

## CHAPTER 8: **Developing a Strategic Management Plan**

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### **Prevention**

Yellow starthistle infests 10 to 15 million acres in California but has the potential to infest nearly 40 million acres (Pitcairn *et al.* 1998b). Preventing its introduction into new areas is the most cost-effective method for starthistle management and is an essential component of a noxious weed management strategy. The major elements of a management program are preventing introduction or reinvasion of yellow starthistle seed, reducing the susceptibility of the ecosystem to yellow starthistle establishment, developing effective education materials and activities, and establishing a program for early detection and monitoring (DiTomaso 2000).

### **AVENUES OF INTRODUCTION**

Yellow starthistle can encroach by establishing small infestations in relatively close proximity to a larger infestation (Sheley *et al.* 1999a). This can be through natural means including wind, water, and animal dispersal mechanisms. To prevent this type of encroachment, neighboring weed infestations on adjacent lands should be contained. The most effective method of containment is to spray the borders of infested areas with herbicide (Sheley *et al.* 1999c).

In many cases, however, yellow starthistle and other noxious weeds are introduced onto grasslands through human-related activities. Seeds or plant parts can be introduced as contaminants of hay or animal feed. This type of spread can be prevented by using certified weed-free feed (Sheley *et al.* 1999c). Transporting soil contaminated with starthistle seed can start new infestations and is a common means of introducing yellow starthistle along roadsides or in construction sites.

Livestock can move starthistle seeds from one area to another in their feces or by transporting seed attached to hair or mud. Seed dispersal by animals can be minimized by avoiding livestock grazing in weed-infested areas during flowering and seeding stages or by holding animals for seven days before moving them to uninfested areas (Sheley *et al.* 1998).

Equipment and vehicles driven through infested landscapes can transport yellow starthistle seed to uninfested areas. Even human clothing can transport seed, particularly in soil stuck to shoes and boots. Equipment and clothing should be cleaned immediately after leaving an infested site.

It is especially important to control or prevent weed invasions along transportation corridors, including roadsides, waterways, and railways. These areas are typically disturbed sites and, consequently, are susceptible to noxious weed establishment (DiTomaso 2000).

### **SUSCEPTIBLE LANDSCAPES**

Yellow starthistle often establishes following disturbances, either natural or through human activity. Although starthistle can invade some undisturbed areas, disturbance usually allows for more rapid establishment and spread. Following soil disturbance, sites should be monitored to prevent establishment and subsequent seed production in these susceptible areas. In many cases, disturbed sites should be revegetated with desirable species to slow the invasion of yellow starthistle.

Proper grazing can maintain desired plants and provide a more competitive environment. Overgrazing should be avoided and grazed plants should be allowed to recover before re-grazing. This ensures that grasses remain healthy and vigorous, maximizing their competitiveness and reducing the potential for starthistle encroachment (Sheley *et al.* 1999c). Revegetation with aggressive perennial grasses can prevent establishment of starthistle (Enloe *et al.* 1999a, 1999b, 2000, Jones and DiTomaso 2003). However, communities most resistant to weed infestations are usually composed of a diversity of plant species. This diversity allows for maximum niche occupation and resource capture (Sheley *et al.* 1999a).

### **EDUCATIONAL PROGRAMS**

Employees and the public can be made aware of noxious weed issues by a number of methods. Information

can be made available through brochures, posters, internet websites, calendars, scientific papers, and other written media. Educational programs can be conducted for landowners, land managers, or the general public. These can include public seminars, professional symposia, school programs, and volunteer field workshops conducted by University Extension, 4-H clubs, church groups, environmental organizations, scouts, and other such groups. The media also play an important role in educating the public through radio or television news stories, public service announcements, newspaper articles, public displays, or even roadside bulletin boards. All these educational activities facilitate greater cooperation among private, federal, state, and county agencies, industries, landowners, and the general public. In addition, they increase the potential for early detection and rapid response to new starthistle infestations.

#### EARLY DETECTION AND MONITORING

The most effective means of controlling noxious weeds is to recognize potential weed problems early, control them before they reproduce and spread, and monitor the site regularly to maintain adequate follow-up control (Rejmanek and Pitcairn 2002). Understanding the potential threats that may exist on surrounding property can provide an early warning system for weed invasion. One successful method for preventing yellow starthistle invasion is to regularly inventory the area by field surveys or aerial photography and remove individual weed plants before they become well established (Sheley *et al.* 1999c).

#### Eradication

Eradication is not often practical for yellow starthistle, but in previously uninfested areas it may be possible to eradicate new small invasions. An effective eradication program is closely tied to prevention. The keys to successful eradication are early recognition of yellow starthistle populations and rapid response to prevent reproduction and the development of a seedbank. Control options in an eradication program are typically limited to mechanical removal, including hand pulling, and herbicide treatment. The objective is to completely eliminate the species from that site, not to manage the population. Eradication is not complete until all viable starthistle seeds are depleted from the soil.

Eradication efforts are usually confined to small-

er infestations of a few acres. These can be satellite populations adjacent to large infestations or isolated invasions far from other infestations. In some cases, eradication efforts can focus on the borders of large infestations (Zamora and Thill 1999). Different plans may be developed for small (<10 acres) or large (>100 acres) starthistle infestations. Financial resources, available technology, potential benefits, and social and geographical constraints will limit the size of the area that can be targeted for starthistle eradication (Zamora and Thill 1999). Large eradication programs may require revegetation to completely eliminate yellow starthistle. However, it is unlikely that infestations larger than 2500 acres can be eradicated (Rejmanek and Pitcairn 2002).

#### Developing a Management Strategy

An effective yellow starthistle management strategy should include three major goals: 1) controlling the weed; 2) achieving land-use objectives such as forage production, wildlife habitat and ecosystem preservation, or recreational land maintenance; and 3) preventing reinvasion of starthistle or invasion of other noxious species. All these goals are tied together with improving the degraded rangeland community and reestablishing a functioning ecosystem. To accomplish these goals, land managers need to understand the land use objectives, management limitations, and ecology of the system.

Understanding the land use objectives of a weed management strategy is critical to determining the proper management approach. Management strategies will differ whether the primary goal is to enhance forage, restore native vegetation or endangered species, or increase recreational value. In addition, selection of the proper management techniques depends on a number of factors including weed species, effectiveness of the control techniques, availability of control agents or grazing animals, length of time required for control, environmental considerations, chemical use restrictions, topography, climatic conditions, and relative cost of the control techniques (Sheley *et al.* 1999a).

One of the most important steps in developing a noxious weed management strategy is to locate and map lands infested with the weed(s) (Sheley *et al.* 1998). Knowing where infestations occur can help decide land use objectives, determine the control methods to be used, and identify areas where

eradication, containment, or management can be achieved. In addition, this information can prevent unnecessary herbicide treatments.

Weed infestations should be identified on a map. Records should indicate weed species present, areas infested, weed density, rangeland under threat of invasion, soil and range types, and other site factors pertinent to weed management (Sheley *et al.* 1998). Continual monitoring will be necessary to prevent new

or reinvading populations from becoming established. A number of monitoring techniques can be used, including hand drawing infested sites on a map, using GPS (global positioning system) units and plotting the data using GIS (geographical information system) programs (Cooksey and Sheley 1998), or employing more complex techniques such as aerial remote sensing (Lass *et al.* 1995, 1996, 2000, Shafii *et al.* 2004).

An understanding of the biology and ecology of

**Table 4. Summary of control options**

**Mechanical**

<b>Hand pulling, hoeing, weed whipping</b>	
Advantages	Excellent when only a few plants persist or when new small infestations occur. Good method for organizing volunteer programs; requires little training.
Disadvantages	Difficult to use with large or dense infestations.
Risks	Can be labor intensive and cause physical injury. Care should be taken to minimize soil disturbance.
Timing	After bolting to very early flowering.
Best fit in strategic management plan	Excellent in final years of a long-term management plan. Late season strategy allows for flexibility. Can save cost compared to other treatments when starthistle population is low.

<b>Tillage</b>	
Advantages	Can provide excellent control in agricultural areas, orchards, vineyards, roadsides, urban areas and other sites where tillage is possible.
Disadvantages	Not usually practical in wildlands or rangeland systems.
Risks	Increased erosion, non-selective control, soil disturbance can lead to invasion of other undesirable weeds.
Timing	At end of rainy season but before viable seeds are produced.
Best fit in strategic management plan	In non-agricultural areas where it is practical, tillage is a good first or second year option where yellow starthistle density is high. Not as practical when starthistle populations are low. In agricultural areas, tillage can be used every year.

<b>Mowing</b>	
Advantages	Relatively inexpensive. Removes skeletons.
Disadvantages	Generally will not provide complete control. Can damage late season natives. Only practical in relatively flat, accessible areas.
Risks	Improper timing or growth form of starthistle can lead to increased infestation. In rocky areas, sparks from rocks contacting blades can start fires. Flying debris can also be dangerous to humans.
Timing	Very early flowering stage ( $\leq 2\%$ of spiny heads in flower).
Best fit in strategic management plan	Useful in later years of a long-term control program. Late season method that gives more flexibility to choose most appropriate control option depending on the level of infestation and growth form of plant. With moderate infestation and erect growth form, mowing can be a very effective method.

**Table 4. Summary of control options** (continued)

**Cultural**

<b>Grazing</b>	
Advantages	Good forage when grazed at proper time. Can release small forbs from shade suppression if area is not too overgrazed.
Disadvantages	Generally will not provide complete control.
Risks	Poisonous to horses through ingestion, mechanical injury to eyes of other livestock if grazed in spiny stages. May have negative impact on ecosystem when vegetation is overgrazed. High grazing pressure can disturb soil and create sites for invasion of other weeds.
Timing	From time yellow starthistle begins to bolt to development of spiny seed heads. Goats can be used longer into season.
Best fit in strategic management plan	Good in early or later years of a long-term control program. In first year of a control program, grazing should be combined with other control options. In later years, it can be used to maintain low levels of starthistle. Proper grazing can be a good method of preventing reinfestation.

<b>Prescribed burning</b>	
Advantages	Very effective control when complete burn can be achieved. Can stimulate native plants, particularly legumes and perennial grasses. Releases the yellow starthistle seedbank for control the following year.
Disadvantages	Harmful to biological control agents. May injure some late season natives.
Risks	Escaped fires and air quality issues. Can cause animal mortality.
Timing	Very early flowering stage ( $\leq 2\%$ of spiny heads in flower).
Best fit in strategic management plan	Can be used in the first, second or third year of a long-term management strategy. If burning can be used only once, it is probably best in the first year when an herbicide can be applied in the second year. Because fire will stimulate yellow starthistle germination it should not be used in the last year of a long-term program.

<b>Revegetation</b>	
Advantages	Can give long-term sustainable control and good forage or diversity. If grazed properly may provide sustainable control of yellow starthistle.
Disadvantages	Expensive and requires a good understanding of the system. Success may be dependent on weather patterns, particularly when plants are becoming established.
Risks	When a non-native species is used, it may spread to become invasive in areas it is not desired. Can reduce diversity if a reseeded species becomes a monoculture.
Timing	Late fall to early spring, depending on the area and whether an integrated approach is used.
Best fit in strategic management plan	First year strategy nearly always integrated with chemical control to assist in establishment of desired species. Can also be used in second year after weed populations have been reduced after first year control program.

**Table 4. Summary of control options** (continued)

**Biological control**

Advantages	Can reduce yellow starthistle seed production by 50-75%. With potential new introductions of insects or pathogen, there is the possibility of long-term and sustainable management.
Disadvantages	Not successful when used as the sole control option.
Risks	Small risk that organisms might shift host to native or economically important species.
Timing	All effective organisms well distributed, no timing issues to be concerned with.
Best fit in strategic management plan	Should be part of any integrated management strategy, even those that are harmful to the insect, e.g. prescribed burning. Organisms quickly recover and will provide some inhibition in seed production.

**Chemical control**

<b>2,4-D (many names), dicamba (Banvel®, Vanquish®), triclopyr (Garlon®, Remedy®)</b>	
Advantages	Good postemergence control of broadleaf weeds.
Disadvantages	Can injure desirable broadleaf species. Does not provide residual control of seeds germinating after treatment. Grazing restrictions.
Risks	Herbicide drift. Applicator safety.
Timing	Most effective when applied to seedlings, but can control mature plants to nearly the flowering stage. Triclopyr not as effective as 2,4-D or dicamba on larger plants.
Best fit in strategic management plan	Can be used as a late season spot treatment in a follow-up program. Best used when treating starthistle plants growing in close proximity to desirable perennial grasses. Not effective as broadcast applications in early years of a long-term management strategy.

<b>Glyphosate (Roundup®)</b>	
Advantages	Very effective for starthistle control, including late season when plants are in bolting, spiny or early flowering stage.
Disadvantages	Non-selective control. Will injure desirable broadleaf or grass species. Does not provide residual control of seeds germinating after treatment. Grazing restrictions.
Risks	Herbicide drift. Applicator safety.
Timing	Although it controls seedlings, it is best used to manage mature plants from bolting to early flowering stage. Should not be applied to drought stressed plants.
Best fit in strategic management plan	Can be used as a late season spot treatment in a follow-up program or to small patches in a prevention program. Not effective as broadcast applications in early years of a long-term management strategy.

<b>Chlorsulfuron (Telar®), Metsulfuron (Escort®)</b>	
Advantages	Good preemergence control of starthistle and excellent control of other invasive weeds, particularly mustards such as perennial pepperweed. Will not injure most grasses.
Disadvantages	Metsulfuron is not registered in California. No postemergence control.
Risks	Herbicide drift. Applicator safety. Can leach with excess water.
Timing	Fall when used alone, but best to treat in late winter or early spring if in combination with 2,4-D, dicamba, or triclopyr.

**Table 4. Summary of control options** (continued)

**Chemical control** (continued)

<b>Chlorsulfuron (Telar®), Metsulfuron (Escort®) (continued)</b>	
Best fit in strategic management plan	Not often used for control of yellow starthistle. Can be used when other invasive weeds are present, particularly those in the mustard family. Metsulfuron provides less control than chlorsulfuron. (Imazapyr (Stalker®, Chopper®, Arsenal®) has same mode of action and similar effect on yellow starthistle, but is not registered for use in rangeland.)
<b>Clopyralid (Transline®) and Aminopyralid (Milestone™)</b>	
Advantages	Provide excellent control at low rates. Give both pre- and postemergence activity for full season control. Low toxicity. No grazing restrictions. Very selective, no injury to grasses and many broadleaf species.
Disadvantages	Can injure legumes (Fabaceae) and other desirable members of the sunflower family (Asteraceae). May lead to selection for other invasive annual grasses. Resistant biotypes have been reported for other herbicides with this mode of action, but only in Washington.
Risks	Herbicide drift. Applicator safety.
Timing	From late fall to early spring is best, when plants are in rosette stage. Can still get good control in mid-spring, but may have to use higher rates. In states other than California, a combination of 2,4-D and clopyralid (Curtail®) can be used in spring.
Best fit in strategic management plan	Very effective in the first year of a long-term management strategy. Can also be used in the second year.
<b>Picloram (Tordon™)</b>	
Advantages	Provides excellent control. Has both pre- and postemergence activity. Active in soil for at least two seasons. No injury to grasses.
Disadvantages	Not registered for use in California.
Risks	Reported to be in groundwater in other states where it is used heavily. Herbicide drift. Applicator safety.
Timing	Best when applied in spring.
Best fit in strategic management plan	May be used in combination with biological control and perennial grass revegetation. Because of its long residual activity, it is not typically used in other integrated strategies.

yellow starthistle is necessary for long-term management. It is also important to be familiar with characteristics of the ecosystem. This can include an awareness of other species present (both weeds and desirable plants), the potential for invasion into uninfested sites in the area, impact of the management strategy on sensitive species and habitats, and ecosystem parameters such as soil conditions and rangeland types.

A coordinated effort among interested parties,

including landowners, agencies, the public, and environmental organizations, can lead to a more effective management plan. A cooperative program can eliminate duplication of effort, reduce avenues for reintroduction, consolidate equipment and labor costs, and decrease the risk of repeating previous failures. In addition, coordinated management teams can obtain cost-sharing grants to manage large infestations more effectively. This coordination is typically achieved through development of a Weed Management Area.



## Implementing a Strategic Plan

Implementing a strategic plan is the most critical stage in yellow starthistle management. This step typically requires input from weed management experts. Before any option can be employed, financial considerations must be addressed and a budget must be prepared to keep project costs within reasonable limits. Funding limitations may require prioritizing areas of greatest concern. For example, the decision to revegetate must consider direct costs (seedbed preparation, seeds and seeding, follow-up management), indirect costs (risk of failure, non-use during establishment period), and benefits (increased forage, improved ecosystem function, soil conservation) (Jacobs *et al.* 1999, Smathers *et al.* 1985).

Control options should include a site-appropriate integration of mechanical, cultural, biological, and chemical techniques. Regardless of the approach employed, annual monitoring and evaluations should be conducted to determine the adequacy of the management plan (Sheley *et al.* 1999c). Changes in the management approaches may be necessary to adjust to any unforeseen problems and improve the strategy.

A long-term commitment of three or more years usually will be necessary to deplete the weed seedbank. It is not unusual for a yellow starthistle infestation to appear more vigorous after a single year of control (Callihan and Lass 1996). It will require a significant reduction in the starthistle seedbank and an increase in seedbanks of competing species before dramatic results can be observed.

Once the desired objectives have been attained, a yearly follow-up program will be necessary to prevent starthistle reinfestation. This may involve annual hand pulling, spot herbicide treatments, or even periodic mowing or burning (DiTomaso 2000). In addition, changes in grazing practices may be required to ensure that rangeland conditions do not become susceptible to rapid reinfestation. If follow-up is not made for two to three years following a control program, the grassland will usually become reinfested in a short time.

### CLOPYRALID IN A STRATEGIC MANAGEMENT PLAN

In most circumstances, clopyralid can be an important component in a yellow starthistle management program. For example, clopyralid is often an effective first year option in a multi-year program. This is particularly true in heavily infested areas. The herbicide

can substantially reduce the starthistle population, thus depleting much of the seedbank. Because clopyralid is typically used in late winter to very early spring before starthistle seedlings and young grasses begin to compete for soil moisture, the control of yellow starthistle will result in high grass forage production during that growing season (DiTomaso *et al.* 1999b). If yellow starthistle seedling numbers in the second winter are also very high, a second year of treatment may be needed. However, in subsequent years it may be advantageous to delay the use of clopyralid or other preemergence herbicides until the extent of the problem can be evaluated. Possibly a prescribed burn, mowing or physical removal can be used instead. In some instances one or two years of control can reduce the starthistle infestation to low or even insignificant levels. When this occurs, an additional broadcast application of clopyralid or another herbicide would be unnecessary.

## Examples of Integrated Management Strategies

Each control method has its own strengths and limitations (see Table 4). However, most often a single method does not give sustainable control of a range weed. A successful long-term management program should be designed to include combinations of mechanical, cultural, biological, and chemical control techniques. There are many possible combinations that can achieve the desired objectives, but these choices must be tailored to the site, economics, and management goals. Typically, control techniques must be used in a particular sequence to be successful.

### CASE STUDY 1. COMBINATION OF HERBICIDES AND REVEGETATION WITH A PERENNIAL BUNCHGRASS

In order to develop an integrated approach for starthistle control in rangeland, an experimental project was established on a site near Yreka, California (Siskiyou County) heavily infested with yellow starthistle (Enloe *et al.* 1999a, b, 2000, 2005). The goal of this revegetation project was to develop sustainable high quality range conditions, improved wildlife habitat, and long-term starthistle control without the need for continued herbicide treatments.

In this severely degraded rangeland site, a March treatment with glyphosate and clopyralid (1, 2 or 3 years) was used to provide a window of reduced competition for the subsequent establish-

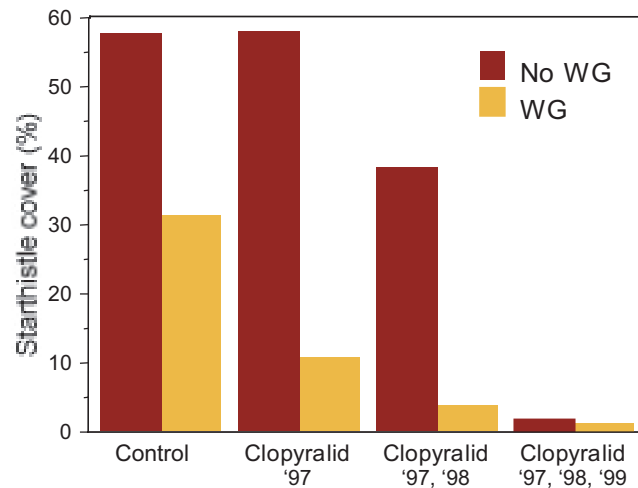
ment (March planting) of drill seeded pubescent wheatgrass ('Luna' pubescent; *Thinopyrum intermedium*) (Enloe 2002, Enloe *et al.* 2005). Roché *et al.* (1997) reported that pubescent wheatgrass was highly effective in suppressing yellow starthistle in Washington. Although not a native species, wheatgrass seed was considerably less expensive than native perennial grass seed. In addition, it provides good forage and is not considered invasive (Enloe 2002).

The study area was monitored for six years (Enloe *et al.* 2005). Clopyralid treatment significantly reduced yellow starthistle, and glyphosate gave control of the annual grasses. This combination allowed pubescent wheatgrass to establish with a single year of treatment. Once pubescent wheatgrass seedlings survived the first year, additional applications of clopyralid did not improve their establishment. In the absence of any treatment with clopyralid and glyphosate, pubescent wheatgrass establishment was very limited. Untreated plots developed very poor stands over the six-year period, with slightly less than 10% cover (Enloe *et al.* 2005).

Once the wheatgrass was established, it provided near complete suppression of yellow starthistle (as well as other exotic annual grasses and forbs) without the need for additional control methods. Treatments with clopyralid alone (without reseeding wheatgrass) gave good control of yellow starthistle, but the plant community was susceptible to invasion by noxious annual grasses. In particular, downy brome (*Bromus tectorum*) was released from competition with starthistle and increased dramatically. Within a couple of years after the final herbicide treatment, the site reverted to yellow starthistle (Enloe *et al.* 2005).

In this same project, Enloe (2002) also considered the reintroduction of grazing. He found that the best timing for grazing was early in the season prior to flower development, when the perennial grass was least susceptible to damage. Unfortunately, this was also the time that yellow starthistle was least susceptible to damage. Grazing the perennial grass when it was most susceptible (also the susceptible timing for yellow starthistle) reduced the competitiveness of the perennial grass and increased the starthistle population.

The results of this study illustrate the use of an integrated approach for the long-term management



**Fig. 22. Effectiveness of clopyralid with revegetation.** In this study, clopyralid in combination with revegetation with wheatgrass (WG) produced the greatest reduction in late season yellow starthistle cover (Enloe *et al.* 2005).

of yellow starthistle. This approach is compatible with the survival of yellow starthistle biocontrol agents, which are already widespread in the state.

#### CASE STUDY 2. LONG-TERM MANAGEMENT USING PRESCRIBED BURNING, CLOPYRALID AND BIOCONTROL

Fire has been an important factor in the development and continuance of most grassland systems. In addition, it can be an effective tool for managing yellow starthistle infestations, as well as enhancing native plant diversity and increasing the survival of competitive native perennial grasses. However, repeated use of burning can negatively impact air



**GPS-guided helicopter application.** A helicopter with on-board GPS was used to accurately apply clopyralid in a long-term management study at Fort Hunter Liggett. (Photo: A. Hazebrook)



quality and compromise establishment of biocontrol agents. Prescribed burns take a great deal of coordination and can lead to catastrophic wildfires should they escape containment. Consequently, it is unlikely that ranchers or land managers would be able to obtain permits and utilize local fire departments to conduct repeated burnings over multiple years.

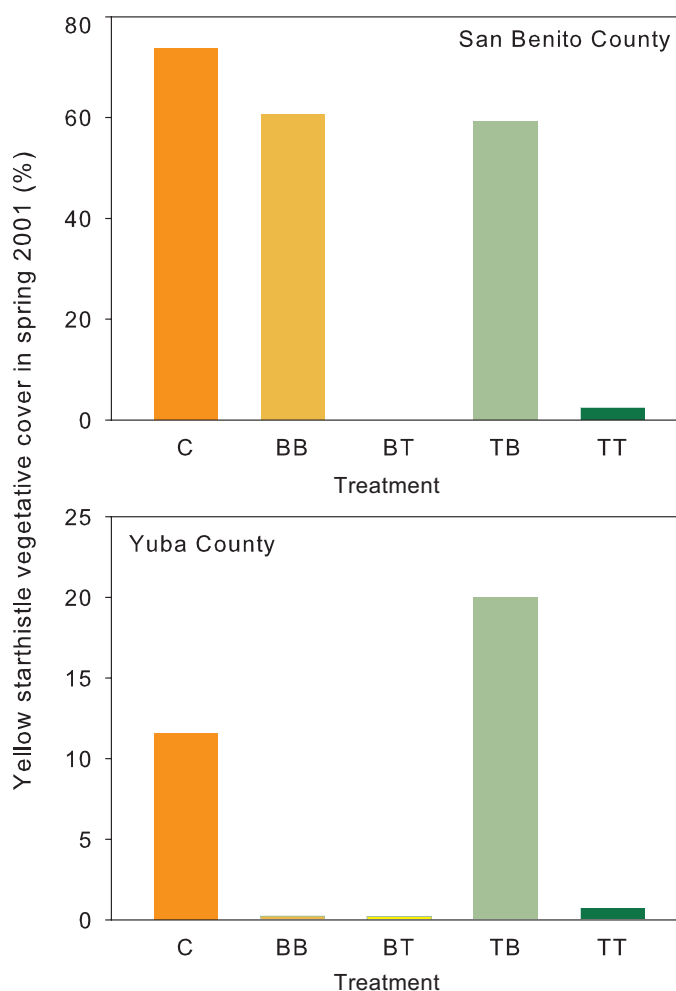
The continuous use of clopyralid also can have undesired outcomes. For example, legume species are important components of rangelands, pastures, and wildlands; repeated clopyralid use over multiple years may have a long-term detrimental effect on their populations. Another possible drawback to the continuous use of clopyralid is the potential to select for other undesirable species, particularly annual grasses such as medusahead (*Taeniatherum caput-medusae*) or barb goatgrass (*Aegilops triuncialis*). Furthermore, the potential exists for the development of resistance to clopyralid if the herbicide is used year after year.

As a result, studies were designed to evaluate an integrated strategy combining clopyralid and prescribed burning for management of yellow starthistle and improvement of rangeland function (DiTomaso *et al.* 2003a). Surprisingly, the order in which the two techniques were used gave very different responses. When clopyralid was used in the first year and a prescribed burn was used in the second year, the population of yellow starthistle in the year after the two treatments was higher than in the untreated areas. This was presumably due to stimulation of yellow starthistle germination in fall and winter after the burn. In contrast, a first year prescribed burn followed by a second year clopyralid treatment gave nearly complete control of yellow starthistle in the year after the last treatment. Thus, the stimulation in starthistle seed germination after the burn probably depleted the seedbank more rapidly, and those seedlings were controlled by the subsequent clopyralid treatment. This strategy may reduce the number of years necessary to intensively manage yellow starthistle and allow land managers to transition into a follow-up management program sooner.

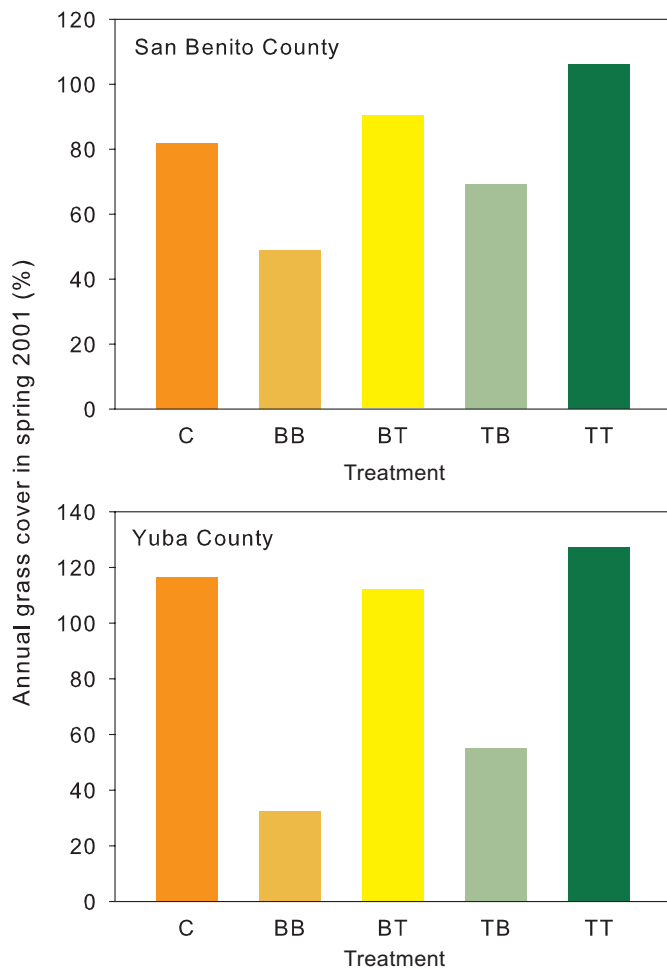
An additional benefit of incorporating a prescribed burn into the yellow starthistle management program is the control of noxious annual grasses. In this study (DiTomaso *et al.* 2003a), both ripgut brome and medusahead were dramatically

reduced when a burn was included in the management strategy.

This integrated approach was also tested in a large-scale management project at Fort Hunter Liggett (FHL), a 165,000-acre military installation in Monterey County, California. At least 12% of FHL is covered by grassland vegetation (Jones and Stokes 1992) and is dominated by annual non-native grasses and forbs (Osborne 1998). Yellow starthistle has increased dramatically over the past two decades, expanding its range along riparian corridors and in grasslands and woodlands. It interferes with military training, recreational activities, and livestock and wildlife grazing at the installation.



**Fig. 23. Effectiveness of burning integrated with clopyralid.** Yellow starthistle cover was greatly reduced by a first year burn followed by a second year clopyralid treatment, but reversing the treatments produced poor results (DiTomaso *et al.* 2006). C = untreated control, BB = burned for two years, BT = burned first year & clopyralid second year, TB = clopyralid first year & burned second year, and TT = treated with clopyralid for two years.



**Fig. 24. Effect of burning + clopyralid on annual grasses.** In integrated burn/clopyralid trials at two sites, annual grass cover was reduced in the year following a burn (DiTomaso et al. 2006). See Fig. 23 for abbreviations.

In addition, the weed has displaced native plants and decreased animal habitat. In 1999, it was estimated that approximately 20,000 acres (or 12%) of FHL land was infested with yellow starthistle.

The integrated control methods used in the small plot studies (e.g., herbicide application and prescribed burning) were applied to several infested areas of FHL ranging in size between 30 and 300 acres over a period of two to three years (1999-2002) (Torrence et al. 2003a, b, Miller 2003). Following the burning or herbicide treatments, follow-up maintenance was used in those areas that had received at least two consecutive years of treatment. In addition, hairy weevils were introduced in several areas of the base to assist in the long-term maintenance program, and populations were monitored throughout the study (Joley et al. 2002).

In one yellow starthistle-infested site at FHL, a first year prescribed burn (1999) was followed by a fixed-wing aerial application (2000) of 6 oz product/acre clopyralid. In the following year (2001) a helicopter was used to aerially broadcast clopyralid at the same rate. These treatments gave over 99% control of yellow starthistle in 2002. The second herbicide treatment was probably unnecessary in this situation, as 98-99% control of yellow starthistle was achieved even after the first application (2000).

After three years of treatment, a follow-up maintenance plan was implemented to prevent any potential reinfestation. A 5-acre subplot was designated for hand pulling. Yellow starthistle plants were present but relatively sparse (approximately 88 plants/acre). Maintenance in the 5-acre subplot required 35 minutes. A total of 408 plants were hand-pulled. A first year maintenance cost estimate was estimated at \$5.25/acre, based on three technicians each paid \$15/hour (Miller 2003).

It is useful to note failures in management techniques. For example, in another yellow starthistle-infested site on FHL, a first year burn (1999) was followed by a second year (2000) aerial application of clopyralid (8 oz product/acre). The summer evaluation in the following year (2001) indicated that yellow starthistle control was approximately 98% in



**Fig. 25. Effectiveness of burning followed by clopyralid treatment.** Results from integrated burn/clopyralid trials were confirmed in large-scale applications at Fort Hunter Liggett (Miller 2003). Treated fields showed few if any yellow starthistle plants.

this site. However, in the third year (summer 2001) the site was burned again. In the year following the burn, starthistle control decreased to 95%. When a follow-up maintenance program using handpulling was employed in 2002, the estimated population of yellow starthistle was 25.8 plants/m<sup>2</sup>. In contrast to the \$5.25 cost per acre previous described in the successful management area, this site required an estimated 395 hours an acre to handpull the remaining yellow starthistle plants, with estimated costs at \$4819/acre (Miller 2003). The second burn was counterproductive.

This project demonstrated that yellow starthistle populations could be controlled with two years of properly timed, intensive management. This integrated management program is now used on more than 4,500 acres of FHL (Anonymous 2003). The most successful long-term, large-scale yellow starthistle control treatment was to follow a first year prescription burn with a broadcast clopyralid application treatment the next year. Following this successful intensive management regime, yellow starthistle seeds in the seedbank should decline as seed production is prevented each year.

#### **CASE STUDY 3. USING CLOPYRALID IN COMBINATION WITH BIOCONTROL AGENTS**

Using another integrated approach, Pitcairn *et al.* (1999a, 2000a) hypothesized that combining clopyralid applications with insect biocontrol agents might provide for more effective long-term control of yellow starthistle. An initial clopyralid application would reduce plant density and the seed bank. In subsequent years, biocontrol insect attacks on escaped plants should slow the rate of reinfestation by impacting the few seed heads available. A field test of this hypothesis found that following a clopyralid treatment in early 1997, biocontrol agents suppressed seed production by 76% in 1997 and 43% in both 1998 and 1999 (Pitcairn and DiTomaso 2000). In addition, the reduction in starthistle resulting from the herbicide treatment did not affect the ability of the insects to attack the seed heads of escaped plants. It is hoped that seed destruction by established biological control agents can delay reinfestation by 4-6 years and thereby reduce the need for continuous herbicide treatments. This would lower the economic cost of long-term management of yellow starthistle.

#### **CASE STUDY 4. MOWING OR GRAZING WITH REVEGETATION**

Thomsen *et al.* (1996a, 1997) developed a long-term integrated approach for yellow starthistle control using combinations of grazing, mowing, and clover plantings. For example, seeding with subterranean clover (*Trifolium subterraneum*), grazing three times, and mowing once at the early flowering stage resulted in 93% reduction in yellow starthistle seed production and a dramatic increase in standing dry matter (Thomsen *et al.* 1996a). In another experiment, two timely repeated mowings combined with a subterranean clover planting gave nearly complete control of yellow starthistle (Thomsen *et al.* 1997).

#### **OTHER EXAMPLES**

In a revegetation effort along a yellow starthistle-infested canal and roadside, the first step was to intensively manage starthistle (Brown *et al.* 1993, Thomsen *et al.* 1994b). The second step was to reseed with competitive, deep-rooted native perennial grasses. In the final stage, native broadleaf forbs such as California poppy and lupines were seeded into the system.

In Australia, the technique of applying sub-lethal applications of 2,4-D amine in combination with heavy stocking rates of grazing sheep is a long-accepted integrated approach for control of thistles (Dellow 1996).

#### **Conclusion**

Research by many scientists and land managers during the past 20 years has demonstrated that a variety of weed control techniques can be effective on yellow starthistle management. These include the mechanical, cultural, chemical and biological tools described in this report. However, it is clear that integrated approaches using combinations of these methods can be more effective for long-term suppression of yellow starthistle and for recovery of more functional and productive ecosystems. As in any weed management program that seeks to deplete a plant's seedbank and to prevent new seed recruitment from off-site sources, managers must recognize that any control tool or combination of techniques may still require subsequent follow-up to prevent re-invasion of yellow starthistle or another invasive plant. This report aims to give land managers the benefit of currently accumulated knowledge when they work to design effective programs to control one of our most serious invasive plants.