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Emex australis

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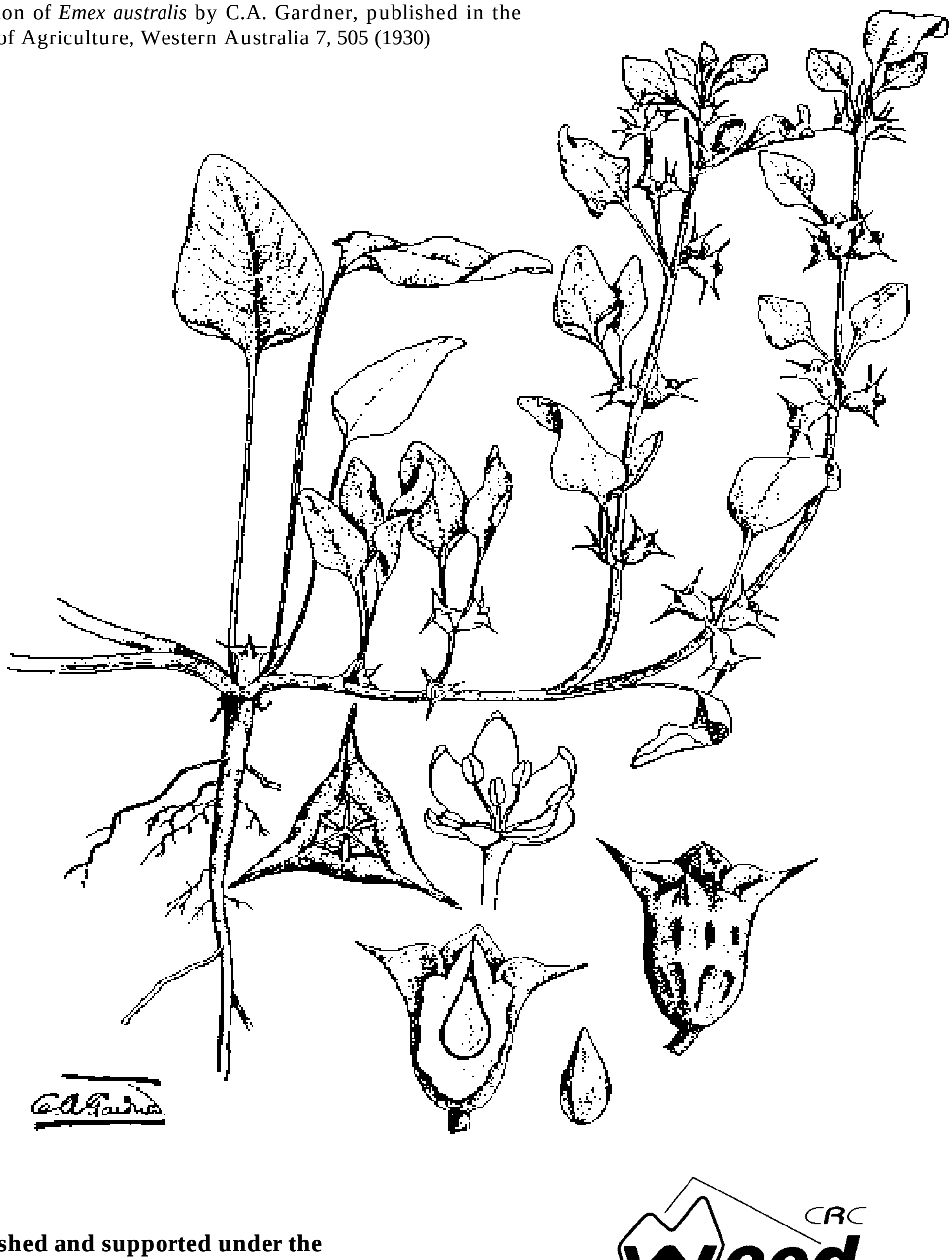
biology, management and research

Proceedings of a workshop held at CSIRO Floreat Laboratories, Floreat, Western Australia on 11 December 1995. This is the first in a series of workshops sponsored by the Co-operative Research Centre for Weed Management Systems.

Editors: John K. Scott, David G. Bowran and Sharon A. Corey

Illustration of *Emex australis* by C.A. Gardner, published in the Journal of Agriculture, Western Australia 7, 505 (1930)



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CRC Weed management systems

Co-operative Research Centre for Weed Management Systems

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MISSION STATEMENT

The CRC is committed to increasing the sustainability of agriculture and protecting the natural environment by developing ecologically sound, cost effective weed management systems.

OBJECTIVES

- To reduce the impact of weeds on farm productivity and profitability by developing sustainable management programs that optimize the integration of chemical, biological and ecological approaches for annual crop and pasture systems in the cropping zone of southern Australia.

- To develop practical integrated weed management systems that reduce weed infestation, protect the environment and enhance sustainability and productivity of Australian temperate perennial pasture ecosystems.

- To develop integrated strategies for the sustainable management of weeds invading natural ecosystems in temperate Australia, in order to maintain biological diversity of native flora and fauna and to prevent further degradation of natural habitats.

- To implement a suite of weed science and weed management education programs which, for the first time in Australia, offers a coordinated approach to educating undergraduates, postgraduates, professional land and natural resource managers, and the community.

- To interact with researchers and land managers to communicate the results of weed research and foster the adoption of resulting weed management strategies.

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Organized by John Scott, CSIRO and David Bowran, Agriculture Western Australia, and sponsored by the Co-operative Research Centre for Weed Management Systems.

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Preface

Emex australis (doublegee or three cornered jack) has become an important agricultural problem of southern Australia since the weed's arrival in the 1830s. Its only relative, *Emex spinosa* (lesser jack), arrived in Australia more recently and has yet to realize its potential as a weed although it is already locally important. The first summary of studies on *Emex* species was provided by Gilbey (1974) which was followed by the paper on *E. australis* as part of the Biology of Australian Weeds series (Gilbey and Weiss 1980). In 1990 the problem with spiny weed seeds (chiefly *E. australis*) lead to a workshop in Mildura, Victoria (Buchanan 1990) which was supported by the Australian Dried Fruits Research and Development Council.

Emex australis was included as a weed for study by the recently formed Co-operative Research Centre for Weed Management Systems in its annual agro-ecosystems program. The workshop on *E. australis* was held over one day at CSIRO Floreat, Western Australia on 11 December 1995. The workshop addressed the biology, regional significance and control of *Emex* species. The papers provide a snapshot of current research on these weeds. Past work is acknowledged in the bibliography provided at the end of the proceedings. Examples of future work are outlined in the summary of the workshop discussions. Together these form the proceedings presented here. It is our hope that increased research will be undertaken into the control of *E. australis* and that the ideas presented in this workshop will be pursued. We also hope that future workshops or meetings can report significant progress towards control of this pernicious problem.

We gratefully acknowledge the support provided by the Co-operative Research Centre for Weed Management Systems, Agriculture Western Australia and the CSIRO Division of Entomology. CSIRO Floreat provided facilities for the workshop. We are most grateful to the efforts the participants put into the workshop and in preparing their subsequent reports. We also would like to thank Rick Horbury and Chris Stansbury for their assistance on the day.

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Predicting the distribution of *Emex* in Australia

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Abstract

The potential distribution of *Emex australis* and *E. spinosa* in Australia was predicted using information on the present distribution and conditions suitable for plant growth. Two computer based systems, CLIMEX and the Agriculture Western Australia program, Climate, were used to make the predictions. The results indicate that the present distribution of *E. australis* is close to its potential, but could spread further along the south coast of Western Australia and into Tasmania. *Emex spinosa* is also widespread, but the potential distribution is considerably more than the existing distribution.

Introduction

The *Emex* genus is a member of the Polygonaceae family and consists of two species, *E. australis* and *E. spinosa*, native to southern Africa and the Mediterranean/Middle Eastern region, respectively. *E. australis* has naturalized in Australia, USA (California and Hawaii), India, Kenya, Madagascar, Malawi, New Zealand, Pakistan, Taiwan, Trinidad and Zimbabwe (see Shivas and Sivasithamparam 1994 for references), but is a major weed only in South Africa and Australia (Holm *et al.* 1979). *E. spinosa* has naturalized in Australia, Kenya, Mauritius, USA (California and Hawaii) (Holm *et al.* 1979), Ecuador (Brandbyge 1989), Pakistan (Siddiqi 1973) and India (Varma *et al.* 1984), but has not become particularly weedy anywhere.

Climate is a key factor which limits the potential distribution of a species, although biotic, edaphic and land management factors are also important. Climate data is well documented for most parts of the world and computer based programs have been developed to predict the potential distribution of organisms on the basis of climate. One such program is CLIMEX (Sutherst and Maywald 1985) which is used to develop a predictive model based upon the temperature and moisture requirements of a species. The model is then fine tuned to the known species distribution before being used to make a prediction to new areas.

An alternative approach, particularly where detailed biological information on the species is lacking, is to generate a prediction based only on the climate of the known distribution. The Climate System, developed by Agriculture Western Australia, adopts some of the principles of the BIOCLIM system (Nix 1986).

The results of a climate analysis can indicate where further spread of a species is possible, or provide insights towards other factors which will determine the distribution. In this paper, climate matching techniques are used to compare known against predicted distributions for *Emex* species in Australia.

Materials and methods

A CLIMEX (Climex for Windows 1.0) model for *E. australis* was developed from the temperature requirements for growth (Weiss and Simmons 1977), the distribution in southern Africa (Scott and Way 1990) and the phenology of plant growth in southern Africa (Scott 1992, Scott unpublished). The final parameters used are listed in Table 1.

A CLIMEX model for *E. spinosa* was developed from a general model for a species associated with a Mediterranean type climate (given in CLIMEX), which was modified to match the known distribution in the Mediterranean basin (Azores, Balearic Islands, Corsica, Crete, Greece, Spain, Italy, Portugal, Sardinia and Sicily (Tutin *et al.* 1964)), Egypt, Israel, Morocco (Holm *et al.* 1979) and Libya (Siwicki 1967). The model was then further modified to include the countries of introduction, excluding Australia. Finally the model was used to predict the distribution in Australia. The final parameters used are listed in Table 1.

The Climate System uses meteorological station data from around the world. Stations within the range of the known distribution of the species were individually matched to grid points in Australia, at a spatial resolution of 0.5°. Meteorological data at the grid points were generated by the BIOCLIM system (Nix 1986). The known distribution of both species outside of Australia was used to predict the potential distribution in Australia using the Climate System. The South African distribution for *E. australis* is taken from Panetta (1990), Scott and Way (1990) and additional naturalized locations in USA (California), New Zealand, Taiwan, Kenya and Zimbabwe were based on Holm *et al.* (1979) and regional floras. Similarly, the native distribution of *E. spinosa* was taken from regional floras of the Mediterranean and Middle East regions, in addition to naturalized locations in USA (California and Hawaii), Peru and Argentina. The resultant distributions are probably not exhaustive, but representative of the climates in which the species are present and sufficiently prominent to be recorded in the literature. The actual distributions of the species in Australia are based on information supplied by Gilbey and Weiss (1980), Hnatiuk (1990) and Parsons and Cuthbertson (1992). This information was not used to generate the predicted distribution.

Results

Emex australis

The world CLIMEX prediction for *E. australis* is shown in Figure 1. The Climate system produces a similar result (map not reproduced here). The known distribution is contained within the predicted range but the Mediterranean region, South America, eastern Africa and southern parts of North America also contain areas with suitable climates. In Australia, CLIMEX predicts a distribution covering most of the southern half of Australia excluding the inland deserts and mountain ranges, which fits well with the current distribution (Figure 2).

Table 1. Parameters used for CLIMEX predictions. Parameter codes are those given in Sutherst and Maywald (1985).

	Parameter	*E. australis*	*E. spinosa*
Temperature	DV0	5°C	10°C
	DV1	12.5°C	16°C
	DV2	22.5°C	24°C
	DV3	30°C	28°C
	PDD	600	600
Moisture	SMO	0.1	0.1
	SM1	0.2	0.4
	SM2	0.8	0.7
	SM3	1.5	1.5
Cold stress	TTCS	6°C	0°C
	THCS	0.002	0.005
	DTCS		15
	DHCS		0.001
Dry stress	SMDS	0.1	0.02
	HDS	0.0005	0.05
Wet stress	SMWS	1.2	1.6
	HWS	0.001	0.0015
Hot/wet stress	TTHW	23°C	23°C
	MTHW	0.8	0.5
	PHW	0.03	0.075

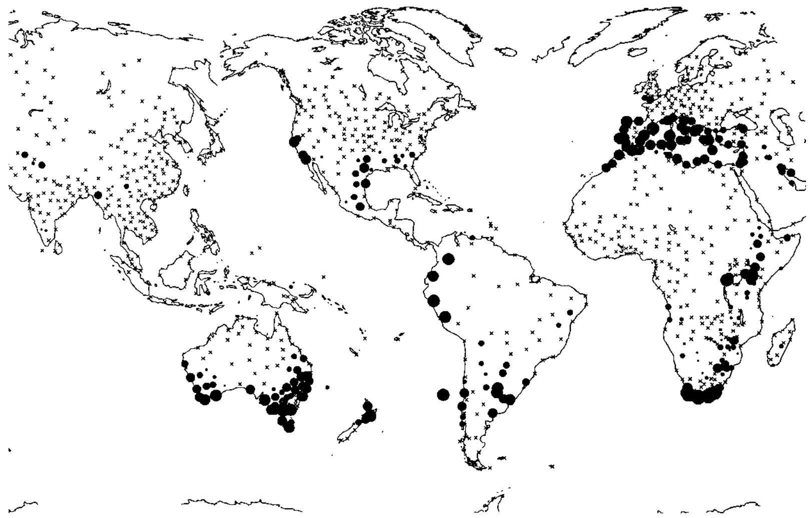


Figure 1. Prediction of world distribution of *E. australis* by CLIMEX. The larger the circle, the more suited the site is for growth of *E. australis*. Crosses indicate unsuitable sites.

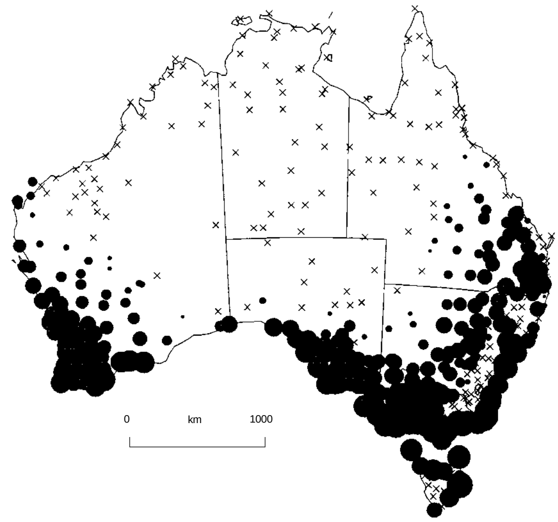


Figure 2. Prediction of Australian distribution of *E. australis* by CLIMEX.

The potential distribution of *E. australis* in Australia, as predicted by the Climate System, is shown in Figure 3. All of southern Australia, much of northern Queensland and coastal parts of north-western Australia may be climatically suitable. However, as with the CLIMEX prediction, the more favourable areas tend to be further south with highest matching areas in southern and south-western Australia. The actual distribution is enclosed by the predicted distribution except, for the northern reaches of the distribution in Western Australia.

Emex spinosa

The world CLIMEX prediction for *E. spinosa* is shown in Figure 4. The Climate system produces a similar result (map not reproduced here). The known distribution is contained within the predicted range but parts of South America, South Africa, Mexico and Australia also contain areas with suitable climates. In Australia, CLIMEX predicts a distribution similar to, but less extensive than that of *E. australis* (Figure 5).

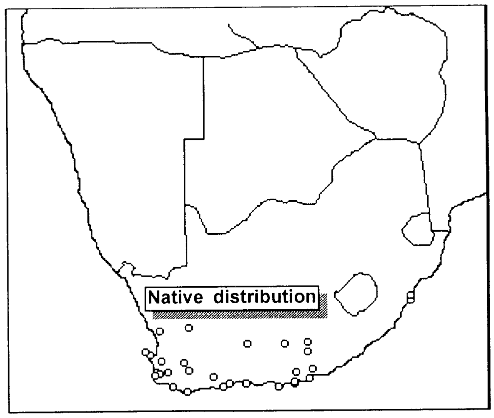
The potential distribution of *E. spinosa* in Australia, as predicted by the Climate System, is shown in Figure 6. South and south-western Australia are the most climatically suitable. Its recorded distribution is enclosed by the predicted distribution.

Discussion

The native distributions of the two *Emex* species are quite distinct and do not overlap, although both species have become naturalized in other areas with temperate climates, such as California, Hawaii and southern Australia.

Emex australis is climatically well suited to temperate Australia and this is confirmed by the actual distribution (Figure 3). It is a weed of areas subject to disturbance and is not normally found in natural ecosystems in Australia (Keighery 1996). Worldwide, the species is suited to growing in many areas (Figure 1), but the actual distribution is much more restricted. Outside Australia, the species has not become particularly weedy where it has naturalized. Presuming that the species has had adequate opportunities to become established, other factors such as the soil type or land management may not be appropriate or pests of Polygonaceae may be active and restrict the proliferation of the species in the climatically suitable areas.

Emex spinosa is widely regarded as a minor weed (Holm *et al.* 1979). Although well suited to the climate of southern Australia, and south-western Western Australia in particular, the actual distribution is limited to a few small areas (Figure 6). The reasons for this are unclear. *E. spinosa* is more competitive than *E. australis* in pot experiments (Weiss 1977) and the author of that study suggested that *E. spinosa* may well displace *E. australis* as the dominant species where the two co-exist. Nevertheless, after nearly 20 years *E. australis* continues to predominate.



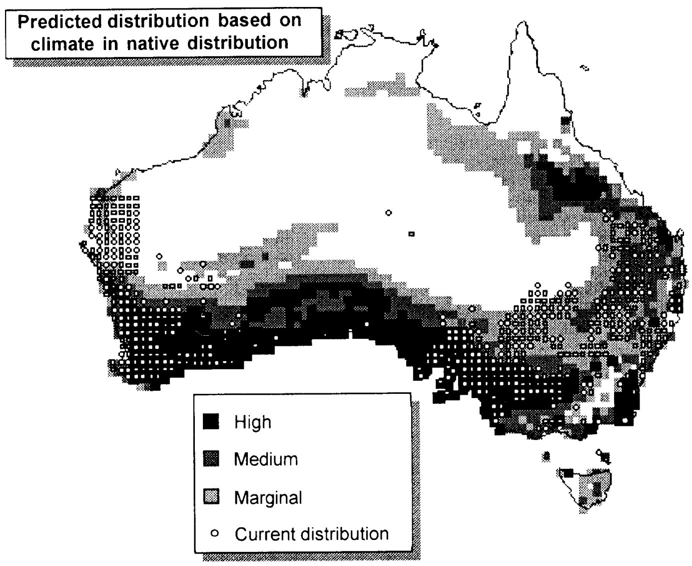


Figure 3. Prediction of Australia distribution of *E. australis* by Climate System. Locations within the native distribution in South Africa (shown) and additional naturalized locations outside of Australia were used to generate the prediction.

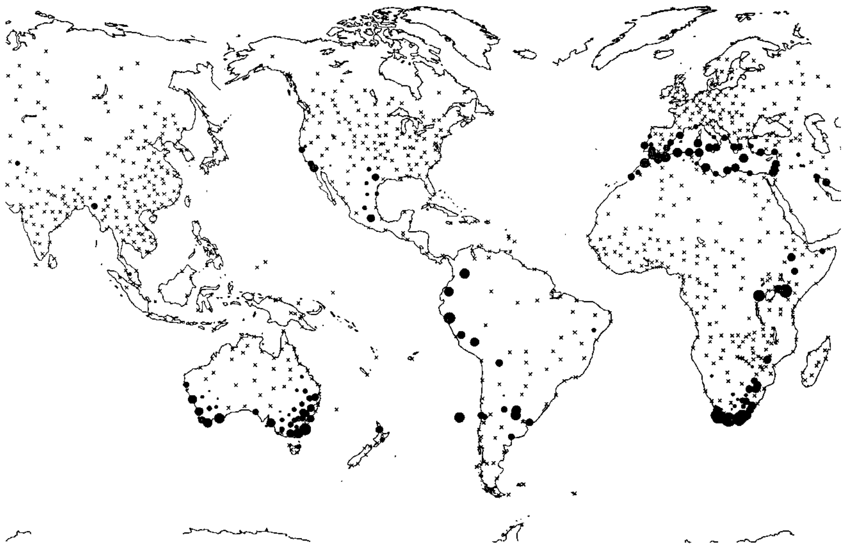


Figure 4. Prediction of world distribution of *E. spinosa* by CLIMEX.

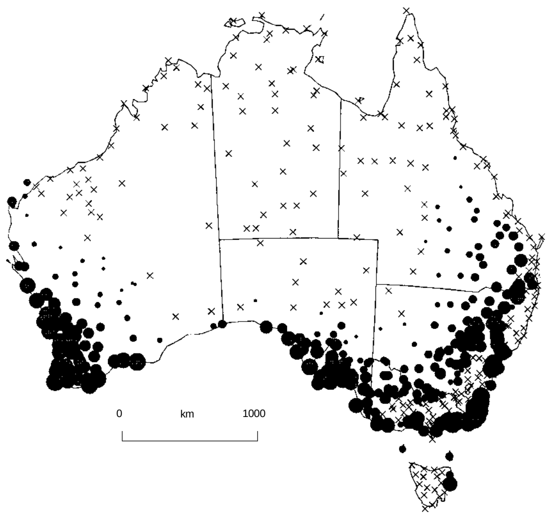


Figure 5. Prediction of Australian distribution of *E. spinosa* by CLIMEX.

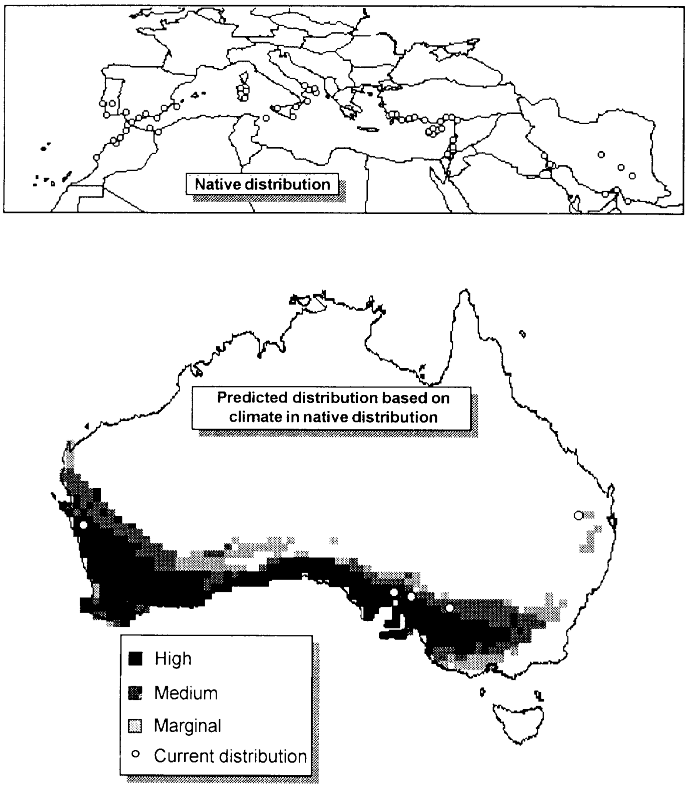


Figure 6. Prediction of Australian distribution of *E. spinosa* by Climate System. Locations within the native distribution in South Africa (shown) and additional naturalized locations outside of Australia were used to generate the prediction.

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Doublegee (*Emex australis* Steinh.) seed banks

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Abstract

Farmers can control doublegee, *Emex australis,* on an annual basis by integrating cultural and chemical control methods, but it is still not possible to achieve long-term control or eradication of this weed. It is suggested that any control measure that reduces the seed dormancy or destroys the dormant seed bank would be of immense value in the long-term management of this weed. Unfortunately, practical methods for achieving this are still unavailable. Nevertheless, some important studies on its seed dormancy behaviour and the persistence of its seed banks have been undertaken in Western Australia. This paper discusses the findings of these studies.

Introduction

The vast majority of seeds entering the seed bank in arable land come from annual weeds growing on that land (Roberts 1981, Hume and Archibold 1986). Seed dormancy is a major factor contributing to persistence of seed banks (Bewley and Black 1982). The persistence of doublegee, *Emex australis* (Steinh.), in cropping systems is due to its seed dormancy and longevity. Any long-term management strategy against this weed therefore requires a good understanding of the functioning of its seed banks.

Dormancy in relation to seed bank

The most recent contribution to our knowledge on dormancy in doublegee seed comes from the work of Panetta and Randall (1993a). An understanding of the seed dormancy behaviour is an important prerequisite for developing strategies of weed management.

Using four Western Australian accessions of doublegee, they found that seeds of all accessions were dormant when freshly harvested, but gradually after-ripened over the summer months. A peak in germinability was reached during autumn. Depending on accessions, the phases of maximum germinability varied from a matter of weeks (or days) to a number of months. In a separate experiment, they found that plants from two accessions that were grown in a common environment produced seeds with virtually identical dormancy/non-dormancy cycles, thus suggesting that such cycles are influenced primarily by the environment in which the seeds are produced. They also found that a fall in temperatures preceded a drop in germinability for three of the accessions. This suggests that the induction of secondary dormancy in doublegee seeds may be related to decreasing soil temperatures during early winter. The proportion of the populations which became dormant ranged from 50 to 90%. The existence of these dormancy cycles in doublegee seeds therefore indicates that the dormant bank of seeds in the soil is in a state of continual physiological change which ensures that their dormancy status is always appropriate for the prevailing seasonal conditions.

Seedling emergence

Although the proportion of non-dormant seeds could range from 70 to nearly 90% during the phases of maximum germinability (Panetta and Randall 1993a), only a small proportion of the seed bank can produce seedlings each growing season. In one study, Panetta and Randall (1993b) recorded 17.6% emergence which is close to our figure of 17%, based on the mean over 4 depths (Cheam 1987). In any one year it is the seeds near the surface, within the top 5 cm of soil, which are likely to cause weed problems (Table 1). At depths greater than 5 cm the numbers of seed capable of completing emergence declined sharply so that no doublegee emerged from 15 cm or deeper. If the soil is left undisturbed, most seeds are confined to the soil surface, resulting in few established seedlings. A higher germination level of the buried seeds is expected because the better seed-soil contact allows the seeds to imbibe sufficient water for germination. The higher level of germination of the shallow-buried seeds suggests that shallow cultivation before sowing a crop would improve seed germination and so reduce the size of the seed bank. The resulting seedlings are then easily controlled by herbicides. However, the overall low emergence in any one year means that under normal herbicide treatment, only a small percentage of the total population is destroyed.

Table 1. Emergence per year (per cent of sown viable seeds) of doublegee from seeds sown at five depths. The data are means over three sites.

Depth (cm)	Year 1	Year 2	Year 3	Year 4
0	11.0	5.3	5.6	1.6
1	42.8	7.4	2.0	1.7
5	13.3	11.4	2.0	1.4
10	1.3	2.0	0	0
15	0	0	0	0

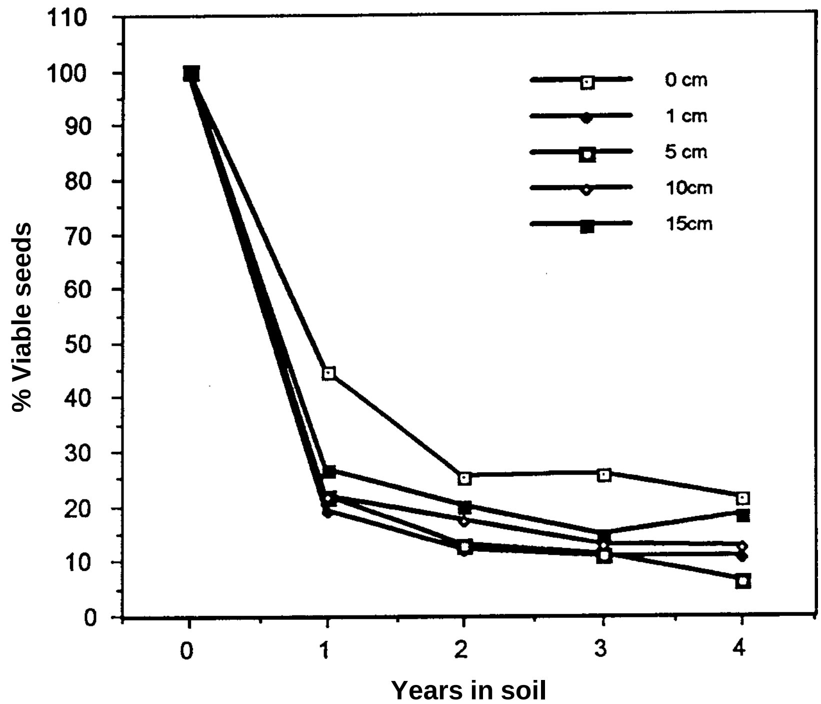

Figure 1. Decline of doublegee seeds at various depths.

Table 2. State of doublegee seeds after four years of burial.

Depth (cm)	Enforced dormant (%)	Induced / innate dormant (%)	Total viable (%)	Field germ. / rotted (%)
0	2.7	18.3	21.0	79.0
1	1.5	9.0	10.5	89.5
5	1.2	4.8	6.0	94.0
10	2.3	9.9	12.2	87.8
15	3.1	15.2	18.3	81.7

Table 3. Pre-planting soil compaction and other operations on the emergence of doublegee seedlings.

Treatment	Seedling no. m^{-2}
Compaction with flexi-coil land packer	620
Compaction with plain roller	1132
Compaction with ribbed roller	767
Direct drilling	20
Conventional cultivation	281

Seed survival

The depth of seed burial appears to have an effect on the rate of decline of viable doublegee seeds. The mean results over three sites indicated the greatest decline within the 1-5 cm depth, the slowest for the surface and deeply buried seeds (Figure 1) (Cheam 1987).

It was also noted that there was a higher retention of dormant seeds at cooler and wetter sites. Cooler temperatures may induce secondary dormancy as suggested by Panetta and Randall (1993a) and hence the more slowly seed viability declines (Schafer and Chilcote 1970, Harrington 1972) particularly at greater soil depths (Egley and Chandler 1983). The extended life-span of seeds in wetter conditions could be due to self-repair or replacement of cellular components (Villiers 1974). Thus, climate has a significant role in the rate of decline of viable doublegee seeds.

The persistence of doublegee and its ability to survive control measures is therefore directly related to the dormancy and longevity of its seeds. Survival of up to eight years was reported by Gilbey (1987) in one study. Cheam (1987) found that the seeds that survived after four years of burial were mainly in a state of induced or innate dormancy (Table 2). Hence, any measure that reduces seed dormancy or destroys the dormant seeds would be of immense value in the long-term management of doublegee. Unfortunately, practical methods for achieving this are still unavailable. Until we succeed, we are merely treating the symptom rather than the cause of doublegee infestations.

Stimulating germination to reduce seed bank

An attempt has been made to stimulate doublegee seed germination and then eliminate the seedlings as part of a strategy to reduce its seed bank (Cheam unpublished). Doublegee seeds are extremely sensitive to water stress. When the seeds were incorporated into the soil as soon as there was sufficient germinating rain, immediate compaction of the soil using a plain roller resulted in four times more emergence than the cultivation treatment and 57 times that of the direct-drilled (Table 3). Compaction gives better seed-soil contact resulting in better moisture movement from soil to seed. However, this technique of depleting the seed bank may not appeal to growers because it delays the sowing programme. Delayed sowing often results in less competitive crop stands and reduced yield.

Research needs

It is apparent that current weed control technology does not attempt to reduce the dormant seed bank of doublegee. Any measure (physical, chemical or biological) that reduces seed dormancy or destroys the dormant seeds would be of immense value in the long-term management of this weed. There is also a continuing need to quantify the relationship between weed density and crop yield with a view to provide threshold guidelines for farmers. In this regard, a study of its population dynamics under various cropping systems is required.

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Emex australis in Western Australia; an amenity or conservation problem?

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Abstract

***Emex australis* is widespread in Western Australia, with numerous records from most large national parks and nature reserves. Generally found only in highly disturbed sites (roads, tracks, firebreaks, picnic sites, old homesteads and clearings) in conservation reserves. On pastoral properties it is also mainly found on tracks, stock pens and watering points. Natural areas invaded by *Emex* include edges of creeks, riverine flats, alluvial flats (claypans, edges saline lakes) and granite rocks. These are the sites of biological diversity and refugia in arid Western Australia. *Emex* is also recorded as a major weed of naturally disturbed seabird rookeries of the Abrolhos Islands.**

***Emex* has become a food source for Major Mitchell cockatoos, inland red tailed black cockatoos, galahs, little and long billed corellas in the largely cleared northern wheatbelt.**

Introduction

Emex australis is a widespread weed in southern Australia, and especially in Western Australia. Where it is found from the Great Sandy Desert to the Nullarbor. The species is absent from the Kimberley (there is one record from the Kununurra Research Station), very uncommon in the Pilbara and the wetter regions of the south-west forests. Despite its wide range there is little information on this species occurrence in conservation reserves and its potential impact on these areas. This paper attempts to briefly review what is known about the occurrence and potential impact of *E. australis* on conservation in Australia.

The situation in eastern Australia

Because of its impact on agriculture, *Emex australis* is a declared noxious weed in most of Australia. However, it barely rates a mention in lists of major environmental weeds of Australia, as detailed in Humphries *et al.* (1991) and Swarbrick and Skarratt (1994).

At the regional level *Emex* is also considered largely an agricultural weed. Smith (1995) does not list it for the Northern Territory. Kleinschmidt and Johnson (1977) list it as a weed of 'disturbed sites around buildings, cultivated paddocks and along roadsides' for Queensland as does Wilson (1990) for New South Wales. Carr *et al.* (1992) list *Emex* for Victoria as of 'limited distribution and occurring in small populations, but list it as a serious threat to lowland grassland and grassy woodlands.' Kloot (1986) lists it as widespread weed of cereal crops for South Australia, but not for native vegetation. Keighery (1995) lists *Emex* as a 'widespread weed of agriculture, wasteland, tracks, occasional in grazed woodlands and granite rocks' for Western Australia.

However, as shown in Table 1, *Emex* is frequently recorded from conservation areas in all mainland states where it is widespread. However, this information is contained largely in the 'grey' literature of management plans, interim plant lists and internal reports. *Emex* is probably more common in many states since all recent ecological studies of reserves and pastoral lands in semi-arid New South Wales (Morcom and Westbrooke 1990, Porteners 1993, Westbrooke and Millar 1995) list *Emex*. The impact and invasiveness of this species is unfortunately never discussed.

The situation in Western Australia

Conservation lands

Again most information is from the grey literature and personal observations. There are numerous records from most large national parks and nature reserves, south of the Pilbara (Table 2). *Emex* was also frequently cited as a problem by CALM operations staff from all regions south of the Pilbara (Goble-Garratt and Keighery 1992).

Generally *Emex* is found only in highly disturbed sites (roads, tracks, firebreaks, picnic sites, old homesteads and clearings), and in parks subjected to past or present grazing (Pigott 1988). *Emex* is recorded as a major weed of naturally disturbed and nutrient enriched seabird rookeries of the Abrolhos Islands.

Pastoral lands

Curry and Hacker (1990) state 'A number of exotic species have become established, but most have not become more than a minor component of the vegetation. Amongst the more widespread introductions are the doublegee (*Emex australis*), Ward's Weed (*Carrichtera annua*) and one perennial grass (*Cenchrus ciliaris*). Nearly all of the common exotic species grow mainly on highly disturbed sites which have either undergone soil redistribution

Table 1. *Emex* in eastern Australian conservation parks and bushland.

Northern Territory	Uluhru National Park.
Queensland	Present, but unrecorded in many conservation reserves in arid and semi- arid regions, usually in disturbed sites.
New South Wales	National Parks in semi-arid Western New South Wales.
Victoria	Minor weed, scattered in grassland and grassy woodland remnants, parks and reserves in Mallee Region.
Tasmania	Only Flinders Island (Bass Strait).
South Australia	National Parks in semi-arid (e.g. Flinders Ranges), coastal dunes, offshore islands and roadsides.

Table 2. *Emex* in Western Australian conservation parks and bushland.

Kimberley	One record from Kununurra.
Pilbara	No records, rarely recorded from conservation areas (S. van Leeuwen personal communication.).
Desert	Rudall River, Cape Range, Mount Augustus, Kennedy Range, Zuytdorp, Francois Peron, Goongarrie and Boorabbin National Parks. Wanjarrie Nature Reserve. Mount Elvirie State Forest.
Northern sandplains	Kalbarri National Park (major weed along Murchison River flats), many nature reserves, Abrolhos Islands.
Wheatbelt	Lake Magenta Nature Reserve, many other nature reserves (D. Mitchell personal communication).
Swan and forests	Scattered records in reserves and offshore islands around Perth. Tuart Forest and Leeuwin-Naturaliste National Parks.
Karri and south coast	Scattered records in reserves, National Parks and offshore islands from Denmark to Cape Arid (J. Moore personal communication). Eucla National Park.

Table 3. Areas affected.

Disturbed Sites:	Previously heavily grazed Stock holding pens Old building sites Tourist sites Firebreaks, tracks Watering points
Riverine Sites	
Alluvial Flats:	Claypans Edges saline lakes
Granite Rock Margins	
Semi-arid Islands:	Seabird colonies Fisherman settlements

or nutrient enrichment, such as on degraded or eroded areas or in stockyards and holding paddocks. Exotic species are generally rare or absent in areas not otherwise degraded'.

On pastoral properties it is found on tracks, stock pens and watering points. Natural areas invaded by *Emex* in the pastoral zone are edges of creeks, riverine flats, alluvial flats (claypans, edges saline lakes) and granite rocks.

Areas impacted

Table 3 lists areas and habitats affected by *Emex*. While it is true that highly disturbed sites predominate, some naturally disturbed sites such as seabird rookeries are invaded and *Emex* has become a major weed of the Abrolhos Islands. These islands contain some of the largest rookeries in Australia.

Natural areas invaded by *Emex* are edges of creeks, riverine flats, alluvial flats (claypans, edges saline lakes) and granite rocks. These are the areas recognized by Morton *et al.* (1995) as centres of biological diversity and refugia in arid Western Australia. Transference of resources and habitat to weedy species such as *Emex* in these areas is undesirable. A biological control program would be the only option in these remote areas.

Positive effects

Emex has become a major food source for Major Mitchell cockatoos and inland red tailed black cockatoos, and a minor source for galahs, little and long billed corellas in the farming areas of the north-eastern Wheatbelt since clearing (Rowley 1990 and Saunders *et al.* 1985). Both the Major Mitchell cockatoos and inland red tailed black cockatoos have expanded their ranges into these areas following farming and Saunders and Ingram (1995) feel that any successful control of doublegee will see the loss of the first two birds from these areas.

Conclusion

Emex australis is a widespread weed of conservation reserves in southern Australia, mostly occurring in disturbed sites. It does, however, invade naturally disturbed and high productivity areas in arid and semi-arid Western Australia, which can be of considerable conservation significance. There is little known about the effects of such invasion in these remote areas.

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Doublegee (*Emex australis*) in the great southern areas of Western Australia

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Abstract
Doublegee is a prickly weed of crops, pastures, orchards, vineyards, horticultural and industrial areas of the great southern areas of Western Australia.

Distribution
It occurs predominantly on the fertile loamy soils and sand over ironstone soils. It rarely forms heavy infestations on the deeper sands.

Significance
Doublegee could be classed as a minor weed of crops and pastures and a significant weed of horticulture in the great southern area of Western Australia.

Control
In cereals it is usually controlled by dicamba or chlorsulfuron. In grain legumes it is usually controlled by simazine, cyanazine or diuron. In orchards and vineyards glyphosate and paraquat are usually used. In industrial areas and for eradicating small areas a combination of Tordon® and dicamba is common. In clover based pastures Broadstrike® is providing high levels of control especially when applied early in the season. Late germinations can be a problem that may require a second application. Broadstrike is cheaper and less damaging than the older treatments of Tribunil®, 2,4-DB and diuron + 2,4-DB. Increased sowing of perennial pasture species is also leading to a natural decline in the effects of doublegee in pasture. In most situations, except lupins, the new crop and horticultural species, there are now adequate techniques for controlling doublegee.

Emex australis in northern agricultural regions of Western Australia

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Abstract
***Emex australis* is a major problem in the northern region of Western Australia's wheatbelt, particularly when a legume phase is included in rotations. The weed's staggered germination and lack of registered herbicides for all situations exacerbate the problem. Examples of herbicides and associated costs for lupins, field peas, faba beans, chickpeas and wheat are given.**

Introduction
Emex australis is a one of the three major broadleaf weeds in the northern region and the majority of growers rely heavily on herbicides for control of *E. australis* in cropping rotations. My aim is to impress on you the extent of the problem of *E. australis* (doublegees in Western Australia) and the related cost of control to growers in the northern region of Western Australia's wheatbelt.

The region
Northern region extends from Northam up to Ajana. Rainfall ranges from 600 mm on the coast through to less than 325 mm inland. Soils in the region range from deep yellow sands, acid wodgill sands and leached white sands, through to duplex soils, red loamy sands. The season is best described as short—cropping begins in late April and ceases by late June, and harvest begins in late October, finishing by late December—depending on the season.

Doublegees are a problem throughout a large part of the region, particularly when a legume phase is included in the rotations. The warmer conditions in the northern region are conducive to its development.

Influence of crop rotations
In the region, legumes are an important component of continuous cropping rotations. The cereal/lupin rotation has been developed for sandplain soils in the last 20 years, with the development of pulses in rotation with cereals on the heavier soils in the last five years. However, it is the difficulty in controlling *Emex australis* in legumes that has lead to its importance as a major weed in the region.

Control of *Emex australis* is reliant on pre-seeding or post-seeding herbicides however there are no options registered for post-emergence *Emex australis* control in legumes. The only option growers have for control in the crop are suppression or unregistered salvage options. This problem is exacerbated with the staggered germination of doublegees.

Canola is being developed in the region and at present, there are no registered herbicides to control *Emex australis*. A promising development in the control of *Emex australis* is the triazine resistant canola, suited to the lower parts of the region. Shorter season varieties suitable to the upper part of the region are being developed and should be released in 1996.

The legume component of pastures varies and both low stocking rates and reduced herbicide efficacy ensure *Emex australis* populations explode in the pasture/cereal rotations.

Cost
Competition from *Emex australis* with the crop will reduce yields although competition curves have not been defined to my knowledge at present. Contamination with the grain can be easily removed, but at a cost of between $12–18 per tonne of grain. Herbicide control can be costly, particularly if post-emergence control is required (Table 1). About 30% of cases can control doublegees with just one spray application but with 50% of cases they need to use a two pass operation, a cost of up to $32.

It is very important for growers to aim for excellent control in the wheat phase due to the difficulty of control in legumes. In addition, *Emex australis* can be easily moved within a paddock; and from paddock to paddock on tyres.

Conclusion
Emex australis is a pain, both physically and economically and a large proportion of growers in the northern region have to actively undertake control.

Table 1. Herbicides used to control *Emex australis*.

	Pre-seeding	Pre-emergence	Post-emergence
Lupins	simazine, diuron, atrazine	diuron	simazine, metosulam
Field peas	Bladex®	Spinnaker®	Bladex
Faba beans		Spinnaker	
Chickpeas	nothing		
Wheat	chlorsulfuron Logran®		metsulfuron methyl Jaguar®, Terbutryne® diuron +2,4 D amine, diuron+ MCPA
Cost ha^{-1} (approx.)	$7–18	$13–21	$6–15

Emex spp. in South Australia

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Abstract

***Emex australis* (three-cornered jack) is found throughout the agricultural areas of South Australia, although it is of greater importance in the cropping and Riverland horticultural areas than in the high rainfall zones of the state. *E. spinosa* (lesser jack) is not as widespread. In the cropping areas *Emex* spp. can contaminate grain, in particular pulse crops. However, current herbicide strategies have kept the number of declined or contaminated loads to a minimum. In the horticultural areas *E. australis* has caused problems as a contaminant of dried fruit. *Emex* spp., if not managed effectively by urban councils, can reduce the amenity value of sports fields and parklands.**

Introduction

Emex australis is commonly known in South Australia as three-cornered jack and is found throughout the agricultural areas of the State. *E. australis* was first recorded in South Australia in 1848 and has since been proclaimed under various Acts of Parliament including Noxious Weeds Act 1931–39, Weeds Act 1956–69, Pest Plant Act 1975 and the Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986. It causes most problems as a weed of annual crops and pastures in the cereal zone and as a contaminant of dried vine fruit in the Riverland horticultural areas. In addition, if not controlled, it can reduce the amenity value of public lands.

Distribution in South Australia

Emex australis is more commonly found in the lower rainfall cereal zone of the state (250–500 mm annual rainfall) (Figure 1). Within these areas it tends to be more common on the lighter soil types although it can grow successfully on the heavier soils. In the high rainfall zone where grazing is the dominant land use *E. australis* is not a common weed although movement of achenes to these areas in fodder does occur. However, it does occur where cereal and pulse crops are grown in preference to pastures for grazing in the upper part of the South-East region and in the high rainfall zone of the Central region north of Adelaide (Figure 2).

Weiss and Simmons (1977) found that under either high or low temperature regimes (day / night temperatures of 30 / 25°C or 10 / 5°C respectively) flowering was delayed and seed production reduced when compared to optimum day / night temperatures for growth of 15 / 10°C to 20 / 15°C. Panetta and Randall (1993) reported that *E. australis* was a weak competitor in a grazed annual pasture where *Trifolium* and *Hordeum* spp. were present.

Gilby and Weiss (1990) reported that unburied *E. australis* seed has a low germinability and that cultivation and subsequent seed burial increased plant emergence. These results were supported by Panetta and Randall (1994) who also reported that the amount of natural seed burial in a grazed pasture was relatively low.

These factors could explain why *E. australis* is less common in those parts of the high rainfall zone which have a large proportion of agricultural land devoted to pasture production and grazing and have a relatively cool climate. In the lower rainfall areas pastures tend to be less vigorous and have lower pasture plant densities than pastures in high rainfall areas and this may allow *E. australis* to set more seed and thus increase the amount of seed in the soil seed bank. Frequency of cultivation is less in areas under permanent pasture than where annual grain crops are grown as part of the rotation.

Emex spinosa (lesser jack) is less widespread and, at this stage, is most commonly found in the western portion of the mid and upper north of the Central Region and in the eastern portion of Eyre Peninsula Region of South Australia (Figure 2).

Importance as a weed

Emex australis, if not controlled, can compete with cereal and pulse crops and reduce grain production. Black and Dyson (1993) collated trial data from many herbicide evaluation trials in the major cereal growing areas of South Australia to produce a model which can predict the likely yield benefits in cereal crops if a weed or combination of weeds at various weed densities is controlled with herbicides at several different growth stages of the crop. Information is presented in this model for 38 weeds including *E. australis*. If, for example, 33 plants m^{-2} of *E. australis* are controlled at the early post-emergence stage (one to four leaves) in a cereal crop with a weed-free yield potential of 2000 kg ha^{-1}, the predicted yield benefit from controlling the weed is 122 kg ha^{-1}.

In addition to competing with the crop and affecting grain yields *Emex* spp. can contaminate grain samples. The plant has the ability, when supported by a grain crop, to develop a more erect growth habit and as a result *Emex* spp. achenes can be harvested with the grain. The majority of the achenes can be removed if the seed is graded and cleaned. However, the removal becomes more difficult if the spines

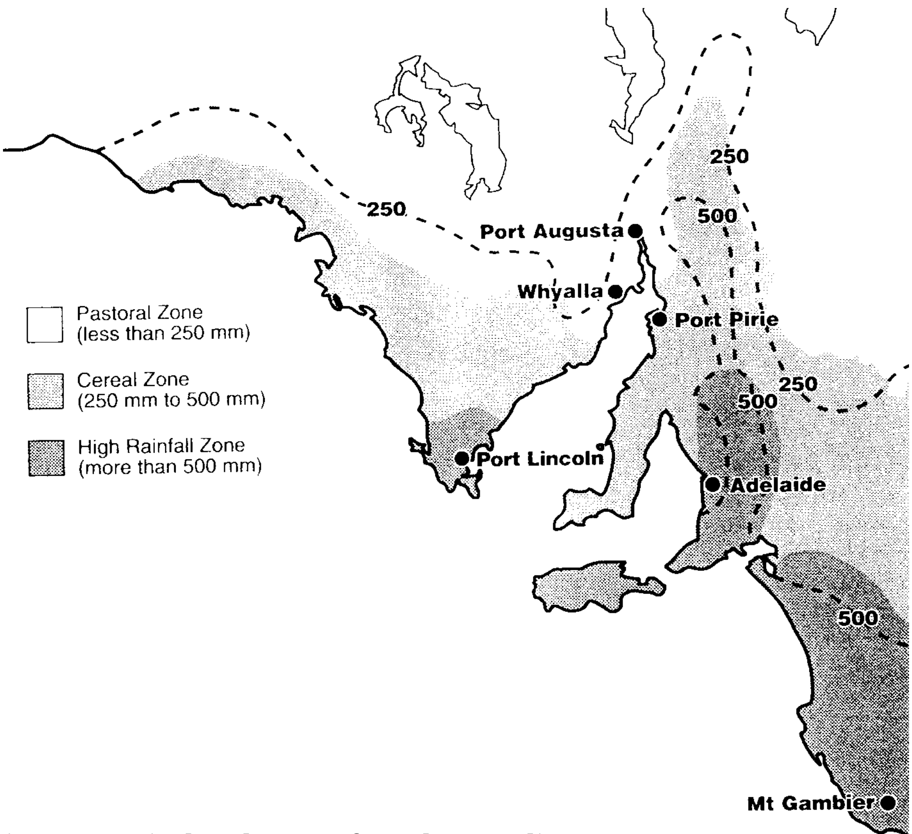

Figure 1. Agricultural zones of South Australia.

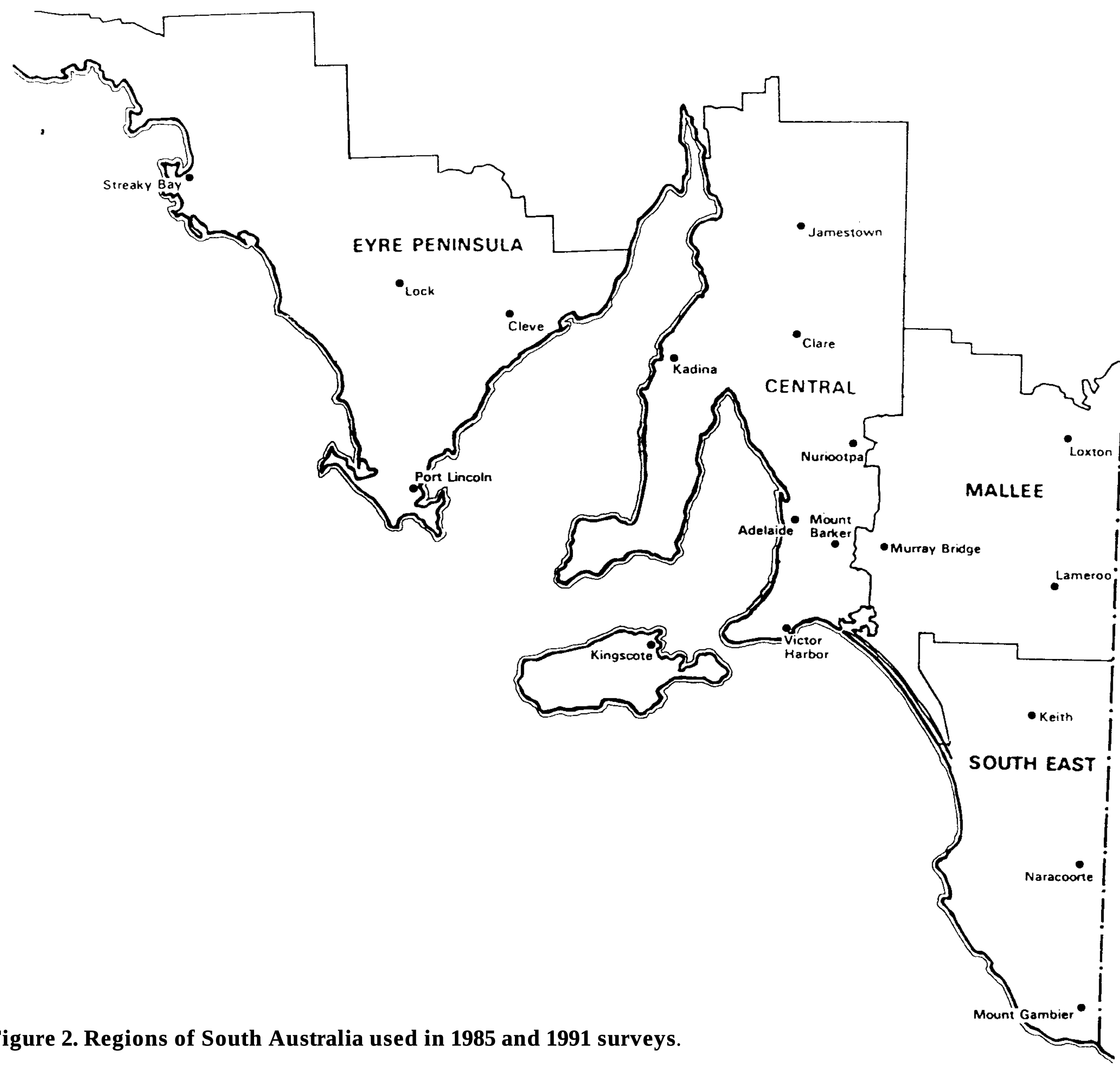

Figure 2. Regions of South Australia used in 1985 and 1991 surveys.

are broken off during the threshing process or the seeds are present in a pulse grain sample such as vetch (*Vicia* spp.) or peas (*Pisum sativum*).

Tolerance levels for *Emex* spp. as a contaminant range from nil achenes in a sample for malting and F1 (feed) barley and milling oats to five achenes 200 g^{-1} for pulse grains (Table 1).

Although the receival standards are clearly defined for *Emex* spp. the number of barley samples contaminated (Table 2) and detections in wheat and pulse grain silo samples (Table 3) is relatively low compared to the number of samples tested. The approximate number of barley samples tested annually ranges from 13 000 to 18 000 depending on seasonal conditions. The number of wheat and pulse grain silos tested is approximately 120 and 30–40 respectively.

In addition to the contaminated samples accepted by the Australian Wheat Board and Australian Barley Board the South Australian Co-operative Bulk Handling Ltd. (SACBH), which operates the silo system in rural areas, can decline to accept loads due to many clearly defined causes including high moisture content, live insects, specific seed contaminants, unmillable material and unspecified foreign material. Table 4 gives details of the number of declined loads due to *Emex* spp. contamination and also gives an annual total of loads declined from all causes. The number of declined loads due to *Emex* spp. contamination is very low given that the number of loads checked by SACBH is any one year can range between 150 000 and 300 000 depending on seasonal conditions. However, these figures may under-estimate the amount of grain contamination as farmers can deliver contaminated grain direct to stock feed processors instead of through SACBH to the Australian Wheat or Barley Boards.

Table 1. South Australian cereal and pulse grain receival standards for *Emex* spp. contamination (1994/95).

Grain	Category, grade or commodity	Tolerance levels for *Emex* spp. achenes
Wheat[A]	All grades	8 / half litre
Triticale[A]	All grades	4 / half litre
Pulse crops[A]	peas, lupins, chickpeas, faba beans	5 / 200 grams
Barley[B]	Malting, F1 (feed), F2 (feed)	nil, nil, 1 / 100 grams
Oats[B]	Milling, feed	nil, 5 / litre

[A] Source: Australian Wheat Board.
[B] Source: Australian Barley Board.

Whilst *Emex* spp. contamination of grain does cause some concern it is more of a potential problem if management practices currently used to control the plant fail and the control obtained in grain crops, particularly grain legumes, becomes less effective.

In 1980 a review panel investigated the status and needs of weed research in South Australia (D.W. Stephenson unpublished data) and a list of the ten worst weeds of pastures was proposed (Table 5). *Emex* spp. was not listed. This proposed list did not consider weeds of crops.

As information on the distribution, abundance and relative importance of crop and pasture weeds in South Australia was limited, a farmer survey was conducted in 1985 (J.A. Crocker and G.J. Mitchell unpublished data). The information obtained from this survey was to be used as a guide for determining future research and extension priorities. Subsequent to this a follow-up survey was conducted in 1991 (A.H. Mayfield and R. Edwards unpublished GRDC report) to provide a basis for prioritizing weed research in South Australia.

The 1991 survey also included agronomists, resellers and pest plant officers. The number and regional origin of replies obtained in each of the surveys is presented in Table 6.

In the 1985 survey *E. australis* ranked as the sixth most important weed (Table 7). Rankings were based on the relative severity rating which was calculated from the rating given to the weed and the number of times the rating was assigned to a particular weed by the respondents. D.W. Stephenson (unpublished data) extracted data from the 1985 survey which related specifically to pastures and the ranking obtained by *E. australis* in pastures was eight (Table 7).

However, in the 1991 survey *E. australis* was ranked fourteen (Table 8) which suggested that farmer perceptions of the importance of it as a weed of crops and pastures had declined since 1985. Agronomists, resellers and pest plant officers ranked it thirteen (Table 8) indicating that all people involved in the surveys held similar opinions on *E. australis*. However, it is of interest that farmers tended to rank perennial weeds much lower than the other survey respondents. This may be because they are not as aware of the difficulty in managing these weeds once they become established.

Table 2. *Emex* spp. contamination in barley samples in South Australia.

Year	Site	Number of contaminated samples	Annual total number of contaminated samples
1993/94	Apamurra	1	
	Cowell	1	
	Lameroo	1	
	Port Pirie	2	
	Wudinna	1	
	Arno Bay	2	
	Port Adelaide	2	
	Kyancutta	1	11
1994/95	Bordertown	1	
	Wharminda	1	2

Source: Australian Barley Board.

Table 3. *Emex* spp. detections in silo samples of wheat and pulse grains in South Australia.

Year	Silo Site	Grain	Level detected seeds kg^{-1}
1992/93	Mallala	wheat	5
	Monarto South	wheat	4
1993/94	Hamley Bridge	pea	4
	Hamley Bridge	faba beans	1
	Mallala	pea	3
	Strathalbyn	pea	2
	Wilmington	wheat	1
1994/95	–	–	–

Source: Australian Wheat Board.

Table 4. Number of declined loads due to *Emex* spp. contamination and the number of declined loads from all causes.

Year	Number of declined loads				
	Emex spp.				Annual total from all causes
	Site	Grain	Loads at each site	Annual total (all sites)	
90/91	–	–	–	Nil	274
91/92	Crystal Brook	peas	1		566
	Wallaroo	peas	1		
	Balaklava	barley	1		
	Mallala	peas	1		
	Nantawarra	barley	1		
	Paskeville	barley	1		
	Two Wells	peas	1	7	
92/93	Ardrossan	peas	2		1110
	Balaklava	barley	3		
	Port Giles	barley	7		
	Port Pirie	barley	2		
		lupins	1		
	Wallaroo	barley	1		
		chickpeas	1		
		peas	3		
		wheat	1	21	
93/94	Port Adelaide	peas	1		423
	Tumby Bay	barley	1		
	Port Pirie	lupins	1	3	
94/95	Wallaroo	peas	1	1	306

Source: South Australian Co-operative Bulk Handling Limited.

Table 5. 1980 Review Panel proposal of the worst weeds of pastures in South Australia.

Rank	Weed
1.	Capeweed (*Arctotheca calendula*)
2.	Soursob (*Oxalis pes-caprae*)
3.	Thistles (various)
4.	Barley grass (*Hordeum leporinum*)
5.	Dock and sorrel (*Rumex* spp.)
6.	Horehound (*Marrubium vulgare*)
7.	Brome grass (*Bromus* spp.)
8.	Cape tulip (*Homeria* spp.)
9.	Storksbill (*Erodium* spp.)
10.	Bracken (*Pteridium* spp.)

Table 6. Number and origin of survey replies.

Region[A]	1985 Survey		1991 Survey	
	Number of replies	%	Number of replies	%
Eyre Peninsula	86	38	64	26
Central	92	40	109	45
Mallee	23	10	35	15
South-East	26	12	34	14
Total	227	100	242	100

[A] See Figure 2.

Table 7. The 1985 survey results showing overall rank (and relative severity rating) for weeds in crops and pasture (Crocker and Mitchell, unpublished data) and pasture only (Stephenson, unpublished data).

Weed	Crop and pasture		Pasture only	
	Rank	(relative severity rating)	Rank	(relative severity ranking)
Brome grass (*Bromus* spp.)	1	(46.9)	3	(20.9)
Rye grass (*Lolium rigidum*)	2	(46.0)	4	(19.8)
Barley grass (*Hordeum* spp.)	3	(36.9)	2	(23.0)
Wild oats (*Avena* spp.)	4	(34.0)	14	(7.5)
Soursob (*Oxalis pes-caprae*)	5	(25.8)	5	(16.6)
Three cornered jack (*Emex australis*)	6	(23.1)	8	(11.6)
Salvation Jane (*Echium plantagineum*)	7	(21.8)	1	(23.1)
Horehound (*Marrubium vulgare*)	8	(20.9)	7	(14.1)
Turnip (*Brassica tournefortii*)	9	(19.2)	13	(7.7)
Capeweed (*Arctotheca calendula*)	10	(16.3)	6	(15.0)
Cut leaf mignonette (*Reseda lutea*)	11	(15.2)	12	(8.7)
Ice plant (*Gasoul crystallinum*)	12	(12.3)	19	(5.3)
Radish (*Raphanus raphanistrum*)	13	(11.8)	–	–
Mustard (*Sisymbrium orientale*)	14	(11.4)	16	(7.0)
Silver grass (*Vulpia* spp.)	15	(11.3)	9	(10.0)
Saffron thistle (*Carthamus lanatus*)	16	(11.1)	17	(6.8)
Yellow burr weed (*Amsinckia* spp.)	17	(10.7)	18	(6.2)
Skeleton weed (*Chondrilla juncea*)	18	(10.4)	15	(7.2)
Onion weed (*Asphodelus fistulosus*)	19	(10.2)	20	(5.1)
Dock (*Rumex* spp.)	20	(9.5)	10	(9.0)

Table 8. A comparison of farmer and agronomist, reseller and pest plant officer rankings of weeds in the 1991 survey with the overall ranking of the same weeds in 1985.

Weed	1991 Survey results		Overall rank in 1985 survey
	Farmer rankings	Agronomist, reseller and pest plant officer rankings	
Rye grass (*Lolium rigidum*)	1	1	2
Capeweed (*Arctotheca calendula*)	2	6	10
Wild oats (*Avena* spp.)	3	18	4
Brome grass (*Bromus* spp.)	4	5	1
Barley grass (*Hordeum* spp.)	5	11	3
Soursob (*Oxalis pes-caprae*)	6	>20	5
Skeleton weed (*Chondrilla juncea*)	7	2	18
Bedstraw (*Galium tricornutum*)	8	4	40
Silver grass (*Vulpia* spp.)	9	3	15
Mustard (*Sisymbrium orientale*)	10	>20	14
Radish (*Raphanus raphanistrum*)	11	=13	13
Turnip (*Brassica tournefortii*)	12	>20	9
Sheepweed (*Buglossoides arvensis*)	13	15	20
Three cornered jack (*Emex australis*)	14	=13	6
Stemless thistle (*Onopordum acaulon*)	15	19	22
Saffron thistle (*Carthamus lanatus*)	16	>20	16
Cut leaf mignonette (*Reseda lutea*)	17	8	11
Silver leaf nightshade (*Solanum elaeagnifolium*)	18	9	31
Wireweed (*Polygonum* spp.)	19	>20	29
Yellow burr weed (*Amsinckia* spp.)	20	>20	17

In addition to its importance in grain crops and dryland pastures *E. australis* is a major weed in the horticultural areas of the Riverland area of South Australia. The main problem is contamination of dried fruit and fresh table grapes with the spiny achenes which affects both local and export markets (W. Panagiotopoulos personal communication). Horticultural crops, in general, have less tolerance to many of the herbicides which can be used to control *E. australis* than dryland cereal and pulse crops and this increases the severity of the problem. The problem of *E. australis* in dried vine fruit production is covered in greater detail elsewhere in the proceedings and the issues raised in that paper are relevant to the South Australian situation.

Emex spp. are not a major problem in the small seeds industry as it can either be controlled with selective herbicides or graded out of seed after harvest (P. Smith personal communication).

In irrigated pastures *E. australis* can be controlled effectively. However, poor and run-down pastures with low numbers of desirable species are unable to compete strongly and in this situation it can cause problems if the pasture is cut for hay as the achenes make handling of the hay difficult, especially with small square bales, and reduce the palatability of the product.

In non-agricultural situations *Emex* spp. are a problem in amenity areas such as sports fields and parklands where the spiny achenes can affect the enjoyment of these facilities. In reserves and parks where cultivation does not occur and soil disturbance from other causes is minimal *Emex* spp. are not a major problem and their spread and growth tends to be restricted to car park areas and tracks (R. Carter personal communication).

Discussion

Emex spp. are widespread in South Australia although only causing serious problems in cropping and horticultural areas. In permanent or long term pasture areas problems generally occur when the pasture becomes run-down and non-competitive.

In the cropping areas the use of selective herbicides, in particular trifluralin, when incorporated thoroughly, in both the cereal and pulse phases of rotations and the sulfonylureas in the cereal phase, has reduced the farmer perception of *Emex* spp. as a problem weed. This is reflected in the survey results of 1985 and 1991. The farmer perception appears to be supported by information from grain handling authorities relating to the number of declined loads and contaminated samples as a result of the presence of *Emex* spp. achenes.

One of the issues of *Emex* spp. management is the life of the soil seed bank and seed dormancy. It is of interest that where a nematicide, Nemadi® (a.i. 1950g L^{-1} EDB) was used to control cereal cyst nematodes (*Heterodera avenae*) in cereals during the early to mid 1980s the emergence of *E. australis* was visually far greater than in adjacent untreated areas (T. Dillon personal communication and personal observations). This tended to suggest that the active ingredient (EDB) may have had some effect on seed dormancy.

Emex spp. are a proclaimed weeds under the Animal and Plant Control Act, 1986 and the objectives of the *Emex* spp. policy are to eradicate small isolated infestations of *Emex* spp., to minimize spread from generally infested areas and to prevent introduction of *Emex* spp. to clean areas. Landowners are required to destroy the plant and inhibit its propagation as far as is reasonably possible (R. Carter personal communication).

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Emex australis and dried vine fruit production in Sunraysia

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Abstract

Australia is renowned for the production of quality dried sultanas free of contaminants. However, one contaminant which poses a threat to Australia's reputation is *Emex australis*. Because of the spined nature of the seed, it readily contaminates fruit during the harvest and drying processes conducted on growers properties. Once in the fruit they are difficult to remove despite rigorous cleaning at packing sheds. Controlling *E. australis* in the vineyard is difficult and costly with growers seeking an alternative control strategy which is cheaper and more effective than cultivation, mulch, cover crops or weedicide.

Introduction

The thought of biting into a piece of cake or muesli bar and ending up with a mouthful of prickles is enough to put anyone off buying products containing dried sultanas! People bearing witness to such experiences to family members and friends, rapidly develop concerns about buying products from the same company or even buying sultanas full stop. This is a very real problem for companies such as Kellogg's and Uncle Tobys who buy thousands of tonnes of Australian dried sultanas each year and it only takes one seed to cost these companies thousands in lost sales.

In 1990 a workshop was held in Mildura initiated by the Dried Fruits Research and Development Council, to investigate a group of weeds called Spiked Weed Seeds (which included *Emex australis*) and their control in vineyards (Buchanan 1990). As a result of this workshop the project 'Spiked Weed Seed Management and Elimination' was developed to try and prevent spiked weed seed contamination of dried vine fruit by identifying the points during production that are at risk of contamination, evaluating cleaning methods used in packing sheds and developing vineyard management practices to prevent growth and seed production from these weeds (Pohlner 1994).

How do the seeds of *E. australis* get into the fruit in the first place?

In order to minimize the amount of contamination which occurs on growers properties, the points during production which are at risk of contamination were identified during the two main steps conducted on growers properties; picking and drying.

During picking plastic buckets are used to collect the fresh grapes from the vineyard. These are the main source of contamination. When these buckets are thrown into the vineyard or dragged between vines during picking, the *E. australis* seeds on the ground stick into the sides or bottom of the soft plastic. This was observed to occur mainly in the undervine area where the buckets are left until they are collected. When the buckets are stacked on a trailer to take them to the drying racks, the seeds dislodge and fall onto the full bucket of fruit beneath it resulting in direct contamination.

Drying of grapes starts on drying racks where fruit is spread evenly over different levels of wire netting and left for a couple of weeks to reduce the moisture levels in the berries. When they have reached a certain moisture level they are shaken down through the levels of wire netting and spread over a plastic ground-sheet to 'finish' dry in the sun. During finish drying, seeds may flick into the fruit when people walk past the plastic, when corners of the plastic flap in the wind or when the edges of the plastic are folded in to prevent the fruit from taking up moisture overnight and when it rains. During this process seeds are scraped off from the underside of the plastic and fall directly into the fruit. Fruit is then collected into bulk bins (½ tonne) and delivered to central packing sheds for cleaning.

Measures employed to remove *E. australis* from dried vine fruit

It is difficult to remove seeds from dried vine fruit as they are similar in terms of size and colour to dried sultana berries. Many seeds actually embed into the dried berries camouflaging themselves. Packing sheds employ extensive cleaning processes whereby the fruit is washed, put through vibrating sieves, passed through blowers, vacuum extractors, an infra-red laser sorter and hand sorted in an attempt to remove all contaminants before the fruit is packed.

Trials conducted in the packing shed, which involved sorting through trash to recover *E. australis* seed removed at each extraction point during cleaning, indicated that the majority of seeds were extracted by 'blowers' because loose seeds are lighter in weight than the fruit. Infrared laser sorters are a relatively recent addition to packing sheds. A lot of emphasis is placed on the laser sorter to remove every trace of contamination from the dried vine fruit. Our trials did not recover any seed from the trash removed at the laser-sorter during the processing of 100 tonnes of dried vine fruit.

When cleaning dried sultanas, there are no guarantees that the final product will be completely free of *E. australis* even if it has passed through a laser-sorter. The only way to guarantee this is to make sure there is no seed on the property on which the fruit is produced.

The dried vine fruits industry has undertaken a couple of methods to minimize the amount of *E. australis* seeds in the fruit delivered to the packing sheds. Financial penalties are in place which vary depending on the amount of contamination in the fruit. The effectiveness of this technique is limited because of the difficulty in detecting the seeds by sight at the shed door, with few growers having received a penalty. A more positive approach has been to offer a financial incentive of $40 per tonne of dried sultanas to those growers who can show that their property is 'spiked weed seed free'. Few growers are registered for this scheme as stringent conditions apply making many growers ineligible.

Review of vineyard management practices to control *E. australis*

Treatments

A field trial was set up to test combinations of four primary weed control methods commonly used in vineyards to control weeds; mulching, cover cropping, chemical use and cultivation. Treatment applications are summarized in Table 1.

Treatments were replicated and randomly applied over 274 plots (1 × 10 m) using an incomplete block design over three separate sites.

All plots were cultivated initially and every following May and September (except plots with permanent cover crops and mulch) to simulate block operations of incorporating fertilizers, sowing cover crops or incorporating winter weed growth for frost control.

Cultivations Cultivations were conducted using a 1.4 m wide rotary cultivator to a depth of approximately 5 cm as this is the documented depth from which the majority of seeds germinate.

Herbicides Herbicides were applied using a hand pushed, covered spray unit designed to cover the width of the plots. The unit had three outlets (Dalveen color jet LF 110°2 nozzles) and ran at 150 kPa.

The herbicide unit was passed over the plots twice ensuring a uniform distribution of chemical, and spray mixes were calibrated accordingly. Rates of herbicides applied were; Basta 5 L ha^{-1}, Tribunil 550 mL ha^{-1}, simazine 5 L ha^{-1}, Diuron(800) 1.7 L ha^{-1}, Solicam 5 kg ha^{-1} (year 1) and 2.5 kg ha^{-1} (year 2).

Solicam applied for treatments G and K appeared to severely inhibit the development and growth of the cereal cover crops and failed to effectively control the growth of *E. australis.* In the second year Diuron(800) was substituted for Solicam, at the rate 1.7 kg ha^{-1}, recommended to control three cornered jacks in wheat and barley. Diuron(800) is registered for use in vineyards as a residual herbicide. The rate used in conjunction with the cover crop was half the recommended rate for vineyards making it cheaper with less risk of vine damage from chemical leaching.

Treatments H, I, J and K, were assigned a single summer application of Basta (Table 1) but an application error saw three sprays applied at five weekly intervals. These treatments differed by a final spray from treatments D, E, F, and G where Basta was applied every five weeks.

Table 1. Treatments developed for spiked weed seed control in vineyards including three cornered jack.

	Summer control	Winter control
A	Cultivated every five weeks	Cultivated every five weeks
B	Plots left untreated until March cultivation	Plots left untreated until September
C	Plots left untreated until March cultivation	Solicam applied once after cultivation
D	After weed emergence, Basta was applied every five weeks	After weed emergence, Basta was applied, annual legume cover crop was sown late May
E	After weed emergence, Basta was applied every five weeks	After weed emergence, Basta was applied, annual cereal cover crop was sown late May
F	After weed emergence, Basta was sprayed every five weeks	Annual cereal cover crop was sown immediately after cultivation and Tribunil was applied in April and mid June
G	After weed emergence, Basta was sprayed every five weeks	Annual cereal cover crop was sown immediately after cultivation and separate applications of Tribunil and Solicam were made on the same day, mid May
H	After weed emergence, Basta was sprayed once	After weed emergence, Basta was applied, annual legume cover crop was sown late May
I	After weed emergence, Basta was sprayed once	After weed emergence, Basta was applied, annual cereal cover crop was sown late May
J	After weed emergence, Basta was sprayed once	Annual cereal cover crop was sown immediately after cultivation, Tribunil was applied mid May and mid June
K	After weed emergence, Basta was sprayed once	Annual cereal cover crop was sown immediately after cultivation, Tribunil and Solicam were applied mid May as separate sprays on the same day
L	Winter cover crop mulched	After weed emergence, Basta was applied, annual cereal cover crop was sown in April, Tribunil was applied mid May and mid June
M	Perennial cover crop	After weed emergence, Basta was applied, perennial cover crop was sown in April, Tribunil was applied mid May and mid June
N	Perennial cover crop	Perennial cover crop was sown (no herbicides)
O	Cultivated every five weeks	Annual cereal cover crop was sown (no herbicides)
P	Winter cover crop was mulched	Annual cereal cover crop was sown (no herbicides)
Q	Cultivated every five weeks	High density cereal cover crop was sown (no herbicides)
R	Winter cover crop was mulched	High density cereal cover crop was sown (no herbicides)
S	Solicam was applied late October	Solicam was applied late April
T	Mulch topped up	Grapemark Mulch was applied
U	Simazine was applied late October	Simazine was applied late April

Cover crops All plots with cover crops were fertilized annually with double super phosphate at a rate of 1200 kg ha^{-1}, distributed evenly on the soil's surface using a mechanical broadcaster and watered in with a 4 h overhead sprinkler irrigation.

The annual cereal cover crops used in the first year was rye corn at a rate of 90 kg ha^{-1}. The rye corn produced few tillers, leaving the soil's surface uncovered and exposed to sunlight. It appeared to have little competitive effect against the germination and growth of the *E. australis* and so was replaced with Forest barley in the second year. Forest barley was chosen for its early tillering and high bulk density offering an early dense soil cover. Forest barley was sown using a Connor Shea seed drill at a rate of 66 kg ha^{-1}. Paraggio medic was the annual legume cover crop used in both years of the trial at a rate of 1.5 kg ha^{-1}.

High density cover crop treatments Q and R, consisted of rye corn at a rate of 180 kg ha^{-1} and Forest barley at a rate of 132 kg ha^{-1}.

Summer mulching of cereal cover crops, using a Nobili BNE Triturator mulcher, was conducted in September (treatments L and P), leaving the mulch on the soil surface to suppress summer weed growth.

The permanent cover crop sown was a seed mix called 'Blockout' composed of rye corn, fescue, and clover seed at rate 160 kg ha^{-1}. Permanent cover crops were mulched with a Triturator mulcher in August simulating frost control practices in vineyards.

Mulch Plots assigned to the mulch treatments were initially sprayed with Solicam at 5 kg ha^{-1} with grape mark (dried grape bunch stems) applied to a depth of approximately 30 cm. Weeds that grew through the mulch, or germinated from seed settling on top of the mulch, were controlled with a single application of Basta (5 L ha^{-1}) in early spring, to simulate frost control practices, and in autumn to control summer weed growth. After the first year the mulch was topped up where it had decomposed to maintain its effective volume. The mulch depth was maintained throughout the experiment.

Results

A 20 inch soil auger was used to take three soil samples for each plot at the start of the trial and after two years of treatment application. The seeds from these soil samples were removed and counted.

A Genstat analysis, with a $\log_{10}$ +1 transformation, was conducted using soil seed counts to determine the amount of seed production over the two years for the various treatments. Changes in the number of seeds present was expressed in terms of 'per cent change' over the two years (Table 2). 'Per cent Change' was calculated using the equation; per cent change = 100 x $[10^{(\text{mean difference})} -1]$. A negative 'per cent change' indicated a reduction in seed number and a positive 'per cent change' indicated an increase in seed number from the original seed count for each plot conducted before the application of treatments.

Table 2. Changes in seed numbers for various treatments after two years of treatment application (1992–94).

Treatment	% change	Mean difference
J	-82.4	-0.755
F	-82.3	-0.752
T	-81.0	-0.722
I	-78.7	-0.672
E	-75.2	-0.606
G	-74.4	-0.593
A	-74.2	-0.588
K	-73.9	-0.584
U	-70.6	-0.532
D	-68.5	-0.502
O	-62.4	-0.425
Q	-60.5	-0.403
S	-53.6	-0.334
R	-48.9	-0.291
H	-47.2	-0.277
C	-27.4	-0.139
B	-8.5	-0.039
M	-2.0	-0.009
L	1.0	0.005
P	10.0	0.042
N	59.8	0.204

LSD (mean difference) = 0.2364

Cultivation effects Cultivating every five weeks during summer and winter (treatment A) reduced the level of seed produced by 74% and was significantly more effective than applying no control measure after an initial cultivation (treatment B).

Herbicide effects

Solicam A single application of Solicam in the winter (treatment C) resulted in seed levels not significantly different from applying no control treatment over the two years. However applying Solicam in summer, in addition to the winter application (treatment S) was more effective than no control (treatment B).

Simazine Simazine applications in summer and winter (treatment U) resulted in significantly fewer seed than applying no control (treatment B). Over the two years this treatment was equally as effective as cultivating every five weeks (treatment A) in reducing the level of seed production.

Tribunil Tribunil applications combined with cereal cover crops (treatments J, F and G, K) resulted in reduced seed levels that were amongst the best control treatments used. Although still in the processes of being registered for use in vineyards, this chemical has great potential for use in Sunraysia vineyards.

When Tribunil was used in conjunction with the perennial cover crop Blockout (treatment M) the seed levels produced were not significantly different from treatment N, where no Tribunil was applied. These treatments were significantly less effective at preventing seed production than when no treatment was applied (treatment B).

Diuron Diuron application in conjunction with a cereal cover crop, although not evident in the seed counts, resulted in fewer seedlings of three cornered jacks, emerging. After a number of years of application, it is suspected that this treatment has great potential in reducing soil seed levels. Because of Diuron's high solubility in water it has the potential to damage the vines if it enters the root zone. However, the rates used in the trial were at least half the rate recommended for use in vineyards on the label (1.7 L ha^{-1} compared with 3.5 to 7.2 L ha^{-1}), thereby reducing the risk of leaching.

Cover crop effects Legume cover crops (treatments D and H) produced seed levels that were not significantly different from the levels produced when a cereal cover crop was used (treatment E and I). The advantages of having legumes, which fix atmospheric nitrogen, growing between the vine rows is that the nitrogen is released into the soil as the legumes breakdown. This improves the fertility of the soil and encourages vine growth, but it also encourages the growth of *E. australis* (Gilbey and Weiss 1980). Therefore in areas of high infestation levels of *E. australis* it may be better to use a cereal cover crop rather than a legume until numbers are reduced.

Table 3. A summary of recommended vineyard control methods for *E. australis*.

Between -row	Undervine
• cultivate once every five weeks beginning in March for first year, or • sow a cereal cover crop (e.g. Barley) early in March, apply a selective herbicide to control the weeds during cover crop establishment e.g. Diuron, or • sow a perennial cover crop (e.g. Blockout) in March and apply a selective herbicide during establishment	• apply and maintain a thick layer of mulch (regions not prone to frost (damage) • apply Simazine in March and again in September.

Mulch effects Grapemark mulch (treatment T) was equally as effective at controlling *E. australis* as cultivating every five weeks (treatment A), and significantly more effective than no treatment application (treatment B).

Discussion

Those treatments which best control *E. australis* (i.e. with the largest negative percent change), while maintaining the productivity of the vineyard, are those with cereal cover crops used in conjunction with herbicides e.g. treatments J and F. Cultivating every five weeks over winter and summer is a short term method which may be used to rapidly reduce the number of seeds in a property with high levels of infestation but would not be recommended for a long term practice as it rapidly destroys soil structure, impeding root growth and water infiltration. Under the vine, simazine is effective in reducing the number of seeds produced or in areas not prone to frost damage, grapemark as mulch may be used (Table 3).

Problems with controlling E. australis

There are many problems involved in the control of *E. australis* in vineyards. Firstly the timing of weed growth coincides with the busy season of pruning vines. After the post-harvest clean up of summer weed growth little attention is paid to controlling weeds in the vineyard. During spring growers will either slash mulch or cultivate, into the soil, winter weed growth to reduce frost risk. By this stage most of the seedlings have grown to full maturity depositing enormous amounts of seed on the soil's surface ready to contaminate the fruit in the coming season.

The growth of winter cover crops in Sunraysia relies heavily on rainfall. In the past few years when the winters have been relatively dry these crops have not established well enough to prevent *E. australis* emergence or growth. Sowing dates for medics and clovers falls around February–early March. This coincides with the harvest period so that many such cover crops are sown late, i.e. in April, reducing the potential bulk for the cover crop.

Cultivating or spraying with knockdown herbicides every five weeks to prevent seed set, is a costly form of weed control in terms of time and fuel and may be degrading on the soil structure over a long period.

Confining the problem of *E. australis* growth is also difficult in Sunraysia vineyards as often property boundaries exist as headlands which are shared by neighbouring growers. It is common to see one grower surrounded by three or four neighbouring properties. Seed deposited on these headlands may be spread with vehicle movement within and between properties.

Growers themselves do not directly feel the effect from 'loss of sales' due to contaminated fruit because of pooled-marketing of dried vine fruit by packing sheds. If a grower receives no penalties, but is ineligible for the $40 per tonne premium, he would be reluctant to spend the extra time, effort and money required to control *E. australis* and their attitude toward doing so is largely negative. Many growers comment that it is 'too much work' and 'too expensive' to even start thinking about. Growers who do make a concerted effort to try and control *E. australis* are often disappointed when they continually find outbreaks on their property each year.

Conclusion

Eliminating *E. australis* from vineyards is a challenging task for all growers. Success will be achieved only by those growers who continue with regular control treatments of the weeds for many years. With emphasis placed on the need to reduce the amount of chemicals used in food products and the trend toward minimal cultivation the options for weed control are becoming increasingly limited. I believe that the level of contamination with *E. australis* will not be reduced until growers individually feel the benefits of improving weed control or until an alternative form of control, which is more cost and time effective, is discovered and adopted.

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Spiny emex (*Emex australis*) in the cropping zone of New South Wales

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Abstract

Spiny emex is most prevalent in the western, central and northern regions of the wheat-belt. Generally, it is spreading slowly but sudden dramatic increases can occur, especially after droughts or wet summers and autumns. There are no recent data on the distribution of emex in New South Wales, or its impact on crops and pasture. In heavy infestations, it is a strong competitor against crops and reduces pasture production, especially in lucerne. It damages the feet and mouths of farm animals. It is easy to control in pasture and cereal crops with herbicides, but no chemicals are registered for control in canola or safflower. Recommendations for future research are given.

Spiny emex was introduced to New South Wales (NSW) and Victoria in about 1883 (Parsons and Cuthbertson 1992). A survey of the distribution of the weed in NSW was done in 1966 based on observations of agronomists (Anon. 1970). The most recent estimate of its distribution was made in 1990 (Parsons and Cuthbertson 1992), and emex is likely to have only spread slightly since then. Spiny emex occurs in the far west, the central and northern areas of NSW. It is generally not found in the Tablelands or the far south coast. Heavy infestations are along the Murray flood plain, presenting problems for vineyards, fruit growing and lucerne production. In the wheat-belt it is found in the western, central and northern regions. The most dense infestations occur in the south-western region (mallee soils and sandy loams around Balranald), the central region (West Wyalong, Narromine, Tottenham and Condobolin on the red loam light soils and the red pine-box soils) and the northern region. There are no recent quantitative data of the distribution of emex in NSW, or its impact on crop or pasture production.

In Victoria, a survey of cereal crops in 1981 (Velthius and Amor 1982) found emex only in the Goulburn and north-east region, at a relative abundance of 0.6 plants m^{-2}, compared to 39 plants m^{-2} for wild radish and 835 plants m^{-2} for capeweed. However, it is mainly a problem in the Mallee and northern Wimmera, an area not included in this survey.

Generally, spiny emex is spreading slowly in NSW, but sudden dramatic increases can occur, especially following drought, or wet summers and autumns. New infestations were recorded after the droughts of 1982 and 1994. Emex fruit spread on the tyres of vehicles, on shoes, in flood waters and as a contaminant of forage material. Therefore, it is often found in isolated patches along roadsides, near dams and around buildings. Seed in fodder can lead to dramatic, new and large infestations. Emex is not a major contaminant of crop grain.

Spiny emex is strongly competitive against crops and pastures. For example, Dellow *et al.* (1984) found that the grain yield of wheat was reduced 40% by emex at 30 plants m^{-2}. It damages the feet and mouths of farm animals, especially sheep, and can prevent sheep dogs working to the extent leather shoes are sometimes necessary. Heavy infestations reduce land values.

In cereals and pastures, a number of chemical control options are available. In wheat, the preferred recommendations are metsulfuron, dicamba plus MCPA and bromoxynil. Effective control is dependent on timing. Cyanazine and metribuzin are registered in chickpea, field pea, lentil and faba bean, except metribuzin is not registered in lentil. Some of these chemicals are dependent on moisture for activity and hence are sometimes unreliable. Imazethapyr is registered in field pea and faba bean. In pastures and lucerne, registered herbicides are: imazethapyr, methabenzthiazuron, diflufenican plus MCPA, diflufenican plus bromoxynil, bromoxynil and 2,4-DB. No chemicals are registered for control in canola or safflower, and this could be a major limitation to the adoption of these crops in the dryer areas of the wheat-belt.

Recommendations for future research are:

- Investigate alternative control options in canola and grain legumes.
- Determine impact of emex on crop and pasture production.
- Determine current distribution and factors affecting spread.
- Determine critical weed density / yield loss relationships in crops and pasture.
- Improve chemical control, e.g. cultivation x timing x rates in crops and pastures.
- Impact of control in pasture phase on weed seed bank in the soil.
- Evaluate more biological control agents, including bio-herbicides.

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Legal and economic constraints on *Emex*

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Abstract

***Emex australis* is a declared weed in many parts of Australia and the declaration status for each State is presented. *Emex australis* is also a contaminant of crops, with restrictions on delivery of produce containing achenes applied for grains and dried grapes. The receival standards for grain crops are presented, while the costs of cleaning dried grapes with spiked seed contamination are given.**

Introduction

Various restrictions apply to *Emex* around Australia. These include requirements for prevention of spread or control by landholders, and to costs associated with delivery of goods grown where *Emex* occurs. Many of these restrictions are established in law and legally enforceable by either government agencies or by the purchasing agencies. This paper gives an overview of the types of legal and economic constraints which apply to *Emex* in Australia.

Noxious or declared weed status

Emex australis is considered to be either a noxious or declared weed in all or part of all States of Australia and the Northern Territory. Table 1 shows the declaration status for this species across Australia.

The related species *Emex spinosa* is also declared in Western Australia at the same locations.

Restrictions on delivery of produce

Emex, like many other weeds, has restrictions placed on it when the seeds are delivered in agricultural produce. The two crop areas for which these restrictions are present are grains (cereals, pulses, oilseeds) and dried fruit (dried grapes). The receival standards for grain delivered to marketing authorities are presented in Table 2.

As can be seen from Table 2, the only crop for which contamination levels are standardized across Australia is for wheat. While pulse crops have the same levels within States, differences occur between States, with NSW generally being the strictest.

The other crop for which restrictions are placed on the presence of *Emex* in produce is dried fruit and in particular, dried table grapes. In this case a more general approach is taken with all spiked seeds being grouped. This class also includes caltrop and spiny burr grass. The costs associated with these seeds as a group are presented in Table 3.

Under the Australian Dried Fruit Association Weed Free Property Assurance Program a $40 t^{-1} premium applies for dried fruit from certified properties. Thirty four growers were in the scheme at December 1994.

Acknowledgments

The assistance of the Australian Wheat Board and Co-operative Bulk Handling (WA) in providing information on grain receival standards is gratefully acknowledged.

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Table 3. Spiked seed cleaning costs in dried fruit (Anon. 1994).

Contamination level	Cleaning cost
1 or 2 / bin	$A20
3-20 / bin	$A75
21+ / bin	$A100

Table 2. Receival standards for grain crops contaminated with *Emex*. (Maximum counts per unit).

Crop		WA	SA	VIC	NSW	QLD
Wheat (all grades)		8 / 0.5 L	8 / 0.5 L	8 / 0.5L	8 / 0.5 L	8 / 0.5 L
Barley	– malt	1 / 0.5 L	0 / 0.5 L	0 / 100 g	1 / 0.5 L	
	– feed	20 / 0.5 L	1 / 100 g	0 / 100 g	2 / 0.5 L	
Oats	– milling	1 / 0.5 L	0 / 100 g	8 / 0.5 L	5 / 0.5 L	
	– feed	1 / 0.5 L	5 / 0.5 L	8 / 0.5 L	5 / 0.5 L	
Sorghum					2 / 0.5 L	
Lupins		20 / 0.5 L	5 / 200 g	4 / 200 g	2 / 200 g	
Field peas	– milling	5 / 0.5 L	5 / 200 g	4 / 200 g	2 / 200 g	
	– feed	15 / 0.5 L	5 / 200g	4 / 200 g	2 / 200 g	
Chick pea		5 / 0.5 L	5 / 200 g	4 / 200 g	2 / 200 g	
Faba bean		5 / 0.5 L	5 / 200 g	4 / 200 g	2 / 200 g	
Canola		1 / 0.5 L			2–3% fm	
Sunflower					2–3% fm	
Soybean					2–3% fm	

fm = foreign material

Table 1. Declaration status of *Emex australis* in Australia (From: Parson and Cuthbertson 1992).

State or Territory	Status	Notes
New South Wales	Certain shires and municipalities	Owners required to control or eradicate weed
Victoria	Whole State except Melbourne metropolitan area	Owners required to control or eradicate weed
Queensland	P2 – local authority area of Atherton	P2 = to be destroyed in area
South Australia	Class 2 – whole State	Class 2 = control or destruction required
Northern Territory	Class B and C, whole Territory	Class B = to be controlled – further spread prevented and small infestations eradicated Class C = introduction prohibited
Western Australia	P1, Zone 6 (South-west corner)	P1 = plants not to be introduced
	P1, P3, Jerramungup region	P3 = populations must be reduced
	P5 in saleyards, railway yards, recreational areas of the Lakes and Esperance regions	P5 = plants which are to be treated on roadsides or reserves
	Pest plant in six shires	'pest plant' = shire can proscribe plant
Tasmania	Noxious and prohibited	Not to be introduced and must be eradicated if found

Control of *Emex* species

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Abstract

Highlights of the research carried out in Western Australia on the control of *Emex australis* from the early 1950s are briefly reviewed. A concise appraisal of the present state of knowledge is presented as a basis for proposals on future directions.

Introduction

In this paper I would like to briefly review some highlights of the doublegee control research that has been carried in Western Australia to this point in time, and propose directions for further research.

Scott and Beasley's (1996) bibliography of over 300 publications indicates the magnitude of world wide research that has been carried out on this plant, and although doublegee has had a high priority for research in this State, it still only represents a portion of that which has been completed.

Highlights up to 1970

- Geoff Pearce and others had developed reliable recipes for chemical control of doublegee in cereal crops.
- Pearce had demonstrated the benefit of an 'autumn tickle' used in conjunction with chemical control (IWM)?
- Pearce had also developed the 'Spray Graze Technique' for control in pastures, but because of stock management constraints with the technique, control was still unreliable for large areas of infested pasture.
- Some studies had been carried out on seed longevity and seedling emergence.

Research during the 1970s and early 1980s

The main aim of research during this time was to develop more reliable methods of doublegee control in subterranean clover pastures. Some highlights of this period are:

- Burnett (then with Bayer Australia) and Gilbey developed Tribunil® for use in pastures.
- Gilbey also developed 2,4-DB as alternative for use in pastures.
- The best sites for these herbicide evaluation trials were always in first year clover pastures following a cereal crop. Attempts to continue the studies beyond this year generally failed because the doublegee numbers were too low to detect significant difference between treatments.

These observations were supported by the results of sampling paddocks over several years on several research stations, for doublegee seeds in the soil. The results from 1974 (Table 1) indicate that more viable doublegee seed was found in the soil following a year of clover pasture, than that following a year of cereal crop.

Other highlights were :

- Seed longevity studies showed that dormant seed was more persistent in northern areas than the Great Southern (10% at Chapman after four years compared to less than 10% after one year at Katanning) and that viable seed could be detected after eight years at all sites.
- Depth of seedling emergence studies showed that few seedlings emerged from seed below 75 mm in the soil.
- Further paddock surveys in the mid 1970s showed maximum seedling numbers of over 900 plants m^{-2} at Wongan Hills, over 300 plants m^{-2} at Chapman and 50–80 plants m^{-2} in the Great Southern.
- In spite of the large number of products evaluated, no reliable chemical control method was developed for doublegee control in pastures.
- Collaboration with Ken Harley, Mic Julian and Paul Weiss of CSIRO lead to the first releases and evaluation of *Perapion antiquum*. This insect had not established successfully by the time John Scott joined the research group and continued the biological control research program.

Recent research highlights

- Dane Panetta and Rod Randall studied the emergence and survival of seedling cohorts.
- Panetta and Randall also studied the competitive effects of other pasture species on doublegee, and were developing a management strategy based on competition with pastures grasses when Dane transferred to Queensland.
- Gilbey by now working on weed control in lupins showed that doublegee can be controlled with pre-emergence applied simazine providing the crop is sown into moist soil. The size of the lupin crop in Western Australia, and the occurrence of late opening rains now dictates that large areas of lupins are sown dry and consequently doublegee control is often unsatisfactory.
- Bowran and Cooper developed metribuzin for post-emergence doublegee control in lupins, with supporting varietal tolerance data which showed that the varieties Gungurru and Merritt tolerated metribuzin better than other varieties, such as Danja.

The situation today

The present state of knowledge with respect to the control of doublegee can be summarized by the following:

- Reliable control can be achieved in cereal crops.
- Reliable control can be achieved in lupins, except for dry sown crops.
- Broadstrike® is now available for doublegee control in pasture, but it is yet to be demonstrated that there is a reliable method of control in pasture.
- All progress achieved in reducing soil seed populations under continuous cropping or pasture land use, is totally reversed by a change from one to the other. Up to 10 000 achenes m^{-2} have been recovered from soil at Wongan Hills following a year of pasture.
- The economic incentive for growers on broad area farming systems is not high enough for them to modify their farming systems for the sole objective of doublegee control.
- Eradication of doublegee has been demonstrated on a vineyard in Mildura, where the economic incentives in the dried fruit industry were high enough for the grower to adopt specific doublegee control strategies.
- Flexible control strategies have yet to be developed that are effective over various land uses.

Future directions

The main strength of doublegee is its ability to recover on the change from cultivation to non cultivation land uses and vice versa in broad area farming. This should be a target for further research.

It is also clearly an ideal candidate for integrated weed management by:

- cultural, chemical and biological control methods,
- rotations within farming systems and,

Table 1. Survey of doublegee seed in the soil following crop or pasture. Sampled in March 1974 (Gilbey 1977).

Site	Viable seeds m^{-2} after pasture	Viable seeds m^{-2} after crop
Avondale Research Station	2373	94
Wongan Hills Research Station	1062	433
Chapman Research Station	1431	261

- different farming systems.

There is a need to set priorities and targets for integrated weed management for the various land uses.

e.g. dried fruit industry
pulse crops
recreational areas
conservation areas

Separate IWM information packages are required for growers in the various land use categories. Preparation of this material would identify specific areas for further research. I believe that a team comprising of an industry liaison officer and a research officer working closely with growers, would lead to the most rapid advances in reducing the impact of doublegee in Australia.

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Dicamba control of *Emex australis*

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Abstract

Dicamba has long been used for the control of Polygonaceae weeds. The high efficacy against *Emex australis* is one of the major strengths of dicamba in southern Australia. The sulfonylurea group of chemicals also provides good control of *Emex*, however, there are two main benefits of using dicamba. Firstly, the very short plant back period of dicamba prevents the possibility of residue carryover into the next phase of the crop rotation. Secondly, the long term effects of continued use of Group B chemistry needs to be considered in terms of herbicide resistance. Rotation of herbicide groups is an essential component of Integrated Weed Management. The high efficacy of dicamba, in addition to these two factors, should favour the continued use of dicamba to control *Emex*.

Introduction

Dicamba was first discovered as a laboratory molecule in 1961 and registered for use in Australia in 1971. This initial registration was on primarily polygonaceous weeds, which remains the strength of dicamba in today's agriculture. Dicamba was used extensively for *Emex* control throughout Australia during the 1970s and early 1980s, prior to the discovery of the sulfonylurea (SU) chemistry. These chemicals were less expensive and provided control of a wider weed spectrum. Subsequently, the use of dicamba decreased. However, the use of dicamba for *Emex* control has been increasing during the mid-1990s due to factors that will be addressed in this paper.

Dicamba is a broad spectrum chemical that provides effective control of a number of annual, biennial and perennial broadleaf weeds. Plants absorb dicamba through the leaves, stems and roots and it accumulates at the areas of greatest metabolic activity.

At the site of activity, dicamba causes an imbalance in plant hormones, specifically auxin, thus interfering with cell elongation and nucleic acid and protein synthesis. The result is a disruption to normal metabolic and growth activities, and death of susceptible species. Due to its action as a disruptor of cell growth, dicamba is grouped with the phenoxy and pyridine herbicides in Group I.

Methods

Three protocols of dicamba/doublegee trials will be referred to in this paper. The first is a rate response determination, the second is a comparison with metsulfuron, and the third involves mixtures of dicamba and metsulfuron with glyphosate. Metsulfuron was selected for comparison because it is currently the most common post-emergent SU herbicide used for *Emex* control.

A hand held boom was used to apply the treatments in trials of the first two protocols (A and B below). The output from the boom was 100 L ha^{-1}. Plots were 3 m wide by 10 m long, with four replicates.

The third protocol (protocol C below) was designed and conducted by SBS Rural IAMA. A boom connected to a 4-wheel motorbike was used to apply the treatments. Compressed air was used as a propellent, at a spray volume of 50 L ha^{-1}. Plots were 3 m wide by 20 m long, with three replicates.

Protocol A. Rate response

A single trial was conducted during 1995 to determine a rate response curve for dicamba against doublegee. The *Emex* were at the two leaf stage when sprayed. The rates of dicamba (g a.i. ha^{-1}) used were 0, 40, 60, 80, 120, 160 and 320. The trial was sprayed under the following conditions; 13ºC, 70% relative humidity, no wind, overcast, dry leaves, and moist soil.

Assessments were made on percent efficacy at 35 DAT (days after treatment).

Protocol B. Metsulfuron comparisons

A single trial was conducted during 1995 to determine the comparative efficacy of low rates of dicamba and label rates of metsulfuron. The *Emex* were at the two leaf stage when sprayed. Rates of dicamba and metsulfuron were (g a.i. ha^{-1} of dicamba + g ha^{-1} of metsulfuron, respectively): 0+0, 60+0, 80+0, 0+3, 0+5, 60+3, 60+3, 80+3, and 80+5. The trial was sprayed under the following conditions; 12ºC, 80% relative humidity, no wind, clear sky, dry leaves, and moist soil.

Assessments were made on percent efficacy at 35 DAT.

Protocol C. Glyphosate mixtures

A single trial was conducted during 1992 to determine the comparative efficacy of dicamba and metsulfuron when mixed with glyphosate. The *Emex* had been transplanted by cultivation and were 15 to 30 cm in diameter. Rates applied were (mL ha^{-1} of glyphosate + g a.i. ha^{-1} of dicamba + g ha^{-1} of metsulfuron, respectively): 0+0+0,

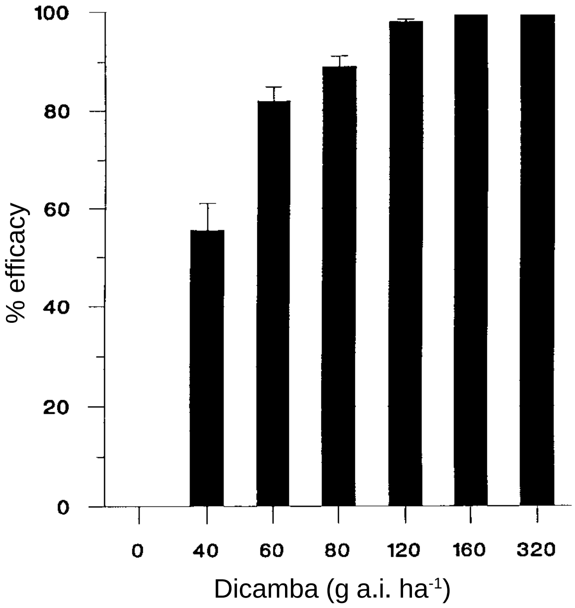

Figure 1. Rate response curve of 2 leaf *Emex* to dicamba. Values are per cent efficacy ± SE at 35 DAT.

800+0+0, 700+60+0, 700+72+0, 700+0+3, and 700+0+4.

Counts of surviving plants per square metre were performed at approximately 35 DAT, and these counts converted to percent efficacy.

Results

Protocol A. Rate response

The response of *Emex* to treatment with dicamba followed a classical rate response curve (Figure 1). Complete control was achieved at 160 g a.i. ha^{-1} and above.

Suppression of the surviving *Emex* was observed at all rates of dicamba. General symptoms of suppression were a decrease in shoot growth, with fewer and smaller leaves produced, and stem production was greatly reduced in number and length.

Protocol B. Metsulfuron comparisons

The low rates of dicamba provided similar control to the label rates of metsulfuron (Table 1). Mixtures of the two compounds did not increase efficacy except at the top rates of both. When applied individually, low rates of dicamba and label rates of metsulfuron did not provide complete control. However, the surviving plants were severely suppressed and exhibited similar symptoms to those previously described.

Protocol C. Glyphosate mixtures

The addition of either dicamba or metsulfuron to glyphosate provided good control of large *Emex* (Table 2). There was no difference in efficacy between the mixtures of dicamba plus glyphosate or metsulfuron plus glyphosate. The addition of either compound provided greater control than glyphosate alone.

Discussion

Dicamba is highly efficacious on *Emex australis*. Complete control of two leaf *Emex* is provided at rates of 160 g a.i. ha^{-1} and above. Lower rates of dicamba may be acceptable in a non-eradication or commercial application. This lower level of control is very similar to that provided by label rates of metsulfuron. The addition of low rates of dicamba to glyphosate greatly increases efficacy on large *Emex* in a knockdown situation. Again, this is comparable to the addition of label rates of metsulfuron to glyphosate.

Plants surviving low application rates of dicamba are severely suppressed. In a commercial application, a reduction in the rate of dicamba would provide less than complete control of *Emex* but would eliminate the competitive effect on the crop. The elimination of competition should be considered in terms of Integrated Weed Management (IWM), applicable only in a non-eradication program. Further research should be conducted on the efficacy of low rates of dicamba, specifically at early weed growth stages.

Dicamba and metsulfuron provide very similar control of *Emex*, with efficacy being determined by rate. However, dicamba has two distinct advantages over metsulfuron and the other SUs. These are plant-back period and IWM.

The plant-back period of dicamba is very short compared to the SUs. Dicamba has a plant-back period of days (Table 3), as opposed to months with the metsulfuron (Table 4). SUs vary in the length of their plant-back period, dependent on which SU, soil pH, rainfall and other factors. For example, chlorsulfuron and triasulfuron are inherently more residual and have longer plant-back periods than metsulfuron.

The SU molecules are degraded by acid hydrolysis and micro-organisms that function at low to medium soil pH. The activity of the micro-organism at a particular pH is further influenced by moisture regime (i.e. rainfall).

Thus, SU molecules are broken down faster in low pH soils with adequate rainfall. In high pH soils, there is greater residue carryover and the plant-back period is longer. Chlorsulfuron and triasulfuron are not recommended to be used on soils with a pH greater than 8.5 due to very low rates of residue breakdown.

Agriculture during the 1990s is moving towards greater inclusion and reliance upon legumes in the rotation. Use of long plant-back period chemicals to control *Emex* during a cropping phase places legumes in later phases at high risk, especially on high pH soils. Dicamba has a specific role in *Emex* control where a legume or oilseed is to be grown in the year immediately following a cereal crop.

The second advantage of using dicamba over a post-emergent SUs herbicide is in IWM. During the cereal phase, large areas of the agricultural regions are treated with a pre-emergent SU herbicide. Rotation of herbicide groups, a key element of IWM, necessitates using a different group for post-emergence control. However, it has been common practice to use a post-emergent SU, often in the same year as a pre-emergent SU and for consecutive years. Already, a high degree of selection pressure has been placed upon the *Emex* populations by this chemical group.

Release from patent for metsulfuron and chlorsulfuron has resulted in conversions of these molecules to commodity products. Cheaper production methods have lowered the price of these herbicides to growers, and it could be predicted that their use will subsequently increase. The combination of increased use of metsulfuron and chlorsulfuron with the development and adoption of new Group B herbicides to control *Emex* will increase the selection pressure on *Emex*.

Table 1. The comparative efficacy of dicamba and metsulfuron on two leaf *Emex*. Values are per cent efficacy ± SE at 35 DAT.

Dicamba (g a.i. ha^{-1})	Metsulfuron (g ha^{-1})	Efficacy (%) ± SE
0	0	0 ± 0
60	0	82 ± 1.9
80	0	88 ± 2.2
0	3	86 ± 2.6
0	5	93 ± 1.4
60	3	84 ± 1.8
60	5	88 ± 1.1
80	3	88 ± 1.3
80	5	98 ± 0.5

Table 2. The comparative efficacy of dicamba and metsulfuron, when mixed with glyphosate, on 15–30 cm diameter *Emex*. Values are per cent efficacy at 35 DAT.

Dicamba (g a.i. ha^{-1})	Metsulfuron (g ha^{-1})	Glyphosate (mL ha^{-1})	Efficacy (%)
0	0	800	56
60	0	700	91
72	0	700	92
0	3	700	87
0	4	700	90

Table 3. The plant-back period for dicamba (days) (Chambers 1995).

Crop	Rate (g a.i. ha^{-1})			
	100	140	280	80–120[A]
Wheat	1	7	14	1
Barley	1	7	14	1
Oats	1	7	14	1
Triticale	1	7	14	1
Canola	7	10	14	7
Sunflower	1	7	14	1
Field peas	ND	14	21	
Chick peas	ND	21	28	
Faba beans	ND	21[B]	28[B]	
Safflower	14	21	28	
Lupins	7	14	21	
Clover/medic	7	14	21	
Cereal rye				1
Sorghum				1
Maize				1
Millet				1
Soybeans				5
Mung Beans				5
Cotton				7

ND = Not determined.
[A] Queensland and Northern Territory only, For all crops and rates above 120 g a.i. ha^{-1}, plant back period is 21 days following a rainfall of at least 15 mm after application.
[B] Estimation from limited data.

Table 4. The plant-back period for metsulfuron in soil with a pH 5.6–8.5 as determined by laboratory analysis using 1:5 water suspension method (Chambers 1995).

Crop	Plant-back	Crop	Plant-back
Wheat	10 days	Safflower	9 months
Barley	6 weeks	Lucerne	9 months
Oats	9 months	Clover/Medic	9 months
Faba beans	9 months	Soybeans	14 months
Chick peas	9 months	Jap. Millet	14 months
Peas	9 months	Maize	14 months
Lupins	9 months	Sorghum	14 months
Canola	9 months	Sunflower	14 months

Table 5. The most commonly used chemicals to control *Emex* in Australia (Chambers 1995).

Name	Group	Name	Group
Metsulfuron	B	Cyanazine	C
Chlorsulfuron	B	Simazine	C
Triasulfuron	B	Diuron	C
Flumetsulam	B	Metribuzin	C
Imazethapyr	B	Terbutryn	C
Triasulfuron + Terbutryn	B + C	Dicamba	I
Bromoxynil + Diflufenican	C + F	Dicamba + Glyphosate	I + M
Bromoxynil + MCPA	C + I	Paraquat + Diquat	L
Dicamba + MCPA	I + I	Glyphosate	M

Currently, the range of herbicides used to control *Emex* is limited (Table 5). Of these herbicides available, Group B and C are the most commonly used. Group C herbicides are widely used throughout Western Australia in lupins, South Australia and Victoria in field peas, and Victoria in chick peas. Increased usage of Group C herbicides is likely upon adoption of triazine tolerant varieties of canola.

Use of the Group B and C broad-spectrum herbicides for control of *Emex* also places high selection pressure on other weed species. Group Bs are considered to be at high risk from herbicide resistance due to their mode of action on a single enzyme target. Continuous application of these herbicide groups places selection pressure on *Emex* and other weed species, some of which have already been reported to be resistant. The likely outcome of continued use of these herbicides without IWM is increased resistance problems. Dicamba should be included in the herbicide rotation as a part of IWM to decrease/delay the onset of resistance in *Emex* and other weed species.

Dicamba has demonstrated high efficacy against *Emex* during the two decades of its commercial application and small trial work. Whether used as a stand-alone product or in mixtures with glyphosate, dicamba is at least as efficacous as metsulfuron. However, dicamba has a considerably shorter plant back period and less risk of causing herbicide resistance.

Acknowledgments
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Sulfonylurea chemistry on *Emex australis* (doublegee)

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Abstract

Trials showing the degree of *Emex australis* (doublegee) control with the sulfonylurea herbicides, Glean® (chlorsulfuron), Ally® (metsulfuron methyl) and Muster® (ethametsulfuron methyl) are described.

Glean® (chlorsulfuron)

Glean was first trialed in Australia from 1979 with commercial release in 1982. The active herbicide chlorsulfuron inhibits the 'ALS' target site in susceptible plants. For *Emex australis*, the herbicide is taken up primarily via root uptake (soil residual) at weed emergence in winter cereal crops, e.g. wheat. Post-emergent control with chlorsulfuron is weak unless mixed with a companion product(s).

Glean is compatible with the pre-emergent knockdown herbicides glyphosate, glyphosate trimesium; paraquat/diquat and post-emergent herbicides bromoxynil + MCPA, phenoxy herbicides (2,4-D, MCPA etc.), diflufenican + MCPA and diflufenican + bromoxynil.

Factors effecting efficacy

Chlorsulfuron is more readily degraded in acid soils, and leaches more readily in sandy soils. The amount of soil moisture at application and subsequent rainfall can affect activity – moist conditions favour weed control. Most Glean is applied before seeding and incorporated by the sowing process. Doublegee control is usually good when used this way (Table 1). Evenness of incorporation into the soil profile is important in determining the level of control achieved as poor incorporation can lead to stripping of the herbicide.

The addition of a knockdown is required when used pre-emergent to actively growing weeds. For post-emergent application, Glean activity is enhanced if used with products containing either bromoxynil or a phenoxy herbicide. Glean application rates for doublegee are usually in the order of 15–20 g ha^{-1}.

Note: Triasulfuron (Logran®) is consistently less efficacious in controlling doublegee.

Ally® (metsulfuron methyl)

Ally was first trialed in Australia from 1983 and commercial use started in 1987. The active herbicide metsulfuron methyl inhibits the 'ALS' target site in susceptible plants. Ally controls actively growing doublegee primarily by foliar uptake either alone or with a compatible product(s) for use in winter cereals, i.e. wheat, barley (Table 2). It can be applied either pre-seeding of crop with knockdown herbicides or post-emergent to actively growing doublegee. Ally is more active on doublegee in Western Australia (WA) than in South Australia (SA)/Victoria. The addition of a non-ionic wetting agent is required. The addition of phenoxy products such as MCPA, 2,4-D may sometimes reduce the effectiveness of Ally in controlling doublegee (MCPA – 15%, 2,4-D amine – up to 13%), but may at the same time improve crop safety (Table 3).

Factors effecting weed efficacy

Metsulfuron methyl is readily degraded in most soils but some persistence is expected on alkaline soils. It leaches more readily in sandy soils. The amount of soil moisture at application and subsequent rainfall can affect activity – moist conditions favour weed control, while water or temperature stressed doublegee are more difficult to control. Frost after application of Ally will slow the speed of kill on doublegee. Ally gives good control of doublegee over a wide range of plant sizes and plant densities and this makes it one of the preferred options for doublegee control.

Ally is compatible with the knockdown herbicides glyphosate, glyphosate-trimesium, and the post-emergent herbicides bromoxynil + MCPA, bromoxynil + diflufenican, diuron + MCPA, MCPA, MCPA + diflufenican, and some other less widely used herbicides. Application by either ground sprayer or by aerial application are equally effective, but uniformity is generally better with the ground sprayer. Ally application rates in WA are 5 g ha^{-1} while in SA and Victoria 5–7 g ha^{-1} are used.

Muster® (ethametsulfuron methyl)

Muster was first trialed in Australia from 1983 in WA. The first experiments for the control of doublegee in lupins and canola were in 1992. The active herbicide ethametsulfuron inhibits the 'ALS' target site in susceptible plants. Muster controls actively growing doublegee primarily by foliar uptake either alone or with a compatible product(s) (Tables 4 and 5).

Muster is compatible with the post-emergent products diflufenican, metosulam, metribuzin, and clopyralid.

Table 1. Control of doublegee in wheat (Kulin) with Glean® and Logran incorporated at seeding.

Treatment (per ha)	% doublegee control
Glean 15 g	90
Glean 20 g	93
Logran 30 g	58
Logran 35 g	58
Glean 5 g + Logran 20 g	85
Untreated	0

Table 2. Control of doublegee with Ally and mixtures with Ally (post-emergence). Doublegee plants were at the 3-8 true leaf stage

Treatment (per hectare)	% doublegee control Trial A	Trial B
Ally – 5 g + 0.1% BS1000	98	99
MCPA amine – 0.7 L	0	8
MCPA amine – 1.0 L	0	13
Ally + MCPA – 5 g + 0.7 L	95	97
Ally + MCPA – 5 g + 1.0 L	93	98
Terbutryn + MCPA – 0.55 + 0.6 L	0	30
Ally + Terbutryn + MCPA – 5 g + 0.55 + 0.6 L	99	100
Tigrex® – 1.0 L	0	23
Ally + Tigrex – 5 g + 1.0 L	95	100
Bromoxynil MCPA – 1.0 L	0	60

Table 3. Control of doublegee with Ally and mixtures of Ally with phenoxy herbicides. Doublegee plants were at the 2–4 true leaf stage.

Treatment (per hectare)	% doublegee control
Ally® 5 g[A]	99
Ally® + 2,4-D amine, 5 g + 0.5 L[A]	89
Ally® + 2,4-D amine, 5 g + 0.7 L[A]	89
Ally® + 2,4-D amine, 5 g + 1.0 L[A]	86
Ally® + MCPA amine, 5 g + 1.0 L[A]	95

[A] + 0.1% BS1000.

Table 4. Doublegee control in lupins (Gungurru) with Muster. Doublegee were at the 5–7 true leaf stage and 10 plants m^{-2}.

Treatment (per hectare)	% Crop phytotoxicity at 38 days	% doublegee control
Muster 30 g[A]	0	80
Muster 60 g[A]	0	90
Muster 90 g[A]	0	90
Muster + Brodal®, 30 g + 100 mL[A]	0	85
Eclipse 10 g	5	65

[A] 0.2% BS1000 added.

Table 5. Doublegee control in wheat (Kulin) with Muster. Doublegee were at the 1–2 true leaf stage and 37 plants m^{-2}.

Treatment (per hectare)	% Crop phytotoxicity at 38 days	% doublegee control
Muster 30 g[A]	25	100
Muster 60 g[A]	25	100
Muster 90 g[A]	60	100
Ally 5 g	0	100

[A] 0.2% BS1000 added.

Proposed Muster application rates are 30–40 g ha^{-1}, plus a nonionic wetting agent.

Note: Muster patent in Australia lapsed in 1995, thus is highly unlikely to be granted registration as a stand alone product by the National Registration Authority, but may be possible in a mixture.

Possible factors in effecting weed efficacy

Muster gives good control of growing doublegee over a wide range of plant sizes and plant densities and this makes it one of the preferred options for doublegee control in lupins and canola. The effectiveness of Muster in the broad leaf crops may be reduced by the canopy effect of the crop leaves. Early application for these crops is likely to be critical.

Emex australis: resistance to sulfonylurea chemistry

Glean, Ally and Muster are highly efficacious on doublegee. Repeated exposure to Glean, Ally and Muster alone could lead to doublegee resistance to sulfonylurea chemistry. More competitive pricing of sulfonylurea chemistry will increase their exposure to doublegee. Other factors which could effect control measures are the biology of doublegee, habitat, seed longevity, and depth of seed in the soil profile.

Utilizing existing natural enemies to enhance the control of *Emex australis* in south-west Australia

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Abstract

The natural enemy complex on *Emex australis* in Australia includes the stem blight fungus, *Phomopsis emicis*, the dock sawfly, *Lophyrotoma analis* and the dock aphid, *Brachycaudus rumexicolens*. The latter species is suitable for incorporation into a weed management system that includes strategies to augment or conserve the natural enemies on the weed. A system of providing alternative hosts for the aphid so as to increase its impact on the weed is proposed.

Introduction

The regulation of known or potential pest and weed densities by natural enemies has been recognized for centuries, but is often not appreciated until the balance is upset by events such as the misuse of pesticides, the creation of agricultural monocultures and the translocation of potential pests or weeds to new areas (Waage 1992). The effectiveness of a natural enemy in regulating a weed population at a low density will depend upon its searching ability, specificity and reproductive capacity relative to the pest. Adverse environmental conditions can, however, render theoretically effective enemies ineffective (DeBach and Rosen 1991). Environmental manipulation and periodic releases of natural enemies are two possible approaches to overcome particular ecological shortcomings of a natural enemy (van den Bosch and Telford 1964, Knipling 1977, Parrella *et al.* 1992). The appropriate approach and the success of weed management programme depends largely on incorporating a sound knowledge of the weed natural enemy complex into an integrated weed management system (Huffaker *et al.* 1977, Herzog and Funderburk 1986, Wapshere *et al.* 1989, DeBach and Rosen 1991, Williams and Leppla 1992).

Emex australis has acquired a natural enemy complex in the 150 years since its arrival in Australia. Among the natural enemies are three that are being examined in Western Australia: the stem blight fungus, *Phomopsis emicis* Shivas, the dock sawfly, *Lophyrotoma analis* (Costa) and the dock aphid, *Brachycaudus rumexicolens* (Patch). The sawfly is native to Australia, the fungus may have arrived with the plant and the aphid is a recent introduction. Any natural enemy selected for *E. australis* needs to be specific enough to not affect beneficial organisms, physiologically adapted to the environment in which the plants are growing and able to locate and establish on the plants early enough to affect seed quality and/or quantity. This paper discusses the possibility of manipulating the environment and/or releasing these natural enemies to effectively control (below economic thresholds) *E. australis* in the agro-ecosystem of south-west Australia.

The stem blight fungus, *Phomopsis emicis*

This fungus is widespread on *E. australis* within Western Australia (Shivas, Lewis and Groves 1994). Young *E. australis* plants appear to have an immunity to the fungus as the pathogen only causes severe disease on mature plants. Field trials have shown up to 30% of *E. australis* seeds are killed by the fungus (Shivas and Scott 1994). The utilization of this fungus as a mycoherbicide, where spores are mass cultured and directly applied to *E. australis*, was being investigated when it was discovered that *P. emicis* contains a powerful mammalian toxin, phomopsin (Shivas, Allen *et al.* 1994). Further research on developing *P. emicis* into a mycoherbicide will depend upon incorporating the technologies of genetic manipulation to remove the toxicity from the fungus and selecting pathogenic toxin-free strains (Shivas and Sivasithamparam 1994).

The dock sawfly, *Lophyrotoma analis*

The adults of this insect are large (2 cm long), have a bright orange abdomen and are poor fliers. They feed on nectar and pollen. The female uses her ovipositor to separate the upper and lower lamellae at the edge of a leaf and eggs are deposited in a row between the layers. The larvae emerge and then feed on the leaves. Larvae have been observed feeding on the leaves of *E. australis* and closely related plants in the genera *Rumex* and *Muehlenbeckia* (docks and native sarsaparilla). Total defoliation may result, however the insects avoid eating the main veins of the leaves and the stems of the plants. When fully developed, the larvae descend to the ground and pupate in the soil. In Perth, during spring, the sawfly takes 2 to 3 months to complete a generation. Aside from these general observations, the biology and potential for population increase is unknown. Occasionally the sawfly is sufficiently abundant to be noticed by farmers, who ask about the 'new' biological control agent.

A close relative of the dock sawfly is the cattle poisoning sawfly, *L. interrupta* (Klug). As its common name suggests, this insect is toxic to mammals due to lophyrotomin, an octapeptide containing 4 D-amino acids (Dadswell *et al.* 1985). The toxicity of the dock sawfly has not been ascertained, but its toxic close relative and its bright 'warning' coloration indicate that it is highly unlikely to be suitable for encouraging large densities among plants used as food for livestock.

The dock aphid, *Brachycaudus rumexicolens*

This small (1.2–1.5 mm) aphid is a fortuitous accidental introduction that has been recorded on *Rumex* spp. and a *Muehlenbeckia* sp. in Europe and North America. It was first recorded in Australia in 1985, in Western Australia in 1988 and by 1991 it had spread rapidly throughout the south-west of Australia (Berlandier and Scott 1993).

It has a winged form (alatae), primarily for dispersal and a non-winged form (apterae), primarily for reproduction. The alatae deposit live young onto the host plant. These feed on the sap of the plant and develop into the apterae which produce many more offspring. For aphids in general, the type of morph that these offspring develop into depends upon the condition of the plant, the aphid density on the plant and environmental cues (temperature and photoperiod) (Dixon 1985).

On *E. australis* and *Rumex* spp., the dock aphid feeds preferentially on the new unfurled leaves, the growing tips of the stems and the flower buds of the plant. Highly distorted and curled leaves, stunted stems and damaged seeds result. Presumably a more suitable microhabitat is created as individuals congregate within the curls of the distorted leaves and amongst the flower buds. As the density of insects increases, individuals spill out onto the uncurled leaves and along the stems.

A 30% reduction in the seed weight of *E. australis* plants growing in pasture has been attributed to natural infestations of dock aphid. Lower seed weight in *E. australis* has been related to a reduced period of seed dormancy (Scott *et al.* 1994). In glasshouse experiments, dock aphids caused an 80% reduction in seed number (Scott and Yeoh, unpublished observations). The dock aphid appears to have potential as a biological control agent for *E. australis*. However, before embarking on increasing its effectiveness, it was essential to determine its full host range potential and temperature requirements for suitable development.

Host specificity

Specificity tests were conducted on over 100 species of plants from over 40 different families (Scott and Yeoh unpublished). In cages in the glasshouse, populations of dock aphid could, in general, only be sustained on plants within the Polygonaceae (in particular *Rumex* spp. and *Emex* spp.). Lupins (narrow leaf) and wheat were, however, found to be sub-optimal hosts under these laboratory conditions. The survival of the dock aphid on these crops, appears to be an artefact of the sheltered laboratory conditions, as recent extensive surveys of lupin crops (F.A. Berlandier personal communication) and wheat crops (M. Grimm personal communication) in Western Australia, both indicated that these crops are not dock aphid hosts.

Restriction of successful dock aphid development only on Polygonaceae was further supported by recent sampling of a range of crop and pasture plants growing intermixed with dock aphid infested *E. australis* plants (Scott and Yeoh unpublished observations). Unlike *Rumex* spp. and *Emex* spp. plants, the leaves of lupin and wheat plants did not grow distorted when infested with the dock aphid. The insect's inability to modify the microhabitat in these plants may explain the observed differences in survival under laboratory and field conditions.

Temperature requirements for optimal development

The developmental rate of the dock aphid is maximal between 23–28°C. Some development was estimated to occur between 6°C and 32°C, but the population was not sustainable above 30°C. Nymphs failed to reach maturity above 32°C. At 25°C, an individual aptera requires 5 days to mature and, during its life will produce 35 offspring at an average of 1.6 per day. An alate takes six days to mature and produces 15 offspring at an average of 1.3 per day. Between 10°C and 35°C, and under a summer photoperiod (14 h light: 10 h dark), only asexual forms were produced (Yeoh and Scott, unpublished observations). No sexual forms of the aphid have been discovered in the field in Australia.

Strategies for increasing the effectiveness of the Dock aphid

The dock aphid will have maximum impact on *E. australis* plants and the resulting seed bank if it can establish on plants soon after germination. The temperature requirements of the aphid are well suited to the ambient temperatures that are likely to be experienced in the south-west Australian wheatbelt (Bureau of Meteorology 1975) during the April–May start to the *E. australis* growing season. By inducing distorted growth in the plant, it appears the aphid can modify the microhabitat, at least to some degree, to suit its requirements for high relative humidity. The insect's high innate capacity to increase should allow an individual dock aphid, once in contact with the plant, to rapidly build up damaging population levels.

The major factors affecting the efficacy of the dock aphid are likely to be the lag period from *E. australis* germination to dock aphid infestation (which will be influenced by the number of aphids searching an area and their ability to locate the *E. australis* within that area) and the mortality rate of the aphids.

Without a temperature resistant stage, the dock aphid is unlikely to survive the summer temperatures experienced in most of the south-west wheatbelt area. Each season they would therefore have to reinvade from colonies in cooler habitats. Aphids are only capable of flying at 1.6–3.2 km h^{-1}. Their small size, however, enables them to be carried by the wind and by utilizing convection currents and low-level jet streams, they can be transported very rapidly over great distances (Dixon 1985).

A continual 'rain' of dock aphids is presumably falling from the sky. Prior to the break of season in the wheatbelt (around April), the temperature is suitable for the dock aphid, but there are no *E. australis* and in the absence of alternative host plants (i.e. another Polygonaceae species) these aphids would die. Earlier establishment in the local area could occur if these alternative host plants were provided. These insects could increase in number and then provide a localized source of insects to colonize *E. australis* plants once they emerge.

The alternative host plant needs to be a non-pest species. It could be either evergreen, irrigated or vegetatively respond quicker (compared to *E. australis* seeds) to the break of season. Two types of alternative host could be considered:

i. *Muehlenbeckia adpressa* (native sarsaparilla), an evergreen climber that is native to south-west Australia. This could be encouraged to grow along fences and road edges and conserved in local reserves.
ii. *Rumex crispus* (curled dock), a non invasive, introduced, perennial dock that restricts itself to waterways and drainage areas in the wheatbelt. Its seeds do not have burrs and are therefore not likely to be a contaminant of wool. As the plant has large dormant tap roots, it has the potential to sprout leaves and then grow rapidly in response to rain. The *E. australis* seed has to imbibe, germinate and reach the surface of the soil before any foliage is produced. *Rumex crispus* plants could be planted along creek beds, road ditches and dam edges and protected from grazing.

Increasing natural enemy numbers by mass rearing and then periodically releasing them is usually expensive to develop and implement. This process, like chemical control, is a repetitive one so the costs are recurring. For these reasons, DeBach and Rosen (1991) recommend that this method 'be restricted to those natural enemies which have been demonstrated by research to be inherently effective in prey population regulation, but are prevented from doing so principally because they are not adequately adapted to weather extremes, are not synchronized with the necessary stages of the host or are otherwise rendered ineffective by periodic environmental unfavourability'. In this agro-ecosystem, the germination of the *E. australis* seeds is reasonably synchronous. A single release of aphids at the beginning of each season would therefore seem potentially adequate. If the provision of alternative hosts failed to increase the rate of dock aphid colonization on *E. australis* seedlings, then it may still be economically viable to purchase and manually disperse commercially mass reared dock aphids. The viability of commercial mass production will greatly increase if conventional herbicides fail to give adequate control (e.g. herbicide resistance), are too expensive or are socially unacceptable (Jutsum 1988).

Aphids are attacked by a wide range of natural enemies including syrphids, coccinellids and hymenopterous parasitoids. However, there are few records of indigenous natural enemies reliably and effectively controlling aphids. Van Emden (1988) states 'co-evolution would seem to have led to a delay in the arrival of predators and parasites after aphid immigration, and their functional and numerical responses are geared to follow rather than overtake the high innate capacity for increase of aphid populations'. In the wheatbelt agro-ecosystem, dock aphids are one of the first aphid species to establish (Scott and Yeoh unpublished observations). The delay in finding aphid populations will be greatly increased if the natural enemies also have to re-invade each season. This would result in a small impact on the dock aphid population in autumn, when damage to *E. australis* would be most beneficial.

Aphids are known to be major vectors of plant viruses. *Emex australis* and *E. spinosa* have been shown to be locally susceptible to 10 out of 27 viruses tested, but re-isolation of the test viruses was not achieved (Horvath 1986), indicating that these plants are unlikely to be reservoirs of viruses. *Emex spinosa* has also been excluded as a factor in the persistence of legume viruses (Eid 1983). Bwye *et al.* (1995) state that *B. rumexicolens* is a poor vector of cucumber mosaic virus. The presence of an aphid with a restricted host range among an existing abundant fauna of polyphagous aphids in Australia is unlikely to increase the risk of virus transmission (cf. Briese 1989).

Incorporation of natural enemies into a general pest management scheme

It is now accepted that integrating natural predators with cultural control methods and selective pesticides can be an effective method of pest control (van Emden 1988, Wapshere *et al.* 1989, Greathead 1995, Messersmith and Adkins 1995). The use of the natural enemies of *E. australis*, especially the dock aphid, present us with the possibility of such an approach.

A typical management plan for a wheatbelt agro-ecosystem may be as follows. Suitable alternative hosts are planted along field edges. As a result, dock aphids colonize the *E. australis* in the pasture early in the season. Any spraying of insecticides needed to control other aphids in the pasture is delayed as long as possible to maximize the effect of the dock aphid on the *E. australis*. Spraying is then restricted to below recommended rates of Pirimor to reduce aphid numbers but encourage aphid-specific predators (Niehoff and Poehling 1995). In years favourable to the dock aphid, many *E. australis* seedlings could be killed and few seeds would enter the seed bank. In years where conditions favour *E. australis* (aphids colonize late, heavy aphid mortality), *E. australis* sets seed but because of nutritional stress, seeds would be smaller and fewer. The dormancy of such seeds is greatly reduced so most would germinate the following year (crop phase). In this crop phase, selective herbicides can be used to kill *E. australis* and prevent seed entering the following pasture phase.

Our current research is directed at assessing the colonization rates of dock aphid in areas with and without suitable alternative host plants and measuring the impact of this on the *E. australis* population. We are also attempting to increase the number of biological control agents in the system by introducing suitable exotic insects (classical biological control).

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Assessment of potential biological control insects associated with *Emex spinosa*

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Abstract

Seven insects, *Apion miniatum* Germar (Coleoptera: Apionidae), *Perapion neofallax* (Gyll.) (Coleoptera: Apionidae), *Perapion violaceum* (Kirby) (Coleoptera: Apionidae), *Coniocleonus excoriatus Gyll.* (Coleoptera: Curculionidae), *Kokujewia ectrapela* Konow (Hymenoptera: Argidae), *Dysaphis emicis* (Mimeur) (Hemiptera: Aphididae), and *Haploprocta sulcicornis* (F.) (Hemiptera: Coreidae), are proposed as potential biological control agents for *Emex* species in Australia. The biology, distribution and recorded host range of each species is reviewed. The host specificity assessment of the first of these insects, *Apion miniatum,* is nearing completion.

Introduction

The genus *Emex* probably evolved from the genus *Rumex* or a shared common Polygonaceae ancestor found in Europe. *Rumex* has many species in Europe and *Emex* one species, *E. spinosa* which is found in the Mediterranean region. The second *Emex* species, *E. australis* is native to southern Africa and probably arose via migration from north Africa and subsequent separation due to climatic changes over the geological history of the African continent. Few *Rumex* species are found in southern Africa, but these may well represent the remnants of a very early cosmopolitan distribution. A consequence is that the genus *Rumex* in Europe, and *E. spinosa,* have many associated herbivores (Scott 1985, Scott and Sagliocco unpublished observations) reflecting a long coevolved history. A corollary is that *E. australis,* being isolated from related species and having arisen following migration from the source area is found with very few associated insects (Scott and Way 1990).

The objectives of the current program of selecting biological control agents for the control of *Emex* spp. are:

- to select effective biological control agents among the insects that have evolved in association with *E. spinosa,*
- to determine which potential biological control agents will survive southern hemisphere conditions on *E. australis,* and
- to establish the host specificity and safety for release in Australia of the potential biological control agents.

Seven insect species are under consideration. Here we review progress in the assessment of these species.

Apion miniatum Germar (Coleoptera: Apionidae)

Apion miniatum is a small (3.3–4.3 mm long) apionid weevil found throughout Europe and the eastern Mediterranean region (Hoffmann 1958). It has been found on *Emex spinosa* in Israel (Scott unpublished observations), and is reported on *Rumex* species in the subgenus *Lapathium, R. hydrolapathum, R. obtusifolius,* and *R. conglomeratus* (Hoffmann 1958), and *R. crispus* (Dieckmann 1973). *Rumex thyrsoides* and *R. sanguineus* (Hoffmann 1958) are possibly doubtful host records given the biology of the insect. Samedov (1963 in Ter-Minassian 1972) records the insect in Azerbaijan on *R. acetosa, R. pulcher, Rheum* and *Ribes*, the latter two being unlikely host plants based on published insect host associations in Europe.

Apion miniatum collected from Israel complete their life cycle on *E. spinosa.* The adult feeds on leaves, making small 'shot holes' in the youngest leaves. The female uses its rostrum (snout) to make a hole in the stem or base of a petiole into which an egg is laid. The larva completes development inside the plant, feeding at the stem nodes, base of the stem and the upper tap root. Pupation occurs inside the plant. There appears to be one generation a year with adults emerging in late spring. Young adults feed on *E. spinosa* leaves for about two weeks before adopting a negative geotrophic behaviour (climbing up objects) and oversummering by remaining dormant for three to six months. *Apion miniatum* can complete its life cycle on *E. australis* and has been synchronized to southern hemisphere conditions (Scott and Yeoh unpublished observations).

Tests to determine the host specificity of *A. miniatum* are nearing completion. *Emex* and introduced *Rumex* species (which are also biological control targets) were suitable for development of larvae. The insect lays eggs on native Australian *Rumex* species, but survival of larvae is considerably lower than on *Emex* or introduced *Rumex* species. Eggs were found on *Antigonum* and one *Polygonum* species (Polygonaceae), but the larvae did not develop and died in first instar. Eggs were found on one *Begonia* plant (Begoniaceae), but the larvae died in first instar. No egg laying was observed on any of the other non Polygonaceae. An application for authorization to release *A. miniatum* will be made if the results of remaining tests are consistent with earlier results.

Perapion neofallax (Gyll.) (Coleoptera: Apionidae)

Perapion neofallax is a small apionid weevil which is only known from Morocco (Krauss 1963). The adult feeds on leaves of *E. spinosa*, making small 'shot holes' in the youngest leaves. The female uses its rostrum to make a hole in the stem or base of a petiole into which an egg is laid. The larva completes development inside the plant, feeding in the stem. Pupation occurs inside the plant. There appears to be one generation a year.

Perapion neofallax has been bred in quarantine under southern hemisphere conditions, although few F1 adults were obtained. Host specificity tests have not started on *P. neofallax*.

Perapion violaceum (Kirby) (Coleoptera: Apionidae)

This small (2.5–3.5 mm long) apionid weevil is closely related to *P. neofallax* and has a similar biology. *Perapion violaceum* is found throughout Europe and around the Mediterranean (Hoffmann 1958). *Perapion violaceum* has been recorded from Israel (Melamed-Madjar 1969) although not on *E. spinosa* (Scott unpublished observations), whereas it is found on this plant in Portugal (Krauss 1963). Its recorded hosts are *E. spinosa* and *Rumex* species from the subgenera *Rumex (Rumex)* and *Rumex (Acetosa),* and *Polygonum* species. Scott (1985) reports on preliminary tests on the host specificity of this weevil. The species feeds on a wide range of *Rumex*, including Australian native species.

Coniocleonus excoriatus Gyll. (Coleoptera: Curculionidae)

Coniocleonus excoriatus is a medium sized (11–14 mm long) weevil (Hoffmann 1950). The adult feeds on leaves of *E. spinosa* or *Rumex* species. Larval development occurs underground, outside the plant at the junction of the stem and the upper tap root. Pupation occurs in the soil. There appears to be one generation a year. *Coniocleonus excoriatus* is found throughout the Mediterranean basin (Hoffmann 1950). The only recorded host plant is *E. spinosa* (Julien 1981).

Adults and larvae were obtained from Morocco and Israel and imported into quarantine. The larvae completed development. The adults produced eggs, but the resulting larvae did not survive. The eggs were laid on the soil surface near the host plant or at the base of the stems at soil level. The eggs were laid singly and were covered with frass. Progress with specificity testing *C. excoriatus* awaits improvement in the rearing techniques.

Kokujewia ectrapela Konow (Hymenoptera: Argidae)

Kokujewia ectrapela is a medium sized (10–12 mm long) sawfly. The biology of this insect has not been studied, but it is possible to deduce gross details of the biology from related genera. The short-lived adult probably does not take nectar or feed from flowers. The adult female inserts eggs into the leaf or stem of the host plant by using its saw-like ovipositor. The larvae feed externally on leaves, usually completing development on a single plant. Pupation occurs in the soil. There may be one to three generations per year.

Kokujewia ectrapela is recorded from Israel, Turkey, Georgia, Azerbaijan and North Ossetia (Benson 1968, Muche 1977). Synonyms of *K. ectrapela* include *K. clementi* Zirnbiebl and *K. palestina* Benson (Benson 1954, Benson 1968). Benson (1954) in his original description of *K. palestina* notes 'larva on ? *Rumex*'. The following year he changed the host record to 'larvae on *Emex*' (Benson 1955), and this is repeated by Smith (1982); however Muche (1977) in his review of Argidae gives the host plant as *Rumex*. The distribution of *K. ectrapela* indicates that both *Rumex* and *Emex* are likely hosts, if there is only one species involved (cf. Benson 1968).

Some species of *Arge* (Argidae) in Europe are known to cause 'sawfly poisoning' when the larvae are eaten by mammals (Kannan *et al.* 1988). The cause of the poisoning is a toxin, lophyrotomin, an octapeptide containing 4 D-amino acids. In Australia this type of poisoning occurs in Queensland from an unrelated sawfly in the family Pergidae, *Lophyrotoma interrupta* (Dadswell *et al.* 1985). *Kokujewia ectrapela* would have to be examined for presence of the toxin before it could be released as a biological control agent.

We were interested in this insect because a native pergid sawfly, *Lophyrotoma analis*, is the only insect causing extensive defoliation of *Emex* and *Rumex* in Australia (Scott and Yeoh unpublished observations). *Lophyrotoma analis* is active mainly in the warmer months and is usually found on introduced and native Polygonaceae. The scarce information on *K. ectrapela* suggests that it completes development during winter. Thus the insect would be present at the same time as *Emex* species and is thus likely to cause greater defoliation than *L. analis*.

Extensive searches in both Israel and Morocco failed to find *K. ectrapela* (Scott and Sagliocco unpublished observations), excluding it from further study. Its absence is difficult to explain. It could be that the insect's presence when first collected in 1945 (Benson 1954) was due to a rare range extension from northern regions.

Dysaphis emicis (Mimeur) (Hemiptera: Aphididae)

Dysaphis emicis is a small aphid, 1.8 to 2.0 mm long (alate viviparae – winged reproductive females). Aptera (wingless forms) have been found on roots of *Emex spinosa* in March, the winged form being produced towards the end of the same month (Mimeur 1934). The insect has also been collected on *Rumex crispus* (Ilharco 1967) and *Rumex* sp. (Van Harten 1974). An association with ants has been noted by Mimeur (1934) and Van Harten (1974).

Dysaphis emicis is known from Morocco (Mimeur 1934), Madeira and Porto Santo (Ilharco 1976), continental Portugal (Ilharco 1967, Van Harten 1976), Sicily (Barbagallo and Stroyan 1980) and Israel (Scott unpublished).

The aphid was originally described as *Anuraphis emicis* by Mimeur (1934) from specimens collected in Rabat, Morocco. *Dysaphis rheicola* Daniarova, an aphid described from rhubarb (*Rheum rharbarum*) in Russia (Narzikulov and Daniarova 1971), is given as a synonym by Eastop and Hille Ris Lambers (1976). *Dysaphis emicis* has also been synonymized with *Dysaphis albocinerea* Hille Ris Lambers, an aphid described from sorrel (*Rumex acetosella*) in the Netherlands (Shaposhnikov 1956), but Stroyan (1963) maintains that biological evidence is necessary to determine whether these are all the same species.

A permit to import this aphid into quarantine has been obtained, but the insect has yet to be studied. The ephemeral nature of *Emex* species means that biological control agents will need to either have very long lived resistant stages or able to migrate into weed infested areas and rapidly multiply. Aphids such as *Brachycaudus rumexicolens* fall into the later category. A study of *Dysaphis emicis* will be necessary to determine if it also has attributes of a useful biological control agent.

Initial studies of *D. emicis* will need to establish if the aphid is able to survive on rhubarb and other Polygonaceae species.

Haploprocta sulcicornis (F.) (Hemiptera: Coreidae)

This coreid bug has a circum-Mediterranean distribution, extending into central Europe (Linnavuori 1960). The biology and host plants of the species appear to be unknown although Linnavuori (1960) mentions that it occurs 'on xerophilous vegetation'. In Israel this insect was observed on *E. spinosa* and *Rumex bucephalophorus* L. which grow together on the coastal sand dunes. No nymphal stages were observed on the *Rumex* so it is not known if it can develop on these plants, whereas young stages are frequently found on *E. spinosa*. The colour of this insect closely resembles the red stems of Polygonaceae such as *E. spinosa* and *R. bucephalophorus*, and this suggests that there might be an association between it and this family of plants. The species has not been recorded as an agricultural pest in Israel (Avidov and Harpaz 1969). Even so, further information is required before this insect would be considered for importation as a candidate biological control agent.

Discussion

All seven species should be considered as potential biological control agents since there are comparatively few species available. Our initial observations have determined that *A. miniatum* and *P. neofallax* aestivate and thus may be suitable to survive the Australian summer. For this reason both species are being given priority for study. Practical considerations also are important since *P. neofallax* and *C. excoriatus* have proved difficult to rear in southern hemisphere conditions (Julien 1981), and the availability of other species (*D. emicis* and *K. ectrapela*) will determine when they are studied. However, an examination of *P. violaceum* should wait until *P. neofallax* has been tried since both species have a similar biology.

It is likely that the host range of these insects will include *Rumex* species. Five of the introduced *Rumex* species are also targets for biological control in Australia and an insect able to attack both genera may be useful. However, there are seven species of native *Rumex* that need to be considered in any host specificity assessment (Scott and Yeoh 1995).

The technical difficulties of switching the life-cycle of each species to southern hemisphere conditions is also a major hurdle to be crossed for each insect that is studied. A useful start has been made, but this component of the work helps set order that the species are studied. *Perapion neofallax* and *Dysaphis emicis* will be the species assessed following *A. miniatum*.

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Bibliography of the weeds, *Emex australis* and *Emex spinosa*

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Abstract
Publications concerning the weeds *Emex australis* and *Emex spinosa* are listed in a bibliography of 291 references.

Introduction
This bibliography on the weeds *Emex australis* and *Emex spinosa* was prepared as an aid to establishing research priorities for the weed and to document research efforts up to 1995. It is also intended to be an introduction to *Emex* species for researchers and students and as preparatory material for the CRC for Weed Management Systems workshop on *Emex australis.*

Methods
Searches
The bibliography is based on literature searches up to 1994 and partially into 1995. Searches were made in the following abstracting systems and databases for references to *Emex* species; Agriculture Victoria – Library Catalogue, Agris International, Australian Bibliography of Agriculture, Australian Bibliographic Network (Supersearch)., Bibliography of Agriculture, Biobusiness, Biological Abstracts, CAB Abstracts (including Weed Abstracts)., Chemical Abstracts, CSIRO Index, Current Contents, Life Science Collection, Pascal, and Union List of Higher Degree Thesis in Australian University Libraries.

Secondly, the reference lists in Gilbey (1974), Gilbey and Weiss (1980), Buchanan (1990) and Shivas and Sivasithamparam (1994) were consulted.

Finally, a draft of the bibliography was circulated to weed researchers with knowledge of the weed for comment and feedback.

Selection of references
Where possible, references in the informal literature (such as unpublished reports). have been included where the material has been deposited in a library and / or entered onto computer based indexing systems. An asterisk (*) indicates those references not seen during compilation of the bibliography. In general, botanical, taxonomic, and weed texts and herbicide guides were excluded, unless containing information beyond listing the species.

Compilation method
The original articles were consulted (except where indicated by an asterisk before the first author's name) before being selected for entry into the bibliography. Each reference was entered into Procite 3.1 for Windows.

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Workshop to identify research priorities for *Emex* species

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Introduction

The afternoon of the workshop on 11 December 1995 was reserved for an analysis of the opportunities and threats facing research to control *Emex* species (mainly *E. australis*). Time precluded assessing strengths and weaknesses which in any case are probably better examined at the level of each of the participating organizations. The 28 participants were distributed in five groups. An initial discussion was held to frame the problem. Each table was asked to state their concept of the problem. This was followed by table discussions to generate research ideas. The ideas were then presented to the group by soliciting new ideas from each table in succession (round robin). Ideas were sought for each of the following areas: biology, ecology, herbicide, biological and cultural control, education and training, technology transfer, regulatory, economic and regional issues. Once the ideas were consolidated, the participants ranked the ideas for feasibility (is the idea achievable? can it be done?) and for attractiveness (if it could be done, would it be a good thing to do now?). This method is not without criticisms; for example, new work would be favoured over current work. Also the ideas were not exposed to criticism nor were they championed (time not permitting). However, the results can be used as a guide to some of the issues and possible new areas of research.

Table 1 shows how the group at the workshop defined the problem caused by *E. australis*. The problem can be summarized as '*Emex australis* seed populations increase as a result of agricultural practices and a lack (or non-implementation) of suitable control measures. This results in reduced productivity and increased contamination problems'. As is often the case with weeds, the problem is multifaceted, with economic and biological components. The economic component is that the weed problem is largely a result of agricultural practices (pasture/crop rotations) that are not likely to change because of other reasons. The biological component is the plant's ability to produce abundant, long lived seed banks.

Ideas proposed during the round robin are presented in Table 2. These were rated for feasibility and attractiveness (Figure 1). Feasibility and attractiveness are positively correlated ($r^2 = 0.49$) (Figure 1) indicating that participants were possibly not distinguishing between the two attributes. For this reason, caution is required when using this information to set research priorities. Caveats aside, the workshop activities allows the proposal of a set of research topics culled from the suggestions in Table 1 and 2 and emphasizing the ideas allocated to the top right hand quarter of Figure 1.

Key result areas: research directions

i. Update the review of *E. australis* in the Biology of Australian Weeds series. An update is planned for inclusion in a future volume of Biology of Australian Weeds being edited by Groves, Shepherd and Richardson.

ii. Herbicide resistance in *E. australis* is unknown at present, but has arisen in similar species. A pro-active approach of assessing the risk of *E. australis* developing herbicide resistance should be undertaken and complemented by an extension program on the rotation of herbicide combinations to minimize the development of resistance in this weed.

iii. Determine the factors (herbicides, biotic and environmental stresses) affecting seed production by the plant. This work should be undertaken with vii (below) and incorporated into a model of seed production and survival.

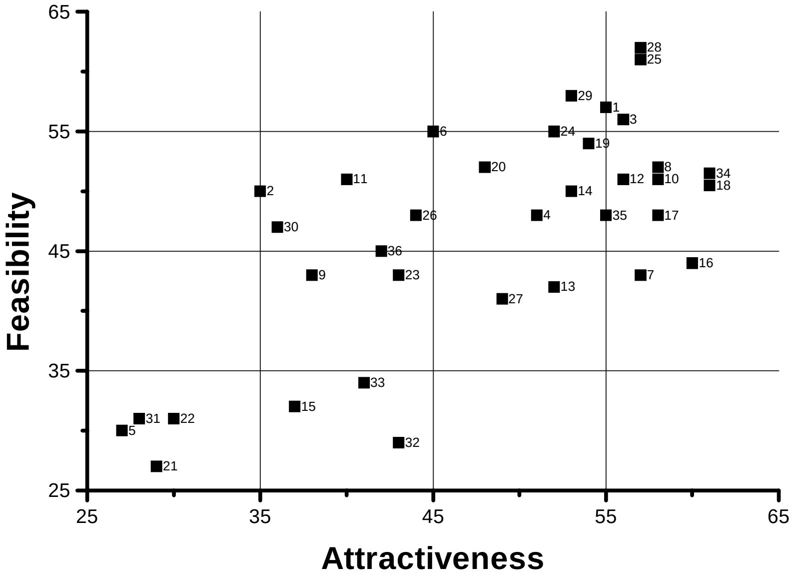

Figure 1. Ranking of research ideas. Each of the ideas in Table 2 was scored by the workshop participants (23 scores were obtained). The ideas were scored for low (L), medium (M) and high (H) feasibility or attractiveness. A composite score for the attractiveness or feasibility of each idea was obtained by the sum of L + 2*M + 3*H.

Table 1. Identification of the problem; ideas presented during the workshop.

1	Reduces productivity and quality of crops, pastures and animals because there is no reliable long term control program.
2	Emex is a major threat; to product quality in horticulture and for human consumption of export grains, to future production of various pulse crops
3	High seed production in non crop year after summer rain, and in some phases of the rotation, causes a population explosion of *E. australis*, resulting in a lack of management options.
4	A focus on pasture is needed – treat pasture as a crop and improve competition between species. Integrate management of *E. australis* across rotations, especially addressing seed bank ecology.
5	Is it really a problem? Is the problem control or extension? For example; * dry seeding versus wet seeding in lupins, * lack of control in vines due to cost!! It is a problem in pasture (mainly overgrazed pasture) rather than crops. Known controls need to be integrated into sustainable rotations.

Table 2. Round robin of ideas to improve control of *Emex* species.

Issues		Research / extension proposed / needed
Biological	1	Factors affecting seed production
	2	Comparative studies of *E. spinosa*, *E. australis* and their hybrids
Ecological	3	Competition studies between *E. australis*, new pulses and oil seeds
	4	Effect of rotating herbicide resistant crops (e.g. Triazine resistant canola, Basta resistant lupin) on weed seed banks
	5	Impact of *E. australis* control on native bird populations
	6	Effects of herbicides on seed quality, e.g. Lontrel
	7	Control to target seed bank: e.g. allelopathy / cultivation
	8	a) Influence of environmental factors on seed bank dynamics – study, model and predict b) Effects of soils, stubble and zero till on dormancy status c) Effects of environmental factors / stresses on seed dormancy
	9	Influence of sheep on pasture ecology with respect to *E. australis*
Herbicide	10	Assess the risk of *E. australis* developing herbicide resistance
	11	Comparative dose responses for all *E. australis* herbicides
	12	Develop registered herbicide packages to use in the legume phase of rotations, then extend to all stages of the rotation
	13	Further development of generic 'out of patent' herbicides
Biocontrol	14	Effect of biological control on seed production and quality
	15	Produce benign (non-toxic) *Phomopsis*
	16	a) Fast track biological control programs b) More evaluation of new bio-control agents especially in combinations
	17	Incorporate biological control into integrated weed management (IWM)
Cultural control	18	a) Put technology into improving pastures 'good pastures, not weeds' b) Sow pasture species to compete against *E. australis*
	19	Maintain a broad IWM perspective
	20	Control *E. australis* germinating in summer to prevent seed bank top up
	21	Reduce palatability of pasture species to improve *E. australis* intake
	22	Evaluate effectiveness of seed catching at harvest
	23	Control *E. australis* in non-agricultural, amenity and conservation areas
Education & training	24	Develop education packages for each control situation
	25	More extension on rotation of herbicide combinations to minimize resistance
	26	Identify communication gaps
Technology transfer	27	Predictive model for *E. australis* germination for control
	28	Review biology of *E. australis* (in Biology of Australian Weeds series)
	29	Devise information package for farmers and for 'technocrats'
	30	Set up *Emex* species email 'fan club' or internet page
Regulatory trends	31	Uniform regulations, especially receival standards
	32	Consumer liability for use of herbicides 'insurance' (minor use registration)
	33	Review patent / new product rules that apply to chemical companies
Economic trends	34	Define / measure the impact of *Emex* species on Australian agriculture
	35	Cost benefit analysis of control of *E. australis* in rotations and horticulture
Regional trends	36	Obtain data on real and potential distribution in Australia – survey distribution of both species

iv. Measure the competitive interactions between *E. australis* and new crops such as pulses, oil seeds and new pasture legumes.

v. Improve extension of information for each control situation, for example the need to sow pasture species to compete against *E. australis*.

vi. Define and measure the impact, including a cost benefit analysis of control of *E. australis* in Australian agriculture.

vii. Study, model and predict the effects of environmental factors / stresses (e.g. soils, cultivation, allelopathy, stubble and zero till) on seed dormancy and seedling recruitment.

viii. Develop registered herbicide packages to use in the legume phase of rotations, then extend to all stages of the rotation. Similar action is possibly required for control in vineyards.

ix. Evaluate new and existing biological control agents for the possibility of incorporation into integrated weed management.

Conclusions

The success of this workshop will be measured by the completion of new research that leads to significant improvements in the control of *E. australis* and *E. spinosa.* A follow-up workshop should be held in four to five years time to examine how much progress has occurred.

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