

June 1987

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Recommended Citation

Jeffords, Michael R. and Case, Laurie J. 1987. "Effect of Prey Density on Diurnal Activity and Ovarian Development in *Calosoma Calidum* (Coleoptera: Carabidae): Implications for Biological Control of the Gypsy Moth, *Lymantria Dispar* (Lepidoptera: Lymantriidae) in the Midwest," *The Great Lakes Entomologist*, vol 20 (2)

Available at: <https://scholar.valpo.edu/tgle/vol20/iss2/9>

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**EFFECT OF PREY DENSITY ON DIURNAL ACTIVITY AND
OVARIAN DEVELOPMENT IN *CALOSOMA CALIDUM*
(COLEOPTERA: CARABIDAE): IMPLICATIONS FOR BIOLOGICAL
CONTROL OF THE GYPSY MOTH, *LYMANTRIA DISPAR*
(LEPIDOPTERA: LYMANTRIIDAE) IN THE MIDWEST**

Michael R. Jeffords and Laurie J. Case¹

ABSTRACT

Four feeding treatments were used in the laboratory to study the effects of the availability of prey on diurnal behavior and ovarian development of *Calosoma calidum*. Activity was closely monitored for six weeks. No significant differences were found between male and female behavior patterns. Diurnal beetle activity was found to be inversely related to prey density; in treatments where prey was available, diurnal activity declined during the course of the experiment. At the end of six weeks, dissections of female beetles showed that ovarian development and fat body quantity were dependent upon the number of prey available for consumption.

The gypsy moth, *Lymantria dispar* (L.), is expanding its range from the northeastern United States into the Midwest, where it is increasing in number. In 1984 moderate to heavy defoliation occurred on nearly 6500 acres of central Michigan, an increase of over 1300% from the previous year. Such dramatic increases are likely to occur in a number of midwestern states that have a history of low-level infestation. Because gypsy moth populations remain very low in most midwestern states, however, researchers have a unique opportunity to study interactions between the gypsy moth and naturally occurring biological control agents.

One group of organisms that may have a significant impact on gypsy moth populations is predatory beetles in the genus *Calosoma*. Attributes of these beetles that make them suitable control agents for leaf-feeding lepidopterous caterpillars include the following: (1) they kill many more prey items than they eat and appear to be highly efficient hunters, (2) they are relatively long-lived, and (3) many species are arboreal (Burgess and Collins 1917). Their major drawback as predators appears to be their relatively low reproductive potential and the time needed for their numbers to catch up to those of the gypsy moth (Vasic 1972).

In Yugoslavia, where the gypsy moth is a native insect, its most important predator is considered to be *Calosoma sycophanta* L. (Vasic 1972). This species was introduced and established in the northeastern United States around 1910 (Burgess 1911). Weseloh (1985b) demonstrated that it can have substantial impact on gypsy moth populations. In one instance, adult and larval *C. sycophanta* destroyed nearly 70% of the gypsy moth pupae in a Connecticut forest during a single season. Information on the effect of native *Calosoma* species on gypsy moth populations in the United States, however, is sparse and consists of feeding records and a few early laboratory studies on climbing behavior, fecundity, and longevity (Burgess and Collins 1917). A. G. Burgess (1896) rated three

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native *Calosoma* species for their efficiency against the gypsy moth and considered *C. frigidum* Kirby to be the most important, followed by *C. calidum* Fabricius and *C. scrutator* (Fabricius). The potential of native *Calosoma* species as predators of gypsy moths cannot be evaluated without more biological information concerning how the various species interact with populations of leaf-feeding caterpillars. *Calosoma calidum* was chosen for this study because it is one of the more common species found in the Midwest during outbreaks of lepidopterous defoliators and because it is distributed over much of the eastern United States. Burgess and Collins (1917) reported that *C. calidum* adults are often found under burlap bands feeding on gypsy moth caterpillars. Adult beetles overwinter in cells constructed in the soil and usually emerge from diapause in early May. Females can begin oviposition within a month. Mature larvae pupate in the soil, and beetles emerge in late summer to feed actively until they reenter the soil to overwinter. Adults probably live from 1 to 2 years (Burgess and Collins 1917). In this initial laboratory study we investigated the effects of density of prey (using *Pseudoplusia includens* (Walker) as prey) on diurnal activity patterns and ovarian development of first year *C. calidum* adults.

MATERIALS AND METHODS

Newly emerged *C. calidum* adults reared from eggs laid by second generation, laboratory-reared females were used in the experiment. The colony originated from adults collected in southern Illinois. Twenty males and 20 females were randomly selected and paired. Each pair was placed in a plastic container (dia. 17 cm, depth 9 cm) with a loose-fitting plastic lid. Each container had been filled with fine soil to a depth of 5 cm, and a small, plastic petri dish was placed on the soil surface to serve as a water basin. The beetles had not fed before the experiment began.

Five beetle pairs were randomly assigned to each of four feeding treatments designed to simulate various prey densities: (1) no food, (2) one prey item/beetle/96 h, (3) one prey item/beetle/48 h, and (4) three prey items/beetle/24 h. Last-instar soybean looper, *Pseudoplusia includens* (Walker), larvae were used as prey. Gypsy moth larvae were unavailable at the time of beetle emergence, but Burgess and Collins (1917) have shown that gypsy moth larvae are readily acceptable prey to *C. calidum* adults.

The experiment was conducted in an environmental chamber at 25°C under a photoperiod of 15L:9D to mimic late spring-early summer conditions in Illinois. Observations of beetle location on or under the soil surface were made at hourly intervals from 0800 to 1700 h on weekdays for six weeks. Each container was checked daily for ovipositional activity.

At the end of the six weeks each female was dissected and examined under a dissecting microscope; the degree of ovarian development and the status of the fat body were evaluated. Ovarian development was evaluated by observing the appearance of the ovaries and assigning each female to one of four categories of development: (1) no differentiation of ovarioles, ovaries threadlike, (2) no differentiation of ovarioles, slight thickening of ovaries, (3) slight differentiation of ovarioles, moderate thickening of ovaries, and (4) ovarioles evident, moderate thickening of ovaries. Females that died during the course of the study were immediately dissected, except for those cannibalized by males.

RESULTS

No significant differences (paired-sign test [Jerome 1964]) were found in male and female behavior; therefore, all replicate pair data for each treatment were combined.

The behavioral observations are summarized in Figure 1. Two trends are readily apparent: (1) diurnal beetle activity is inversely related to prey density, and (2) with the exception of treatment 1 (no food) diurnal activity declined during the course of the experiment. The a posteriori analysis with the paired-sign test indicated that treatments 1

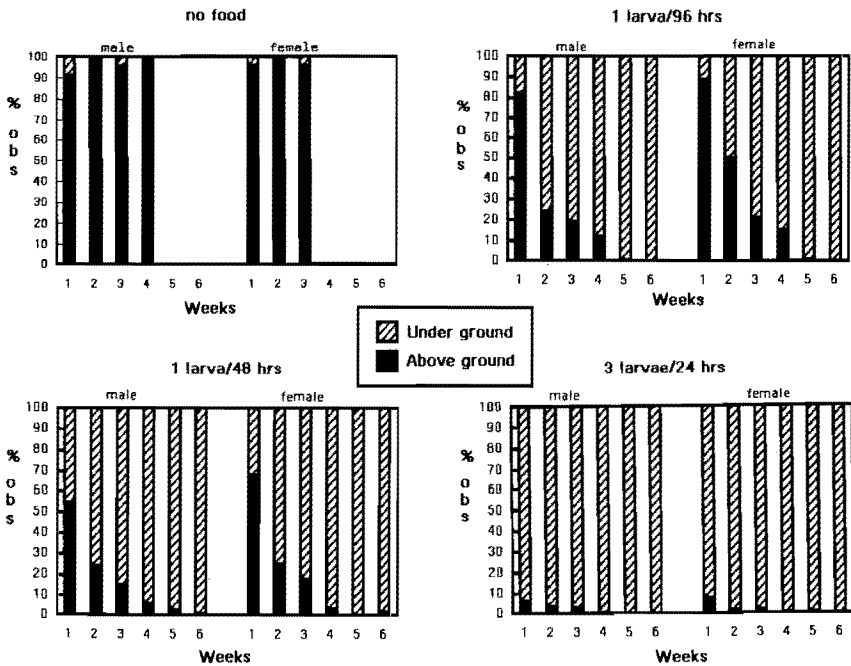


Fig. 1. Percentage of observations of above and below ground behavior exhibited by male and female adult *Calosoma calidum* under four treatments. All beetles that received no food died by the end of the fourth week.

and 4 were significantly different ($P < 0.05$) from the other treatments. Treatments 2 and 3 did not differ from each other but were significantly different from 1 and 4, respectively. Both males and females in treatment 1 were almost constantly in motion throughout the experiment, either walking around the container or palpating the soil surface with their antennae. Their speed and mobility declined significantly after 10 days, but they remained active for four weeks; at the end of this period all beetles in treatment 1 had died. Males lived approximately one week longer than females. Beetle survival was consistently high in treatments 2–4, indicating that the amount of food in each of these three treatments was sufficient to sustain the adults. Prey items were fed to each beetle individually, and all prey offered during the experiment were consumed. Four instances of mortality occurred in treatments 2–4 because of cannibalism (one female cannibalized in treatments 2, 3, and 4, and one male in treatment 3).

No oviposition occurred during the experiment. Dissections of females revealed differences in ovarian development and quantity of fat body (Table 1). Body cavities of females denied food (treatment 1) were virtually empty, with only the nerve cord, threadlike gut, and ovaries visible. Females that had undergone treatments 2–4 showed ovarian development roughly proportional to the amount of food they had received; reserves of the fat body were extensive.

Table 1. Condition of ovaries and fat body in *Calosoma calidum* females.

No. of Females Dissected	Treatment	Fat Body	Ovarian Development ^a
5	no food	none present	0
4 ^b	1 larva/96 h	filled abdomen	+
4	1 larva/48 h	filled abdomen	++
4	3 larvae/24 h	filled abdomen	+++

^a0 = no differentiation of ovarioles, ovaries threadlike; + = no differentiation of ovarioles, slight thickening of ovaries; ++ = slight differentiation of ovarioles, moderate thickening of ovaries; +++ = ovarioles evident, moderate thickening of ovaries.

^bNumbers lower than 5 reflect cannibalized females.

DISCUSSION

A comparison of our data on *C. calidum* and those of other researchers on *C. sycophanta* is useful in interpreting our experimental results. The two species appear to differ markedly in their response to very low prey density. When no food was available in our experiment, *C. calidum* continued to search for prey and remained active until their reserves were exhausted and they died. Vasic (1972), however, found that in years when prey density was low, *C. sycophanta* adults either remained beneath the soil in diapause or emerged only briefly to "test" the level of prey populations. If sufficient prey were not found, *C. sycophanta* adults reentered their hibernacula and did not emerge until the following year. In a two-year, mark-recapture study, Weseloh (1985a) found that some *C. sycophanta* adults emerged in low-density gypsy moth populations in Connecticut. He postulated that these were first-year adults since very few of the adults he recaptured had been marked the previous year. Apparently, older beetles tended to remain in the soil.

Calosoma calidum and *C. sycophanta* also differ in life span. Burgess and Collins (1917) found that *C. calidum* adults live 1.5–2 years. Our data on *C. calidum* biology agree. *Calosoma sycophanta*, however, live 3–4 years (Vasic 1972, Burgess and Collins 1917).

Another difference between *C. sycophanta* and *C. calidum* is host range. The gypsy moth is the primary food source for *C. sycophanta*, and the life histories of the two species are in close synchrony (Vasic 1972). In contrast, Burgess (1896) and Burgess and Collins (1917) thought *C. calidum* to be an opportunistic feeder not dependent on a particular species. Our field observations in Illinois support their contention that *C. calidum* is a generalist predator.

The apparent inactivity of *C. sycophanta* during years of low gypsy moth abundance may be a plausible strategy for a relatively long-lived predator that depends on a narrow range of prey items (Vasic 1972). The life-history strategy of *C. calidum* appears to be quite different. Its shorter life span and generalist feeding habit make season-long periods of latency of little merit as an evolutionary strategy. Our behavioral data suggest that after spring emergence *C. calidum* adults actively search for prey throughout the season and do not permanently return to the soil when prey density is low. Treatment 1 represented an extreme case since a predaceous beetle is unlikely to emerge in the spring and find no food available; nevertheless, the behavior of *C. calidum* under these conditions strongly suggests that low densities of prey do not send them back to the soil until the end of the growing season. This characteristic is important if *C. calidum* is to be effective in reducing low-density gypsy moth populations in the Midwest.

Prey density also had an observable effect on *C. calidum* ovarian development. Even though no oviposition occurred during the experiment, ovarian development progressed roughly in proportion to the availability of food (Table 1). The absence of oviposition may be explained by at least two factors. First, the quantity of food available to the females may have been insufficient to allow for complete ovarian development and subsequent

oviposition. If oviposition is dependent on the availability of food, *C. calidum* populations might decline during years when little prey is available. A second explanation for the lack of oviposition in *C. calidum* is that first-year females simply may not lay eggs. Burgess and Collins (1917) found that *C. sycophanta* females lay very few or no eggs during their first year, and that may be the case for *C. calidum*. In the field a population of mixed-age females would ensure that some oviposition would occur each season.

While results of lab studies cannot be generalized to field situations, information from our study allows us to make some predictions about the potential impact of *C. calidum* on gypsy moth populations in the Midwest. Our study demonstrated that *C. calidum* searched actively for prey when prey densities were low. This behavior is encouraging since gypsy moth populations in the Midwest are often low density and scattered. Our study further indicates that ovarian development and possibly oviposition may be related to the availability of prey. Thus in years when gypsy moth populations increase to high densities in areas of the Midwest, *C. calidum* may be able to respond by increasing oviposition, thereby serving as a significant factor in the control of gypsy moth populations. Field studies in areas of the Midwest where gypsy moths are currently established could clarify the role of *C. calidum* as a biological control of the gypsy moth.

ACKNOWLEDGMENTS

This publication, a contribution of the Illinois Natural History Survey, a division of the Illinois Department of Energy and Natural Resources, and of the Illinois Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign, was supported in part by contract 1-5-39997, STILENENR-IP2-GYPSY-997, from the Illinois Department of Energy and Natural Resources. We would like to thank J. Wissmann and K. O'Hayer for their expert assistance throughout this study and J. V. Maddox, C. E. Eastman and J. Bouseman for reviewing the manuscript.

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