

YELLOW STARTHISTLE INFORMATION
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INTRODUCTION AND SPREAD

Initial introduction

The center of origin of yellow starthistle (*Centaurea solstitialis* L.) is believed to be Eurasia, where it is native to Balkan-Asia Minor, the Middle East and southcentral Europe (Maddox 1981). Its introduction in North America probably occurred sometime after 1849 as a seed contaminant in Chilean-grown alfalfa seed, also known as Chilean clover (Gerlach et al. 1998). A detailed review of the introduction and spread of yellow starthistle is described by Gerlach (1997a, b). Historical records indicate that alfalfa was first introduced to Chile from Spain in the 1600s and from Chile to California at the time of the gold rush. Despite its origin from Spain, the source of alfalfa in California before 1903 was only from Chile. After 1903, it was likely that alfalfa was also introduced from Spain, France, Italy, and perhaps Turkestan. In the early period of introduction farmers often reported that alfalfa seed was contaminated with weed seed, presumably this included yellow starthistle.

Spread and current distribution in California

It has been speculated that the spread of yellow starthistle in California occurred through a multiple step process (Gerlach 1997a, b). The first report of alfalfa cultivation was near Marysville, California, in 1851. Before the 1870's alfalfa was grown primarily along river levees near Sacramento, Marysville and San Francisco. These areas were characterized by deep, well-drained soils and easy access to drinking and irrigation water. Both animal and alfalfa forage were distributed only short distances. As a result, yellow starthistle infestations that accompanied alfalfa stands were fairly localized. From 1870 to about 1905 much of the surrounding areas previously consisting of dry-farmed wheat and barley fields were converted to both dryland and irrigated alfalfa fields. During this period, yellow starthistle established as dense local populations in these areas and along adjacent roadsides. The use of tractors and other equipment spread starthistle seed to other locations, including grain fields. Gerlach (1997a) indicates that yellow starthistle in California probably decreased between 1920 and 1940, most likely due to changes in crop production techniques and the widespread use of inorganic herbicides, such as sodium arsenite and sodium chlorate, along roadsides. However, around the 1930's or 1940's yellow starthistle began to invade the foothill grasslands. Thus, yellow starthistle now became a part of the grazing/weed system. By 1958, the weed was estimated to have invaded over 1 million acres of California (Maddox and Mayfield 1985), much of this in range or grasslands.

Since the 1960's three factors greatly contributed to its further spread, including an extensive road building program, increased suburban development, and an expansion in the ranching industry. These factors all contributed to the rapid and long-range dispersal of seed and the establishment of new satellite populations (Gerlach et al. 1998). Over the past 40 years, yellow starthistle has spread exponentially to infest rangelands, native grasslands, orchards, vineyards, pastures, roadsides, and wasteland areas. Infestations reached nearly 8 million acres in California by 1985 (Maddox and Mayfield 1985). Today, it is thought to have spread to over 15 million acres in California, and can be found in 56 of the 58 counties in California (Pitcairn et al. 1998b).

Spread and distribution the United States and the world

Introduction of yellow starthistle to other western states occurred in the 1870's and 1880's (Gerlach 1997a, Roche 1965). The first report outside of California was in Bingen, Washington (Sheley et al. 1999b). These first introductions likely occurred through contamination of alfalfa seed (Gerlach 1999a). During the 1920's, yellow starthistle expanded rapidly in grasslands within the Pacific Northwest states. By the mid-1980's it was estimated to occupy 280,000 acres in Idaho, 135,000 acres in Oregon, and 148,000 in Washington (Sheley et al. 1999b). In 1989, Callihan et al. estimated that yellow starthistle continues to invade 7,000 to 20,000 acres of rangeland per year in the west. By 1994, Sheley and Larson (1994c) estimated the rate of spread to be twice as rapid (15,000 to 50,000 acres per year).

When given a list of 15 rangeland weeds, a 1982 survey of 249 farmers and ranchers in Idaho indicated that yellow starthistle was the most important weed problem, with 53% of the respondents reporting it to be a serious problem. In a similar survey conducted in 1988, yellow starthistle also ranked as the number one problem, with 63% considering it serious (Carlson et al. 1985, 1990). In 1982, 23% of those surveyed indicated that yellow starthistle infested over 30% of their land. By 1988, however, 47% of the respondents estimated that the level of infestation was over 30%.

Today, yellow starthistle can be found in 23 of the 48 contiguous states, extending as far east as New York (Maddox et al. 1985). It has also extended into Canada from British Columbia to Ontario. Today yellow starthistle can be found in most of the temperate areas around the world (Maddox et al. 1985).

Mechanisms of spread

Human activities are the primary mechanisms for the long distance movement of yellow starthistle seed. Seed is transported in large amounts by road maintenance equipment and on the undercarriage of vehicles. The movement of contaminated hay and uncertified seed are also important long distance transportation mechanisms. Once at a new location, seed is transported in lesser amounts and over short to medium distances by animals and humans. The short, stiff, pappus bristles are covered with microscopic, stiff, appressed, hair-like barbs that readily adhere to clothing and to hair and fur. The pappus is not an effective long distance wind dispersal mechanism as wind dispersal moves seeds only a few feet (Roché 1992).

IMPACT

Rangelands

Although no economic assessments have been conducted for yellow starthistle, millions of dollars in losses probably occur from interference with livestock grazing and forage harvesting procedures, and lower yield and forage quality of rangelands (Callihan et al. 1982, Roché and Roché 1988). Because of the spiny nature of yellow starthistle, livestock and wildlife avoid grazing in heavily infested areas. Thus, yellow starthistle can greatly increase the cost of managing livestock. Although the nutritional component of yellow starthistle leaves is highly digestible by ruminants during the growing season (Callihan et al. 1995), its nutrient value declines as the plants mature. Yellow starthistle in the pre-spiny stage contains between 8 to 14% protein (Thomsen et al. 1990). However, an analysis of the nutritional status of cattle manure in the fall indicated that yellow starthistle-infested pastures contain considerably less crude protein and total digestible nutrients compared to uninfested pastures (Barry 1995).

Other impacts

In addition to rangeland, pastures and grasslands, yellow starthistle is the most important roadside weed problem in much of central and northern California and has, on occasion, caused problems in dryland cereals, orchards, vineyards, cultivated crops, and wastelands (Maddox et al. 1985). It can also reduce land value and reduce access to recreational areas (DiTomaso et al. 1998, Roché and Roché 1988). In addition, starthistle infestations can reduce wildlife habitat and forage, displace native plants, and decrease native plant and animal diversity (Sheley and Larson 1994a). Dense infestations not only displace native plants and animals, but also threatening natural ecosystems and nature reserves by fragmenting sensitive plant and animal habitat (Scott and Pratini 1995). A related species, *Centaurea melitensis* (tocalote), significantly reduces the seed production of the endangered plant species *Acanthomintha ilicifolia* (E. Bauder unpublished data) and yellow starthistle invasions on the Agate Desert Preserve in southwest Oregon threatens *Lomatium cookei*, a globally rare plant species (Randall 1994).

Water consumption

Recent studies indicate that yellow starthistle significantly depletes soil moisture reserves in annual grasslands in California (DiTomaso et al. 2000a, Dudley 2000) and in perennial grasslands in Oregon (Borman et al 1992). Because of its high water usage, yellow starthistle threatens both human economic interests as well as native plant ecosystems (Dudley 2000). It was recently acknowledged by the State Water Resources Control Board that control of weeds could significantly conserve water. Based on a conservative estimate of the weeds coverage in the Sacramento River watershed, Gerlach estimated (Dudley 2000) that yellow starthistle may cause an annual economic loss of \$16 to \$56 million in water conservation costs alone.

Toxicity to horses

Numerous reports have characterized the toxic effect of yellow starthistle on horses (Cheeke and Shull 1985, Cordy 1978, 1954a, b, Kingsbury 1964, Larson and Young 1979, Martin et al. 1971, McHenry et al. 1990, Mettler and Stern 1963, Panter 1990, 1991, Young et al. 1970). When ingested by horses, yellow starthistle causes a neurological disorder of the brain called nigropallidal encephalomalacia or “chewing disease”. Continued feeding results in brain

lesions and mycosal ulcers in the mouth (Kingsbury 1964). There is no known treatment for horses that have been poisoned by yellow starthistle. In most cases the animals will die from starvation or dehydration (Panter 1991).

The poisoning is a chronic condition affecting the horse primarily after the animal has ingested fresh or dried plant material over an extended period, typically a 30 to 60 day period, at cumulative fresh weight of 60 to 200% of the animal's body weight (Panter 1990, 1991). Cheeke and Shull (1985) reported the lethal dose to be 2.3 to 2.6 kg yellow starthistle per 100 kg of body weight per day. The clinical signs of poisoning include drowsiness, difficulty in eating and drinking, twitching of the lips, tongue flicking, and involuntary chewing movements. The peak months of poisoning are mid-summer (June-July) and more importantly mid-fall (October-November) (Cordy 1954a, b, 1978). The summer peak is associated with the rapid growth phase following spring and the second peak is likely due to autumn rainfalls that stimulate growth of plants surviving through the summer.

Yellow starthistle poisoning is generally most dangerous when it is the only feed available or when it is a significant contaminant of dried hay. In some cases, however, horses acquire a taste for yellow starthistle and seek it out even when other forage is available (Panter 1991). In northern California in 1954, it was estimated that at least 100 cases of horse poisoning by yellow starthistle occurred annually (Cordy 1954b). Because the toxicity and identification of starthistle is better understood today, veterinarians and researchers note that cases of yellow starthistle poisoning in horses are now relatively uncommon (Seagall, pers. comm.).

The symptoms of yellow starthistle poisoning resemble Parkinson's disease in humans (Panter 1991). Because of this similarity, it has been suspected that repin, a sesquiterpene lactone isolated from yellow starthistle, may be responsible for the symptoms in horses (Akbar et al. 1995, Hamburger et al. 1993, Merrill and Stevens 1985). Repin has been shown to cause neurological disorder in other animals (Robles et al. 1998). This compound is also found in Russian knapweed (*Acroptilon repens*) (Cassady et al. 1979), which is also known to poison horses (Young et al. 1970). In another study, however, researchers provided evidence suggesting that the amino acids aspartate and glutamate may also be involved in the toxic effects of yellow starthistle on horses (Roy et al. 1995). These amino acids occur at high concentrations in starthistle and have been shown to exert neurotoxic properties in animals. The investigators suggested that the neurologic disorder in horses following heavy ingestion of yellow starthistle may be caused by a combination of these and other neurotoxins reported to occur in starthistle.

Interestingly, it appears that only horses are affected by ingestion of yellow starthistle. Even mules and burros seem to be unaffected. However, all grazing animals can sustain damage to their eyes from the plant's long sharp spines (Carlson et al. 1990).

Bee industry

Not every aspect of yellow starthistle is detrimental. The weed is regarded as an important honey source plant in California (Edwards 1989, Goltz 1999). In 1959, there were about 150,000 bee colonies that utilized yellow starthistle as a source of pollen and nectar. At that time the estimated the value of honey from yellow starthistle was between \$150,000 and \$200,000 annually (Maddox et al. 1985).

BIOLOGY AND ECOLOGY

Yellow starthistle is a winter annual widely distributed in the Central Valley and adjacent foothills of California. It is currently spreading in mountainous regions of the state below 7,000 ft and in the Coast Ranges, but is less commonly encountered in the desert, high mountains and moist coastal sites. It is typically found in full sunlight and deep, well-drained soils, where annual rainfall is between 10-60 inches.

Taxonomy and identification

Of the 12 species of *Centaurea* in California, all are non-native and 9 have purple to white flowers. The three yellow flowered species include *Centaurea solstitialis* (yellow starthistle), *Centaurea melitensis* (tocalote, Napa or Malta starthistle), and *Centaurea sulphurea* (Sicilian starthistle). In addition to having yellow flowers, these three species also have long sharp spines associated with their flowerheads. The Jepson Manual (1993) separates the three species by the following key.

Corolla generally >25 mm	<i>Centaurea sulphurea</i>
Corolla generally 10-20 mm	
Central spines of main phyllaries 5-10 mm	<i>Centaurea melitensis</i>
Central spines of main phyllaries 10-25 mm	<i>Centaurea solstitialis</i>

For a more detailed description of the identification and distribution of these three species double click on the highlighted words in the parentheses (yellow-flowered *Centaurea* fact sheet). Photos of seedlings, bolting plants, flowering plants, flowerheads, and seeds (achenes) can also be viewed. In other western states, *Centaurea macrocephala* (bighead knapweed) also has yellow flowers but does not have long sharp spines on the flowerheads (Roché 1991). Roché et al. (1991) and Roché and Roché (1993) have published other excellent keys to the western species of *Centaurea*.

Researchers have studied a variety of yellow starthistle populations to determine if there is genetic diversity or biotype differences throughout its range. Sheley et al. (1983a, b, c) found numerous significant differences in morphological characteristics among 16 populations of yellow starthistle collected from Oregon, Washington, Idaho and California, but these differences were not correlated with location or precipitation zones. They suggested that populations of starthistle might be composed of significantly different genetic makeup. After analyzing protein bands in 13 genotypically differing populations of yellow starthistle collected in Washington, Idaho, and California, no significant differences were found (Schumacher et al. 1982).

Using allozyme electrophoretic surveys, Sun (1997) conducted more a detailed analysis of the genetic structure for 22 yellow starthistle populations from California, Washington and Idaho, including the southern and northern extremes of its distribution. Interestingly, high levels of allozyme variation occurred with populations. The level of genetic diversity was similarly high in all populations tested, with little interpopulation divergence. The author suggested that yellow starthistle was probably colonized by many genotypes in the Pacific States and that high levels of gene flow have occurred among local populations.

Reproduction

Flowering and pollination

In California, yellow starthistle typically begins flowering in late May and continues through September. There are very low levels of self-fertilization in yellow starthistle (Harrod and Taylor 1995, Maddox et al. 1996, Sun and Ritland, 1998). Thus, a significant amount of cross-fertilization insures a high degree of genetic variability within populations.

Honeybees play an important role in the pollination of yellow starthistle, and have been reported to account for 50% of seed set (Maddox et al. 1996). Bumblebees are the second most important floral visitor to starthistle flowers, but several other insects also contribute to fertilization of the ovules (Harrod and Taylor 1995).

In a study conducted by Barthell et al. (2000) on Santa Cruz Island in California, investigators found that honeybees visited yellow starthistle 33 times more than native bees. By comparison, native bees visited a native gumplant species (*Grindelia camporum*) in the same family 46 times more than honeybees. In addition, they found that when honeybees were excluded from visiting starthistle but native bees were not, the average seedhead weight of yellow starthistle significantly declined. This also supports the hypothesis that honeybees are the most important insect to yellow starthistle seed production.

Phenology of flower and seed development

On average, seedheads required approximately 21 days to progress from pre-bloom to petal abscission (Benefield et al. 2001). Flowers remained in full bloom for just over two days before they began to senesce. Senescence required an additional 14 days, with the late senescence stage requiring the longest transition time (7-9 days).

The time period from flower initiation to the development of mature viable seed is only 8 days. No germinable seeds were produced until 2% of the spiny heads had initiated flowering (Benefield et al. 2001). By 10% flowering, an estimated 100 germinable seeds were produced per 100 flowerheads. Achene production increased exponentially as percent flowering progressed. Thus, to prevent seed production, it is most practical to gauge timing of late season control practices around flower initiation, as this stage is easily recognized. Effective long-term control may be compromised if control practices are delayed too long after flower initiation, as it will allow production of viable seed. Therefore, to prevent new achene recruitment, late-season control options such as tillage, mowing, prescribed burning, and herbicides should be conducted before approximately 2% of the total spiny heads have initiated flowering.

Seed dispersal

The pappus-bearing seed are usually dispersed soon after the flowers senesce and drop their petals. However, non-pappus-bearing seeds can be retained in the seed head for a considerable period of time, extending into the winter (Callihan et al. 1993). These seed have no wind dispersal mechanism and the majority simply fall to the soil just below the parent plant. With pappus-bearing seed, the pappus is not an effective long distance wind dispersal mechanism. Roché (1991a, 1992) reported that 92% of yellow starthistle seed fall within 2 feet of the parent plant, with a maximum dispersal distance of 16 ft over bare ground with wind gusts of 25 miles/hr. By comparison, birds such as pheasants, quail, house finches, and goldfinches feed heavily on yellow starthistle seeds and are capable of long distance dispersal (Roché 1992).

Human influences, including vehicles, contaminated crop seed or hay, road maintenance, and moving livestock, can also contribute to rapid and long distance spread of the seed.

Germination and dormancy

Seed production and types

Average seed production per seedhead ranged from about 35 to over 80 achenes (Benefield et al. 2001, Maddox 1981), depending upon the site. Large plants can produce over 100,000 seeds. Several authors have suggested that the number of seedheads and achenes per seedhead can vary dramatically and are often determined by soil moisture and other soil properties (Maddox 1981, Pitcairn et al. 1997, Roché 1991a).

Yellow starthistle infestations have been reported to produce 125-250 million achenes per hectare (Callihan et al. 1992, DiTomaso et al. 1999a, Maddox 1981). Unlike most other species within the genus *Centaurea*, yellow starthistle produces dimorphic achenes, one type with a distinct pappus, and the other with a pappus either poorly developed or absent (Callihan et al. 1992). The pappus-bearing achenes are light to dark brown with tan striations throughout. By comparison, the non-pappus-bearing achenes are dark brown to black without striations. Non-pappus-bearing achenes occur in a single ring around the periphery of the head, whereas pappus-bearing achenes occur in many rings in the center of the seedhead. Development of achenes occurs centripetally, from the outer non-pappus-bearing achenes to the inner pappus-bearing achenes (Maddox et al. 1996). Of the total achenes produced, between 75% and 90% are pappus-bearing and 10% to 25% are non-pappus-bearing (Benefield et al. 2001, Maddox 1981, Roché 1965).

Time requirement for development of viable seed

Very few germinable seed were found before the late senescence stage of flower development (Benefield et al. 2001). Seedheads at the middle senescence stage or earlier contained only partially filled or unfilled seeds. Germination of both achene types significantly increased from the late senescence to the achene dispersal stage. Maddox et al. (1996) also reported a consistent increase in the mean number of germinating achenes with advancing phenological stage.

Although germinable seeds did not typically develop until the late senescence stage, eight days after flower initiation, some seed were viable even at the initial senescence stage five days after flower initiation. Consequently, to prevent significant seed production, late season management options should be conducted at very early stages of flower development.

Germination

Studies indicate that over 90% of yellow starthistle achenes are germinable one week after seed dispersal (Benefield et al. 2001, Joley et al. 1997, Roché et al. 1997, Sheley et al. 1983c, 1993). Maximum germination of yellow starthistle achenes (nearly 100%) occurred when seeds were exposed to moisture, light and constant temperatures of 10, 15, or 20 °C, or alternative temperatures of 15:5 or 20:10 °C (Joley et al. 1997, Roché et al. 1997). At temperatures above 30 °C germination was dramatically reduced (Joley et al. 1997, Roché et al. 1997). Germination occurs rapidly (typically by 24 h) with nearly all seed germinating within 96 hours (Sheley et al. 1983c, 1993). Although previous

studies are inconclusive (Joley et al. 1997), yellow starthistle appears to have a light requirement for germination (Joley, unpublished data).

Germination of both achene types was high, but germination of the pappus-bearing achenes was slightly greater than that of the non-pappus-bearing achenes. In viability experiments using tetrazolium, Benefield et al. (2001) showed that germination rates and viability were not statistically different with achenes collected one week after dispersal. Thus, nearly all viable seed are able to germinate at the dispersal stage, suggesting that yellow starthistle may not have an innate or induced dormancy mechanism. Interestingly, achenes will germinate within a narrow temperature range shortly after dispersal. However, with increasing exposure to higher temperatures and low moisture (within 1 month), as would occur in later summer, achenes experience a secondary dormancy (Enloe, unpublished data). This ensures that all seed do not germinate following an occasional late summer thunderstorm, where subsequent seedling mortality may occur when no additional moisture is received over an extended time period.

Affect of stress on germination

Germination of yellow starthistle achenes can also be influenced by water or salt stress. Studies (Kiemnec and McInnis 1994, Larson et al. 1992, Larson and Kiemnec 1997) indicated that a slightly greater percentage of pappus-bearing achenes germinated at higher moisture stress than non-pappus bearing achenes. In addition, yellow starthistle germination was more sensitive to moisture stress than salt stress. The authors concluded that dimorphic achenes might be associated with success of yellow starthistle in exploiting highly variable soil moisture regimes in semi-arid environments.

Seasonal germination pattern

Maddox (1981) and Benefield et al. (2001) reported that yellow starthistle seed germination was closely correlated with winter and spring rainfall events. Although germination occurred throughout the rainy season, emergence was highest after early season rainfall events. The extended timing of germination increases the difficulty of controlling yellow starthistle populations during the late winter and early spring, as subsequent germination often results in significant infestations.

The germination rate of the pappus-bearing seed is higher in late fall and winter, whereas the non-pappus-bearing seed germinate more in spring. As a possible explanation, Roché (1965) found that non-pappus-bearing seed have a higher temperature requirement for germination. This could account for the increased germination of pappus-bearing seed in January and February. By the end of each growing season, however, there was no statistical difference between total germination of the two seed types (Benefield et al. 2001).

Consequently, effective late-season control strategies such as mowing, tillage, prescribed burning, or postemergence herbicides should be conducted after seasonal rainfall events are completed, but before viable seeds are produced. In addition, the use of preemergence herbicides applied from late fall to early spring should provide residual control extending beyond the rainy season.

Seed longevity and seedbank depletion

Several investigators have attempted to determine the time required to deplete yellow starthistle seedbanks assuming there is not new seed recruitment. In a study conducted in Idaho, Callihan et al. (1989, 1993) reported no effects of burial depth on achene longevity, and showed that the average longevity of non-pappus-bearing and pappus-bearing achenes was six and ten years, respectively. Even after six years of burial, 9% of the pappus-bearing seed germinated. In a similar study in California, Joley et al. (1992) found significant differences in achene longevity at various soil depths. After burying seeds in bags for one year, they reported 88% viability in seed planted 5 cm deep, but only 4% viable seed remaining in bags 1 cm deep. Consequently, there is some confusion as to longevity of yellow starthistle achenes under typical field conditions. The discrepancy between these two studies may be due to ecotypic variability among populations from Idaho and California, various differences in soil or climatic conditions that could influence the rate of microbial degradation, or invertebrate predation of the achenes.

In the same study, Joley et al. (1992) dispersed yellow starthistle achenes on the soil surface. After one year, they reported 80% depletion in the seedbank, and by 3 years only 3.9% of the original seeds had not germinated and were still viable. They attributed this rapid decline in the seedbank to germination, achene mortality and predation. In addition, one year of prescribed summer burning in Sonoma County, California, reduced the seedbank of yellow starthistle by 74% and three consecutive years of burning, with no further seed recruitment, depleted the seedbank by 99.6% (DiTomaso et al. 1999a). This suggests that the longevity of viable seeds under normal field conditions in California may be shorter than previously believed.

In a recent study by Benefield et al. (2001), the investigators attempted to determine the contribution of achene degradation and germination to yellow starthistle seedbank dynamics in a California site. Both emergence and degradation were monitored within an 18 month time period. In the first year, 44% of pappus-bearing and 39% of non-pappus-bearing achenes germinated in the period from January to June. At the end of the first season (October), 88% of the ungerminated pappus-bearing achenes and 81% of the non-pappus-bearing achenes were damaged or degraded by microbial or insect activity. In the second season, beginning with the first rains in November and extending until July, an additional 7% of pappus-bearing and 9% of non-pappus-bearing seeds germinated. Thus, of the seed that emerged over the two year period, the vast majority germinated in the first year. These results support the findings of both Joley et al. (1992) and DiTomaso et al. (1999a), suggesting that yellow starthistle achenes are relatively short-lived under California soil and climatic conditions. Furthermore, under these conditions, microbial degradation and invertebrate predation of yellow starthistle achenes probably contribute significantly to the rapid depletion of the soil seedbank.

This indicates that yellow starthistle management programs may require only two to three years of effective control to dramatically reduce the soil seedbank and infestation. In support of this, DiTomaso et al. (1999a) demonstrated that three consecutive years of prescribed burning reduced yellow starthistle seedbanks by 99.6% and vegetative cover by 91%. For long-term sustainable management to be achieved, land managers will be required to prevent achene recruitment from the remaining seedbank germinants or new introduction of dispersed achenes from off-site sources.

Growth and establishment

Seedling establishment

In several infested areas, yellow starthistle seed production can be over 50 million seed per acre (DiTomaso et al. 1999a, Maddox 1981, Sheley and Larson 1994a). In exposed areas, high germination can result in extremely dense seedling populations. Seedlings are more likely to establish in soils with deep silt loam and loam with few coarse fragments (Larson and Sheley 1994). In many areas, a significant amount of self-thinning occurs and only a small fraction of seedlings reach reproductive maturity (Larson and Sheley 1994, Sheley and Larson 1994a). Thus, in heavily infested areas, starthistle populations produce far more seed than are necessary to re-infest the area year after year.

Roots

Growth and development

Following germination, yellow starthistle allocates resources initially to root growth, secondarily to leaf expansion, and finally to stem development and flower production (Sheley et al. 1983c, 1993, Roché et al. 1994). Root growth during the winter and early spring is rapid and can extend well beyond 3 feet in depth. Starthistle roots elongate at a faster rate and to greater depths than potentially competitive species, including weedy annual grasses and clovers (Sheley et al. 1993). During this same time period, rosettes expand slowly. In a study conducted in Washington by Roché et al. (1994), roots grew at a mean rate of 0.5 cm per day and as fast as 2.1 cm per day. They found that 140 days after planting, roots grew out the bottom of 123 cm long (4 ft) tubes. Their study additionally showed little above ground rosette growth during winter months when roots were quickly growing. Other studies also demonstrated rapid yellow starthistle root growth during late winter and early spring (DiTomaso, unpublished data, Sheley et al. 1993, Sheley and Larson 1992, 1994b). Using minirhizotron tubes in the field, DiTomaso (unpublished data) showed that root depth increased exponentially with time and by 64 days roots reached depths of 2 ft. Within 80 days from planting (end of March), roots in most plots extended beyond the depth of the acrylic tubes (3.5 ft). In tubes, roots extended beyond 6 ft after two months of growth.

Rapid germination and deep root growth in yellow starthistle extends the period of resource availability into late summer, long after seasonal rainfall has ended and shallow-rooted annual grasses have senesced. By extending the period of resource availability, competition is reduced at the reproductive stage. This can greatly benefit starthistle by ensuring ample seed production into the dry summer months (Sheley et al. 1993).

The potential density of yellow starthistle in a particular site can be closely associated with soil depth and, thus, late season water storage capacity. Roché et al. (1994) demonstrated a direct relationship between the number of starthistle plants per unit area and the soil moisture depth.

Shading of young rosettes can have a dramatic affect on root growth (Roché et al. 1994). Reduced root growth correlated with increased shading (DiTomaso, unpublished data). Roots of yellow starthistle required 94, 138, and 163 days to reach a 60 cm depth in the unshaded, 80%, and 92% shaded plots, respectively. Roots of plants growing under 80% light reduction required an additional month and a half to reach a 2 ft soil depth, whereas an additional two months was required for plants grown under 92% light reduction.

Since yellow starthistle plants germinate over an extended time period beginning with the first fall rains and ending with the last spring rain event, the resulting canopy would likely consist of plants in several stages of development. In dense stands of starthistle, the population would be represented by both large canopied plants receiving full sunlight and an understory of smaller shaded plants. Thus, light suppression would likely be a significant factor regulating root growth. The roots of larger plants exposed to full sunlight quickly grow to great depths, while roots of shaded plants underneath the starthistle canopy would occupy shallower depths for longer periods of time. Under these conditions, starthistle would rapidly deplete soil moisture from all depths in the soil profile.

Water use

Heavy infestations of yellow starthistle in grasslands with loamy soils can use as much as 50% of annual stored soil moisture (Gerlach, unpublished data). In deep Central Valley soils of California, starthistle can significantly reduce soil moisture reserves to depths greater than six feet, and in three-foot-deep foothill soils it can extract soil moisture from fissures in the bedrock (Gerlach et al. 1998).

Competition with introduced annual grasses

Root partitioning between yellow starthistle and competing vegetation can greatly influence the invasibility of grasslands to starthistle. Since the root systems of most annual species are comparatively shallow, there is little competition for moisture between yellow starthistle and annual grasses during late spring and early summer. In addition to utilizing deep soil moisture, yellow starthistle can also survive at extremely low soil water potential (< -6.0 MPa) as compared to annual grasses (> -2.1 MPa) (Gerlach, unpublished data).

In a number of experiments Sheley and Larson (1994b, 1994c, 1995) showed that *Bromus tectorum* (cheatgrass or downy brome) has a relatively shallow fibrous rooting system and is better suited for water and nutrient capture in shallow soils. In comparison, yellow starthistle has an advantage over cheatgrass in deep soils (>0.5 m) where its roots can penetrate deeper into the soil. Thus, seedlings of many annual grasses avoid competition with yellow starthistle by occupying different rooting zones (Sheley and Larson 1994c). In addition, annual grasses, such as cheatgrass, mature earlier than yellow starthistle, which also allows them to avoid competition at later stages of growth. In contrast, the use of soil moisture by yellow starthistle was shown to be similar to that of perennial grasses (Borman et al. 1992). Like yellow starthistle, perennial grasses also have an extended growing season. These factors account for the increased competition between yellow starthistle and perennial species, compared to annual species.

Seasonal moisture can also influence the competitive advantage between yellow starthistle and annual grasses. Under dry spring conditions, early maturing annual grasses would have an advantage over late season annuals, as they utilize the available moisture and complete their life cycle before the later maturing species, such as starthistle (Larson and Sheley 1994). In contrast, under moderate or wet spring conditions, starthistle would have an advantage by continuing its growth later into the summer and fall and producing more seed.

Thus, in grassland systems, the greatest advantage for yellow starthistle would occur in areas 1) dominated by annual grasses, 2) with deep soil, and 3) in years with moderate to wet spring rainfall (Sheley and Larson 1992). Under these conditions, yellow starthistle would mature later, have increased seed production, and have little competition for deep soil moisture.

In annual grasslands, the least competitive situation for yellow starthistle would be areas with shallow soils and low spring rainfall.

Yellow starthistle density can also affect the competition with annual grasses for soil moisture. At low densities, Sheley and Larson (1997) showed that yellow starthistle grew faster and roots grew to greater soil depths than cheatgrass. In other experiments by DiTomaso (unpublished data), yellow starthistle plants at low density acquire moisture primarily from greater depths in the soil profile and did not significantly utilize moisture in the upper soil zone. In contrast, when yellow starthistle was at high densities, soil moisture was depleted from all depths in the soil profile throughout the duration of the season. Thus, high densities of yellow starthistle can produce growth conditions that simulate drought in grassland ecosystems. This can severely hamper restoration efforts, where surface soil moisture is critical to the establishment and survival of seeded perennial grasses and desirable annual forbs.

Competition with native species

The characteristics that enable yellow starthistle to invade grasslands can threaten native species and ecosystems processes. Native species such as blue oak (*Quercus douglasii*) and purple needlegrass (*Nassella pulchra*) depend on summer soil moisture reserves for growth and survival (Gerlach et al. 1998). Yellow starthistle, however, uses deep soil moisture reserves earlier than blue oak or purple needlegrass. Thus, from the perspective of native species, infested sites can experience drought conditions even in years with normal rainfall (Gerlach et al. 1998).

Heavy yellow starthistle infestations can remove large amounts of stored soil moisture through plant transpiration (Gerlach et al. 1998). Most soils in California grasslands store about twelve inches of rainfall for each three feet of soil depth. In most years annual grasses reduce soil moisture reserves by about four inches of stored rainfall in the top three feet of soil. By comparison, yellow starthistle can reduce soil moisture levels by eight inches of stored rainfall for each three feet of soil depth. This is about the same as that of a mature oak tree. As a result, large yellow starthistle populations are transpiring at least an additional four inches of rainfall for each three feet of soil depth during average rainfall years and about eight inches during wet years (Gerlach et al. 1998).

Shoots

Growth and development

Seedlings that typically germinate in late fall or early winter overwinter as basal rosettes. Rosettes develop slowly throughout the early spring. In the Central Valley and foothills of California, bolting typically occurs in early summer and by mid-summer spines appear on developing seedheads. At the more mature stages of development, the pubescence and waxy grayish coating on the foliage of yellow starthistle reflects a considerable amount of light. This reduces the heat load and the transpiration demand during the hot and dry summer months. The winged stems add surface area and also act to dissipate heat like a radiator (Prather 1994). These characteristics, as well as a deep root system, allow yellow starthistle to thrive under full sunlight in hot and dry conditions. Vigorous shoot growth coincides with increased light availability due to senescence and desiccation of neighboring annual species. Moreover, the presence of spines on the bracts surrounding the seedhead provides protection against herbivory. This is particularly important during the vulnerable flowering and seed development stages.

Senescence typically occurs in fall when moisture becomes limiting and plants are exposed to frost. Flowers can abort development before completion. Senesced stems can contain

the non-pappus-bearing seeds for about a month until the spiny bracts and phyllaries fall off. Because the receptacle of the flowerheads contain an abundant amount of fine chaff, the seedheads will have a cotton-tip appearance. In contrast, tocalote and sulfur starthistle do not have cotton-tip seedheads after senescence. Stems of yellow starthistle degrade slowly and may remain erect for at least one year. In addition, both tocalote and sulfur starthistle have only pappus-bearing seed that disperses once the seedhead has lost its senesced flowers.

Light

In grasslands where yellow starthistle rosettes are exposed to low light, the leaves are larger and develop a more vertical or erect growth form that may reach 10 inches in height. This upright form allows them to capture more light until the reproductive shoots bolt through the senescing canopy of the annual grasses (Roché et al. 1994). In contrast, when rosettes are exposed to full sunlight, they develop flatter and more compacted leaves horizontally oriented to the soil surface.

Dense yellow starthistle seedling cover can significantly suppress the establishment of annual grasses and forbs. However, yellow starthistle rosettes are also very susceptible to light suppression, and will produce short roots, larger leaves, more erect rosettes, and fewer flowers than plants in full sunlight (Roché and Roché 1991, Roché et al. 1994). Consequently, yellow starthistle does not survive well in shaded areas, and is less competitive in areas dominated by shrubs, trees, taller perennial forbs and grasses, or late season annuals. For this reason, infestations are nearly always restricted to open disturbed sites or grasslands dominated by annuals or disturbed sites. Even in areas dominated by yellow starthistle, the level of competition for light can be so intense that seedlings will vigorously compete with each other, accounting for the low rate of seedling survival through self-thinning.

Temperature

Yellow starthistle plants are insensitive to photoperiod and lack a vernalization requirement (Roché et al. 1997). This allows late germinating plants to continually reproduce provided moisture is adequate. Flowering continues until newly developing buds are killed by frost. In climates with milder winters, plants can act as biennials. However, in colder climates more typical to Northern California or other western states, mature plants rarely survive the winter. Whereas seedling can survive extended frost periods, mature plants are not considered to be frost tolerant. Cold tolerance (hardiness) appears to be lost during the transition from vegetative to reproductive phases.

Allelopathy

A number of researchers have isolated a variety of chemical compounds from yellow starthistle (Binder et al. 1990, Bruno et al. 1991, Buttery et al. 1986, Merrill 1989, Merrill and Stevens 1985, Stevens and Merrill 1985, Stevens et al. 1990). One of the major groups of compounds identified in starthistle is the sesquiterpene lactones (Binder et al. 1990, Merrill and Stevens 1985, Stevens and Merrill 1985). The sesquiterpene lactone repin has been implicated in the toxicity of starthistle in horses.

It has been suggested that yellow starthistle might release chemical compounds that inhibit the growth of other plants, a process known as allelopathy (Kelsey and Bedunah 1989, Merrill and Stevens 1985, Stevens and Merrill 1985, Zamora et al. 1983). Allelopathy involves the release of chemical substances by one plant that inhibit the growth or development of other

plants. The release of allelopathic compounds could be through glands or duct on the stem or foliage, leaching from degrading plant residue, or exudate from roots. In addition to its possible toxic effect on horses, repin has been postulated to be allelopathic to plants (Merrill and Stevens 1985, Stevens and Merrill 1985). Despite these implications, there is no direct evidence to substantiate the claim that yellow starthistle has an allelopathic effect on surrounding vegetation.

MANAGEMENT

The goal of any management plan should be not only controlling the noxious weed, but also improving the degraded community, enhancing the utility of that ecosystem, and preventing reinvasion or invasion by other noxious weed species. To accomplish this usually requires a long-term integrated management plan. A number of considerations can influence the choice of options; most important being the desired land-use objective. This can include forage production, preservation of native or endangered plant species, wildlife habitat development, or recreational land maintenance. Selection of the proper management tool(s) and program also may depend on other factors including weed species and associated vegetation, initial density of yellow starthistle infestation, effectiveness of the control techniques, years necessary to achieve control, environmental considerations, chemical use restrictions, topography, climatic conditions, and relative cost of the control techniques.

Before 1987 there were few options for the control of yellow starthistle, and long-term sustainable management plans had not yet been developed. However, considerable progress has been made in the past decade. Currently, there are a number of control options available for the management of yellow starthistle, including grazing, mowing, manual removal, clover or perennial grass reseeding, burning, chemical, and biological control.

Recent emphasis has been on the development of integrated systems for the long-term sustainable management of yellow starthistle. Such systems include various combinations of a number of these newly developed techniques. In many cases, three or more years of intensive management may be necessary to significantly reduce a yellow starthistle population. Although uncommon, it is possible to substantially reduce the infestation with one year of control. However, it is believed that a more established starthistle population, with a large residual seedbank, would require a longer-term management program (DiTomaso 2000).

When developing a yellow starthistle management program is to important to consider the advantages and disadvantages of each approach and to judge how each option may best fit into a long-term program. It is possible that several different strategies can prove successful in a given location. The consistent components of a successful program should include persistence, flexibility, and, most importantly, preventing new seed recruitment (DiTomaso et al. 2000d). A summary of the advantages, disadvantages, risks, timing and fit into a strategic plan for each control option can be accessed by double clicking on this sentence.

Mechanical control

Mechanical control options for yellow starthistle typically include hand pulling, hoeing, weed whipping, tillage or mowing.

Hand pulling, hoeing or weed whipping

Hand pulling and hoeing are the oldest forms of weed control used by humans. Although they are labor intensive and relatively ineffective for the control of perennial weeds (with exception of the weed wrench on some shrubs), they typically cause minimal environmental impact. When using manual removal techniques it is important to minimize soil disturbance around the removed plants. Disturbance can create an ideal site for re-establishment of new seedlings or rapid invasion of another undesirable species (DiTomaso 1997).

Manual removal of yellow starthistle is most effective with small patches or in maintenance programs where plants are sporadically located in the grassland system. This usually occurs with a new infestation or in the third year or later in a long-term management program. It can also be an important tool in steep or uneven terrain where other mechanical tools (e.g., mowing and tillage) are impossible to use (Woo et al. 1999). To ensure that plants do not recover it is important to detach all above ground stem material. Leaving even a 2 inches piece of the stem can result in recovery if leaves and buds are still attached to the base of the plant (Benefield et al. 1999). The best timing for manual removal is after plants have bolted but before they produce viable seed (early flowering). At this time, plants are easy to recognize and some or most of the lower leaves have senesced. Hand removal is particularly easy in areas with competitive vegetation. Under this condition, starthistle will develop a more erect slender stem with few basal leaves. These plants are relatively brittle and easy to remove. In addition, they rarely have leaves attached at the base and, consequently, are unlikely to recover, even when a portion of the stem is left intact (see mowing for more detail).

In the Bradley method (Fuller and Barbe 1995), a larger starthistle population can be controlled through physical removal by starting at the outward edge of the population and moving in. The technique requires repeated visits, but ensures that no new seeds are produced, and soil disturbance is minimized. Using the Bradley method, it is possible to control relatively large starthistle-infested areas (<40 acres) with low-cost and low-impact.

Tillage

Tillage can utilize plows or discs that can control annual weeds by burying plant parts. This is more effective on annuals than perennials. In contrast, harrows, knives, and sweeps can be used to damage root systems or to separate shoots from roots in younger plants and can also be used to damage roots in larger plants (Thomsen et al. 1996b). This technique must be applied when the surface soil is dry, or fragmented plant segments will re-grow and possibly magnify the problem (DiTomaso 1997).

Early summer tillage will control yellow starthistle provided the roots are detached from the shoots. Repeated cultivation can be used in the same season when rainfall stimulates additional germination between tillage practices (Thomsen et al. 1996b). This will rapidly deplete the starthistle seedbank, but may also have the same effect on the seedbank of other desirable species. To be effective, tillage must be conducted before viable seeds are produced. This technique is occasionally used on roadsides, but is often used in agricultural lands and probably accounts for the uncommon occurrence of starthistle as a weed in these environments. In wildlands and rangelands, tillage is usually not an appropriate option for control of yellow starthistle. It can damage important desirable species, increase erosion, alter soil structure, and expose the soil for rapid re-infestation if subsequent rainfall occurs (DiTomaso and Gerlach 2000a).

Mowing

Mowing is a popular control technique along highways and in recreational areas and has less impact on the environment than tillage. Although mowing can be a cost-effective method for control of starthistle, it is not feasible in many locations due to rocks and steep terrain. Even when mowing is employed as a control technique, it is not always successful and can decrease the reproductive efforts of insect biocontrol agents, injure late growing native forb species (Rusmore 1995), and reduce fall and winter forage for wildlife and livestock (DiTomaso 1997, DiTomaso et al. 2000d). In addition, its success depends on proper timing and the growth form of the plant. Mowing plants before the seedheads reach the spiny stage can suppress competing vegetation, thus enhancing light penetration and increasing the starthistle problem. Even repeated mowing conducted to early will not control starthistle and may extend the life cycle. Mowing after plants have produced viable seed will not substantially reduce the seedbank and the following year's infestation.

Despite the limitations of mowing, Thomsen et al. (1994, 1997) and Benefield et al. (1999) demonstrated the successful use of mowing for yellow starthistle control. Thomsen et al. (1994, 1997) consistently demonstrated over 90% control of yellow starthistle using two timely repeated mowings per year over a three year period. Benefield et al. (1999) also showed that mowing conducted at the early flowering stage, before viable seed production, was most effective in controlling yellow starthistle. However, they also demonstrated that the success of mowing as a control strategy not only depended on mowing timing, but also on the plant's growth form and branching pattern. Plants with an erect, high-branching growth form were effectively controlled by a single mowing at the early flowering stage, while sprawling, low-branching plants were not controlled even with repeated mowings at the proper timing.

Mowing may be an alternative strategy for small landowners that do not wish to use herbicides. A few land managers have successfully controlled yellow starthistle using continuous mowing over multiple years. However, since mowing is a late season management tool it is best employed in the later years of a long-term management program or in a lightly infested area. This gives the landowner or manager the ability to assess the level of infestation and the flexibility of choosing the most appropriate and cost effective option, which can include mowing. If the infestation is extremely low, with only a few plants present, hand pulling may be a most desirable method than mowing.

Cultural control

Cultural control techniques are defined as those practices that require manipulation of the environment either through controlled burning, grazing management, or re-vegetation programs.

Grazing

Proper grazing management can minimize the spread and effectively manage noxious weeds in many rangeland systems, including yellow starthistle. Different strategies can be used for managing weeds. For example, moderate grazing levels can minimize the impact on native plants and reduce soil disturbance; intensive grazing will counteract inherent dietary preferences of livestock, resulting in equal impacts on all forage species including weeds; and multispecies grazing distributes the impact of livestock grazing more uniformly among desirable and undesirable species (Olson 1999).

Timing also can be critical to the success of grazing. The ideal time to graze is when the noxious species is most susceptible to defoliation or when the impact on the desirable vegetation

is minimal. Improperly timed grazing can lead to rapid selection for yellow starthistle. For example, livestock grazing in late winter or early spring will 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 generally stimulates yellow starthistle growth during the late spring and early summer. On the other hand, livestock grazing in the mid- to late summer months will selectively avoid spiny yellow starthistle plants, thus allowing heavy seed production and the next year's survival of the weed.

Thomsen et al. (1989, 1990, 1993) they showed that properly timed (May and June) intensive grazing by cattle or goats resulted in reduced growth, canopy cover, survivability, and reproductive capacity of yellow starthistle. The success of this approach was attributed to grazing yellow starthistle after the stems had bolted but before the development of spiny seed heads. Although sheep did not reduce starthistle infestations in the 1993 Thomsen et al. study, they observed many localities outside of the trials where sheep routinely grazed starthistle late in the season and effectively reduced dense stands. 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. It is important to note, however, that grazing alone will not provide long-term management or eradication of yellow starthistle. However, it can be a valuable tool in an integrated management program.

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. After livestock are moved to another area of the pasture, the grazed area is allowed to recover for at least a month before grazing is repeated. This system typically results in more uniform and complete forage utilization. In addition, 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. In a report by Weber (1985), it was noted that when Roché delayed spring grazing of wheatgrass, starthistle was controlled because ungrazed, taller wheatgrass plants blocked sunlight from the rosettes of starthistle.

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 can result in a more uniform composition of range plant species and more balanced competitive relationships among native and non-indigenous species (Olson 1999).

In contrast, conventional grazing or overgrazing can lead to the invasion of yellow starthistle and many other rangeland weeds. Excessive trampling of livestock was shown to increase the density of yellow starthistle (Miller et al. 1998). In some cases, grazing can select for a less palatable weed or group of weeds. Animals forage around these plants, eliminating their competition. This selective pressure can lead to more rapid infestation. In contrast, grazing

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

Prescribed burning

Fire has long been an important component in the development and continuance of most grassland systems. In addition to controlling some important noxious annual grasses, such as barbed goatgrass (*Aegilops triuncialis*), medusahead (*Taeniatherum caput-medusae*) and ripgut brome (*Bromus diandrus*), prescribed burning can all be used successfully to control yellow starthistle (DiTomaso et al. 1999a).

As with mowing, the success of this method depends on proper timing. Unfortunately, the best time for burning is in early to mid-summer (late June to early July), 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 has yet to produce viable seed. By comparison, seeds of most desirable species have dispersed and grasses have dried to provide adequate fuel. Fire has little if any impact on seeds within the soil. Since grassland fires only transiently heat the soil surface to about 200 °C, seeds on the soil surface are not typically damaged and may actually be stimulated to germinate, as is probably the case with many legumes.

After a single year of burning, the resident seedbank of yellow starthistle will be sufficiently high enough to allow re-infestation the following year. However, burning will reduce the thatch layer, expose the soil, and recycle nutrients trapped in the dried vegetation. In the first growing season after the burn, plant diversity will often increase, particularly native species, including perennial grasses and forbs. It is speculated that this increase in plant diversity may be due to increased light penetration and/or increased soil temperature earlier in the season (DiTomaso et al. 1999a). After three consecutive years of burning, DiTomaso et al. (1999a) showed that starthistle seedbanks were reduced by over 99%, with vegetative control greater than 90% in spring and summer measurements.

Despite its effectiveness, there are some risks associated with prescribed burning as a method of controlling yellow starthistle (DiTomaso 1997). Air quality issues can be a significant problem when burns are conducted adjacent to urban areas. This potential problem can be avoided by conducting burns only in more isolated regions not adjacent to urban areas. Public relations problems can be avoided by educating residents of the intended goals of the project prior to the burn. A 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 involvement of local fire departments and the California Department of Forestry (CDF). Fire can also have a significant impact on small animals and insects unable to escape the burn. For example, burning for control of yellow starthistle during the summer undoubtedly damages seedhead feeding biocontrol insects and their larvae. In some areas, burning can lead to rapid invasion by other undesirable species with wind dispersed seeds, particularly members of the sunflower family.

Continuous burning as a control strategy can also 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. Although this is a

potential concern, data from Sonoma County, California, showed that only a few plants were negatively impacted by prescribed summer burning and most of them were introduced species. Some plants were unaffected by burning, but several species, particularly native legumes, were enhanced by the burn (DiTomaso et al. 1999a, Hastings and DiTomaso 1996).

The ability to use repeated burning depends on climatic and environmental conditions. In areas where resources are ample and total plant biomass is abundant, two or three consecutive years of burning may be practical. However, in other environments or years, fuel loads may not be sufficient to allow multiple year burns. Consequently, prescribed burning may be a more appropriate option as part of an integrated approach. A possible combination may be a first year clopyralid treatment, which is likely to suppress legumes and stimulate grasses, followed by a second year burn. In the second year fuel loads should be high and the previously suppressed legume populations are likely to be stimulated by the burn (DiTomaso et al. 2000d). Since prescribed burning is a late season tool, it can be considered as part of a flexible strategic management plan. For example, if the risk of burning in a particular year is too high, another late season technique (mowing, manual removal, or postemergence herbicide treatment) could be substituted.

In addition to summer burning, yellow starthistle seedlings have been controlled using winter or early spring flaming techniques (Rusmore 1995). This reduces the risk of escaped fires and avoids major air quality issues. However, this technique is somewhat non-selective and the successful 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.

Re-vegetation

Before the introduction of annual grasses, perennial bunchgrasses were the primary natives species in rangelands west of the Rocky Mountains. This included *Festuca idahoensis*, *Poa secunda*, *Festuca kingii*, *Pseudoroegneria spicata*, *Leymus cinereus*, *Elymus elymoides*, *Achnatherum hymenoides*, *Hesperostipa comata*, and *Achnatherum* (Billings 1994). These perennial grass species do not have high seedling vigor nor do they readily recover from overgrazing (Callihan and Evans 1991). With the introduction of exotic annual grasses and livestock, 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, including 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). In many cases, these broadleaf species produce an extensive taproot system that can extract more moisture from deep within the soil profile. Thus, they remain green longer into the dry season than do the annual grasses. In addition, these invasive broadleaf species typically produce a large number of seeds (Roché et al. 1994).

In a re-vegetation program designed to suppress noxious weeds, a major limitation 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 re-vegetating western grasslands, but broadleaf species such as legumes can also be used in re-vegetation 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). In the absence of adequate surface soil moisture during the critical spring growing season, re-vegetation programs are likely to fail (Roché et al. 1997). The method of re-vegetation can also determine the level of success. Re-vegetation 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.

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 re-vegetation program, a perennial grass with high forage production may be the appropriate choice (Jacobs et al. 1999). Though perennial grasses have been shown to be most successful in competing with rangeland weeds, using a combination of species with various growth forms and ecological traits may be best, although quite expensive. 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). Using seed mixtures, however, may limit the options for noxious weed control (e.g., using selective herbicides). Thus, a re-vegetation program may require initial seedling with perennial grasses during the weed management phase followed by subsequent reseeding with broadleaf species. Under this condition, re-vegetation programs may require several years to successfully accomplish.

Re-vegetation programs for yellow starthistle control generally rely on re-seeding with native species or perennial grasses (Callihan et al. 1986, Johnson 1988, Larson and McInnis 1989a, Lass and Callihan 1995a, Northam and Callihan 1988a, 1988b, 1988c, 1990a, 1990b, Prather et al. 1988, Prather and Callihan 1989a, 1989b, 1990, 1991). Consequently, these programs are not only trying to eliminate starthistle, but also the invasive annual grasses that have created a susceptible ecosystem for starthistle invasion. Re-vegetation with desirable and competitive plant species can be the best long-term sustainable method of suppressing weed invasions, establishment, or dominance, while providing high forage production. In western states, other than California, competitive grasses used in re-vegetation 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*), Bozoiisky 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.

Because of California's Mediterranean climate, re-vegetation programs for control of yellow starthistle are more difficult than those in other western states where summer rainfall is critical to the establishment and survival of native perennial grasses. In the most desirable cases, competitive, endemic, native species should be re-established. This may not always be possible depending on the objective of the land use and the location of the site. In many cases non-native perennial grasses or legumes with high forage quality and quantity are used in re-vegetation programs.

For example, in a study underway near Yreka (Siskiyou County, California) Enloe et al. (1999a, 1999b, 2000) have combined herbicides, biological control, and competitive perennial grass reseeding, perennial wheatgrass ('Luna' pubescent; *Thinopyrum intermedium*). To establish the perennial grass they employed a late winter glyphosate treatment for annual grass control in the first year and one to three consecutive years' treatment with clopyralid for starthistle control. In the first year, pubescent wheatgrass was spring drill seeded following the herbicide treatments. The goal of this re-vegetation project is to develop sustainable high quality range conditions and improved wildlife habitat capable of providing long-term starthistle control without the need for continued herbicide treatments.

Their results show a first year only treatment with clopyralid and glyphosate was sufficient to allow wheatgrass establishment. In this case, the wheatgrass provided some level of starthistle control in subsequent years, but was not as effective as two or three years of clopyralid treatment with wheatgrass (Enloe et al. 2000). Plots treated with clopyralid and not seeded with pubescent wheatgrass were dominated by annual species, particularly grasses. They also showed that yellow starthistle infestations could deplete soil moisture to a greater degree than rangeland dominated by annual grasses or pubescent wheatgrass. Wheatgrass was able to utilize soil moisture at shallow and intermediate soil depths, whereas starthistle depleted soil moisture at the deeper soil levels. Heavy infestations of yellow starthistle led to inadequate deep soil moisture recharge after the rainy season. The investigators concluded that on severely degraded rangeland an integrated combination of clopyralid treatment and wheatgrass seeding can be very effective in suppressing yellow starthistle seed production and provides a more effective long-term solution than applying clopyralid alone.

In Oregon, subterranean clover (*Trifolium subterraneum*) was used for re-seeding 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, results are inconsistent in yellow starthistle dominated grasslands because starthistle has similar patterns of initial growth.

In California studies, Thomsen et al. (1996a, 1997) and Thomas (1996, 1997) tested several species in the legume family (Fabaceae) for their competitive effect on yellow starthistle. Thomsen et al. (1996a, 1997) found subterranean clover varieties to be the best. In addition to providing some competitiveness against yellow starthistle when combined with grazing and mowing, they were also palatable, self-seeding, and produced flowers and seeds below the bite of grazing animals. Used as a sole control option, however, subterranean clovers 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, he reported an 80 to 90% reduction in yellow starthistle one year after planting with crimson clover.

In any re-vegetation program utilizing non-native species, it is important to ensure that an introduced species will not itself become invasive. For example, Harding grass (*Phalaris aquatica*) is a perennial bunchgrass native to the Mediterranean region. It was commonly planted 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 re-vegetation efforts can present potential problems. Native seed collected in one area of the state but used in a re-vegetation 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 combination of species to use in various environments, which species or combination will aggressively compete with yellow starthistle, and how to economically establish these species.

Biological control

The goal of a biological control program is not to eradicate the target weed, but to exert sufficient environmental stress to reduce its dominance in the plant community and shift the competitive balance to more desired species (Wilson and MacCaffery 1999). With insect agents this can be achieved by boring into roots, shoots and stems, defoliation, seed predation, or extracting plant fluids. All these effects can reduce the competitive ability of the plant relative to the surrounding vegetation.

Ideally, biological control of weeds is considered to be environmentally safe, energy self-sufficient, cost-effective, and often self-sustaining. Over the past 100 years, over 200 control agents have been released against 114 weed species worldwide (Blossey et al. 1994). Of these, 165 have been imported and released in the continental United States and Canada (Goeden 1993). Although biological control agents can include nematodes, pathogens, and vertebrates, 114 of the 165 released organisms are arthropods (insects and mites) (Julien 1989). The vast majority of released agents for terrestrial weeds are targeted for non-indigenous weeds of rangeland (Julien 1992). Despite the many attempts to control rangeland weeds through biological control, most cases have proven unsuccessful. Of the 23 weed species where biocontrol has been attempted in the United States, only 29% have demonstrated complete or significant levels of control in large areas (DeLoach 1991).

Despite the overwhelmingly positive aspects of biocontrol, some risks do exist. Most biocontrol agents introduced to the United States are native to other continents. Although we often study the host specificity of these organisms under quarantine conditions, little is known of their impact on the ecosystem as a whole, including other insect populations (DiTomaso 1997). In addition, our understanding of the nature of host specificity is poor. Consequently, there is no guarantee that the introduced biocontrol agent will not itself become a pest by changing its food preference from weeds to desirable plants after it is released. For example, based on chemical similarity yellow starthistle is most closely related to purple starthistle (*Centaurea calcitrapa*) and safflower (Stevens et al. 1990). Thus, there is the potential that biocontrol agents for starthistle may shift to this commercially important crop. Fortunately, this host shift has only rarely occurred with plant biocontrol organisms (Rees 1978). It has, however, arisen on many occasions with the introduction of animal control agents (Civeyrel and Simberloff 1996).

In some cases, accidental introductions of pathogens or insects can occur when biocontrol agents are released. For example, the pathogen *Nosema* was accidentally introduced as a contaminant of *Trichosirocalus horridus*, a weevil introduced for the control of musk thistle

(*Carduus nutans*) (Andres and Rees 1995). More recently, a second species of peacock fly (*Chaetorellia succinea*) was identified as a contaminant of released populations of *C. australis* for the control of yellow starthistle (Balciunas and Villegas 1999).

Insects for yellow starthistle control

The USDA, Agricultural Research Service's Exotic and Invasive Weed Management Research Unit in Albany and the CDFA's (California Department of Food and Agriculture) Biological Control Program have been active in developing an effective biological control program for yellow starthistle in California and other western states. Since the first established biological control insect in California (seed-head weevil; *Bangasternus orientalis*) was reported in California in 1986 (Maddox et al. 1986), there have been five additional insects released and established in the state. Today, three of these have become widespread: seed-head weevil, seed-head fly (*Urophora sirunaseva*), and the hairy weevil (*Eustenopus villosus*). A fourth insect, the false peacock fly (*Chaetorellia succinea*) was accidentally released in 1991, and is now widespread and more effective against yellow starthistle than the intentionally released peacock fly (*Chaetorellia australis*) (Balciunas and Villegas 1999). Fortunately, the false peacock fly appears to be host specific to yellow starthistle and does not attack native thistles or related commercial crops, such as safflower (Villegas et al. 1999, 2000b). One other insect has been released, the flower weevil (*Larinus curtus*), but has yet to become well established (see tables). All six insects attack the flower heads of yellow starthistle and produce larvae that develop within the seedhead and feed on seeds.

Of the four insects that are well established (Villegas 1999, Villegas et al. 2000a) only two, the false peacock fly and the hairy weevil, have any significant impact on seed production (Table A, B, C) (Pitcairn and DiTomaso 2000, Pitcairn et al. 1999a, 2000a). The combination of these two insects has been reported to reduce seed production by 43 to 76% (Pitcairn and DiTomaso 2000). Balciunas and Villegas (1999) reported a 78% reduction in seed production when seed heads contained false peacock fly larvae. Although this level of suppression is not sufficient to provide long-term starthistle management, the use of biological control agents can be an important component of an integrated management approach (see Integrated Approaches). A more successful biological control program will likely require the introduction of plant pathogens or other insect organisms capable of feeding on roots, stems, or foliage. Currently, a root-boring weevil (*Ceratapion basicorne*) is in quarantine and may have potential for release on yellow starthistle in the next few years.

Establishment, impact and publications on yellow starthistle biological control insects.

Species	Common name	Establishment	Impact	Publications
<i>Bangasternus orientalis</i>	Seed-head weevil	Wide	Low	Campobasso et al. 1998 Maddox et al. 1986, 1991 Maddox and Sobhian 1987 Sobhian 1993a Sobhian et al. 1992 Wood 1993
<i>Urophora sirunaseva</i>	Seed-head fly	Wide	Low	Maddox et al. 1986 Sobhian 1993b Turner 1994 Turner et al. 1994 White and Clement 1987 White et al. 1990
<i>Eustenopus hirtus</i>	Weevil	No	None	Clement et al. 1988
<i>Eustenopus villosus</i>	Hairy weevil	Wide	Moderate	Connett and McCaffrey 1995 Fornasari et al. 1991 Fornasari and Sobhian 1993 Villegas et al. 2000a Woods et al. 1998
<i>Chaetorellia australis</i>	Peacock fly	Limited	Low	Maddox et al. 1990 Turner et al. 1996 Villegas 1998 Villegas et al. 2000b White et al. 1990
<i>Chaetorellia hexachaeta</i>	Fly	No	None	Sobhian and Pittara 1988
<i>Chaetorellia succinea</i>	False peacock fly	Wide	Moderate	Balciunas and Villegas 1999 Pitcairn et al. 1998a Villegas 1998 Villegas et al. 1999 Villegas et al. 2000b
<i>Larinus curtus</i>	Flower weevil	Limited	Low	Fornasari and Turner 1992 Sobhian and Fornasari 1994 Villegas et al. 1999 Villegas et al. 2000c

General articles on insect biological control of yellow starthistle	
Topic	Publications
Discovery	Clement 1990, 1994 Clement and Sobhian 1991
Effect of natural insect populations of starthistle	Johnson et al. 1992 Pitcairn et al. 1999b
Reviews	Jette et al. 1999 McCaffrey and Wilson 1994 Pitcairn et al. 2000c Rosenthal et al. 1991 Turner 1992 Turner and Fornasari 1992 Wood 1993

Plant pathogens

Plant pathogens are not typically used as weed biological control tools. However, at least two pathogens have been commercially available for control of agricultural weeds (Collego® [*Colletotrichum gloeosporioides* f. sp. *aeschynomene*] and DeVine® [*Phytophthora palmivora*]). Although no pathogens have yet been released for the control of yellow starthistle, a number of species have been evaluated including *Fusarium oxysporum* f. sp. *carthami*, *Verticillium dahliae*, *Phytophthora* spp., *Botrytis cinerea*, *Sclerotinia sclerotiorum*, *Sclerotinia minor*, *Ascochyta* n. sp., *Colletotrichum gloeosporioides*, and *Puccinia jaceae*. Some of these pathogens have shown promise.

Under laboratory conditions, Klisiewicz (1986) looked at the effect of several pathogenic fungi on yellow starthistle rosettes. The species evaluated included *Fusarium oxysporum* f. sp. *carthami*, *Verticillium dahliae*, *Phytophthora* spp., *Botrytis cinerea*, and *Sclerotinia sclerotiorum*. Starthistle plants developed symptoms from all these organisms and, with the exception of *B. cinerea*, the diseases were frequently lethal. However, these pathogens are not host specific and, thus, have the potential to attack other economically or ecologically important plant species.

An undetermined or perhaps new species of *Ascochyta* n. sp., *Sclerotinia minor*, and *Colletotrichum gloeosporioides* were evaluated by CDFA scientists (Pitcairn et al. 2000b, Woods 1996, Woods and Fogle 1999). All three of these species are already naturally present in California. Seedlings of yellow starthistle are susceptible to *Ascochyta* n. sp. under cool conditions typical of the winter months (Woods 1996). In addition, the pathogen appears to be fairly host specific. However, it has been difficult to maintain a high level of virulence in laboratory cultures (Woods and Fogle 1999). *Sclerotinia minor* has also been able to cause high mortality rates in starthistle seedlings; particularly in areas where skeletons of previous years starthistle plants provide shading. Unlike *Ascochyta* n. sp., *Sclerotinia minor* is not host specific and is able to infect important crops including lettuce (Pitcairn et al. 2000b). The host specificity of the isolate of *Colletotrichum gloeosporioides* has not yet been determined, but this fungus appears to be quite common in California and may have a significant impact on yellow starthistle (Pitcairn et al. 2000b). In contrast to *Ascochyta* n. sp., it is most aggressive at warmer

temperatures, causing symptoms characterized by wilting and yellowing (Woods and Fogle 1999). It is possible to isolate a host specific form of the pathogen that might be used as a mycoherbicide in starthistle-infested grasslands.

The most widely studied pathogen for yellow starthistle control is the Mediterranean rust fungus *Puccinia jaceae*. This work was initiated in 1978 from isolates collected in Turkey. At that time, these isolates were not specific to yellow starthistle (Bruckart 1989, Shishkoff and Bruckart 1993, 1996) and also attacked safflower (Bruckart and Dowler 1986). However, the pathogen was most aggressive on rosettes of yellow starthistle and bachelor buttons, also known as cornflower (*Centaurea cyanus*). *Puccinia jaceae* is well suited to environmental conditions found in California and other areas of infestation in North America (Bennett et al. 1991). It can attack the leaves and stem of starthistle, causing enough stress to reduce flowerhead and seed production. Additional experiments are currently underway at the USDA-ARS Foreign Disease Introduction Laboratory in Fort Dietrick, Maryland, and the organism may be available for introduction in 2001 or 2002 (Pitcairn 1999).

Chemical control

Herbicides are the most widely used method for controlling weeds, both in agricultural and non-crop environments, and are generally considered the most economic and effective. Of the 400 million ha of rangeland in the United States, about 25% were treated with herbicides in 1997 (Bussan and Dyer 1999). Herbicides can be applied to rangeland and grasslands by a number of methods, including fixed wing aircraft, helicopter, ground applicators, backpack sprayers, and rope wick applicators.

The potential risks associated with herbicide use have been widely publicized both in the scientific literature and the public press. Although these risks are often greatly exaggerated, improper use of herbicides can lead to several potential problems, including spray or vapor drift, water contamination, animal or human toxicity, selection for herbicide resistance in weeds, and reduction in plant diversity.

Risks

Spray and Vapor Drift

Herbicide drift may injure susceptible crops, ornamentals, or non-target native species. Drift can also cause non-uniform application in a field and/or reduce herbicide efficacy in controlling weeds (DiTomaso 1997).

Several factors influence drift, including spray droplet size, wind and air stability, humidity and temperature, physical properties of herbicides and their formulations, and method of application. For example, the amount of herbicide lost from the target area and the distance it moves both increase as wind velocity increases. Under inversion conditions, when cool air is near the surface under a layer of warm air, little vertical mixing of air occurs. Spray drift is most severe under these conditions since small spray droplets will fall slowly and move to adjoining areas even with very little wind. Low relative humidity and high temperature cause more rapid evaporation of spray droplets between sprayer and target. This reduces droplet size, resulting in increased potential for spray drift.

Vapor drift can occur when a herbicide volatilizes. The formulation and volatility of the compound will determine its vapor drift potential. Potential of vapor drift is greatest under high

temperatures and with ester formulations. Ester formulations of 2,4-D and triclopyr are very susceptible to vapor drift and should not be applied at temperatures above 80°F (26.5°C).

Nozzle height will depend on the type of application. It controls the distance a droplet must fall before reaching the weeds or soil. Less distance means less travel time and less drift. Wind velocity is often greater as height above ground increases, so droplets from nozzles close to the ground would be exposed to lower wind speed. Applications are more likely to be above the inversion layer when herbicides are aerially applied. This will not allow herbicides to mix with lower air layers and increase long distance drift.

A number of measures can be taken to minimize the potential for herbicide drift. Chemical treatments should be made under calm conditions, preferably when humidity is high and temperature is relatively low. Ground equipment reduces the risk of drift, and rope wick or carpet applicators nearly eliminate it. Use of the correct formulation under a particular set of conditions is important. For example, applying an ester formulation of postemergence herbicides during the hotter periods of the summer is not recommended.

Groundwater and Surface Water Contamination

Most herbicide groundwater contamination results from “point sources.” Point source contaminations include spills or leaks at storage and handling facilities, improperly discarding containers, and rinsing equipment in loading and handling areas, often times into adjacent drainage ditches. Point sources are characterized by discrete, unidentifiable locations discharging relatively high local concentrations. These contaminations can be avoided through proper calibration, mixing, and cleaning of equipment.

Non-point source groundwater contaminations of herbicides are relatively uncommon. They can occur, however, when a mobile herbicide is applied in areas with a shallow water table. In this situation, the choice of an appropriate herbicide or alternative control strategy can prevent contamination of the water source.

Surface water contamination with herbicides can occur when chemicals are applied intentionally or accidentally into ditches, irrigation channels or other bodies of water, or when soil-applied herbicides are carried away in runoff to surface waters. Direct application into water sources is generally used for control of aquatic species. In these cases, there is a restriction period prior to the use of this water for human activities. Accidental contamination of surface waters can occur when irrigation ditches are sprayed with herbicides or when buffer zones around water sources are not wide enough. In many situations, alternative methods of herbicide treatment, including rope wick application, will greatly reduce the risk of surface water contamination.

Loss of a preemergence herbicide through erosion may occur when a heavy rain follows a chemical treatment. It is possible to minimize herbicide runoff to surface waters by carefully monitoring weather forecasts before applying herbicides. Applications of preemergence herbicides should be avoided when forecasts call for heavy rainfall. Predictions of precipitation between 0.5 and 1 inch should allow a preemergence herbicide to percolate into the soil profile, thus minimizing the subsequent risk of surface runoff.

Toxicology

When used improperly, herbicides can pose a health risk. This can be minimized with proper safety techniques. Applicators should follow label directions and wear appropriate safety apparel. This is particularly true during mixing, when the applicator is exposed to the highest concentration of the herbicide.

Although animals can also be at some risk from herbicide exposure, most herbicides registered for use in non-crop areas, particularly natural ecosystems, are relatively non-toxic to wildlife. To prevent injury to wildlife, care should be taken to apply these compounds at labeled rates.

The trend in herbicide toxicity of the past 25 years has been toward registration of less toxic compounds. From 1970 to 1994, the percentage of herbicides with an LD₅₀ value (lethal dose in mg herbicide/kg fresh animal weight which kills 50% of male rats) of between 1 and 500 mg/kg decreased from 15 to 7%, while herbicides in the least toxic category (>5000 mg/kg) increased from 18 to 42%. In addition, the average LD₅₀ of herbicides registered in the United States increased from 3031 to 3806 mg/kg (DiTomaso 1997).

Herbicide Resistance

Selection for herbicide-resistant weed biotypes is greatly accelerated with the continuous use of the same herbicides, or several different herbicides with a common mode of action. The first case of herbicide resistance in yellow starthistle was detected in 1989 in Dayton, Washington (Gibbs et al. 1995, Sterling et al. 1991). This selection for picloram-resistant starthistle occurred through the continuous use of the herbicide (Callihan and Schirman 1991). In this case, the level of resistance was between 3- and 35-fold greater than a susceptible population, depending on the site of application and growth conditions (Fuerst et al. 1994, 1996). This population was also cross-resistant to clopyralid, dicamba and fluroxypyr, which have a similar mode of action as picloram (Valenzuela-Valenzuela et al. 1997), but not to triclopyr or 2,4-D, which also have the same mode of action (Fuerst et al. 1994). Although this resistance biotype has been studied by several researchers (Fuerst et al. 1996, Prather et al. 1991, Sabba et al. 1998), the specific mechanism has yet to be elucidated.

The development of picloram-resistant starthistle indicates the potential for development of resistance to clopyralid if the herbicide is used year after year. Integrated approaches for the control of invasive weeds can greatly reduce the incidence of herbicide resistant biotypes.

Effects of Herbicides on Plant Diversity

Continuous broadcast use of one herbicide or a combination will often select for plant species demonstrating greatest tolerance. In the absence of a healthy plant community composed of desirable species, one noxious weed may be replaced by another equally undesirable species insensitive to the herbicide treatment. When broadleaf selective herbicides are used, noxious annual grasses such as medusahead (*Taeniatherum caput-medusae*), downy brome (*Bromus tectorum*), or barbed goatgrass (*Aegilops triuncialis*) may become dominant. Population shifts through repeated use of a single herbicide may also reduce plant diversity and cause nutrient changes that decrease the total vigor of the range (DiTomaso 1997). For example, legume species are important components of rangelands, pastures, and wildlands and are nearly as sensitive to clopyralid as yellow starthistle. Repeated clopyralid use over multiple years may have a long-term detrimental effect on legume populations. Thus, herbicide use in rangelands should be part of an integrated weed management system.

Interestingly, in a study conducted by Northam and Callihan (1989), they showed that the number of plant species per square meter in a yellow starthistle infested area increased from 11 (untreated) to 12 following clopyralid treatment. In contrast, more non-selective postemergence herbicides, including 2,4-D and dicamba, decreased the number of species per square meter to less than 9. This experiment, however, measured species changes after only a single year of

treatment. Multiple years of herbicide application may have a more negative impact on plant diversity.

Herbicides

For yellow starthistle control, herbicides are an appropriate tool on large infestations, in highly productive soils, and around the perimeter of infestations to contain their spread (Sheley et al. 1999b). Most available compounds used for starthistle control in grasslands provide postemergence activity and very few give preemergence control (see table). In a couple of cases, a herbicide can provide excellent postemergence activity and a significant period of preemergence control, e.g. clopyralid, picloram and imazapyr. Herbicides are categorized below as preemergence, postemergence and both pre- and postemergence.

Preemergence

To be effective preemergent herbicides must be applied before seeds germinate. The long germination period of yellow starthistle requires that a preemergent material have a lengthy residual activity. Applications should be made before a rainfall, which will move the material into the soil. Because these materials adhere to soil particles, offsite movement and possible injury of susceptible plants could occur if the soil is dry and wind occurs before rain. When yellow starthistle plants have already emerged, it is possible to combine a postemergent herbicide (to control emerged plants) with a preemergent herbicide (to provide residual control of any subsequent germination) for an effective control strategy (Callihan and Lass 1996, DiTomaso et al. 1999c).

A number of non-selective preemergence herbicides will control yellow starthistle to some level, including simazine, diuron, atrazine, imazapyr, imazapic, metsulfuron, sulfometuron, chlorsulfuron, bromacil, tebuthiuron, oxyfluorfen and prometone. All these compounds are registered for use on right-of-ways or industrial sites (although not all in California), but few can be used in rangeland, pastures, or wildlands. In rangeland, only metsulfuron (not registered in California) and to some degree chlorsulfuron (not registered for pastures or rangeland in any state) provide selective control of yellow starthistle without injuring desirable grasses.

- **Atrazine** (Aatrex®) is a photosynthetic inhibitor that can control yellow starthistle at rates of 1 to 1.5 lb ai/acre (Lass and Callihan 1994a, 1994b, Lass et al. 1993b). Since atrazine is primarily a root-absorbed chemical, applications should be made before seedlings emerge. Because of ground and surface water concerns, this product is a restricted-use herbicide and requires a permit from the county agricultural commissioner (California) for its purchase or use. It is not typically used for control of yellow starthistle, except along roadsides or on industrial sites.
- **Tebuthiuron** (Spike®) is also a photosynthetic inhibitor that is used for total vegetation control. It will control yellow starthistle preemergence, but will also injure other herbaceous and woody vegetation (Callihan et al. 1991).
- **Chlorsulfuron** (Telar®) and **sulfometuron** (Oust®) are registered for roadside and other non-crop uses and are very effective at controlling yellow starthistle when applied at 1 to 2 oz ai/acre. **Metsulfuron** (Escort®) is registered in other western states, but not California, for use in rangelands. These compounds provide excellent

pre- to postemergence control of many weed species. Metsulfuron is safest on grasses, chlorsulfuron is safe on most grasses but will injure some, and sulfometuron is the most non-selective. Little postemergence activity occurs on yellow starthistle with these three compounds. The best control is achieved when applications are made before weeds emerge (Callihan et al. 1991, DiTomaso et al. 1999b, Lass and Callihan 1995b, Wilson and Costa 1986). Chlorsulfuron and metsulfuron do not have postemergence activity on yellow starthistle and therefore, must be used in combination with 2,4-D, dicamba, or triclopyr to provide some level of yellow starthistle control in grasslands. Metsulfuron appears to be more inconsistent than chlorsulfuron, sometimes providing good control and other times giving poor control (Table A, Table B). When chlorsulfuron (at 1 or 2 oz ai/acre) was combined with 2,4-D or triclopyr, yellow starthistle control improved to near 90% (Table A, B) (DiTomaso et al. 1999b).

Postemergence

A limited number of postemergence herbicides are registered for use in California rangelands, pastures, and wildlands. They include 2,4-D, dicamba, triclopyr and glyphosate. These postemergent herbicide treatments generally work best on seedlings. However, they are not effective for the long-term management of starthistle when used in spring, as they have no soil residual activity and will not control yellow starthistle plants germinating after application. Since yellow starthistle has the ability to germination throughout winter, spring and into summer whenever moisture is available, achieving control with a single application is almost impossible. A treatment following the first flush of seedlings opens the site up for later flushes. Waiting until later in the rainy season to apply a postemergent herbicide allows a greater number of seedlings to be treated, but larger plants will require higher herbicide rates and may not be controlled (DiTomaso et al. 1999c). As a result, repeated applications of broadleaf selective postemergence herbicides are often necessary (DiTomaso et al. 1999b). This increases the risk of drift to non-target species and is expensive.

Thus, the most effective way to use postemergence compounds for starthistle control is to incorporate them into later stages of a long-term management program. In particular, they are effectively used to spot-treat escaped plants or to eradicate small populations in late season when starthistle is easily visible but has yet to produce viable seed. By using spot applications in late season, total herbicide use and expenses can be reduced because only small sections or individual plants are treated. It is important to note that plants should only be treated when not exposed to severe stress. Drought stress can especially reduce the efficacy of most herbicides.

The use of glyphosate may not be desirable in areas where desirable perennial grasses are present unless starthistle plants can be directly treated without contacting non-target vegetation. Similarly, 2,4-D will cause damage to late season broadleaf species, including desirable natives.

- **2,4-D** can provide acceptable control of yellow starthistle if it is applied at the proper rate and time. Treating plants in the rosette growth stage provides better control than later applications. Amine forms are as effective as ester forms at the small rosette growth stage, but amine forms reduce the chance of off-target movement.

Application rates of 0.5 to 0.75 lb ae/acre will control small rosettes.

Applications made later in the season, when rosettes are larger or after bolting has been initiated, require a higher application rate (1 to 2 lb ae/acre) to achieve

equivalent control (DiTomaso et al. 1999b, Northam and Callihan 1991, Whitson and Costa 1986) [see Tables A, B, C]. 2,4-D is a growth regulator selective herbicide and will control other broadleaf plants, but generally will not harm grasses. It has little, if any soil activity. Drift from 2,4-D applications is common, particularly from the ester formulations. 2,4-D is a restricted use pesticide, requiring a permit for use.

- **Dicamba** is very effective at controlling yellow starthistle at rates as low as 0.25 lb ae/acre (Callihan and Schirman 1991). When yellow starthistle rosettes are small, about 1 to 1.5 inches across, the 0.25 lb ae/acre rate works well, but higher rates (0.5 to 1.0 lb ai/acre) are needed if plants are larger (Northam and Callihan 1991). Applications made in late rosette to early bolting stages have provided excellent control, although earlier treatments are better.

Dicamba is also a growth regulator selective herbicide that controls many broadleaf plants, but generally will not harm grasses. Its soil activity is very short. Like 2,4-D, it also is available in both an amine and ester formulation. Drift from dicamba applications is common, especially from the ester formulation. Dicamba is a restricted use pesticide, requiring a permit to use.

- **Triclopyr** at 0.5 lb ae/acre provides fair to complete control of yellow starthistle seedlings. Larger plants require higher rates, up to 0.75 or 1.5 lb ae/acre (DiTomaso et al. 1999b, Northam and Callihan 1991). Higher rates can give almost complete control (Callihan et al. 1991), but are too expensive and may be above labeled rates. Like 2,4-D and dicamba, triclopyr is a growth regulator herbicide with little or no residual activity. It is foliar-absorbed and active on broadleaf species, and typically will not harm grasses. Triclopyr is formulated as both an amine and ester. The ester formulation is more sensitive to drift than the amine form. Triclopyr does not seem to be as effective as either dicamba or 2,4-D on older starthistle plants.
- **Glyphosate** controls yellow starthistle at 1 lb ae/acre (DiTomaso et al. 1999b). Good coverage, clean water, and actively growing yellow starthistle plants are all essential for adequate control. Unlike the growth regulator herbicides, glyphosate is non-selective and controls most plants, including grasses. It has no soil activity and has an excellent toxicology profile (Giesy et al. 2000). A 1% solution of glyphosate also provides effective control and is used at this concentration for spot treatment of small patches. Glyphosate is a very effective method of controlling starthistle plants in the bolting, spiny, and early flowering stages at 1 to 2 lb ae/acre. However, it is important to use caution when desirable perennial grasses are present.

Late-season starthistle control

In all late season treatments, except with glyphosate, a surfactant should be added (DiTomaso et al. 1999b). Because late-season control typically occurs during the warmer spring or early summer months, amine formulations of 2,4-D, dicamba, and triclopyr are more appropriate than ester forms. Triclopyr provides only marginal control in the bolting stage and poor control at later growth stages. Glyphosate, dicamba, and higher rates of clopyralid and triclopyr are effective with plants in the bolting stage (DiTomaso et al. 1999b).

If late-season yellow starthistle control is necessary, the best time to treat with glyphosate is after annual grasses or broadleaf species have completed their life cycle, but prior to yellow starthistle seed production (<5% flowering). Control is less effective when mature plants show physical signs of drought stress. When clopyralid was previously applied in late winter or early spring, glyphosate can be used in a broadcast or spot treatment follow-up program to kill uncontrolled plants before they produce seed. It can also be used to prevent the proliferation of potential clopyralid-resistant plants. Broadcast treatment with glyphosate is not recommended when desirable perennial grasses or broadleaf species are present.

Pre- and postemergence

The most effective herbicides for season-long control of yellow starthistle are those that provide postemergence control of seedlings and rosettes, as well as soil residual activity for at least a couple of months until spring rainfall is completed. Of the compounds that have these characteristics, clopyralid (Transline®, Stinger®) and picloram (Tordon®) are the most effective and are the least injurious to grasses. Picloram is not registered in California.

Imazapic and imazapyr

Both imazapic (Plateau®) and imazapyr (Stalker®, Arsenal®, Chopper®) are branched-chain amino acid inhibitor with the same mode of action as chlorsulfuron, metsulfuron, and sulfometuron.

Imazapic is not yet registered in California. It is a broad spectrum herbicide often used in perennial grass re-vegetation efforts. Although it has some activity on yellow starthistle, results are very inconsistent (Shinn and Thill 1998, 1999, 2000a, 2000b). The use of imazapic alone is not likely to provide effective control of yellow starthistle.

Imazapyr is also a broad spectrum herbicide with both pre- and postemergence activity on yellow starthistle (Northam and Callihan 1991). Unlike the growth regulator compounds, imazapyr will cause significant injury to grasses.

Clopyralid

General characteristics. Prior to 1998, few herbicides were available in California for season-long control of yellow starthistle in pasture, rangeland or wildland areas. With the registration of clopyralid in California in 1998, ranchers and land managers have a highly selective herbicide available for starthistle management. It is a growth regulator with similar activity to 2,4-D, dicamba, triclopyr, and picloram. Unlike 2,4-D, dicamba, and triclopyr, clopyralid has excellent soil (preemergence) and foliar (postemergence) activity. It is important to remember, however, that it is a much slower acting compound than the other postemergence growth regulators and often requires two months to control starthistle. Injury symptoms are typical of other growth regulators and include epinastic bending and twisting of the stems and petioles, stem swelling and elongation, and leaf cupping and curling. This is followed by chlorosis (yellowing), growth inhibition, wilting and eventually death. At low concentrations, the young leaf tips may develop narrow feather-like extensions of the midrib.

Clopyralid is very effective for the control of yellow starthistle at extremely low rates (1.5 to 4 oz ae/acre; 4 to 10 oz product/acre). It also has a broad timing window, does not appear to negatively impact insect biological control agents (Pitcairn and DiTomaso 2000), and has a very low toxicology profile (Caution Signal Word) with no grazing restrictions. For a detailed evaluation of the toxicology of clopyralid click on this sentence. The registration of this

compound in California has generated great interest by ranchers and landowners threatened by large yellow starthistle infestation.

Soil properties. Clopyralid is weakly adsorbed to soil, does not volatilize, and is not photodecomposed to any degree. It is degraded by microbial activity with an average half-life in soil of between 12 and 70 days, depending on the soil type and climate. The mobility of clopyralid in soil is considered moderate, so some leaching can occur. For example, following a 4 oz ae/acre treatment (highest labeled rate) of clopyralid to bare ground in Fresno, California, 99% of the residual herbicide was found in the top 18 inches of the soil 4 months (80% normal rainfall) after treatment. In the same study, clopyralid degraded to 1% of the total applied herbicide after 3 months. Thus, under normal rainfall conditions in yellow starthistle infested western grassland, clopyralid leaching into groundwater is not likely to present a problem.

Selectivity. Clopyralid is a very selective herbicide and does not injure grasses or most broadleaf species. However, depending on the timing of application, it does damage or kill most species in the legume family (Fabaceae), as well as the sunflower family (Asteraceae), and this may not be a desired outcome in a control program with the goal of increasing native plant diversity or enhancing a threatened native plant population susceptible to the herbicide. It can also cause some injury in members of the nightshade (Solanaceae), knotweed (Polygonaceae), carrot (Apiaceae), and violet (Violaceae) families. In contrast, many other broadleaf species, including species in the mustard family (Brassicaceae) and filarees (*Erodium* spp.), are very tolerant to the herbicide.

Rate and timing. Clopyralid provides excellent control of yellow starthistle seedlings and rosettes between its registered use rates of 1.5 and 4 oz ae/acre (Carrithers et al. 1997, DiTomaso et al. 1999b, Gaiser et al. 1997, Johnson 2000, Lass and Callihan 1995b, Northam and Callihan 1991, Wrynski et al. 1999) [Table A, B]. In other western states the highest use rate of clopyralid is 8 oz ae/acre. Season-long control can be obtained with one application made from December through April, but maximum grass forage was obtained with mid- to late winter treatments (DiTomaso et al. 1999b). The most effective timing for application is from January to February, when yellow starthistle is in the early rosette stage. Applications earlier than December may not provide full season control and treatments after May usually require higher rates.

Clopyralid is also effective on plants in the bolting and bud stage, but higher rates (4 oz ae/acre) are required. Applications made after the bud stage will not prevent the development of viable seed (Carrithers et al. 1997, Gaiser et al. 1997).

Combinations and adjuvants. When clopyralid is used to control seedlings a surfactant is not necessary (DiTomaso et al. 1999b). However, when treating older plants or plants exposed to moderate levels of drought stress, surfactants can enhance the activity of the herbicide.

A combination of clopyralid and 2,4-D amine is sold as Curtail® in western states other than California. It can be used at 0.25 to 1 pint/acre after the majority of starthistle rosettes have emerged but before bud formation.

Clopyralid can also be treated using a liquid fertilizer as a carrier (Evans 1998). This can provide effective control of starthistle and enhance the growth of desirable grasses and broadleaf species.

Effects of forage. Late season treatments with clopyralid (April to June) can have a negative impact on forage quantity. Reduced forage at later treatment times is likely due to the competitive effects of yellow starthistle on grass development during the early spring months. Desirable forage biomass is maximized with an early season treatment (December to March). At this timing, yellow starthistle is in the early rosette stage. Early season treatments also give better control.

Coverage with previous years skeletons. It is often questioned whether clopyralid treatment over the top of skeletons from the previous years' infestation will reduce the activity of the herbicide. However, DiTomaso et al. (1999c) demonstrated that control of yellow starthistle was better in the presence of skeletons compared to the areas where skeletons were removed. This difference was attributed to the reduced number of seedlings present in the area shaded by the previous year's skeletons. Consequently, fewer seedlings were available to escape injury in the shaded plots.

Fit into strategic management plan. In most circumstances clopyralid can be an important component in a yellow starthistle management program. For example, clopyralid is often a very 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 when the competitive interactions for soil moisture are minimal, 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 more advantageous to delay the use of clopyralid or other preemergence herbicide until the extent of the problem can be evaluated. In these situations, a prescribed burn, mowing, physical removal, or spot application can be sufficient. In some instances one or two years of control can dramatically reduce the starthistle infestation to very low or even nearly insignificant levels. When this occurs, an additional application of clopyralid or another postemergence herbicide would be unnecessary.

Picloram

Picloram is the most widely used herbicide to control yellow starthistle in western states other than California, where it is not registered. It acts much like clopyralid, but gives a broader spectrum of control and has much longer soil residual activity. Picloram is applied (usually with a surfactant) at a rate between 0.25 lb and 0.375 lb ae/acre when plants are still in the rosette through bud formation stages (Callihan et al. 1989, Callihan and Lass 1996, Callihan and Schirman 1991, Carrithers et al. 1997, Gaiser et al. 1997, Larson and McInnis 1989b, Lass and Callihan 1995b, Northam and Callihan 1991, Whitson and Costa 1986) [Table A, B, C]. This is typically from late winter to early spring. This treatment can provide effective control for about two to three years (Callihan et al. 1989). Although well developed grasses are not usually injured by labeled use rates, young grass seedlings with less than four leaves may be killed (Sheley et al. 1999b).

Commonly used herbicides for yellow starthistle control (in part from Bussan and Dyer 1999).

Common name	Trade name	Mode of action	Weed Spectrum	Soil residual	Registered in California	Effectiveness on yellow starthistle
2,4-D	Weedar [®] , Weedone [®] and many others	Growth regulator	Broadleaf species	No; less than 2 weeks	Yes	Yes; postemergence only from seedling to bolting
Chlorsulfuron	Telar [®]	Amino acid synthesis inhibitor	Mainly broadleaf species	Yes; at least 2 months	Yes; not in rangelands	Yes; preemergence only
Clopyralid	Transline [®] Stinger [®]	Growth regulator	Certain broadleaf families (e.g., Asteraceae, Fabaceae, Umbelliferae, Solanaceae, Polygonaceae)	Yes; full season	Yes	Yes; effective both pre- and postemergence
Dicamba	Banvel [®] Vanquish [®]	Growth regulator	Broadleaf species	No; less than 1 month	Yes	Yes; postemergence only from seedling to bolting
Glyphosate	Roundup [®]	Amino acid synthesis inhibitor	Non-selective	No	Yes	Yes; postemergence only from seedling to early flowering
Imazapyr	Stalker [®] Arsenal [®]	Amino acid synthesis inhibitor	Non-selective	Yes; full season	Yes; not in rangelands	Yes; mainly as a preemergence treatment, postemergence control with seedlings or rosettes
Metsulfuron	Escort [®]	Amino acid synthesis inhibitor	Broadleaf species	Yes; at least 2 months	No	Fair; preemergence only
Picloram	Tordon [®]	Growth regulator	Broadleaf species, weak on mustards	Yes; up to 3 years	No	Yes; effective both pre- and postemergence; applied fall, winter or spring
Triclopyr	Garlon [®] , Remedy [®]	Growth regulator	Broadleaf species	No; less than 1 month	Yes	Yes; postemergence only, good on seedlings, fair on mature plants

Integrated approaches

Most often a single method is not effective in the 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 will have to be tailored to the site, economics, and management goals. Sometime the control techniques must be in a particular sequence to be successful. For example, in a re-vegetation effort along a yellow starthistle infested canal and roadside the first step was to intensively manage starthistle (Brown et al. 1993, Thomsen et al. 1994). The second step was to reseed with deep-rooted native perennial grasses. In the final stage, native broadleaf forbs such as California poppy and lupines were seeded into the system.

In another study, 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, 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).

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

Using another integrated approach, Pitcairn et al. (1999a, 2000a) hypothesize that combining clopyralid applications with insect biocontrol agents might provide for more effective long-term control of yellow starthistle. Clopyralid applications would reduce plant density and the seed bank. The attack of biocontrol insects on escaped plants in subsequent years should slow the rate of re-infestation by impacting the few seedheads available. Results thus far indicate that the combination of 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 seedheads of escaped plants (Table A, B). It is hoped that seed destruction by the established biological control agents can retard resurgence to 4-6 years and thereby reduce the need for continuous herbicide treatments. This would lower the economic costs required for effective long-term management of yellow starthistle.

A number of other studies are underway to assess various combinations of techniques for starthistle control. UC researchers are investigating the effectiveness of integrating summer prescribed burning and clopyralid treatment. The objective is to determine which sequence is likely to have the greatest benefit for rangeland health, as indicated by plant species diversity and by forage quality and quantity.

In a multi-agency large-scale study at Fort Hunter Liggett in southern Monterey County, researchers are testing integrated approaches combining spring and summer herbicide applications, prescribed burning, and biological control agents. Five-year management plans have been developed for open grasslands 1) used primarily for military training, 2) surrounded by valley and blue oaks, and 3) with rare plants or species of concern. The goal of each of these management plans is to control yellow starthistle, enhance the integrity and utility of the ecosystem, and prevent re-invasion.

As previously described, re-vegetation projects for yellow starthistle control nearly always rely on integrated strategies. In most cases, it is difficult to establish desired plants without the management of competing vegetation, including starthistle and annual grasses. The goal of these re-vegetation projects is to develop sustainable high quality range conditions and improved wildlife habitat capable of providing long-term starthistle control without the need for continued herbicide treatments.

In a project on severely degraded rangeland in northern California, an integrated combination of clopyralid treatment and pubescent wheatgrass seeding (see re-vegetation section) was shown to be very effective in suppressing yellow starthistle seed production and providing a more effective long-term solution than applying clopyralid alone (Enloe et al. 1999a, 1999b). This strategy is also compatible with the survival of, yellow starthistle biocontrol agents. With the integration of these insects, it is possible that starthistle seed production will be reduced, further slowing the re-infestation rate.

Summary of control options

<u>MECHANICAL</u>	
Hand pulling, hoeing, weed whipping	
Advantages	Excellent when only a few plants persist or when new small infestations occur. Good method when 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 of other treatments when starthistle population is low.

<u>MECHANICAL</u>	
Tillage	
Advantages	Can provide excellent control in agricultural areas, orchards, vineyards, roadsides, urban areas and other sites where tillage is practical.
Disadvantages	Not usually practical in wildlands or most rangelands.
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.

<u>MECHANICAL</u>	
Mowing	
Advantages	Relatively inexpensive. Removes skeletons.
Disadvantages	Generally will not provide complete control. Can damage late season natives and biological control insects.
Risks	Improper timing or growth form of starthistle can lead to increased infestation. Hazards associated with sparks and flying debris.
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.

<u>CULTURAL</u>	
Grazing	
Advantages	Good forage when grazed at proper time. Can release small forbs from shade suppression if area is not 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.
Timing	From time yellow starthistle begins to bolt to development of spiny seedheads. Goats can be used later 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 option(s). In later years, it can be used to maintain low levels of starthistle. Proper grazing can be a good method of preventing re-infestation.

<u>CULTURAL</u>	
Prescribed burning	
Advantages	Very effective control with complete burn. Can stimulate native plants, particularly legumes and perennial grasses.
Disadvantages	Harmful to biological control agents. May injure some late season natives.
Risks	Escaped fires and air quality issues. Can cause wildlife 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 second year when the first year's control method provides increased grass biomass for fuel in the second year.

<u>CULTURAL</u>	
Re-vegetation	
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.
Risks	When re-vegetating with non-natives: re-seeded species may spread to become invasive in areas it is not desired.
Timing	Late winter to early spring, depending on the area and whether an integrated approach is used.
Best fit in strategic management plan	First year strategy in combination with chemical control. Can also be used in second year after weed populations have been reduced in first year. Should always be part of an integrated management approach.

<u>BIOLOGICAL CONTROL</u>	
Advantages	Reduces starthistle seed production by 50-75%. With potential new introductions there is the possibility of long-term and sustainable management.
Disadvantages	Not usually successful when used as the sole control option.
Risks	Small risk that organisms might shift host to native or economically important species.
Timing	All 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.

<u>CHEMICAL</u>	
2,4-D (many names), dicamba (Banvel), triclopyr (Garlon, Remedy)	
Advantages	Good postemergence control of broadleaf weeds.
Disadvantages	Can injure desirable broadleaf species. Do 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.

<u>CHEMICAL</u>	
Glyphosate (Roundup)	
Advantages	Very effective for starthistle control.
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 seedlings are controlled, 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.

<u>CHEMICAL</u>	
Chlorsulfuron (Telar), Metsulfuron (Escort)	
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	In California, chlorsulfuron is only registered for use in non-crop areas, not rangelands. 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 in combination with 2,4-D, dicamba, and triclopyr.
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. In other states, metsulfuron will provide less control than chlorsulfuron and is registered for use in rangelands. Imazapyr (Stalker in California) has same mode of action and similar effect on yellow starthistle, but is not registered for use in rangeland.

<u>CHEMICAL</u>	
Clopyralid (Transline)	
Advantages	Provides excellent control at low rates. Gives both pre- and post emergence 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 with continuous use. Resistant yellow starthistle biotype has been reported in Washington, but not in California.
Risks	Herbicide drift, applicator safety.
Timing	From late fall to early spring is best. 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.

<u>CHEMICAL</u>	
Picloram (Tordon)	
Advantages	Provides excellent control. Gives both pre- and postemergence control. Active in soil for at least two seasons. No injury to grasses.
Disadvantages	Not registered for use in California. Resistant yellow starthistle biotype has been reported in Washington.
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	Because of the long residual activity of picloram, it is not typically used in an integrated approach in combination with strategies other than biological control and perennial grass re-vegetation.

DEVELOPING A STRATEGIC MANAGEMENT PLAN

Prevention

Yellow starthistle infests about 15 to 20 million acres in California, but has the potential to infest nearly 40 million acres (Pitcairn et al. 1998b). Consequently, preventing the introduction of rangeland weeds 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 programs are to prevent introduction or re-invasion of starthistle weed seed, reduce the susceptibility of the ecosystem to yellow starthistle establishment, develop effective education materials and activities, and establish 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 a herbicide (Sheley et al. 1999c).

In many cases, however, introduction of yellow starthistle and other noxious weeds onto grasslands can be associated with human-related activities. Seeds or plant vegetative fragments can be introduced as contaminants of hay or animal feed. This can be prevented by using feed that is certified as weed-free (Sheley et al. 1999c). Transporting soil contaminated with starthistle can lead to new infestations. This is a common method of introducing yellow starthistle seed along roadsides or in construction sites.

Livestock can move starthistle seeds from one area to another by passing viable seed through their digestive system or by transporting seed attached to hair or soil particles. 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 un-infested areas (Sheley et al. 1998).

Equipment and vehicles driven through infested landscapes can transport yellow starthistle seed to un-infested areas. Even human clothing can transport seed, particular in soil particles attached to shoes and boots. Equipment and clothing should be cleaned immediately after leaving an infested site.

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

Susceptible landscapes

Yellow starthistle often becomes established 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 re-vegetated with desirable species to slow the invasion of yellow starthistle.

Proper grazing can maintain desired plants and provide a more competitive environment. To minimize starthistle invasions, overgrazing is discouraged 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). Re-vegetation with aggressive perennial grasses can prevent establishment of starthistle (Enloe et al. 1999a, 1999b, 2000). 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

Educating employees and the public can be accomplished 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 academia, industry, landowners, land managers, or the general public. These can include public seminars, professional symposia, school programs, academic field demonstrations, and volunteer field workshops conducted by church groups, environmental organizations, scouts, and several other 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 events or 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 best management of starthistle 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. 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 un-infested areas it may be possible to eradicate new small invasions. An effective eradication program is closely tied to prevention. The key element to a successful eradication plan is 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 seed are depleted from the soil.

Eradication efforts are usually confined to smaller infestations (< 2 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). An eradication plan can be developed for small (<5 ha) or large (>50 ha) starthistle infestations. Financial resources, available technology, potential benefits, and social and geographical constraints will limit the size of the infested area that can be targeted for starthistle eradication (Zamora and Thill 1999). In some cases, large eradication programs require re-vegetation to completely eliminate yellow starthistle. Even when all these issues are considered, complete eradication of large infestations is rare.

Developing a Management Strategy

Once yellow starthistle is well established, eradication is not practical without extremely high financial and labor inputs. The ultimate objective under these circumstances is to manage the infested area and contain the large-scale infestation. However, the goal of any management plan should not simply be control of the noxious weed(s), but improvement of the degraded rangeland community, enhanced utility of the ecosystem, and prevention of reinvasion or invasion by other noxious weed species. In severely deteriorated starthistle-infested grasslands, it may be necessary to reintroduce desirable plant mixtures. Ideally, a healthy weed-resistant plant community would consist of a diverse group of species that occupy most of the niches.

An effective yellow starthistle management strategy should include three major goals; 1) effective control of the weed, 2) achieve the desired land-use objectives such as forage production, wildlife habitat development, or recreational land maintenance, 3) prevention of re-

invasion of starthistle or invasion of equally invasive species. To accomplish these goals, land managers will require an understanding of the land use objectives, management limitations, and biology of the system.

Understanding the land use objectives of a weed management system is critical to determining the proper management approach. Management strategies will differ if the primary goal is to enhance forage quantity and quality for livestock and wildlife, restore native vegetation or endangered species, or increase recreational value. In addition, selection of the proper management tool(s) and program may depend 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 aspects in developing a yellow starthistle or any noxious weed management strategy is to accurately identify and map lands infested with the weed(s) (Sheley et al. 1998). Knowing where the infestations occur can determine the control method used, assist in prioritizing the management strategy, and identify areas where eradication, containment, or management can be achieved. In addition, this information can prevent unnecessary herbicide treatments and slow the spread of the weed.

Weed infestations should be identified on a map and records should contain weed species present, areas infested, weed density, rangeland under threat of invasion, soil and range types, and other site factors pertinent to successful management of noxious weed-infested rangeland (Sheley et al. 1998). Continual monitoring will be necessary to prevent reinvading populations from becoming established. A number of monitoring techniques can be used, including hand drawing infested sites on a map, using GPS (global positions system) units and plotting the data using GIS (geographical information system) programs (Cooksey and Sheley 1998), or more sophisticated techniques such as using aerial remote sensing equipment (Lass et al. 1995, 1996, 2000, Price et al. 1998).

A thorough understanding of the biology and ecology of yellow starthistle, as well as the grassland system it infests, is necessary for long-term management. Much of this information is available in the Biology and Ecology section of this site. In addition to understanding the biology and ecology of the weed, it is important to be familiar with characteristics of the ecosystem. This can include an awareness of other desirable and weedy species present, the potential for invasion into other yet un-infested sites within the area, impact of the management strategy on sensitive species and habitats, soil conditions and range types present, as well as other ecosystem parameters.

A coordinated effort among interested parties, including the general public, private and public landowners, federal, state and county agencies, 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 is typically achieved through the development of a Weed Management Area (see specific section on WMA or the California Department of Food and Agriculture web site at <http://www.cdfa.ca.gov/wma>).

To view the "Strategic Plan for the Coordinated Management of Noxious Weeds in California" produced by the Range Management Advisory Committee click on this sentence.

Implementing Strategic Plan

Implementing a strategic plan is the most critical aspect of yellow starthistle management and 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. Limited funding may require prioritizing areas of greatest concern. For example, the decision to re-vegetate 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, whenever possible, an integration of mechanical, cultural, biological, and chemical techniques. A long-term commitment of three to many years will be necessary in nearly all cases to deplete the weed seedbank. It is not unusual for yellow starthistle plants to be larger after a single year of control (Callihan and Lass 1996). It will require a significant reduction in the seedbank and an increase in seedbank of the desirable competing species before dramatic results can be observed. 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.

Once the desired objectives have been attained, a yearly follow up program will be necessary to prevent starthistle re-infestation. This may involve annual hand pulling, spot herbicide treatments, or even periodic burning (DiTomaso 2000). In addition, changes in grazing practices may be required to ensure that rangeland conditions do not become susceptible to rapid re-infestation. If follow-up is not made for 2 to 3 years following a control program, the grassland will usually become heavily re-infested in a short time.

WEED MANAGEMENT AREAS

Weed Management Areas (WMAs) are local organizations that bring together landowners and private, city, county, state, and federal managers in a county, multi-county, or other geographical area to coordinate efforts and expertise against common invasive weed species (Schoenig 2000a, b). The WMA functions under the authority of a mutually developed memorandum of understanding (MOU). To date, groups in California have been initiated by either the leadership of the County Agricultural Commissioner's Office or a Federal Agency employee.

The participants of WMAs have been quite diverse and can include 1) federal agencies (BLM, Forest Service, NRCS, Park Service, and the Department of Defense), 2) state agencies (CDFA, parks, Fish and Game, forestry and fire, CalTrans, UC Cooperative Extension), 3) county agencies (ag department, roadways, parks, fire abatement), 4) environmental organizations (CNPS, CalEPPC), and 5) private groups (growers, cattlemen, RCDs, forest industry, landowners, volunteers, pest control operators and advisors, open spaces, water districts, city officials, railroads, utilities, and nurserymen).

Some of the activities of the WMAs include developing weed I.D./control brochures, organizing weed education events, writing and obtaining grants, coordinating demonstration plots, and instituting joint eradication, mapping, outreach, and other effective weed management projects (Ebright 2000). For general information on WMAs or individual information on

specific WMAs see the CDFA Cooperative Weed Management Area website (www.cdfa.ca.gov/wma).

LEGISLATION

Awareness of invasive species, including yellow starthistle, has increased dramatically in the past few years. Numerous television and radio reports, news stories, and review articles have targeted their educational efforts at the general public (DiTomaso et al. 2000d). As a result of these efforts, pressure to manage yellow starthistle and other noxious wildland weeds has led to legislative changes and increased funding opportunities. In addition, state and federal public agencies have focused much greater attention on noxious weed management. For example, CalTrans and the California Department of Food and Agriculture (CDFA) have teamed up to map the leading edge of yellow starthistle encroachment along the eastern and southwestern side of the Sierra Nevada range. The main product of this effort is to identify areas of high priority and implement management options to prevent further movement in California.

With the confidence that options now exist for successful management of yellow starthistle, California legislators introduced Assembly Bill 1168 in 1999 and Senate Bill 1740 in 2000 that create Noxious Weed Management Funds. The Governor signed both these bills. Assembly Bill 1168 appropriated \$200,000 a year for three years. This money was used to assist the more established Weed Management Areas (WMAs) and was primarily used to map and control yellow starthistle. Senate Bill 1740 appropriated \$5 million dollars, of which \$4,250,000 will be used to assist WMAs in their control efforts. To receive funding, the WMAs are required to develop a strategic plan for the management of yellow starthistle or other important invasive weed species. Another \$250,000 will be used internally by CDFA for the coordination of WMAs and to administer the funding. Finally, \$500,000 will be directed toward a competitive research program for studying the biology and management of noxious weeds in California. For a copy of SB 1740 double-click on the bill number.

On a national level, President Clinton signed the Executive Order on Invasive Species in 1999. This order puts greater federal emphasis on invasive species management, including noxious weeds. To facilitate these efforts, a national panel of invasive weed researchers recently published recommendations for improving prevention practices, public awareness, monitoring and reporting, mitigation and control, and legislation and regulation of invasive plant species (Mullin et al. 2000).

REFERENCES

1. Akbar, S., D.S. Fries, and M.H. Malone. 1995. Effect of various pretreatments on the hypothermic activity of repin in naive rats. *Journal of Ethnopharmacology* 49(2):91-99.
2. Andres, L.A. and N.E. Rees. 1995. Musk thistle. Pages 248-251. Nechols, J.R., L.A. Andres, J.W. Beardsley, R.D. Goeden and C.G. Jackson, eds. In, *Biological Control in the Western United States*. University of California, Division of Agriculture and Natural Resources, Oakland, California. Publication 3361.
3. Balciunas, J. and B. Villegas. 1999. Two new seed head flies attach yellow starthistle. *California Agriculture* 53(2):8-11.

4. Barry, S. 1995. Cattle fecal fax. University of California, Cooperative Extension. October Report, Nov. 7, 1995.
5. Barthell, J.F., R.W. Thorp, A.M. Wenner, and J.M. Randall. 2000. Yellow star-thistle, gumplant, and feral honey bees on Santa Cruz Island: A case of invaders assisting invaders. Proc., California Islands Sym. 1999. Camarillo, CA. 5:269-273.
6. Benefield, C.B., J.M. DiTomaso, and G.B. Kyser. 1998. Impacts of yellow starthistle density on the soil moisture profile and rangeland management. Proc., Western Society of Weed Science. 51:66.
7. Benefield, C.B., J.M. DiTomaso, G.B. Kyser, S.B. Orloff, K.R. Churches, D.B. Marcum, and G.A. Nader. 1999. Success of mowing to control yellow starthistle depends on timing and plant's branching form. California Agriculture 53(2):17-21.
8. Benefield, C.B., J.M. DiTomaso, G.B. Kyser, and A. Tschohl. 2001. Reproductive biology of yellow starthistle (*Centaurea solstitialis*): Maximizing late season control. Weed Science 49:83-90.
9. Bennett, A.R., W.L. Bruckart, and N. Shishkoff. 1991. Effects of dew, plant age, and leaf position on the susceptibility of yellow starthistle to *Puccinia jaceae*. Journal of the American Phytopathological Society 75(5):499-501.
10. Billings, W. D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. Pages 22-30. S.B. Monsen and S.G. Kitchen, eds. In, Proc. Ecology and Management of Annual Rangelands. U.S.D.A. For. Serv. Intermt. Res. Stat., General Tech. Rept. INT-GTR-313, Ogden, UT.
11. Binder, R.G., C.E. Turner, and R.A. Flath. 1990. Comparison of yellow starthistle volatiles from different plant parts. Journal of Agricultural and Food Chemistry 38:764-767.
12. Blosssey, B., D. Schroeder, S.D. Hight, and R.A. Malecki. 1994. Host specificity and environmental impact of the weevil *Hylobius transversovittatus*, a biological control agent of purple loosestrife (*Lythrum salicaria*). Weed Sci. 42:128-133.
13. Borchert, M.I. and S.K. Jain. 1978. The effect of rodent seed predation on four species of California annual grasses. Oecologia 33:101-113.
14. Borman, M.M., D.E. Johnson, and W.C. Krueger. 1992. Soil moisture extraction by vegetation in a Mediterranean/Maritime climatic regime. Agronomy Journal 84:897-904.
15. Borman, M.M., W.C. Krueger, and D.E. Johnson. 1991. Effects of established perennial grasses on yields of associated annual weeds. Journal of Range Management 44:318-322.
16. Brown, C.S., R.L. Bugg, and J.H. Anderson. 1993. Roadside planting of perennial grasses. Grasslands 3(4):1-3.
17. Bruckart, W.L. 1989. Host range determination of *Puccinia jaceae* from yellow starthistle. Plant Disease 73:155-160.
18. Bruckart, W.L. and W.M. Dowler. 1986. Evaluation of exotic rust fungi in the United States for classical biological control of weeds. Weed Science 34 (supplement 1):11-14.
19. Bruno, M., J.G. Diaz, and W. Herz. 1991. Guaianolides and lignans from *Centaurea solstitialis* subsp. *schouwii*. Phytochemistry 30:4165-4166.
20. Bussan, A.J. and W.E. Dyer. 1999. Herbicides and rangeland. Pages 116-132 in R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Oregon St. Univ. Press, Corvallis.
21. Buttery, R.G., D.M. Maddox, D.M. Light, and L.C. Ling. 1986. Volatile components of yellow starthistle. Journal of Agricultural and Food Chemistry 34(5):786-788.

22. Callihan, R.H. and J.O. Evans. 1991. Weed dynamics on rangeland. Pages 55-61. J.O. Evans, M.H. Ralphs, and R.D. Child, eds. In, L. F. James, Noxious Range Weeds, Westview Press, San Francisco, CA.
23. Callihan, R.H., C.H. Huston, and D.C. Thill. 1986. Establishment of intermediate wheatgrass in a yellow starthistle- infested range. Res. Prog. Rep. West. Soc. Weed. Sci. pp. 49-50.
24. Callihan, R.H. and L.W. Lass. 1996. Yellow starthistle management with herbicides. Current Info. Series No. 1036, 12 pp. Univ. Idaho, College of Agriculture.
25. Callihan, R.H., L.W. Lass, C.W. Hunt, and G. Pritchard. 1995. Comparative digestibility of yellow starthistle (*Centaurea solstitialis*). Res. Prog. Rep. West. Soc. Weed. Sci. pg 36.
26. Callihan, R.H., F.E. Northam, J.B. Johnson, E.L. Michalson, and T.S. Prather. 1989. Yellow starthistle. Biology and management in pasture and rangeland. Current Info. Series No. 634, 4 pp. Univ. Idaho, College of Agriculture.
27. Callihan, R.H., T.S. Prather, and F.E. Northam. 1993. Longevity of yellow starthistle (*Centaurea solstitialis*) achenes in soil. Weed Technology 7:33-35.
28. Callihan, R.H., R.L. Sheley, and D.C. Thill. 1982. Yellow starthistle: identification and control. Current Info. Series No. 634, 4 pp. University of Idaho, College of Agriculture.
29. Callihan, R.H. and R.O. Schirman. 1991. Effects of five hormone-type herbicides on the survival of yellow starthistle seedlings from a known susceptible population and a suspected picloram resistant population. Res. Prog. Rep. West. Soc. Weed Sci., pp. 40-42.
30. Callihan, R.H., R.O. Schirman, and W.J. Price. 1991. Effects of winter and spring applied herbicides on yellow starthistle density. Res. Prog. Rep. West. Soc. Weed Sci., pp. 36-37.
31. Campobasso, G., R. Sobhian, L. Knutson, and G. Terragitti. 1998. Host specificity of *Bangasternus orientalis* Capiomont (Coleoptera: Curculionidae) introduced into the United States for biological control of yellow starthistle (*Centaurea solstitialis* L., Asteraceae: Cardueae). Environ. Entomol. 27(6):1525-1530.
32. Carlson, J.E., N.K. Konn, and E.L. Michalson. 1985. The behavior and attitudes of North-central Idaho, farmers and ranchers toward yellow starthistle. Res. Bull. Agric. Exp. Stn. Univ. Idaho. Series No. 138. 8 pp. Moscow, Idaho.
33. Carlson, J.E., D.B. Willis, E.L. Michalson, and R.H. Callihan. 1990. Yellow starthistle in North-Central Idaho: A survey of farmers' and ranchers' behavior and attitudes (1982 and 1988). Bull. Idaho Agric. Exp. Stn. Series No. 11[712], pp. 2-10. Moscow, Idaho.
34. Carrithers, V.G., D.R. Gaiser, C. Duncan, and D. Horton. 1997. Seed germination of yellow starthistle and spotted knapweed after treatment with picloram or clopyralid. Proc., West. Soc. Weed Sci. 50:39-40.
35. Cassidy, J.M., D. Abramson, P. Cowall, C. Chang, and J.L. McLaughlin. 1979. Centaurepensin: a cytotoxic constituent of *Centaurea solstitialis* and *C. repens* (Asteraceae). Journal of Natural Products 42:427-429.
36. Cheeke, P.R. and L.R. Shull. 1985. Other plant toxins and poisonous plants. Ch. 11. Pages 358-392. In, Natural Toxicants in Feeds and Poisonous Plants. The Avi Publ. Co., Westport, CT.
37. Civeyrel, L. and D. Simberloff. 1996. A tale of two snails: is the cure worse than the disease? Biodiversity and Conservation. 5:1231-1252.

38. Clement, S.L. 1990. Insect natural enemies of yellow starthistle in Southern Europe and the selection of candidate biological control agents. *Environmental Entomology* 19(6):1882-1888.
39. Clement, S.L. 1994. Resistance among populations of yellow starthistle to thistle-head insects: results from garden plots in Italy. *Biol. Control* 4(2):149-156.
40. Clement, S.L., T. Mimmocchi, R. Sobhian, and P.H. Dunn. 1988. Host specificity of adult *Eustenopus hirtus* (Waltl.) (Coleoptera: Curculionidae), a potential biological control agent of yellow starthistle, *Centaurea solstitialis* L. (Asteraceae, Cardueae). *Proc., Entomological Society of Washington* 90:501-507.
41. Clement, S.L. and R. Sobhian. 1991. Host-use patterns of capitulum-feeding insects of yellow starthistle: results from a garden plot in Greece. *Environ. Entomol.* 20(2):724-730.
42. Connett, J.C. and J.P. McCaffrey. 1995. *Eustenopus villosus*: an enemy of yellow starthistle. *Knapweed* 9:6.
43. Cooksey, D. and R. Sheley. 1998. Mapping noxious weeds in Montana. Publ. No. EB148. Montana State University Extension Service, Bozeman, MT. 21 pp.
44. Cordy, D.R. 1954a. Nigropallidal encephalomalacia (chewing disease) in horses on rations high in yellow star thistle. *Proc., Am. Vet. Med. Assoc.* 91:149-154.
45. Cordy, D.R. 1954b. Nigropallidal encephalomalacia in horses associated with ingestion of yellow star thistle. *Journal of Neuropathology and Experimental Neurology* 13:330-342.
46. Cordy, D.R. 1978. *Centaurea* species and equine nigropallidal encephalomalacia. R.F. Keeler, K.R. Van Kampen, and L.F. James, eds. Pages 327-336. In, *Effects of Poisonous Plants on Livestock*. Academic Press, New York.
47. Dellow, J.J. 1996. Herbicide techniques for thistle management. *Plant Protection Quarterly* 11:276- 277.
48. DeLoach, C.J. 1991. Past successes and current prospects in biological control of weeds in the United States and Canada. *Natural Areas Journal.* 11:129-142.
49. DiTomaso, J.M. 1996. Yellow starthistle: biology and life history. *Proc., California Exotic Plant Pest Council.* 2:61-64.
50. DiTomaso, J.M. 1997. Risk analysis of various weed control methods. *Proc., California Exotic Pest Plant Council Symposium* 3:34-39.
51. DiTomaso, J.M. 1998. Biology and impact of yellow starthistle. Pg. 82-84, M.S. Hoddle, ed. In, *California Conference on Biological Control. Innovation in Biological Control Research.*
52. DiTomaso, J.M. 2000. Invasive weeds in rangelands: Species, impacts and management. *Weed Science* 48:255-265.
53. DiTomaso, J.M., C. Benefield, and G.B. Kyser. 1998a. Reproductive biology of yellow starthistle (*Centaurea solstitialis*) maximizing late season control. Kelly, M., E. Wagner, and P. Warner, eds. *Proc., California Exotic Pest Plant Council Symposium* 4:58.
54. DiTomaso, J.M. and J. Gerlach. 2000a. *Centaurea solstitialis* (yellow starthistle). C. Bossard, J.M. Randall, M. Hoshovsky, eds. Pages 101-106. In, *Invasive Plants of California's Wildlands*. UC Press, Berkeley.
55. DiTomaso, J.M. and J. Gerlach. 2000b. *Centaurea melitensis* (ticolate). C. Bossard, J.M. Randall, M. Hoshovsky, eds. Pages 98-100. In, *Invasive Plants of California's Wildlands*. UC Press, Berkeley.

56. DiTomaso, J.M., E. Healy, S. Enloe. 2000c. California's Noxious Weeds. <http://pi.cdfa.ca.gov/weedinfo/>
57. DiTomaso, J.M., G.B. Kyser, and M.S. Hastings. 1999a. Prescribed burning for control of yellow starthistle (*Centaurea solstitialis*) and enhanced native plant diversity. *Weed Science* 47: 233-242.
58. DiTomaso, J.M., G.B. Kyser, S.B. Orloff, and S.F. Enloe. 2000d. Integrated approaches and control option considerations when developing a management strategy for yellow starthistle. *California Agriculture* 54(6):30-36.
59. DiTomaso, J. M., G. B. Kyser, S. B. Orloff, S. F. Enloe, and G. A. Nader. 1999b. New growth regulator herbicide provides excellent control of yellow starthistle. *California Agriculture* 53(2):12-16.
60. DiTomaso, J.M., W.T. Lanini, C.D. Thomsen, T.S. Prather, C.E. Turner, M.J. Smith, C.L. Elmore, M.P. Vayssieres, and W.A. Williams. 1999c. Yellow starthistle. *Pest Notes* 3:1-4. Univ. of California, Div. Ag. Nat. Res., Oakland, CA.
61. DiTomaso, J.M., S.B. Orloff, G.B. Kyser and G.A. Nader. 1998b. Influence of timing and chemical control on yellow starthistle. *Proc., Calif. Weed Sci. Soc.* 50:190-193.
62. Dowell, R.V. and C.J. Krass. 1992. Exotic pests pose growing problem for California. *California Agriculture* 46(1):6-12.
63. Dudley, D.R. 2000. Wicked weed of the west. *California Wild* 53:32-35.
64. Ebright, S. 2000. Developing and implementing a Weed Management Area: The Plumas-Sierra counties experience. *Proc. California Weed Science Society* 52:144-145.
65. Edwards, B. 1989. Research to control yellow star thistle: the dilemma between a valuable honey plant and a noxious weed. *American Bee Journal* 129:489-490.
66. Enloe, S., J.M. DiTomaso, S. Orloff, and D. Drake. 1999a. Integrated management of yellow starthistle on California rangeland. *Proc., California Weed Science Society* 51:24-27.
67. Enloe, S., J.M. DiTomaso, S.B. Orloff, and D. Drake. 1999b. Selective yellow starthistle management and revegetation strategies for annual rangelands. *Proc., Forest Vegetation Management Conference* 20:29-32.
68. Enloe, S.F., J.M. DiTomaso, S. Orloff, and D. Drake. 2000. Integrated strategies for the attrition of yellow starthistle on Northern California rangeland. *Proc., California Weed Science Society* 52:31-34.
69. Evans, R. R. 1998. Transline/fertilizer combination boosts forage on range. *Ag Alert*. Sept. 23.
70. Ferrell, M.A., T.D. Whitson, D.W. Koch, and A.E. Gade. 1993. Integrated control of leafy spurge (*Euphorbia esula*) with Bozoiisky Russian wildrye (*Psathyrostachys juncea*) and Luna pubescent wheatgrass (*Agropyron intermedium* var. *trichophorum*). *Proc., West. Soc. Weed Sci.* 46:36-38.
71. Fornasari, L. and R. Sobhian. 1993. Life history of *Eustenopus villosus* (Coleoptera: Curculionidae), a promising biological control agent for yellow starthistle. *Environmental Entomologist* 22:684-692.
72. Fornasari, L. and C.E. Turner. 1992. Host specificity of the Palearctic weevil *Larinus curtus* Hochhut (Coleoptera: Curculionidae), a natural enemy of *Centaurea solstitialis* L. (Asteraceae: Cardueae). Delfosse, E. S. and R. R. Scott, eds. Melbourne. *Proc, VIII International Symposium on Biological Control of Weeds*. 8.

73. Fornasari, L., C.E. Turner, and L.A. Andres. 1991. *Eustenopus villosus* (Coleoptera: Curculionidae) for biological control of yellow starthistle (Asteraceae: Cardueae) in North America. *Environ. Entomol.* 20(4):1187-1194.
74. Fuerst, E.P., M.A. Norman, G.P. Irzyk, T.S. Prather, and R.H. Callihan. 1994. Picloram-resistant yellow starthistle: cross-resistance and absorption, translocation, and metabolism of picloram. *Proc., West. Soc. Weed Sci.* 47:88-89.
75. Fuerst, E.P., T.M. Sterling, M.A. Norman, T.S. Prather, G.P. Irzyk, Y. Wu, N.K. Lownds, and R.H. Callihan. 1996. Physiological characterization of picloram resistance in yellow starthistle. *Pestic. Biochem. Physiol.* 56:149-161.
76. Fuller, T.C. and G.D. Barbe. 1985. The Bradley method of eliminating exotic plants from natural reserves. *Fremontia* 13(2):24-25.
77. Gaiser, D.R., V.F. Carrithers, and C. Duncan. 1997. Efficacy of picloram or clopyralid applications at three timings on spotted knapweed or yellow starthistle. *Proc., West. Soc. Weed Sci.* 50:42-44.
78. Gerlach, J.D., Jr. 1997a. How the west was lost: reconstructing the invasion dynamics of yellow starthistle and other plant invaders of western rangelands and natural areas. *Proc., California Exotic Pest Plant Council Symposium* 3:67-72.
79. Gerlach, J.D., Jr. 1997b. The introduction, dynamics of geographic range expansion, and ecosystem effects of yellow starthistle (*Centaurea solstitialis*). *Proc., California Weed Science Society* 49:136-141.
80. Gerlach, J.D., A. Dyer, and K.J. Rice. 1998. Grassland and foothill woodland ecosystems of the Central Valley. *Fremontia* 26:39-43.
81. Gibbs, L.A., M.W. Murray, T.M. Sterling, and N.K. Lownds. 1995. Comparison of picloram-resistant and -susceptible yellow starthistle in a replacement series. *Proc., West. Soc. Weed Sci.* 48:26.
82. Giesy, J.P., S. Dobson, and K.R. Solomon. 2000. Ecotoxicological risk assessment for Roundup herbicide. *Rev. Environ. Contam. Toxicol.* 167:35-120.
83. Goeden, R.D. 1993. Arthropods for suppression of terrestrial weeds. Pages 231-237. R. D. Lumsden, R.D. and J.L. Vaughn, eds. In, *Pest Management: Biologically Based Technologies*. Amer. Chem. Soc., Washington, DC.
84. Goltz, L. 1999. Yellow starthistle on the hit list in California. *American Bee Journal* 139(5):383-384.
85. Hamburger, M., J.L. Wolfender, and K. Hostettmann. 1993. Search for chlorinated sesquiterpene lactones in the neurotoxic thistle *Centaurea solstitialis* by liquid chromatography-mass spectroscopy, and model studies on their possible artifactual formation. *Nat. Toxins* 1(6):315-327.
86. Harrington, K.C. and W.T. Lanini. 2000. *Phalaris aquatica*. Pages 262-266. C. Bossard, J.M. Randall, M. Hoshovsky, eds. In, *Invasive Plants of California's Wildlands*. UC Press, Berkeley.
87. Harrod, R.J. and R.J. Taylor. 1995. Reproduction and pollination biology of *Centaurea* and *Acroptilon* species, with emphasis on *C. diffusa*. *Northwest Science* 69(2):97-105.
88. Hastings, M.S. and J.M. DiTomaso. 1996. The use of fire for yellow starthistle (*Centaurea solstitialis*) management and the restoration of native grasslands at Sugarloaf Ridge State Park. *Proc., California Weed Science Society* 48:114-119.
89. Hickman, J.C. 1993. *The Jepson Manual. Higher Plants of California*. Pages 222-223. University of California Press, Berkeley, CA.

90. Huston, C., R.L. Sheley, R.H. Callihan, and D.C. Thill. 1982. Genotypic variation among yellow starthistle populations. Res. Prog. Rep. West. Soc. Weed Sci. pg. 33.
91. Huston, C.H., R.L. Sheley, R.H. Callihan, D.L. Zamora, and D.C. Thill. 1983. Effect of maturation on viability and germination of yellow starthistle seed buried at three depths. Res. Prog. Rep. West. Soc. Weed Sci. pp. 43-44.
92. Jacobs, J.S., M.F. Carpinelli, and R.L. Sheley. 1999. Revegetating noxious weed-infested rangeland. Pages 133-141. R.L. Sheley and J.K. Petroff, eds. In, Biology and Management of Noxious Rangeland Weeds. Oregon St. Univ. Press, Corvallis.
93. Jette, C., J. Connett, and J.P. McCaffrey. 1999. Biology and biological control agents of yellow starthistle. [FHTET-98-17]. Morgantown, WV. Forest Health Technology Enterprise Team. 93 pp.
94. Johnson, D. 1988. Forage species for replacement of yellow starthistle in Oregon. Knapweed 2:3.
95. Johnson, D.E. and M.M. Borman. 1992. Yellow starthistle control research in Southwestern Oregon. Knapweed 6:3-4.
96. Johnson, J.B., J.P. McCaffrey, and F.W. Merickel. 1992. Endemic phytophagous insects associated with yellow starthistle in northern Idaho. Pan-Pacific Entomologist 68(3):169-173.
97. Joley, D.B., D.M. Maddox, B.E. Mackey, S.E. Schoenig, and K.A. Casanave. 1997. Effect of light and temperature on germination of dimorphic achenes of *Centaurea solstitialis* in California. Canadian Journal of Botany 75(12):2131-2139.
98. Joley, D.B., D.M. Maddox, D.M. Supkoff, and A. Mayfield. 1992. Dynamics of yellow starthistle (*Centaurea solstitialis*) achenes in field and laboratory. Weed Science 40:190-194.
99. Johnson, S.A. 2000. Thistle and bush management for rural and foothill landowners. Proc., California Weed Science Society 52:20-25.
100. Julien, M.H. 1989. Biological control of weeds worldwide: trend, rates of success and the future. Biocontr. News Info. 10:299-306.
101. Julien, M.H. (ed.). 1992. Biological Control of Weeds: A World Catalogue of Agents and Their Target Weeds, 3rd ed., CAB International, Wallingford, U.K., 186 pp.
102. Kelsey, R. and D. Bedunah. 1989. Ecological significance of allelopathy for *Centaurea* species in the Northwestern United States. Knapweed 3:1-3.
103. Kiemnec, G.L. and M.L. McInnis. 1994. Management implications of yellow starthistle adaptations in the Pacific Northwest. Ecology and Management of Annual Rangelands. Pp. 83-84.
104. Kingsbury, J.M. 1964. Poisonous Plant of the United States and Canada. Pages 396-397. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.
105. Klisiewicz, J.M. 1986. Susceptibility of yellow starthistle to selected plant pathogens. Plant Disease 70:295-297.
106. Knapp, E.E. and K.J. Rice. 1997. Ecotypes of native species: how local is local in restoration plantings? Proc., California Exotic Pest Plant Council Symposium 3:51-55.
107. Larson, L. 1994. Comparative growth and competition between cheatgrass and yellow starthistle seedlings. Knapweed 8:3-4.
108. Larson, L. and G. Kiemnec. 1997. Differential germination by dimorphic achenes of yellow starthistle (*Centaurea solstitialis* L.) under water stress. J. Arid Environ. 37(1):107-114.

109. Larson, L., G. Kiemnec, and M. McInnis. 1992. Effects of water and salt stress on yellow starthistle germination and root growth. *Knapweed* 6:3.
110. Larson, L.L. and M.L. McInnis. 1989a. Impact of grass seedlings on establishment and density of diffuse knapweed and yellow starthistle. *Northwest Science* 63:162-166.
111. Larson, L.L. and M.L. McInnis. 1989b. Response of yellow starthistle (*Centaurea solstitialis*) and grass biomass to grass, picloram, and fertilizer combinations. *Weed Technology* 3:497-500.
112. Larson, L.L. and R.L. Sheley. 1994. Ecological relationships between yellow starthistle and cheatgrass. *Ecology and Management of Annual Rangeland*. Pp. 92-94.
113. Larson, K.A. and S. Young. 1970. Nigropallidal encephalomalacia in horses in Colorado [*Centaurea solstitialis*]. *Amer. Vet. Med. Assoc. J.* 156(5):626-628.
114. Lass, L.W. and R.H. Callihan. 1994a. Fall application of herbicides to yellow starthistle. *Res. Prog. Rep. West. Soc. Weed Sci.* pg. I-39-40.
115. Lass, L.W. and R.H. Callihan. 1994b. Herbicide evaluation for yellow starthistle control. *Res. Prog. Rep. West. Soc. Weed Sci.* pg. I-41-42.
116. Lass, L.W. and R.H. Callihan. 1995a. The effects of grass planting time on establishment in yellow starthistle infestations. *Res. Prog. Rep. West. Soc. Weed Sci.* pg. 33.
117. Lass, L.W. and R.H. Callihan. 1995b. Testing the potential use of quinclorac for yellow starthistle control. *Res. Prog. Rep. West. Soc. Weed Sci.* pg. 31-32.
118. Lass, L.W., R.H. Callihan, and F.E. Northam. 1993a. Effects of winter and spring applied herbicides on picloram resistant yellow starthistle. *Res. Prog. Rep. West. Soc. Weed Sci.* pg. I-102.
119. Lass, L.W., R.H. Callihan, and F.E. Northam. 1993b. Yellow starthistle control in semiarid annual non-crop grassland. *Res. Prog. Rep. West. Soc. Weed Sci.* pg. I-103-104.
120. Lass, L.W., H.W. Carson, and R.H. Callihan. 1995. Detecting yellow starthistle with high resolution remote sensing equipment. *Res. Prog. Rep. West. Soc. Weed Sci.* pp. 34-35.
121. Lass, L.W., H.W. Carson, and R.H. Callihan. 1996. Detection of yellow starthistle (*Centaurea solstitialis*) and common St. Johnswort (*Hypericum perforatum*) with multispectral digital imagery. *Weed Technology* 10:466-474.
122. Lass, L.W., B. Shafii, W.J. Price and D.C. Thill. 2000. Assessing agreement in multispectral images of yellow starthistle (*Centaurea solstitialis*) with ground truth data using a Bayesian methodology. *Weed Technology* 14:539-544.
123. Maddox, D.M. 1981. Introduction, phenology, and density of yellow starthistle in coastal, intercoastal, and central valley situations in California. *ARR-W-20*, pp. 1-33. USDA-ARS.
124. Maddox, D.M., D.B. Joley, A. Mayfield, and B.E. Machey. 1991. Impact of *Bangasternus orientalis* (Coleoptera: Curculionidae) on achene production of *Centaurea solstitialis* (Asterales: Asteraceae) at a low and high elevation site in California. *Environmental Entomology* 20:335-337.
125. Maddox, D.M., D.B. Joley, D.M. Supkoff, and A. Mayfield. 1996. Pollination biology of yellow starthistle (*Centaurea solstitialis*) in California. *Canadian Journal of Botany* 74:262-267.
126. Maddox, D.M. and A. Mayfield. 1985. Yellow starthistle infestations are on the increase. *California Agriculture* 39(11/12):10-12.

127. Maddox, D.M., A. Mayfield, and N.H. Poritz. 1985. Distribution of yellow starthistle (*Centaurea solstitialis*) and Russian knapweed (*Centaurea repens*). *Weed Science* 33(3):315-327.
128. Maddox, D.M., A. Mayfield, and C.E. Turner. 1990. Host specificity of *Chaetorellia australis* (Diptera: Tephritidae) for biological control of yellow starthistle (*Centaurea solstitialis*, Asteraceae). *Proc., Entomological Society of Washington* 92:426-430.
129. Maddox, D.M. and R. Sobhian. 1987. Field experiment to determine host specificity and oviposition behavior of *Bangasternus orientalis* and *Bangasternus fausti* (Coleoptera: Curculionidae), biological control candidates for yellow starthistle and diffuse knapweed. *Environment Entomology* 16:645-648.
130. Maddox, D.M., R. Sobhian, D.B. Joley, A. Mayfield, and D. Supkoff. 1986. New biological control for yellow starthistle. *California Agriculture* 40(11/12):4-5.
131. Martin, A.A., F.G. Yanarella, R.A. Maurel, and J. Ruager. 1971. Nigropallidal encephalomalacia in horses provoked by chronic intoxication with yellow star thistle (*Centaurea solstitialis*). *Analecta Vet.* 3(1/3):43-53.
132. McCaffrey, J. P. and L.M. Wilson. 1994. Assessment of biological control of exotic broadleaf weeds in Intermountain rangelands. *Ecology and Management of Annual Rangelands*. pp. 101-102.
133. McHenry, W.B., R.B. Bushnell, M.N. Oliver, and R.F. Norris. 1990. Three poisonous plants common in pastures and hay. Leaflet No. 21483, 10 pp. Cooperative Extension, University of California. Publication.
134. Merrill, G.B. 1989. Eupatoriochromene and encecalin, plant growth regulators from yellow starthistle. *Journal of Chemical Ecology* 15:2073-2087.
135. Merrill, G.B. and K.L. Stevens. 1985. Sesquiterpene lactones from *Centaurea solstitialis*. *Phytochemistry* 24:2013-2018.
136. Mettler, F.A. and G.M. Stern. 1963. Observations on the toxic effects of yellow star thistle. *Journal of Neuropathology and Experimental Neurology* 22:164-169.
137. Miller, T.W., S.L. Shinn, R.H. Callihan, L.W. Lass, and D.C. Thill. 1998. Livestock trampling of grass seedlings for enhanced establishment on yellow starthistle-infested rangelands. *Proc., Western Society of Weed Science* 51:114-116.
138. Mullin, B.H., L.W.J. Anderson, J.M. DiTomaso, R.E. Epliee and K.D. Getsinger. 2000. Invasive plant species. Council for Agricultural Science and Technology. Issue Paper. No. 13, 18 pp.
139. Northam, F.E. and R.H. Callihan. 1988a. Adaptation of selected grasses to a semi-arid yellow starthistle infested site. *Res. Prog. Rep. West. Soci. Weed Sci.* Pp. 64-67.
140. Northam, F.E. and R.H. Callihan. 1988b. Perennial grass response to environment and herbicides in a yellow starthistle site. *Proc., West. Soc. Weed Sci.* 41:84-86.
141. Northam, F.E. and R.H. Callihan. 1988c. Yellow starthistle presence in 29 month-old stands of eight grasses. *Res. Prog. Rep. West. Soc. Weed Sci.* Pp. 60-63.
142. Northam, F.E. and R.H. Callihan. 1989. The effects of herbicides on the species composition of an annual weed community. *Res. Prog. Rep. West Soc. Weed Sci.* Pp. 112-115.
143. Northam, F.E. and R.H. Callihan. 1990a. Evaluation of soil conservation plant materials for herbicide tolerance and revegetating semi-arid land infested with yellow starthistle. *Res. Prog. Rep. West Soc. Weed Sci.* Pp. 75-78.

144. Northam, F.E. and R.H. Callihan. 1990b. Grass adaptation to semi-arid, yellow starthistle infested canyonland. Res. Prog. Rep. West Soc. Weed Sci. Pp. 79-82.
145. Northam, F.E. and R.H. Callihan. 1991. Effects of herbicides on yellow starthistle density and vegetation biomass components of a rangeland yellow starthistle weed community. Res. Prog. Rep. West Soc. Weed Sci. Pp. 43-46.
146. Northam, F.E. and R.H. Callihan. 1994. Interpreting germination results based on differing embryonic emergence criteria. Weed Science 42:474-481.
147. Northam, F. E., T. S. Prather, and R. H. Callihan. 1989. Viability and germination of buried yellow starthistle seed. Res. Prog. Rep. West Soc. Weed Sci. Pp. 124-126.
148. Olkowski, H. and W. Olkowski. 1992. Using animals for weed management. Common Sense Pest Control Quarterly 8(2):5-13.
149. Olson, B.E. 1999. Grazing and weeds. Pages 85-96. R.L. Sheley and J.K. Petroff, eds. In, Biology and Management of Noxious Rangeland Weeds. Oregon St. Univ. Press, Corvallis.
150. Panter, K.E. 1990. Toxicity of knapweed in horses. Knapweed 4:3-4.
151. Panter, K.E. 1991. Neurotoxicity of the knapweeds (*Centaurea* spp.) in horses. Pages 316-324, L. F. James, J. O. Evans, M. H. Ralphs, and R. D. Child, eds. In, Noxious Range Weeds. Westview Press, San Francisco, CA.
152. Pitcairn, M.J. 1999. Advancements in biological control of weed species via insects and fungi. Proc., Forest Vegetation Management Conference 20:60-63.
153. Pitcairn, M.J and J.M. DiTomaso. 2000. Rangeland and uncultivated areas: integrating biological control agents and herbicides for starthistle control. Pages 65-72, M.S. Hoddle (ed.), In, California Conference on Biological Control II.
154. Pitcairn, M.J. and J.M. DiTomaso, and J. Fox. 1999a. Integrating chemical and biological control methods for control of yellow starthistle. Pages 77-82. D.M. Woods, ed. In, Biological Control Program Annual Report, 1998. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
155. Pitcairn, M.J., J.M. DiTomaso, and V. Popescu. 2000a. Integrating chemical and biological control methods for control of yellow starthistle. Pages 58-61. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
156. Pitcairn, M.J., D.B. Joley and D.M. Woods. 1997. Impact of plant density on yellow starthistle seedhead production. Pages 59-61. D.M. Woods, ed. In Biological Control Program Annual Summary, 1996. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
157. Pitcairn M.J., D.B. Joley, D.M. Woods, and V. Popescu. 1998a. Impact of *Chaetorellia succinea* on yellow starthistle, *Centaurea solstitialis*. Page 57 D.M. Woods, ed. In, Biological Control Program Annual Summary, 1997. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
158. Pitcairn, M.J., R.A. O'Connell, and J.M. Gendron. 1998b. Yellow starthistle: survey of statewide distribution. Pages 64-66. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1997. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
159. Pitcairn M.J., V. Popescu, D.B. Joley, and D.M. Woods. 1998c. Estimating the number of flowers per head from head diameter in yellow starthistle in California. Pages 60-63. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1997. California

- Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
160. Pitcairn, M.J., D.M. Woods, D.B. Joley, D.G. Fogle, and V. Popescu. 2000b. Impact of seedling pathogens on yellow starthistle in California. Pages 52-54. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
 161. Pitcairn, M.J., D.M. Woods, D.B. Joley, and V. Popescu. 2000c. Five-year population buildup and combined impact of biological control insects on yellow starthistle. Pages 55-57. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
 162. Pitcairn M.J., D.M. Woods, E.F. Van Mantgem, and R.K. Wall. 1999b. Endemic natural enemy fauna of yellow starthistle and purple starthistle in central California. Pages 83-84. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1998. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
 163. Prather, T.S. 1994. Biology of yellow starthistle. Proc., California Weed Conference 46:219-223.
 164. Prather, T.S. and R.H. Callihan. 1989a. Interactions between a yellow starthistle community and a pubescent wheatgrass community. Res. Prog. Rep. West. Soc. Weed Sci. Pp. 81-83.
 165. Prather, T.S. and R.H. Callihan. 1989b. Yellow starthistle trends in perennial and annual communities. Res. Prog. Rep. West Soc. Weed Sci. Pg. 130.
 166. Prather, T.S. and R.H. Callihan. 1990. Yellow starthistle population dynamics in perennial and annual communities. Res. Prog. Rep. West Soc. Weed Sci. Pp. 87-88.
 167. Prather, T.S. and R.H. Callihan. 1991. Interference between yellow starthistle and pubescent wheatgrass during grass establishment. Journal of Range Management 44(5):443-447.
 168. Prather, T.S., R.H. Callihan, and D.C. Thill. 1988. Revegetating yellow starthistle infested land with intermediate wheatgrass. Res. Prog. Rep. West Soc. Weed Sci. Pp. 68-69.
 169. Prather, T.S., P. Fuerst, and R.H. Callihan. 1991. Uptake and translocation of picloram in apparently resistant and known susceptible yellow starthistle. Res. Prog. Rep. West. Soc. Weed Sci. Pp. 312-315.
 170. Price, W.J., B. Shafii, L.W. Lass, and D.C. Thill. 1998. Assessing variability of agreement measures in remote sensing using a Bayesian approach. Appl. Stat. Agric. Pp. 43-54.
 171. Randall, J.M. 1994. Weeds and the preservation of natural areas. Proc., California Weed Science Society 46:143-154.
 172. Rees, N.E. 1978. Interactions of *Rhinocyllus conicus* and thistles in the Gallatin Valley. Pages 31-38. K.E. Frick, editor. In, Biological Control of Thistles in the Genus *Carduus* in the United States. USDA Science and Education Administration, Agricultural Research Service. Washington, D.C.
 173. Rejmanek, M. 1999. Invasive plant species and invasional ecosystems. Pages 79-102. O.T. Sandlund, P.J. Schei, and A. Viken, eds. In, Invasive Species and Biodiversity Management. Kluwer Academic Publ., Dordrecht.

174. Robles, M., B.H. Choi, B. Han, K. Santa Cruz and R.C. Kim. 1998. Repin-induced neurotoxicity in rodents. *Exp. Neurol.* 152(2):129-136.
175. Roché, B. 1965. Ecologic studies of yellow star-thistle (*Centaurea solstitialis* L.). 1965. Ph.D. Dissertation, University of Idaho.
176. Roché, B. 1991a. Yellow starthistle: wind, birds, and humans. *Knapweed* 5:3-4.
177. Roché, B.F. and C.T. Roché. 1991. Identification, introduction, distribution, ecology, and economics of *Centaurea* species. Pages 274-291, L. F. James, J. O. Evans, M. H. Ralphs, and R. D. Child, eds. In, *Noxious Range Weeds*. Westview Press. Boulder, CO.
178. Roché, B.F., Jr. 1991b. Seeds-From start to finish. *Knapweed* 5:1.
179. Roché, B.F., Jr. 1992. Achene dispersal in yellow starthistle (*Centaurea solstitialis* L.). *Northwest Science* 66:62-65.
180. Roché, B.F., Jr., C.T. Roché, and R.C. Chapman. 1994. Impacts of grassland habitat on yellow starthistle (*Centaurea solstitialis* L.) invasion. *Northwest Science* 68:86-96.
181. Roché, C. 1990. Yellow starthistle seeded after Hells Canyon fire. *Knapweed* 4:4.
182. Roché, C. 1991c. Bighead knapweed (*Centaurea macrocephala* Puschk.). *Weeds*. A Pacific Northwest Extension Publication, #PNW386. Washington, Idaho, Oregon. 2 pp.
183. Roché, C.T. and B.F. Roché, Jr. 1988. Distribution and amount of four knapweed (*Centaurea* L.) species in eastern Washington. *Northwest Science* 62:242-253.
184. Roché, C.T. and B.F. Roché, Jr. 1993. Identification of knapweeds and starthistles in the Pacific Northwest. A Pacific Northwest Extension Publication, #PNW432. Washington, Idaho, Oregon. 22 pp.
185. Roché, C.T., D.C. Thill, and B. Shafii. 1997. Reproductive phenology in yellow starthistle (*Centaurea solstitialis*). *Weed Science* 45:763-770.
186. Rosenthal, S.S., G. Campobasso, L. Fornasari, R. Sobhian, and C.E. Turner. 1991. Biological Control of *Centaurea* spp. Pages 292-302, L.F. James, J.O. Evans, M.H. Ralphs, and R.D. Child, eds. In, *Noxious Range Weeds*. Westview Press. Boulder, CO.
187. Roy, D.N., D.H. Peyton, and P.S. Spencer. 1995. Isolation and identification of two potent neurotoxins, aspartic acid and glutamic acid, from yellow starthistle (*Centaurea solstitialis*). *Natural Toxins* 3:174-180.
188. Rusmore, J.T. 1995. Use of fire and cutting to control yellow starthistle. Pages 13-19, Kelly, M. and Lovich, J., eds. *Proc., California Exotic Pest Plant Council Symposium*.
189. Sabba, R.P., T.M. Sterling, and N.K. Lownds. 1998. Effect of picloram on resistant and susceptible yellow starthistle (*Centaurea solstitialis*): the role of ethylene. *Weed Science* 46:297-300.
190. Schirman, R.D. 1991. Follow-up necessary for yellow starthistle control. *Knapweed* 5(4):3-4.
191. Schoenig, S.E. 2000a. Weed Management Areas in California. *Proc., Forest Vegetation Management Conference* 21:96-97.
192. Schoenig, S.E. 2000b. Weed Management Areas in California. *Proc., California Weed Science Society* 52:141-143.
193. Schumacher, A.E., R.L. Sheley, R.H. Callihan, and D.C. Thill. 1982. Chemotaxonomic analysis of seed proteins as a means of biotype identification of yellow starthistle. *Res. Prog. Rep. West Soc. Weed Sci.* Pp. 31-32.
194. Scott, T. and N. Pratini. 1995. Habitat fragmentation: the sum of the pieces is less than the whole. *California Agriculture* 49(6):56.

195. Sheley, R.L., R.H. Callihan, C.H. Huston, and D.C. Thill. 1983a. Genotypic variation among yellow starthistle populations. Res. Prog. Rep. West Soc. Weed Sci. Pp. 53-54.
196. Sheley, R.L., R.H. Callihan, and D.C. Thill. 1982a. Survey of yellow starthistle (*Centaurea solstitialis*) infestations in Idaho. Res. Prog. Rep. West Soc. Weed Sci. Pp. 29-31.
197. Sheley, R.L., C.L. Huston, R.H. Callihan, and D.C. Thill. 1982b. Effect of maturation on viability and germination of yellow starthistle seed buried at 3 depths. Res. Prog. Rep. West Soc. Weed Sci. Pg. 35.
198. Sheley, R.L., J.S. Jacobs, and M.F. Carpinelli. 1998. Distribution, biology, and management of diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*Centaurea maculosa*). Weed Technol. 12:353-362.
199. Sheley, R.L., S. Kedzie-Webb, and B.D. Maxwell. 1999a. Integrated weed management on rangeland. Pages 57-68 in R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Oregon St. Univ. Press, Corvallis.
200. Sheley, R. and L. Larson. 1992. Is yellow starthistle replacing cheatgrass? Knapweed 6(4):3.
201. Sheley, R.L. and L.L. Larson. 1994a. Observation: Comparative live-history of cheatgrass and yellow starthistle. Journal of Range Management 47:450-456.
202. Sheley, R.L. and L.L. Larson. 1994b. Comparative growth and interference between cheatgrass and yellow starthistle seedlings. Journal of Range Management 47:470-474.
203. Sheley, R.L. and L.L. Larson. 1994c. Comparative growth and competition between cheatgrass and yellow starthistle seedlings. Knapweed 8(2):3-4.
204. Sheley, R.L. and L.L. Larson. 1995. Interference between cheatgrass and yellow starthistle at 3 soil depths. Journal of Range Management 48:392-397.
205. Sheley, R.L. and L.L. Larson. 1997. Cheatgrass and yellow starthistle growth at 3 soil depths. Journal of Range Management 50(2):146-150.
206. Sheley, R.L., L.L. Larson, and J.S. Jacobs. 1999b. Yellow starthistle. Pages 409-416. Sheley, R.L. and J.K. Petroff, eds. In, Biology and Management of Noxious Rangeland Weeds. Oregon State University Press, Corvallis.
207. Sheley, R.L., L.L. Larson, and D.E. Johnson. 1993. Germination and root dynamics of range weeds and forage species. Weed Technology 7(1):234-237.
208. Sheley, R.L., M. Manoukian, and G. Marks. 1999c. Preventing noxious weed invasion. Pages 69-72 in R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Oregon St. Univ. Press, Corvallis.
209. Sheley, R.L., B.F. Roche, and R.H. Callihan. 1983b. Genotypic variation among yellow starthistle populations. Proc., West. Soc. Weed Sci. 36:200.
210. Sheley, R.L., D.L. Zamora, C.H. Huston, R.H. Callihan, and D.C. Thill. 1983c. Seed and seedling root growth characteristics of several populations of yellow starthistle (*Centaurea solstitialis* L.). Res. Prog. Rep. West Soc. Weed Sci. Pp. 62-63.
211. Shinn, S.L., T.W. Miller, and D.C. Thill. 1998. Yellow starthistle control with imazapic. Res. Prog. Rep. West Soc. Weed Sci. pp. 20.
212. Shinn, S.L. and D.C. Thill. 1999. Yellow starthistle response to imazapic. Proc., Western Society of Weed Science 52:39.
213. Shinn, S. L. and D. C. Thill. 2000a. The effect of imazapic on yellow starthistle control and pasture grass production. Res. Prog. Rep. West Soc. Weed Sci. Pg. 29.

214. Shinn, S.L. and D.C. Thill. 2000b. Yellow starthistle control with imazapic. Res. Prog. Rep. West. Soc. Weed Sci. Pg. 30.
215. Shishkoff, N. and W. Bruckart. 1993. Evaluation of infection of target and nontarget hosts by isolates of the potential biocontrol agent *Puccinia jaceae* that infects *Centaurea* spp. Phytopathology 83:894-898.
216. Shishkoff, N. and W.L. Bruckart. 1996. Water stress and damage caused by *Puccinia jaceae* on two *Centaurea* species. Biol. Control 6(1):57-63.
217. Smathers, R.L., R.O. Brooks, and E.L. Michalson. 1985. Controlling yellow starthistle economic considerations. Bull. Idaho Agric. Exp. Stn. 8(650):1-8.
218. Sobhian, R. 1993a. Two biotypes of *Bangasternus orientalis* (Coleoptera: Curculionidae) found in Greece. Proc., Entomol. Soc. Wash. D.C. 95(2):163-164.
219. Sobhian, R. 1993b. Life history and host specificity of *Urophora sirunaseva* (Hering) (Dipt., Tephritidae), a candidate for biological control of yellow starthistle, with remarks on the host plant. Journal of Applied Entomology 116:381-390.
220. Sobhian, R., G. Campobasso, and P.H. Dunn. 1992. Contribution to the biology of *Bangasternus orientalis* Capiomont (Col., Curculionidae). Journal of Applied Entomology 113:93-102.
221. Sobhian, R. and L. Fornasari. 1994. Biology of *Larinus curtus* Hochhut (Coleoptera: Curculionidae), a European weevil for biological control of yellow starthistle, *Centaurea solstitialis* L. (Asteraceae), in the United States. Biol. Control 4(4):328-335.
222. Sobhian, R. and I.S. Pittara. 1988. A contribution to the biology, phenology and host specificity of *Chaetorellia hexachaeta* Loew (Dipt., Tephritidae), a possible candidate for the biological control of yellow starthistle (*Centaurea solstitialis* L.). Journal of Applied Entomology 106:444-450.
223. Sterling, T.M., N. K. Lownds, E.P. Fuerst, T.S. Prather, and R.H. Callihan. 1991. Potential mechanism of picloram resistance in yellow starthistle (*Centaurea solstitialis* L.). Weed Science Society of America Abstracts 31:80.
224. Stevens, K.L. and G.B. Merrill. 1985. Sesquiterpene lactones and allelochemicals from *Centaurea* species. Pages 83-98. In, A.C. Thompson, ed. In, The Chemistry of Allelopathy. Ser. Am. Chem. Soc. No. 268. Am. Chem. Soc. Sym.
225. Stevens, K.L., S.C. Witt, and C.E. Turner. 1990. Polyacetylenes in related thistles of the subtribes Centaureinae and Carduinae. Biochemical Systematics and Ecology 18:229-232.
226. Sun, M. 1997. Population genetic structure of yellow starthistle (*Centaurea solstitialis*), a colonizing weed in the western United States. Canadian Journal of Botany 75(9):1470-1478.
227. Sun, M. and K. Ritland. 1998. Mating system of yellow starthistle (*Centaurea solstitialis*), a successful colonizer in North America. Heredity 80:225-232.
228. Sunderland, A. 1976. Yellow starthistle [*Centaurea solstitialis*]--a major range weed problem. Pract. Nutr. 10(3):22-24.
229. Thomas, F. 1996. Using annual legumes to manage weeds. Proc., California Weed Science Society 48:120-122.
230. Thomas, F. 1997. Selecting cover crops to suppress weeds. Proc., California Weed Science Society 49:68-71.
231. Thomsen, C.D., M.P. Vayssieres, and W.A. Williams. 1994. Grazing and mowing management of yellow starthistle. Proc., California Weed Conference 46:228-230.

232. Thomsen, C.D., M.P. Vayssieres, and W.A. Williams. 1997. Mowing and subclover plantings suppress yellow starthistle. *California Agriculture* 51(6):15-20.
233. Thomsen, C.D., W.A. Williams, and M.R. George. 1990. Managing yellow starthistle on annual range with cattle. *Knapweed* 4:3-4.
234. Thomsen, C.D., W.A. Williams, M.R. George, W.B. McHenry, F.L. Bell, and R.S. Knight. 1989. Managing yellow starthistle on rangeland. *California Agriculture* 43(5):4-7.
235. Thomsen, C.D., W.A. Williams, W. Olkowski, and D.W. Pratt. 1996a. Grazing, mowing and clover plantings control yellow starthistle. *The IPM Practitioner* 18:1-4.
236. Thomsen, C.D., W.A. Williams, M. Vayssières, and F.L. Bell. 1994. Yellow starthistle control. *Range Science Report #33*, 6 pp.
237. Thomsen, C.D., W.A. Williams, M. Vayssières, F.L. Bell, and M.R. George. 1993. Controlled grazing on annual grassland decreases yellow starthistle. *California Agriculture* 47(6):36-40.
238. Thomsen, C.D., W.A. Williams, M. Vayssieres, C.E. Turner, and W.T. Lanini. 1996b. Yellow starthistle biology and control. Univ. Calif., Div. Agr. Nat. Res. Publication #21541. 19 pp.
239. Turner, C.E. 1992. Biological approaches to weed management. Pages 32-67. T. Beall, ed., In, *Beyond Pesticides. Biological Approaches to Pest Management in California*. Div. Ag. Nat. Resources, Univ. Calif., Oakland.
240. Turner, C.E. 1994. Host specificity and oviposition of *Urophora sirunaseva* (Hering) (Diptera: Tephritidae), a natural enemy of yellow starthistle. *Proc., Entomological Society of Washington* 96:31-36.
241. Turner, C.E. and L. Fornasari. 1992. Biological control of yellow starthistle (*Centaurea solstitialis* L.) in North America. Delfosse, E. S. and Scott, R. R., eds. *Proc., Eighth International Symposium on Biological Control of Weeds*. Canterbury, New Zealand. 8:1-13.
242. Turner, C.E., G.L. Piper, and E.M. Coombs. 1996. *Chaetorellia australis* (Diptera: Tephritidae) for biological control of yellow starthistle, *Centaurea solstitialis* (Compositae), in the western USA: establishment and seed destruction. *Bull. Entomol. Res.* 86(2):177-182.
243. Turner, C.E., R. Sobhian, D.B. Joley, E.M. Coombs, and G.L. Piper. 1994. Establishment of *Urophora sirunaseva* (Hering) (Diptera: Tephritidae) for biological control of yellow starthistle in the Western United States. *Pan-Pacific Entomologist* 70:206-211.
244. Valenzuela-Valenzuela, J., N.K. Lownds, and T.M. Sterling. 1997. Clopyralid uptake, translocation and ethylene production in resistant and susceptible yellow starthistle plants. *Proc., West. Soc. Weed Sci.* 50:36.
245. Villegas, B. 1998. Distribution of the yellow starthistle seedhead flies, *Chaetorellia succinea* and *Chaetorellia australis* in California. Pages 55-56. D.M. Woods, ed. In, *Biological Control Program Annual Summary, 1997*. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
246. Villegas, B., T. Lenigar, and D. Haines. 2000a. Releases of the hairy weevil, *Eustenopus villosus*, in California for the biological control of yellow starthistle. Pages 47-50. D.M. Woods, ed. In, *Biological Control Program Annual Summary, 1999*. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.

247. Villegas, B., D.A. Mayhew and J. Balciunas. 1999. Survey of *Chaetorellia* seedhead flies on commercial and non-commercial safflower in California. Pages 85-87. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1998. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
248. Villegas, B., D.A. Mayhew, F. Hrusa, and J. Balciunas. 2000b. Survey of *Chaetorellia* seedhead flies on *Cirsium* thistles in close proximity to *Centaurea* spp. in California. Pages 62-63. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
249. Villegas, B., M. J. Pitcairn, and E. Coombs. 2000c. Releases of *Nosema*-free *Larinus curtus* for the biological control of yellow starthistle in California in 1992-1999. Pages 35-37. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
250. Weber, E. 1985. Grazing management controls weeds. Soil and Water Conservation News 6:4-5.
251. Westbrooks, R.G. 1991. Plant protection issues. I. A commentary on new weeds in the United States. Weed Technology 5(1):232-237.
252. White, I.M. and S.L. Clement. 1987. Systematic notes on *Urophora* (Diptera, Tephritidae) species associated with *Centaurea solstitialis* (Asteraceae, Cardueae) and other palaeartic weeds adventive in North America. Proc., Entomol. Soc. Wash. 89(3):571-580.
253. White, I.M., K. Groppe, and R. Sobhian. 1990. Tephritids of knapweeds, starthistles and safflower: results of a host choice experiment and the taxonomy of *Terellia luteola* (Wiedemann) (Diptera:Tephritidae). Bull., Entomological Research 80:107-111.
254. Wilson, L.M. and J.P. MacCaffrey. 1999. Biological control of noxious rangeland weeds. Pages 97-116. R.L. Sheley and J.K. Petroff, eds. In, Biology and Management of Noxious Rangeland Weeds. Oregon St. Univ. Press, Corvallis.
255. Whitson, T.D. and R. Costa. 1986. Evaluation of various herbicides for control of yellowstar thistle (*Centaurea solstitialis* L.). Res. Prog. Rep. West. Soc. Weed Sci. Pg. 51.
256. Woo, I., L. Swiadon, T. Drlik, and W. Quarles. 1999. Integrated management of yellow starthistle. IPM Practitioner 21(7):1-10.
257. Wood, M. 1993. Weed-eating insects take the starthistle challenge. Agricultural Research 41:10-11.
258. Woods, D.M. 1996. A new seedling disease of yellow starthistle, *Centaurea solstitialis* L. in California. Weed Science Society of America Abstracts 36:52.
259. Woods, D.M. and D.G. Fogle. 1998. *Colletotrichum gloeosporioides* as a seedling disease of yellow starthistle, *Centaurea solstitialis*. Page 59. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1997. California Department of Food and Agriculture, Plant Health and Pest Prevention Services Sacramento, CA.
260. Woods, D.M., D.B. Joley and M.J. Pitcairn. 1998. Assessment of yellow starthistle at long term *Eustenopus* release sites. Pages 58-59. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1997. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.

261. Wrynski, J., P. Robins, G. Vesperat, and J.M. DiTomaso. 1999. Clopyralid demonstration trial Yolo County, California. Proc., California Weed Science Society 51:114-119.
262. Young, S., W.W. Brown, and B. Klinger. 1970. Nigropallidal encephalomalacia in horses fed Russian knapweed (*Centaurea repens* L.). Amer. J. Vet. Res. 31(8):1393-1404.
263. Young, J.A. and W.S. Longland. 1996. Impact of alien plants on Grant Basin rangeland. Weed Technol. 10:384-391.
264. Zamora, D.L., R.H. Callihan, and D.C. Thill. 1983. The allelopathic potential of yellow starthistle. Res. Prog. Rep. West. Soc. Weed Sci. Pp. 310-311.
265. Zamora, D. L. and D. C. Thill. 1999. Early detection and eradication of new weed infestations. Pages 73-84 in R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Oregon St. Univ. Press, Corvallis.

NEW PUBLICATIONS (2000-2001)

1. Barthell, J.F., R.W. Thorp, A.M. Wenner, and J.M. Randall. 2000. Yellow star-thistle, gumplant, and feral honey bees on Santa Cruz Island: A case of invaders assisting invaders. Proc., California Islands Sym. 1999. Camarillo, CA. 5:269-273.
2. Benefield, C.B., J.M. DiTomaso, G.B. Kyser, and A. Tschohl. 2001. Reproductive biology of yellow starthistle (*Centaurea solstitialis*): Maximizing late season control. Weed Science (49:83-90).
3. DiTomaso, J.M. 2000. Invasive weeds in rangelands: Species, impacts and management. Weed Science 48:255-265.
4. DiTomaso, J.M. and J. Gerlach. 2000. *Centaurea solstitialis* (yellow starthistle). Pages 101-106. C. Bossard, J.M. Randall, M. Hoshovsky, eds. In, Invasive Plants of California's Wildlands. UC Press, Berkeley.
5. DiTomaso, J.M. and J. Gerlach. 2000. *Centaurea melitensis* (tocolate). Pages 98-100. C. Bossard, J.M. Randall, M. Hoshovsky, eds. In, Invasive Plants of California's Wildlands. UC Press, Berkeley.
6. DiTomaso, J.M., E. Healy, S. Enloe. 2000. California's Noxious Weeds. <http://pi.cdfa.ca.gov/weedinfo/>
7. DiTomaso, J.M., G.B. Kyser, S.B. Orloff, and S.F. Enloe. 2000. Integrated approaches and control option considerations when developing a management strategy for yellow starthistle. California Agriculture (54(6):30-36).
8. Dudley, D. R. 2000. Wicked weed of the west. California Wild 53:32-35.
9. Enloe, S.F., J.M. DiTomaso, S. Orloff, and D. Drake. 2000. Integrated strategies for the attrition of yellow starthistle on Northern California rangeland. Proc., California Weed Science Society 52:31-34.
10. Johnson, S.A. 2000. Thistle and bush management for rural and foothill landowners. Proc., California Weed Science Society 52:20-25.
11. Lass, L.W., B. Shafii, W.J. Price and D.C. Thill. 2000. Assessing agreement in multispectral images of yellow starthistle (*Centaurea solstitialis*) with ground truth data using a Bayesian methodology. Weed Technology 14:539-544.

12. Pitcairn, M.J and J.M. DiTomaso. 2000. Rangeland and uncultivated areas: integrating biological control agents and herbicides for starthistle control. Pages 65-72, M.S. Hoddle, ed. In, California Conference on Biological Control II.
13. Pitcairn, M.J., J.M. DiTomaso, and V. Popescu. 2000. Integrating chemical and biological control methods for control of yellow starthistle. Pages 58-61. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
14. Pitcairn, M.J., D.M. Woods, D.B. Joley, D.G. Fogle, and V. Popescu. 2000. Impact of seedling pathogens on yellow starthistle in California. Pages 52-54. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
15. Pitcairn, M.J., D.M. Woods, D.B. Joley, and V. Popescu. 2000. Five-year population buildup and combined impact of biological control insects on yellow starthistle. Pages 55-57. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
16. Shinn, S.L. and D.C. Thill. 2000. Yellow starthistle control with imazapic. Res. Prog. Rep. West. Soc. Weed Sci. Pg. 30.
17. Shinn, S.L. and D.C. Thill. 2000. Yellow starthistle control with imazapic, picloram, clopyralid, 2,4-D, and dicamba. Res. Prog. Rep. West. Soc. Weed Sci. Pg. 31.
18. Villegas, B., T. Lenigar, and D. Haines. 2000. Releases of the hairy weevil, *Eustenopus villosus*, in California for the biological control of yellow starthistle. Pages 47-50. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
19. Villegas, B., D. A. Mayhew, F. Hrusa, and J. Balciunas. 2000. Survey of *Chaetorellia* seedhead flies on *Cirsium* thistles in close proximity to *Centaurea* spp. in California. Pages 62-63. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.
20. Villegas, B., M. J. Pitcairn, and E. Coombs. 2000. Releases of *Nosema*-free *Larinus curtus* for the biological control of yellow starthistle in California in 1992-1999. Pages 35-37. D.M. Woods, ed. In, Biological Control Program Annual Summary, 1999. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, CA.