The ecology of saffron thistle in France and eastern Australia

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Summary Saffron thistle (*Carthamus lanatus* L.) is a serious weed in pastures and rangelands throughout much of Australia, but is rarely a problem in Europe where it originated. We compared various aspects of its population dynamics between Australian and French sites to determine what factors may limit its abundance in its native range.

Australian pastures generally had a higher density of thistles than French pastures, and soil seedbanks in Australia were much larger than those in Europe. These differences in seedbanks are probably due to high levels of post-dispersal seed predation in Europe. Australian thistles produced more seeds per plant, but this may not be due to insect herbivores attacking the plant in its native range, as a wide range of insects also fed on thistles in Australia. There were no insects boring into thistles in Australia, and this suggests that if such an insect were introduced as a biological control agent, it would face no competition for niches. The potential for biological control of saffron thistle is discussed.

Keywords *Carthamus lanatus*, pastures, biological control, seedbanks, native range.

INTRODUCTION

Saffron thistle (*Carthamus lanatus* L.), arguably Australia's worst thistle, is a serious weed of pastures throughout much of temperate and semi-arid Australia. It is however, rarely considered to be a problem around the Mediterranean basin and western Asia, where it originated (Parsons and Cuthbertson 1992). The population dynamics of saffron thistle within Australia have been studied (Grace 2001). This paper compares these data with those from plant populations in their native range. If there are fewer saffron thistles per unit area in its native range, then an understanding of the factors that regulate saffron thistle populations in European pastures may suggest management strategies for Australian pastures. Plant densities in European pastures, however, have not specifically been measured.

Some weeds may produce more seeds per unit area outside their native range, and this can be a result of higher seed production per plant, as well as a higher density of reproductive plants. Individual plants of several weeds are more fecund in Australia than in their native French range e.g. *Vulpia* spp. (Lonsdale *et al.* 1999), *Carduus nutans* L. (Woodburn and Sheppard 1996). The fecundity of individual saffron thistle plants has been investigated in conjunction with research into potential biological control agents (Aeschlimann 1997, Sheppard and Vitou 2000), but there are no data on saffron thistle seed production per unit area in Europe, or in comparison with plants in Australia.

Many introduced weeds have seedbanks that are much larger in Australia than in their native range, e.g. *Carduus nutans* (Woodburn and Sheppard 1996). These larger seedbanks may result from higher seed production per plant in Australia (Woodburn and Sheppard 1996), or because fewer seeds become incorporated into the seedbank in the weed's native range than in Australia. The number of saffron thistle seeds in the soil in European pastures has not been investigated, and the proportion of seeds produced that become incorporated into the seedbank is also unknown.

Pasture weeds can be affected by interspecific competition. Pastures in southern Europe may provide more competitors for germination niches than do temperate Australian pastures, and this increased competition with forbs in European pastures may limit the germination and establishment of seedlings of broadleaved weeds.

Phytophagous insects have evolved with saffron thistle in its native range, while Australia, which has no native thistles, would not be expected to have any native thistle feeding specialists. Mortality rates of up to 50% of saffron thistle plants have been attributed to insects and fungi in Europe (Aeschlimann 1997), suggesting that biocontrol may have potential against this weed.

For this study to be meaningful, it is important to verify that the same species of plant is investigated in both countries. The taxonomy of the plant must be investigated. Unfortunately, the taxonomy of the genus has not been resolved. Hanelt (1976) suggested that *C. lanatus* is a complex containing two subspecies, *C. lanatus* ssp. *lanatus*, and *C. lanatus* ssp. *baeticus*, as well as intermediate hybrids. Two different phenotypes of saffron thistle have been observed in

Australia (Peirce 1990). If biological control agents are to be introduced into Australia, then there is a need to revise the taxonomy on this species in Australia and Europe.

We aimed to compare aspects of the ecology of saffron thistle in Australia and Europe, to determine what factors may regulate the density of saffron thistle in its native range. Results are discussed in relation to the potential for biological control and other management options.

MATERIALS AND METHODS

Site descriptions The three Australian study sites were near Armidale (Northern Tablelands of NSW), Barraba (North West Slopes of NSW) and near Canberra (ACT) have been described previously (Grace 2001). The three French sites were near Viols-en-Laval in southern France (43° 51' N, 3° 35' E). All sites were grazing properties with infestations of saffron thistle. All French data were collected in June 1999, and Australian data were collected over three growing seasons 1997–1999, unless otherwise stated.

Density and seed production Density of saffron thistle plants in the three Australian sites were measured and seed production was estimated previously (Grace 2001). Seed production of the French plants was estimated by counting the number of plants in three 2 × 2 m plots at each site. Five mature plants per plot were harvested, dried, then weighed, and seed production was estimated using a linear equation from Sheppard and Vitou (2000). Plant density and seed production were compared between countries using quasi-likelihood general linear models in S-Plus 2000, to account for over dispersed Poisson error distributions P values were estimated using *F* distributions.

Insect herbivores Fifteen flowering plants from each site were collected, taking care not to dislodge any insects. Plants were then dissected in the laboratory, and insects identified as far as possible.

Seedbanks The post-germination soil seedbank in Australia was measured by taking soil cores (5 cm diameter and 10 cm deep), sifting the soil and counting the seeds in 1997. Sixty cores were analysed for each plot at the Armidale, and 30 cores for each plot at both Canberra and Barraba. We sampled the French plots similarly, using twelve cores per plot from each of the nine French plots.

Post-dispersal seed predation was investigated by presenting seeds in feeding stations. There were three replicates for each treatment at each site, at three sites in each country. Twenty seeds were placed in each dish, and each dish was placed near the plots used to estimate density and seed production. This experiment was performed at Armidale in November 1999, Barraba in January 2000 and Canberra in February 2000. The number of seeds per core, and seeds removed after 48 hours were compared between countries.

Pasture composition Pasture composition and biomass was estimated by clipping all vegetation in three subplots (12.5 × 12.5 cm) placed at random around each plot. Clipped vegetation was classified, dried then weighted. The Australian sites were sampled in January and February 1999. The Shannon index of species diversity was calculated for each sample on a dry-weight composition of the pastures. Species diversity was then compared between countries using ANOVA. The numbers of forb and grass species in each plot were compared between countries using general linear models, with gamma error distributions.

Taxonomy The morphology of ten capitula from each site was compared using Hanelt (1976). Samples from the N.C.W. Beadle Herbarium (NE), collected across New South Wales, were also investigated.

RESULTS

Density and seed production The Australian sites had higher densities of saffron thistle overall than did the French sites (Table 1). The French sites had fewer thistles than Barraba or Canberra, but more than Armidale.

Individual plants in Australia produced more seeds than French plants. This difference was significant ($F_{1,156}$=7.8; P=0.005), as were differences between sites within countries ($F_{4,156}$=3.4; P=0.013). Fecundity in Armidale was however, calculated from one surviving plant. Mean values for French plants were comparable to Aeschlimann's (1997) data for Viols (8.6 seeds per plant for plants attacked by insects, and 9.9 for unattacked plants). Seed production per unit area at Barraba and Canberra was much higher than for Viols or Armidale (Table 1), but there were no significant differences between countries ($F_{1,11}$=0.07; P=0.8).

Seedbanks Australian sites had much greater numbers of seeds in the soil than the French sites, indeed very few seeds were found in the French soil (Table 1). French plots suffered higher rates of seed removal than Australian plots (Table 1), and ants (*Messor* spp.) were observed removing seeds within minutes of the seeds being placed in French pastures. The few seeds that were lost in Australia (all at Armidale) may have been blown out of dishes by strong winds during the experimental period.

Invertebrate herbivores A wide range of insects attacked saffron thistle in Australia and France (Table 2). There were no Australian insects that fed inside stems or roots but *Helicoverpa armigera* larvae sometimes fed inside the capitula. All other Australian insects were either sap-suckers or leaf-chewers (Table 2). The French plants, however, were under attack from inside, with root feeding wasps, crown borers (*Botanophila turcica*), and two capitulum-feeding insects. There was no sign of any fungi or other pathogens on any of the plants sampled.

Pasture composition The French sites were dominated by annual grasses, especially *Aegilops ovata*, *Avena barbata*, *Medicago minima* and *Bromus secalinus*, whereas the Armidale and Barraba pastures had high proportions of perennial grasses. The French pastures sampled generally had a higher species diversity than those of Australia (Table 1), and this also varied between sites within each country ($F_{5,48}$=8.4; P<0.001). The French sites generally contained significantly more forb species than the Australian sites sampled ($F_{1,46}$=14; P=0.001) but both had similar numbers of grass species ($F_{1,46}$=2.5; P=0.1). The Barraba site, however, contained similar numbers of forb species to the French sites.

Taxonomy Australian and French plants showed considerable variation in floral morphology, and plants showed characteristics of both *C. lanatus* spp. *baeticus* and ssp. *lanatus* as described by Hanelt (1976). The more conservative characters (anther colour and bract curvature) suggest plants resemble ssp. *baeticus*. No large differences between accessions from Australia and Viols were apparent.

DISCUSSION

Plant density and seed production We found that saffron thistle occurred at higher densities at Canberra and Barraba than at Viols, and Armidale had fewer thistles than all other sites. Seed production per unit area was much greater at Barraba and Canberra than at Viols, but no significant difference was found between countries. Seed production per unit area reflected plant density rather than differences in fecundity.

The fecundity of individual saffron thistle plants

Table 1. Parameters for saffron thistle populations and the pastures in which they grew, in Australia and France.

	Australia			France			
Parameter	Armidale	Barraba	Canberra	Viols 1	Viols 2	Viols 3	Significance[a]
Mature plants m^{-2}	0.1 ± 0.1	68.3 ± 23.4	53.9 ± 15.1	45 ± 1.0	2.0 ± 0.4	1.9 ± 0.2	$F_{1,48}$=9 P=0.004
Pasture species diversity	0.3 ± 0.1	0.8 ± 0.1	0. 6 ± 0.1	0.7 ± 0.2	1.7 ± 0.2	1.8 ± 0.1	$F_{1,48}$=146 P<0.001
Seedbank (seeds m^{-2})	815 ± 770	1780 ± 540	2290 ± 770	9 ± 1	9 ± 1	61 ± 10	$F_{1,680}$=100 P<0.001
Seeds removed (% day^{-1})	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.05 ± 0.00	1.33 ± 0.08	0.07 ± 0.05	$F_{1,49}$=29 P<0.001

[a] *F* and P values are for tests between populations in Australia and France. Data show means ± s.e.m.

Table 2. Phytophagous insects found on saffron thistle plants in Australia and France. Plants attacked shows the percentage of plants sampled that were infected by these insects.

Location, Feeding	Australian plants		French plants	
	Species	Plants attacked	Species	Plants attacked
Root borer	None		*Aulacidea* sp. (Hymenoptera)	13%
Crown borer	None		*Botanophila turcica* (Diptera)	13%
Capitulum feeder	*Helicoverpa armigera* (Lepidoptera)	9%	*Larinus flavescens* (Coleoptera) *Stenodes straminana* (Lepidoptera)	16% 13%
Sap sucker	several aphids (Hemiptera) several thrips (Thysanoptera) *Nysius* sp. + others (Hemiptera)	56% 20% 13%	*Uromelan* sp. + *Protaphis* sp. (Hemiptera)	38%

varied between sites in France, and plants at Viols produced fewer seeds than other French sites (Aeschlimann 1997). Thistle fecundity also varied considerably between sites in Australia (Grace 2001).

Seedbanks French pastures had virtually no saffron thistle seedbanks, whereas Australian pastures had seedbanks of up to 3000 m^{-2} (Grace 2001). These differences appeared to be due to predation rather than differences in seed production. Predation of saffron thistle seeds was much higher in France than in Australia, from ants and possibly rodents. Sheppard (2000) described this phenomenon in other weeds. Unfortunately, the fate of the seeds that were removed is unknown.

Invertebrate herbivores Saffron thistle plants in Australia had a range of insects feeding on them, however there were no phytophagous insects that tunnelled into saffron thistle roots, stems or crowns in contrast to Europe. This suggests that if a burrowing insect such as *Botanophila turcica* was introduced as a classical biological control agent, it is unlikely to face niche competition. *B. turcica* appears to be the only potential classical biological control agent for use against saffron thistle (Aeschlimann 1997, Sheppard and Vitou 2000).

Pasture composition The French sites had higher species diversity than Australian sites overall. These differences were due mainly to the French sites containing more species of forbs than Australian sites. Further research could investigate pasture composition and cover in autumn and early winter in France, as this has a large effect on saffron thistle emergence (Grace *et al*. in press) and hence, population size.

Taxonomy Our results agree with Peirce (1990), who suggested that Australian and French plants belong to *C. lanatus* ssp. *baeticus* 'despite wide variation'. Plants in Eastern Australia fitted into the two forms that Peirce (1990) found in Western Australia. However, the taxonomy of the genus urgently requires revision.

Management implications Our results suggest that although plants in Australia produced more seeds per plant than in Europe, this was not necessarily due to phytophagous insects in Europe, as a. wide range of insects were also found on Australian plants.

The effects of the one potential classical biocontrol agent (*B. turcica*) on saffron thistle were investigated in France (Sheppard and Vitou 2000). Population models using these data suggested that *B. turcica* may help reduce thistle numbers, but grazing management aimed at maintaining pasture cover in autumn is much more likely to control saffron thistle (Grace 2001).

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REFERENCES

Aeschlimann, J.P. (1997). Reappraising the potential of biological control against the weed *Carthamus lanatus. Entomophaga* 42, 559-68.

Grace, B.S. (2001). The ecology and management of saffron thistle (*Carthamus lanatus* L.) in Australian pastures. Ph.D. Thesis, University of New England.

Grace, B.S., Whalley, R.D.B., Sheppard, A.W. and Sindel, B.M. (in press). Managing saffron thistle in pastures with strategic grazing. *The Rangeland Journal*.

Hanelt, P. (1976). Carthamus. *In* 'Flora Europea' Vol 4, eds T.G. Tutin, A.D. Chater, A. DeFilips and T.B.K. Richardson, pp. 302-3. (Cambridge University Press, Cambridge).

Lonsdale, W.M., Dowling, P.M. and Vitou, J. (1999). Population dynamics of vulpia in exotic and native ranges. Proceedings 12th Australian Weeds Conference, pp. 389-95.

Parsons, W.T. and Cuthbertson, E.G. (1992). 'Noxious weeds of Australia'. (Inkata Press, Melbourne).

Peirce, J.R. (1990) Morphological and phenological variation in three populations of saffron thistle (*Carthamus lanatus* L.) from Western Australia. *Australian Journal of Agricultural Research* 41, 1191-1201.

Sheppard, A.W. (2000). Population dynamics. *In* 'Australian weed management systems', ed. B.M. Sindel, pp. 253-265. (R.G. and F.J. Richardson, Melbourne).

Sheppard, A.W. and Vitou, J. (2000). The effect of a rosette-crown fly, (*Botanophila turcica*) on growth, biomass allocation and reproduction of the thistle *Carthamus lanatus*. *Acta Oecologia* 21(6), 1-11.

Woodburn, T.L. and Sheppard, A.W. (1996). The demography of *Carduus nutans* as a native and an alien weed. *Plant Protection Quarterly* 11, 236-8.