these agents to the areas. The participants will thus gain a sound understanding of the principles of biological control of weeds and will learn the practical skills in managing release sites, monitoring and the collection and redistribution of agents in their area. If this process is well managed, the spread of agents will be faster than if they were left to spread naturally, allowing a greater chance to control weeds in selected and targeted areas that might otherwise not be controlled.

It is imperative that we educate our client groups that biological control agents:

- may not be the appropriate control technique in all areas infested by the weed,
- are not always successful,
- may take many years, if not decades, before they become effective,
- may not work in all climatic or geographical situations,
- will never eradicate a weed, but may reduce its population to a more manageable level or may reduce its ability to invade new areas,
- may not be effective against all species, strains or races of a weed,
- is only part of an overall management strategy. Landholders must endeavour to rehabilitate land after weed control has been carried out. If biological control is successful and landholders do not revegetate the land, then the weed controlled by biological control may be replaced by another undesirable weed species.

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Biological control of environmental weeds

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Abstract

Environmental weeds are alien plants that invade native vegetation. Of the 800 or so taxa listed as invasive in Australia, 584 are recorded from Victoria. A high proportion of taxa were deliberately introduced into Australia for ornamental, agricultural or amenity uses. While some environmental weeds are economically important in agricultural ecosystems and urban areas, most are confined to native vegetation where they can have a serious impact on biodiversity, aesthetic values and recreation activities. Taxa that have a broad ecological range, are difficult to control using conventional techniques, have long-distance dispersal capabilities, and produce high biomass levels present the most serious threat. Infestations of these species are subject to control campaigns using either hand-pulling, fire, herbicides or a combination of these, but such efforts are invariably restricted to small and accessible locations. Treatment of large areas with these techniques is either impractical or may result in unacceptable non-target damage. As a result, environmental weed infestations are often neglected or treated in a superficial manner, despite concern over their impact on conservation values.

Classical biological control techniques offers the only possibility for control for many environmental weeds. In native vegetation, target specificity, self-dispersal, persistent action and long-term cost effectiveness offer advantages over alternative control techniques. In Australia, classical biological control programs have commenced on 33 environmental weed genera, five of which were initiated for the protection of nature conservation values (*Chrysanthemoides monilifera, Cytisus scoparius, Mimosa pigra, Myrsiphyllum asparagoides, Protasparagus* spp.), while 27 were initiated primarily for the protection of agricultural ecosystems (*Acacia nilotica**, *Ageratina* spp*., *Ambrosia artemisiifolia, Baccharis halamifolia, Carduus* spp., *Cirsium vulgare, Chondrilla juncea, Cryptostegia grandiflora**, *Echium plantagineum, Emex* spp., *Eriocereus* spp., *Heliotropium europeaum, Hypericum androsaeum, H. perforatum**, *Lanatana camara**, *Marrubium vulgare**, *Onopordium acaulon, Opuntia* spp., *Parkinsonia aculeata**, *Parthenium hysterophorus, Prosopis* spp.*, *Rubus* spp.*, *Rumex* spp., *Silybum marianum, Senecio jacobaea, Sida* spp., *Ulex europaeus*) and waterways (*Eichhornia crassipes**, *Pistia stratiotes, Alternanthera philoxeroides*), but ten of these (marked *) are also serious environmental weeds.

Despite these programs, the increasing rate of decline of native vegetation caused by the invasion of environmental weeds continues to threaten the integrity and, in some instances, the existence of native plant and animal communities in Australia. If current expectations and standards of nature conservation in Australia are to be maintained, a far greater emphasis on the control of environmental weeds is required. Integrated control programs that incorporate classical biological control offer the best prospects for reducing the ecological impact of a range of environmental weeds. Selection criteria for future targets for biological control should be based on current and potential distribution, rate of spread, ecological impact, susceptibility to conventional control techniques and relationship with

disturbance. Weed taxa that are closely allied to economically important plants or indigenous plants e.g., Poaceae should not be excluded from consideration due to the high level of host specificity demonstrated by some organisms. Australian native plants that are weeds outside their natural range may also make suitable targets for biological control, particularly where substantial geographical barriers exist between their introduced and native range. The protocols for conducting such programs are not developed, but require attention before they should be undertaken.

The ultimate criteria for the successful control of environmental weeds, regardless of the techniques used, should be measured as either the level of replacement of the target infestations with other vegetation, or the level of protection provided to uninfested vegetation by a reduction in the rate of spread. Control programs that fail to reduce the fitness of weed infestations to levels below the 'critical ecological threshold' that allows natural regeneration, or significantly reduce dispersal rates cannot be regarded as successful. Where the target weed is replaced by undesirable vegetation with an equal or greater weed status, limited success may be claimed but the contribution of the control program to the protection or enhancement of biological conservation must be rated as negligible. In this respect, biological control programs for environmental weeds should be incorporated into integrated management plans that aim to manipulate post-control succession from weedy to native vegetation. Evaluation processes that record changes in vegetation composition and structure and the reproductive fitness of the target weed as well as the more traditional measures of plant density, biomass and area of distribution are required to determine success of environmental weed control programs.

Overview and use of biological control in pasture situations

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Summary

A number of successful biological control programs against pasture weeds are discussed and related to the state of the programs in Australia. Factors that affect the establishment of biological control agents and how biological control can be integrated into pasture management programs are discussed.

How successful have biological control programs been against pasture weeds?

There have been a number of examples of successful biological control of pasture weed species around the world. St. John's wort, *Hypericum perforatum* L., occupied more than 1 424 300 hectares in North America (Tisdale 1976). Biological control was started in 1946 with the introduction of two chrysomelid beetles, *Chrysolina quadrigemina* (Suffrian) and *Chrysolina hyperici* (Forster). Significant reductions were observed by 1954 and St. John's wort now occupies less than 3% of its original density over much of its former distribution in California. The beetles only feed on St. John's wort in sunny situations, so its distribution has now been largely restricted to shaded locations. Biological control programs against St. John's wort have been most successful in areas with summer droughts, where defoliated plants succumb to water stress and die. It is still a problem in localities with summer rainfall such as British Columbia in Canada, as the plant will regenerate and recover after defoliation and its seed will germinate more readily (Williams 1985).

An excellent example of biological control in Australia is the spectacular success of the moth, *Cactoblastis cactorum* (Berg), in controlling prickly pear cactus, *Opuntia stricta* Haw. Prickly pear once occupied more than 20 million hectares of pastoral and agricultural land in south west to central Queensland and was invading new country at the rate of two hectares every minute (Waterhouse 1978). Fifty one biological control agents were introduced over a 22 year period (1913–1935) of which seventeen were released and 12 established. *C. cactorum* was introduced in 1925 and had controlled most of the prickly pear infestations by 1932 (Wilson 1960).

Another pasture weed, ragwort, *Senecio jacobaea* L., has been biologically controlled in Western Oregon in North America. It has been estimated that ragwort populations have been reduced by 60–70% through the combined actions of the cinnabar moth, *Tyria jacobaeae* (L.), the ragwort flea beetle, *Longitarsus jacobaeae* (Waterhouse) and the ragwort seed fly, *Botanophila seneciella* (Meade) (Brown 1990).

Biological control of blackberry, *Rubus constrictus* Lef & M., has been successful in Chile where the rust fungus, *Phragmidium violaceum* (Shulz), has significantly reduced infestations (Oehrens and Gonzalez 1977). The rust fungus builds up its innoculum over summer and heavy rust infestations defoliates blackberry plants. This allows light to penetrate through the blackberry thicket, enabling seed from competing plant species to germinate and start growing up through the blackberry. This gradually takes nutrients and light away from the blackberry until it is displaced by other plant species.

Musk thistle, *Carduus nutans* L. has been successfully controlled by the weevil *Rhinocyllus conicus* Froel. in Virginia. The weevil has reduced musk thistle density by 95% and six years after release the weevil had spread 32 km (Kok and Surles 1975).

Biological control of pasture weeds in Victoria

Table 1 provides a summary of the current status of biological control projects against pasture weeds in Victoria.

St. John's wort has been partially controlled by biological control in Victoria, especially in agricultural areas experiencing Mediterranean conditions. The best results have occurred when farmers have improved their pasture management practices by sowing strong competing pasture and by keeping it well fertilized (Parsons 1957). It appears that the combination of stress imposed by the biological control agents and the competition from the improved pasture, displaces the weed. St. John's wort is still a serious weed in many areas of Victoria and research is currently being carried out on the host specificity of a fungus, *Colletotrichum gloeosporioides*, and introduction of a mite, *Aculus hyperici*, for its control.

There are three insect species established on ragwort in Victoria. These are the ragwort leaf and crown boring moth, *Cochylis atricapitana* (Stephens), and the ragwort flea beetles, *Longitarsus flavicornis* Ste. and *L. jacobaeae.* Thus far, the