Proceedings of the X International Symposium on Biological Control of Weeds
4-14 July 1999, Montana State University, Bozeman, Montana, USA
Neal R. Spencer [ed.]. pp. 67-79 (2000)

Biological Control of Ragwort (*Senecio jacobaea* L.) in Australia

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Abstract

The history of biological control of ragwort in Australia is outlined. Five biological control species have been released in southern Australia since the 1930s but only 3 have established. The flea beetle, *Longitarsus flavicornis*, has now dispersed over all ragwort infested areas of southern Tasmania and 90% of infestations in northern Tasmania. In some localities it has reduced ragwort densities by up to 95%. *L. flavicornis* has only established in high altitude, high rainfall locations in Victoria from where it has spread very slowly and has not had a significant impact. *Longitarsus jacobaeae* has established in a few isolated locations in Tasmania and Victoria and is yet to have a significant impact. The ragwort stem and crown boring moth, *Cochylis atricapitana*, is establishing in both Victoria and Tasmania with recoveries at 35% and 67% of release sites respectively. At one Victorian site it has dispersed more than 10 sq. km and is reducing the height of flowering ragwort plants and killing smaller rosettes during autumn. Numerous attempts between 1930 and 1983 to establish Northern Hemisphere biotypes of the cinnabar moth, *Tyria jacobaeae*, have failed. Since 1995, attempts have been made to establish a New Zealand biotype that is adapted to Southern Hemisphere conditions. Although recoveries have been made from several sites there is still no evidence that it can be permanently established in Australia. The ragwort plume moth, *Platyptilia isodactyla*, is currently undergoing host specificity testing and, if specific, will be released during spring/summer 1999.

Keywords: Ragwort, *Senecio jacobaea,* biological control, *Longitarsus flavicornis, L. jacobaeae, Cochylis atricapitana, Botanophila seneciella, B. jacobaeae, Platyptilia isodactyla.*

Introduction

Ragwort, *Senecio jacobaeae* L. (Asteraceae), is a weed of major economic significance that invades disturbed high rainfall areas of Australia, North America, Canada, New Zealand, South Africa and Argentina. Ragwort has been accidentally introduced into these countries from its native regions of Europe and Western Asia (Schmidl 1972). Biological control programs are now being undertaken against ragwort in Australia (Field 1989), New Zealand (Syrett 1983), North America (McEvoy *et al*. 1991) and Canada (Harris *et al.* 1984).

Ragwort has been recognised as a serious weed in Australia since late last century when it was first proclaimed under the Victorian *Thistle Act 1890*. It is found in the Otway, Dandenong and Strzelecki ranges of southern Victoria and in high rainfall areas of south-

ern and northern Tasmania. Ragwort has detrimental effects on agricultural production but can also affect natural ecosystems. It is an extremely invasive weed which can quickly spread throughout a property, particularly dairying, beef or equine enterprises where cattle and horses selectively avoid ragwort. In disturbed areas, ragwort seed will germinate and compete with pasture plants, leading to a decline in pasture productivity (Poole and Cairns 1940). The annual cost of ragwort to Australia has been conservatively estimated at $4 million, including lost production to the dairy and beef industries and the costs of control (McLaren and Mickan 1997).

Ragwort is not a serious weed in its native environment in Europe because it is kept in check by more than sixty different insect and pathogen species. These do not occur naturally in Australia (Schroeder 1978). Biological control of ragwort in Australia has been underway since the 1930s with 6 different agents being introduced and 5 being released. This paper outlines the history of these releases and describes the progress being made in controlling this weed.

Materials and methods

To determine establishment of ragwort biocontrol agents in Victoria, 50 randomly selected ragwort plants at the release site were searched for adults, larvae or signs of attack. If attacked plants were found, checks of another 50 plants were undertaken at 50m, 100m, 200m, 300m and 1 km intervals from the release site until no attacked plants were found. Assessments were made at the times of year favourable for detection of the agents.

Studies on the impact of *C. atricapitana* on ragwort growth and survival were undertaken at an established release site at Callignee South, in the Strzelecki Ranges of Gippsland, Victoria. In 1993, *C. atricapiatana* oviposition was observed on many ragwort rosettes. Fifty of these were tagged on 18 March and their diameters were measured and compared to fifty rosettes not colonized by *C. atricapitana* in the same locality. Plant survival and growth (live rosette diameter) were measured at 4 and 6 weeks after plants were tagged. Similarly, in 1998, the heights of fifty flowering ragwort plants attacked by *C. atricapitana* were compared to the heights of fifty unattacked flowering plants.

In Tasmania, establishment assessments for *Longitarsus* spp. were based on the recovery of adults in vacuum samples using a Ryobi Scrub Hornet® vacuum machine fitted with a lawn vacuum attachment. Sampling was conducted from early January to early March, when populations of *L. flavicornis* were at or near maximum densities (Ireson *et al.* 1991). A maximum of 5 vacuum samples was used to determine the presence of *L. flavicornis* adults at any site. Approximate area of spread was determined using the Tasmap 1:100,000 series (Ireson *et al*. 2000).

L. flavicornis was considered to have "established" if the population had survived at the site for at least 2 years and was reproducing and spreading outside the area of release. *L. flavicornis* was classed as "surviving" at a site (but establishment uncertain) if it had survived and reproduced at least 1 year after release (i.e. after 1 generation), but was only located within the area of release. A third category was used for sites at which there were no adult recoveries, suggesting failure to establish (Ireson *et al*. 2000)

Results and discussion

The status and effects of natural enemies imported and released in Australia for biological control of ragwort are shown in Table 1.

Cinnabar Moth, *Tyria jacobaeae* (L.) (Lepidoptera: Arctiidae)

Biological control of ragwort in Australia began when the Council for Scientific and Industrial Research (CSIR) introduced the foliage feeding cinnabar moth, *T. jacobaeae*, into Australia. It was first released in 1930 (Currie and Fyfe 1938). Several introductions of *T. jacobaeae* were made between 1930 and 1982, none of which were successful (Bornemissza 1966; Field 1989).

In 1993, *T. jacobaeae* was imported from New Zealand into Tasmania (Ireson 1998). Progeny from this stock were used for mass rearing and annual field release in Tasmania and Victoria between 1993 and 1998. During this period over 282,000 larvae and over 2,000 (range 300-500 per site) adults were released. The mean number of larvae released per site in Tasmania was approximately 8,000 (range 1,000-42,500) (Ireson 1998).

In Victoria, the rearing and release program was largely undertaken via a network of city and regional schools. The large brightly coloured larvae of *T. jacobaeae* provided an excellent educational tool to help teach students about biological control and how it can be integrated with conventional control methods. Schools were provided with the necessary equipment to rear the insects (donations from local business and support from the Dairy Research and Development Corporation) and the technical help to enable them to successfully rear and release *T. jacobaeae.* As many the students came from farms with ragwort infestations, this program has been invaluable in getting information on ragwort control back to their communities.

In Tasmania, data from monitoring 36 release sites show an annual decline in the size of field populations and the number of sites at which the agent was recovered (Ireson 1998). By January 1999, surviving colonies were found at only 4 (44%) of the 1 year old sites and 1 (20%) of the 2 year old sites. No surviving colonies were found at 3-5 years old sites. In Victoria, recoveries have been made from 5 out of 11 sites assessed with one site surviving for 3 years.

Harris *et al*. (1971) reported that field establishment of *T. jacobaeae* in Canada followed a pattern of high mortality of laboratory reared stock during the first year after release and a stabilisation of the population for the following 2 years. A four to five fold increase in population then occurred in the fourth and later years. Syrett *et. al*. (1991) reported similar trends in New Zealand where establishment was recorded at 35% of the release sites. In Oregon (USA), Isaacson (1973) found no significant increase in either *T. jacobaeae* density or spread at any site until 5 years after the release. Similar trends are not yet apparent in Australia where *T. jacobaeae* populations are going through steady annual decline. The average size of larval populations released in Australia (8,000 or more) is considerably higher than in Canada, the USA or New Zealand (1,000 or less) where establishment has been achieved (Harris *et al*. 1975; Brown 1989; Syrett *et al*. 1991).

Numerous unsuccessful attempts at establishing *T. jacobaeae* in Victoria between 1930 and 1982 were attributed to disease, field predation and the importation of biotypes from Europe that were ill adapted to the ragwort infested areas of Victoria (Bornemissza 1966; Schmidl, 1972, 1981; Field 1989). In particular, Bornemissza (1966) believed predation by the scorpion fly, *Harpobittacus nigriceps* (Selys) was the most serious factor preventing establishment of *T. jacobaeae*. The 1993 introduction of a New Zealand biotype was thought advantageous as the population was synchronised with the southern hemisphere and *Harpobittacus* spp. were uncommon in its primary location for release (Tasmania). However, examination of other potential arthropod predators in Tasmania has

identified carabid, staphylinid and cantharid beetles, mites, spiders, isopods (slaters), ants and the European earwig, *Forficula auricularia* L. (Ireson 1998). These groups or species have been recorded attacking either eggs, larvae and/or pupae of *T. jacobaeae* in overseas studies (Wilkinson 1965; Dempster 1971,1982; Harris *et al*. 1975; Isaacson 1973; van der Meijden 1979).

In Victoria, Bornemissa (1966) recorded *T. jacobaeae* pupae being parasitised by unnamed tachinids and ichneumonids. No vertebrates have been observed attacking *T. jacobaeae* in Australia during the current program of releases and monitoring. It is likely that the combined effect of common arthropod predators and parasites may be a factor in preventing establishment of *T. jacobaeae* in Australia.

Lakhani and Dempster (1981) identified food availability as the main factor determining *T. jacobaeae* abundance. As food supply is not limiting in Australia and large release numbers were used to attempt to overcome predation, it is possible that climatic factors or plant nutritional factors are limiting establishment. Many areas infested with ragwort in Australia are prone to waterlogging during winter. Waterlogging has been shown to be detrimental to the survival of over-wintering pupae of *T. jacobaeae* (Dempster 1971).

Ragwort seed flies, *Botanophila seneciella* (Meade) and *B. jacobaeae* (Hardy) (Diptera: Anthomiidae).

The ragwort seed fly, *Botanophila seneciella*, (formally *Pegohylemia*) was first introduced into Australia in the 1930s from England and New Zealand (Delfosse and Cullen 1982) but due to disease and difficulties in rearing none were released. A further introduction, believed at the time to be *Botanophila seneciella* (referred to as *Hylemia seneciella*), was made in 1958 but was later identified from voucher specimens as *Botanophila jacobaeae* Waterhouse (Hoy 1958). These were released in both Victoria and Tasmania (Hoy 1958, 1960; Schmidl 1981; Field 1989). None of the species have established in Australia (Table 1).

Ragwort flea beetles, *Longitarsus flavicornis* (Stephens) and *L. jacobaeae* (Waterhouse) (Coleoptera: Chrysomelidae).

A species initially identified as *Longitarsus jacobaeae* was introduced to Australia

Table 1.
Natural Enemies imported and/or released in Australia for biological control of ragwort (adapted from Delfosse and Cullen 1982)

Biological Control Agent	Country of Origin	Date Imported	Date Released	Status	Effect on Plant
Tyria jacobaeae (L.)	England via New Zealand	1929-32	1930-32	NE	-
	England	1934-37	1935-38	NE	-
	England	1955, 1957	1955-62	NE	-
	Italy	1955	1955-56	NE	-
	England	1959	1956-60	NE	-
	Switzerland and Austria	1961-62	1962-64	NE	-

Biological Control Agent	Country of Origin	Date Imported	Date Released	Status	Effect on Plant
	Switzerland and Sweden via Canada	1977	1978	NE	-
	Switzerland	1978	1979	NE	-
	Ex France via U.S.A via New Zealand	1993	1993-99	SU	TE
Botanophila seneciella (Meade)	England	1934, 1936	NR	-	-
Botanophila jacobaeae Waterhouse	England via New Zealand	1933		NR	-
	England via New Zealand	1959	1959	NE	-
Longitarsus flavicornis	France	1977	1979-1999	E, A - Tas E, S - Vic	S - Tas N - Vic
(Stephens)	Spain	1984	1985-90	E, R	N
Longitarsus jacobaeae (Waterhouse)	Italy via Oregon USA via New Zealand	1988	1988-91	E, R	N to S locally
Cochylis atricapitana (Stephens)	Spain	1985	1987-98	E, A	L
Platyptilia isodactyla (Zeller)	Spain	1995	NYR	-	-

Status
NYR = Not yet released, but release expected or possible
NR = Not released
E, A = Established and abundant
E, R = Established, rare
E, S = Established, scattered and localised
NE = Not established
SU = Scattered, establishment uncertain

Effect on Plant
N = Negligible
L = Light
S = Significant
TE = Too early to judge
Tas = Tasmania
Vic = Victoria

from Annonay, France in 1977 and released in 1979. It was later identified as the taxonomically similar species, *Longitarsus flavicornis* (Field *et al*. 1988). At some localised sites in Victoria *L. flavicornis* has controlled ragwort infestations (McLaren and Micken, 1997) but to date has not established widely and has yet to impact greatly on ragwort infestations. In 1984, seven populations of *L. flavicornis* were introduced into Australia from Spanish locations thought to climatically match ragwort infested areas in Australia. Though initial recoveries were promising (Field *et al*, 1988) establishment of these new biotypes have also failed to effectively control ragwort in Victoria. In total, only 10 out of 127 *L. flavicornis* releases (most releases exceeded 1000 adult beetles) have established and these have all been in high altitude high rainfall localities of Victoria. However, bio-

logical control agents are capable of adapting quickly to new environments (Myers 1976) and in time it would be expected that *L. flavicornis* will adapt to attack ragwort in Victorian locations where it hasn't established to date.

Tasmanian studies on the biology and efficacy of the French biotype of *L. flavicornis* were carried out at two established sites (Lachlan in the south and Mayberry in the north) from 1985 to 1989 (Ireson *et al.* 1991). *L. flavicornis* was released at both sites in 1979 and by May 1989 (approximately 9 years after its release) had reduced ragwort densities by as much as 90%. High densities of the French biotype of *L. flavicornis*, and corresponding reductions in ragwort densities, have occurred over the same time scale recorded by Ireson *et al.* (1991) in all the major ragwort infested regions of the state (Ireson 1993; Ireson 1995). A successful redistribution program has accelerated population dispersal (Ireson *et al.* 2000). This has involved the field collection and transfer of almost 2 million adults to 875 new sites. About 88% of the transfers took place between 1993 and 1999 (Ireson *et al*. 2000). By February 1999, it was estimated that the French biotype of *L. flavicornis* had spread throughout all ragwort infestations in southern Tasmania and about 90% of the major infestations in northern Tasmania (Ireson *et al*. 2000).

On many dairy farms in northern Tasmanian, the impact of *L. flavicornis* is being restricted, possibly as a result of unfavourable site conditions and incompatible management practices. It is suspected that the pugging of wet ground by cattle is causing high larval mortality at some sites (Ireson *et al*. 2000) and use of boom sprayed herbicides may also be a limiting factor (Boersma 1996). Integrated management strategies are now being developed that will utilise chemical and mechanical control methods and grazing strategies that promote the survival of *L. flavicornis* (Ireson 1998).

An Italian biotype of *L. jacobaeae* was introduced and released in 1988. *L. jacobaeae* adults can aestivate in summer, and survive in localities experiencing dry summer climates (Frick and Johnson 1973). This species has successfully controlled ragwort along the Pacific northwest coast of the United States and was thought to be an appropriate species for drier, low altitude sites in Victoria where *L. flavicornis* had previously failed to establish. In Victoria *L. jacobaeae* was released at 17 and established at 3 sites between 1988 and 1990. *L. jacobaeae* has reduced ragwort density by 95% at one of these sites (McLaren and Mickan 1997) but its spread and overall impact has been minimal to date.

In Tasmania, *L. jacobaeae* was released at 26 sites between 1988 and 1990. Surveys have indicated that it has only survived at 5 sites in northern Tasmania (Ireson 1998).

Ragwort Stem and Crown Boring Moth, *Cochylis atricapitana* (Stephens) (Lepidoptera: Cochylidae).

The ragwort stem and crown boring moth, *C. atricapitana* was introduced into Australia from Salamanca, Spain in 1985 and released in Victoria in 1987 (McLaren 1992). *C. atricapitana* larvae bore into the crowns and stems of ragwort plants from spring through to autumn and may have 2 or 3 generations in a season (McLaren 1992). By 1992, *C. atricapitana* had established at only 2 of the 25 sites (8%) assessed in Victoria (McLaren 1992) but by 1999 it had established at 28 out of 129 sites (22%) (Table 2). At one site, *C. atricapitana* has spread over an area of more than 10 km^2. In Victoria, it has taken *C. atricapitana* 11 years to build up to a population size where it is now dispersing and exerting some impacts on ragwort size and growth. In 1998 (ten years after release), a comparison of the heights of attacked and unattacked flowering ragwort showed that *C. atricapitana* was stunting growth and reducing ragworts height (Figure 1). Similarly, at

Table 2.
Establishment and dispersal of *C. atricapitana* in Victoria to February 1998

Period after release (Years)	1	2	3	4	5	6-12	Total
No. sites assessed	9	30	32	6	12	39	129
Agent not recovered	7	22	22	1	7	25	84
Agent only at site	2	6	6	1	4	5	24
Agent at least 50m from site		1	2	3		2	8
Agent at least 100m from site		1	2			2	5
Agent at least 200m from site					1		1
Agent at least 300m from site				1		2	3
Agent more than 1 km from site						4	3
Sites where agent surviving*	2	8	10	5	5	15	45 (355%)
Sites where agent established**	0	1	2	5	5	15	28 (222%)

\# Does not include destroyed sites (e.geg. spraying, over grazing, fire, etc).

* Sites where *C. atricapitana* is surviving are those where it has been found within100 m of the release site 6 months to 2 years after release.

** Established sites are those where *C. atricapitana* have survived for 3 or more years or are increasing their population and have spread at least 100 m from the release site after two years.

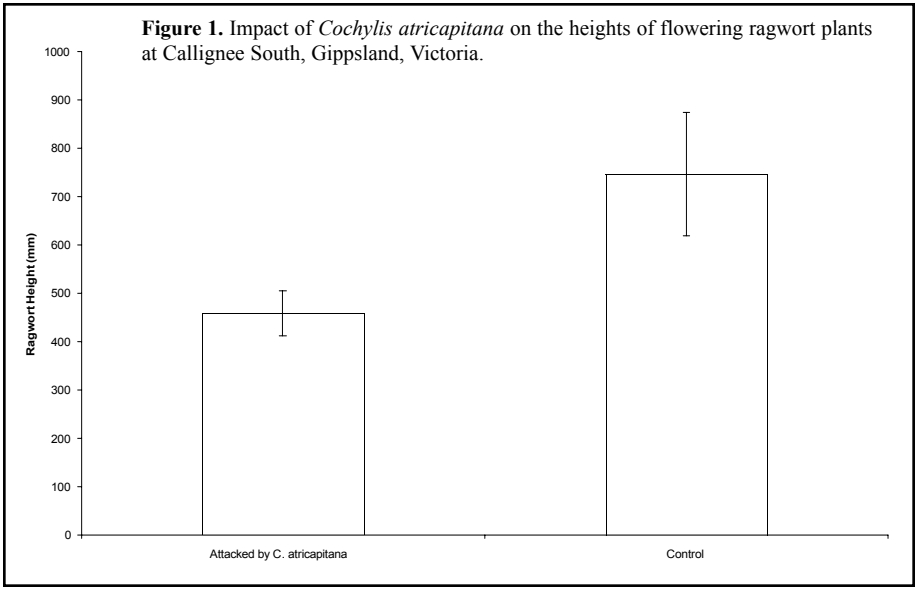

Figure 1. Impact of *Cochylis atricapitana* on the heights of flowering ragwort plants at Callignee South, Gippsland, Victoria.

Figure 2. Impact of *Cochylis atricapitana* on rosette survival and growth between 18/3/93 and 20/4/93 at Callignee South, Gippsland, Victoria.

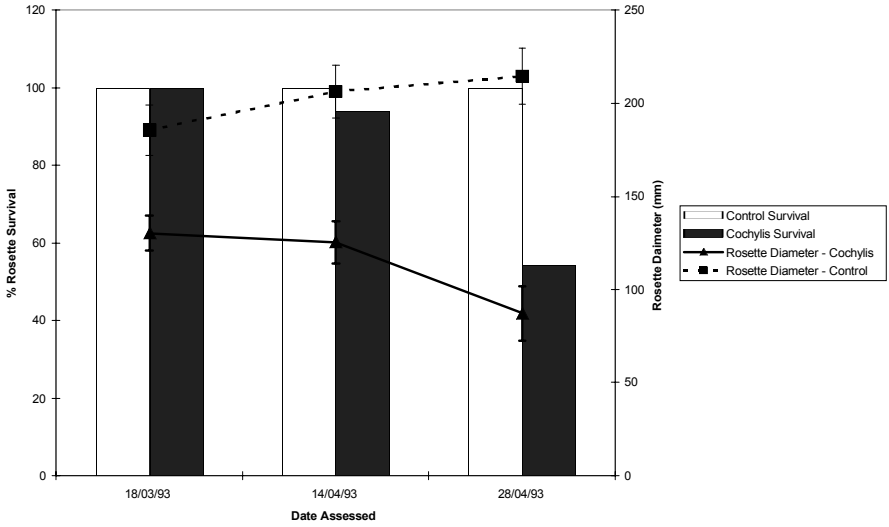

Table 3.
Establishment and dispersal of *C. atricapitana* in Tasmania to February 1999

Period after release (years)	6 months	1	2	3	Total
No. sites assessed	4	13	6	4	27
Agent not recovered	0	7	2	0	9
Agent only at site	4	3	1	1	9
Agent at least 50m from site		2	2		4
Agent at least 100m from site		1	1		2
Agent at least 200m from site				3	3
Sites where agent surviving*	4	6	4	4	18 (67%)
Sites where agent established**	0	0	1	34	45 (15%)

* Sites where *C. atricapitana* is surviving are those where it has been found within 100 m of the release site 6 months to 2 years after release. It also includes established sites.

**Established sites are those where *C. atricapitana* have survived for 3 or more years or are increasing their population and have spread at least 100 m from the release site after two years.

the same site in autumn 1993, a comparison of ragwort rosettes attacked by *C. atricapitana* to unattacked rosettes showed that larvae were killing rosettes and reducing the diameter of live rosette tissues. (Figure 2).

Parasites and predators could be affecting establishment of *C. atricapitana* at some sites in Victoria. An unidentified tachinid (Diptera) was found parasitising a larva while spiders and birds such as the grey fantail, *Rhipidura fuliginosa* (Sparrman), have been observed eating adult moths. The superb fairy wren, *Malurus cyaneus* (Latham) has been observed flying from one flowering ragwort to another, gleaning insect prey which could include *C. atricapitana.*

C. atricapitana was introduced into Tasmania in 1994. The first field release commenced in 1995 and by September 1998 the agent had been released at 27 sites (Ireson 1998). Results of establishment assessments at these sites to February 1999 show that *C. atricapitana* had established at 5 out of 27 sites assessed (15%) but is surviving (but establishment uncertain) at 67% of sites (Table 3). The maximum distance dispersed (200 m in 3 years) is greater than at sites in Victoria where the maximum recorded dispersal in 3 years has been 100 m (McLaren, 1992). This suggests that the agent has the potential to spread more rapidly in Tasmania.

The ragwort plume moth, *Platyptilia isodactyla* (Zeller) (Lepidoptera: Pterophoridae)

Platyptilia isodactyla was selected as a potential biological control agent because it caused substantial damage to ragwort plants (Vayssieres and Rahola 1985) and would only feed on a few plant species within the Tribe Senecionae (Cullen *et al.* 1985). *P. isodactyla* is currently undergoing host specificity testing at the Keith Turnbull Research Institute by the Victorian Department of Natural Resources and Environment. This agent was collected from the province of Lugo in central to northern Spain but has also been recorded in southern Spain (Gielis 1988) and the British Isles (Emmet and Heath 1989). Its most common host is marsh ragwort, *Senecio aquaticus* Hill (Emmet and Heath 1989), which is taxonomically very similar to ragwort. Marsh ragwort and ragwort will hybridize producing plants exhibiting intermediate characters and hybrids are apparently fertile (Turtin *et al*. 1976).

Adults fly in spring and autumn (Emmet and Heath 1989) and lay eggs mainly on the underside of leaves. An average of 100 eggs are laid per female which take 12 days to hatch at 20°C (Masri 1995). Larvae tunnel down into the crown of rosettes or into the stems of flowering plants where they pass through five larval instars. The larvae pupate either inside the plant, within curled ragwort leaves or in the soil surrounding the plant (Masri 1995). Larvae cause considerable damage with only two or three larvae being capable of killing a small ragwort rosette.

Host specificity testing of *P. isodactyla* suggests that this species is unlikely to complete its development on plant species outside the Tribe Senecionaeae. A total of 72 species have been tested according to the centrifugal phylogenetic protocols outlined by Wapshere (1975) with complete development occurring on 7 species. Of these, all were within the Senecionaeae tribe except for aster, *Callistephus chin*, where one adult emerged (0.5%) but was deformed and died within a few hours. In all cases survival on plant species was minimal (less than 6%) compared to ragwort (greater than 45%). Additional host specificity testing is being undertaken to confirm these observations.

Conclusion

Classical biological control using, *L. jacobaeae* (Italian biotype), *T. jacobaeae* and *B. seneciella* has been used successfully to control ragwort in western Oregon (USA) (McEvoy *et al.* 1991). Coombs *et al.* 1996 reports that this has resulted in annual savings of $5 million from reduced livestock losses, herbicide use and increased pasture production. In Tasmania, control of ragwort with *L. flavicornis* has already been achieved at many sites. The number of infestations controlled should increase rapidly now that the species has become widespread and has been recorded in high densities in all the main ragwort infested areas of the state (Ireson *et al.* 2000). It is expected that *C. atricapitana* and perhaps *P. isodactyla* (if released) will augment the impact of *L. flavicornis* in Tasmania. These species will be particularly useful if they can survive well in areas where *L. flavicornis* has failed to have a significant impact.

L. flavicornis has not been as successful in Victoria and perhaps its survival in high altitude, high rainfall locations is equivalent to a 3 to 6 degree shift south in latitude to Tasmania, where the species has performed well. Results obtained with *C. atricapitana* (Figs. 1 and 2) now look promising. At some sites, *C. atricapitana* moths are dispersing over considerable distances and a recent mass rearing program has produced 152 new releases (McLaren 1999). It is anticipated that within the next 1-2 decades, most Victorian ragwort infestations will be colonized by *C. atricapitana*.

It has been shown that the combined impact of two or more insects feeding on different plant parts and at different times of the year can have a greater impact than either insect acting alone (James *et al.* (1992); McEvoy *et al.* (1991)). It is anticipated that the combined actions of *L. flavicornis, L. jacobaeae, C. atricapitana, T. jacobaeae* and *P. isodactyla* (if released) in conjunction with changes in ragwort and grazing management, will have significant impacts on reducing ragwort infestations in Australia in the coming decade.

Acknowledgements

We are grateful to Karen Green and John Stoner (Keith Turnbull Research Institute), Richard Holloway, Wade Chatterton and Wal Ashby (Tasmanian Institute of Agricultural Research), and Sandy Leighton (Meander Valley Weed Strategy, Tasmania) for technical assistance. We also thank Ian Faithfull for reviewing the manuscript. Funding support for the program has been gratefully received from the Dairy Research and Development Corporation and the Natural Heritage Trust.

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