Review

The biology of Australian Weeds 23. *Carthamus lanatus* L.

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Name

Early literature in Australia cited *Carthamus lanatus* (Asteraceae) as *Kentrophyllum lanatum* (L.) DC (Anon. 1892, Ross-Reid 1901, Alexander *et al.*, 1919, Carne 1924) but more recently the name *Carthamus lanatus* L. has taken priority (Hanelt 1976).

Seven species of *Carthamus* have been identified (Hanelt 1976), including the cultivated safflower, *C. tinctorius*. Hanelt refers to *Carthamus lanatus* as a complex, containing two subspecies *lanatus* and *baeticus* which result from crosses with other species of *Carthamus*. Within each subspecies a range of morphological intermediates is found in areas where contact and subspecies hybridization has occurred.

Many common names have been applied to *C. lanatus*: some of which may even have been used incorrectly and refer to other thistles. Confusion existed in South Australia between *Centaurea calcitrapa* L. and *Carthamus lanatus* as both were referred to as star thistle (Clarke 1936). Maiden (1895) gives it the names False star thistle, Star thistle, Chinese thistle and Yellow Chinese thistle, while Schomburgk (cited in Maiden 1895) uses the name Woolly Kentrophyllum. Other names used are Woolly Star thistle (Black 1965), Barnaby thistle (Butcher 1900), Common Star thistle (Ross-Reid 1901), Saffron Star thistle (Breen 1925), Distaff and Woolly safflower (Phillips 1938, Richardson 1952), and Sulphur thistle in Tasmania (Hyde-Wyatt and Morris 1980).

Description and account of variation

C. lanatus is an annual with erect stems, one to two metres in height, although plants in most agricultural infestations grow to about one metre (Meadly 1957). Plants, particularly when young, have upper portions covered with small dense hairs. The feather-shaped leaves are deeply divided and the toothed margins form strong spines. The stalkless flower head is egg-shaped and attached at its broadest end. The single flower heads are surrounded by spreading leaves. Flowers are yellow, and the brown-greyish seeds (achenes), resembling a shuttlecock, have a four-angled base and are about 3 mm in length. Some of the seeds have a pappus of stiff bristles.

The most obvious morphological character to identify *C. lanatus* from other thistles is the colour of its flowers. Most thistles have pink-purple flowers, the exceptions being St. Barnaby's thistle *Centaurea solstitialis* L., Maltese cockspur *Centaurea melitensis* L., Golden thistle *Scolymus hispanicus* L. and Spotted thistle *S. maculatus* L. St. Barnaby's thistle and Maltese cockspur have a much smaller and rounder flower head than *C. lanatus*. Flowers of *S. hispanicus* appear very similar to *C. lanatus* except that the 'petals' are much broader and seeds are flat. The leaves of *C. solstitialis* and *C. melitensis* are not divided and spined like those of *C. lanatus*.

Hanelt's (1976) descriptions of the two subspecies indicates the subspecies *lanatus* (2n = 44) has outer bracts on flowers only about 1.5 times the length of the inner bracts. Spines of the outer bracts are usually borne at an acute angle to the leaf margin. These outer bracts are closely fitting about the flower. This species is thought to have *C. dentatus* (Forhsal) Vahl. as one of the parents and is a tetraploid. *C. dentatus* has been recorded in New South Wales since 1921 and as recently as 1985 in the Ararat district in Victoria (Parsons 1985). The other subspecies *baeticus* (Boiss and Reuter) Nymand, (2n = 64) was previously recorded as *Kentrophyllum baeticum* Boiss and Reuter. It has outer involucral (flower) bracts which are about twice as long as the inner bracts, and the spines on the bracts are borne at right angles to the margin. The outer bracts also tend to bend away more from the flower than in subspecies *lanatus*. It is believed that subspecies *baeticus* is a hexaploid derived from subspecies *lanatus* and *C. leucocaulos*, and originating in the Mediterranean islands, southern Greece and southern Spain. *C. leucocaulos*, which has mauve flowers, is also found in Western Australia near Tambellup in the lower south-west of Western Australia (voucher specimen in W.A. Herbarium (PERTH) 00496022).

Illustrations of *C. lanatus* in various weed publications in Australia, and comments by Hanelt (personal communication) on material sent from Western Australia, suggest that Australian *C. lanatus* belongs to the more maritime subspecies *baeticus*. The illustration used by Maiden (1895), however, suggests that his material had flowering heads more similar to the subspecies *lanatus* than to *baeticus* because of the shorter floral bracts. The correct name according to Hanelt (1976) is *C. lanatus* subspecies *baeticus* (Boiss and Reuter) Nymand and has been cited as such in a publication of Regional Flora in Australia (Lander 1987).

The most obvious morphological features distinguishing the flowers of the two subspecies are illustrated in Figure 1.

Extensive collections of *C. lanatus* have been made in Western Australia and apart from one collection at South Greenough, some 400 km north of Perth (Peirce 1990), all closely resemble plants

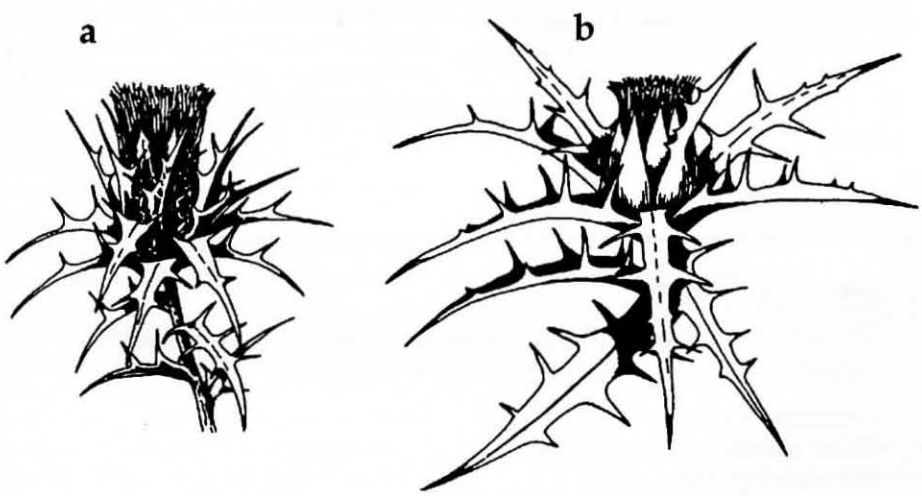

Figure 1. Capitula of *C. lanatus*, subspecies *lanatus* (a) and subspecies *baeticus* (b).

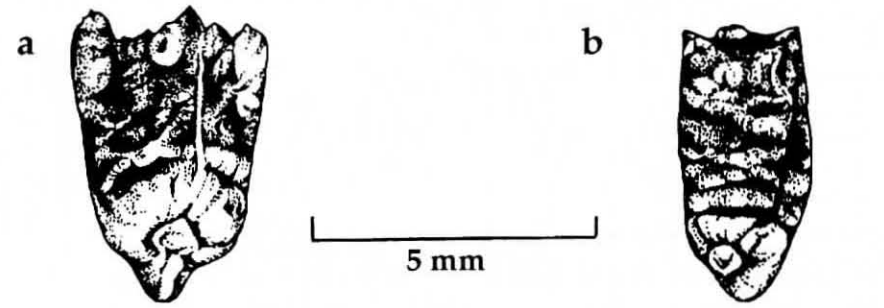

Figure 2. Morphological variation of *C. lanatus* seed from three accessions from South Greenough (a), Moorine Rock and Salmon Gums (b) grown at a common site for two generations (from Peirce 1990).

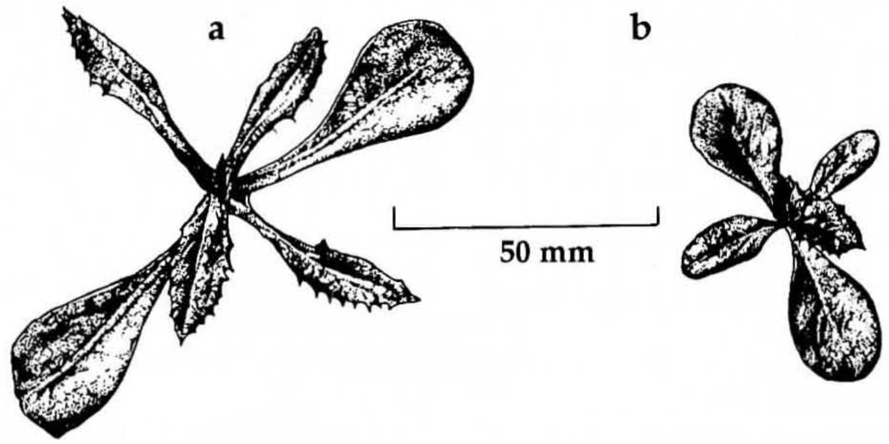

Figure 3. Morphological differences in rosettes between the forms of *C. lanatus* from South Greenough (a), Moorine Rock and Salmon Gums (b) in Western Australia (from Peirce 1990).

illustrated by Meadly (1957) and Parsons (1973). The seeds from the South Greenough collection are more ribbed and have a distinct wing-like attachment and generally appear larger (Figure 2). Cotyledons and first leaves of the South Greenough form are more elongated and narrower than the more common form as illustrated by Burford (1965) (Figure 3).

A similar form of *C. lanatus* to that collected from South Greenough was also noted from a collection sent from the Mittyack district in Victoria (Twentyman, personal communication).

History

C. lanatus is native to the Mediterranean region and Western Asia (Meadly 1957, Parsons 1973). Hanelt (1963) suggested that subspecies *baeticus* has its origin around the south Mediterranean in close vicinity of the sea, whilst subspecies *lanatus* belongs to the continental parts of the Mediterranean and sub-Mediterranean areas.

The spread of *C. lanatus* from its origin is not clear. Subspecies *lanatus* has been established in California since 1891 according to Fuller (1979), but no date of introduction is documented for the subspecies *baeticus*, which is found in the coastal areas and also the foothills of the central Sierra Nevada. Harvey and Sonder (1865) recorded the thistle in South Africa.

The exact date of entry into Australia is not clear, probably because the many common names resulted in confusion of locations and authenticity of many of the early sightings. The first introduction was probably in South Australia during the 1860s (Maiden 1895). Because of the problem caused by *C. lanatus* in South Australia, legislation was passed in 1887 to prevent further spread of the weed in that State. Kloot (1986) indicated the first official record in South Australia was 1874 and the earliest collection from Tepper in 1888. In 1883 *C. lanatus* was included on a list of thistles that should be eradicated in Victoria. At this time, the weed was widespread in South Australia and Victoria, but not in New South Wales. The first recording of *C. lanatus* in New South Wales was made near Urana (Anon. 1892). Ewart (1930) indicates that the weed was considered naturalized in Victoria by 1887. Bailey (1890) made no mention of *C. lanatus* in a list he prepared on indigenous and naturalized plants in Queensland but, more recently, Kleinschmidt and Johnson (1977) indicated that the weed was established in southern Queensland.

The exact method of entry and method of spread into Australia is unknown, but several theories are presented. Maiden (1895) found references to its medicinal properties for promoting perspiration (sudorific), curing fever (febrifuge) and destroying intestinal parasites (anthelmintic) expounded by the Parisians. In South Australia *C. lanatus* may have gained entry as a contaminant in fodder for bullock teams (Kloot 1986). It was widely cultivated in tropical Africa, probably for its oil or colouring because of its close relationship to safflower. Michael (1968) also suggests it may have been deliberately introduced as a possible useful species or unintentionally as the closely related safflower. He also suggests that it is amongst the most common contaminants of wheat grain. Mears (1968) suggests because seed is hard to grade from wheat, clean areas have often become infested from sowing wheat seed contaminated with *C. lanatus*. It was introduced into New Zealand as a contaminant in Australian wheat (Parsons 1973).

C. lanatus seed in Tasmania is usually a contaminant of feed wheat from mainland Australia, and the only record of crop infestation has occurred when imported feed wheat was used for seeding (Hyde-Wyatt and Morris 1980).

According to the records of settlement and publications on undesirable plants in Western Australia, it could be concluded that *C. lanatus* was first introduced in the early 1900s. In a list of noxious weeds and poison plants (Anon. 1909), there was no mention of *C. lanatus*. However, within ten years, Alexander, *et al.* (1919) included *C. lanatus* on a list of plants of economic importance and weeds established in Western Australia. According to State Herbarium records, specimens were collected at Coogee (1923), Gnowangerup (1924) and Toodyay (1925). There is a strong possibility that the first introductions to Western Australia were by way of seeds contaminating wheat (Carne 1924) and *C. lanatus* was listed as a prohibited seed in grain.

Geographical distribution

World

C. lanatus has spread to the temperate areas of the world, but is not regarded as a weed in countries other than Australia (Parsons 1973). It is established in California (Abrams and Ferris 1959) and New Zealand (Parsons 1973). *C. lanatus* is the most widely distributed of all the *Carthamus* species (Hanelt 1963). It is found throughout the entire Mediterranean, including north-west Africa and the Canary and surrounding Islands. The distribution extends to central Asia, the central Asian Soviet Republic, and to Afghanistan, Kashmir, Iran and Iraq. Beyond the Mediterranean, *C. lanatus* is also found in the sub-Mediterranean part of Europe; its northern boundary reaches from Normandy, central France, southwest Switzerland, upper Italy, south Tyrol, the southern foot of the North

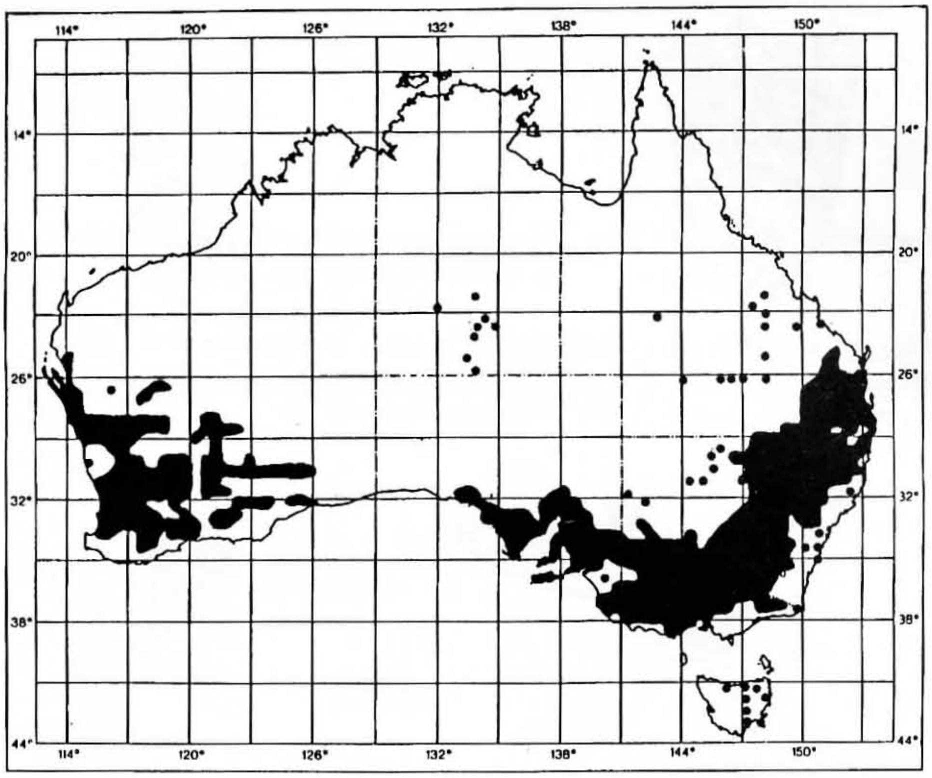

Figure 4. Distribution of *C. lanatus* in Australia (from Parsons and Cuthbertson 1992).

Carpathians (Hungary and Czechoslovakia) to the south of Ukraine. In the last two hundred years, *C. lanatus* has been introduced to South Africa, California and Australia.

Australia

Mears (1968), and Jacobs and Pickard (1981) give the distribution of *C. lanatus* in New South Wales, while Parsons (1973) has prepared a map of its distribution for Victoria.

Hyde-Wyatt and Morris (1980) indicate that infestations in Tasmania are small (usually less than one hectare) and mainly confined to pastoral areas. Kleinschmidt and Johnson (1977) give the distribution in Queensland as being mainly on the Darling Downs and Burnett districts.

According to several sources, *C. lanatus* is widespread in South Australia. It is present in the upper Eyre Peninsula (Holden 1970), the north-eastern region of the lower and eastern Eyre Peninsula (Bicknell 1970), northern Yorke Peninsula (Webber and Matz 1970), Upper North (Mowatt 1970), Lower North (Michelmore 1970), the south-east and central regions of the Upper South-East (Marrett 1970), the entire Murray Mallee (Hincks 1970) and eastern and central areas of the lower Murray Basin (Williams 1970).

Although present in the higher rainfall areas in the south-west of Western Australia the infestations are only small. The largest infestations are found in cereal growing districts in the north and east that border with the pastoral areas (Peirce 1981).

Parsons and Cuthbertson (1992) have prepared a map showing the current distribution of *C. lanatus* in Australia (Figure 4).

Habitat

Climatic requirements

C. lanatus is a serious weed in drier areas having an annual rainfall between 500–875 mm (Michael 1968). Under drier conditions as experienced in the pastoral areas in Western Australia, *C. lanatus* is confined to natural water courses.

C. lanatus is a very hardy plant, and can withstand periods of cold. Compared to another wild species of *Carthamus* and the cultivated *C. tinctorius*, *C. lanatus* rosettes showed no seedling mortality after at least four cycles of four hour treatments using temperatures of -13°C (Zimmerman and Buck 1977).

Substratum

Michael (1968) indicates that *C. lanatus* has no preference for a given soil fertility, but claims it suffers under conditions of high soil fertility when well established pastures such as subterranean clover compete strongly.

More recent studies of several thistles by Austin *et al.* (1985) indicated that *C. lanatus*, collected from New South Wales, achieved maximum yield when grown in low nutrient concentrations compared to other thistles and tended to dominate the others at low nutrient status. Their explanation was that some early growth advantage may be achieved because of its large seed. In addition, rosettes remained very flat, even under low light intensities, and tended to be less successful in mixtures at high nutrient status because other thistles tended to produce erect rosette leaves.

C. lanatus does not appear to have affinity to a particular soil type in most States of Australia. In South Australia, for example, it is present over a wide range from stony calcareous sands, reddish or grey-white sands (Hincks 1970), mallee loams-sandy loams (Williams 1970), well-drained sand and limestone soils to heavy clay "crab-hole" soils (Marrett 1970), and red-brown earths (Michelmore 1970). In Western Australia it is more confined to the heavier-reddish clay soils that tend to form "crab-holes". Agricultural infestations are not common on sandy soils, probably because of the sensitivity of germinating seeds to moisture stress (Groves and Kaye 1989).

Communities in which the species occurs

Mears (1968) suggests that *C. lanatus* can establish where-ever soil has been disturbed and native species, particularly perennial grasses, have been thinned or removed. It can compete with annual grasses so is often present in cereal crops. Drought stress or overgrazing assists in removing native pastures, allowing establishment of *C. lanatus* (Michael 1968). Although often found in grazing areas, it is essentially a weed of cultivation, particularly wheat-growing areas.

Fuller (1979) stated that *C. lanatus* is abundant on the dry grasslands of the coastal areas of central California, whilst a variant of the species is found at a middle elevation of the Sierra Nevada where gold mining activity had occurred.

Growth and development

Morphology

Although the rosettes are often grazed by animals, once erect growth occurs and the plants become more rigid and spiny, most animals tend to avoid thick infestations (Mears 1968). This gives some measure of protection to the seed which, because of its relatively high feed value (Parsons 1973), is readily eaten by animals. Despite the prickly nature of the plant, animals will eventually work their way into infestations as their food supply decreases. While many of the seeds, particularly those having a pappus, are shed at early maturity, some are retained in the seed head by the floral bracts. These seeds can then be released and often lodge in the wool of sheep and carried to new areas.

C. lanatus seeds are relatively large and, despite having a pappus are not moved any distance with the wind (Mears 1968): however the pappus will permit the seed to float on water (Parsons 1973), and was one of the methods responsible for

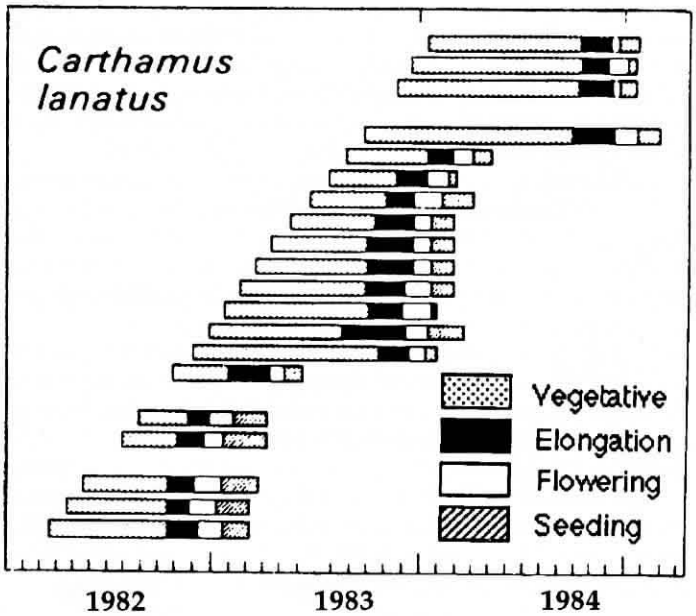

Figure 5. Developmental stages of plants of *C. lanatus* grown in a common environment at Canberra, seed of which was sown monthly between March 1982 and February 1984 (from Groves and Kaye 1989).

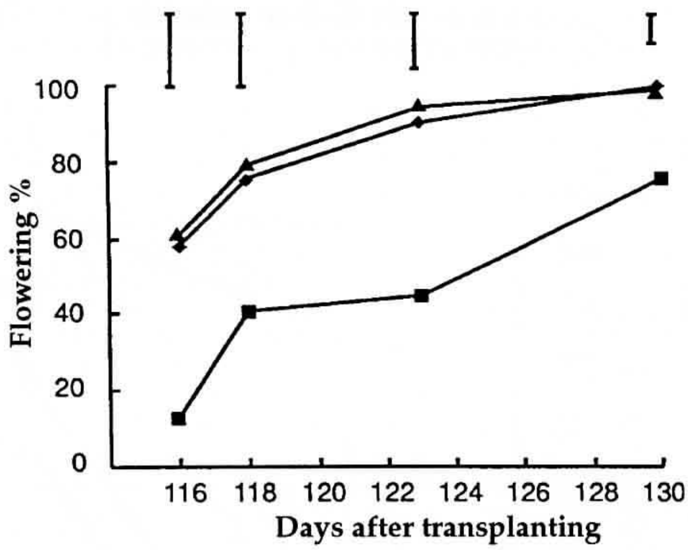

Figure 6. The percentage of *C. lanatus* plants from three different accessions from South Greenough (■), Moorine Rock (▲) and Salmon Gums (◆) with first flowers having florets at anthesis at four dates between 116 and 130 days inclusive after transplanting. Vertical bars are least significant differences (P < 0.001) (from Peirce 1990).

Table 1. Seed production from three accessions of *C. lanatus* after two generations grown at South Perth (from Peirce 1990)

	Origin of seed			
	South Greenough	Salmon Gums	Moorine Rock	LSD
Flowering capitula/plant	8.5	9.8	13.5	3.4**
Fully formed seeds/capitulum	8.3	13.1	13.1	1.9***
Fully formed seeds/plant	70.4	127.7	176.9	43.5***
Total seeds/capitulum	10.2	15.4	15.1	2.0***
Fully formed seeds with pappus (%)	65.9	58.7	61.4	4.0*

* (P < 0.05). ** (P < 0.01). *** (P < 0.001).

spreading the weed in the Wimmera and Mallee areas in Victoria. In addition, the stiff hairs on the seeds permit them to adhere to clothing, bags, wool and fur. In some instances whole seed heads (capitula) have broken away from plants, with the surrounding prickly bracts of the head becoming attached to wool and fur.

Physiological

There is little information documented for the rate of growth of *C. lanatus*. Measurements taken in Western Australia indicated that different growth patterns existed between the two forms (Peirce 1990). In addition the rate of stem elongation varied between seasons. In two successive years the commencement of elongation varied by as much as two months, which is consistent with results obtained by Groves and Kaye (1989), and the rate of elongation varied from 1.5 cm per day to 0.7 cm per day (Peirce unpublished).

Phenology

Seeds germinate mainly after the first rains in autumn, although a minor percentage can germinate over an extended period to September–October (Meadly 1957, Mears 1968, Parsons 1973). Over winter, the plants remain as rosettes and in late September–early October the flowering stem elongates. Flowers are produced in early summer and, depending on moisture supply, can continue forming over an extended period. Once stem elongation commences, the plant's spines become more rigid, therefore less attractive to grazing stock. Seeds are produced which remain in the flower head until such time as the floral bracts dry out and bend away from the flower to expose them, or wind or stock movement through thistle infestations shake the seeds away from the flower heads.

Reproduction

Floral biology

Like many other thistles *C. lanatus* is pollinated by honey bees (*Apis mellifera*) (Forcella and Wood 1986).

Flowering patterns of seeds planted at monthly intervals were similar over two years of plantings (Groves and Kaye 1989) (Figure 5) and, like other annual/biennial thistles, *C. lanatus* may require a winter cold period to flower.

Flowering usually commences in mid to late November in Western Australia. Under adequate moisture supply, flowering normally begins earlier at the lower latitudes but, under conditions of moisture stress, flowering has been noted to occur first at the higher latitudes. Some time difference in flowering also appears to exist between forms. The form having the narrower cotyledon leaves and displaying the earlier and more rapid stem elongation has been noted to flower some one to two weeks later (Peirce 1990) (Figure 6).

Plants in eastern Australia appear to flower slightly later than those in Western Australia. Forcella and Wood (1986) indicated that flowering at Wagga Wagga commenced in early December and reached 100% between mid-February and late March depending on the season. At Canberra flowering commenced late December to mid-January and full flowering occurred late March to late April.

Seed production and dispersal

There is very little information available on the seed production of *C. lanatus*. As with most other species the production of viable seed could be assumed to be strongly correlated with environmental conditions during the growing period.

Studies of individual plants, in field

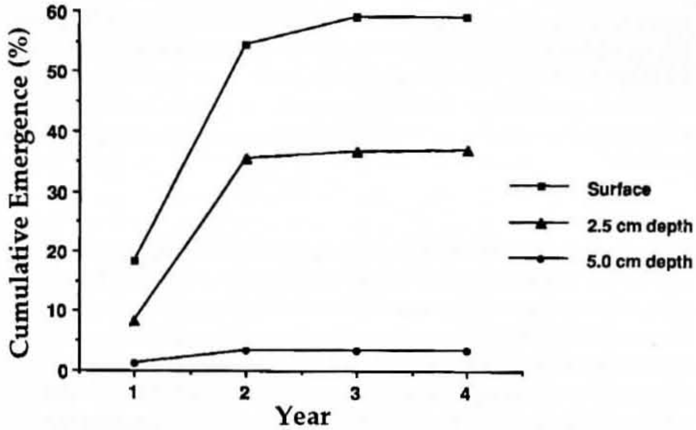

Figure 7. Percentage cumulative emergence over four years of seeds of saffron thistle buried at three depths in the soil (from Quinlivan and Peirce 1968).

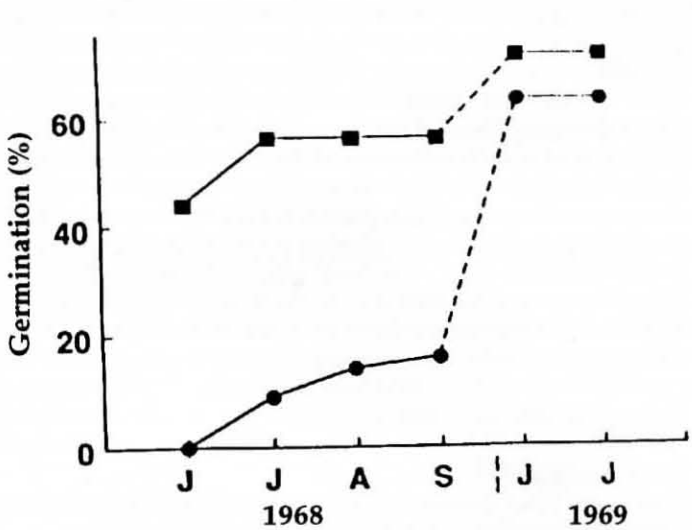

Figure 8(a) Cumulative germination percentage of *C. lanatus* seeds planted on the soil surface at Chapman Valley (■) and Salmon Gums (●). Least significant differences (P < 0.001) less than 2% (from Peirce 1990).

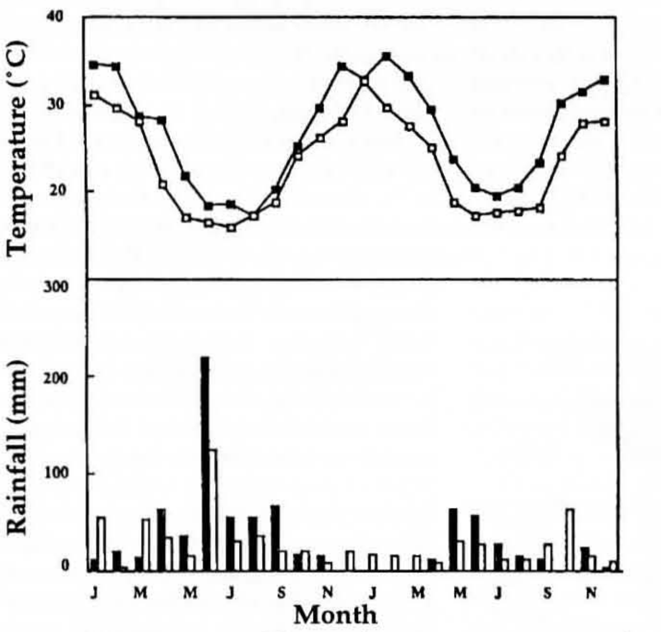

Figure 8(b) Mean monthly maximum temperature and rainfall for Chapman Valley (closed symbols) and Salmon Gums (open symbols) during 1968-69 (from Peirce 1990).

plots under artificial watering and in untended agricultural infestations in Western Australia, indicated individual seed heads can produce from 10–16 seeds (Peirce 1990). A proportion of achenes (seeds) are produced with a stiff row of hairs (pappus), and the proportion of viable seeds having a pappus varies from 59–66% depending on the form (Peirce 1990) (Table 1).

Under artificial growth conditions, seed production varied from 70–177 seeds per plant, with capitula per plant varying from 8.3–13.3 depending on the form (Peirce 1990). Even under artificial conditions the capitula per plant varied from less than ten to over forty per plant with as many as 255 viable seeds per plant on the latter (Peirce unpublished).

According to Michael (1968), *C. lanatus* produces the heaviest seeds for some of the annual thistles growing in south-eastern Australia (26 mg per seed). Seed weight varies considerably in Western Australia and is probably affected by seasonal conditions. Seed weights have ranged from 12.3 mg to 25 mg per seed (Peirce unpublished). Groves and Kaye (1989) collected seeds around Canberra in 1982 and recorded weights of 17.18 ± 0.013 mg per seed. The perennial artichoke thistle *Cynara cardunculus* L. has the largest seeds of any thistle (35 mg) (Michael 1968).

Physiology of seeds and germination

Field studies at Geraldton in the north-west of the cereal growing districts in Western Australia indicated that seeds formed in any one year, if placed at or close to the soil surface, spread their germination over the following three seasons, with most seedlings appearing in the first two years (Quinlivan and Peirce 1968). The proportion of seed emerging fell sharply with increas-

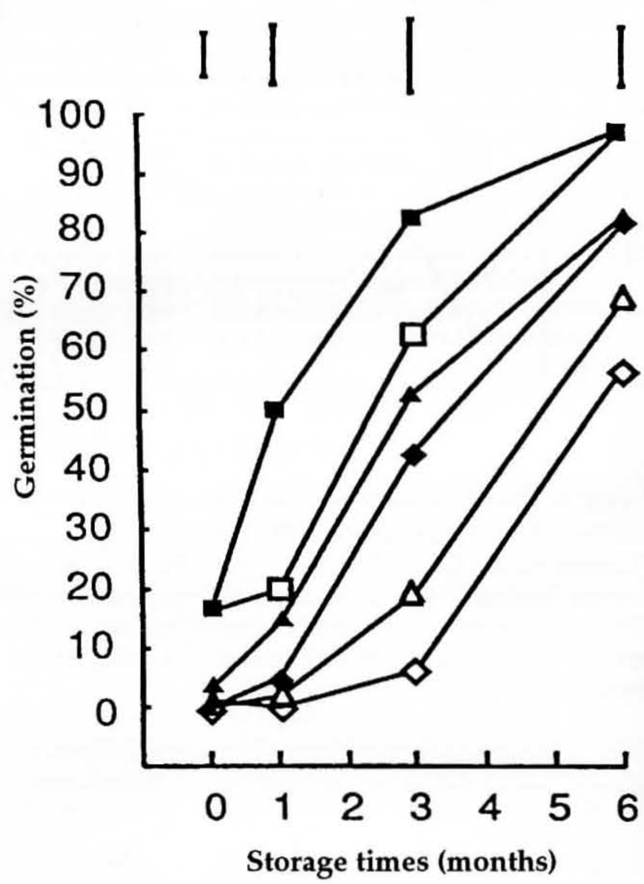

Figure 9. Effect of time of storage on the percentage germination of leached (closed symbols) and unleached (open symbols) seeds of *C. lanatus* from South Greenough (■), Moorine Rock (▲) and Salmon Gums (◆) grown at South Perth for two generations. Vertical bars are least significant differences (P < 0.001) (from Peirce 1990).

ing depth, and few seedlings emerged from below depths of 5 cm (Figure 7). They found the life span of the seeds buried at depth in the soil did not extend beyond eight years, and termite attack was a major cause of seed destruction. Without the influence of termites, Quinlivan (1965) found that seed, extracted from depths of 10–15 cm in soil that was not disturbed for ten years, gave a germination of 33%.

Seed dormancy is a major problem in controlling *C. lanatus*, because seed produced in any one year can remain viable up to eight years, although most germinates within three years of release (Quinlivan and Peirce 1968). Results of further research by Peirce and Quinlivan (1971) indicated that dormancy varied with the source of seed, there being less dormancy in seeds collected from accessions in the northern and central cereal-growing districts compared to the southern districts. Differences in germination were detected when a single accession was sown at two sites, one in the northern cereal growing districts (warm temperatures) and the other in the south (low rainfall and temperatures) of Western Australia (Peirce 1990) (Figures 8a & b). *C. lanatus* from Canberra gave a maximum germination, although low compared to other thistle species, of about 55% at 20/10°C (Groves and Kaye 1989). Prolonged storage, high storage and germination temperatures and leaching the seeds with water increased germination (Peirce and Quinlivan 1971). In addition to the influence of the environment on germination, Peirce and Quinlivan (1971) suggested that variation in germination characteristics might also reflect varietal differences within *C. lanatus*.

Dormancy in *C. lanatus* is usually high in freshly formed seed (Peirce and Quinlivan 1971. Wright *et al.* 1980, Groves and Kaye 1989). Storage temperatures and length of storage have a significant influence on the loss of dormancy, and germination was greater using a daily alternating temperature of 15/30°C, than a constant temperature of 15°C (Peirce and Quinlivan 1971). Prior to germination, a daily alternating storage temperature of 15/60°C for one month was more effective in reducing dormancy than a constant temperature of 15°C. Quinlivan (1965) suggested that a water soluble inhibitor was responsible for the dormancy; later, the existence of such an inhibitor was demonstrated (Peirce and Quinlivan 1971). Subsequently, Wright *et al.* (1980) demonstrated that leaching during imbibition in the presence of red light would break dormancy; and found that the inhibitor, which may be abscisic acid (ABA), was mainly associated with the embryo. Storage at higher temperatures may also play a significant part in the breakdown of any inhibitor present in intact seeds.

After two generations at a common site, germination in the presence or absence of leaching with water or after storage at daily fluctuating temperatures of 15–60°C indicated that there were differences between forms as well as between different accessions of the same form (Peirce 1990) (Figure 9). Because of the greater dormancy, even after two generations at a common site, of the accession collected from the cooler agriculture areas in the south of Western Australia, Peirce (1990) suggested that genetic as well as environmental influences are responsible for the development of dormancy.

Of seven species of thistles tested for germination, *C. lanatus* was the most sensitive to moisture stress (Groves and Kaye 1989). However, once germination had commenced, the extension growth of the radicle of *C. lanatus* was the least sensitive of the seven thistles when moisture stress was imposed.

Hybrids

Hybridization between other species of *Carthamus* has been possible with successful crosses being accomplished with *C. tinctorius*, *C. tenuis*, *C. alexandrinus* and *C. baeticus* (Ashri and Knowles 1960). These authors also suggest that hybridization could also occur with a blue-flowered species *C. leucocaulos* which has been recorded in Australia.

In their studies Ashri and Knowles (1960) separate four distinct groups according to the number of chromosome pairs. They were: 10 (*C. alexandrinus*, *C. glaucus*, *C. syriacus*, and *C. tenuis*), 12 (*C. arborescens*, *C. caerubens*, *C. oxycantha*, *C. palaestinus*, *C. tinctorius*) 22 (*C. lanatus*) and 32 (*C. baeticus*).

Geographical strains of *C. lanatus* have been intercrossed successfully. Many of the probable hybrids produced have not been recognized because of insufficient identifying markers. Hybrids of both *C. oxycantha* and *C. tinctorius* with *C. lanatus* were obtained when the latter was used as the male parent in the artificial crossing. Failure of reciprocal crosses may have resulted from damage to the styles during emasculation. All hybrids between parents with different chromosome number were sterile, except those for *C. baeticus* × *C. lanatus* which were partially fertile. In this fertile cross the hybrid produced only about one third the normal number of seeds.

The existence in Western Australia of a wide range of intermediates that may arise by hybridization, could explain why similar morphological forms, when collected from different locations and grown at a common site for two or more years, still show marked differences in dormancy (Peirce 1990).

Population dynamics

Kaye and Groves (1982) indicated that little information was available on population biology of *C. lanatus*. Data from unpublished research in Western Australia suggest that seedling mortality, when density exceeds 20 plants m^{-2} in grazed pasture containing grasses and subterranean clover, can be as high as 40% between July and September. When some grasses and broad-leaved pasture were removed chemically, the mortality declined only by 18%.

Observations indicate that plants are grazed while the rosettes remain small, but large rosettes and plants running up to flower are avoided by sheep because the spines become tougher as the plant matures.

Importance

Detrimental

Meadly (1957), Parsons (1973) and Hyde-Wyatt and Morris (1975) give detailed descriptions of the various problems encountered with *C. lanatus*. Many of these have been summarized by Watson (1990) and include:

- Competition for moisture, light and soil nutrients in pasture and crops.
- Little or no feed or grazing value.
- Restricts or eliminates pasture growth in low fertility soils, thereby reducing carrying capacity and preventing livestock grazing.
- Restricts livestock movement during late spring to summer.
- Causes major difficulties in mustering both sheep and cattle and moving working dogs, horses and vehicles.
- Potential to contaminate wool with vegetable matter.
- Causes or predisposes the livestock to eye and mouth injury.
- Reduces grain yields by 50–70%.
- Decreases property values and potential income.

In a survey of thistles as pasture weeds causing economic loss to wool growers, *C. lanatus* was responsible for an estimated loss of $1.73 M to the industry in South Australia, Victoria and New South Wales (Anon. 1988). The seeds of *C. lanatus* were the most common of all the thistles found in wool, but because they are easy to remove it does not attract a large discount.

Verticillium dahliae (Kleban), an important disease of cotton in the Namoi Valley in New South Wales, may have been introduced and spread by the achenes of *C. lanatus* (Evans 1971). According to this author, the stem and tap root of *C. lanatus* was also infected, thereby indicating the weed may play an important role as a host for the disease.

Stovold (1973) showed, that in New South Wales, the fungus *Phytophthora drechsleri* (Tucker) which is the major cause of root-rot of safflower in that State has *C. lanatus* as an alternative host.

Produce such as hay or seed which contains seeds of any noxious weed is usually prohibited from sale (Carne 1924, Bean 1969) and subjected to inspections after attempts have been made to remove the offending seeds. This causes delays and financial losses. Seeds harvested with wheat cause discoloration of flour (Mears 1968) and, in addition, milling equipment can be damaged (Davidson 1966).

Beneficial

Several reports from New South Wales and South Australia have indicated that *C. lanatus* plants have some feed value. In the Western plains of New South Wales, *C. lanatus* helped to provide ground cover and prevent erosion (Carn 1939); Carn suggested that the plant was not a strong pasture competitor and diminished as the grasses improved. After unsuccessful attempts at mechanical control, it was reported by a farmer in South Australia that sheep were fattened by eating the plants during September and October and sheep fed on *C. lanatus* produced mutton that had a good flavour (Anon. 1900). Turkeys have been fattened on *C. lanatus* in some areas of the Mallee in Victoria (Parsons 1973). He also mentions that, during the 1920s, figures were quoted suggesting that *C. lanatus* seed had a greater number of food units per unit weight than commercially available stock feed. In Western Australia farmers have indicated that it gives some measure of clover seed conservation because sheep do not graze in heavy stands of thistles, thus preserving any clover seed for the following growing season (Peirce unpublished). Analysis of *C. lanatus* seed in Western Australia showed it to have about the same crude protein level as wheat but a fairly low digestibility (26.3%) (Peirce unpublished). The strong tap root of *C. lanatus* was thought to open up the soil and allow moisture and air to enter (Clarke 1936).

C. lanatus is highly resistant to leaf spot *Alternaria carthami* Chowd. and bacterial blight caused by *Pseudomonas syingae* Von Hall, which are serious diseases of safflower (Heaton and Klisiewiez 1981). A disease-resistant alloploid was obtained by crossing safflower and *C. lanatus*; it thus has the potential as a gene source for disease resistance in the cultivated safflower.

The seed of *C. lanatus* has some value as a source of oil for paint manufacture (Richardson 1952).

Legislation

Limits to the numbers of seeds contained in wheat grain are set for the various categories of wheat which form the receival standards set each year by the Australian Wheat Board.

In Queensland the Rural Lands Protection Act of 1985 categorized *C. lanatus* as a P3 plant for the whole of the State and under this categorization the infestations are to be reduced (Herron 1986).

It was first proclaimed in Victoria in 1892 under the Thistle Act of 1890 and then in 1922 was proclaimed by the Vermin and Noxious Weed Act for the whole of the State, except the metropolitan area (Parsons 1973).

C. lanatus was gazetted as a Noxious Weed for the whole of the State of Western Australia in 1924 (Carne and Gardner 1926). Under the Agriculture and Related Resources Protection Act, 1976, *C. lanatus* was listed as a declared plant and categorized in various classes associated with different areas. This Act was updated in 1990 and Saffron thistle was included under four classes (Anon. 1990):

- P1–Introduction and movement within Western Australia is prohibited.
- P2–Plants in an area should be eradicated.
- P3–Plant numbers, distribution or both should be reduced.
- P4–Plants should be prevented from spreading.

Moves to have *C. lanatus* proclaimed a noxious weed in South Australia commenced in 1874, but this was not achieved until December 1890 (Carter personal communication). The weed at that time was gazetted as Star thistle *Kentrophyllum lanatum*. Proclamation continued under various legislations until March 1990, when under the Animal and Plant Control (Agricultural Protection and other Purposes) Act, 1986 it was revoked. Because *C. lanatus* was widespread in the cereal growing areas it was considered no longer necessary to retain the weed's proclamation. Carter (personal communication) also mentions that local councils in 1938 attempted unsuccessfully to have *C. lanatus* removed from the noxious weed list.

The declaration in New South Wales first occurred in the New England Tablelands weed county council area in the late 1940s, around the time the council was formed in May, 1947 (R. Trounce personal communication).

C. lanatus in Tasmania is a declared noxious weed under the Noxious Weed Act 1964 (Anon. 1971) and, although there is not an eradication campaign, the Department of Agriculture in that State required landholders to undertake control measures.

Response to chemicals

Considerable research has been undertaken on *C. lanatus* in most of the southern mainland States of Australia. One of the first control recommendations involved the use of 27 kg ha^{-1} of Arsenate of Soda, applied in some 4,500 litres of water ha^{-1} to plants ranging from 15 cm to about 1.8 m tall (Breen 1925).

With the introduction of the phenoxy herbicides, attention was directed at different growth stages for control in both crops and pastures. A rate of 450 g a.i. ha^{-1} for MCPA or 2,4-D was used to control actively growing plants in South Australia (Richardson 1952). In Western Australia, Meadly (1957) suggested that 2,4-D ester at this rate was only effective on rosettes less than 5 cm across and that, if the amine formulation was used, the rate had to be increased to about 700 g a.i. ha^{-1}. He recommended that the rate of ester should be increased to 1.0 kg a.i. for plants with rosettes 10–15 cm across, 1.5 kg a.i. ha^{-1} for plants with flowering stem emerging and 2.0 kg a.i. ha^{-1} for plants as they approached flowering stage. Quinlivan and Pearce (1964), Mears (1968) and Pearce (1976) also indicate that rates of 2,4-D need to be increased as plants become larger. Most eastern States recommendations (exception for Anon. 1971, Watson 1990) suggest clovers and medics will suffer only mild retardation when treated with the low rates of 2,4-D, (Richardson 1952, Mears 1968). Damage to clovers, trefoils and medics will occur at these rates in Western Australia (Meadly 1955, Pearce 1976).

MCPA gives good control in the eastern States of Australia (Davidson 1966, Mears 1968). Watson (1990) obtained similar results, but the addition of clopyralid at 150 g a.i. ha^{-1} caused damage to both medics and subterranean clover. He also found 2,4-DB at 700–900 g a.i. ha^{-1} gave good control. This was an expensive treatment however, and was not suitable for large areas. *C. lanatus* density was reduced by about 90% twelve months after applications of MCPA at 375–750 g a.i. ha^{-1} (Watson 1990).

C. lanatus has been controlled in cereal crops using the phenoxy herbicides (Meadly 1957, Parsons 1973, Pearce 1976) which are applied once cereals commence to tiller. Herbicides such as bromoxynil, linuron, dicamba and methabenz-

Table 2. Control of seed set in *C. lanatus* using 100 g a.i. ha^{-1} each of paraquat and diaquat (from Peirce unpublished)

Phenological stage	% Reduction in seed formation
Before flowering (October 5)	99.9
Primary flowers opening (November 4)	92.0
Secondary flowers opening (November 11)	87.0
Full flowering (November 18)	81.0

thiazuron (Davidson 1966, Mears 1968, Parsons 1973, Pearce 1976) can be applied when the cereal has three leaves (Z13) and when mixed with 2,4-D can be applied once the crop has formed five leaves (Z15) (Pearce 1976). Clopyralid either alone or mixed with MCPA or 2,4-D has given good control in research undertaken in South Australia (Mitchell, Maslen and Carter 1987).

Restricting the ability of *C. lanatus* to form viable seed has been successful in South Australia (Fromm 1990), New South Wales (Watson 1990) and Western Australia (Quinlivan and Pearce 1964, Peirce unpublished).

Paraquat (200 g a.i. ha^{-1}), glyphosate (216 and 270 g a.i. ha^{-1}) and a proprietary mixture of paraquat (125 g a.i.) and diquat (75 g a.i. ha^{-1}), when applied to flowering *C. lanatus*, reduced the number of normal seed heads formed (Fromm 1990). Timing was critical for maximum reduction, as Watson (1990) showed reductions of 98% at green bud stage, 90% as first primary flowers opened, 70% when secondary flowers were opening and only 55% when *C. lanatus* was in full flower. Using 100 g a.i. ha^{-1} each of paraquat and diquat in a proprietary mix, Peirce (unpublished 1987) obtained a similar trend, but more effective control at the last two flowering growth stages (Table 2). The results obtained by treating *C. lanatus* at flowering are similar to those obtained with Nodding thistle *Carduus nutans* L. (Martin and Rahman 1987).

Benefits from late spraying include confidence that no more germinations will occur in that season and the application is delayed beyond the time that annual grasses, clover and medics will be affected. Some problems adjusting spray equipment to the correct height (Peirce unpublished) and regrowth and new seed heads forming when rain occurs after treatment have been reported (Fromm 1990, Watson 1990). A proprietary mixture of glyphosate 150 g a.i. ha^{-1} and 2,4-D amine 150 g a.i. ha^{-1} will also substantially reduce the amount of viable seed formed, as does glyphosate 157 g a.i. ha^{-1} and 2,4-D ester 240 g a.i. ha^{-1} applied at flowering (Peirce unpublished).

Response to other human manipulations

Cultivation

The major proportion of *C. lanatus* seed germinates within two or three years after formation and Pearce (1976) suggests the most practical method of control is continuous cropping plus spraying in the crop to prevent any further seed formation.

Ploughing brings dormant seeds to the surface and provides suitable conditions for germination (Meadly 1957). However, because seeds may germinate over an extended period in any one season, an integrated approach to control is needed. Cultivation was the only practical method for control before the phenoxy herbicides were introduced (Mears 1968).

Fertilizers

According to Michael (1968), *C. lanatus* does not show any preference for fertilizers or high soil fertility and, like Watson (1990), he suggests that there is a negative response to fertilizer due to increased competition from pasture species. This is in direct contrast to many of the species of thistles that show a positive response to fertilizers, in particular, superphosphate (Wheatley 1982).

Pasture establishment

Strong competition from a good legume pasture will assist in the reduction of plant density (Parsons 1973, Pearce 1976). In New South Wales large areas badly infested with *C. lanatus* have returned to high level production when annual ryegrass and a suitable legume have been established with adequate levels of fertilizer (Mears 1968). Annual applications of superphosphate (100 kg ha^{-1}) for two successive years reduced the density of *C. lanatus* by 90% in New South Wales (Watson 1990). However, it was stressed that improved pasture will only be successful if overgrazing, which will permit the growth of heavy infestations of seedling *C. lanatus*, is avoided.

Mowing and slashing

One of the earliest control methods involved cutting the plants before they reached full flowering (Maiden 1895) and has always been included in any control strategy (Carne and Gardner 1926, Richardson 1952, Meadly 1957, Mears 1968, Anon. 1971, Wheatley 1982). Timing of the cutting or mowing is critical for most thistles because of the uneven maturity (Wheatley 1982). Dodd (1989) also found that timing of cutting was critical for reducing the amount of viable seed formed by variegated thistle *Silybum marianum* (L.) Gaertn.

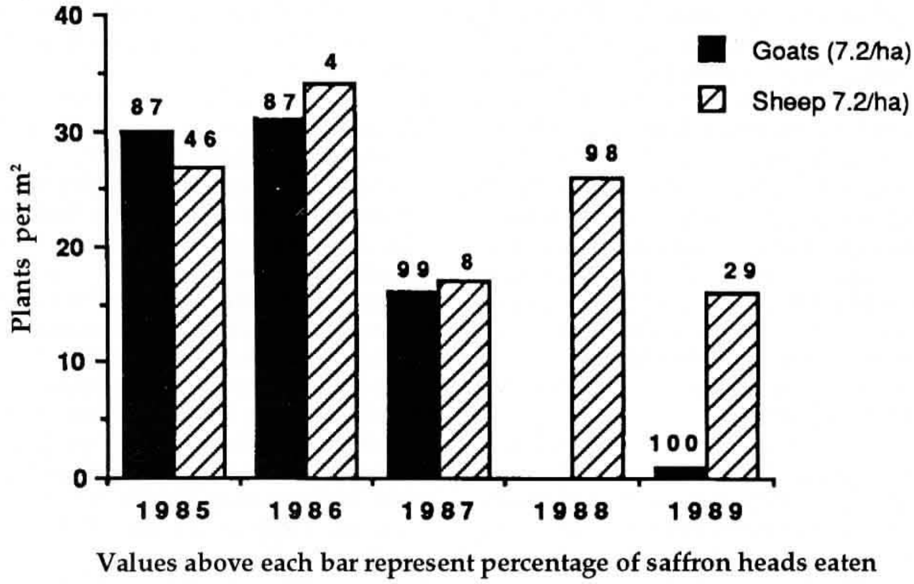

Figure 10. Change in density (plants m^{-2}) of mature *C. lanatus* plants over five years with grazing by sheep or goats (from Peirce 1991).

Grazing

Sheep have not been effective in grazing out rosettes of *C. lanatus*, and in fact usually encourage the weed because, unable to reach the flat rosettes, they remove other pasture first, resulting in an increased density of *C. lanatus* (Parsons 1973). In Western Australia Pearce (1976) outlined the principle of "spray grazing", which involved the application of a sub-lethal rate of 2,4-D amine to *C. lanatus* in September, just as the flowering stalks commenced elongation. Seven days after spraying, the wilted saffron is grazed by sheep at four-five times the normal stocking rate. The grazing pressure is maintained until the paddocks show signs of overgrazing. In the wilted condition, *C. lanatus* was selectively grazed and eaten out, while little damage occurred to subterranean clover which had formed sufficient seed to establish the following year's pasture.

Cattle are considered of little value in controlling established thistle plants, but goats and horses have significant effects on thistles at early stages of an infestation (Wheatley 1982). More recently Peirce (1991) has shown that goats are effective in reducing seed formation in *C. lanatus* in Western Australia (Figure 10). Because of the seed dormancy, hence large seed bank in the soil, it took three years before any significant reduction in plant density was noticed.

Mitchell (1985) and Davidson (1990) have also reported that goats control *C. lanatus*. Most observations indicate that goats show little interest in the thistles until they commence flowering, and even then only remove the flowering head thereby preventing seed formation. Goats have eaten entire plants some months after they have been treated with 750 g a.i. ha^{-1} of 2,4-D amine in September (Peirce unpublished).

Response to natural enemies

Biological control

C. lanatus was found to be immune to Verticillium wilt and *Puccinia carthami* (Zimmer 1967), which are serious diseases of cultivated safflower. However, because of the similar genetic background to safflower (saffron thistle is probably partially derived from safflower), agents active on saffron thistle may also affect safflower (Wapshere personal communication). For this reason, saffron thistle has not been given a high priority amongst the thistle species targeted for biological control.

A form of biological control has been observed in Western Australia when native bud worms (*Helicoverpa punctigera* Wallengren) bore into the flowering head (capitulum). However, Sproul (personal communication) suggests that the activity of bud worms depends on the presence of green plant material and they would only be active on *C. lanatus* after all other green pasture feed, such as capeweed *Arctotheca calendula* (L.) Levyns, has dried off. Seeds of *C. lanatus* in the northern agricultural districts of Western Australia are attacked in the soil by termites (Quinlivan and Peirce 1968).

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