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INFLUENCE OF YELLOW STARTHISTLE (*CENTAUREA SOLSTITIALIS*) ON SMALL MAMMALS IN CENTRAL CALIFORNIA

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ABSTRACT.—Yellow starthistle (*Centaurea solstitialis*) is native to Europe and Asia and has quickly invaded disturbed grasslands and rangelands in the western United States. The purpose of our study was to determine the effects of starthistle on rodents at Beale Air Force Base, Yuba County, California, by examining rodent species diversity, species abundance, age structure, and reproductive condition among locations with low, medium, and high percent cover and height of starthistle. Listed in decreasing order of abundance, the rodents were house mouse (*Mus musculus*), California vole (*Microtus californicus*), deer mouse (*Peromyscus maniculatus*), western harvest mouse (*Reithrodontomys megalotis*), and roof rat (*Rattus rattus*). Indices of diversity did not differ among starthistle cover categories. Regression analyses showed that *Reithrodontomys megalotis* was more abundant in high-cover starthistle plots, with 90.5% of captures occurring in at least 40% starthistle cover. Significant differences were found in capture rates, reproduction, and age between season only. To manage for all rodent species, an area with medium percent cover and height of starthistle will likely provide adequate protective cover.

Key words: small mammals, rodents, yellow starthistle, Centaurea solstitialis, *Beale Air Force Base, Yuba County, California.*

Yellow starthistle (*Centaurea solstitialis;* Asteraceae) is an aggressive, invasive annual plant from the Mediterranean region of Europe and Asia. The first introductions in California may have occurred as early as 1824 and were followed by subsequent introductions throughout the century (Roche et al. 1997). Starthistle has rapidly occupied grasslands and rangelands that have previously undergone disturbance as a result of agriculture, construction, military activities, or other means. It is currently considered California's most invasive weed, occupying up to 6 million hectares in California (DiTomaso 1998, DiTomaso et al. 1999). The main feature that gives this plant an advantage over annual and perennial competitors is the difference in the timing of its life cycle. In late spring, when most grasses are flowering, yellow starthistle plants are just beginning to emerge from the ground as small rosettes. By the time the grasses have matured and the annuals have become dormant, starthistle is just beginning its reproductive stage (Roche et al. 1994). Roche et al. (1994) showed that the starthistle plant concentrates its early growth on developing a deep taproot and later develops its leaves. This strategy may allow it to survive summer drought conditions by reaching water that the grasses could not use. Starthistle has become an economic hardship on agriculture by inhibiting the growth of other plants in orchards, vineyards, and rangelands (DiTomaso 1998).

Exotic plant species also are recognized as a potential threat to the existence of many wildlife species. Several studies have documented the negative effects of invasive plant species on Burrowing Owls (*Athene cunicularia;* Coulombe 1971, Zarn 1974) and Swainson's Hawks (*Buteo swainsoni;* Estep 1989). The effects of nonnative plants on rodents have also been documented. In New Mexico the use of exotic vegetation by rodents correlated only with short-term weather fluctuations, while native vegetation was used consistently (Ellis et al. 1997).

Our goal was to determine, by examining differences in rodent assemblages between locations of starthistle and those with mainly annual grasses, whether the introduction of yellow starthistle has been detrimental to nocturnal rodents. We determined whether differences existed in rodent (1) species diversity, (2) species abundance, (3) age, and (4) reproductive condition among locations with low, medium, and high percentages of cover and height of starthistle. Although most grasses at

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the site also are nonnative, these species are more closely related to the natural vegetation of the region than is starthistle, which differs substantially from most native and nonnative grasses in its height, canopy cover, and life cycle.

Van Horne (1983) and Pulliam (1988) recognized that the presence of animals in an area does not necessarily imply that the area is of high quality. A high-quality habitat, or source, is one in which reproductive success outweighs mortality (Van Horne 1983). If the highest-quality habitat is saturated, the young or less fit animals may be forced into areas of lesser quality. In such sinks, little or no reproduction takes place and mortality is relatively high (Van Horne 1983, Pulliam 1988, Meffe and Carroll 1994). Therefore, we collected data on age and reproductive condition in an attempt to determine the quality of the habitat.

STUDY SITE

Beale Air Force Base (AFB; 39°8′N, 121°26′W) is in Yuba County, California, on the eastern edge of the Central Valley between the agricultural lands of the valley and the foothills of the western Sierra Nevada. The base is 9285 ha in size, of which approximately 80% is undeveloped. Elevation varies from 26 m to 213 m above mean sea level, generally with the higher elevation on the east side of the base in the Sierra Nevada foothills (U.S. Army Corps of Engineers 1999).

The site has cool, moist winters and hot, dry summers. Average annual precipitation is approximately 52 cm, most of which occurs between November and March. Average monthly temperatures range from 4°C in December and January to 36°C in July (Beale AFB Combat Climatology Center unpublished data).

The rainy season of 1997–98 was under the effects of the El Niño ocean currents. Rainfall at the study site from July 1997 to June 1998 was 103.48 cm, approximately double the average. The rainy season that usually ends in March continued into June 1998 with localized flooding. Abnormal freezing temperatures occurred in mid-December (Beale AFB Combat Climatology Center unpublished data).

The land comprises mostly exotic annual grassland, about 50% of which supports cattle grazing from November through May of each year. Common nonnative grasses at the site are medusahead (*Taeniatherum caput-medusae*), ripgut brome (*Bromus diandrus*), Italian ryegrass (*Lolium muliflorum*), soft chess (*Bromus hordeaceus*), and wild oat (*Avena fatua*). Forbs and native perennial grasses also occur, but they are relatively rare compared with dominant introduced grasses. The base also supports relatively smaller areas of riparian oak (*Quercus* spp.) woodlands and oak savannah (U.S. Army Corps of Engineers 1999), but it is mainly the grassland areas that have widespread, heavy infestation of yellow starthistle.

METHODS

We established 21 sampling plots that consisted of varying amounts of starthistle cover. Sampling plots were chosen by visually estimating the percentage of starthistle within the proposed trapping area. We conducted our study from April 1998 through March 1999 for a total of 6745 trap-nights. Trapping was divided into 4 seasons: spring, April–June 1998 (1889 trap-nights); summer, July–September 1998 (1890 trap-nights); autumn, October 1998–early January 1999 (1529 trap-nights); and winter, late January–March 1999 (1437 trap-nights). We sampled all 21 plots each season. Trap-nights varied between seasons because high capture rates in some seasons required the reduction in number of traps set in the interest of animal safety (i.e., because of wet or cold weather); most plots were sampled for 3 nights. Because of unequal trapping efforts, we express relative rodent abundance as a capture index, calculated by multiplying the number of new animals caught per trap night by 100 trap-nights (Nichols and Conroy 1996, Morrison and Hall 1998).

Because many plot sizes were limited by boundaries such as fences, grazed pastures, firing ranges, and buildings, standard plot configurations were not possible. Instead, each plot consisted of 3 lines spaced 15 m apart, and each line contained 10 trap stations with each trap spaced 10 m away from the next; thus, each plot covered approximately 2700 m^2.

Large Sherman live-traps (7.6 × 8.9 × 22.9 cm) were baited with a rolled oats and peanut butter mixture. They were furnished with polyester batting material and covered on the tops and sides with soil and plant material to decrease the chance of hypothermia. When necessary, we also protected traps from rain and excessive heat by placing cedar shingles on top. Traps were set out in late afternoon and checked each morning. All mammals captured were identified to species and marked with a permanent marking pen and toenail clipping to determine whether animals were recaptured within the same session.

Age, mass (weight in grams), and reproductive-condition data were used to compare the quality of plots. Age was categorized as adult, subadult, or juvenile depending on established weights and pelage color for each species. Reproductive condition was scored as nonreproductive, scrotal testes, perforated vagina, enlarged nipples, and/or pregnant. All animals were released at the capture site. To correct for closed but empty traps, we adjusted trapnights prior to analysis following Jackson (1952) and Nelson and Clark (1973). A reproductive-condition index was determined by dividing the number of reproductive animals by the total number of different individuals captured, while an age-structure index was calculated as total number of different adults captured divided by total number of individuals captured.

We quantified vegetation cover using the point-intercept method (Higgins et al. 1996, Elzinga et al. 1998) once per season in each of the 21 trapping plots. Additionally, in each trapping plot we assessed vegetation at 19 points spaced 5 m apart along each of the 3 transects for a total of 57 points per trapping plot. Starthistle cover was calculated as a percentage in each plot by dividing total number of points scoring positive for starthistle by total number of points measured. This process allowed the placement of each plot into a starthistle category: low (0%–33%), medium (34%–67%), or high (68%–100%) starthistle cover. Average yellow starthistle height at each plot was calculated, and 3 average height categories were established: low (≤25 cm), medium (26–49 cm), or high (≥50 cm).

We initially tested all data for normality using the Kolmogorov-Smirnov goodness-of-fit test (Zar 1996:471). Data that were not normal were transformed via logarithmic or arcsine transformations and tested again for normality. Because the data did not deviate severely from the assumptions of the tests, we used parametric tests for their increased power (Zar 1996: 187). All statistics were performed with alpha ≤ 0.05. Using the species abundance indices, we calculated a Shannon-Wiener diversity index (Zar 1996:39) for each starthistle cover category within each season and performed a 2-way ANOVA of season versus cover category.

Starthistle cover categories, starthistle height categories, and the 4 seasons were used as independent variables in 3-way factorial ANOVA tests (Zar 1996:179) on the dependent variables of abundance capture index, reproductive-condition index, and age-structure index for all captures combined as well as each species individually. In reporting ANOVA test results, we will discuss only the main effects unless we specifically state that an interaction occurred between independent variables. When the null hypothesis was rejected in any ANOVA, the Tukey test (Zar 1996:212) was used to determine where differences existed.

Additionally, we performed separate simple linear regression analyses (Zar 1996:319) on the percentage of starthistle cover versus rodent abundance for each species and total animal abundance within each season. This set of tests was performed to assess whether the level of starthistle in an area can be a predictor of abundance of each species caught or of total animal abundance.

RESULTS

Listed in decreasing order of abundance, the 5 rodent species captured were house mouse (*Mus musculus*), California vole (*Microtus californicus*), deer mouse (*Peromyscus maniculatus*), western harvest mouse (*Reithrodontomys megalotis*), and roof rat (*Rattus rattus;* Table 1). Only a single *R. rattus* was captured during the study, and while it was used in calculating diversity indices, the species was not used in all statistical tests.

All 4 predominant species were captured in all categories of starthistle cover. Indices of diversity did not differ among seasons (F = 2.34, df = 3, P = 0.15) or starthistle cover categories (F = 0.89, df = 2, P = 0.44).

For overall species abundance, no significant differences were detected among the low, medium, and high categories of starthistle cover (F = 1.38, df = 2, 81, P = 0.26) or starthistle height (F = 2.63, df = 2, 81, P = 0.08), but significant differences in abundance existed between seasons (F = 23.53, df = 3, 81, P < 0.001). The spring capture rate was significantly lower than all other seasons in that it represented only 4.3% of total captures

TABLE 1. Abundance indices by season and species at Beale Air Force Base, Yuba Co., CA, during yellow starthistle study from April 1998 to March 1999. Abundance index = (number of different individuals / number of trap-nights) × 100.

Season	Total	*Mus musculus*	*Microtus californicus*	*Peromyscus maniculatus*	*Reithrodontomys megalotis*	*Rattus rattus*
Spring	3.5	0.6	1.8	1.2	0.0	0.0
Summer	17.1	7.3	8.2	1.2	0.4	0.0
Autumn	35.7	16.3	16.9	1.2	1.4	0.0
Winter	25.0	10.9	5.4	5.8	2.9	0.1

in our study. Summer had a significantly lower capture rate (21.0% of total captures) than autumn (43.9% of total captures; Table 1).

The abundance of *Mus* was significantly ($F = 11.62$, df = 3, 81, $P < 0.001$) lower in spring than in all other seasons. When rodent abundance versus starthistle cover, height, and season was analyzed for each species individually, significant differences were detected for *R. megalotis* and *M. californicus.* An interaction between starthistle cover and season was identified for *R. megalotis* abundance ($F = 4.42$, df = 6, $P = 0.001$). The winter season accounted for 61.7% of all *R. megalotis* captures, and 90.5% of all individuals of this species were in plots with at least 40% starthistle cover. An interaction was detected between starthistle cover and height ($F = 4.59$, df = 4, $P = 0.003$) and starthistle height and season ($F = 2.43$, df = 5, $P = 0.046$) for *M. californicus* abundance. The autumn season accounted for 52.3% of all individuals of *M. californicus* captured, with the highest percentage (48.2%) caught in low starthistle. Only 5.6% of *M. californicus* were captured in spring, with most (96.7%) of these in medium and tall starthistle.

There was a significant relationship between starthistle cover and abundance of *R. megalotis* over all seasons ($r^2 = 0.08$, $n = 84$, $P = 0.01$) and specifically in winter ($r^2 = 0.37$, $n = 21$, $P < 0.01$). Sixty-two percent of the captures of this species occurred in winter.

When reproductive condition was assessed in relation to starthistle cover and height and season, only the effect of season was significant. *Microtus californicus* had lower reproductive activity (3.5% of all captures) in autumn than in spring and winter seasons, when 25.3% and 31.2% of individuals, respectively, were reproductively active ($F = 5.13$, df = 3, $P = 0.004$). *Mus musculus* was more reproductively active during the summer season (65.2% of all captures) in comparison with all other seasons when the reproductive rate ranged from 3.2% to 27.3% ($F = 22.43$, df = 3, $P < 0.001$). *Reithrodontomys megalotis* was more reproductively active in the summer season (50% of all captures) compared with the other seasons in which the reproductive rate ranged from 0% to 4.9% ($F = 10.58$, df = 2, $P = 0.004$). The overall reproductive index for summer was at least 24% lower than all other seasons.

In testing individual species for age-related effects of starthistle cover, starthistle height, and season, significant differences were found only for *R. megalotis* by season. More adult animals were captured in autumn (85.7% of captures) and winter (95.1% of captures) as opposed to only 50% in the summer ($F = 6.79$, df = 2, $P = 0.016$). No *R. megalotis* individuals were captured in the spring.

DISCUSSION

All 4 main rodent species captured were found in all 3 categories of starthistle cover. However, capture rate was lowest in spring. This low capture rate was likely related to the heavy rain during the spring season and is probably not typical of all years. Localized flooding conditions may have forced rodents to abandon their burrows or other nesting sites, at which time they became more exposed to predation (Getz 1985).

Vegetative cover is thought to be the most important factor in supporting healthy *Microtus* populations, and in most studies population size tends to correlate positively with cover (Rose and Birney 1985). Increased cover provides protection from predators and perhaps regulates humidity and temperature. Predation is one of the most significant pressures on *Microtus* as this species is a frequent prey item in most grasslands (Pearson 1985). Because our results did not indicate a positive relationship between *Microtus* abundance and starthistle cover, we think that areas with high starthistle cover and areas with the other plant species (primarily nonnative grasses) present at our study site provide adequate cover for this species to survive and reproduce.

Reithrodontomys megalotis and *M. californicus* are cover-dependent species that avoid areas that lack plant cover (Kaufman and Kaufman 1989, Poopatanapong and Kelt 1999). In our study *R. megalotis* was the only species to significantly increase in abundance in response to increased yellow starthistle cover. The low r^2 (0.08) for *R. megalotis* over all seasons was likely the result of the few captures of this species over the entire study. Because 62% of all *R. megalotis* captures occurred in the winter, this higher number of captures within fewer trapping sessions may account for the relatively higher r^2 value of 0.37. We think the higher capture rate of *Reithrodontomys* in high starthistle cover particularly supports the idea of cover dependence.

Mus, the most abundant species captured during our study, was ubiquitous across the study plots regardless of starthistle height and cover. It is unlikely, therefore, that this species can be managed through changes in starthistle structure.

Although some differences in abundance were found, we ascertained no significant relationships between reproductive-condition index and starthistle development (cover or height). It appears, therefore, that individuals were able to reproduce in all categories of starthistle even though abundances might be relatively low in certain categories. Thus, no differences in habitat quality as measured by reproductive condition were evident.

At Beale AFB and other locations in the region, attempts are being made to restore native plant communities. We do not know the impact that such restoration activities might have on rodent communities, including the influence on abundance of the exotic *Mus*. We have, however, shown that even a noxious weed such as yellow starthistle can provide high-quality habitat for rodents. Planting bunchgrasses such as purple needlegrass (*Nassella pulchra*) might provide the necessary habitat components, including protective cover, with which these animals evolved. If large areas of native bunchgrasses can be successfully established, they would provide a situation in which an investigation could be conducted to compare starthistle and nonnative grassland areas with restored sites composed of native grasses.

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