CHAPTER 5: Cultural Control

Cultural control techniques involve manipulation of the environment by non-mechanical means such as controlled burning, grazing management, or revegetation programs.

Grazing

A successful grazing program significantly reduces the population of yellow starthistle, limits damage to desirable vegetation, achieves goals for livestock production, and supports an integrated weed management strategy (Frost and Launchbaugh 2003). Used properly, grazing management can also minimize the spread of noxious weeds in rangeland systems.

The specific goal of livestock (cattle, goats or sheep) grazing for weed control is to manipulate the pattern of defoliation so that the target weed is at a competitive disadvantage relative to other more desirable plants in the community (Frost and Launchbaugh 2003). This can be achieved either by (1) timing the grazing so as to damage the target species when it is most vulnerable, or (2) controlling the behavior of the grazing animals so they concentrate their efforts primarily on the target weed.

Although grazing can help to manage yellow starthistle populations, it is important to note that grazing alone will not provide long-term management or eradication of yellow starthistle. It can, however, be a valuable tool in an integrated management program.

Cattle grazing. *When used as part of an integrated management program, grazing can reduce the growth and spread of yellow starthistle and other noxious weeds. (Photo: C. Thomsen)*

ECONOMICS

One advantage over other methods for the control of yellow starthistle is that grazing animals can convert the weed into a saleable product (Frost and Launchbaugh 2003). However, some significant costs can be associated with grazing, including the purchase or lease of the animals, maintaining them in proper health, and monitoring their grazing activity to minimize harm to desirable forage. This may require the use of a herder or penning animals at night. Other expenses can include stock dogs, fencing, and sometimes supplemental feeding, especially late in the season when the nutritive value of yellow starthistle is low (Frost and Launchbaugh 2003). Without this supplemental feed, production losses can occur.

METHODS AND TIMING

Different grazing strategies have different advantages. For example, grazing at moderate levels can minimize impact on native plants and reduce soil disturbance, while intensive grazing will counteract inherent dietary preferences of livestock, resulting in equal impacts on all forage species including weeds, and multispecies grazing will distribute the impact of livestock grazing more uniformly among desirable and undesirable species (Olson 1999).

Short periods of intensive grazing have been widely adopted in other countries (DiTomaso 2000). In this system pastures are intensively grazed from 3 to 5 days, often with the use of electric fencing. The pasture is subsequently allowed to recover for at least a month before grazing is repeated. Forage is not completely grazed and recovery occurs rapidly. This can increase total season forage production and the stocking capacity of the area.

As an added benefit of short duration intensive

grazing, the remaining forage reduces light penetration to the soil surface and can suppress weed establishment and growth. In contrast, conventional grazing practices allow animals to forage grasses and other plants nearly to the soil surface. Yellow starthistle has been shown to be very susceptible to light suppression (Roché *et al*. 1994). Shading reduces seedling survival rates. Weber (1985) noted that Roché delayed spring grazing of wheatgrass and was able to control starthistle because ungrazed, taller wheatgrass plants blocked sunlight from the starthistle rosettes.

Intensive time-controlled grazing can also minimize the grazers' ability to avoid less palatable noxious weed species. High stocking rates may force cattle to graze typically less preferable species, including yellow starthistle. This should result in a more uniform composition of range plant species and more balanced competitive relationships among native and non-indigenous species (Olson 1999).

Because so many animals are required to be successful, practice of high intensity grazing on a large scale is limited. It has been estimated that 1900 head of cattle would be needed to properly treat 1000 acres (Connor 2003). Furthermore, for effective control, grazing would have to continue beyond the time when yellow starthistle is most palatable, thus compromising livestock production.

Timing also can be critical to the success of grazing for yellow starthistle control. The ideal time to graze is when plants are most susceptible to defoliation or when the impact on desirable vegetation is minimal. Thomsen *et al*. (1989, 1990, 1993) showed that properly timed (May and June) intensive grazing by cattle or goats resulted in reduced

Spiny stage. *At the spiny stage, cattle and sheep will not graze yellow starthistle, but goats will continue to browse it.*

Table 1. Comparison of grazing characteristics of cattle, sheep and goats (Frost and Launchbaugh 2003)

Animal	Digestive systems	Feeding behavior	Classification
Cattle	Large rumens adapted to ferment fibrous material	Best for managing fibrous herbaceous vegetation, prefer grasses but will also graze yellow starthistle at the bolting stage	Grass and roughage eaters
Sheep	Large rumen adapted to ferment fibrous material	Can selectively graze and tolerate high fiber content, diet dominated by forbs, will control yellow starthistle when grazed at bolting stage, but not in rosette stage	Forb and roughage eaters, more easily managed by human herders, used for strategic grazing
Goats	Large liver mass that allows processing of secondary compounds less digestible or more toxic to other grazers	Mouths designed to strip leaves from woody plants and chew branches, will also feed on yellow starthistle in the spiny stage	Browsers used often to control woody species

growth, canopy cover, survivability, and reproductive capacity of yellow starthistle. Repeated high-intensity cattle grazing reduced flowering heads of yellow starthistle by 78-91% (Thomsen *et al*. 1993). These plants were grazed after the stems had bolted but before the development of spiny seed heads. Cattle and sheep tend to avoid starthistle once the buds produce spines, whereas goats continue to browse plants even in the flowering stage (Thomsen *et al*. 1993). For this reason, goats have become a more popular method for controlling yellow starthistle in relatively small infestations. Thomsen *et al*. (1990, 1993) also reported that grazing the weed during the bolting stage could provide palatable high protein forage (8 to 14%). This can be particularly useful in late spring and early summer when other annual species have senesced.

Selecting the proper grazing species is important to successful management. In the case of yellow starthistle, cattle, sheep and goats have all been shown to be effective tools, but each has a slightly different feeding behavior that may affect the level of yellow starthistle control under a particular set of conditions (see Table 1).

Although grazing alone may not provide adequate long-term control of yellow starthistle, it is most valuable for its potential to increase the effectiveness of other control methods. For example, goat grazing has been shown to increase the subsequent efficacy of herbicides on leafy spurge (*Euphorbia esula*) (Lym *et al*. 1997). It is possible that grazing may also increase the effectiveness of postemergence herbicides on yellow starthistle, although this has not been studied.

RISKS

Conventional grazing or intensive overgrazing can lead to the invasion of yellow starthistle and many other rangeland weeds (Billings 1994). Improperly timed grazing can lead to rapid selection for yellow starthistle. For example, in late winter or early spring livestock primarily feed on young grasses with an erect growth form, causing little damage to seedling yellow starthistle rosettes. This practice increases light penetration through the canopy and stimulates yellow starthistle growth during the late spring and early summer. Thomsen *et al*. (1993) showed that the density of yellow starthistle increased if sheep grazed while plants were in the rosette stage. On the other hand, livestock grazing in the mid- to late summer months will avoid spiny yellow starthistle plants, thus allowing heavy seed production and the next year's survival of the weed.

Excessive trampling by livestock can increase the density of yellow starthistle (Miller *et al*. 1998). Grazing also can spread noxious weeds over a wide range when seeds become attached to hair or when they remain intact after passing through the digestive system (DiTomaso 1997). In some cases, grazing can select for a particular weed or group of weeds. Animals forage around these plants, eliminating their competition. This selective pressure can lead to more rapid infestation.

Grazing can also be very non-selective and may endanger sensitive non-target species. Goats, for instance, are typically browsers and can effectively control certain noxious species. However, they can forage both desirable and undesirable species when confined and may even strip the bark off trees. Livestock can also trample desirable sensitive species.

Prescribed fire. *California Department of Forestry & Fire Protection conducts a prescribed burn at Sugarloaf Ridge State Park in California.*

Prescribed Burning

Fire has been an important factor in the development and continuance of most grassland systems. As a result, many native grassland plants appear adapted to periodic disturbance by fire. The hard seeds of some broadleaf plants such as legumes may require scarification by fire. Other species mature before the fire season begins and drop their seed to the ground, where grassland fire temperatures are

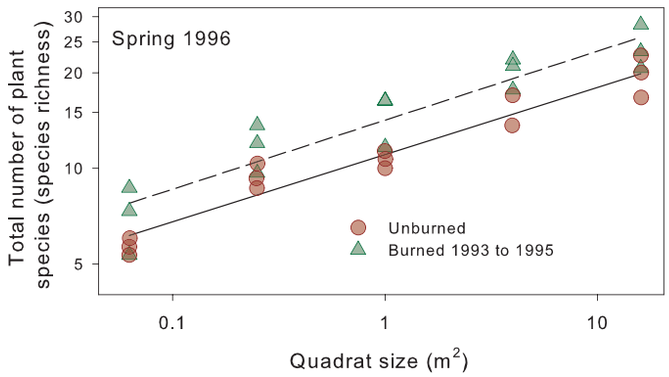

Fig. 14. Effect of burning on yellow starthistle cover. *An increase in plant species richness was found following three years of burning to control yellow starthistle, Sugarloaf Ridge State Park (DiTomaso* et al. *1999a).*

not hot enough to kill seeds. Because native plants have fire adaptations such as hard seeds and early maturation, prescribed burning has been shown to favor germination and establishment of many species, particularly legumes (Kyser and DiTomaso 2002). In contrast, late-season noxious weeds, including yellow starthistle and annual grasses such as barbed goatgrass (*Aegilops triuncialis*), medusahead (*Taeniatherum caput-medusae*) and ripgut brome (*Bromus diandrus*), have all shown potential for control by prescribed burning (DiTomaso *et al*. 1999a).

By shifting the competitive advantage to fire-adapted species, prescribed burning in California grasslands can increase plant diversity as well as control noxious weeds. In the first growing season after the burn, plant diversity and species richness often increase (Hastings and DiTomaso 1996, DiTomaso *et al*. 1999a). Two or more years of burning have resulted in both a reduction in yellow starthistle and a dramatic increase in perennial grasses such as purple needlegrass (*Nassella pulchra*) and California barley (*Hordeum brachyantherum*), legumes, and filaree (*Erodium* spp.).

Prescribed burns also recycle nutrients trapped in the dried vegetation and remove the thatch layer, thus increasing light exposure at the soil surface and allowing the upper layer of soil to warm quickly in spring. This can enhance germination of seeds of desirable plants, but also has been shown to cause an increase in subsequent fall and winter germination of yellow starthistle seed still in the seedbank. In many cases, this enhanced germination will actually increase the starthistle infestation in the year following a burn (DiTomaso *et al*. 2003a). This helps to deplete the yellow starthistle soil seedbank, but it means that controlling starthistle in the year after a burn is critical.

Native forbs return. *Native forbs especially benefited from reintroduction of a burn regime at Sugarloaf Ridge.*

Native grass resprouting. *In the winter following burns at Sugarloaf Ridge, the native bunchgrass* Nassella pulchra *resprouts from old clumps.*

Results after three annual burns. *Three years of burning at Sugarloaf Ridge shifted the competitive advantage from yellow starthistle to fire-adapted native plants.*

In deciding whether to use prescribed burning in management, it may be helpful to refer to the historic burn regime, e.g., every 2 to 10 yr at Sugarloaf Ridge (Finney and Martin 1992). The goal of the management program may be to return an area to its historic burning regime. Several years of consecutive burns may constitute excessive disturbance and may not achieve the intended result.

The goal of a successful burn program for yellow starthistle is to reduce or, in time, eliminate the soil seedbank. At the end of a consecutive three-year burn regime in Sugarloaf Ridge State Park in Sonoma County, the yellow starthistle seedbank and seedling populations in the burned sites dropped to less than 0.5% that of adjacent unburned sites (DiTomaso *et al*. 1999a). This corresponded to a 91% reduction in yellow starthistle vegetative cover during the summer following the third year of burning.

ECONOMICS

The economics of conducting a prescribed burn can vary depending upon the area and cooperation with federal, state or local agencies. At the Sierra Foothill Research and Extension Center in Yuba County, the cost of burning for yellow starthistle control was not substantially less than that for applying herbicide. Out-of-pocket expenses for labor, fuel, minor equipment repairs, permits, and seed and fertilizer for firebreaks totaled $23 per burned acre (Connor 2003). In this study, California Department of Forestry and Fire Protection (CDF) crews provided no-cost assistance with fire ignition and control. CDF assistance is available to private landowners, but there are many more requests annually than can be filled. At Fort Hunter Liggett, with the help of local fire groups, the cost for prescribed burning was only $0.60 to $1.00 per acre (A. Hazebrook, Fort Hunter Liggett, pers. comm.). It is important to remember that in most cases financial liability for escapes is the responsibility of the land owner unless he or she can get into one of the limited number of CDF programs available (Connor 2003).

METHODS AND TIMING

As with mowing, the success of burning depends on proper timing. The best time for burning is in early to mid-summer (late June to early July in most areas of California), which may not be feasible in some areas. At this time starthistle is in the very early flowering stage (similar to ideal mowing timing) and will not have produced viable seeds, whereas seeds of most desirable species will already have dispersed and grasses will have dried to provide adequate fuel.

In some cases, yellow starthistle seedlings have been controlled using winter or early spring "flaming" techniques, in which heat is applied to wet plants with a propane torch (Rusmore 1995). This reduces the risk of escaped fires and avoids major air quality issues. However, this technique is

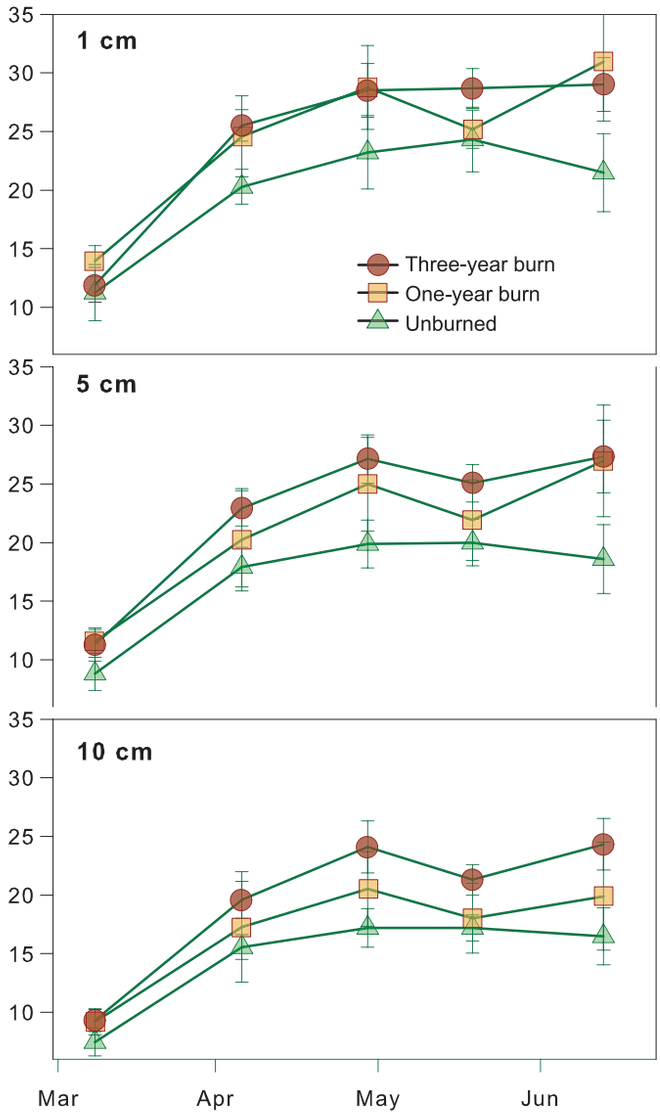

Fig. 15. Effect of burning on soil temperature. *In the spring after burning at Sugarloaf Ridge State Park to control yellow starthistle, higher soil temperatures were measured compared to unburned sites (DiTomaso* et al. *1999a).*

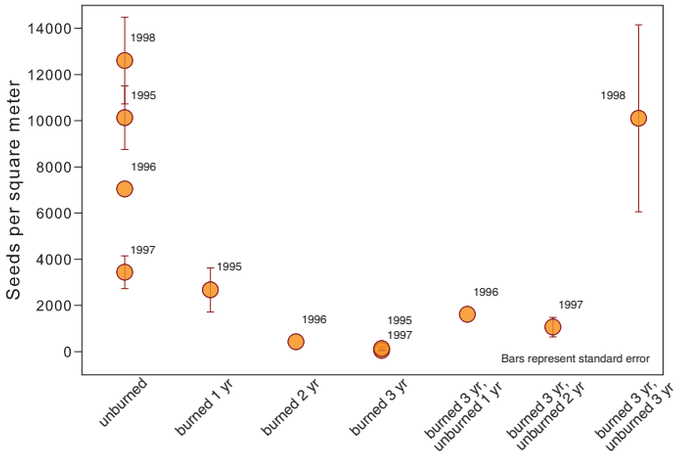

Fig. 16. Effect of burning on seedbank. *At Sugarloaf Ridge State Park, yellow starthistle soil seed density was monitored during a three-year burn project and for three years after burning ceased. The seedbank was greatly reduced but recovered quickly in the absence of followup management (Kyser and DiTomaso 2002).*

somewhat non-selective and the control of yellow starthistle has proven inconsistent. When spring drought follows a flaming treatment, control of starthistle can be excellent (Rusmore 1995). In contrast, a wet spring can lead to complete failure and increased starthistle infestation, particularly since competing species may be dramatically suppressed. Fall or winter burns may not control yellow starthistle, but will likely stimulate germination of the seedbank. If a successful management method is employed in the following spring or summer, it is possible to more rapidly deplete the seedbank, thus reducing the long-term cost of management.

In a study by Kyser and DiTomaso (2002) at Sugarloaf Ridge State Park, a site burned three consecutive years (1993-1995) was monitored for an additional four years (1996-1999). Following the cessation of the burn program, the grassland degraded rapidly as the competitive advantage shifted away from fire-adapted forbs. These species, particularly native legumes, gradually declined, as did total species richness. Within three years the burned grassland was not significantly different from the unburned area, with the exception that yellow starthistle population levels remained significantly lower. These results indicate that reduction in yellow starthistle by means of burning at Sugarloaf Ridge did not result in a stable community but rather a community in transition back to

Timing for burns. *Burning for control of yellow starthistle is most successful at the beginning of flowering, when other plant species are dry but yellow starthistle seed is not yet viable.*

yellow starthistle-dominated grassland. (It should be noted that adjacent areas remained infested, providing a ready source of yellow starthistle seed.) It was concluded that without periodic fire and/or intensive management (e.g., herbicides or controlled grazing), and in the absence of many of the original dominant grassland species (Heady 1973), the community is at constant risk of invasion (Kyser and DiTomaso 2002). A follow-up management program is essential to the long-term control of yellow starthistle. This can include spot herbicide treatments or a mechanical control method.

The ability to use repeated burning depends on climatic and environmental conditions, as well as

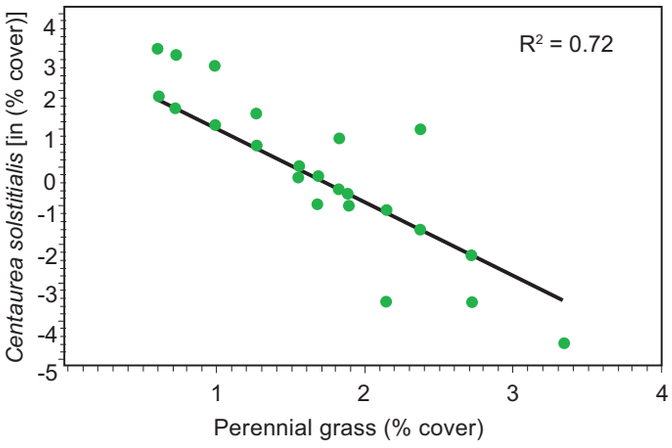

Fig. 17. Competition with perennial grasses. *A negative correlation between yellow starthistle cover and cover of perennial grass indicates that the two plant types compete directly (Enloe 2002).*

political and sociological concerns. Even when these obstacles are overcome, fuel loads may not be sufficient to allow multiple-year burns. Consequently, prescribed burning may be most appropriate as part of an integrated approach. A combination of burning and other control techniques, such as herbicide treatments or intensive grazing, may be more practical and still prove to be very effective.

RISKS

There are a number of risks associated with prescribed burning as a method of controlling yellow starthistle and other invasive plants. For one, air quality issues and requirements, including PM10 emissions, can be a significant problem when burns are conducted adjacent to urban areas (Campbell and Cahill 1996). This potential problem can be avoided by conducting burns only in more isolated regions. Public relations problems can be minimized by educating residents of the intended goals of the project prior to the burn.

Another major risk of prescribed burning is the potential of fire escapes. This is particularly true when burns are conducted during the summer months. This can be minimized by proper preparation and through involvement of local and state fire departments.

Because of these air quality and fire escape concerns, public agencies have restricted prescribed burns to periods of proper wind, humidity, and temperature parameters (Connor 2003). Given these restrictions, plus the ever-present possibility of variable weather during desired burn periods, it can be problematic to achieve a burn within the time period required for weed control.

Another potential risk is that continuous burning may increase soil erosion and impact the plant composition within a site. Species that complete their life cycle before the burn will be selected for, while those with later flowering times will be selected against. In some areas, burning can lead to rapid invasion by other undesirable species with wind-dispersed seeds, particularly members of the sunflower family. Although this is a potential concern, and a few plants are negatively impacted by continuous burning for yellow starthistle control, the survival of most native species is enhanced by burns (Hastings and DiTomaso 1996).

Perhaps the most overlooked risk of burning is the impact fire may have on small animals and insects unable to escape the burn. For example, burning for control of yellow starthistle during the summer undoubtedly damages seed head feeding biocontrol insects and their larvae.

Reseeding. *This site in Siskiyou County, California, was reseeded with wheatgrass as part of a yellow starthistle control program.*

Revegetation

Before the introduction of annual grasses, perennial bunchgrasses were the primary native species in rangelands west of the Rocky Mountains. Bunchgrass species included *Festuca idahoensis, Poa secunda, Festuca kingii, Pseudoroegneria spicata, Leymus cinereus, Elymus elymoides*, *Achnatherum hymenoides, Hesperostipa comata,* and *Achnatherum occidentalis* (Billings 1994). These perennial grass species do not have high seedling vigor nor do they readily recover from grazing (Callihan and Evans 1991). With the introduction of exotic annual grasses and livestock,

Seed drill. *A seed drill attachment used for reseeding.*

Competitive planting. *Wheatgrass, here shown establishing along seed drilling rows, can be used to out-compete yellow starthistle after other management methods have removed it.*

Two years after reseeding. *Wheatgrass was planted two years ago on this site in Siskiyou County*

native perennial grass plants were overgrazed and quickly replaced by introduced winter annual grasses (Young and Longland 1996).

During the past half-century, many noxious broadleaf species have expanded their range in the western United States. Although this can be associated with soil disturbance by human activities, it is also due to selection by livestock overgrazing the annual grasses. Spiny broadleaf species such as yellow starthistle tend to be avoided by livestock. This can favor a rapid shift in the dominant species within these communities (Callihan and Evans 1991). Many of these broadleaf species produce extensive taproot systems that extract more deep soil moisture than do annual grasses, thus they remain green longer into the dry season. In addition, these invasive broadleaf species typically produce a large number of seeds (Roché *et al*. 1994).

Revegetation seeks to replant an area with competitive species that have wildland or forage value. These can be native perennial bunchgrasses or other species. In a revegetation program designed to suppress noxious weeds, one major challenge is choosing a species or combination of species that is more vigorous than the invasive weed. Only a limited number of species have proven to be aggressive enough to displace invasive species, and the proper species choice varies depending on the location and objective. Perennial bunchgrasses are among the most common species used for revegetating western grasslands, but broadleaf species such as legumes can also be used in revegetation programs to suppress rangeland weeds. In addition to using a competitive species, seeded species also need to be adapted to the soil conditions, elevation, climate, and precipitation level of the site (Jacobs *et al*. 1999).

Reseeding rangeland. *A land manager using a seed drill on rangeland.*

Because of its extended dry season, revegetation in California is more difficult than in other western states. Summer rainfall can be critical to the establishment and survival of native perennial grasses. In Siskiyou County, where the summer weather pattern is more similar to the Great Basin states, average rainfall between May and September is around 4 inches. In contrast, the Sacramento and San Joaquin valleys average 0.75 inches or less of precipitation during that same time period.

ECONOMICS

The primary limitation to the use of native species in revegetation programs is their high cost. Few producers are available and the demand for seed

is low. This increases the cost of seed and reduces availability of genetically endemic biotypes of native species. In many cases, the cost of using native seed can be in the hundreds to even thousands of dollars per hectare. Access to seeding equipment can also be a major limitation. Drill seeders are not often available and cannot be used in steep terrain or rocky sites. Broadcast seeding reduces the chances of successful establishment.

In a native legume and perennial grass restoration effort at Fort Hunter Liggett, reseeding cost between $500 and $2000 per acre) (A. Hazebrook, Fort Hunter Liggett, pers. comm.). In this trial, the native species represented 5 to 30% of the total vegetative cover two years after seeding.

METHODS AND TIMING

In the absence of adequate surface soil moisture during the critical spring growing season, revegetation programs are likely to fail (Roché *et al*. 1997). In California, it is not uncommon to experience a month of more without precipitation during the rainy season. Under these conditions, germinated seedlings cannot survive and a fall reseeding timing program may fail. In contrast, a spring reseeding may not survive under conditions of low spring rainfall. Although there has been little work in this area, winter may prove to be the best time for reseeding; however, it is generally the most difficult time to transport equipment into the site.

The method of revegetation can also determine the level of success. Revegetation can be accomplished by broadcast seeding or interseeding forage grasses and/or legumes into existing communities, or by drill seeding into plowed, disked, herbicide-treated, or no-till rangeland (Jacobs *et al*. 1999). Drill seeding programs are considerably more successful than those utilizing broadcast seeding techniques. Broadcast seeding disperses seeds on the top of the soil, so the seeds are more susceptible to predation or decay. In addition, if the seeds germinate on the soil surface they have a higher probability of desiccating under subsequent dry conditions.

The choice of species that best fit the intended use of the site is also important. For example, if livestock grazing is the primary objective of a revegetation program, a perennial grass with high forage production may be the appropriate choice (Jacobs *et al*. 1999).

Clover cover crop. *When used as a cover crop, crimson clover (*Trifolium incarnatum*) reduced yellow starthistle cover by up to 90%.*

Perennial grasses are the most successful in competing with rangeland weeds. For the long term, however, it is best to use a combination of species with various growth forms when designing seed mixes. In other regions of the country, seed mixtures of grasses with legumes improved the rate of microbial and soil structure recovery compared to grasses alone (Jacobs *et al*. 1999). Seed mixtures are expensive, however, and their use may limit the options for noxious weed control (e.g., using selective herbicides). Thus, a revegetation program may require initial seeding with perennial grasses during the weed management phase followed by subsequent reseeding with broadleaf species. Under this condition, revegetation programs may take several years to succeed.

Revegetation programs for yellow starthistle control generally rely on reseeding with native species or perennial grasses (Callihan *et al*. 1986, Johnson 1988, Jones and DiTomaso 2003, Larson and McInnis 1989a, Lass and Callihan 1995a, Northam and Callihan 1988a, b, c, 1990a, b, Prather *et al*. 1988, Prather and Callihan 1989a, b, 1990, 1991). These programs try to eliminate not only starthistle, but also the invasive annual grasses that create an ecosystem susceptible to starthistle invasion. Revegetation with desirable and competitive plant species can be the best long-term sustainable method of suppressing weeds, while providing high forage production. In western states other than California, competitive grasses used in revegetation programs for yellow starthistle management include crested wheatgrass (*Agropyron desertorum*), intermediate wheatgrass (*Elytrigia intermedia* [=*Agropyron intermedium, Thinopyrum intermedium*]), thickspike wheatgrass (*Agropyron dasystachyum*), big bluegrass (*Poa ampla*), Bozoisky Russian wildrye (*Psathyrostachys juncea*), sheep fescue (*Festuca ovina*), tall oatgrass (*Arrhenatherum elatius*), or orchardgrass (*Dactylis glomerata*) (Borman *et al*. 1991, Ferrell *et al*. 1993, Prather and Callihan 1991, Sheley *et al*. 1999b). These species provide good livestock forage and a sustainable option for rangeland maintenance.

Ideally, competitive, endemic, native species should be re-established. The native perennial grass species most commonly studied include purple needlegrass (*Nassella pulchra*), blue wildrye (*Elymus glaucus*), and creeping wildrye (*Leymus triticoides*) (Jones and DiTomaso 2003). Some native perennial broadleaf species, such as common gumplant (*Grindelia camporum*), are also used. In preliminary studies in the Sacramento Valley (Jones and DiTomaso 2003), blue wildrye or combinations of blue wildrye and common gumplant were very effective in preventing the encroachment and establishment of yellow starthistle. In many other cases non-native perennial grasses or legumes with high forage quality and quantity are used in revegetation programs, as it is not always practical or economical to use native species.

In Oregon, subterranean clover (*Trifolium subterraneum*) has been used for reseeding programs in foothill ranges (Sheley *et al*. 1993). This species is effective in annual grass dominated rangelands because of its rapid germination and establishment. However, it establishes inconsistently in yellow starthistle-dominated grasslands because starthistle has similar patterns of initial growth.

In California, Thomsen *et al*. (1996a, 1997) and Thomas (1996, 1997) tested several legume species for their competitive effect on yellow starthistle. Thomsen *et al*. (1996a, 1997) found that subterranean clover varieties were somewhat competitive against yellow starthistle when combined with grazing and mowing. Subterranean clover was also palatable and self-seeding, and produced flowers and seeds below the bite of grazing animals. Used as a sole control option, however, the clover did not provide adequate seasonal control of starthistle. Thomas (1996, 1997) used a combination of subterranean clover and/or crimson clover (*Trifolium incarnatum*) as a cover crop in starthistle-infested pasture. In a completely infested field, Thomas (1997) reported an 80 to 90% reduction in yellow starthistle one year after planting with crimson clover. Unlike subterranean clover, crimson clover does not appear to be self-sustaining over a long time period.

RISKS

Introducing competitive species into infested non-crop areas as part of a control program is essential to sustainable management of noxious weeds. Preferably, competitive, endemic, native species should be re-established. For example, native willows (*Salix* spp.) and cottonwoods (*Populus* spp.) have been used to replace saltcedar in riparian areas. However, in most cases, particularly rangeland environments, endemic native species do not appear capable of outcompeting noxious weeds.

In yellow starthistle-infested areas, many studies have used more competitive non-native species. Although non-native, these species provide good livestock forage and a sustainable option for rangeland maintenance. A potential concern is that, once established, many of these species, especially the perennial grasses, can develop into near monocultures. This can have a dramatic impact on total plant and animal diversity within these sites. In addition, it is important to ensure that an introduced species will not itself become invasive and spread from the planted area into wildlands. For example, Harding grass (*Phalaris aquatica*) is a perennial

bunchgrass native to the Mediterranean region that was planted commonly as high-value pasture forage, but has escaped to colonize wildland areas and displace native species (Harrington and Lanini 2000).

Even the use of native species in revegetation efforts presents potential problems. Native seed collected in one area of the state but used in a revegetation program in a different region may be genetically different, due to ecotypic variability. It has been argued that over time, as a result of genetic contamination, the native population may lose its adaptive advantage in its evolved ecosystem (Knapp and Rice 1997).

Because of the ecological diversity within California, no single species or combination of species will be effective under all circumstances. Although pubescent wheatgrass has proved successful in Siskiyou County, it may not be appropriate in most other areas of the state that lack summer rainfall. Unfortunately, few studies have been conducted on the restoration of yellow starthistle-infested grasslands, particularly with native species. Major questions yet to be addressed include what combinations of species to use in various environments, which species or combination of species will aggressively compete with yellow starthistle, and how to economically establish these species.