An Overview of Biological Control of Weeds in Tasmania

J. E. Ireson, R. J. Holloway and W. S. Chatterton

Tasmanian Institute of Agricultural Research/University of Tasmania, 13 St John's Avenue, New Town, Tasmania 7008, Australia.
John.Ireson@utas.edu.au Richard.Holloway@utas.edu.au Wade.Chatterton@utas.edu.au

Summary

Thirty-five agents have been deliberately released for the biological control of 16 weed species in Tasmania, Australia, with 31 of these released during the last twenty years. The agents include three fungal pathogens and 32 species of invertebrates of which 29 are insects and three are mites. Of these, 24 have established, seven have failed to establish and the establishment of four is still to be confirmed. Four of the seven agents that failed to establish were foliage feeders on boneseed (*Chrysanthemoides monilifera* ssp. *monilifera* (L.) T. Norl.). Only the ragwort (*Jacobaea vulgaris* Gaertn.) program has been completed, with the establishment of a root feeder and two stem and crown borers now providing substantial to complete control. The benefit:cost ratio of the ragwort program has been estimated at 32:1 through annual multimillion dollar savings in lost production to pastoral industries, with benefits expected to increase through the continuing dispersal of established agents. Work on continuing programs involves inputs into the host testing, rearing and release of additional agents, the redistribution of established agents from nursery sites and agent efficacy assessments. Completion will continue to rely heavily on long term funding from state and national governments if the potential public benefits that these and future programs offer are to be achieved.

Introduction

In 2006, the annual cost of weeds to Tasmanian pastures and field crops was conservatively estimated at *ca*. $58 million (Ireson et al., 2007). This figure consisted of approximately $49.2 million in production losses and $8.8 million in herbicide costs. Labour costs and other associated weed control activities were not included in the estimate of $857 million which was about 7% of the then gross annual value of agricultural production in Tasmania. There has been no attempt to calculate the cost of environmental weeds to Tasmania due to the lack of quantitative data, although a system for rating weed impact in Tasmanian natural ecosystems has been described (Rudman 2006).

Biological control programs in Tasmania are currently targeting 11 species of pasture weeds, and five predominantly environmental weeds including blackberry (*Rubus fruticosus* L. aggregate) which is also a significant pasture weed. The majority (89%) of the biological control agent releases have been conducted over the last two decades. Only four agents were released in Tasmania prior to 1990 with the gorse seed weevil, *Exapion ulicis* (Forster), being the first in1939. The ragwort seed fly, *Botanophila jacobaeae* (Hardy), was released 24 years later in 1963, but failed to establish. These were followed by the initial releases of two species of ragwort flea beetle, *Longitarsus flavicornis* (Stephens) and *Longitarsus jacobaeae* (Waterhouse), in 1979 and 1988 respectively. This paper lists the agents that have been deliberately released for the biological control of weeds in Tasmania and summarises the current status of each program.

Method of agent introductions

Many of Tasmania's most important pasture and environmental weeds are also problems in other parts of south-eastern mainland Australia especially Victoria and to a lesser extent South Australia and south-eastern New South Wales. Therefore, in most cases, Tasmania has been the recipient of biological control agents from programs initiated either by the Commonwealth Scientific and Industrial and Research Organisation (CSIRO) or jointly by CSIRO and State Government Departments of Primary Industries in other states, particularly Victoria. An exception was the biological control program for gorse (*Ulex europaeus* L.). Gorse, a Weed of National Significance (Thorp and Lynch, 2000) and a serious problem in Tasmania, was declared a target for biological control in 1995 by the Standing Committee of Agriculture and Resource Management after nomination by the then Tasmanian Department of Primary Industry and Fisheries (Ireson et al., 1999a). The Tasmanian Institute of Agricultural Research (TIAR) contracted Landcare Research New Zealand Ltd. to conduct host specificity tests on gorse agents established in New Zealand with funding support from the Commonwealth Government's Natural Heritage Trust. Agents were introduced to Australia through the Department of Primary Industries (DPI) Victoria, using the quarantine facility at Frankston. Agents for boneseed (*Chrysanthemoides monilifera* ssp. *monilifera* (L.) T. Norl.), English broom (*Cytisus scoparius* (L.) Link), Cape broom (*Genista mospessulana* (L.) L.A.S. Johnson) and ragwort (*Jacobaea vulgaris* Gaertn.) were also introduced to Tasmania through this quarantine facility or through collections from established mainland field sites. The agents have either been released directly into the field or used to start mass rearing cultures to provide stock for ongoing release programs. All weed biological control programs in Tasmania are now conducted through TIAR.

Results

By the end of 2011, 35 agents had been deliberately released for the control of 16 weed species. The agents include three fungal pathogens and 32 species of invertebrates of which 29 are insects and three are mites (Table 1). Of these, 24 (68.6%) have established, seven (20.0%) have failed to establish and the establishment of four (11.4%) is still to be confirmed. The guild of invertebrate agents released includes 13 foliage feeders, eight root and crown feeders, three stem and/or crown feeders, three seed feeders, two bud feeders, one branch borer and one inflorescence feeder (Table 1). Four of the seven agents that have failed to establish were foliage feeders on boneseed (Table 1). Failure of these agents to establish was attributed to high levels of predation by a complex of mainly generalist predators (Ireson et al., 2002).

Of the programs currently underway (Table 1), only the ragwort project is close to completion. The root feeding effects of the ragwort flea beetle, *Longitarsus flavicornis* (Stephens), have provided effective control at many sites around the state. In areas where the impact of this agent has been restricted by site conditions (Potter et al., 2007), there is now anecdotal evidence that the complementary effects of the ragwort stem and crown boring moth, *Cochylis atricapitana* (Stephens) and the ragwort plume moth, *Platyptilia isodactyla* (Zeller) are now resulting in effective control as they continue to spread naturally. Work being conducted on the other programs includes the host testing, rearing and release of additional agents, the widespread redistribution of established agents from localised nursery sites and assessment of agent efficacy (Table 1).

Discussion

Using the criteria of Hoffmann (1995) the biological control of ragwort can be classified as ranging from substantial to complete in many of parts of Tasmania where the weed has been a major problem. Evidence that *L. flavicornis* has been a key factor in the control of ragwort comes from long term efficacy studies, the widespread establishment of *L. flavicornis* and photographic records (Ireson et al., 1991; Ireson et al., 2007). The control achieved by *L. flavicornis* is now producing significant economic benefits (Page and Lacey, 2006); however, on some properties unfavourable site conditions and incompatible management strategies have restricted its impact. Two other agents, the ragwort stem and crown boring moth, *C. atricapitana*, and the ragwort plume moth, *P. isodactyla*, are also now well established in Tasmania. In Victoria, McLaren et al. (2000) and Morley and Bonilla (2008) showed that

these agents are capable of significantly reducing plant vigour and reproductive output. Both species have been observed causing considerable damage to crowns and stems at field sites in Tasmania (Ireson, unpubl. data) and are expected to provide significant control in areas where *L. flavicornis* impact is restricted.

Apart from ragwort, the other Tasmanian weed biological control programs vary in their stage of development and the amount of resources available for their continuation. Of the other weeds targeted, gorse, blackberry, spear thistle (*Cirsium vulgare* (Savi) Tenore), slender thistle species (*Carduus* spp.), horehound (*Marrubium vulgare* L.) and dock species (*Rumex* spp.), were all listed among the top twenty weeds either across the state or regionally following landholder surveys (Ireson et al., 2007). Agent releases have also been conducted for Paterson's curse (*Echium plantagineum* (L.)) and cotton thistle (*Onopordium acanthium* L.). Although causing problems in localised areas, these two pasture weeds are not serious problems in Tasmania compared to other states. The small, scattered infestations of these weeds in Tasmania are being contained through spray programs and, if persistent enough, could enable eradication from the localised areas in which they occur. However, as biological control is being used against these weeds in mainland states, agents have been introduced to Tasmania and selectively released at sites which have been difficult to access by conventional control methods. In the long term it is hoped that these sites can act as nursery sites from which the agents can either disperse naturally or can be collected and distributed to other sites in areas and suppress these weeds where control has been found difficult.

More work is required on the establishment and redistribution of agents for spear thistle, slender thistles, nodding thistle and cotton thistle in Tasmania. Host specific strains of the thistle receptacle weevil, *Rhinocyllus conicus* (Frolich), adapted to the life cycle of spear thistle, slender thistles and nodding thistle have been released in Victoria and New South Wales, but field surveys to determine their distribution in these states are yet to be conducted. As no previous releases have been conducted in Tasmania, transfer could be undertaken if the agents are found to be well established at any mainland release sites. The spear thistle crown weevil, *Trichosirocalus horridus* (Panzer), the nodding thistle gall fly, *Urophora solstitialis* L., and two cotton thistle agents, the crown weevil, *Trichosirocalus briesei* (Alonso-Zarazaga & Sánches-Ruiz) and the noctuid moth, *Eublemma amoena* (Hübner), have also been released at mainland sites so these agents could also be considered for transfer to Tasmania once their establishment status has been assessed. A continuing redistribution programme for the thistle crown weevil, *Trichosirocalus mortadelo* (Alonso-Zarazaga & Sánches-Ruiz) (Alonso-Zarazaga and Sánches-Ruiz 2002), on species of slender thistle is also required from the one established Tasmanian site where it was released in 1998 (Table 1).

Boneseed, English broom and Cape broom are currently the main focus of biological control programmes on environmental weeds in Tasmania. Bridal creeper (*Asparagus asparagoides* (L.) Druce) infestations are relatively small and localised in Tasmania, but the relevance of biological control will now depend on the outcome of attempted eradication programs.

Host specificity testing to enable the introduction of new agents is either underway or planned for several weed species. For instance, three folivores and one seed feeder have already been released for gorse but it is evident that an additional agent or agents will still be required to significantly reduce plant vigour (Ireson et al., 2006; Hill et al., 2008). The seed-feeding gorse pod moth, *Cydia succedana* (Denis and Schiffermüller) is widely established in New Zealand and, in combination with the gorse seed weevil, *Exapion ulicis* (Forster) has resulted in seed destruction levels as high as 92% (T.R. Partridge unpubl. data cited by Hill and Gourlay, 2002). Modelling studies (Rees and Hill, 2001) have indicated this should be high enough to reduce the recruitment of gorse below replacement levels. The gorse pod moth therefore has the potential to play a significant role in the biological control of gorse and host specificity studies are underway to determine whether the agent is safe to release in Australia. The host specificity of the broom leaf beetle, *Gonioctena olivacea* Förster, the broom shoot moth, *Agonopterix assimilella* Treitschke, on English broom (Sagliocco, 2009; Sagliocco, pers. comm.) and the boneseed rust, *Puccinia mysirphylli* G. Winter, are also currently under investigation.

Weeds that may be the target of future programs include sea spurge (*Euphorbia paralias* L.), a major environmental weed along the coast of southern

Australia and a significant problem along the Tasmanian coastline. The weed was declared a target for biological control by the Australian Weeds Committee in 2010 following nomination by CSIRO and Department of Primary Industries and Water, Tasmania (Scott et al., 2010b). Potential agents were reviewed by Scott et al. (2010a). Investigations into the biological control of serrated tussock (*Nassella trichotoma* (Nees) Arech.) (Casonato et al., 2004) may also eventually result in agents being made available for control of this weed in Tasmania.

The economic benefits of successful Australian biological control programs have been demonstrated (Page and Lacey, 2006), but as many programs may take longer than twenty years it can be difficult to justify continued funding over such a long period. Consequently, many biological control programs are often poorly resourced and not fully evaluated once the agents are released (McFadyen, 2000). Therefore, it will be important that evidence of any long-term successes are recorded in order to justify further investment in weed biological control (McFadyen, 2000; Briese et al., 2003).

In recent years, a combination of factors including new regulatory procedures, an overall decline in funding as well as the retiring of experienced practitioners or loss of experienced staff due to funding cuts has contributed either to a declining trend in the number of agents released in Australia or lack of project continuity during the last decade. In Tasmania as in other Australian states, the maintenance of weed biological control programs faces an uncertain future.

Acknowledgements

We thank Jamie Davies, Department of Primary Industries, Parks, Water and Environment and Barry Rowe, Honorary Research Associate, Tasmanian Institute of Agricultural Research, for their comments on the manuscript.

References

Alonso-Zarazaga, M.A. & Sánchez-Ruiz, M. (2002) Revision of the *Trichosirocalus horridus* (Panzer) species complex with description of two new species infesting thistles (Coleoptera: Curculionidae, Ceutorhynchinae). Australian Journal of Entomology **41**, 199–208.

Bachelor, K.L. & Woodburn, T.L. (2002) Population development and impact of the bridal creeper leafhopper *Zygina* spp. in Western Australia. In Proceedings of the 13th Australian Weeds Conference, 8–13 September 2002, Perth, Western Australia (eds Spafford Jacob, H., Dodd, J. & Moore, J.H.), pp. 381–384. Plant Protection Society of Western Australia.

Briese, D.T., Heard, T.A., McFadyen, R.E., Sheppard, A.W. & Spafford Jacob, H. (2003) The selection, testing and evaluation of weed biological control agents: Is there still room for improvement? In: Improving the selection, testing and evaluation of weed biological control agents (eds Spafford Jacob, H. & Briese, D.T.), pp. 1–3. University of Western Australia, Perth.

Burdon, J.J., Thrall, P.H., Groves, R.H. & Chaboudez, P. (2000) Biological control of *Carduus pycnocephalus* and *C. tenuiflorus* using the rust fungus *Puccinia cardui-pycnocephali*. Plant Protection Quarterly **15**, 14–17.

Casonato, S.G., Lawrie, A.C., Butler, K.L. & McLaren, D.A. (2004) Endemic fungi inhibit germination of serrated tussock seed: An alternative to classical biological control? Proceedings of the 14th Australian Weeds Conference, 62-9 September 2004, Wagga Wagga, New South Wales (eds. Sindel, B.M. & Johnson, S.B.), pp. 321–324. Weed Society of New South Wales.

Davies, J.T., Ireson, J.E. & Allen, G.R. (2007) The impact of the gorse spider mite, *Tetranychus lintearius*, on the growth and development of gorse, *Ulex europaeus*. Biological Control **41**, 86–93.

Davies, J.T., Ireson, J.E. & Allen, G.R. (2008) The phenology and impact of the gorse seed weevil, *Exapion ulicis*, on gorse, *Ulex europaeus*, in Tasmania. Biological Control **45**, 85–92.

Downey, P.O., Holtkamp, R.H., Ireson, J.E., Kwong, R.M. & Swirepik, A.E. (2007) A review of the *Chrysanthmoides monilifera* biological control program in Australia: 1987–2005. Plant Protection Quarterly **22**, 24–32.

Evans, J.W. (1942) The gorse weevil. Tasmanian Journal of Agriculture **13**, 15–18.

Henry, K., Ivory, S., Lush, A.L. & Kent, J. (2009) Importation, rearing and field release of the Cape broom psyllid, *Arytinnis hakani*. Final Report,

Land and Water Australia, Canberra, <http://lwa.gov.au/products/pn22422>, viewed 4 February 2011.

Hill, R.L. & Gourlay, A.H. (2002) Host-range testing, introduction, and establishment of *Cydia succedana* (Lepidoptera: Tortricidae) for biological control of gorse in New Zealand. Biological control **25**, 173–186.

Hill, R.L., Ireson, J., Sheppard, A.W., Gourlay, A.H., Norambuena, H., Markin, G.P., Kwong, R. & Coombes, E.M. (2008) A global view of the future for biological control of gorse, *Ulex europaeus* L. In Proceedings of the 12th International Symposium on Biological Control of Weeds, 22–27 April, La Grande Motte, France (eds Julien, M.H., Sforza, R., Bon, M.C., Evans, H.C., Hatcher, P.E., Hinz, H.L. & Rector, B.G.), pp. 680–686. CAB International Wallingford, UK.

Hoffmann, J.H. (1995) Biological control of weeds: The way forward, a South African perspective. Proceedings of the BCBP Symposium 1995, Brighton, BCPC, pp. 77–89.

Ireson, J.E., Friend, D.A., Holloway, R.J. & Paterson, S. (1991) Biology of *Longitarsus flavicornis* (Stephens) (Coleoptera: Chrysomelidae) and its effectiveness in controlling ragwort (*Senecio jacobaea* L.) in Tasmania. Journal of the Australian Entomological Society **30**, 129–141.

Ireson, J.E., Gourlay, A.H., Kwong, R.M., Holloway, R.J. & Chatterton, W.S. (1999a) Progress on the rearing, release and establishment of the gorse spider mite, *Tetranychus lintearius* Dufour, for the biological control of gorse in Australia. In Proceedings of the 12th Australian Weeds Conference, 12–16 September 1999, Hobart (eds Bishop, A.C., Boersma, M. & Barnes, C.D.), pp. 320–324. Tasmanian Weed Society, Devonport, Tasmania.

Ireson, J.E., Holloway, R.J., Chatterton, W.S. & Leighton, S.M. (1999b) An overview of the establishment, distribution and efficacy of biological control agents for ragwort, *Senecio jacobaea* L., in Tasmania. In Proceedings of the 12th Australian Weeds Conference, 12–16 September 1999, Hobart (eds. Bishop, A.C., Boersma, M. & Barnes, C.D.), pp. 425–430. Tasmanian Weed Society, Devonport, Tasmania.

Ireson, J.E., Holloway, R.J. & Chatterton, W.S. (2000a) Progress on the rearing, release and establishment of the horehound plume moth, *Wheeleria spilodactylus* (Curtis), for the biological control of horehound in Tasmania. Plant Protection Quarterly **15**, 33–35.

Ireson, J.E., Leighton, S.M., Holloway, R.J. & Chatterton, W.S. (2000b) Establishment and redistribution of *Longitarsus flavicornis* (Stephens) (Coleoptera: Chrysomelidae) for the biological control of ragwort (*Senecio jacobaea* L.) in Tasmania. Australian Journal of Entomology **39**, 42–46.

Ireson, J.E., Davies, J.T., Holloway, R.J. & Chatterton, W.S. (2002) Attempts to establish biological control agents for boneseed in Tasmania. In Proceedings of the 13th Australian Weeds Conference, 8-13 September 2002, Perth Western Australia (eds Spafford Jacob, H., Dodd, J. & Moore, J.H.), pp. 407–411. Plant Protection Society of Western Australia.

Ireson, J.E., Gourlay, A.H., Kwong, R.M., Holloway, R.J. & Chatterton, W.S. (2003) Host specificity, release and establishment of the gorse spider mite, *Tetranychus lintearius* Dufour (Acarina: Tetranychidae), for the biological control of gorse, *Ulex europaeus* L. (Fabaceae), in Australia. Biological Control **26**, 117–127.

Ireson, J.E., Davies, J.T., Kwong, R.M., Holloway, R.J. & Chatterton, W.S. (2006) Biological control of gorse, *Ulex europaeus* L. in Australia: Where to next? In Proceedings of the 1st Tasmanian Weeds Conference, 13–14 October 2005, Launceston (eds. Hanson, C. & Stewart, L.), pp. 15–19. Tasmanian Weed Society Incorporated, Devonport, Tasmania.

Ireson, J.E., Davies, J.T., Friend, D.A., Holloway, R.J., Chatterton, W.S., Van Putten, E.I. & McFadyen, R.C. (2007) Weeds of pastures and field crops in Tasmania: Economic impacts and biological control. Technical Series no. 13, CRC for Australian Weed Management, Adelaide.

Ireson, J.E., Gourlay, A.H., Holloway, R.J., Chatterton, W.S., Foster, S.D. & Kwong, R.M. (2008) Host specificity, establishment and dispersal of the gorse thrips, *Sericothrips staphylinus* Haliday (Thysanoptera: Thripidae), a biological control agent for gorse, *Ulex europaeus* L. (Fabaceae) in Australia. Biological Control **45**, 460–471.

Julien, M.H. & Griffiths, M.W. (1998) Biological Control of Weeds: a World Catalogue of Agents and their Target Weeds. Fourth edition. CABI Publishing, Wallingford, UK.

McFadyen, R.C. (2000) Successes in the biological control of weeds. In Proceedings of the X International Symposium on Biological Control of Weeds, 4–14 July1999, Bozeman (ed Spencer, N.R), pp. 3–14. Montana State University, Bozeman, USA.

McLaren, D.A. (1992) Observations on the life cycle and establishment of *Cochylis atricapitana* (Lep: Cochylidae), a moth for biological control of *Senecio jacobaea* in Australia. Entomophaga **37**, 641–648.

McLaren, D.A., Ireson, J. & Kwong, R.M. (2000). Biological control of ragwort (*Senecio jacobaea* L.) in Australia. In Proceedings of the X International Symposium on Biological Control of Weeds, 4–14 July1999, Bozeman, Montana (ed Spencer, N.R.), pp. 67–79. Montana State University, Bozeman, USA.

Meggs, J. (1995) Biotic resistance to a chrysomelid beetle (*Chrysolina* sp.) introduced to Australia for the biological control of boneseed *(Chrysanthemoides monilifera* spp. *monilifera)*. B. Sc. (Hons) Thesis, Monash University, Melbourne.

Miller, D. (1929) Control of ragwort through insects. Experimental work with cinnabar moth. New Zealand Journal of Agriculture **39**, 9–17.

Morin, L., Willis, A.J., Armstrong, J. & Kriticos, D. (2002) Spread, epidemic development and impact of the bridal creeper rust in Australia: Summary of results. In Proceedings of the 13th Australian Weeds Conference, 8–13 September 2002, Perth Western Australia (eds Spafford Jacob, H., Dodd, J. & Moore, J.H.), pp. 385–388. Plant Protection Society of Western Australia.

Morley, T. & Bonilla, J. (2008) Ragwort plume moth (*Platyptilia isodactyla*) reduces ragwort (*Senecio jacobaea*) plant vigour and makes a useful contribution to biological control of ragwort in Australia. Australia and New Zealand Biocontrol Conference Abstracts.

Page, A.R. & Lacey, K.L. (2006) Economic impact assessment of Australian weed biological control. CRC for Australian Weed Management Technical Series 10, 151 pp.

Potter, K.J.B., Ireson, J.E. and Allen, G.R. (2007). Survival of larvae of the ragwort flea beetle, *Longitarsus flavicornis* (Stephens) (Coleoptera: Chrysomelidae), in water–logged soil. Biocontrol Science & Technology **17**, 765–770.

Rees, M. & Hill, R.L. (2001) Large-scale disturbances, biological control and the dynamics of gorse populations. Journal of Applied Ecology **38**, 364–377.

Rudman, T. (2006) Ecological impact rating system for naturalised plants in Tasmania: First iteration. In Proceedings of the 1st Tasmanian Weeds Conference, 13–14 October 2005, Launceston (eds Hanson, C. & Stewart, L.), pp. 10–14. Tasmanian Weed Society Incorporated, Devonport, Tasmania.

Sagliocco, J-L. (2000) The insect fauna associated with horehound (*Marrubium vulgare* L.) in western Mediterranean Europe and Morocco: Potential for biological control in Australia. Plant Protection Quarterly **15,** 21–25.

Sagliocco, J-L. (2009) Application for the approval of a host test list for the leaf beetle *Gonioctena olivacea*, a potential biological control agent for Scotch broom, *Cytisus scoparius* subsp. *scoparius.* Department of Primary Industries Victoria, unpublished report, 17pp.

Sagliocco, J-L. & Weiss, J. (2004) Importation, establishment and preliminary impact assessment of *Chamaesphecia mysiniformis* (Lepidoptera: Sesiidae) for the biological control of horehound in Australia. In Proceedings of the 14th Australian Weeds Conference (eds Sindel, B.M. & Johnson, S.B.), pp. 388-390. Weed Society of New South Wales, Wagga Wagga.

Scott, J.K. & Sagliocco, J-L. (1991) *Chamaesphecia doryliformis* (Lep.: Sesiidae), a potential agent for the control of *Rumex* spp. (Polygonaceae) in Australia. Entomophaga **36**, 245–51.

Scott, J.K., Jourdan, M.L., Morin, L., Thomann, T. & Yeoh P.B. (2010a) Exploration for potential biological control agents of *Euphorbia paralias*, a major environmental weed of coastal ecosystems in Australia. In Proceedings of the 17th Australasian Weeds Conference, 26–30 September 2010, Christchurch, New Zealand (ed S.M. Zydenbos), pp. 223–226. New Zealand Plant Protection Society.

Scott, J.K., Rudman, T. & Gill, N. (2010b) Nomination of a target weed for biological control. Target: *Euphorbia paralias* L. CSIRO/ Department of Primary Industries & Water, Tasmania unpublished report, 25 pp.

Thorp, J.R. & Lynch, R. (2000) The Determination of Weeds of National Significance. National Weeds Strategy Executive Committee, Launceston,

Tasmania, 234 pp.
Woodburn, T.L. (1997) Establishment in Australia of *Trichosirocalus horridus* a biological control agent for *Carduus nutans* and preliminary assessment of its impact on plant growth and reproductive potential. Biocontrol Science and Technology **7,** 645–656.
Woodburn, T. & Swirepick, A. (2002) Establishment of the crown weevil *Trichosirocalus horridus* on a novel host, *Cirsium vulgare* in Western Australia. In Proceedings of the 13th Australian Weeds Conference, 8–13 September 2002, Perth, Western Australia (eds Spafford Jacob, H., Dodd, J. & Moore, J.H.), p. 430. Plant Protection Society of Western Australia.

Table 1. Status of weed biocontrol agents deliberately released in Tasmania (E = established, EU = establishment uncertain, N = not established)

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
Asparagus asparagoides (L.) Druce (Bridal creeper)	*Zygina* sp. Hemiptera: Cicadellidae) (Bridal creeper leafhopper)	Foliage, stem	1999 2000	E	Ex South Africa (Bachelor and Woodburn, 2002). Established at the only release site in northern Tasmania and on Flinders Island. As bridal creeper infestations in Tasmania are relatively small and localised, attempts have been made to eradicate them using herbicide.
	Puccinia myrsiphylli G. Winter (Uredinales: Phragmidiaceae) (Bridal creeper rust fungus)	Foliage	2000	E	Ex South Africa (Morin et al., 2002). Established after release at site in northern Tasmania and on Flinders Island where it is still surviving with *Zygina* sp. despite the abovementioned eradication program.
Chrysanthemoides monilifera ssp. *monilifera* (L.) T. Norl. (Boneseed)	*Chrysolina scotti* Daccordi (Coleoptera: Chrysomelidae) (Black boneseed beetle)	Foliage	1991-1993 1995-1996	N	Ex South Africa (Downey et al., 2007). Failed to establish after multiple releases. Biotic resistance by invertebrate predators is suspected as a key factor in preventing establishment (Meggs, 1995; Ireson et al., 2002).
	Comostolopsis germana Prout (Lepidoptera: Geometridae) (Bitou tip moth)	Foliage	1993-1995 1996-1997	N	As above.
	Chrysolina sp. B (Coleoptera: Chrysomelidae) (Painted boneseed beetle)	Foliage	1995	N	As above.

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
	Tortrix sp. (Lepidoptera: Tortricidae) (*Chrysanthemoides* leaf roller moth)	Foliage	2000-2004	N	As above.
	Aceria sp. (Acari: Eriophyidae) (Boneseed leaf buckle mite)	Foliage	2008-2011	EU	Ex South Africa. Surviving only at release point at five sites and starting to disperse from one site, up to three years after release. Establishment still uncertain.
Carduus spp. (Slender thistles, nodding thistle) *Carduus pycnocephalus* (L.) (Slender thistle), *Carduus tenuiflorus* Curtis (Winged slender thistle), *Carduus nutans* L. (Nodding thistle)	*Puccinia cardui-pynocephali* Sydow (Uredinales: Phragmidiaceae) Slender thistle rust fungus)	Foliage	1993, 1994, 1997	E	Ex France and Italy. Now widespread. Releases of two aggressive Mediterranean isolates were made in Tasmania in 1993 and again in 1994 and 1997 on *C. pycnocephalus*. *C. tenuiflorus* was also present at some release sites Tasmanian studies showed that the rust could reduce plant size and flower production (Burdon et al., 2000) but the impact of the pathogen alone was insufficient to reduce thistle densities.
	Trichosirocalus mortadelo Alonso-Zaraza-ga & Sánches-Ruiz (Coleoptera: Curculionidae) (Rosette weevil)	Root crown	1998	E	Ex Germany via Canada via New Zealand (Woodburn, 1997). Originally established at one site at Westbury in northern Tasmania on slender thistle. The site has been used as a nursery to collect and transfer adults to other sites. Agent also uses spear thistle (*Cirsium vulgare*) (present at Westbury site) as marginal host (Woodburn and Swirepick, 2002). Dispersal and impact in Tasmania has not been assessed.

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
Cirsium vulgare (Savi) Tenore (Spear thistle)	Urophora stylata (Fabricius) (Diptera: Tephrididae) (Spear thistle gall fly)	Seed head	1997 2010	E	Ex France. Not established from release in 1997, but now established at two sites following re-releases in 2010 following transfer from site in Victoria.
Cytisus scoparius (L.) Link (English broom)	*Leucoptera spartifoliella* (Hübner) (Lepidoptera: Lyonetiidae) (Broom twig mining moth)	Branches	1996 1998 2004-2008	E	Ex Europe via New Zealand. Failed to establish from releases of material imported from New South Wales in 1996 and again in 1998 at seven sites. Recovered and spreading from one site in the Tasmanian midlands in 2005 following release in 2004 of material collected from New South Wales site. Releases have been conducted at four other sites since 2004 from a shade-house culture but establishment surveys at these sites are yet to be conducted.
	Arytainilla spartiophila (Forster) (Hemiptera: Psyllidae) (Broom psyllid)	Buds, new growth	1996	EU	Ex United Kingdom via New Zealand. Released at three sites at the same time as *L. spartifoliella* (above) but not recovered. Establishment still possible from planned additional releases of field collected stock from mainland.
	Aceria genistae (Nalepa) (Acarina: Eriophyidae) (Broom gall mite)	Buds	2009-2011	E	Ex France (Sagliocco, pers. com.). Released at 37 sites. Agent has been recovered and is dispersing.

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
Genista monspessulana (L.) L.A.S. Johnson (Cape broom, Montpellier broom)	*Arytinnis hakani* (Loginova) (Hemiptera: Psyllidae) (Cape Broom Psyllid)	Foliage, stems, branches	2009-2011	E	Ex France (Henry et al., 2009). Released at 40 sites. Agent is becoming widespread and causing severe damage.
Echium plantagineum (L.) (Paterson's curse)	*Dialectica scalariella* (Zeller) (Lepidoptera: Gracillariidae) (Echium leaf miner)	Foliage	1990	N	Ex France and Portugal. Reared then released at 14 sites in Tasmania between July 1990 and April 1992 (Ireson, unpubl. data). Initially recovered and dispersed rapidly from release sites but population subsequently declined possibly due to its inability to survive cold winters.
	Mogulones larvatus (Schultz) (Coleoptera: Curculionidae) (Paterson's curse crown weevil)	Crown, petioles, foliage	2004 2007 2008	E	Ex France. Field collected adults imported from South Australia and released at three sites. Recovered and dispersing from one site.
	Mogulones geographicus (Goeze) (Coleoptera: Curculionidae) (Paterson's curse root weevil)	Taproot, petioles, foliage	2004 2006-2007 2009	E	Ex France. Field collected adults imported from South Australia and released at three sites. Recovered and dispersing from two sites.
	Longitarsus echii (Koch) (Coleoptera: Chrysomelidae) (Paterson's curse flea beetle)	Taproot, crown, foliage	2004 2008-2009	E	Ex France and Spain. Field collected adults imported from South Australia and released at six sites. Established and dispersing from two sites. Establishment assessments at other sites yet to be conducted.

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
	Meligethes planiusculus (Heer) (Coleoptera: Nitidulidae) (Paterson's curse pollen beetle)	Flower buds, pollen, ovules, immature seed	2008	EU	Ex France. Field collected adults imported from South Australia and released at three sites. Establishment assessments yet to be conducted.
Onopordum acanthium L. (Cotton thistle)	*Lixus cardui* O1ivier (Coleoptera: (Curculionidae) (Stem-boring weevil)	Stem, foliage	1997 2009	E	Ex France. Field collected stock imported from New South Wales. Release at one site in northern Tasmania in 1997 and at site in Tasmanian midlands in 2009. Agent has been recovered and is dispersing.
	Larinus latus Herbst (Coleoptera: Curculionidae) (Seedhead weevil)	Seed	1999 2009	E	Ex Greece. As for *L. cardui* (above).
Rubus fruticosus L. aggregate (Blackberry)	*Phragmidium violaceum* (Schultz) Winter (Uredinales) Phragmidiaceae) (Blackberry rust)	Foliage, buds, fruit, canes	2009	E	Ex Europe. Three different strains released at three separate sites are established and spreading. It is hoped these new strains will hybridise with existing rust populations and produce genotypes with a greater impact on the growth and vigour of blackberry than an illegally introduced strain first identified in Tasmania in 1985.

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
Rumex spp. (Dock) Common Tasmanian pasture species are: *Rumex crispus* (L.) (Curled dock) & *Rumex obtusifolius* (L.) (Broadleaf dock)	*Pyropteron doryliformis* (Ochsenheimer) (Lepidoptera: Sesiidae) (Dock moth)	Roots, root crown	1997	E	Ex Morocco (Scott and Sagliocco, 1991). Released at three sites in northern Tasmania and recovered during surveys in 2006. Although no efficacy study has been conducted, anecdotal and visual evidence indicates *P. doryliformis* has had a significant impact on *Rumex* spp.
Jacobaea vulgaris Gaertn. (Ragwort)	*Botanophila jacobaeae* (Hardy) [formerly *Pegohylemia jacobaeae* (Hardy), also referred to as *Hylemia jacobaeae* Meade and incorrectly as *Hylemia seneciella* (Meade)][3] (Diptera: Anthomyiidae) (Ragwort seed fly)	Seed	1963	N	Ex England via New Zealand.
	Longitarsus flavicornis (Stephens) (Coleoptera: Chrysomelidae) (Ragwort flea beetle)	Roots, foliage, root crown	1979-1985	E	Ex France. Now widespread. High level of control in most areas with reductions in plant densities in excess of 90% (Ireson et al., 1991; Ireson et al., 2000b).

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
			1986-1989		Ex Spain. Established at six sites but dispersal unknown due to difficulties in distinguishing field populations from the dominant French biotype (Ireson et al., 1999b). Efficacy probably similar.
	Longitarsus jacobaeae (Waterhouse) (Coleoptera: Chrysomelidae) (Ragwort flea beetle)	Roots, foliage, root crown	1988-1992	E	Ex Italy via Oregon USA via New Zealand. Established at six sites but dispersal unknown due to difficulties in distinguishing field populations from *L. flavicornis* (Ireson et al., 1999b).
	Tyria jacobaeae (L.) (Leidoptera: Arctiidae) (Cinnabar moth)	Foliage, flowers	1993-1999	N	Ex England via New Zealand (Miller, 1929). Not established probably because of high levels of predation and lack of suitable pupation sites (Ireson et al., 1999b).
	Cochylis atricapitana (Stephens) (Lepidoptera: Cochylidae) (Ragwort stem and crown boring moth)	Stem, root crown	1995-2000 2004-2005 2009-2010	E	Ex Spain (McLaren, 1992). Dispersing from 22 release sites. No Tasmanian efficacy studies conducted but surveys indicate larval feeding stunting growth of flowering plants and contributing to a decline in rosette density as in Victoria (McLaren et al., 2000).
	Platyptilia isodactyla (Zeller) (Lepidoptera: Pterophoridae) (Ragwort plume moth)	Stem, root crown	2000-2007	E	Ex Spain (McLaren et al., 2000). Dispersing from 17 release sites. Significant larval damage to plants observed. No Tasmanian efficacy studies conducted but impact on plant vigour and reproductive output probably similar to that recorded in Victoria (Morley and Bonilla, 2008).

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
Ulex europaeus L. (Gorse)	*Exapion ulicis* (Forster) (Coleoptera: Brentidae) (Gorse seed weevil)	Seed	1939	E	Ex England via New Zealand (Evans, 1942). Now widespread (Ireson et al., 2006). Destruction to mature seed ranges from 12.4-55.4% annually but is below that required to have impact on gorse (Davies et al., 2008).
	Tetranychus lintearius Dufour (Acari: Tetranychidae) (Gorse spider mite)	Foliage	1998-2001	E	Ex England, Portugal and Spain via New Zealand (Ireson et al., 1999a). Now widespread (Ireson et al., 2003). Reductions in foliage dry weight of ca. 36% over 2.5 years from the time of release have been measured (Davies et al., 2007). Surveys indicate predation by Chilean predatory mite (*Phytoseiulus persimilis*) and predatory ladybird beetles (*Stethorus* spp.) restrict impact (Ireson et al., 2003).
	Sericothrips staphylinus Haliday (Thysanoptera: Thripidae) (Gorse thrips)	Foliage	2001-2009	E	Ex England via New Zealand (Ireson et al., 2008). Now widespread throughout the state but populations have been slow to increase and no visible foliar damage has yet been recorded.
			2003-2009		Ex Portugal via Hawaii via New Zealand (Ireson et al., 2008). Now widespread. Populations now mixed with populations ex England via New Zealand.
	Agonopterix umbellana (Fabricius) (Lepidoptera: Oecophoridae) (Gorse soft shoot moth)	Foliage	2007-2010	E	Ex England via New Zealand (Ireson, unpubl. data). Dispersing from two sites and recovered from another four. Releases and monitoring are continuing.

Target weed	Agent	Part of plant affected	Year(s) released[1]	Status	Comments[2]
Marrubium vulgare L. (Horehound)	*Wheeleria spilodactylus* (Curtis) (Lepidoptera: Pterophoridae) (Horehound plume moth)	Foliage	1997-1999	E	Ex France (Sagliocco, 2000). Widespread (Ireson et al., 2000a; Ireson unpubl. data). No efficacy studies conducted in Tasmania, but severe defoliation by larvae during spring probably reducing plant vigour and seed output.
	Chamaesphecia mysiniformis (Boisduval) (Lepidoptera: Sesiidae) (Horehound clearwing moth)	Roots	2008-2011	EU	Ex France (Sagliocco and Weiss, 2004). Releases at one trial site following importation from South Australia. Releases and monitoring at site continuing.

[1]This refers not only to the year the first release of the agent was conducted but also the periods over which the agent has been released from cultures if there has been an ongoing mass rearing program. Periods over which field redistribution programs have been conducted for some agents are not included. Mass rearing and field release programs have continued in Tasmania over several years for some agents difficult to establish or slow to disperse.

[2]Agent origin as listed by Julien and Griffiths (1998) unless otherwise indicated.