Recent news about saffron thistle (*Carthamus lanatus* L.)

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Summary
Saffron thistle (*Carthamus lanatus* L.) costs Australian agriculture around $111 million per annum, yet until recently, little was known about its population dynamics, how it could be managed in pastures or the potential for biological control. This paper discusses research that addressed these areas. Populations of saffron thistle vary between sites and years, largely in response to environmental conditions and pasture cover. Seed germination and seedling establishment is strongly affected by rainfall, pasture cover, seasonal cycles and seed density. Growth, development, survival and fecundity are strongly influenced by pasture competition and grazing. Seedbanks ranged from 800 to 2300 seeds m^{-2} in Australia and between 9 and 61 seeds m^{-2} in southern France, within its native range. Grazing management techniques such as rotational grazing can reduce thistle density in pastures, mainly by increasing the amount of pasture cover in autumn, which reduces seedling emergence. There is one potential classical biological control agent, a crown-feeding fly *Botanophila turcica*, which appears to be specific to saffron thistle. The fly, however, has little impact on saffron thistle populations in its native range. Fungal pathogens with potential to be used in mycoherbicides have been identified in Australian pastures. Further research into saffron thistle taxonomy, potential distribution and biological control is required.

Introduction
Saffron thistle (*Carthamus lanatus* L.) is a major problem in temperate pastures and crops throughout much of New South Wales, South Australia, southern Queensland and Western Australia, with potential to spread into arid areas in central Australia. Despite the scale of the problem, there was virtually nothing known about population dynamics of saffron thistle when the literature was reviewed in 1995 (Peirce 1995). There was, however, a considerable amount of literature available on control of saffron thistle using herbicides and cultivation. Unfortunately, these options are not applicable to much of the permanent pasture and rangeland infested with saffron thistle. Since then there has been much research into the population dynamics of saffron thistle in pastures, management with grazing as well as the potential for classical biological control and mycoherbicides. This paper aims to review recent work on saffron thistle, and suggest future research priorities.

Taxonomy
Accessions from pastures in eastern Australia and southern France were all highly variable, but most closely fitted the description of *C. lanatus* ssp. *baeticus* (Boiss and Reuter) Nymand described by Hanelt (1976) (Grace *et al.* 2002a), as Peirce (1990) found for Western Australian plants.

Carthamus lanatus ssp. *baeticus* was probably derived from a cross between *C. lanatus* ssp. *lanatus* and *C. leucocaulos* (glaucous star thistle) or *C. nitidus* (Ashri and Knowles 1960). *Carthamus lanatus* ssp. *lanatus* may in turn be derived from *C. dentatus* (Hanelt 1976). Australian populations may have since hybridized with *C. dentatus*, *C. glaucus*, *C. leucocaulos*, or *C. tinctorius* (safflower) (Lazarides *et al.* 1997). A specimen of *C. dentatus* in the N.C.W. Beadle Herbarium (NE) was recorded as growing alongside *C. lanatus*.

The taxonomy within the genus still remains to be resolved satisfactorily (Vilatersana *et al*. 2000). Biochemical and morphological variation within Australian populations is currently being investigated (Gavin Ash personal communication).

Distribution
There is some evidence that saffron thistle is expanding its range in Australia. Many graziers from northern New South Wales considered that saffron thistle was spreading, despite increased control measures (Sindel 1996). It is also a growing concern in pastoral regions of central Australia, south of Alice Springs (Fuller 1998). Climate matching or climate modelling may suggest if further spread is likely, or, as Grace (2001) suggested it has already reached the climatic limits of its range.

Saffron thistle has been present in the USA since 1891, and is abundant in dry coastal areas of California (Fuller 1979). There is confusion about which strains or species of *Carthamus* are present, but recent reports suggest that both *C. lanatus* ssp. *baeticus* and *C. lanatus* ssp. *lanatus* are present, each subspecies having a slightly different range (USDA, NRCS 2002).

Habitat
Saffron thistle is a weed of cultivation in Western Australia (Peirce 1995), but it is often troublesome in permanent pastures in eastern Australia (Briese 1988, Bowman *et al*. 1999). Although persisting poorly in sandy soils in Western Australia, it shows little preference for any particular soil type in eastern Australia and has been observed in porous limestone soils in southern France. Grazing regime and type of stock may affect thistle abundance (Trotter and Sindel 1999, Grace *et al.* 2002c).

Growth and development
Morphology
Rosettes are generally not grazed because of their flat habit. A vigorously growing pasture can force rosettes to grow more upright, making leaves more likely to be grazed by sheep (Grace *et al.* 2002c). Growth rates vary with site and insect attack in southern France (Sheppard and Vitou 2000).

Mean weights of individual seeds vary with year, site, pasture competition and grazing. Air dried seeds had mean ± s.e.m. weights of 17 ± 1 mg at Armidale on the Northern Tablelands of New South Wales, 18 ± 1 mg at Manilla on the North West Slopes of New South Wales and plants of a different strain growing on the Southern Tablelands near Canberra had seeds weighing 12 ± 0.4 mg (Grace 2001).

Phenology
Most seeds germinate after rain in autumn and early winter, but a small proportion may germinate after rain throughout the year. Plants that germinated in late spring or early summer in pastures all flowered that summer, suggesting that it is a strict annual that does not require a cold period to trigger flowering (Sheppard and Vitou 2000, Grace 2001).

Reproduction
Dormancy and germination of saffron thistle seeds is complex. Seeds were previously understood to require light and

leaching to germinate (Wright *et al.* 1980), but later investigations with seeds from a different source found strong seasonal patterns in seed germinability in the field. Seeds germinated most readily in winter and spring (Grace *et al.* 2002b), but seedling emergence was strongly inhibited by even a short layer of grass (Grace *et al.* 2002c), possibly due to pasture reducing the intensity of certain light wavelengths reaching seeds (Wright *et al.* 1980).

Seeds that were sown at a high density produced proportionally fewer seedlings than seeds sown at low density (Grace *et al.* 2002b). This is possibly a means of avoiding losses resulting from self thinning, although population models suggest that natural selection is unlikely to favour this effect (Grace, unpublished data).

Population dynamics

Kaye and Groves (1982) mentioned that little information was available on the population dynamics of *C. lanatus*. By 1995, Peirce had found no published data to review. This prompted the then Cooperative Research Centre for Weed Management Systems to fund research to redress this lack of information.

Recruitment

Seedling emergence at three sites across New South Wales and the Australian Capital Territory was found to vary hugely between years (Grace 2001), as would be expected given the species' complex germination requirements and the variability of Australian climate. One site near Canberra had over 1000 seedlings m^{-2} emerging, whereas a site on the Northern Tablelands had less than 200 seedlings m^{-2} (Grace 2001). Most seedlings on the Northern Tablelands of New South Wales emerged between February and May, and seedling numbers were strongly correlated with rainfall and pasture cover. Years with little summer rain would result in poor pasture cover in autumn, and if this were followed by heavy autumn rain that favours saffron thistle germination, then large numbers of thistles would be expected to emerge.

Survival

Similarly to seedling emergence, survival varied strongly between years and sites in New South Wales (Grace 2001) and between sites in France (Sheppard and Vitou 2000). Survival from seedling to reproduction was reduced by grazing and pasture competition (Grace 2001).

Seed production

Seed production also varied considerably between years and sites (Table 1). Individual plants produced between 1 and 2000 seeds and dense patches of saffron thistle can produce over 5000 seeds m^{-2} (Grace *et al.* 1999). Fecundity of individual plants was correlated with plant size at maturity in France and Australia, so seed production can be reduced by any factor that reduces plant growth or maximum size, such as phytophagous insects (Sheppard and Vitou 2000), grazing and intra- and inter-specific competition (Grace *et al.* 1999, Grace 2001).

Table 1. Density of mature plants and seed production per m² (mean ± s.e.m.) averaged over three years in grazed pastures at three sites in eastern Australia. (Grace, unpublished data).

Site and Location	Plant density	Mean seed production
Armidale, Northern Tablelands of NSW	3 ± 1	83 ± 34
Manilla, North-West Slopes of NSW	65 ± 21	1599 ± 530
Canberra, Southern Tablelands of NSW/ACT	55 ± 13	467 ± 112

When fecundity was regressed against plant dry weight, the intercept was never significantly different from zero for either French or Australian plants, suggesting that there is no minimum size that rosettes must reach before flowering can be induced (Sheppard and Vitou 2000, Grace 2001).

Seedbanks

Seedbanks under saffron thistle-infested pastures in New South Wales were very patchy, and ranged from 810 to 2300 seeds m^{-2} after the main germination flush. Most seeds were lost within the first six months of being in the soil, and proportionally more seeds were lost in the first year than in subsequent years. Seeds on the surface were lost more rapidly than buried seeds (Grace *et al.* 2002b).

Saffron thistle populations in France had very small (9–61 seeds m^{-2}) seedbanks, compared with those in New South Wales. This was apparently due to post-dispersal seed harvesting by ants (*Messor* spp.), rather than differences in seed production, which was roughly comparable in the two locations (Grace *et al.* 2002a).

Importance

A large-scale survey suggested that saffron thistle costs Australian agriculture in the order of $111 million per annum in control measures and lost production (Paul Jupp unpublished data). Saffron thistle was the weed of most concern to graziers from northern New South Wales (Sindel 1996). A separate survey found that saffron thistle was the second most widespread and troublesome thistle for farmers in the Northern Tablelands of New South Wales, after spear thistle (*Cirsium vulgare* (Savi) Ten.) (Trotter and Sindel 1999). Although not currently a major problem, saffron thistle is considered to have potential to become a major pest in central Australia (Fuller 1998).

Weed management

Grazing management

Trotter and Sindel (1999) surveyed land managers on the Northern Tablelands of New South Wales and concluded that rotational grazing was part of Best Practice Management for thistles while Grace *et al.* (2002c) demonstrated in the field that rotational grazing resulted in fewer thistles than did continuous grazing. This was attributed to more perennial grasses and better ground cover in autumn (which would limit seedling emergence in rotationally grazed pastures) although crash grazing with sheep can kill some rosettes and bolting plants.

There have been no reports of toxicity to stock from saffron thistle, although a range of pharmacologically active compounds have been extracted from capitula and leaves (San Feliciano *et al.* 1990, Novruzov and Shamsizade 1999), some of which have a sedative action on mice (Benedi *et al.* 1986).

Natural enemies

Wapshere (1984) suggested that the close relationship between saffron thistle and the commercial crop safflower (*Carthamus tinctorious*) would mean that classical biological control would be either difficult to instigate, or ineffective in Australia. Preliminary investigations into potential biological control agents have found one potential agent, and a native pathogen has also been found that has potential for use in a mycoherbicide.

Saffron thistle in New South Wales and the ACT was attacked by a range of phytophagous insects, but very few of these burrowed inside the plants. Plants in southern Europe, however, were attacked by several boring insects (Grace *et al.* 2002a) and two fungi (Groves and Burdon 1996). Of these insects and fungi attacking *C. lanatus* in its native range, most survived on safflower (Aeschlimann 1997, Louise Morin personal communication). Only the rosette crown-feeding fly *Botanophila turcica* Hennig (Diptera: Anthomyiidae) appears incapable of completing development in safflower (Vitou *et al.* 2001), and can therefore be considered for introduction into Australia. Formal host-specificity testing is required before

B. turcica could be released into Australia but funding is not currently available for this.

The potential impact of a classical biological control agent is difficult to assess before it is released, but available data suggest that *B. turcica* is unlikely to decimate saffron thistle in Australia (Grace 2001). *Botanophila turcica* reduced seed production of saffron thistle in France by about 9% (Sheppard and Vitou 2000). Insects attacking saffron thistle in Europe may only kill or severely reduce reproductive output if other stresses are present (Aeschlimann 1997). Up to 33% of saffron thistle plants in southern France were attacked by *B. turcica*, most plants with one larva or egg (Vitou *et al.* 2001).

Fungal pathogens (*Phomopsis* spp.) already present on saffron thistle in Australia have been isolated, and these have potential for use in mycoherbicides (Crump *et al.* 1996a,b). Such fungi often require a humid environment for several days for them to infect plants. With recent developments in formulations that will consistently satisfy this dew-point requirement, the potential for a mycoherbicide being developed is good (Crump *et al.* 1999).

Future directions

This update suggests that there are several areas where future work could help in managing this weed. The taxonomy of the genus *Carthamus* requires further work, and this may become a high priority if classical biological control proceeds.

The potential distribution, including predicted plant densities should be determined using climate modelling. Ideally this should include historical weather data or some simulated stochastic seasons, especially for arid areas Australia. This would assist in making decisions about assigning resources to biological control programs and in developing integrated weed management packages for various regions.

There is a need to educate graziers that saffron thistle can be cheaply managed in perennial pastures using strategic grazing. Producers must, however, expect that exceptional climatic conditions may mean that large thistle populations can emerge in some years. There is therefore a need to develop strategies for integrating grazing with other weed control measures such as herbicides or possibly biological control.

Biological control of this weed should remain a priority. The considerable amount of preliminary work that has been done towards developing a classical biocontrol program and a mycoherbicide against this weed means that these would be relatively cheap to produce compared with most other weeds where this background information is not available. Given that saffron thistle is a problem in four Australian States and two Territories, as well as the USA, the cost of any biological control program could be shared between agencies.

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