Biological control of weeds and the dried fruits industry

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Summary

I propose that weed species of importance to the dried fruits industry can be divided into three groups. The first group contains the most important weeds to the industry: *Emex* spp. (especially three-cornered jack, *E. australis*); puncturevine or caltrop (*Tribulus terrestris*); and gentle Annie and related *Cenchrus* spp. The second group contains weeds of lesser importance to the industry, but because of their importance to other sectors of Australian agriculture and the environment, are current targets for biological control programs: skeleton weed (*Chondrilla juncea*), Bathurst burr (*Xanthium spinosum*); Noogoora burr (*X. strumarium*); thistles (*Carduus*, *Cirsium*, *Onopordum* and *Silybum* spp.); Paterson's curse (*Echium plantagineum*); common heliotrope (*Heliotropium europaeum*); St. John's wort (*Hypericum perforatum*); docks and sorrels (*Rumex* spp.); and silverleaf nightshade (*Solanum elaeagnifolium*). The third group contains a large number of weeds of occasional, sporadic or geographically-limited importance to the industry, some of which are targets for biological control programs in early stages of development.

Discussion of biological control programs provides information on the types of weeds and biological control agents currently studied by CSIRO. Also discussed briefly are aspects of foreign exploration, opportunities for co-operation between Rural Industry Research Funds, and co-operation between CSIRO and the States in implementation of the programs.

Introduction

There has been an enormous amount of recent activity in biological weed control in Australia (Cullen and Delfosse 1990) for three main reasons: increasing farmer-grazier and rural industry support; greater environmental awareness by the population as a whole; and much-heightened interest by local, State and Federal politicians in non-chemical pest control. Most of this activity has centred around classical biological control, where the target weed is from outside Australia, and effective natural enemies of the weed are imported from the weed's native range.

A major problem relating to weed management in the dried fruits industry is that the weeds affecting the industry have not been determined. Therefore, I propose three groups for weeds important to the industry: a small group of high-priority weed species in three genera (*Emex*, *Tribulus* and *Cenchrus*); a group of about 16 weed species which are important targets for biological control for other reasons; and a group of about 50 weed species which are of occasional, regional or sporadic importance, some of which are also future targets for biological control.

To place biological weed control in context, some of CSIRO's current projects are discussed briefly, including some weeds in all three categories. This is followed by recommendations on how such work could proceed to maximize the benefit to the industry and to the science of biological control.

A proposed breakdown of weeds of importance to the dried fruits industry

One of the most difficult aspects of determining target weed species for biological control for different commodity or special interest groups is obtaining specific details on which weeds are important to each group. After considerable checking, I could not find such a list for the dried fruits industry.

Therefore, I propose to divide weeds of importance to the industry into three groups (Table 1). This is obviously a starting point only, and will change as new technology, chemical and cultural practices, etc., are introduced.

Group One contains the three most important genera of weeds to the dried fruits industry:

1. *Emex* spp., especially three-cornered jack (*E. australis* Steinheil, from South Africa; also known as spiny emex or doublegee) and lesser jack (*E. spinosa* [L.] Campdera, from northern Africa and western Europe);
2. *Tribulus terrestris* L. (puncturevine, from southern Africa and Mediterranean Europe; also known as caltrop); and
3. Burr grasses (*Cenchrus* spp., from North and Central America), especially gentle Annie (*C. longispinus* [Hackel] Fernald).

Group Two contains about 16 weed species (Table 1) which are already targets for biological control because they are important environmentally, to another commodity sector, or are likely to be targets in the near future. Some of these, such as skeleton weed (*Chondrilla juncea* L.; Asteraceae) and Bathurst burr (*Xanthium spinosum* L.; Asteraceae) can have a very severe impact on the industry; the others are usually less important.

Group Three contains over 50 weed species which can occur heavily on a local, seasonal or sporadic basis. Many of these are potential targets for biological control should funding become available.

Biological Weed Control Programs of Interest to the Dried Fruits Industry

Group One Weed Species

Three-cornered jack and caltrop. Speakers at this Workshop have covered ecology, chemical control and biological control of three-cornered jack and caltrop in detail (Cooke 1990, Bruzzese 1990, Gilbey 1990, MacGregor 1990, Scott 1990a,b, Shepherd 1990, Weiss 1990), and interested readers should refer to these papers for further details on these topics.

Spiny burr grasses, *Cenchrus* spp. (Poaceae). There are ten *Cenchrus* spp. in Australia, mostly from Central or North America, but there are also two native species, and some beneficial pasture species (Auld and Medd 1987). Further complicating the situation is that the beneficial and native species can also be weedy.

In addition to invading pastures, *Cenchrus* spp. can be weedy because of the spines or burrs produced at flowering (Auld and Medd 1987). Considerable interest was expressed by the Wool Research and Development Fund (WRDF) for biological control of *Cenchrus* species, such as Mossman River grass, *C. echinatus* L. (an American bristly species), spiny burr grass or sandburr, *C. incertus* M. Curtis, and spiny burr grass or gentle Annie, *C. longispinus* (both Central American species). The WRDF funded a literature review of the genus, which revealed a considerable amount of information on distribution and control, but virtually nothing on potential biological control agent species.

Biological control of *Cenchrus* spp. would require foreign exploration in America to find natural enemies of the weeds and to study their ecology. This process would take a minimum of three years at a cost of about $100,000 p.a.

Group Two Weed Species

Skeleton weed, *Chondrilla juncea* L. (Asteraceae). The first use of a fungal phytopathogen, *Puccinia chondrillina* Bubak & Sydenham (Uredinales), in biological control was with this program (Cullen *et al.* 1973, Delfosse *et al.* 1985). Three genetically-distinct apomictic forms of skeleton weed occur in Australia. The introduced strain of the fungus is extremely host-specific (only attacking one of the forms of the weed), and stable (it is as virulent now as it was when introduced nearly 20 years ago). The program has a very high benefit:cost ratio, giving tremendous economic returns to the wheat industry via the Wheat Research Council (WRC), 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 other forms of the weed.

Other agent species have been released against skeleton weed (Julien 1987), but only the rust fungus contributes significantly to its control. Current work in Europe has characterized over 300 forms of the weed, and has defined two areas in western Turkey which have the highest level of variability and offer the best chance of obtaining additional useful strains of *P. chondrillina*. Several new strains of the fungus which are virulent against the remaining two forms of the weed have been found, but none are as virulent as the initial strain for the narrow-leaf form (J.M. Cullen, personal communication, 1990).

Bathurst burr, *Xanthium spinosum* L. (Asteraceae). This South American species was included, inappropriately, in the initial investigations on Noogoora burr in North America, where it is an introduced weed. No insects have been introduced deliberately for classical biological control of this species. However, an accidentally-introduced seed fly, *Euaresta bullans* Wiedemann (Diptera: Tephritidae) was first noted in 1918. It is widely established and destroys large numbers of seeds, but seems to have no effect on the overall distribution and abundance of the weed (Wilson 1960).

Recently, Bathurst burr has been the target of an augmentative/inundative biological control program where the aim is to develop a mycoherbicide from an indigenous pathogen, *Colletotrichum xanthii* Halsted (Melanconiaceae), known to be capable of extensively damaging the weed in the field. It was first reported by Butler (1951). Commercial production of this promising pathogen is currently being investigated (Auld *et al.* 1986). Natural enemies for Bathurst burr will also be investigated soon as part of a new CSIRO/New South Wales Department of Agriculture and Fisheries initiative, funded by the WRDF.

Noogoora burr, *Xanthium strumarium* L. (Asteraceae). This intractable species was one of the first target species for biological control in Australia, starting in 1929 (Wilson 1960, Julien 1987, Wapshere 1974). Several agent species were released, including: a seed fly species, *Euaresta aequalis* Loew (Diptera: Trypetidae) from North America in 1932 (which established, but provides no control); two beetle species, *Mecas saturnina* Le Conte (Coleoptera: Cerambycidae) from North America in 1963, and *Nupserha vexator* (Pascoe) (Coleoptera: Cerambycidae) from India in 1964 (both species established but neither provides any significant control); an accidentally-introduced rust fungus, *Puccinia xanthii* Schweinitz (Uredinales), found in 1974, before proposed work on it as an agent species was carried out (very damaging to the weed under particular conditions, but effectiveness varies from season-to-season and from region-to-region; Julien *et al.*

Table 1. Priority weeds to the dried fruits industry.

Weed species	Country of origin
Group 1 (priority weeds to the dried fruits industry for biological control)	
1. Three-cornered jacks (*Emex australis* Steinheil; Polygonaceae)	South Africa
2. Lesser jack (*E. spinosa* [L.] Campdera; Polygonaceae)	northern Africa and western Europe
3. Caltrop (*Tribulus terrestris* L.; Zygophyllaceae)	southern Africa and Mediterranean Europe
Spiny burr grasses (Asteraceae; ten weedy *Cenchrus* spp. in Australia), especially	
4. Mossman River grass (*C. echinatus* L.)	North America
5. Spiny burr grass or sandburr (*C. incertus* M. Curtis)	Central America
6. Gentle Annie (*C. longispinus* [Hackel] Fernald)	Central America
Group 2 (important weeds to the industry which are or have been targets for biological control)	
1. Skeleton weed (*Chondrilla juncea* L.; Asteraceae)	Transcaspian Central Europe
2. Bathurst burr (*Xanthium spinosum* L.; Asteraceae)	Chile
3. Noogoora burr (*X. strumarium* L.)	North America
4. Scotch and related thistles (*Onopordum* spp.; Asteraceae)	Mediterranean Europe
5. Slender and nodding thistles (*Carduus* spp.; Asteraceae)	Mediterranean Europe
6. Spear thistle (*Cirsium vulgare* [Savi] Tenore; Asteraceae)	Mediterranean Europe
7. Variegated thistle (*Silybum marianum* [L.] Gaertner; Asteraceae)	Mediterranean Europe
8. Slender and nodding thistles (*Carduus* spp.; Asteraceae)	Mediterranean Europe
9. Paterson's curse/salvation Jane (*Echium plantagineum* L.; Boraginaceae)	Mediterranean Europe
10. Common heliotrope (*Heliotropium europaeum* L.; Boraginaceae)	Mediterranean Europe to North Africa
11. St. John's wort (*Hypericum perforatum* L.; Clusiaceae)	Mediterranean Europe
12. Horehound (*Marrubium vulgare* L.; Lamiaceae)	Mediterranean Europe
13. Docks and sorrels (*Rumex* spp.; Polygonaceae)	Europe
14. Silverleaf nightshade (*Solanum elaeagnifolium* Cavanilles; Solanaceae)	Central and South America
Group 3 (important weeds to the industry which are not currently targets for biological control)	
1. African lovegrass (*Eragrostis curvula* [Schrader] Nees; Poaceae)	South Africa
2. Amaranth (*Amaranthus* spp.; Amaranthaceae)	tropical and subtropical America
3. Barley grasses (*Hordeum* spp.; Poaceae)	Europe and Asia
4. Barnyard grass (*Echinochloa crus-galli* [L.]; Beauvisage; Poaceae)	Europe and India
5. Blackberry nightshade (*Solanum nigrum* L.; Solanaceae)	Cosmopolitan
6. Burr marigold (*Bidens subalternana* DC.; Asteraceae)	America
7. Capeweed (*Arctotheca calendula* [L.] Levyns.; Asteraceae)	South Africa
8. Cobbler's pegs (*Bidens subalternana* DC.; Asteraceae)	America
9. Common evening primrose (*Oenothera stricta* Ledebour ex Link; Onagraceae)	South America
10. Couch grass (*Cynodon dactylon* [L.]; Persoon; Poaceae)	Cosmopolitan
11. Fat hen (*Chenopodium album* L.; Chenopodiaceae)	European and Asian (possibly cosmopolitan)
12. Field bindweed (*Convolvulus arvensis* L.; Convolvulaceae)	Europe
13. Fumitory (*Fumaria* spp.; Fumariaceae)	Europe
14. Johnson grass (*Sorghum halepense* [L.] Persoon; Poaceae)	Mediterranean region
15. Kikuyu (*Pennisetum clandestinum* Hochstetter ex Chiovenda; Poaceae)	Africa
16. Mallow (*Malva* spp.; Malvaceae)	Mediterranean
17. Medics (*Medicago* spp.; Fabaceae)	Mediterranean
18. Morning glory (*Ipomoea* spp.; Convolvulaceae)	tropical
19. Nutgrass (*Cyperus rotundus* L.; Poaceae)	Cosmopolitan

continued

Table 1. Priority weeds to the dried fruits industry (continued).

Weed species	Country of origin
20. Onion weed (*Asphodelus fistulosus* L.; Liliaceae)	Mediterranean Europe
21. Oxalis and sorrels (*Oxalis* spp.; Oxalidaceae)	South Africa, South America and cosmopolitan spp.
22. Paspalum (*Paspalum dilatatum* Poiret; Poaceae)	South America
23. Perennial thistle (*Cirsium arvense* [L.] Scopoli; Asteraceae)	Europe
24. Phalaris (*Phalaris aquatica* L.; Poaceae)	Mediterranean region
25. Pigeon grass (*Setaria* spp.; Poaceae)	Central and South America
26. Prickly lettuce (*Lactuca serriola* L.; Asteraceae)	Europe
27. Rhodes grass (*Chloris gayana* Kunth; Poaceae)	tropical America
28. Silverleaf nightshade (*Solanum elaeagnifolium* Cavanilles; Solanaceae)	Central and South America
29. Soursob (*Oxalis pes-caprae* L.; Oxalidaceae)	South Africa
30. Stinging nettle (*Urtica* spp.; Urticaceae)	Europe
31. Stinkweed (*Navarretia squarrosa* [Eschscholtz] Hooker & Arnott; Polemoniaceae)	North America
32. Subterranean clover (*Trifolium subterraneum* L.; Fabaceae)	Europe
33. Thistles, annual (*Carduus, Cirsium, Onopordum, Silybum* spp.; Asteraceae)	Europe
34. Thornapples (*Datura* spp.; Solanaceae)	America
35. White clover (*Trifolium repens* L.; Fabaceae)	Europe
36. Willow herb (*Epilobium billardierianum* Seringe; Onagraceae)	Australia
37. Wild oats (*Avena fatua* L.; Poaceae)	Mediterranean region
38. Wild radish (*Raphanus raphanistrum* L.; Brassicaceae)	Europe
39. Wimmera ryegrass (*Lolium rigidum* Gaudin; Poaceae)	Mediterranean region
40. Wireweed (*Polygonum aviculare* L.; Polygonaceae)	Cosmopolitan
41. Yellow burr weeds (*Amsinckia* spp.; Boraginaceae)	North and Central America
Unspecified species	
42. Annual broadleaf weeds	many countries
43. Annual grasses	many countries
44. Perennial broadleaf weeds	many countries
45. Perennial grasses	many countries

1979); and a moth, *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae) in 1984 (introduced for control of annual ragweed and parthenium weed, but which also produces considerable damage to Noogoora burr). Thus over the last 10 to 15 years, damage to the weed (particularly by *P. xanthii* in tropical and subtropical areas) has increased significantly and its importance has declined in some areas, but further biological control agent species are certainly required to produce better control.

Saffron thistle, *Carthamus lanatus* L. (Asteraceae) Detailed attention has not yet been given to saffron thistle, but work on this species is planned in the long term.

Slender and nodding thistles, *Carduus* spp. (Asteraceae). Nodding thistle, *Carduus nutans* L., and slender thistles, *C. pycnocephalus* L. and *C. tenuiflorus* Curtis, were the first thistle species examined in detail, commencing in 1986.

Nodding thistle has been successfully controlled with natural enemies in other parts of the world, so 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 (Sheppard *et al.* 1989). So far two agent species have been introduced to Australia: three populations of a seed-head weevil, *Rhinocyllus conicus* Froehlich (Coleoptera: Curculionidae), released in 1988-89 at sites on the southern and northern Tablelands of New South Wales; and a seed fly, *Urophora solstitialis* (L.) (Diptera: Tephritidae), which was imported into quarantine in 1990 for host-specificity testing. Studies are in progress on other natural enemies of nodding thistle.

A population of *R. conicus* which attacks the slender thistles and variegated thistle, *Silybum marianum* (L.) Gaertner, has been introduced and release in Victoria, in cooperation with the Victorian Department of Conservation and Environment (VDC&E). A weevil, *Ceutorhynchus trimaculatus* (F.) (Coleoptera: Curculionidae), is being evaluated in Europe, and a search is being made for virulent strains of a rust fungus which is already present in Australia, *Puccinia carduipycnocephali* H. Sydow & P. Sydow (Uredinales).

Variegated thistle. So far, the only agent species to be released for variegated thistle is the type of *R. conicus* which also attacks slender thistle, as mentioned above. Detailed attention has not yet been given to this species, but work is planned in the long term.

Spear thistle, *Cirsium vulgare* (Savi) Tenore. Surveys for potential biological control agents are underway on this species in Europe, along with surveys on other thistle species. A population of *R. conicus* for spear thistle has been imported into quarantine from southwest France, and application has been made for importation of a seed fly, *Urophora stylata* (F.) (Diptera: Tephritidae).

Scotch and related thistles, *Onopordum* spp. (Astraceae). Detailed study of Scotch thistle, *Onopordum acanthium* L., Illyrian thistle, *O. illyricum* L., and stemless thistle, *O. acaulon* L., started in 1987-88. In progress are population studies on Illyrian thistle in Australia, and assessment of several natural enemies in Europe. These include: seed-attacking weevils, *Larinus cynareae* F. and *L. latus* (Coleoptera: Curculionidae) (the latter species is now in quarantine in Australia for host-specificity testing), seed-attacking flies, *Tephritis postica* Loew and *Terellia gynecochroma* Hering (Diptera: Tephritidae); a stem-boring beetle, *Lixus cardui* Olivier (Coleoptera: Curculionidae); and a sap-feeding bug, *Tettigometra suphura* Mulsant (Hemiptera: Tettigometridae).

Paterson's curse and related *Echium* spp. (Boraginaceae). Biological control of *Echium* spp. was delayed from 10 July 1980 to 17 November 1988 by a High Court injunction granted on behalf of two beekeepers and two graziers. Because of this conflict-of-interest, it is probably the best known current CSIRO project. This delay cost the Australian community more than $300 million in direct losses, and much more in indirect losses. Specific legal aspects of this program have been documented (Cullen and Delfosse 1985, Delfosse 1985a, Delfosse and Cullen 1981b) and will not be discussed here.

The first agent species to be imported against Paterson's curse since the legal conflict was resolved is a leaf-mining moth, *Dialectica scalariella* (Zeller) (Lepidoptera: Gracillariidae) (Cullen and Delfosse 1990). This species was released in mid-1980, but did not establish due to a combination of low numbers and premature removal of the host plant that season due to drought and grasshopper plagues (Delfosse *et al.* 1987). As a result of large releases by the States in this cooperative program, *D. scalariella* is widely established, spreading rapidly, and extremely large numbers have been recorded in some areas. The critical point will be the population level it eventually attains and is able to maintain, particularly if attacked by native parasites.

There are at least twenty agent species available for *Echium*. Some of the higher-rated approved species are: two rosette- and root-attacking weevils, *Ceutorhynchus larvatus* Schultze and *C. geographicus* (Goeze) (Coleoptera: Curculionidae); two rosette- and root-attacking flea beetles, *Longitarsus echii* Koch and *L. aeneus* Kutsch (Coleoptera: Chrysomelidae); two cell-sucking bugs, *Dictyla nassata* Puton and *D. echii* Schrank (Hemiptera: Tingidae); and a stem-boring beetle, *Phytoecia coerulescens* (Scopoli) (Coleoptera: Cerambycidae).

Small numbers of *C. larvatus* were released at one site in mid-1989. A current delay is the lack of an efficient rearing system for this difficult species, but further releases are expected in 1990-91. *L. aeneus* is also being reared under quarantine conditions. Other species to be tested include: a rosette- and bud-attacking moth, *Ethmia bipunctella* F. (Lepidoptera: Ethmiidae); *Ethmia terminella* Fletcher, whose larvae attack stem buds; two species of flower beetles, *Meligethes planiusculus* Heer. and *M. tristis* Sturn. (Coleoptera: Nitidulidae); an eriophyid mite, probably *Eriophyes echii* Canestrini (Acari: Eriophyidae), and several pathogens.

With the wide interest in this program, there is extensive collaboration between CSIRO and all State Departments, and an intensive cooperative program of release, monitoring and evaluation is underway. European studies on the ecology of the plant and its natural enemies are on-going.

Common heliotrope, *Heliotropium europaeum* L. (Boraginaceae). This summer-growing, annual Mediterranean weed (Delfosse and Cullen 1981a) causes damage in excess of $46 million p.a. (Delfosse and Cullen, unpubl. data). The unreliable, 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 species, *Longitarsus albineus* (Foudras) (Coleoptera: Chrysomelidae), was released several times from 1979 to 1989. Though recoveries have been made at eastern sites, results have been disappointing. Further European and Australian ecological studies of soil type, fertility and plant growth are underway to try to explain the insect's unexpected poor performance (Delfosse 1985b).

Two more common heliotrope agents being prepared for release are a leaf-attacking rust fungus, *Uromyces heliotropii* Sredinski (Uredinales) and a foliage- and root-attacking weevil, *Pachycerus cordiger* Germar (Coleoptera: Curculionidae). The rust is extremely damaging to common heliotrope in Europe, causing death of the plant and massive reduction of seeding (Hasan 1985). A proposal for release has been made. Adults of *P. cordiger* feed on common heliotrope foliage, and larvae feed on roots. It attacks a wide range of Boraginaceae under cage conditions (Huber and Vayssieres 1990), but is more restricted in the field; testing of Australian native Boraginaceae under field conditions in Europe, the first time this was done in an Australian program, resulted in a decision to apply for its release for summer 1990-91.

Two other potential agent species are being studied: a bud-feeding moth, *Ethmia distignatella* Erschoff (Lepidoptera: Ethmiidae), for which host-specificity tests will begin in quarantine in Australia as soon as a colony can be established: and another fungal pathogen, *Cercospora heliotropii-bocconi* Scalia (Hyphomycetes), for which tests have begun at the CSIRO Biological Control Unit in Montpellier, France.

Since 1979 there has been extensive collaboration between CSIRO and relevant State Departments on this program. In particular, in 1988 a cooperative program of release, monitoring and evaluation of agents with CSIRO and the Western Australian Department of Agriculture (WADA) was started.

St. John's wort, *Hypericum perforatum* L. (Clusiaceae). The current program aims to improve the level of control exerted by the beetle *Chrysolina quadrigemina* (Suffrian) (Coleoptera: Chrysomelidae) imported in the 1940s (Delfosse and Cullen 1981c). Recent releases include: new populations of *C. quadrigemina*; a foliage-feeding moth species, *Anaitis efformata* Guenèe (Lepidoptera: Geometridae), which failed to establish largely due to ant predation of larvae; another moth, *Actinotia hyperici* Schiff. (Lepidoptera: Noctuidae), which has not been recovered in the field; an aphid, *Aphis chloris* Koch (Hemiptera: Aphididae), which is well-established and spreading; and a new population of *Agrilus hyperici* (Creuzer) (Coleoptera: Buprestidae), which is being evaluated (Briese 1986, 1989). The most promising agent species is currently in quarantine in Canberra. It is a mite, *Aculus hyperici* (Liro)(Acari:Eriophyidae), which we hope to release this year.

Horehound, *Marrubium vulgare* L. (Lamiaceae). A preliminary survey for natural enemies of horehound was conducted in Europe by CSIRO several years ago, and several potential agents were identified. Currently, there is renewed interest in this weed due to problems it is causing in conservation areas, and a detailed program will commence later this year as a cooperative program between CSIRO and the VDC&E.

Docks and sorrel, *Rumex* spp. (Polygonaceae). Several dock species (*Rumex* spp.) plus sorrel (*R. acetosella* L.) are weeds in several States, particularly *R. pulcher* L. in Western Australia. A WADA-CSIRO project has identified two highly-promising moth species in Europe: *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 summer 1989-90, with initial indications of high survival rates. Further work will concentrate on the second species, followed, if necessary, by two other potential agent species, *Perapion violaceum* Kirby (Coleoptera: Apionidae) and *Pegomyia nigritarsus* Zett. (Diptera: Anthomyidae).

Silverleaf nightshade, *Solanum elaeagnifolium* Cavanilles (Solanaceae). Biological control of silverleaf nightshade has been required for a number of years. Studies have been made in Australia, the USA and South Africa (Field *et al.* 1988, Orr *et al.* 1975, Robinson *et al.* 1978, Zimmermann 1974). Apart from problems of lack of specificity of several possible agents (Siebert 1975, 1977), there was little prospect of success, mainly because most natural enemies of silverleaf nightshade are adapted to the presumed area of origin of the plant in north-eastern Mexico, and are climatically unsuited to the regions of Australia infested by the weed (Wapshere 1988).

The potential agent species with the highest priority is a nematode, *Orrinia phyllobia* (Thorne) (Nematoda: Neotylenchidae), which has been the subject of detailed study in a joint project of the Victorian Departments of Agriculture and Rural Affairs, and Conservation and Environment. The nematode forms galls on silverleaf nightshade, which weaken and can gradually kill the plant. Studies of its host-specificity have demonstrated that under certain conditions, galls can be formed on egg plant, *Solanum melongena* L., and on some native species of *Solanum*. The risk that this poses is currently being evaluated (R. Field, pers. comm., 1990).

Group Three Weed Species: Future Biological Control Programs of Potential Interest to the Dried Fruits Industry

Most problem weeds in Australia have been proposed as targets for biological control, but only a proportion have so far been tackled. A few important species have not yet been considered in any detail or are only at a very preliminary stage of investigation. For example, 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), and there are many more in earlier stages of development.

It is important to note three things:

1) In contrast to earlier times, many of these projects are collaborative ventures between CSIRO and State groups;
2) Australia has only one current augmentative/inundative mycoherbicide project, no programs involving conservation of natural enemies, and no programs involving grass weeds as targets for biological control; and
3) All of the following programs are funded to a very large degree by Rural Industry Research Funds (RIRFs), particularly the WRC, the Australian Meat and Livestock

Research and Development Corporation (AMLRDC) and the WRDF. Without these funds, the research could not be conducted.

Some potential targets for biological control include:

Onion weed, *Asphodelus fistulosus* L. (Liliaceae). Onion weed has never been the subject of detailed surveys, but a damaging rust fungus, *Puccinia barbeyi* (Roum.) Magn. (Uredinales) was found to have some potential during preliminary surveys of this plant in Europe. The biology has now been elucidated and this rust seems to be host-specific and quite damaging.

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 causes considerable losses (Sloan *et al.* 1989). In Western Australia however, although recognized as a problem, it has a more ambivalent status, many farmers consider it as valuable feed for stock, and call it "Capefeed"! While this precludes a biological control program in the short term, a possible change in attitude in the long term would allow a program to proceed. A preliminary survey of capeweed in South Africa has revealed some promising natural enemies (Scott and Way 1990), but further work cannot be justified at present.

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).

Grass weeds. There has been no work on classical biological control of grass weeds in Australia, but the potential for their control has recently been reviewed (Wapshere 1990). There is some potential for classical biological control of certain species, which should be investigated in more detail. These include grasses of the genera *Bromus*, *Holcus*, *Echinochloa*, *Nasella*, *Cortaderia*, *Eleusine* and *Rottboellia*, plus Johnsongrass, *Sorghum halepense* (L.) Persoon (Massein and Lindow 1986, McFayden 1985).

Despite the above reference to classical biological control of grass weeds, currently, the only acceptable approach to these species would be by using mycoherbicides. Work is currently in progress to investigate the potential of mycoherbicides for control of several annual grass weeds by infection of the seeds while in the soil (Medd *et al.* 1986). The importance of several grass weeds in pastures, their ambivalent status in certain areas and the question of specificity of agent species where the weed is very closely-related to important pasture, crop and native species, would all suggest that the potential for mycoherbicides should be investigated in considerably more detail. While repeated application of a mycoherbicide, with its associated cost, is necessary, the very fact that its effect is limited in time and space allows the avoidance of conflict-of-interest problems, whether concerning the target weed in different situations or related non-target species.

Potential augmentative/inundative programs. This area has great potential for development. Current research is quite limited, the only group involved concentrating on Bathurst burr and the seeds of grass weeds. In this commercial field, the size of markets will play a major role in determining targets (Wapshere 1987). Even though the Australian market will be relatively small, increasing restrictions on herbicide use, pressure from environmental lobby groups, and increase in weed resistance to herbicides could all force further development.

Native woody weeds. Cullen and Delfosse (1990) concluded that native woody weeds, which have become a major problem in the pastoral zone of inland New South Wales and Queensland, are potential targets for augmentative/inundative biological control, but not generally for classical biological control. They all already have coevolved natural enemies in Australia, but these are ineffective because of environmental factors, such as changes in land management. However, significant levels of attack have sometimes been observed on native woody weeds, and it is possible that at least the pathogens offer possibilities for development of mycoherbicides.

Examples of potential native woody weeds as targets for augmentative/inundative biological control are: turpentine bush, *Eremophila sturtii* R. Brown; budda or false sandalwood, *E. mitchellii* Bentham (Myoporaceae); hop bush, *Dodonaea attenuata* A. Cunningham and *D. viscosa* Jacquin var. *angustifolia* (Sapindaceae); punty bush, *Cassia nemophila* J. Vogel (Caesalpinaceae); gidgea, *Acacia cambagei* R. Baker (Mimosaceae); galvanized burr, *Sclerolaena birchii* (F. Mueller) Domin (Chenopodiaceae); bracken fern, *Pteridium esculentum* (G. Forster) Cockayne (Dennstaedtiaceae) (which is currently the target of a European biological control project, and Australia may be able to capitalize on advances made here; Kirk 1982, Lawton 1988); and *Erodium crinitum* Carolin (Geraniaceae).

Discussion and conclusions

This brief review has indicated some of the progress being made in biological control of weeds of interest (or potential interest) to the dried fruits industry.

Sadly, however, funding for biological control of weeds is still only given retroactively (when a given weed covers an enormous area, and all other methods of management have failed), rather than proactively, which is preferred. Until biological control is considered among the first options for management of a pest weed, most programs will continue to take two decades of scientist years research to become successful.

Two further points also indicate likely expansion in this area. The first is increasing cooperation between RIRFs. A mechanism is developing which enables RIRFs which have a common problem weed to fund jointly the biological control research. The first example of this was with *Echium*, which is funded equally by AMLRDC and WRDF. As RIRFs become used to this concept, it should result in increased funding for new activities. The current awareness by RIRFs that a strong commitment to basic ecological research will pay dividends in having programs get off the ground quicker and be successful faster.

The second point is increasing co-operation between CSIRO and State researchers. Several programs (e.g., *Echium*, common heliotrope, skeleton weed, thistles, St. John's wort, etc.) are built on a multi-disciplinary and multi-agency approach as equal partners. This will also result in faster and better understood programs.

In summary, biological control is not a panacea. It cannot be used in all situations (for example, it never eradicates the target), but is the method of choice where it is appropriate. Society must exploit biological control to the maximum extent. This will require long-term funding for ecological studies in the native range of each weed coupled with similar studies in Australia, and that proactive rather than retroactive programs are designed and conducted before massive losses due to the weeds occur.

Acknowledgments

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References

Auld, B.A. and R.W. Medd. (1987). 'Weeds. An Illustrated Botanical Guide to the Weeds of Australia.' Inkata Press, Melbourne, 255 p.

Auld, B.A., McRae, C.F. and Nikandrow, A. (1986). Proceedings of a Workshop on the Potential for Mycoherbicides in Australia, May 1986, Orange, New South Wales. Auld, B.A. (ed.) New South Wales Government Printer, pp. 20-1.

Briese, D.T. (1986). Factors affecting the establishment and survival of *Anaitis efformata* (Lepidoptera: Geometridae) introduced into Australia for the biological control of St. John's wort, *Hypericum perforatum*. II. Field trials. *Journal of Applied Ecology* 23, 821-39.

Briese, D.T. (1989). Host-specificity and virus-vector potential of *Anaitis efformata*, introduced into Australia for the biological control of St. John's wort. *Entomophaga* 34, 75-92.

Bruzzese, E. (1990). Protocols for Biological Control of Weeds and Current Victorian Priorities. *In* 'Control of *Emex*, *Tribulus* and *Cenchrus* in vineyards.' Ed. G.A. Buchanan. Proceedings of a workshop held at Mildura, Victoria on 13-14 August 1990. *Plant Protection Quarterly* 5, 98 - 99.

Butler, F.C. (1951). Anthracnose and seedling blight of Bathurst burr caused by *Colletotrichum xanthii* Halst. *Australian Journal of Agricultural Research.* 2, 401-10.

Cooke, J. (1990). The control of three-cornered jack (*Emex australis*) and other spined weeds on public land in Victoria. *In* 'Control of *Emex*, *Tribulus* and *Cenchrus* in vineyards.' Ed. G.A. Buchanan. Proceedings of a workshop held at Mildura, Victoria on 13-14 August 1990. *Plant Protection Quarterly* 5, 120 - 121.

Cullen, J.M. (1985). Bringing the cost benefit analysis of biological control of *Chondrilla juncea* up to date. Proceedings of the Sixth International Symposium on Biological Control of Weeds, 19-25 August 1984, Vancouver, Canada. Delfosse, E.S. (ed.). Agric. Can., Ottawa, pp. 145-52.

Cullen, J.M. and Delfosse, E.S. (1985). *Echium plantagineum*: Catalyst for conflict and change in Australia. Proceedings of the Sixth International Symposium on Biological Control of Weeds, 19-25 August 1984, Vancouver, Canada. Delfosse, E.S. (ed.). Agric. Can., Ottawa, pp. 249-92.

Cullen, J.M. and Delfosse, E.S. (1990). Progress and prospects in biological control of weeds. Proceedings of the 9th Australian Weeds Conference, 6-10 August 1990, Adelaide, South Australia. Heap, J. (ed.). pp. 452-75.

Cullen, J.M., Kable, P.F. and Catt, M. (1973). Epidemic spread of a rust imported for biological control. *Nature, London.* 244, 462-4.

Delfosse, E.S. (1985a). *Echium plantagineum* in Australia: effects of a major conflict of interest. Proceedings of the 9th Australian Weeds Conference, 19-25 August 1984, Vancouver, Canada. Delfosse, E.S. (ed.). Agric. Can., Ottawa, pp. 293-9.

Delfosse, E.S. (1985b). Re-evaluation of the biological control program for *Heliotropium europaeum* in Australia. Proceedings of the 9th Australian Weeds Conference, 19-25 August 1984, Vancouver, Canada. Delfosse, E.S. (ed.). Agric. Can., Ottawa, pp. 735-42.

Delfosse, E.S. and Cullen, J.M. (1981a). New activities in biological control of weeds in Australia. I. Common heliotrope, *Heliotropium europaeum*. Proceedings of the Fifth International Symposium on Biological Control of Weeds, 22-27 July 1980, Brisbane, Australia. Delfosse, E.S. (ed.). CSIRO, Melbourne, pp. 545-61.

Delfosse, E.S. and Cullen, J.M. (1981b). New activities in biological control of weeds in Australia. II. *Echium plantagineum*: Curse or salvation? Proceedings of the Fifth International Symposium on Biological Control of Weeds, 22-27 July 1980, Brisbane, Australia. Delfosse, E.S. (ed.). CSIRO, Melbourne, pp. 563-74.

Delfosse, E.S. and Cullen, J.M. (1981c). New activities in biological control of weeds in Australia. III. St. John's wort, *Hypericum perforatum*. Proceedings of the Fifth International Symposium on Biological Control of Weeds, 22-27 July 1980, Brisbane, Australia. Delfosse, E.S. (ed.). CSIRO, Melbourne, pp. 575-81.

Delfosse, E.S., Hasan, S., Cullen, J.M. and Wapshere, A.J. (1985). Beneficial use of an exotic phytopathogen: *Puccinia chondrillina* as a biological control agent for skeleton weed, *Chondrilla juncea*, in Australia. Ch. 28 *In* 'Pests and Parasites as Migrants; an Australian Perspective.' Gibbs, A.J. and Meischke, H.R.C. (eds.). Proceedings of the Australian and New Zealand Association for the Advancement. of Science. Australian Academy of Science Joint Symposium on Exotic Diseases, 15-18 May 1984. Australian Academy of Science, pp. 171-7.

Delfosse, E.S., Lewis, R.C. and Smith, C.S. (1987). Effect of drought and grasshoppers on establishment of *Dialectica scalariella* Zeller (Lepidoptera: Gracillariidae), a potential biological control agent for *Echium plantagineum* L. (Boraginaceae). *Journal of Australian Entomological Society* 26, 279-80.

Field, R.P., Goldsworthy, H. and Ferguson, A. (1988). Biennial Report, Land Protection Division, Research, Inventory and Assessment Branch. Clinnick, P., Yugovic, J. and Brouwer, J. (eds.). Department of Conservation, Forests and Lands, Victoria, pp. 33-4.

Gilbey, D. (1990). Control of *Emex* with herbicides in Western Australia. *In* 'Control of *Emex*, *Tribulus* and *Cenchrus* in vineyards.' Ed. G.A. Buchanan. Proceedings of a workshop held at Mildura, Victoria on 13-14 August 1990. *Plant Protection Quarterly* 5, 107 - 109.

Hasan, S. (1985). Prospects for biological control of *Heliotropium europaeum* by fungal pathogens. Proceedings of the Sixth International Symposium on Biological Control of Weeds, 19-25 August 1984, Vancouver, Canada. Delfosse, E.S. (ed.). Agric. Can., Ottawa, pp. 617-23.

Huber, J.T. and Vayssieres, J.-F. (1990). *Entomophaga* (in press).

Julien, M.H., Broadbent, J.E. and Matthews, N.C. (1979). Effects of *Puccinia xanthii* on *Xanthium strumarium* (Compositae). *Entomophaga* 24, 29-34.

Julien, M.H. (1987). 'Biological Control of Weeds. A World Catalogue of Agents and Their Target Weeds.' Second edition. CAB International, Wallingford, U.K., 144 p.

Kirk, A.A. (1982). Insects associated with bracken fern *Pteridium aquilinum* (Polypodiaceae) in Papua New Guinea and their possible use in biological control. *Acta. Oecol./Oecol. Appl.* 3, 343-59.

Lawton, J.H. (1988). Biological control of bracken in Britain: constraints and opportunities. *Philosophical Transactions of the Royal Society of London* B 318-55.

MacGregor, A. (1990). The potential for cultural control of *Tribulus*, *Cenchrus* and *Emex* in Sunraysia vineyards. In 'Control of *Emex*, *Tribulus* and *Cenchrus* in vineyards.' Ed. G.A. Buchanan. Proceedings of a workshop held at Mildura, Victoria on 13-14 August 1990. *Plant Protection Quarterly* 5, 116 - 119.

Marsden, J.S., Martin, G.E., Parham, D.J., Ridsdill-Smith, T.J. and Johnston, B.G. (1980). Returns on Australian agricultural research. The joint Industries Assistance Commission - CSIRO benefit-cost study of the CSIRO Division of Entomology. CSIRO, Melbourne, 107pp.

Massien, C.L. and Lindow, S.E. (1986). Effects of *Sphacelotheca holci* infection on morphology and competitiveness of Johnson grass (*Sorghum halepense*). *Weed Science* 34, 883-88.

McFadyen, R.E. (1985). The biological control programme against *Parthenium hysterophorus* in Queensland. Proceedings of the Sixth International Symposium on Biological Control of Weeds, 19-25 August 1984, Vancouver, Canada. Delfosse, E.S. (ed.). Agric. Can., Ottawa, 789-96.

Medd, R.W., Jones, K.H. and Ridings, H.I. (1986). Proceedings of the Workshop on Potential for mycoherbicides in Australia, May 1986, Orange, New South Wales. Auld, B.A. (ed.). New South Wales Gov. Print., pp. 22-5.

Orr, C.C., Abernathy, J.R. and Hudspeth, E.B. (1975). *Nothanguina phyllobia*, a nematode parasite of silverleaf nightshade. *Plant Disease Reporter* 59, 416-8.

Robinson, A.F., Orr, C.C. and Abernathy, J.R. (1978). Distribution of *Nothanguina phyllobia* and its potential as a biological control agent of silverleaf nightshade. *Journal of Nematology* 10, 362-6.

Scott, J.K. (1990a). *Emex* in Southern Africa and Australia: An overview of biology and biological control. *In* 'Control of *Emex*, *Tribulus* and *Cenchrus* in vineyards.' Ed. G.A. Buchanan. Proceedings of a workshop held at Mildura, Victoria on 13-14 August 1990. *Plant Protection Quarterly* 5, 85 - 88.

Scott, J.K. (1990b). *Tribulus terrestris* L. (Zygophyllaceae) in Southern Africa: An Outline of Biology and Potential Biological Control Agents for Australia. *In* 'Control of *Emex*, *Tribulus* and *Cenchrus* in vineyards.' Ed. G.A. Buchanan. Proceedings of a workshop held at Mildura, Victoria on 13-14 August 1990. *Plant Protection Quarterly* 5,103 - 106.

Scott, J.K. and Way, M.J. (1990). A survey in South Africa for potential biological control agents against capeweed, *Arctotheca calendula* (L.) Levyns (Asteraceae). *Plant Protection Quarterly* 5, 31-34.

Shepherd, R. (1990). Past Victorian work on *Emex australis* Stenheil and *Tribulus terrestris* L. *In* 'Control of *Emex*, *Tribulus* and *Cenchrus* in vineyards.' Ed. G.A. Buchanan. Proceedings of a workshop held at Mildura, Victoria on 13-14 August 1990. *Plant Protection Quarterly* 5, 100 - 102.

Sheppard, A.W., Cullen, J.M., Aeschlimann, J.-P., Sagliocco, J.-P. and Vitou, J. (1989). The importance of insect herbivores relative to other limiting factors on weed population dynamics: a case study of *Carduus nutans*. Proceedings of the Seventh International Symposium on Biological Control of Weeds, 6-11 March 1988, Rome, Italy. Delfosse, E.S. (ed.). 1st. Sper. Patol. Veg. (MAF), Rome, Italy, pp. 211-20.

Siebert, M.W. (1975). Candidates for the biological control of *Solanum elaeagnifolium* Cav. (Solanaceae) in South Africa. 1. Laboratory studies on the biology of *Gratiana lutescens* (Boh.) and *Gratiana pallidula* (Boh.) (Coleoptera: Cassidae). *Journal of the Entomological Society of South Africa* 38, 297-304.

Siebert, M.W. (1977). Candidates for the biological control of *Solanum elaeagnifolium* Cav. (Solanaceae) in South Africa. 2. Laboratory studies on the biology of *Arvelius albopunctatus* (DeGeer) (Hemiptera: Pentatomidae). *Journal of the Entomological Society of South Africa* 40, 165-70.

Sloane, Cook and King. 1989. The economic impact of pasture weeds, pests and diseases on the Australian wool industry. Vol. 1. Main Rep. Australian Wool Corporation., Wool Res. & Devol. Trust Fund. AWC, Melbourne, 205 p.

Wapshere, A.J. 1974. An ecological study of an attempt at biological control of Noogoora burr (*Xanthium strumarium*). *Australian Journal of Agricultural Research* 25, 275-92.

Wapshere, A.J. (1987). Implications of the source of weeds in Australia for the development of mycoherbicides. *Journal of the Australian Institute of Agricultural Science* 53, 192-6.

Wapshere, A.J. (1988). Prospects for the biological control of silverleaf nightshade, *Solanum elaeagnifolium*, in Australia. *Australian Journal of Agricultural Research* 39, 187-97.

Wapshere, A.J. (1990). Biological control of Australian grass weeds: An appraisal. *Plant Protection Quarterly* 5,62-75.

Wapshere, A.J., Delfosse, E.S. and Cullen, J.M. (1989). Recent developments in biological control of weeds. *Crop Protection* 8, 227-50.

Weiss, P. (1990). Plant and seed population dynamics of *Emex*. *In* 'Control of *Emex*, *Tribulus* and *Cenchrus* in vineyards.' Ed. G.A. Buchanan. Proceedings of a workshop held at Mildura, Victoria on 13-14 August 1990. *Plant Protection Quarterly* 5, 89 - 90

Wilson, F. (1960). A Review of the Biological Control of Insects and Weeds in Australia and Australian New Guinea. Technical Communication. CIBC, C.A.B. Farnham Royal, England, UK, 102 p.

Zimmermann, H.G. (1974). Preliminary work on the biological control of satanbos, *Solanum elaeagnifolium*. Proceedings of the 1st Medicinal Weeds Conference, South Africa, pp. 151-68.

Questions and discussion

Q. Greg Buchanan. How does CSIRO determine its priorities for biological control?

A. On the basis of advice from Australian Weeds Committee, Rural Industry Research Councils and the contribution of the research to the development of science.

Q. Greg Code. Has Orange Agricultural and Veterinary Research Centre looked at mycoherbicides for the control of weeds other than salvation Jane?

A. Yes, there are also good opportunities for other weeds, and chemical companies should be very interested in their development.