Emex in Southern Africa and Australia: An overview of biology and biological control

John K. Scott*, CSIRO Biological Control Unit, Zoology Department, University of Cape Town, Rondebosch 7700, South Africa.

Summary

The history, distribution, population biology and control methods of *Emex australis* Steinheil (Polygonaceae) in southern Africa are reviewed. The biology of *E. australis* in southern Africa is similar to that in Australia, except for the presence of an associated insect fauna and disease flora and interaction with mammals, which cause soil disturbance in southern Africa. Densities of seedlings, seeds in the soil, and new seed production at a study site in western Cape Province were found to be comparable to sites where the plant is a weed in Australia.

Control of *Emex* species in Australia by biological means remains a viable option despite the lack of success of two weevil species already released. Among potential biological control agents are four fungi, including *Phomopsis* sp. from South Africa, which is being assessed for host specificity. Six weevil species associated with *Emex spinosa* (L.) Campdera in the Mediterranean region, remain to be examined for their potential to control of *Emex* species in Australia.

Introduction

Two species of *Emex*, the doublegee or three-cornered jack, *E. australis* Steinheil, and the lesser jack, *E. spinosa* (L.) Campdera, are introduced weeds in Australia (Gilbey 1974). *Emex australis* is native to southern Africa and *E. spinosa* comes from the Mediterranean region and Middle East (Gilbey and Weiss 1980). The southern African species, *E. australis*, is of greater importance to agriculture (Gilbey and Weiss 1980). Its biology has been a subject of considerable study in Australia (Cheam 1987, Gilbey and Weiss 1980, Panetta 1990, Weiss 1981, Williams, *et al.* 1984) and the potential for biological control has been assessed (Scott and Shivas 1990). The biology of the plant in its region of origin, southern Africa, has only been examined recently (Panetta 1990, Scott unpublished, Scott and Shivas 1990, Scott and Way 1990, Shivas unpublished). Here I give an overview of the biology of *E. australis* in southern Africa, compare this with the situation in Australia, and summarize the options available for the biological control of this weed in Australia.

*Present Address: CSIRO Division of Entomology, Private Bag P.O., Wembley 6014, Western Australia.

Biology of *Emex australis* in Southern Africa

Emex australis is the only species of its genus in southern Africa (Gibbs Russell *et al.* 1987). A recent examination of isozyme variation found a general uniformity in South African populations and it was not possible to identify the source of introductions into Australia (Panetta 1990).

The oldest specimens of *E. australis* are achenes found in an archaeological deposit dated 760 AD in the eastern Cape Province of South Africa (Deacon 1967, Wells 1965). The first recorded collection of the plant occurred in 1685 and in 1772 the plant was noted by Thunberg (quoted in Smith 1966) as being common, and a problem for the feet of slaves and others who walked bare footed. In 1933, *E. australis* was described as a serious weed of cereal crops in the western Cape Province (Vorster 1933).

Based on historical evidence, Smith (1966) states that originally "The species seems to have been confined in its distribution to the south-west and south-east [of Cape Province] but, with the extension of the Settlement further inland, the species was further distributed". Evidence from archaeology, and the associated insect fauna, supports this supposition. The only monophagous insect on *E. australis*, the weevil, *Perapion antiquum* (Gyllenhal), has a distribution largely restricted to the western and south-eastern Cape Province and not elsewhere in the present range of *E. australis* (Scott unpublished observations). Today, *E. australis* is found throughout southern Africa, and has been introduced into Zimbabwe (Wild 1955), Kenya (Graham 1958) and elsewhere in the world (Scott and Shivas 1990).

Habitat

Emex australis is a winter annual in areas of Mediterranean type climate in the western Cape Province, although populations can be found during summer in irrigated lands. In areas of year-round rainfall and subtropical environments (the southern and eastern Cape Province and Natal) the plant is present at all times of the year, but remains an annual.

During 1985 to 1987, 52 populations of *E. australis* in the Cape Province were examined by Scott and Way (1990). Sites were found in the road verge (44%), fields used for crops (chiefly wheat) (34%) and pasture, horticultural crops and river beds in dryer regions (e.g. the Karoo). Most sites (73%) were on sandy soils, but other sites were on a range of soils including loams and clay.

The plant was only found in areas where the soil had been disturbed. Usually this was due to human activity, but in the western Cape Province the disturbance was due to excavation mounds produced by the Cape dune mole rat, *Bathyergus suillus* (Schreber) (Rodentia: Bathyergidae), which were abundant in sandy areas. In the Addo Elephant Park in the eastern Cape Province the plant was found in areas where the soil has been disturbed by large mammals (elephants, buffaloes). It is likely that the original habitat of *E. australis* was in soil disturbed by mammals other than humans prior to the spread of agriculture to the Cape Province.

Growth and development

Plants of *E. australis* in the Cape Province are of a similar size to those in Australia (Gilbey and Weiss 1980, Scott, unpublished observations). The largest *E. australis* plants were found in the western Cape Province where the average length of the longest stem (maximum plant radius) was 21.1 cm and the average total stem length was 162.9 cm. The largest plant found had 45.7 m of stem. Plants from the western Cape Province had on average 2.6 stems arising from the collar region above the taproot. In contrast, plants in the eastern Cape had significantly shorter stems (mean = 14.7 cm), but more stems in the collar region (mean = 4.5). Even so, the total length of stems (average 154.4 cm) was not as long as for plants from the Western Cape Province. Plants from Natal were similar in size to those in the Eastern Cape Province and compact in appearance in comparison with those from the southern and western Cape Province. Seed production is positively correlated with stem length in *E. australis* (Scott unpublished) so the size of a plant has a bearing on its reproductive success. Reasons for the size differences are not known, but possible explanations include the greater number of insect species which feed on the plants in the eastern Cape Province (Scott and Way 1990), different soils (sands in the western Cape Province versus clays and loams elsewhere) and different climates (winter rainfall versus year-round rainfall).

Population dynamics

The seed bank and plant demography of *E. australis* was examined at a study site near Langebaan (33°05'S;18°07'E) in the western Cape Province. The methods used were those of Weiss (1981). This site (average rainfall 265 mm per annum) has a climate which closely resembles that of areas of severe *Emex* infestation in the northern wheat belt in Western Australia. The site was on a wide road verge, next to fields with a wheat, sheep rotation, in which *Emex* plants were controlled by herbicide. The soil was sand which was tunnelled by Cape dune mole rats and Cape gerbils, *Tatera afra* (Gray) (Rodentia: Cricetidae). A preliminary analy-

Table 1. State of seeds of *E. australis* at the beginning of the season at Langebaan, South Africa, in 1987.

Depth (cm)	Germinated in field (%)	Dormant (%)	Dead (%)	Empty (%)	Eaten by gerbils (%)	Total No. m^{-2}	Range m^{-2} in Australia (Weiss 1981)
0	0	16	16	32	36	6608	160-6584
0-5	5	11	10	46	28	5392	1100-4625
5-10	0	9	11	41	40	1383	1080-2562
10-15	0	3	3	78	16	800	*

* Not measured.

Table 2. Summary of density and survivorship data for *E. australis* at Langebaan, South Africa, compared with the average of the largest cohort for the 9 samples of Australian data from Table 1 of Weiss (1981).

Date of first emergence	Density of seedlings (no. m^{-2})	Survivorship from emergence to flowering (%)	Survivorship from emergence to seed production (%)	Time from emergence to flowering (weeks)	Time from emergence to 50% survivorship (weeks)
South Africa 1986					
18 June	238.7	51.9	46.7	8	11
23 July	8.7	20.0	5.0	5	5
South Africa 1987					
20 May	159.0	53.1	50.6	12	15
24 June	6.6	47.8	47.8	9	12
29 July	1.0	0.0	0.0	0	5
Australia					
Largest cohort	245.6	56.4	39.6	11	17
First cohort	155.0	57.3	47.9	12	18

Table 3. Plant densities, stems per plant, seed production, below and above ground seeds at Langebaan, South Africa, compared with results in 1977 from Australia (Weiss 1981).

Source	Plants m^{-2}	Stems per plant	Seeds m^{-2} below ground	Seeds m^{-2} above ground	Total seeds m^{-2}
Langebaan 1986	247.4	1.4 ± 0.6	254.6 ± 97.8	797.6 ± 401.8	1052
Langebaan 1987	166.6	1.4 ± 0.6	399.7 ± 105.2	1710.7 ± 367.7	2110
Ungarie A 1977	275.2	1.2	*	*	73
Ungarie B 1977	678.4	1.4	*	*	1368
Two Wells 1977	191.8	0.8	*	*	1118

* Not measured

sis of the results from this study is presented here.

The seed bank at this site was similar to sites in Australia which were studied by Weiss (1981) (Table 1). Large numbers of achenes were found of which 5% were those that germinated in the year of the study. The presence of a large dormant seed pool (1691 seeds m^{-2}) ensured the continued recruitment of seedlings each year (Scott unpublished observations). Weiss (1981) found a range of 279 to 2590 dormant seeds per square meter at sites in eastern Australia. A sizable proportion of seeds are eaten by gerbils at Langebaan. Rodents are also known to destroy about a quarter of *E. australis* seeds in Australia (Weiss 1981).

Likewise, the abundance of seedlings and their survival was similar between Langebaan and sites in Australia studied by Weiss (1981) (Table 2). A comparison for the end of the plant's season is given in Table 3. Again the study site in South Africa was similar to those in Australia. The number of seeds produced was four to ten times the number of plants. Approximately a quarter of seeds are those at the base of the stem, and it is possible that these seeds contribute disproportionately to the next generation, as above ground seeds are more likely to be eaten by gerbils or dispersed. An abundance of plants was observed at the study site in 1988 and 1989, but measurements were not taken. In 1990 the density of seedlings was at the levels observed in 1986 and 1987, which suggests that there is a stable population of *E. australis* at this site (Scott and Shivas unpublished).

Importance and control

In South Africa *E. australis* is an important weed of cereal crops (Loubser and Le Roux 1980, Vorster 1933) and vineyards (Fourie and Van Huyssteen 1987) in the western Cape Province. The spiny achenes cause injury to the feet of animals (Henderson and Anderson 1966), and it is recorded as a seed contaminant (type of seed not stated) by Wells *et al.* (1986). Given the abundance of *E. australis* in agricultural crops of the western Cape Province it is perhaps surprising that this plant has not attracted more attention as a weed in South Africa.

In the past frequent cultivation was the only method of control in South Africa (Vorster 1933). Today a number of post-emergence herbicides are listed for weeds in cereal crops (Vermeulen and Grobler 1986), but recommendations have not been published specifically for *E. australis*. Loubser and Le Roux (1980) suggested the use of pre-emergence herbicides for the control of weeds in cereals, including *E. australis*, but this is not included in current recommendations (Vermeulen and Grobler 1986). Recently, herbicides suggested for *E. australis* control have been Express A (DPX-L5300 + metsulfuron methyl 20%) (Van Zyl and Eksteen 1989) and triasulfuron mixed with bromoxynil (Van Biljon *et al.* 1988). Fourie and Van Huyssteen (1987) mention the pre-emergence herbicide, oxadiazon, for *E. australis* control along with a number of other herbicides for general weed control in vineyards.

Comparison with Australia

In most respects, the biology and population dynamics of *E. australis* in South Africa, where the plant is native, appears to be similar to that in Australia where the plant has been introduced. There is, however, a major difference. In Australia the density of *E. australis* appears to decline after the first year of clover pasture, probably due to lack of cultivation and competition (Gilbey and Weiss 1980). Our observations at Langebaan (Scott and Shivas unpublished) found no such decline in density of *E. australis* from 1986 to 1990 at a site free from cultivation and chemical treatments. Domestic herbivores were also absent at Langebaan, but it seems unlikely that lack of grazing would favour the weedy species over palatable legume and grass species occurring at this site.

The persistence of high population levels of *E. australis* in the western Cape Province of South Africa is probably tied to the presence of the Cape dune mole rat. The mole rats produce surface mounds as a result of burrowing. These mounds weather away during summer to become the seed bed for annual plants, such as *E. australis*, the following year. Large fossorial rodents and analogous species are absent from Australia where high plant densities are dependent on human activity. In addition, the mole rats are not known to feed on *E. australis* plants and seeds (Davies and Jarvis 1986), but feed on plants among which are potential competitors such as *Oxalis* species.

Potential biological control agents

Biological control of *Emex* and potential agents which remain to be studied are reviewed in Scott and Way (1990) and Scott and Shivas (1990). The potential agents are listed in Table 4. Surveys for agents on *E. australis* in southern Africa have been completed (Scott and Way 1990). Further survey work is needed in the Mediterranean distribution of *E. spinosa*, and in the introduced range of both species, for example in California (Scott and Shivas 1990) to establish the full extent of available agents. To date, two weevil species have been released in Australia.

The first insect to be released was the southern African weevil, *Perapion antiquum*, which had previously provided control of *Emex* species in Hawaii (Julien 1987). Despite extensive releases in Australia this weevil became established at few localities and without providing control of the weed (Julien 1987). Recent work on this weevil in its original habitat in South Africa (Scott unpublished) found that it over-summers above ground in shrubs and small trees. Thus it seems that lack of an over-summering behaviour is not the reason for the failure of this weevil to survive Australian summers. Climatic differences between southern Africa and southern Australia, especially the maximum temperature during summer, appeared important in that *Emex*-infested areas in Australia, except for regions near the coast, are unsuitable for the weevil (Scott unpublished).

The second weevil released in Australia, *Lixus cribricollis*, came from Morocco. It failed to establish in eastern Australia and establishment in Western Australia has yet to be assessed (Julien 1987).

Potential agents for *Emex* control in Table 4 are ranked in order of perceived importance. Only one species is currently being studied. The stem blight fungus, *Phomopsis* sp., is being assessed for host specificity and an application has been made to import this fungus into quarantine in Australia for further study (Shivas unpublished).

The insect species judged to have the greatest potential are the weevils, *Coniocleonus excoriatus* and *Erythrapion miniatum*, which attack the crown of the plant and which have been found in parts of Israel which are very dry and hot in summer (Scott unpublished). This suggests that they could be better adapted to climatic conditions of *Emex*-infested areas of Australia than the weevils used in previous biological control attempts. In addition, these weevils attack the crown of the plant and may provide better control than insects which feed in the stem. Another weevil, *Perapion neofallax*, is given a high priority in Table 4 since it is only known from *E. spinosa* and may prove to be specific to the genus *Emex*. It is evident from Table 4 that most potential agents and the released agent, *Lixus cribricollis*, include *Rumex* species as hosts. *Rumex* is closely related to *Emex* so this host range is not unexpected. Five *Rumex* species are approved targets for biological control in Australia, but there are a number of native *Rumex* species (Rechinger 1984) which will need to be considered in any future host specificity testing of agents for *Emex* control.

Table 4. Potential agents including agents already released in Australia for *Emex* control. Based on Scott (1990 and unpublished), Scott and Shivas (1990), Shivas (unpublished).

Agent species	Source *Emex* species	Other genera included in host range	Future research priority*
Fungi			
Phomopsis sp.	*E. australis*	?*R. pulcher* L.	1
Cercospora tripolitana Sacc. & Trott.	*E. australis* & *E. spinosa*	*Rumex*	2
Peronospora rumicis Corda	*E. spinosa*	*Rumex*, *Fallopia*	2
Uromyces rumicis (Schum.) Wint.	*E. australis*	*Rumex*	2
Insects			
Coniocleonus excoriatus Gyllenhal	*E. spinosa*	*Rumex*	1
Erythrapion miniatum (Germar)	*E. spinosa*	*Rumex*	1
Perapion neofallax (Warner)	*E. spinosa*	None recorded	1
Perapion violaceum (Kirby)	*E. spinosa*	*Rumex*	2
Lixus cribricollis Boheman	*E. spinosa*	*Rumex*	3
Perapion antiquum (Gyllenhal)	*E. australis*	Host specific	3

* 1 indicates species with high priority for future research; 2 indicates species with lower priority; 3 indicates released species requiring assessment in Australia.

In conclusion, the biology of *E. australis* in southern Africa is similar to that in Australia except for the presence of an associated fauna and disease flora and interaction with mammals which cause soil disturbance. Included amongst these organisms and those associated with *E. spinosa*, are a number of potential biological control agents which remain to be assessed for the biological control of *Emex* weeds in Australia.

Acknowledgements

I thank E. Brown, K. Harmer, J. Hoffmann, C. Kleinjan, and R.G. Shivas for their comments on drafts of the manuscript and access to unpublished information.

References

Cheam, A.H. (1987). Emergence and survival of buried doublegee (*Emex australis* Steinh.) seeds. *Australian Journal of Experimental Agriculture* 27, 101-106.

Davies, K.C. and Jarvis, J.U.M. (1986). The burrow systems and burrowing dynamics of the mole-rats *Bathyergus suillus* and *Crytomys hottentotus* in the fynbos of the south-western Cape, South Africa. *Journal of Zoology, London*. (A) 209, 125-147.

Deacon, H.J. (1967). Two radiocarbon dates from Scott's cave, Gamtoos valley. *South African Archaeological Bulletin* 22, 51-52.

Fourie, J.C. and Van Huyssteen, L. (1987). Practical hints for the control of weeds in vineyards. *Deciduous Fruit Grower* 37, 347-356.

Gibbs Russell, G.E., Welman, W.G., Retief, E., Immelman, K.L., Germishuizen, G., Pienaar, B.J., Van Wyk, M. and Nicholas, A. (1987). List of species of southern African plants. Edition 2, Part 2. *Mem. Bot. Surv. S. Afr. No.* 56, 1-270.

Gilbey, D.J. (1974). *Emex* species in Australia with particular reference to Western Australia. *Journal of the Australian Institute of Agricultural Science*. 40, 114-120.

Gilbey, D.J. and Weiss, P.W. (1980). The biology of Australian weeds 4. *Emex australis* Steinh. *Journal of the Australian Institute of Agricultural Science* 46, 221-228.

Graham, R.A. (1958). Polygonaceae. *In* 'Flora of Tropical East Africa'. Eds. W.A. Turrill and E. Milne-Redhead. pp 1 - 40.

Henderson, M. and Anderson, J.G. (1966). Common weeds in South Africa. *Mem. Bot. Surv. S. Afr. No.* 37, 1 - 440.

Julien, M.H. (1987). 'Biological control of weeds. A world catalogue of agents and their target weeds. 2nd Edition'. CAB International, Wallingford, 144 pp.

Loubser, J.W. and Le Roux, D.J. (1980). The use of pre-emergence herbicides on wheat in the Western Cape. Proceedings of the 3rd National Weeds Conference of South Africa. pp. 123-129.

Panetta, F.D. (1990). Isozyme variation in

Australian and South African populations of *Emex australis* Steinh. *Australian Journal of Botany* 38, 161 - 67.

Rechinger, K.H. (1984). *Rumex* (Polygonaceae) in Australia: a reconsideration. *Nuytsia* 5, 75-122.

Scott, J.K. (1990). Prospects for the biological control of *Rumex* species in Australia. Proceedings of the VII International Symposium on Biological Control of Weeds, 6 to 11 March 1988, Rome, Italy. (in press).

Scott, J.K. and Shivas, R.G. (1990). Potential biological control agents for *Emex* spp. Proceedings of the 9th Australian Weeds Conference, 480 - 483.

Scott, J.K. and Way, M.J. (1990). The phytophagous insects of *Emex australis* Steinheil in southern Africa and their potential for biological control in Australia. *Plant Protection Quarterly* 5, 43 - 48.

Smith, C.A. (1966). Common names of South African plants. *Mem. Bot. Surv. S. Afr. No.* 35, 1-642.

Van Biljon, J.J., Hugo, K.J. and Iwanzik, W. (1988). Triasulfuron: a new broadleaf herbicide in wheat and barley. *Applied Plant Science* 2, 49-52.

Van Zyl, W. and Eksteen, F.H. (1989). Granstar and Express A: new broadleaf herbicides in cereals. Abstracts of the Combined Conference of the South African Societies of Crop Production, Soil Science and Weed Science, p 34.

Vermeulen, J.B. and Grobler, H. (1986). 'A guide to the use of herbicides'. 9th Edition. Department of Agriculture and Water Supply, Republic of South Africa, 112 pp.

Vorster, P.W. (1933). The chief weeds of grain lands. IV. The "Duwweltjie" (*Emex australis*). *Farming in South Africa*, July 1933, 263.

Weiss, P.W. (1981). Spatial distribution and dynamics of populations of the introduced annual *Emex australis* in south-eastern Australia. *Journal of Applied Ecology* 18, 849-864.

Wells, M.J. (1965). An analysis of plant remains from Scott's cave in the Gamtoos valley. *South African Archaeological Bulletin* 20, 79-84.

Wells, M.J., Balsinhas, A.A., Joffe, H., Engelbrecht, V.M., Harding, G., and Stirton, C.H. (1986). A catalogue of problem plants in southern Africa. *Mem. Bot. Surv. S. Afr. No.* 53, 1-658.

Wild, H. (1955). 'Common Rhodesian weeds'. Government Printer, Salisbury, unpaged.

Williams, J.D., Groves, R.H., Weiss, P.W., and Nicholls, A.O. (1984). Competition between wheat and two *Emex* species. *Australian Journal of Agricultural Research* 35, 453-461.

Questions and discussion

Q. Greg Code. What are the chances of *Emex* becoming a biennial if there is a good water supply?

A. *Emex* will still remain an annual - it will however grow over a longer time.

Q. Greg Buchanan. How important is *Emex* in the cultivated cropping areas of northern South Africa?

A. *Emex* has spread outside its natural habitat and has not been restricted to specific soil types. It is not however seen as a weed of cropping districts.

Q. Vicki Bates. How effective are cultural methods, such as mulching, in control of *Tribulus*?

A. Recommendations were contained in extension material.

Q. John Heap. Can seeds of *Emex* that were buried germinate once they are brought to the surface?

A. Yes, however there is no information on the longevity of survival in South Africa.

Q. Greg Buchanan. What is the present distribution of *Tribulus* in South Africa?

A. *Tribulus* is now distributed throughout the Cape province of South Africa however they do not know how many species there are.