Fire Controls Yellow Starthistle (*Centaurea solstitialis*) in California Grasslands.

Burns timed to prevent seed maturation have nearly eliminated this exotic, and increased natives within test plots at Sugarloaf Ridge State Park, CA

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Yellow starthistle (*Centaurea solstitialis*) first invaded open grassland sites within the San Francisco Bay Area sometime before 1869 when a specimen was collected in Oakland. Native to Eurasia, it was apparently introduced in association with livestock use during the Mexican and post-mission period (Maddox and Mayfield 1985). A fast-growing, aggressive annual herb, yellow starthistle reaches a height of 0.3 to 2 meters, and often grows in dense stands, mainly in grasslands. It rapidly crowds out less-aggressive natives. At present it is the most widely distributed weed in California, infesting over 4 million hectares, or approximately 10 percent of the total surface area of the state. In addition, it has infested large areas in Washington, Oregon and Idaho, and is present in smaller numbers scattered throughout much of the United States and Canada (Maddox 1981). Infestations of yellow starthistle can have devastating effects on both natural and agricultural ecosystems under certain conditions. It is of economic importance where it invades grainfields, orchards and vineyards, pastures, roadsides and wastelands. In pasture lands, for example, starthistle can lower forage yield and quality, interfere with grazing, cause problems in harvesting of forage and crops, and cause "chewing disease" in horses (Maddox 1981). In natural areas, yellow starthistle reduces wildlife forage and habitat, displaces native grassland plants and decreases native plant and animal diversity (Sheley and Larson 1994).

Sugarloaf Ridge State Park is located in Sonoma County, in the northern Coast Range near Santa Rosa. It contains a complex mosaic of vegetation types which include chaparral, mixed evergreen forest, woodland-savanna, grassland and conifer forest. Open grasslands occupy approximately 280 hectares of the park's 1,080 hectares. Although these areas have been heavily influenced by livestock grazing and related agricultural practices since before 1900, they have considerable value as examples of the now extremely rare native California grassland. The current grassland complex of the park includes both a native perennial component dominated by purple needle grass (*Nassella pulchra*), blue wildrye (*Elymus glaucus*), and creeping wildrye (*Leymus triticoides*), and a variety of annual European grassland species dominated by ripgut brome (*Bromus diandrus*), soft brome or blando brome (*Bromus hordeaceus*), silver European hairgrass (*Aira caryophyllea*), wild oats (*Avenafatua*), and little quakinggrass (*Briza minor*). Of special concern are scattered populations of the rare California endemic Sonoma ceanothus, *(Ceanothus sonomensis)* found growing on serpentine outcrops along the grassland and chaparral margins at Sugarloaf Ridge. This species appears on the

California Native Plant Society (CNPS) List 1B of plants considered rare, threatened or endangered in CA and elsewhere.

There are good reasons, including the dramatic changes in the forests and grasslands during the past century, to suspect that the invasion of areas like Sugarloaf Ridge State Park by yellow starthistle is due at least in part to dramatic reductions in fire frequency since the early 1800's. Finney and Martin (1992) surveyed the history of fire in redwoods at Annadel State Park, 16 kilometers northwest of Sugarloaf Ridge. Using fire scars on old redwoods, they determined that the historical fire frequency within the Sonoma Valley varied from 6.2 to 20.9 years, with intervals of between two and 10 years being most common.

Prior to European settlement in the mid-19th century, these fires would have been started by lightning, but probably more often by the indigenous people of the area, who apparently used fire systematically to maintain the open character of the vegetation. Indeed, since 1939, only two lightning-caused wildfires have been recorded in the Sonoma Valley, suggesting that most fires in the pre-settlement period were set by humans, in most cases deliberately. This undoubtedly had a profound influence on the composition and structure of the vegetation of the area, resulting in a variety of plant communities that depend on burning to arrest succession, reduce competition, remove thatch, enrich the soil, and scarify seeds (Biswell 1989).

Similarly, the reductions in fire frequencies due to fire suppression activities have had a profound influence on the plant and animal communities of the park. One striking effect is the invasion by Douglas-fir (*Pseudotsuga menziesii*) in large areas where frequent fires formerly limited its spread (Barnhart, McBride and Warner 1996). In general, biodiversity seems to be declining in the park (Whatford 1994), and there is evidence that protection from fire has promoted invasion by a number of troublesome exotics, including yellow starthistle.

Experimental Burns

In 1984, State Park staff members identified yellow starthistle as a serious invasive component of the vegetation at Sugarloaf Ridge. Yellow starthistle had spread rapidly within the park's 280 hectares of grassland since the early 1970's, and had become dominant in many areas.

In 1993, we made our first systematic attempt to control yellow starthistle in the park's infested grasslands. The key to this program was reintroduction of fire, carefully timed, to take advantage of a vulnerable phase in the weed's life cycle. Our previous experience with this plant suggested that seed production can be prevented by a burn, early in the summer, just as the plants begin to flower. Fire, moreover, seems to stimulate germination of seed in the soil, suggesting that a succession of annual burns over a period of several years might rapidly deplete both the seedbank and standing populations of yellow starthistle.

To test this idea, we conducted an initial burn on a 12-hectare unit, called the Pony Gate Compartment, in July, 1993 (July is in the middle of our dry season). The vegetation on this site was predominantly yellow starthistle and annual grasses, with a substantial component of native perennial herbs and grasses. The vegetation carried the fire well, with flame lengths of 0.6 to 2 meters and a temperature of 21 OC (600F), 54 percent relative humidity, and wind at 3-8 kilometers per hour. A steady backing fire was carried downslope against the wind in most locations. An adjacent 4-ha site was left unburned as a control.

The following July (1994) we burned this unit a second time, under similar conditions but with lower relative humidity (30 percent). On this occasion, a heavy dew reduced the fuel consumption early in the burn, but both fuel consumption and destruction of yellow starthistle increased as the dew evaporated.

Following this burn we found one area, in a severely eroded gully, where there was insufficient grass and fine fuel to carry fire and where yellow starthistle cover was approaching 100 percent. In an attempt to remedy this, we broadcast sowed seeds of two non-invasive, non-native annual grasses, zorro fescue (*Vulpia myuros*) and blando brome, on this site in early December, during the beginning of the wet season.

During our third burn, under similar conditions, (relative humidity - 54 percent), the fire carried well, though both flame length and rate of spread were considerably reduced, in part because of elimination of fine-fuel accumulations by previous fires. The fire killed virtually all standing starthistle plants. Fire spread and intensity were reduced under trees, where grasses were still green. During the July 1995, burn we also burned an additional 62 hectares.

Because of speculation that the heat of a fire may stimulate seed germination of Sonoma ceanothus, the burn was planned to include several of these plants. It is generally recognized that *Ceanothus* seeds germinate vigorously following fire (Howald, personal communication), and we wanted to see whether our burns would promote spread of this species.

All burns were conducted in early to mid-summer because fall burning is not appropriate for yellow starthistle control. Burning must occur after the annual and perennial grasses have cured and set their seeds, but before yellow starthistle seed has matured. An additional advantage of early or mid-summer burns is that they reduce the risk of fire to adjacent urban areas just at the time when risk is the greatest.

Burning conditions for all three years were typical for this area. Experience has shown that we can burn safely with temperatures as high as 32'C (891F), and relative humidity as low as 25 percent. Although we used the computer model BEHAVE (Burgen and Rothermel 1984) in planning the burns, the behavior of the fire is extremely variable and site-specific. We have found that models provide only a rough idea of the way a fire will behave, and the effects it will have on the vegetation. The nature of fuels within the park is extremely variable, and site-specific burn prescriptions are always necessary to ensure that a prescribed fire will be both safe and effective.

Results

Although the 1993 burn was not hot enough to completely destroy all starthistle plants, nearly all plants not consumed by the fire were killed by the heat of the burn. Yellow starthistle flowers and immature seed heads remained on these plants, but seeds did not mature and the plants did not recover or resprout. The objective of eliminating yellow starthistle seed production appeared to be fully achieved. More importantly, a dramatic decline in the starthistle populations occurred on burned sites during the first three years of this project.

We quantified our results by conducting three line transects on each of three 50m x 50m plots within each burned and unburned area, recording all plants that intersected vertical lines established at one-foot intervals along the 50-foot (15m) transects. The number of "hits" per transect provided a measure of percent cover for each species.

Data collected in May, 1995 when the weed was in the rosette stage following two consecutive annual burns showed a 90 percent reduction in yellow starthistle cover on burned plots. Even at maturity in July, following two burns in consecutive years, starthistle cover was reduced by 62 percent, while the relative cover of other forbs, particularly native species such as *Trifolium* spp., *Astragalus gambelianus, Sidalcea diploscypha, Lupinus nanus, Lotus wrangelianus,* and *Linanthus bicolor* nearly doubled. A year later, after three consecutive annual burns, starthistle cover on burned plots had fallen to only 4 percent of that on unburned control plots.

Surprisingly, perennial grass cover was also reduced on burned plots early in the season, but had increased dramatically to nearly 300 percent of cover on control plots by July. We speculate that this increase is due to a reduction in late-season competition with yellow starthistle for space and moisture during the growing season.

Burning also resulted in significant reductions in the number of yellow starthistle seeds in the seedbank. We found that the number of starthistle seeds separated from soil cores declined by 74 percent following two burns and by 99 percent relative to controls following the third burn in 1995 (Table 1). Seedling counts taken the spring following seed-counts declined at about the same rate. Fire seems to be the critical factor here, since others have reported that it takes approximately 10 years to deplete the yellow starthistle seedbank by 99 percent on sites where seed production has been eliminated (Callihan, Prather and Northam 1993).

Table 1.
Yellow Starthistle Seedbank and Seedling Counts Following Burns

Burn Sequence	Seeds per square meter; 5 cm deep (percent of unburned)	Seedlings per square meter (percent of unburned)
Unburned	10,000	1,400
After 1 burn	2,600 (26)	265 (19)
After 3 burns	52 (0.5)	5 (0.4)

As is generally the case in grassland burning, our fires burned unevenly, creating a patchwork of severely and less severely burned areas on a scale of a few meters in size. Although we did not measure the fire intensity, the dramatic and uniform reduction in starthistle cover and seedbank over the entire area indicates that fire intensity is not a critical factor in the reduction of yellow starthistle. What is more important is burning during the appropriate stage of plant development to prevent seed production. Burning should occur late in the floral bud stage, when less than about 10 percent of the flower buds have opened. Burning after the flowers are well-developed may not entirely prevent seed maturation, since plants typically remained green and fleshy for up to four days following scorching. Complete destruction of starthistle plants by fire is not crucial. However, sufficient heat is required to scorch the foliage and stem-girdle the plants. Heat may also be critical for seedbank depletion, since it may stimulate seed germination. (The average temperature at the soil surface during both our first-and third year burns was measured using Tempil pellets at between 201 and 205°C).

In addition to declines in starthistle, we have also documented increases in the abundance and diversity of native plant species on burned sites. Altogether, 15 species, including eight native California forbs, increased on the burned sites during the three years of the project. On the other hand, all six of the species that increased on unburned plots were exotics: *Bromus diandrus*, *Bromus hordeaceus*, *Lolium perenne*, *Geranium carolianum,* and *Lathyrus cicera*. Overall, increase in cover by native species ranged from 11 percent on the unburned site to 25 percent on the site burned two consecutive years.

Although other factors may also be involved, it is possible that reduced yellow starthistle competition, increased light, and higher soil temperatures in the spring may contribute to the recovery of native plant species following burning. Photosynthetically active radiation (PAR) was measured at the soil surface using a line sensor. The light measurements as well as soil temperature at and near the soil surface indicated that the unburned plots contained noticeably more thatch, with a corresponding reduction in light penetration to the soil surface, and significantly lower soil temperatures than the burned plots.

The effects of burns on the native Sonoma ceanothus were puzzling. The fires killed most of the mature plants, but seemed to stimulate germination of seeds, since the year following each burn we found a number of seedlings under fire-killed plants, but none under or around unburned plants. Quantification of these interesting observations might help clarify the effect of fire on this rare native shrub.

Discussion

The current management strategy for the park is to continue with annual burns within the 62-hectare plot and an additional 85-hectare burning compartment. This burning was accomplished in early July, 1996, but the data from the most recent work has not yet been analyzed. We plan to leave the Pony Gate compartment unburned during the next three years to monitor starthistle recolonization there. The results will help park managers develop a cost-effective strategy for controlling yellow starthistle.

Ultimately, the management program will include herbicidal and mechanical control in addition to burning. Prescribed burns appear to be a very effective tool for controlling yellow starthistle - in most park locations, but cannot be carried out on sites near sensitive facilities or along roadsides or on sites lacking sufficient fine fuel to carry fire. In a few areas we will use a flame thrower to control roadside plants that escape scorching during broadcast burns. In addition, fuel can be provided for large areas dominated by yellow starthistle by sowing grass seed the winter prior to a prescribed burn. Ideally, this would be fast-growing native perennial species such as purple needle grass and blue wildrye, which occur on site, but time and budget considerations may make this difficult. In our experience, zorro fescue and blando brome. both non-native annuals, have been effective and have caused no problems in years following burns. On our sites, native species are recovering quickly as starthistle declines.

The value of integrating management strategies was demonstrated in the gully area, where the original starthistle cover had been nearly 100 percent. In addition to fire and reseeding with grasses, we treated yellow starthistle seedlings with a broadleaf selective herbicide, Garlon 4 (triclopyr). A dense cover of both introduced annual grasses and several native perennial grasses now dominate this site.

Herbicide application has been very effective within the 4-ha campground area at Sugarloaf Ridge. A private contractor applied three separate herbicide treatments there during winter and spring, 1994, and early winter, 1995. The broadleaf selective herbicide, Garlon 4 (triclopyr), was applied alone in spring and along with a broadleaf-selective preemergent compound, Telar (chlorsulfuron), during the winter. The meadows were mowed during the summers of 1994 and 1995 after the perennial grasses set seed. Isolated yellow starthistle plants were hand-pulled during the summer of 1994 and 1995. Although the results of this treatment have been excellent, burning is clearly the preferred management technique for the reduction of yellow starthistle on larger areas such as those we are working with at Sugarloaf Ridge. In this way, native plant restoration can be accomplished economically, using a natural process. Since these results demonstrate a remarkable reduction in yellow starthistle seedbank following burning, we burned the campground meadows during the 147 ha prescribed burn conducted during early July, 1996. We also will continue to apply selective herbicides to control yellow starthistle in areas where burning is not appropriate, or to prevent seed production in isolated yellow starthistle patches that escape the fire in the burn sites.

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