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Population Dynamics and Impacts of the Red-Headed Leafy Spurge Stem Borer on Leafy Spurge (*Euphorbia esula*)

Robert A. Progar, George Markin, Joseph Milan, Tom Barbouletos, and Matthew J. Rinella*

We evaluated the efficacy of the biological control agent, red-headed leafy spurge stem borer, against the nonnative invasive plant leafy spurge. Our three treatments were release of the biological control agent into uncaged plots, release of the biological control agent into plots caged to prevent agent escape, and control plots caged to prevent agent entry. These treatments were replicated three times at six sites in the western United States. We measured leafy spurge biomass for 1 or 2 yr following release. We also measured the percentage of leafy spurge stems showing evidence of red-headed leafy spurge stem borer oviposition for either 1 or 2 yr following agent release, depending on the site. Red-headed leafy spurge stem borer did not demonstrably reduce leafy spurge biomass in our study. Moreover, compared to the release year, evidence of red-headed leafy spurge stem borer oviposition declined with time, suggesting the agent population was diminishing. This suggests the agent is incapable of building large populations capable of controlling leafy spurge at the sites we studied. However, after being released, populations of biological control agents sometimes go through long lag phases and then begin rapid population increases, so we cannot completely dismiss the possibility that red-headed leafy spurge stem borer might become effective given more time.

Nomenclature: Red-headed leafy spurge stem borer, *Oberea erythrocephala* Schrank.; leafy spurge, *Euphorbia esula* L.

Key word: Biocontrol, invasive weeds, leafy spurge, *Oberea erythrocephala*.

Leafy spurge (*Euphorbia esula* L.) is a deep-rooted perennial invasive plant that is native to Europe and Asia (Selleck et al. 1962). It was first reported in North America in Massachusetts in 1827 (Britton 1921) and now infests nearly 2 million ha (4.9 million ac) of land in the United States (Duncan et al. 2004). *Euphorbia esula* can negatively impact forage production (Lym and Messersmith 1985), livestock and wildlife carrying capacities (Trammell and

Butler 1995), and native species richness and diversity (Duncan et al. 2004).

Herbicides are sometimes used to control *E. esula*, but they are costly and provide only temporary control (Lym and Messersmith 1994). Furthermore, herbicides often damage desirable nontarget species growing with the weed (Crone et al. 2009, Rinella et al. 2009) and pose potential hazards to human health and the environment (Weisenburger 1993, Kolpin et al. 1998). Grazing by domestic sheep and goats is sometimes used to control *E. esula* (Bangsund et al. 2001; Walker et al. 1994), but these animals compete with cattle for forage and require considerable husbandry (Randall et al. 1999). The disadvantages of herbicides, sheep and goat grazing, and other expensive control measures such as reseeding have encouraged researchers to develop insect biological controls for *E. esula*.

One of the agents released on *E. esula* is the red-headed leafy spurge stem borer (*Oberea erythrocephala* Schrank.) (Coombs et al. 2004), a stem- and root-feeding beetle with a host range limited to a few species in the genus *Euphorbia*. It is native to Eurasia and is currently

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Interpretive Summary

Invasion of nonnative plants into forest and rangelands is of great concern to federal and state agencies, ranchers, and private land owners. The primary methods to control or manage invasive plants are the application of herbicides and biological control. Each of these methods is suited to application in differing situations. Insects as agents to biologically control plants are commonly employed to attack several areas of the plant (roots, stems, foliage, flowers, or seeds). Therefore, several different species of insects are introduced to manage a single species of plant. Some insect species can establish and quickly impact plant vigor and the overall population. Other insect species are slow to establish and take years to impact the host plant. We evaluated the impact of *Oberia erythrocephala*, the red-headed leafy spurge stem borer released in caged and uncaged plots of leafy spurge (*Euphorbia esula*). Our study indicated that within a 2-yr period, this insect does not demonstrably reduce the biomass of leafy spurge. Since large resources are spent in collecting and distributing *O. erythrocephala* this information is of importance and value to land managers throughout the West.

naturalized in several western states (Hansen et al. 1997; Rees et al. 1986; Schroeder 1980).

After metamorphosing into adults in *E. esula* roots, female *O. erythrocephala* leave the roots and mate. They then girdle the upper portion of *E. esula* stems and chew holes just above the girdle where they typically deposit a single egg per stem, which is covered in latex from the plant. Females die shortly after laying up to 40 eggs. Larvae hatch after 7 to 10 d and tunnel through the pith of the stem to the root crown below the soil surface where they feed in the crown and roots until they hibernate for winter. In spring they resume feeding in the roots until mid- to late May when they pupate (Rees et al. 1986; Schroeder 1980).

In addition to *O. erythrocephala*, six species of flea beetle (*Aphthona* spp.) have also been released for *E. esula* control; the larvae of these insects also live in and feed on *E. esula* roots (Gassmann et al. 1996). Root feeding by *Aphthona* spp. larvae, along with adult feeding on aboveground portions of the plant, has reduced *E. esula* populations in some areas (Larson et al. 2008). Our research has focused on determining if *O. erythrocephala* feeding also reduces *E. esula* populations. If this proves effective, it would support collection and redistribution of the insect throughout *E. esula*'s North American range. Adding *O. erythrocephala* to an *Aphthona* spp.-based biological control program could improve *E. esula* control, because it has invaded a wide variety of habitats (riparian, upland, forest, grassland), and incorporating several agents helps ensure that at least one agent will persist everywhere *E. esula* is problematic (Best et al. 1980, Gassmann and Schroeder 1995).

Studies of the efficacy of *O. erythrocephala* for the reduction of leafy spurge stem count or biomass are not well reported. Olson and Mundal (2001) conducted a study that reported a reduction of 4.22 stems m^{-2} (0.4

stems ft^{-2}) at two locations and an increase of 4.6 stems m^{-2} at one location. Our overall objective was to assess the population dynamics of *E. esula* and *O. erythrocephala* after releasing the insect in several habitats. *Oberia erythrocephala* has a tendency to disperse or leave the area of release for a more favorable location. We released *O. erythrocephala* into 2- m^2 cages to determine if we could maintain an established population at a predetermined site. We made releases into uncaged plots and plots that were caged to prevent *O. erythrocephala* from dispersing. We hypothesized that *O. erythrocephala* would reduce *E. esula* biomass and that the reductions would be greatest where dispersal was prevented by caging. We also hypothesized that the percentage of *E. esula* stems showing evidence of *O. erythrocephala* oviposition would increase as populations of the insect grew over our 3-yr study.

Materials and Methods

Sites. We established an upland and a riparian site at each of three locations. These sites were in the Owyhee River drainage near Jordan Valley, OR (42°51'36.000"N, 116°42'42.000"W, 1,555 m [5,102 ft]), on Medicine Lodge Creek near Dubois, ID (44°00'00.000"N, 112°31'48.000"E, 1,775 m), and along the Falls River near St. Anthony, ID (44°0'0.000"N, 111°31'6.000"E, 1,615 m). Average annual precipitation ranged from 29.8 cm (11.7 in) (Dubois) to 41.2 cm (Jordan Valley). All plots have had mild historical grazing, and are characterized by shrub-dominated high desert biomes with subsequent riparian communities. The soil types for all sites are similar and primarily composed of quartzite, quartz monsonite, residuum, colluvium, alluvium, andesite, and basalt.

Experimental Protocol. In three areas from southwest Idaho to northeastern Idaho (Jordan Valley, Dubois, and St. Anthony), two *O. erythrocephala* release treatments and one control treatment was applied at upland and riparian locations. These treatments were comprised of a caged release, an uncaged release, and a caged no-release or control. Treatments were replicated three times for a total of nine plots per site. Plots (2 m by 2 m) were separated by a minimum distance of 75 m. A 2- m^3 screen mesh insect cage (18 mm by 14 mm 6.5 cm^{-2} mesh Lumite®¹) was erected over six of the nine plots at each site. Treatments were assigned randomly. Three of the caged plots served as controls. In late June, each of the three remaining caged plots and the three uncaged plots received a one-time release of 120 *O. erythrocephala*. We did not have enough cages to establish all plots simultaneously. Therefore, we divided plot establishment among 2 yr. Releases at the upland site near St. Anthony, ID, and the riparian sites near Jordan Valley, OR, and Dubois, ID, occurred in 2007, and all other releases occurred in 2008.

Table 1. *Euphorbia esula* biomass (g m^{-2}) means and (SE) from a study of the biological control agent *Oberea erythrocephala*. Plots were treated with no release (control), releases into caged plots, or releases into uncaged plots. Sites were riparian and upland near Jordan Valley, OR; riparian and upland near Dubois, ID; and riparian and upland near St. Anthony, ID.

Site	Year of release			1 yr after release			2 yr after release		
	Control	Caged release	Uncaged release	Control	Caged release	Uncaged release	Control	Caged release	Uncaged release
Jordan Valley riparian	62(8)	61(11)	47(14)	129(43)	60(33)	63(32)	83(9)	59(29)	32(16)
Jordan Valley upland	54(28)	94(54)	70(29)	56(22)	106(36)	114(35)	NA ^a	NA	NA
Dubois riparian	64(13)	70(14)	79(11)	124(26)	106(17)	138(31)	106(27)	69(12)	115(20)
Dubois upland	19(15)	54(26)	14(11)	21(17)	70(34)	16(9)	NA	NA	NA
St. Anthony riparian	102(56)	76(12)	45(7)	86(39)	89(17)	27(14)	NA	NA	NA
St. Anthony upland	37(10)	28(9)	56(24)	69(24)	50(25)	94(30)	52(17)	42(23)	98(47)

^aNA, sites that were not measured 2 yr after release.

Approximately 8 wk after *O. erythrocephala* release, cages were permanently removed and the numbers of *E. esula* stems in each plot were counted with each stem being examined for signs of *O. erythrocephala* oviposition. Following plant senescence in fall, all *E. esula* stems were cut 3 cm above the soil surface from two 1-m² frames in each plot. These samples were weighed after drying to constant weight at 65 C (149 F). Stem counts and biomass sampling were continued for either 1 or 2 yr following release, depending on the when the site was established. The biomass sampling frames were positioned in the same locations each year, but we believe repeated clipping did not affect *E. esula* vigor because it occurred after senescence.

Analysis. *Oberea erythrocephala* did not have an opportunity to greatly influence *E. esula* biomass production the year of release because the beetle was released after most of the *E. esula* growth had occurred for the year. Therefore, we focused our analysis on biomass data gathered the year after release. The linear model for *E. esula* biomass per unit area 1 yr after *O. erythrocephala* release contained parameters for sites, treatments, and their interactions. Treatment effects were considered fixed and other factors were considered random. The biomass data were natural-log transformed to meet modeling assumptions.

In modeling the percentage of *O. erythrocephala*-infested stems, we did not include separate parameters for caged release and uncaged release plots because a preliminary model suggested *O. erythrocephala* activity did not vary appreciably between these two treatments. The percentage data were logit-transformed [$\text{logit } y_i = \ln(y_i/(1 - y_i))$] to meet linear regression modeling assumptions. The model had terms for sites, years, and their interactions with year effects considered fixed and other factors considered random.

We used Bayesian statistics with standard noninformative prior distributions to fit the models to the data

(Gelman and Hill 2007). The Bayesian approach allowed us to account for all relevant sources of uncertainty in our analysis as well as compute Bayesian confidence intervals, which are much easier to understand than classical confidence intervals. For example, a 95% Bayesian confidence interval simply has a 95% chance of bracketing the parameter. We fit the models using code we developed in FORTRAN.²

Results and Discussion

Means and standard errors for *E. esula* biomass for all study years are presented in Table 1. Only data from the year following *O. erythrocephala* release were subjected to formal analysis because *O. erythrocephala* had colonized the control plots by 2 yr after release, so we lacked a benchmark for comparison (Table 2). Confidence intervals quantifying differences between *O. erythrocephala* treatments and controls (treatment minus control) 1 yr after release greatly overlap zero, so our data do not provide compelling evidence that *O. erythrocephala* influenced *E. esula* biomass production (Figure 1). Furthermore, because confidence intervals for caged and uncaged treatments greatly overlap, the data do not support the hypothesis that caged releases reduce *E. esula* biomass more than uncaged releases (Figure 1).

The data also do not support our hypothesis that *O. erythrocephala* population size and oviposition would increase over the study. Evidence of *O. erythrocephala* oviposition was greatest the year of release, and it clearly declined over time (Figure 2). Many of the point estimates are about 0.0 for the release year on the logit scale suggesting *O. erythrocephala* infested an average of about [50% = $100(e^{0.0}/(1 + e^{0.0}))$] of stems that year (Figure 2). By comparison, many of the point estimates after the release year are only about -3.0, suggesting *O. erythrocephala* infested a much smaller average of about [5% = $100(e^{-3.0}/(1 + e^{-3.0}))$] of stems after the year of release.

Table 2. Mean and (SE) of the percentage of *Euphorbia esula* stems infested by the biological control agent *Oberea erythrocephala*. Plots were treated with releases into caged plots or releases into uncaged plots. Sites were riparian and upland near Jordan Valley, OR; riparian and upland near Dubois, ID; and riparian and upland near St. Anthony, ID.

Site	Year of release		1 yr after release		2 yr after release	
	Caged release	Uncaged release	Caged release	Uncaged release	Caged release	Uncaged release
Jordan Valley riparian	93 (7)	39 (6)	3 (2)	23 (19)	18 (17)	13 (4)
Jordan Valley upland	58 (10)	19 (6)	43 (12)	32 (14)	NA ^a	NA
Dubois riparian	95 (2)	38 (7)	0	2 (1)	0	2 (2)
Dubois upland	22 (10)	26 (10)	6 (3)	7 (3)	NA	NA
St. Anthony riparian	37 (2)	15 (9)	0	2 (1)	NA	NA
St. Anthony upland	82 (12)	29 (7)	13 (6)	18 (8)	5 (2)	2 (0)

^aNA, sites that were not measured 2 yr after release.

Our analysis indicates *O. erythrocephala* did not demonstrably reduce *E. esula* biomass 1 yr after release (Figure 1). Moreover, because evidence of *O. erythrocephala* activity was lower 1 and 2 yr after release compared to the year of release (Figure 2), it is unlikely *O. erythrocephala* appreciably reduced *E. esula* biomass two or more years after release, though we could not formally test this because *O. erythrocephala* colonized the control plots in the second year of the study.

These findings suggest *O. erythrocephala* is not an effective biological control agent for *E. esula*. However, considerations that temper the strength of this conclusion should be considered. After entering novel ecosystems, biological control agents and other exotic organisms sometimes appear incapable of population growth for a number of generations

or years, but then the populations begin growing exponentially (Cousens and Mortimer 1995, Ireson et al. 2008). Multiple mechanisms have been proposed to explain this “lag phase” phenomenon including time needed for local adaptation to occur (Marsico et al. 2010) and Allee effects owing to unavailability of mates (Deredec and Courchamp 2007). Our short-term study may have provided insufficient time for *O. erythrocephala* populations to overcome lag phases and grow to levels that would reduce *E. esula* populations. Another possibility is that our short study took place over a sequence of years that were unfavorable for *O. erythrocephala* recruitment, and populations of the insect may grow rapidly once favorable environmental conditions arise. Observations from the site where we collected *O. erythrocephala* for this study provide some support for these assertions. *Oberea erythrocephala* was released at this site in 1998, but we

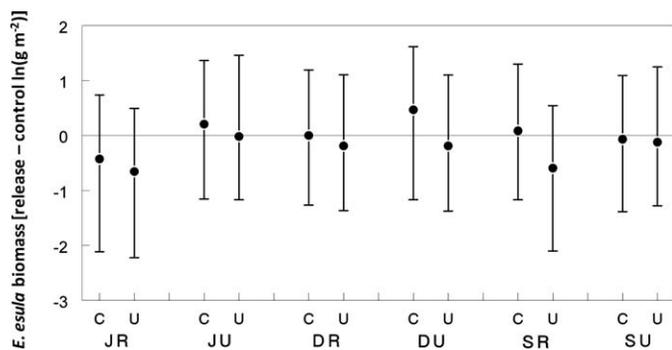


Figure 1. Point estimates (dots) and 95% confidence intervals (bars) describing *Euphorbia esula* biomass responses to caged (C) and uncaged (U) releases of *Oberea erythrocephala*. Sites were riparian (JR) and upland (JU) near Jordan Valley, OR; riparian (DR) and upland (DU) near Dubois, ID; and riparian (SR) and upland (SU) near St. Anthony, ID. The confidence intervals quantify differences between release treatments and controls (release treatment – control), so an estimate of zero indicates biomass was identical in the release treatments and controls. All confidence intervals appreciably overlap zero, so the data provided no evidence that *O. erythrocephala* affected *E. esula* biomass.

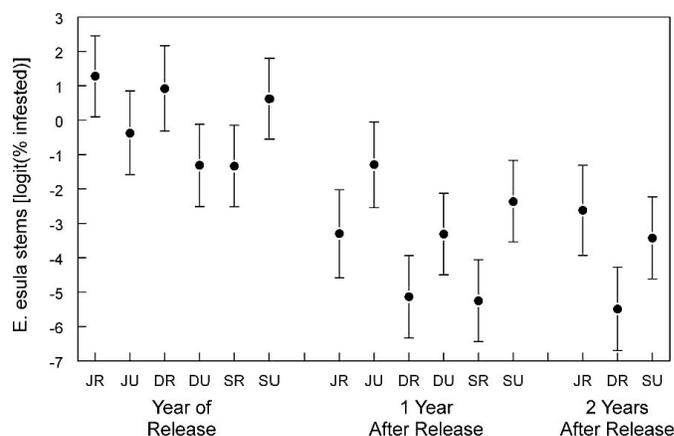


Figure 2. Point estimates (dots) and 95% confidence intervals (bars) describing the percent of *Euphorbia esula* stems showing signs of *Oberea erythrocephala* oviposition after release of the agent at riparian (JR) and upland (JU) sites near Jordan Valley, OR; riparian (DR) and upland (DU) sites near Dubois, ID; riparian (SR) and upland (SU) sites near St. Anthony, ID. The estimates tend to become smaller over time suggesting *O. erythrocephala* populations declined after release.

did not find *O. erythrocephala* or signs of their damage there until 2005, and it was not until 2007 that the population was dense enough to collect sufficient numbers for redistribution (R. A. Progar, unpublished data). Unfortunately, this collection site lacked biological control-free plots for assessing the impact of the agent on *E. esula*.

The possibility of lag phases and unfavorable climate notwithstanding, the bulk of the evidence suggests *O. erythrocephala* is not effective against *E. esula*. Releasing large numbers of insects into our plots did not appreciably reduce weed biomass 1 yr after release. In contrast, *Aphthona* spp. beetles have proven fairly effective against *E. esula*, and these insects have begun reducing *E. esula* populations 1 yr after release (Lym and Nelson 2000, Progar et al. 2010). Furthermore, despite being released into the United States nearly a decade before *Aphthona* spp. (Hansen et al. 1997; Rees et al. 1986), *O. erythrocephala* receives far less attention than *Aphthona* spp. from researchers and managers. A Web of Science search for “*Oberea* and spurge” yielded only three articles whereas a search for “*Aphthona* and spurge” yielded 54 articles, and although managers regularly collect and redistribute *Aphthona*, they rarely collect and redistribute *O. erythrocephala* (Lym 1998; M. J. Rinella, unpublished data). In light of our experimental results, we believe the lack of interest in *O. erythrocephala* likely reflects the lack of efficacy of this insect against *E. esula*.

Sources of Materials

¹ BioQuip products, 2321 Gladwick Street Rancho Dominguez, CA 90220, USA

² Intel Fortran Compiler 10.1, Intel Corporation.

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