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Population Buildup and Combined Impact of Introduced Insects on Yellow Starthistle (*Centaurea solstitialis* L.) in California

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Abstract

Seven exotic seed head insects have been introduced into the western United States for control of yellow starthistle. Six are established; three are widespread. Preliminary evaluations suggest that no one insect species will be able to reduce yellow starthistle abundance in California. Rather, a combination of the current, and possibly, future natural enemies may be necessary. Studies were initiated in 1993 to evaluate the population buildup, combined impact, and interaction of all available biological control insects on yellow starthistle. Three field sites were established in different climatic regions where yellow starthistle is abundant. Four insects, *Bangasternus orientalis*, *Urophora sirunaseva*, *Eustenopus villosus*, and *Larinus curtus*, were released at each site in 1993 and 1994 and long-term monitoring was initiated. The accidentally-introduced insect, *Chaetorellia succinea*, was recovered in 1996-98 at these sites.

Four years after the first releases, we have evidence that these biological control agents are having an impact on yellow starthistle seed production that may translate into a decline in mature plant populations. *E. villosus*, has become the most abundant insect at all sites infesting 47-79% of the flower heads. In addition, feeding damage by adult *E. villosus* kills young developing flower buds. The other three insects, *B. orientalis*, *U. sirunaseva*, and *L. curtus* have increased more slowly and have remained at infestation rates less than 23%. The seed head fly, *C. succinea*, was first recovered in 1996; infestations rates in 1998 ranged from 1-10% among sites. At one site, seed heads infested by at least one biological control insect increased from 22% in 1995 to 83% in 1998. In addition, there has been a concurrent decrease in seed production (13,839 to 3,802 seed / m^2) and seedling density (897 to 234 seedlings / m^2). If this trend continues, we anticipate a significant decline in adult plant density in subsequent years.

Introduction

Yellow starthistle, *Centaurea solstitialis* L. (Asteraceae), is an exotic noxious weed that has become one of California's worst pests. Since its introduction near the San Francisco Bay Area about 1850, it has spread steadily throughout California and other western states (Maddox 1981, Maddox and Mayfield 1985). It infests over 3.2 million hectares (8 million acres) of rangeland, native grassland, orchards, vineyards, pastures, roadsides, wasteland areas, parks, and wildlands in California. Although its establishment is favored by soil disturbance and high light, it is also capable of invading areas undisturbed by humans or livestock activity (Hastings and DiTomaso 1996) and has invaded a

number of nature preserves (J. Randall, The Nature Conservancy, pers. comm.).

Yellow starthistle poses a significant economic impact to public and private landowners. It can reduce rangeland productivity, increase the cost of feeding livestock and conducting vegetation management programs, and poison horses. Infestations in wildlands often dominate the plant community and significantly reduce native plant diversity. In addition, the spiny flower heads reduce visitor use in infested state and federal recreational areas.

The United States Department of Agriculture initiated a classical biological program against yellow starthistle in the 1950's. These efforts have resulted in the approval and introduction of six seedhead insects into the western United States: *Urophora jaculata* Rondani (Diptera: Tephritidae), *Urophora sirunaseva* (Hering) (Diptera: Tephritidae), *Bangasternus orientalis* (Capiomont) (Coleoptera: Curculionidae), *Eustenopus villosus* (Boheman) (Coleoptera: Curculionidae), *Larinus curtus* Hochhut (Coleoptera: Curculionidae), *Chaetorellia australis* Hering (Diptera: Tephritidae) (Turner *et al.* 1995). Five insects are established in the western United States; three species, *B. orientalis*, *U. sirunaseva*, and *E. villosus*, are widespread. Two species, *C. australis* and *L. curtus* are abundant in the Pacific Northwest, but are limited to isolated populations in California. The fly, *U. jaculata*, failed to establish. In addition, a seventh seedhead insect, *Chaetorellia succinea* (Costa) (Diptera: Tephritidae) was accidentally introduced into western North America and is now widespread throughout California and the Pacific Northwest (Balciunas and Villegas 1999). All of these insects attack the flower heads of yellow starthistle and destroy developing seeds.

Preliminary evaluations of the impact of individual species on seed production in California suggest that no single agent will be the dramatic silver bullet in reducing yellow starthistle abundance. Rather, a combination of the current, and possibly, future natural enemies may be necessary to control this plant. A study was initiated in 1993 to evaluate the population buildup, combined impact, and interaction of all currently available biological control insects on yellow starthistle. Field sites were established in Yolo, Placer, and Sonoma Counties to represent three different climates where yellow starthistle occurs in abundance. Here we report on observations spanning the first four years of this study.

Materials and Methods

The Yolo County site is located approximately 40 km (25 miles) northwest of Sacramento in the Sacramento Valley, a large valley in the northern half of the California's great Central Valley. It is at 90 ft elevation and consists of open rangeland. The Placer County site is a small grassland area at 1250 ft elevation in the Sierra Nevada foothills approximate 65 km (40 miles) northeast of Sacramento. The Sonoma County site is a small grassland area in the Coast Range foothills approximately 97 km (60 miles) west of Sacramento.

Four insects (*B. orientalis*, *U. sirunaseva*, *E. villosus*, and *L. curtus*) were released at each site in 1993 and 1994 and long-term monitoring of the weed and insect populations was initiated. The fly, *C. succinea*, was mistakenly released, as *C. australis*, at the Yolo County site in 1996 (Balciunas and Villegas 1999); it invaded the other two sites on its own in 1998. In 1995, study plots were set up at each site. Each plot measures 30 x 30 meters within which 100 quadrats (1 m x 1 m) are located in a systematic 10 by 10 grid. Plant cover estimates of yellow starthistle and competing species, yellow starthistle seedling emergence, adult plant density, and seed head numbers are taken from a 20 x 20

cm area located in the center of each quadrat. Adult plant density is estimated in October, seedling emergence is counted shortly after the first winter rainfall event in November or December, and plant cover is estimated in May of each year. Seed production and insect infestation levels in seed heads were monitored using plants immediately outside the plot area. Two transects, each 20 meters in length, were placed alongside two edges of the plot (total = 4 transects). Rods were placed at 40 positions along each transect using a restricted randomization procedure. The nearest adult plant to each rod were selected for monitoring. Transects were visited every two weeks during flower production and all seed heads on selected plants were enclosed in cloth bags shortly after flowering to retain seeds and insects. Plants were harvested when dead and taken to the laboratory for processing. Seed heads were examined individually for presence, number, and life stage of all insects and number of filled seeds. Seed head size (outside diameter) is also measured. Seed viability was examined by placing all filled seed on moistened blotter paper in petrie dishes and held in a environmental chamber at 20°C and 12 hr light. After one week, all germinating seed are counted. Those seed not germinated are cut open and examined for healthy endosperm. Total viable seed is the total of germinated seed and ungerminated seed with healthy endosperm. Buds and branch tips were scored for damage from feeding by adult *E. villosus* or immature death. All plant materials other than seeds were oven-dried at 60°C until constant weight (approximately 24 hours) and weighed. All seeds were weighed fresh before germinating.

Results and Discussion

All four insects readily established at the study sites (Table 1). Population increase was most rapid for *E. villosus* which has become the most abundant insect at all three sites, infesting 47-79% of the flower heads. In addition, adult *E. villosus* feed on young developing buds. This feeding kills the buds and produces a structural change in the plants which remain dominated by stems. Instead of flowers born on the tips of stems, the early flowers are killed as developing buds. Later, the plant produces new flowers on short stems which arise from the leaf axils along the main stems. The other three insects, *B. orientalis*, *U. sirunaseva*, and *L. curtus* have increased more slowly and have remained at infestation rates less than 23%. The seed head fly, *C. succinea*, was first recovered in 1996 at the Yolo County site and in 1998 at the Placer and Sonoma County Sites. Infestation rates in 1998 ranged from 1-10% of the seed heads among sites. In addition, the occurrence of seed heads attacked by more than one insect species has steadily increased. The proportion of seed heads attacked by at least one species ranged from 60-83% in 1998.

Observations on plant recruitment and seed production show that these biological control agents are having an impact on yellow starthistle seed production that may translate into a decline in mature plant populations. The most dramatic changes have occurred at the Sonoma County site where the rapid increase of *E. villosus* resulted in a steady decline in the number of flowers per plant and the number of seeds per head. The percentage of mature heads infested by at least one biological control insect increased from 22% in 1995 to 83% in 1998. The most immediate result of seed head attack by the introduced biological control agents is the change in average number of seeds per head and seed production (seeds/square meter). At this site, the number of seeds per head decreased from 25 to 8 seeds per head which has resulted in a concurrent decrease in seed production from 13,839 to 3,802 seed per sq. meter. In addition, seedling density has declined from 897 to 234 seedlings per sq. meter. Despite this decline in recruitment, little change occurred in adult

Table 1.
Status of Yellow starthistle and its natural enemies at three multiagent research sites

PLACER COUNTY						
Plant		**95**	**96**	**97**	**98**	**99**
Seedlings/square meter		-	651	669	883	666
Adult plants/square m		332	83	108	151	
Heads/ square meter		679	280	438	378	
Seed/head		8.2	18.0	16.2	6.7	
Seeds/square meter		5,568	5,040	7,096	2,533	
Insect and release year						
B. orientalis	93	6.7%	0.6%	1.6%	12.0%	
U. sirunaseva	93	4.7%	5.0%	8.7%	7.4%	
E. villosus	93	51.6%	50.9%	54.8%	79%	
L. curtus	94	0	0	0.2%	0%	
C. succinea	-	0	0	0	3%	
Heads w/ 1 or more sp		58%	60%	60%	83%	

YOLO COUNTY						
Plant		**95**	**96**	**97**	**98**	**99**
Seedlings/square meter		-	1095	1928	1076	642
Adult plants/square m		975	322	180	422	
Heads/ square meter		1181	369	343	830	
Seed/head		24	27	13	15	
Seeds/square meter		28,344	9,963	4,459	12,450	
Insect and release year						
B. orientalis	91	5%	3%	7%	4%	
U. sirunaseva	93	13%	20%	12%	17%	
E. villosus	93	5%	16%	24%	47%	
L. curtus	94	0	0	0.2%	0%	
C. succinea	96	0	2%	7%	10%	
Heads w/ 1 or more sp		20%	36%	38%	60%	

SONOMA COUNTY						
Plant		**95**	**96**	**97**	**98**	**99**
Seedlings/square meter		-	897	822	624	234
Adult plants/square m		241	233	222	231	
Heads/ square meter		547	442	508	486	
Seed/head		25.3	14.9	8.0	7.8	
Seeds/square meter		13,839	6,586	4,064	3,802	
Insect and release year						
B. orientalis	94	5.4%	9.5%	4.2%	12.4%	
U. sirunaseva	94	4.8%	16.3%	19.7%	22.7%	
E. villosus	94	12.9%	37.3%	73.9%	72.7%	
L. curtus	94	0	0	0.7%	0.5%	
C. succinea	-	0	0	0	1.0%	
Heads w/ 1 or more sp		22%	56%	80%	83%	

plant densities. However, if the decline in seed production and seedling recruitment continues, we anticipate a decline in adult plant density in subsequent years.

The impact on seed production was less clear at the other two sites. At the Yolo County site, the number of seeds per head declined from 24-27 to 13-15 seeds per head. However, despite this decline, seed production increased three-fold in 1998, presumably due to the unusually high rainfall which extended into early summer. Still, the population densities of *E. villosus* and *C. succinea* have increased steadily over the last three years and may increase to densities high enough to cause a sustained decline in plant abundance.

The density of seed head insects at the Placer County site built up quickly but showed little change from 1995-1997. However, a significant increase in insect densities was observed in 1998. *E. villosus* was the most abundant insect, infesting 79% of the seedheads in 1998; the other insects occurred at rates 0-12%. There was little change in adult plant density and seed head production (heads/square meter) at this site, but there has been a steady decline in seed production (5,568-2,533 seeds/square meter). We hope to see an increase in *C. succinea* over the next few years that will complement the impact of the other insects.

Summary

After four years, the introduced seed head insects are still increasing at all three sites. Impact was observed as a reduction in average seed per head and seed production (seeds per sq. meter) at all sites. However, seed destruction to date has not resulted in a decline in adult plant density. If the seed head insect populations continue to increase, we hope that the additional decrease in seed production will translate into a decline in adult plant density. The weevil, *E. villosus,* is clearly the most important insect to date at these sites, increasing to quite high levels. However, plant samples show that activity of this insect is limited to early summer (June-August) and that flowers produced after mid-August are not attacked. It is hoped that the seed head fly, *C. succinea*, which has several generations per year, will continue to increase in number and attack these late-season flowers.

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