Sequential Impacts of Endemic Pathogens, Exotic Mollusks and Insects on Yellow Starthistle (Centaurea solstitialis L.) in California

DALE M. WOODS, MICHAEL J. PITCAIRN, and DONALD B. JOLEY

California Department of Food and Agriculture, Biological Control Program, 3288 Meadowview Road, Sacramento, California 95832, USA

Abstract

Yellow starthistle, *Centaurea solstitialis* L., is an invasive exotic annual weed in the western United States. Introductions of exotic seed head insects have been insufficient to control this weed throughout most of its range. A complex of seedling pathogens and mollusks which attack seedlings and exotic insects which attack seed heads combine in California and together, may cause declines in abundance of yellow starthistle. A study to document seedling mortality began Fall 1997 and continued weekly until Spring 1998. Yellow starthistle germinated in high numbers immediately following the first rain in November with peak abundance of 1,812 seedlings per square meter. Seedling mortality began soon after emergence and most had died after six weeks. On April 29, yellow starthistle average density was 565 seedlings per square meter, a decline of 71% from peak abundance. Peak numbers of 1-leaf stage was 61% lower than observed for peak numbers of cotyledon stage. Declines in peak numbers between 1-leaf and 2-leaf stages and 2-leaf and 3-leaf stages were 22% and 24%, respectively.

The endemic pathogen, *Sclerotinia minor*, was the predominant pathogen during this study with mycelial growth emerging from infected leaves, stems, and petioles following heavy rains. The fungus, *Colletotrichum gloeosporioides* was also detected throughout the season, usually on individual plants. *Ascochyta* n. sp., noted in previous years, was not observed during this study. In addition to occurrence of disease, many seedlings appeared to have been fed upon. Suspected organisms are small rodents, snails and slugs, especially the European grey garden slug, *Deroceras reticulatum*.

A group of four insect species attacking the capitula of yellow starthistle are widespread in California and severely reduce seed production in plants surviving seedling diseases. The combined impact of pathogens, mollusks, and insects may result in declines in adult plant density in the next few years.

Introduction

An ideal biological control program begins with a thorough evaluation of the target weed in the target country. Evaluation of both the presence and impact of endemic herbivores along with basic weed biology may assist in selection of exotic biological control agents. Following the introduction of the exotic agents, a monitoring program should include not only the development and impact of the introduced exotics but also the interaction with endemics. Unfortunately the expense, time and resource commitment required often precludes study of the endemics.

Yellow starthistle, *Centaurea solstitialis* L. (Asteraceae), is an invasive weed in the western United States. This annual plant of Eurasian origin was first reported in California
in 1869 in Alameda County. It has now become widespread, occupying over 3.2 million hectares (8 million acres) statewide (Maddox and Mayfield 1985, Pitcairn et al. 1998). Adult plant populations can reach high densities (200-800 plants per square meter) and produce over one million seeds per acre. Its life cycle begins with the onset of winter rains as seeds are highly germinable and most germinate once wetted. Field studies have shown that extremely high densities of seedlings are present in early winter but, by early spring, densities can drop by 50-75% (Pitcairn et al. 1999c). Plants begin bolting in early summer, set seed and usually die by early fall.

Surveys of yellow starthistle have identified very few pathogens or arthropods attacking mature plants (Johnson et al. 1992, Klisiewicz 1986). Recently, field surveys of yellow starthistle seedlings have identified at least three naturally occurring seedling pathogens in California: Ascochyta n. sp., Colletotrichum gloeosporioides, and Sclerotinia minor. All three appear to cause locally high rates of mortality (Woods 1996).

Six exotic insect species currently are established in California; four species, Bangasternus orientalis (Capiomont) (Coleoptera: Curculionidae), Urophora sirunaseva (Hering) (Diptera: Tephritidae), Eustenopus villosus (Boheman) (Coleoptera: Curculionidae), and Chaetorellia succinea (Costa) (Diptera: Tephritidae) are widespread. The two other species, Chaetorellia australis Hering (Diptera: Tephritidae), and Larinus curtus Hochhut (Coleoptera: Curculionidae), are abundant in the Pacific Northwest, but are limited to isolated populations in California. All of these insects attack the flower heads of yellow starthistle. Details of their impact are presented by Pitcairn et al in this volume.

Studies initiated in 1997 and continuing through 1999 are evaluating the population buildup, combined impact, and interaction of endemic seedling diseases and exotic arthropods on yellow starthistle. Preliminary evaluations suggest that seedling mortality may be substantial and complement the seed destruction by the introduced insects. Declines in yellow starthistle following release of the biological control insects may be first observed in those areas with endemic seedling diseases.

Materials and Methods

A study was initiated at a field site in Solano County during the winter of 1997-98 to evaluate the survival of yellow starthistle from germination to seed production. This site is a grassland along the shores of Putah Creek (a tributary of the Sacramento River) that is heavily infested with yellow starthistle. The site occurs at 18 m (60 ft.) elevation. A 8 x 20 meter plot was divided into ten 4 x 4 meter subplots and two 0.5 x 0.5 meter quadrats were randomly located within each subplot. Each quadrat was divided into four 0.25 x 0.25 meter sub-quadrats and one 10 x 10 cm sample area was randomly located within each sub-quadrat. Thus, there were four sample areas per quadrat and a total of 80 sample areas for the plot. Monitoring consisted of identifying and counting all yellow starthistle seedlings by stage. Seedlings were identified according to developmental stages based on the number of true leaves present: cotyledon, 1-leaf, 2-leaf, 3-leaf, and 4 or more-leaf. To document activity of seedling pathogens, representative samples of diseased seedlings were collected from outside the sample areas and cultured in the laboratory. Monitoring began November 21, 10 days after the first rain event and continued weekly until March 29, 1998 when all surviving seedlings had grown four or more leaves. After March, monitoring continued every four weeks until July 1, 1998. Sample areas were examined again on September 15, and all surviving plants were counted. For each plant, the number of
flower heads was determined, then harvested by cutting the stem at the soil, dried and weighed.

During 1998-1999 evaluations were continued at the Solano site, and at two additional sites where four of the six bioagents were established. The Placer and Sonoma County field sites were established to represent different climates where yellow starthistle occurs in abundance. The Placer County site is at 473 m (1550 ft) elevation in the Sierra Nevada foothills east of Auburn; the Sonoma County site is in the Coast Range foothills southeast of Santa Rosa at 390 m (1280 ft) elevation. Four insects (B. orientalis, U. sirunaseva, E. villosus, and L. curtus) were released at each site in 1993 and 1994. The fifth insect, C. succinea, invaded these sites on its own between 1996-1998. None of these insects were released at the Solano site, but B. orientalis, U. sirunaseva and C. succinea have invaded on their own and occur at low densities.

Results

Impacts on the seedlings. Yellow starthistle seedlings germinated in high numbers immediately following the first rain on November 10, 1997 (Figure 1A). Peak abundance occurred on November 20, ten days later. On this date, seedlings occurred in 79 of 80 sample areas with densities from 0 to 8,400 seedlings per square meter (average density was 1,812 seedlings per square meter). The one sample area without seedlings on this date was occupied on December 31, 1997, thus all sample areas received at least one seedling. Seedling mortality began early and most died by the end of December. The rate of decline was highest in late November and early December (32 seedlings per day). After mid December, the rate of decline was substantially lower (4 seedlings per day). Rainfall was frequent during November and early December, but a dry period occurred in the second half of December. Rainfall was frequent again from early January through February then sporadic thereafter. A second cohort of yellow starthistle seedlings occurred in January possibly due to the re-initiation of rainfall and warmer temperatures. By December 31, 17 of 80 sample areas were without yellow starthistle seedlings. Germination by the second cohort reduced this number to 10 of 80 sample areas without seedlings. Still, the rate of mortality for the second cohort was similar to the first and most died soon thereafter. On April 29, yellow starthistle was absent in 21 of 80 sample areas; average density was 565 seedlings per square meter, a decline of 71% from peak abundance.

Seedling mortality was greatest during the cotyledon stage (Figure 1B). Peak numbers of 1-leaf stage was 61% lower than observed for peak numbers of cotyledon stage. Declines in peak numbers between 1-leaf and 2-leaf stages and 2-leaf and 3-leaf stages were 22% and 24%, respectively. Peak abundance of the 1-leaf stage was three weeks following peak cotyledon abundance. The time between peak abundance for the subsequent stages was two weeks. This suggests that yellow starthistle added one new leaf every two to three weeks during this study.

Field observations of disease symptoms and laboratory cultures of pathogens suggest that S. minor was the predominant pathogen during this study. Fungal hyphae could be seen emerging from infected leaves, stems, and petioles following heavy rains. The infected tissue then collapsed and became slimy prior to complete death. Patches of diseased plants encompassed irregular areas up to 0.5 meter in diameter. The fungus, C. gloeosporioides was detected throughout the season, usually on individual plants. Ascochyta n. sp. was not observed during this study, but had been detected in previous years at this site. In addition to occurrence of disease, many seedlings appeared to have been fed upon. The
cotyledons and leaves of many plants were chewed away or removed. Suspected organisms are small rodents, snails and slugs.

Germination during the second year at the Solano site was more protracted (Figure 2) and had fewer seedlings. The initial group of new seedlings were rapidly attacked by *C. gloeosporioides* and an unidentified species of *Alternaria*. *S. minor* was not detected but this was a relatively dry year and dense seedling stands did not develop. Large populations of the European grey garden slug, *Deroceras reticulatum*, completely consumed the remaining seedlings in the plots. New seedlings emerged over the next two months associated with periods of rain, but were quickly consumed by the slugs.

The Placer and Sonoma sites followed the pattern seen in the first year at the Solano site with a rapid but continual decline in seedling numbers. The primary cause of mortality at these sites was *C. gloeosporioides* (Figure 2) with *S. minor* detected once at the Placer County site but not at the Sonoma County site.

**Mortality during the bolting phase.** The majority of the seedlings that survived to the
four-leaf stage survived to bolt and flower. However, only 26% of the initial seedlings sur-
vived to the early bolting stage (July 1) and only 19.4% were detected on September 15
to contribute seed for the next generation.

Impacts on seed production. Four years after the first releases, seed head attack by the
introduced biological control agents has substantially reduced yellow starthistle seed pro-
duction which may translate into a decline in mature plant populations. The Sonoma
County site, in particular, has had dramatic changes in both insect populations and yellow
starthistle seed production. The proportion of seedheads attacked increased every year
with a concurrent decrease in seed production from 13,839 to 3,802 seed per sq. m.
Seedling density has also declined each year at this site. In contrast, seed production at the
Placer County site has been more variable in spite of high populations of seedhead insects.
This was due to an three-fold increase in seed head production (heads/square meter) by
adult plants in 1998 that resulted from the unusually high rainfall in the spring. We hope
to see further increases in bioagent densities over the next few years that may translate
into steady declines in seed production despite variation in spring rainfall.

Discussion
Seedling mortality of yellow starthistle can be very high. Despite the huge number of
seeds produced annually, less than 20% survive to reproduce. Most mortality occurs prior
to bolting and appears to limit mature plant density. While seedling mortality is an annu-
al event of yellow starthistle, particularly in dense stands, the presence of any single dis-
ease was sporadic or somewhat localized in our studies. This mortality occurred either on
isolated plants or as large patches of dead plants, but has not been noticed because of the
large numbers of plants that remain. During the winter of 1997/1998, *S. minor* was par-
ticularly devastating in high-density settings and where skeletons from the previous years
starthistle plants provided shading. Aerial mycelium was common and fairly easy to
detect. *S. minor* has an extremely broad host range that includes many broad-leaved plant
families and includes major crops such as lettuce. Although the pathogen might poten-
tially have some use as an bioherbicide for yellow starthistle seedlings under moist con-
ditions, the lack of host specificity may limit its usefulness. The fungus, *C. gloeospori*

![Fig. 2. Yellow starthistle densities from October, 1998, through June, 1999, at three locations in central California.](image-url)
oides, has been used as a commercial biological control product, but we have not yet refined the degree of host specialization for our isolate. The field expression of this disease was most commonly detected as single plants that appear wilted, shriveled, or yellowed. Occasionally, small patches of dead seedlings surrounded by symptomatic plants were detected. We have found this disease in several California counties and believe that it can have a significant impact on yellow starthistle.

Following their release four years ago, the population densities of the seed head insects have continued to increase. Seed head attack rates now exceed 80% at both the Placer and Sonoma County sites and have resulted in a substantial decline in seed production. However, seed head attack is concentrated during peak flowering and declines greatly in late summer. Thus, seed destruction by insects is limited. Infection of seedlings by endemic pathogens later in the life cycle may provide additional reduction in plant numbers.

The life cycle of yellow starthistle in California is diagramed in Figure 3. Beginning with seeds in the soil in late summer, the onset of winter rains initiates germination. Mortality occurs at all stages of the life cycle. The impact of the currently introduced biological control agents is restricted to the reduction of seed in the flower heads before dispersal. The destruction of seedlings in winter and spring by endemic plant pathogens compliments the impact of the biological control insects as removal of a seedling is identical to destruction of a seed by an insect. Thus, it is the combined impact of both insects and diseases that determine control of this plant. Field estimates of seed destruction by insects

---

**Fig. 3.** Generalized life cycle of yellow starthistle. Dark boxes indicate points where plants leave the system.
range from 50-80%. Seedling mortality at these three field sites range from 75-100%. Together, plant mortality ranges from 87-100% and may lower plant density to where the population becomes seed-limited.

References


