Proc. Sixth Ann. Conf. Grassld. Soc. NSW, pp 72-81.

WEED CONTROL IN PERENNIAL PASTURES:

BIOLOGICAL CONTROL OF WEEDS - UPDATE ON FRIENDLY FUNGI, BUGS AND GRUBS

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Abstract: *Increasing environmental public concern, and political awareness and activism by rural interest groups, has resulted in tremendous growth in classical biological control in Australia in the last decade. This has caused funding bodies and politicians to re- evaluate chemical methods of pest control. However, programs are still funded retroactively rather than proactively, when biological control could have its greatest benefits. It is not practical to commercialise classical biological control agents, nor to apply them from aircraft.*

Increasing farmer-grazier support, greater public environmental awareness, and much heightened interest by local, State and Federal politicians in non-chemical pest control have resulted in a large increase in biological weed control in Australia.

Recently farmers and graziers have acted as a powerful interest group to try to influence distribution of research funds, and at the same time, influential political bodies (*eg.* the Council of Nature Conservation Ministers - CONCOM, the Australian Conservation Foundation, and the National Parks and Wildlife Service): are becoming increasingly aware of the benefits of biological control in managing weed problems.

The recent heightened environmental interest by politicians has partially resulted in increased support for non-environmentally-damaging methods of pest control, such as biological control and integrated pest management. However, it is unclear if there will be increased funds for biological control in the long term, or simply a transfer of funds from other vital areas of research, which would be counterproductive.

In this review we: (1) bring Cullen and Delfosse (1990) up-to-date; (2) concentrate on biological control programs of importance to New South Wales; and (3) comment on commercialisation of biological control. This review also supplements Delfosse and Cullen (1982), Wapshere *et al.* , (1989) and Cullen (1991).

BIOLOGICAL WEED CONTROL PROGRAMS

There are over 40 current biological control of weeds projects in Australia (Cullen and Delfosse, 1990), most of which involve only classical/inoculative biological control, where both the pest weed and its natural enemies are exotic (Wapshere *et al.*, 1989). Projects are often collaborative ventures between Federal and State groups. Australia has only one current augmentative/inundative project (see below), and no programs involving conservation of natural enemies. Programs of particular interest to New South Wales are discussed below.

ALLIGATOR WEED, *Alternanthera philoxeroides* (Martius) Grisebach (Amaranthaceae)

Successful biological control of this aquatic, mat-forming, South American weed followed successful work by the United States Department of Agriculture (USDA) (Center *et al.*, 1989; Julien, 1981b; 1987). Three agent species have been introduced into Australia for alligator weed: a flea beetle, *Agasicles hygrophila* Selman & Vogt (Coleoptera: Chrysomelidae), which has been very successful in controlling the floating mat form of the weed; a moth, *Vogtia malloi* Pastrana (Lepidoptera: Pyralidae), effective on the floating mat form, but its effects are masked by damage caused by *A. hygrophila*; and, for the terrestrial form, *Disonycha argentinesis* Jacoby (Coleoptera: Chrysomelidae). Unfortunately, the latter species failed to establish (M.Julien, pers. comm., 1990), and the terrestrial form is still a problem. The program has been terminated for now, but additional surveys in Brazil on the terrestrial form of the weed should be conducted to determine if there are potential effective natural enemies for this habitat.

ANNUAL RAGWEED, *Ambrosia artemisiifolia* L. (Asteraceae)

Natural enemies of annual ragweed have been introduced from the United States by the Queensland Department of Lands (QDL) (Julien, 1987; QDL, 1989). A leaf-feeding beetle, *Zygogramma bicolorata* (Pallister) (Coleoptera: Chrysomelidae) was introduced in 1982, and is widely established. A gall moth, *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae), has spread widely and, along with increased competition from grasses, is starting to produce heavy damage on plants. A strain of the rust fungus, *Puccinia xanthii* Schweinitz (Uredinales), is being tested by the International Institute of Biological Control in the UK. Application has been made to import a leaf-feeding caterpillar, *Tarachida candefacta* (Hubner) (Lepidoptera: Noctuidae), and a search for two gall midges, *Contarinia parthenicola* and *Asphondylia ambrosiae* (Diptera: Cecidomyiidae), has been made.

BATHURST BURR, *Xanthium spinosum* L. (Asteraceae)

This species was included, inappropriately, in investigations on Noogoora burr in North America (where it is an introduced weed). No insects have been introduced deliberately for control of the species. An accidentally-introduced seed fly, *Euaresta bullans* Wiedemann (Diptera: Tephritidae), is widely established and destroy large numbers of seeds, but has no effect on the overall distribution and abundance of the weed (Wilson, 1960). Bathurst burr is the target of an augmentative/inundative biological control program, where the aim is to develop a mycoherbicide from a damaging, indigenous pathogen, *Colletotrichum xanthii* Halst (Melanconiaceae) (Butler, 1951). Commercial production of this pathogen shows promise (Auld *et al.*, 1986; Auld *et al.*, 1990). Natural enemies for Bathurst burr may be investigated soon as part of a new CSIRO-NSW Agriculture & Fisheries (NSWAF) initiative.

BLACKBERRY, *Rubus fruticosus* L.Aggr. (Rosaceae)

The rust fungus, *Phragmidium violaceum* (Schultz) Winter (Uredinales) has been released in Victoria, and will soon be released in other states. Fifteen strains were chosen in Europe based on maximum virulence against the most important weedy taxa in Australia. A comprehensive testing program was completed in 1983 (Bruzzese and Hasan, 1986a; 1986b). A strain of rust, illegally introduced in 1984, has established and spread. This strain is not effective against the most weedy taxa and it is hoped that its pressure will not prejudice the establishment and effectiveness of the selected strains.

BONESEED AND BITOU BUSH, *Chrysanthemoides monilifera* (L) Norlindh (Asteraceae)

These southern African weeds are major conservation weeds in Australia, with *C. m. monilifera* (boneseed) generally in inland sites (Victoria, South Australia), and *C. m. rotundata* (Bitou bush), generally coastal (New South wales). In 1987, CONCOM funded a collaborative biological control project for these weeds between the Victorian Department of Conservation, Forests and Lands (VDCFL) and CSIRO. A shoot-tip boring moth, *Comostolopsis germana* (Lepidoptera: Geometridae) was the first species released, and there is now evidence of establishment at one site in northern New South Wales from releases conducted in cooperation with the QDL. *Chrysolina progressa* (Coleoptera: Chrysomelidae) also failed so establish initially (R.Adair, pers. comm., 1990). Other agent species are being considered.

COMMON HELIOTROPE, *Heliotropium europaeum* L. (Boraginaceae)

This summergrowing annual Mediterranean weed (Delfosse and Cullen, 1981a) causes $46 million damage per annum (Delfosse and Cullen, unpubl. data). The unrelible, almost ephemeral occurrence of this species from season-to-season and from paddock-to-paddock suggests that it would be a difficult target for classical biological control with arthropods. A flea beetle, *Longitarsus albineus* (Foudras) (Coleoptera: Chrysomelidae), was released on several occasions from 1979-89 (Delfosse, 1985b), but has not been recovered recently and is, at best, established at a few sites at very low levels. A leaf-attacking rust fungus, *Uromyces heliotropii* Sredinski (Uredinales) was released in summer 1990-91 in New South Wales and Western Australia (Delfosse, unpubl. data). The rust is extremely damaging to common heliotrope, causing death of the plant and massive reduction of seeding (Hasan, 1985). A foliage- and root-attacking weevil, *Pachycerus cordiger* Germar (Coleoptera: Curculionidae), attacks a wide range of Boraginaceae under cage conditions (Huber and Vayssieres, 1990), but distinguishes between different *Heliotropium* spp. in the field. An application for its release is pending. Host-specificity of two other agent species are being studied for common heliotrope: a bud-feeding moth, *Ethmia distigmatella* Erchoff (Lepidoptera: Ethmiidae); and another fungal pathogen, *Cercospora heliotropii-bocconi* Scalia (Hyphomycetes).

DOCKS AND SORREL, *Rumex* spp. (Polygonacea)

Various species of dock (*Rumex* spp.) and sorrel (*R. acetosella* L.) are weeds in several States. *R. pulcher* L. in particular is an important pasture weed in Western Australian. A WADA-CSIRO project has studied the potential for control of *Rumex* spp. Studies in Europe identified four insect species of interest, two of which in particular show considerable promise: the moths *Bembecia chrysidiformis* (Esper) and *Chamaesphaecia doryliformis* (Ochsenheimer) (Lepidoptera: Sesiidae), whose larvae bore into the perennial rootstock of mature plants, often killing them. Both species have been imported and large numbers of *C.doryliformis* were released in the 1989-90 summer, with initial indications of high survival rates. Further work will concentrate on the second species, while no further work is planned for the two other agents (*Perapion violaceum* Kirby; Coleoptera: Apionidae, and *Pegomyia nigritarsus* Zett., Diptera: Anthomyidae), until the success of the sesiids is assessed.

DOUBLE GEE/SPINY EMEX, *Emex australis* Steinhell (Polygonaceae)

Australian studies on the *Emex* spp. commenced in 1973 with introduction of a weevil, *Perapion antiquum* Gyllenhal (Coleoptera: Apionidea), larvae of which destroy stems of *Emex* spp. Establishment is limited to a few sites in eastern Australia, the major problem being the inability of the adult weevils to survive the dry summer conditions without any food supply (Julien, 1987). A weevil, *Lixus cribricollis* Boheman (Coleoptera: Curculionidae), from Morocco, whose larvae mine the root of *E. spinosa*, was also released in 1979, but did not establish (Julien, 1981b, 1987). Two more insect species were not sufficiently specific (Shepherd, 1988; 1989; 1990), detailed studies in South Africa found a seed-borne pathogen, *Phomopsis* (Sphaeropsidales), which shows considerable promise (Morris, 1984), and a joint CSIRO-WADA program commenced late last year to study this species as a potential agent. The species has been introduced to quarantine in Canberra for host-specificity testing.

GROUNDSEL BUSH, *Baccharis halimifolia* L. (Asteraceae)

Several agents have been released, but have not established (Julien, 1987; Tomley, 1989; Willson, 1979). However, *Aristotelia* sp. (Lepidoptera: Gelechiidae), *Megacyllene mellyi* (Chevrolat) (Coleoptera: Chrysomelidae), *Oidaematophorus balanotes* (Meyrick) (Lepidoptera: Pterophoridae), *Rhopalomyia californica* Felt (Diptera: Cecidomiidae), and *Trirhabda baccharidis* (Weber) (Coleoptera: Chrysomelidae) contribute to control. More recently, *Bucculatrix* sp. (Lepidoptera: Lyonetidae) and *Itame varadaria* (Walker) (Lepidoptera: Geometridae) were released, and permission was received for release of a leaf-feeding caterpillar, *Prochoerodes truxaliata* (Guenee) (Lepidoptera: Geometridae).

HARRISIA CACTUS, *Eriocereus martinii* (Labouret) Riccobono (Cactaceae)

A large number of cacti have been targets for biological control from the mid-1920s (Julien, 1987). Most work on these programs have now been terminated due to the success of the agents or acceptance of their limitations. For Harrisia cactus, the mealybug, *Hypogeococcus festerianus* (Lizer y Trelles) (Hemiptera: Pseudococcidae) has been very successful. However, there is still need to spread it to other scrub infestations in Queensland (QDL 1989). Recent releases of *Alcidion cereicola* (Coleoptera: Cerambycidae) continue (QDL 1989).

LANTANA, *Lantana camara* L. (Verbenaceae)

A large number of agents have been introduced against this species (Julien, 1987), and activity has decreased though QDL are still evaluating new species, including pathogens. Control has been sporadic, due to some agents not being established, others being heavily parasitized by native wasps, and inability of agents to attack some horticultural forms of the weed. The most effective species have been the bug, *Teleonemia scrupulosa* Stal (Hemiptera: Tingidae) and the beetles, *Uroplata giardi* Pic (Coleoptera: Chrysomelidae) and *Octotoma scabripennis* Guerin-Meneville (Coleoptera: Chrysomelidae), which certainly help supress the weed in some areas.

LESSER JACKS, *Emex spinosa* (L.) Campdera (Polygonaceae)

Perapion antiquum was released at one site where it became established, but does not control the weed (Julien, 1981b). A recent survey of lesser jack in Israel has suggested that several promising species occur there which might be effective on both *E. spinosa* and *E. australis* (J.K.Scott, pers. comm., 1990).

NODDING THISTLE, *Carduus nutans* L., AND SLENDER THISTLES, *C. pycnocephalus* L. and *C. tenuiflorus* Curtis (Asteraceae)

These were the first thistle species targeted for biological control in Australia. Nodding thistle has been extensively studied overseas, and a large number of natural enemies is known from Europe. Australian studies concentrated initially on the role of natural enemies in regulating the weed's population in Europe and on the biology of the most significant species (Shepherd *et al.*, 1989). These studies have confirmed the importance of seed supply and seed predators; and the first agent introduced was a seed-head weevil, *Rhinocyllus conicus* Froehl. (Coleoptera: Curculionidae). A seed fly, *Urophora solstitialis* (L.) (Diptera: Tephritidae) was imported into quarantine in 1990. Studies are in progress on other natural enemies of nodding thistle. A population of *R. conicus* which attacks slender thistles and variegated thistle, *Silybum marianum* (L.) Gaertn., was released in Victoria, in cooperation with the VDCFL. The effectiveness of the weevil, *Ceutorhynchus trimaculatus* (F.) (Coleoptera: Curculionidae), is being evaluated in Europe, and a search is being made for virulent strains of a rust fungus, *Puccinia cardui-pycnocephali* H. Sydow & P. Sydow (Uredinales). This pathogen is already present in Australia, but is ineffective; however, more virulent strains exist in Europe.

NOOGOORA BURR, *Xanthium strumarium* L. (Asteraceae)

This difficult species was one of the first weeds in Australia considered for biological control, starting in 1929 (Julien, 1987; Wapshere, 1974; Wilson, 1960). A North American seed fly, *Euaresta aequalis* Loew (Diptera: Trypetidera) is established, but provides no control. Two beetles, *Mecas saturnina* Le Conte (Coleoptera: Cerambycidae) and *Nupserha vexator* (Pascoe) (Coleoptera: Cerambycidae) are established, but *M. saturnina* only at one site, and neither species provides significant control. A rust fungus, *Puccinia xanthii* Schweinitz (Uredinales) was found as an accidental introduction in 1974. It can damage the weed significantly, but its effectiveness varies from season-to-season, and from region-to-region (Julien *et al.*, 1979). *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae), also introduced for control of annual ragweed and parthenium weed, is widely established and damages the weed significantly. Damage to the weed has increased significantly over the last decade, and its importance has declined in some areas, but further research is required to produce better control.

PARTHENIUM WEED, *Parthenium hysterophorus* L. (Asteraceae)

Several agent species have been introduced (Julien, 1987: McFadyen, 1985). *Bucculatrix* sp. (Lepidoptera: Lyonetiidae) and *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae) are widely established, but only *E. strenuana* causes significant damage, and additional species are being considered (QDL, 1989). Permission has recently been received for release of a rust fungus, *Puccinia abrupta* (Uredinales: Pucciniaceae)

PATERSON'S CURSE/SALVATION JANE, *Echium plantagineum* L. (Boraginaceae)

After a delay by a High court injunction of 8.5 years, the scientific program is in full progress. The legal aspects of this program will not be discussed here: details can be found in Cullen and Delfosse (1985), Delfosse (1985a), Delfosse and Cullen (1981b), Delfosse et al. (1987), and IAC (1985). This delay cost the Australian community more than $300 million in direct losses, and much more in indirect losses. Several populations of a leaf-mining moth, *Dialectica scalariella* (Zeller) (Lepidoptera: Gracillariidae), have been released. This species is widely established and is starting to affect plants. A rosette- and root-attacking weevil, *Ceutorhynchus larvatus* Schultze (Coleoptera: Curculionidae), was releasd in 1989, and is being evaluated. A second weevil, *C. geographicus* (Goeze) and a rosette- and a root-attacking flea beetle, *Longitarsus aeneus* Kutsch are being reared for release and supply to State collaborators. Several other agent species are approved (another flea beetle, *L. echii* Koch; two cell-sucking bugs, *Dictyla nassata* Puton and *D. echii* Schrank [Hemiptera: Tingidae]; and a stem-boring beetle, *Phyoecia coerulescens* Scopoli [Coleoptera: Cerambycidae]. Host-specificity of a rosette- and bud-sucking moth, *Ethmia bipunctella* Fabr. (Lepidoptera: Ethmiidae) is being investigated in Canberra, and other potential agents are being studied at the CSIRO Biological Control Unit in France including *Ethmia terminella* Fletcher whose larvae attack stem buds; two species of flower beetle, *Meligethes planiusculus* Heer. and *M. tristis* Sturn. (Coleoptera: Nitidulidae); an eriophyid mite, probably *Eriophyes echii* Can. (Acari: Eriophyidea) and other diseases and pests.

SALVINIA, *Salvinia molesta* D.S. Mitchell (Salviniaceae)

This is another floating weed from South America. Following an unsuccessful attempt at its control by CIBC (Julien, 1987), CSIRO examined the weed in its home range of Brazil, and found a new weevil species, *Cyrtobagous salviniae* Calder and Sands (Coleoptera: Curculionidae). This species has been spectacularly successful (Room *et al.*, 1981; 1985), and the agent has been moved to several south-east Asian and African countries, where the successes continue. This project has now been greatly reduced apart from a study of the situation in Kakadu national park (Northern Territory), some modelling, and overseas activities.

SCOTCH BROOM, *Cytisus scoparius* (L.) Link. (Fabaceae)

Scotch broom is another conservation weed, particularly in New South Wales, though it can also become a problem in some agricultural situations. A joint NSWAF-CSIRO program started in 1989, with a view to possible collaboration with New Zealand. It is envisaged that the Australian work will considerably extend the region surveyed in Europe for potential agents. The moth, *Leucoptera spartifoliella* Hubner (Lepidoptera: Lyonetiidae), which is already established in New Zealand, has been introduced for host-specificity testing.

SCOTCH AND RELATED THISTLES (Asteraceae)

Detailed study of the *Onopordum* species, Scotch thistle, *O. acanthium* L., Illyrian thistle, *O. illyricum* L., and stemless thistle, *O. acaulon* L., started in 1987-88. Apart from population studies on Illyrian thistle in Australia, most work on *Onopordum* spp. is in Europe where seed-attacking weevils (*Larinus cynareae* F. and *L. latus*; Coleoptera: Curculionidae), seed-attacking flies (*Tephritis postica* Loew and *Terrellia gynecochroma* Hering; Diptera: Tephritidae), a stem-boring beetle (*Lixus cardui* Olivier; Coleoptera Curculionidae), and a sap-feeding bug (*Tettigonmetra suphura* Muls.; Hemiptera: Tettigometridae) are being studied. *L. latus* has recently been imported into quarantine in Canberra for host-specificity testing.

SILVERLEAF NIGHTSHADE, *Solanum elaeagnifolium* Carvanilles (Solanaceae)

Biological control of silverleaf nightshade has been studied by entomologists from South Africa, where the weed is also a problem (Zimmermann, 1974). Lack of specificity of agents (Siebert, 1975; 1977), and poor climatic match between the presumed area of origin of the plant (Mexico) and infested regions of Australia (Wapshere, 1988) give little hope for success. A nematode, *Orrinia phyllobia* (Thorne) (Nematoda: Neotylenchidae), from Texas can be damaging (Orr *et al.*, 1975; Robinson *et al.*, 1978), but work on it in Australia has been discontinued due to lack of specifity (Field *et al.*, 1988; R.Field, pers. comm., 1990).

SKELETON WEED, *Chondrilla juncea* L. (Asteraceae)

This program involves the first use of a fungal phytopathogen, *Puccinia chondrilla* Bubak & Sydenham (Uredinales) in biological control (Cullen *et al.*, 1973; Delfosse *et al.*, 1985; Julien, 1987). There are three genetically distinct apomictic forms of skeleton weed in Australia. The introduced strain of the fungus has controlled the narrow-leaf strain for nearly 20 years, with tremendous economic returns to the wheat industry, which funded the work (Cullen, 1985; Marsden *et al.*, 1980). The other two forms of the weed are spreading into the areas formerly dominated by the narrow-leaf form, and current work centres around finding strains of the fungus in Europe which are virulent against these two forms of the weed.

SPEAR THISTLE *Cirsium vulgare* (Savi) Tenore (Asteraceae)

This thistle is being surveyed in Europe along with other thistle species, principally on behalf of Victoria, but the only introductions proposed to date are of agents already known from previous work elsewhere. A population of *Rhinicyllus conicus* adapted to spear thistle has been imported into quarantine. Application has also been made for the importation of the seed fly, *Urophora stylata* F. (Diptera: Tephritidae).

ST. JOHN'S WORT, *Hypericum perforatum* L. (Clusiaceae)

St. John's wort has been extensively studied over the last ten years with a view to improving the level of control exerted by the beetle *Chrysolina quadrigemina* (Suffrian) (Coleoptera: Chrysomelidae) imported in the 1940s (Delfosse and Cullen, 1981c). New populations of *C.quadrigemina*, and *Agrilus hyperici* (Creuz.) (Coleoptera: Buprestidae), the moths, *Anaitis efformata* Guenee. (Lepidoptera: Geometridae) and *Actinotia hyperici* Schiff (Lepidoptera: Noctuidae), and the aphid, *Aphis chloris* Koch (Hemiptera: Aphididae) were released (Briese, 1986; 1988). *A. efformata* failed to establish, largely due to predation of the larvae (Briese, 1986), and no recoveries have been made of *Actinotia hyperici*. *A. chloris* spread rapidly, and is now well- established. High populations occur on stems in summer, when *C. quadrigemina* is inactive, and the plants tend to recover. The agent with the most potential is a mite, *Aculus hyperici* (Liro) (Acari: Eriophyidae), for which a release application has been made.

VARIEGATED THISTLE, *Silybum marianum* (L.) Gaertner (Asteraceae)

Like spear thistle, detailed attention has not yet been given to this species, except for release in Victoria of a population of *Rhinocyllus conicus*, with further releases planned.

WATER HYACINTH, *Eichhornia crassipes* (Mart.) Solms-Laubach (Pontederiaceae)

Several agents have been released against this South American floating weed. The moth *Acigona infusella* (Walker) (Lepidoptera: Pyralidae) was released in 1981 (Wright, 1981), but did not become established. A second moth species, *Sameodes albiguttalis* Warren (Lepidoptera: Pyralidae) was released in 1977, and produces spotty, and sometimes severe damage (Center *et al.*, 1989). The most effective agent species is a weevil, *Neochetina eichhorniae* Warner (Coleoptera: Curculionidae) which was released in 1975 (Wright, 1981). A second weevil, *Neochetina bruchi* Hustache has recently been released.

BIOLOGICAL CONTROL OF NATIVE WOODY WEEDS

Woody weeds are major problems in the pastoral zone of inland New South Wales and Queensland. Apart from prickly acacia, they are native to Australia, have their own co- evolved natural enemies, and are not suitable targets for classical biological control. Generally, they have increased through changes in land management. The principal species involved are turpentine bush, *Eremophila sturtii* R.Br.; budda or false sandlewood, *E. mitchelli* Benth. (Myoporaceae); hop bush, *Dodonaea attenuata* A. Cunn. and *D. viscosa* Jacq. var *augustifolia* (Sapindaceae); punty bush, *Cassia nemophila* J.R.T. Vogel (Caesalpinaceae); and gidgea, *Acacia cambagei* R.T.Bak (Mimosaceae).

The only prospect for importing natural enemies for these species is where closely-related species occur overseas (*eg.*, other species of *Cassia* or *Acacia*), whose natural enemies might be capable of transferring. However, their use could be precluded if they attack closely-related beneficial species (*eg. Acacia* spp.).

Other important native weeds are relatively few, apart from some grass species (see next section), galvanised burr, *Sclerolaena birchii* (F.Muell) Domin (Chenopodiaceae), bracken fern, *Pteridium esculentum* (G. Forster) Cockayne (Dennstaedtiaceae), and *Erodium crinitum* Carolin (Geraniaceae). The same considerations with regard to biological control apply to these as to the woody weed species. The native species of bracken fern common in Australia is considered distinct from European and Californian bracken fern, but is very similar and the widespread occurrence of bracken fern around the world has prompted suggestions to transfer natural enemies from one region to another. Studies have concentrated on the possible transfer of natural enemies from the same bracken ferm species; for example, from South Africa to the United Kingdom (Lawton, 1988) or Papua New Guinea to Australia (Kirk, 1982)

BIOLOGICAL CONTROL OF GRASS WEEDS

There has never been work on classical biological control of grass weeds (Poaceae) in Australia, but their importance warrants examination. Potential for their control has recently been reviewed (Wapshere, 1990), including a consideration of classical and inundative (by mycoherbicides) control. There is potential for classical biological control of certain species which should be investigated in more detail, including *Bromus*, *Holcus*, *Echinochloa*, *Nasella*, *Cortaderia*, *Eleusine*, *Rottboellia*, and Johnsongrass, *Sorghum halepense* (L.) Pers. (Massien and Lindow, 1986; Milhollon, 1985).

The importance of grass weeds, their ambivalent status, and the problem of specificity where very closely-related to pasture, crop and native species, would all suggest that the potential for mycoherbicides should be investigated in considerably more detail; *eg.* by infection of the seeds in soil (Medd *et al.*, 1986). Repeated application of a mycoherbicide, with its associated cost, is necessary, but since its effect is limited in time and space, conflict- of- interest problems can be avoided.

FUTURE WORK IN BIOLOGICAL CONTROL OF WEEDS

Many more programs should be conducted in the future, including:

BLUE HELIOTROPE, *Heliotropium amplexicaule* Vahl. (Boraginaceae)

A collaborative project between NSWAF and CSIRO Division of Entomology has begun. NSWAF is determining the ecology and control of the weed in Australia, based at Trangie, and the CSIRO has started to investigate the weed for its natural enemies in its home range of south-central South America.

BRIDAL CREEPER, *Myrsiphyllum asparagoides* (L.) W.F.Wright (Liliaceae)

Bridal creeper is a South African species that has become an important weed of conservation areas in southern Australia. CONCOM have rated it as another important weed for biological control and a preliminary survey for potential agents commenced in 1990.

CALTROP OR PUNCTUREVINE, *Tribulus terrestris* L. (Zygophyllaceae)

A proposal from Victoria has recently resulted in approval of caltrop as a candidate for biological control. There are two weevil species known, *M. lypiriformis* (Wollaston) and *M. lareynii* (Jacquelin du Val), that have been effective in Hawaii and California (Julien, 1987). There could be problems of insufficient host-specificity in Australia because the taxonomy of *T. terrestris* in Australia is not clear, and it has been widely considered as a native species. Currently, the southern form is considered as introduced, while the norther form is still considered native. There are also other closely-related native species and concern over these or the native *T. terrestris* may preclude the release of agents.

CAPEWEED, *Arctotheca calendula* (L.) Levyns (Asteraceae)

This species has often been proposed as a possible target for biological control, but only in eastern Australia, where it is recognised as causing considerable losses (Sloane *et al.*, 1989). In Western Australia, however, although recognised as a problem, it has a more ambivalent status with many farmers considering it a valuable feed for stock, and calling it "Capefeed"! This precluded a biological control program unless there is a change in attitude. A preliminary survey of capeweed in South Africa has revealed some promising natural enemies (Scott and Way, 1990).

GORSE, *Ulex europaeus* L. (Fabaceae)

This weed was the target of a biological control program many years ago, with little reduction of its weed status (Julien, 1987; Wilson, 1960). Additional work in New Zealand may result in effective natural enemies for gorse which could be obtained at little effort or cost.

HOREHOUND, *Marrumbium vulgare* L. (Lamiaceae)

This weed was surveyed in a preliminary way in Europe by CSIRO several years ago, and several potential agents indentified. Currently, there is renewed interest in this weed due to problems it is causing in conservation areas, and a detailed program commenced this year.

ONION WEED, *Asphodelus fistulosus* (Liliaceae)

A rust fungus, *Puccinia barbeyi* (Roum.) Magn. (Uredinales), was found during preliminary surveys of this plant in Europe. The rust seems to be host-specific and quite damaging. Detailed study of *P. barbeyi* with a view to importation and release could be considered.

SOURSOB, *Oxalis pes-caprae* L. (Oxalidaceae)

Very preliminary surveys of this weed in South Africa several years ago seemed to indicate a lack of potential agents, but more recent work has shown the existence of several promising species. A more detailed project is expected to commence in the near future.

YELLOW BURR WEEDS, *Amsinckia* spp. (Boraginaceae)

There have been varying assessments of the importance of these American weeds, with some States rating them higher than others. While low in priority at present, surveys have been made of these weeds in California, and potential agents have been identified (Delfosse, unpubl. data).

MYCOHERBICIDES: AN OPTION FOR AUSTRALIA?

An area of non-classical biological control undoubtedly with tremendous potential is the use of mycoherbicides. Current research in Australia is quite limited (see Bathurst burr and the seeds of grass weeds, above). In the commercial field, size of markets will play a major role in determining targets (Wapshere, 1987).

This factor could be significant in Australia, where the market for commercial products is small by comparison with the international scene. However, increasing restrictions on herbicide use, either by environmental pressures or by an increase in the occurrence of resistance, could force further development of options that might appear uneconomic at present.

Mycoherbicides should be investigated in Australia for control of grass weeds and woody weeds. For grasses as a group, both classical biological control and control by mycoherbicides are possible options, depending on the target species; the international importance of some species could help provide sufficient economic incentive for the latter approach. Mycoherbicides are probably the only option for direct use of natural enemies on woody weeds.

COMMERCIALISATION OF BIOLOGICAL CONTROL AGENTS

Classical/inoculative biological control agents are generally self-perpetuating and self-distributing once established in a new country (Wapshere *et al.*, 1989), so there are generally no prospects for commercialisation. An exception might occur where an agent species is established and locally effective, but has poor dispersal powers, in which case, if it was sufficiently damaging, it might be worthwhile mass-rearing it for sale. However, this type of enterprise would have doubtful, and certainly relatively short-term, economic potential.

Inundative/augmentative biological control, on the other hand, offers significant prospects for commercialisation. We have already mentioned development of mycoherbicides, using native fungi as biological control agents. It has been difficult to interest Australian companies to invest in the research phase of this work, even though there have been some promising results (Charudattan *et al*,. 1986; Trujillo and Obrero, 1978; Walker and Riley, 1982). It appears that use of insects in this field is less promising, even though significant levels of native insect attack have sometimes been observed on native woody weeds. It is difficult to produce economically insect numbers in adequate quantity and at the required frequency.

There are no known prospects for aerial application of any type of weed biological control agent.

DISCUSSION AND CONCLUSIONS

It is clear from this review that there is likely to be considerable progress in a number of individual weed programs and in discrete research areas in the future. However, there are also one or two general points which have emerged while reviewing recent activity which deserve some comment.

There is a lack of knowledge of the possible effects of incompletely host-specific agents on non-target species which has led to rejection of possibly useful agents. This has been heightened by the increasing concern to protect Australia's native flora, and there is an unfounded fear that natural enemies are likely to attack other plants once released (the "cane toad syndrome"; Delfosse, 1990). As well as more and better data in this area, a better procedure is required for informed assessment of whatever information is available. The decision to allow the release of *Euclasta whalleyi* for rubber vine in the knowledge that it could damage native *Gymnanthera* spp. (Asclepiadaceae) (McFadyen and Turnour, 1987) is important, but the overall situation is unclear and liable to lead to frustration and inefficiency.

Bringing a weed under control is ultimately a matter of reducing its density and/or size, which is a function of the population processes of reproduction and survival, either of whole plants or possibly of its component modules. Whereas studies on management of insect pests, with or without biological control, automatically involve research on their population ecology, the same cannot be said for weeds. The extent to which this is seen as a valuable basis for management programs is increasing, and particularly so in biological control, but considerably more development is needed. It is to be hoped that the knowledge being gained in some biological control projects might influence the wider acceptance of this approach. For the projects on *Echium* and on *Carduus* thistles for instance, knowledge of their population ecology, both in Australia and Europe, has allowed decisions on the priority to be given to different agents and the possible effects of other management practices on their effectiveness, which in turn, will be valuable for management in the long-term.

We have already mentioned the different influences which are producing an increased demand for boilogical control. It cannot and probably never will be used in all situations, but we cannot afford not to exploit it to the maximum extent. To do that requires it to be built on a solid foundation, and to conduct proactive rather than retroactive programs.

ACKNOWLEDGEMENTS

Due to severe shortages in funding from Federal and State sources, most biological weed control projects conducted would not be possible without generous support from the RIRFs and other external sources. In particular, the Australian Wool Corporation, the Australian Meat and Livestock Research and Development Corporation, and the Australian Wheat Research Council fund this research extremely well.

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