in hot dry seasons or locations (Bower 1984). However, it is credited with contributing importantly to the effective control of *P. ulmi* in eastern Australia wherever the integrated pest management approach is adopted. It is less successful in Western Australia because of the widespread use of pyrethroids for control of various weevils (J.L. Readshaw, pers. comm.). It is claimed that the *P. ulmi* ovicides clofentezine and hexythiazox will not interfere with the pest management of European red mite (Bower 1990).

Both *T. pyri* and *G. occidentalis* can survive and reproduce on prey or food other than tetranychid mites. Both species feed and reproduce on rust mites (Eriophyiidae), which are common in some orchards. In addition, *T. pyri* feeds on pollen, especially wind-borne grass pollen, which sticks to the underside of apple leaves (J.L. Readshaw, pers. comm.).

Another predatory mite, *Phytoseiulus persimilis*, now occurs naturally in orchards and other crops throughout eastern Australia. It is tropical in origin, has difficulty in overwintering, and is therefore less important than *G. occidentalis* or *T. pyri*. It is reared commercially for controlling *T. urticae* in particular, in many horticultural crops (J.L. Readshaw, pers. comm.).

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Tetranychus urticae Koch Acari: Tetranychidae twospotted mite

Tetranychus urticae has many synonyms, of which *T. telarius* is probably best known. There are three important phytophagous mites of fruit and vegetables in Australia. These are *T. urticae* on the mainland, *Panonychus ulmi* in Tasmania and *Bryobia rubrioculus* generally. The latter was the major pest species before the use of broad-spectrum insecticides, to which it is very susceptible. It is not now found in sprayed environments.

PRECIS

Tetranychus urticae is a cosmopolitan species with an extremely wide host range, including many fruits, cotton and vegetables. Before the use of broad-spectrum pesticides, *T. urticae* was usually very scarce. It was kept under effective control by predators, which are far more susceptible than *T. urticae* to pesticides. The introduction of strains of predacious mites (especially of *Galendromus occidentalis*), tolerant to many of the pesticides, has enabled *T. urticae* to be successfully held at low levels in many crop environments in eastern Australia.

BIOLOGY

Tetranychus urticae adults are up to 0.5 mm long, greenish-yellow and have a dark spot on each side of the body. They move actively and spin a fine webbing over the undersurface of the leaf where they are feeding. Females lay up to 70 eggs over 10 days or so in the tangled webbing.

As is typical in most Tetranychidae, there is a six-legged larva, followed by eight-legged protonymph and deuteronymph stages. Unmated females produce male progeny. A generation from egg to egg takes 7 to 11 days in summer. Breeding is continuous if the temperature does not fall too low. Feeding on deciduous trees ceases in autumn. *T. urticae* overwinters as an orange–red adult female on or near the host plant under loose bark or litter. It does not feed or lay eggs until the following spring (McMurty 1978; Hely et al. 1982). In undisturbed natural ecosystems, *T. urticae* is usually very scarce, peaking at no more than about two mites per leaf, but in disturbed ecosystems mites can increase to very high densities, exceeding 100 per leaf.

PEST STATUS

T. urticae causes serious damage to the leaves of crops sprayed with chemicals for other pests and diseases (e.g. codling moth and apple scab in pome fruit, or *Helicoverpa armigera* in cotton). It is widely polyphagous, attacking a wide range of host plants, especially pome and stone fruits, but also cotton, hops, berry fruits, vegetables, ornamentals and forage crops, such as lucerne and subterranean clover. It was probably introduced from Europe in the early days on host plants.

In the absence of natural enemies, *T. urticae* populations build up rapidly. The mites pierce the cells on the undersurface of the leaves to withdraw sap, leading to spotting, yellowing and drying of the leaves, followed by leaf fall exposing fruit to sunburn. Fruit is undersized and young trees stunted. *T. urticae* is most important in mainland Australia. In Tasmania and the cooler high country in south-eastern Queensland, the European red mite, *Panonychus ulmi* displaces it from that position.

BIOLOGICAL CONTROL

T. urticae and other phytophagous mites are attacked by many native predators (a partial list is shown in Table 44 page 432), which generally held pest numbers well below economic injury levels before the general use of wide-spectrum insecticides.

Of these predators, three species of *Stethorus* (Coccinellidae) (*S. histrio, S. nigripes* and *S. vagans*) are regarded as being particularly effective. *S. nigripes* is active in the hotter inland areas of South Australia (Britton and Lee 1972) and both it and *S. vagans* are abundant in cooler regions (Readshaw 1975a). *S. vagans* appeared to be the dominant species in the Goulburn Valley of Victoria (Field 1979). The many native, predacious phytoseiid mites are generally of lesser importance (Readshaw 1971), although *Typhlodromus victoriensis* was capable of maintaining *T. urticae* populations at low levels in the Murrumbidgee Irrigation Area of New South Wales in the absence of broad-spectrum pesticides (James 1990). Also present were two important exotic mite species, the widespread *Galendromus occidentalis* (probably in Australia for many years) and *Phytoseiulus persimilis* (first recognised in 1988) (Waite 1988a).

T. urticae was of little importance as an orchard pest before the introduction in the late 1940s of dichlorodiphenyltrichloroethane (DDT) to control codling moth, *Cydia pomonella*, and oriental fruit moth, *Grapholita molesta*. Pest status used to be rare and of short duration, occurring when mites migrated in summer from ground vegetation to the fruit trees, or from crops (such as beans) grown between the trees. When DDT (and, later, other synthetic pesticides) killed their natural enemies (coccinellids, neuropterans, predacious thrips and mites), a rapid increase resulted in *T. urticae* populations, which proved to be far less susceptible to pesticides than their predators (Readshaw 1971; Hely et al. 1982).

Target Pest No. 97

Following detailed ecological studies of *T. urticae*, *Bryobia rubrioculus* and *P. ulmi* in unsprayed apple orchards (Readshaw 1975a), attention concentrated on two species of predatory mite, *G. occidentalis* and *Typhlodromus pyri*.

Although the exotic, predacious mite *G. occidentalis* has long been widespread in Australia, the strain present was susceptible to azinphos-methyl and most other insecticides widely used in orchards. As a result, it was seldom present in commercial orchards. However, a strain in North America was reported to be resistant to many insecticides, including azinphos-methyl, widely used for control of codling moth (Croft and Jeppson 1970). This resistant strain was introduced and released in a commercial apple orchard in Canberra, Australian Capital Territory in 1972 and 1973, and also in all mainland States during 1973 (Readshaw 1975b). In most instances, there was rapid establishment (Field 1974). Indeed, *G. occidentalis* was soon shown to be able to reduce *T. urticae* to subeconomic levels in commercial apple orchards throughout eastern Australia, provided chemicals harmful to it were excluded from the spray program (Readshaw 1975b; Field 1978; Thwaite and Bower 1980). This strain was partially effective in peach orchards in Victoria (Field 1976).

A second insecticide-resistant predacious mite, *Neoseiulus fallacis*, was introduced from North America via New Zealand and liberated in Tasmania in 1976, but it established only briefly. A third exotic species, *P. persimilis* was discovered about 1975 in an apple orchard in Victoria (Ridland et al. 1986; J.L. Readshaw, pers. comm.). The time and method of its arrival is unknown, but it now occurs in orchards and other crops throughout eastern Australia. It is tropical in origin, has difficulty in overwintering in cooler areas and is thus less effective than *G. occidentalis*. However, it is reared commercially for release in spring each year against *T. urticae* in many horticultural crops.

A fourth species, the exotic *T. pyri*, already occurred in Australia, but was susceptible to a wide range of pesticides. A strain showing valuable pesticide resistance was introduced from apple orchards in Nelson, New Zealand. It was liberated in the Australian Capital Territory and New South Wales in 1975 and later Australia-wide (Readshaw et al. 1982). Although it was introduced primarily against the European red mite, *P. ulmi*, it also attacks *T. urticae*.

Both *G. occidentalis* and *T. pyri* can survive and reproduce on prey or food (pollen) other than tetranychid mites. Both species attack rust mites (Eriophyidae), which are common in some orchards, and *T. pyri* feeds on pollen, especially wind-borne grass pollen, which adheres to the underside of apple leaves (J.L. Readshaw, pers. comm.).

Integrated control of *T. urticae*, based on *G. occidentalis* and *T. pyri*, is now well established practice in eastern Australia. It is rather less successful in Western Australia, because of the widespread use there of synthetic pyrethroids for the control of various weevils that are not pests in eastern Australia. The predatory mites are susceptible to these compounds (J.L. Readshaw, pers. comm.).

Table 44. Some predators of *Tetranychus urticae*

Species	State	References
HEMIPTERA		
MIRIDAE		
Campylomma livida		Readshaw 1971, 1975a,b
THYSANOPTERA		
PHLAEOTHRIPIDAE		
Haplothrips victoriensis	S.A.	Bailey & Caon 1986
THRIPIDAE		
Frankliniella schultezi	NSW	Wilson et al. 1996
Scolothrips sexmaculatus	NSW, Q	Waite 1988a; Wilson et al. 1998
THRIPIDAE		
Thrips imaginis	NSW	Wilson et al. 1996
NEUROPTERA		
HEMEROBIIDAE		
Micromus tasmaniae	NSW	Wilson et al. 1998
DIPTERA		
CECIDOMYIIDAE	Q	Waite 1988a
COLEOPTERA		
COCCINELLIDAE		
Stethorus histrio	Q, NSW, Vic	Houston 1980
Stethorus nigripes	NSW, ACT, Vic, SA	Britton & Lee 1972; Walters 1974; Field 1979; Houston 1980; Thwaite 1980; Bailey & Caon 1986
Stethorus vagans	NSW, Vic	Walters 1974; Field 1979; Houston 1980; Thwaite 1980
ACARI		
PHYTOSEIIDAE		
Amblyseius lentiginosus	NSW	Schicha 1975a,c
Amblyseius neolentiginosus	Q	Waite 1988b
Amblyseius thwaitei	NSW	Schicha 1977b
Neoseiulella cottieri	Tas	Schicha 1980
Neoseiulella nesbitti	NSW	Schicha 1975c
Neoseiulus barkeri	NSW	Wilson et al. 1998
Neoseiulus fallacis	Vic	Field 1984
Neoseiulus womersleyi	Q, NSW	Schicha 1975a; Markwell 1976; Waite 1988b; Goodwin 1990
Phytoseius fotheringhamiae	NSW	Schicha 1975b,c; Thwaite 1980
Typhlodromus baccetti	NSW	Schicha 1975c, 1977a; Bower 1984
Typhlodromus victoriensis	NSW	James 1989, 1990
ARACHNIDA		
Achaearanea veruculata	NSW	Wilson et al. 1998

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Ommatoiulus moreleti (Lucas) Diplopoda: Julidae
Portuguese millipede

In earlier papers the specific name of this millipede was incorrectly spelt *Ommatoiulus moreletii*.

PRECIS

The Portuguese millipede, *Ommatoiulus moreleti*, was first recorded in South Australia in 1953 and has since spread to all southern States and the Australian Capital Territory. It creates a nuisance by invading houses at night in very large numbers during spring and autumn.

Although attacked by a number of natural enemies in Portugal and Spain, where it is not regarded as a nuisance, there are relatively few enemies of *Ommatoiulus moreleti* in Australia. A parasitic fly, *Pelidnoptera nigripennis*, was introduced to South Australia, but did not become established. Nevertheless, in some areas where *O. moreleti* has been established for more than 20 years, populations (and nuisance value) have declined to those in similar habitats in Portugal. Shortage of suitable food and attack by a native planarian and a nematode may be involved in this decline.

BIOLOGY

The *Ommatoiulus moreleti* egg hatches into a legless pupoid, which is followed by a series of up to 16 instars. The sexes are first distinguishable in instar 6 and most individuals are mature by instar 10 or 11 when 2 years old. Two forms of adult male occur — copulatory and intercalary — which alternate in successive instars. Intercalary males are incapable of mating. Mating and oviposition occur during autumn and early winter. *O. moreleti* is most active during autumn (generally associated with the onset of rains) and to a lesser extent in spring. During summer it aestivates in a cell which it excavates a few centimetres below the soil surface (Baker 1978b, 1979a,b, 1984, 1985a).

O. moreleti is mainly nocturnal. It is common in suburban gardens and occurs both in grassland dominated by introduced broadleaf weeds and in

Eucalyptus woodlands. The food requirements of *O. moreleti* are not known. However, the gut contents consist of a variety of decomposing litter fragments, and it is thought that fungi growing on these may be the most relevant components (Baker and Baez 1989). In Portugal, identifiable gut contents indicated 6% liverworts, 22% mosses, 6% grasses and 66% detritus of woody dicotyledons. Small amounts of root material were also noted (Bailey and de Mendonca 1990).

O. moreleti is native to the Iberian peninsula from which it has spread to several Atlantic islands, South Africa and Australia. It was first recorded at Port Lincoln, South Australia in 1953 (Baker 1978a). The maximum density of instars 7 and older recorded near Port Lincoln in 1983 was 127 per m^2(Baker 1985c). It spread next to Victoria and Tasmania, was first recorded in Perth, Western Australia in 1984 and in the Australian Capital Territory in 1985 (Baker 1985c). *O. moreleti* appears to have occupied a vacant niche among the organisms breaking down detritus in Australia. There is no evidence that it has displaced native millipedes. However, in newly-invaded areas, individuals were larger and more fecund than those in older populations, so it seems to be affected by natural enemies or by depleted food reserves (Baker 1985c).

PEST STATUS

Lights attract *O. moreleti* at night (McKillup 1988) so that, when temperature and rainfall favour locomotion (usually in autumn and spring), many hundreds of millipedes invade houses each night in infested areas (Bailey 1997; Baker 1988). Near Adelaide, South Australia it was found that 20 times as many invade a house when it is lit, compared with when it is unlit. Entry is facilitated by the fact that the floors of most houses are at or near ground level and they also have large windows through which light shines at night. Garden beds with compost are suitable for millipede survival and reproduction. Estimates of density suggest that fewer than 10 individuals per m^2 of instar greater than 7 are generally tolerated, but that densities greater than 30 per m^2 cause severe annoyance. Much higher populations of 60 per m^2 (corresponding to a population of 200,000 per ha) or higher have been encountered (McKillup and Bailey 1987; Bailey 1997).

BIOLOGICAL CONTROL

Baker (1985b,c) recorded small nematodes in, and phoretic mites on, *O. moreleti* in Australia, but commented that they appeared to do no harm and that predation, at least of the larger millipedes, was insignificant. Of several natural enemies recorded in Portugal, the most promising was a sciomyzid fly, *Pelidnoptera nigripennis*, which parasitised a maximum of 32.3% *O. moreleti* of instar 8 and older in a pine woodland (Baker 1985a). This parasitoid was introduced to South Australia in 1988 (Bailey 1989) and released but it did not

become established. It was suggested that, because the millipedes at the release site were of relatively small diameter, the fly eggs were easily dislodged as the millipedes moved through the soil and litter (Bailey 1997). Further, more extensive attempts to establish it were not made, possibly because the abundance of *O. moreleti* had, by that time, declined significantly in many areas where it had previously been abundant. For example, the density of *O. moreleti* in the Adelaide Hills developed to a maximum of 60 per m^2, but later declined to below 10 per m^2 (Baker 1985c).

Baker (1978c, 1985c) and Baker and Baez (1989) suggested that changes in population density (and body size) might be explained by scarcity of suitable food, whereas McKillup et al. (1988) proposed that the changes were due to parasitisation by a native rhabditid nematode, *Rhabditis necromena*. Later, Terrace and Baker (1994) reported predation by the blue land planarian, *Caenoplana coerulea*.

C. coerulea, attains a length of up to 12 cm in moist habitats in Adelaide gardens. When 10 adult planarians with a mean length of 8 cm were each provided with three living *O. moreleti* in instars 6 to 9, they consumed on average one millipede every 3 days, with a maximum consumption by a single planarian of 2 in 24 hours. Too little is known about the ecology of *C. coerulea* to predict what influence it might be having on *O. moreleti* populations, but it is the most voracious predator so far found in Australia. *C. coerulea* will also feed in the laboratory on the native millipede *Oncocladosoma castaneum*, in addition to terrestrial isopods and earwigs, but not on earthworms, snails or slugs (Terrace and Baker 1994).

The evidence for implicating the nematode *R. necromena* in population decline comes partly from the finding that it was not present in millipede populations at Bridgewater near Adelaide, where the mean density exceeded 40 per m^2 but was present in over 80% of individuals in populations with densities below 20 per m^2. The mechanism by which *R. necromena* kills its host is not known. It is swallowed by the millipede and penetrates the gut to enter the haemocoele, carrying with it surface bacteria, some of which may be pathogenic. Unlike entomopathogenic nematodes of the genera *Steinernema* and *Heterorhabditis*, which kill their hosts by symbiotic bacteria contained in their intestine, *R. necromena* does not appear to contain any bacterial symbionts (Bailey 1997). In more recent trials it did not kill *O. moreleti* (Bailey 1997) and there was difficulty in finding it in *O. castaneum*, which was earlier recorded as a native host (McKillup et al. 1988).

MAJOR NATURAL ENEMY

Pelidnoptera nigripennis Diptera: Sciomyzidae

This is a univoltine parasitoid of *Ommatoiulus* spp. in Portugal. Females oviposit during spring and the 1st instar larva penetrates the ventral intersegmental membrane of an abdominal segment between 2 and 6. It spends the summer without moulting, kills the host during autumn when in the 3rd instar and overwinters as a pupa. It occurs in habitats with low bushes, but not in open grasslands. The maximum rate of parasitisation recorded was 32% and specificity tests on 15 species of millipedes found that only julid millipedes were successfully attacked (Baker 1985a; Bailey 1989). In Portugal, the abundance of *P. nigripennis* may be determined by pupal predators (Baker 1978b).

Except for the subfamily Phaeomyiinae, which contains the single genus *Pelidnoptera*, all sciomyzid flies whose biology is known have been recorded as predators or parasitoids of molluscs (Ferrar 1987). It is possible that the subfamily will be promoted to family rank.

Overview

In spite of the fact that no adequate evaluation has been made of the impact of introduced natural enemies on the current economic status of the majority of the target pests, an attempt is made here to stratify the perceived benefits into control levels under three categories:

- exotic species that are still (or have in the past been) major pests in Australia (Table 45 page 439);
- exotic species that are still (or have in the past been) minor pests in Australia (Table 46 page 440); and
- species that are (or may be) native to the Australian region (Table 47 page 440).

Although, in general, separation into these three categories was not difficult, allocation into three effect levels presents many problems from an objective point of view and some allocations are certainly open to challenge. Only a detailed re-evaluation of the current situation would assist in resolving the many uncertainties. Nevertheless, a broad picture does emerge and is outlined below.

In many instances the introduction and establishment of natural enemies has not been the only factor which has contributed to the lowered status of the target pest. At times, this has been due, in part at least, to the use of resistant host varieties (e.g. *Therioaphis trifolii* forma maculata), the alteration of cultural methods, or the use of more highly selective pesticides. Indeed, when all suitable methods are combined in an integrated pest management package, there is a far greater possibility that the overall effectiveness of control will be more robust and that the pest will be far less likely to outbreak, even occasionally.

One of the fathers of modern classical biological control, DeBach (1964) concluded that the success rate in biological control was closely correlated with the amount and quality of the resources invested in a project. This generalisation certainly appears to hold true for the majority of projects, but cannot be applied to a limited number of worldwide failures where there are no natural enemies available that are capable of reducing pest abundance sufficiently to avoid unacceptable economic damage.

Classical biological control does not lead to the elimination of the pest. Where successful, pest numbers have to be reduced either permanently, or for much of the time, below the level at which economic damage is sustained. Often, minor pest damage can be tolerated to a non-marketable portion of the host (a leaf, stem or root), but living infestation of the edible product (e.g. of fruit by larvae of fruit flies or of the struck sheep by blowfly maggots) is totally

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unacceptable. Another group of pests for which, in general, biological control is inappropriate is that of highly mobile species where large numbers migrate long distances from one set of breeding grounds to invade new breeding grounds, leaving behind most or all of their natural enemies. Biological control is then only effective if it is possible to so reduce populations in their initial breeding grounds that the level of emigration is negligible. Examples of pests in this category include noctuid moths of the genera *Helicoverpa* and *Hellula* and plague locusts.

In Category 1 (Table 45 page 439), dealing with exotic pests that have been (or still are) major pests, 44 species are listed. Of these, 20 and possibly 30 (or 67%) have been reduced in abundance in a major way over much of their range by introduced natural enemies. The abundance of the remaining 14 pests remains much the same as before any attempts at biological control. Most of these 14 also fit into the category of pests for which suitable natural enemies are not known worldwide, in spite of the fact that many of them have been the targets of substantial attempts at control. An outstanding exception is the sitona weevil, *Sitona discoideus*, which is well controlled in New Zealand but not in Australia, although in both countries the same natural enemies are present and parasitisation levels are high. The slightly different biology of the sitona weevil in the two countries appears to be responsible for the differences in outcome.

In category 2, exotic species that have been (or are still) minor pests (Table 46), 7 and possibly 19 (68%) of the 28 species have also suffered a valuable reduction in abundance.

In the category of species that are (or may be) native to Australia (Table 47), only 5 out of 15 species or species group (33%) have been reduced in abundance (notably the bush fly, *Musca vetustissima*). None of the native species groups (armyworms, canegrubs, fruit flies, grass grubs, grasshoppers, mosquitoes) has responded to biological control. It is in these groups that there are well over 50 species that were not directly targetted.

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Table 45. Exotic species that have been (or still are) major pests in Australia

Control level			
Highly effective		Moderately effective	Ineffective
Most regions	Over major, but not all, regions	Species no longer important pests	Pest status unchanged
Aleurodicus dispersus	*Acyrthosiphon kondoi*	*Halotydeus destructor*	*Aphis craccivora*
Aonidiella aurantii	*Acyrthosiphon pisum*	*Ips grandicollis*	*Brevicoryne brassicae*
Aonidiella orientalis	*Brontispa longissima*	*Pieris rapae*	*Ceratitis capitata*
Cavariella aegopodii	*Comstockaspis perniciosus*	**Non-target**	*Cosmopolites sordidus*
Ceroplastes destructor	*Nezara viridula*	*Aonidiella citrina*	*Cydia pomonella*
Ceroplastes rubens	*Phthorimaea operculella*		*Grapholita molesta*
Chrysomphalus aonidum	*Plutella xylostella*		*Haematobia exigua*
Coccus hesperidum			*Helicoverpa armigera*
Eriosoma lanigerum			*Hellula undalis*
Hyperomyzus lactucae			*Listroderes obliquus*
Lepidosaphes beckii			*Lucilia cuprina*
Panonychus ulmi			*Rhabdoscelus obscurus*
Phyllocnistis citrellai			*Sitona discoideus*
Planococcus citri			*Therioaphis trifolii* f. clover
Saissetia oleae			**Non-target**
Sirex noctilio			*Aphis gossypii*
Tetranychus urticae			*Myzus persicae*
Therioaphis trifolii f. maculata			
Trialeurodes vaporariorum			
Unaspis citri			

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Table 46. Exotic species that have been (or are still) minor pests in Australia

Control level			
Highly effective		Moderately effective	Ineffective
Most regions	**Over major, but not all, regions**	**Species no longer important pests**	**Pest status unchanged**
Ceroplastes ceriferus	*Diaspis bromeliae*	*Austrolecanium variolosa*	*Bruchus pisorum*
Coccus viridis		*Coccus longulus*	*Caliroa cerasi*
Parasaissetia nigra		*Edwardsiana froggatti*	*Ommatoiulus moreleti*
Parthenolacanium persicae		*Heliothrips haemorrhoidalis*	*Pseudococcus viburni*
Saissetia coffeae		*Macrosiphum rosae*	*Pyrrhalta luteola*
Toxoptera aurantii		*Metopolophium dirhodum*	*Sitotroga cerealella*
Non-target		*Pineus boerneri*	*Stomoxys calcitrans*
Coccus pseudomagnoliarum		*Pineus pini*	*Vespula germanica*
Lepidosaphes gloverii		*Pulvinaria polygonota*	*Vespula vulgaris*
		Saissetia oleae	**Non-target**
		Toxoptera citricidus	*Ceroplastes floridensis*
		Tuberculatus annulatus	*Ceroplastes sinensis*
			Pentalonia nigronervosa
			Rhopalosiphum maidis
			Rhopalosiphum padi

Table 47. Species that are (or may be) native to the Australian region

Control level			
Highly effective		Moderately effective	Ineffective
Most regions	**Over major, but not all, regions**	**Species no longer important pests**	**Pest status unchanged**
Saccharicoccus sacchari	*Musca vetustissima*	*Pseudococcus calceolariae*	armyworms
Eriococcus araucariae		*Pseudococcus longispinus*	*Bactrocera tryoni*
			canegrubs
			Cryptophlebia ombrodelta
			Helicoverpa punctigera
			mirids
			mosquitoes
			Oncopera spp.
			Phaulacridium vittatum
			Teleogryllus commodus

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