The Great Lakes Entomologist

Volume 39
Numbers 3 & 4 - Fall/Winter 2006 *Numbers 3 & 4 - Fall/Winter 2006*

Article 4

October 2006

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VARIATION IN DIEL ACTIVITY OF GROUND BEETLES (COLEOPTERA: CARABIDAE) ASSOCIATED WITH A SOYBEAN FIELD AND COAL MINE REMNANT

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ABSTRACT

Diel activities of carabids (Coleoptera: Carabidae) associated with a coal mine remnant and surrounding soybean field were studied in west-central Illinois from June through October 2002. A total of 1,402 carabids, representing 29 species and 17 genera, were collected using pitfall traps. *Poecilus chalcites* (Say) demonstrated roughly equal diurnal and nocturnal activity in June, but greater diurnal activity thereafter. *Pterostichus permundus* (Say), *Cyclotrachelus seximpressus* (LeConte), *Amara obesa* (Say), and *Scarites quadriceps* Chaudoir showed significant nocturnal activity. Associations between habitat and diel activity were found for three species: *P. chalcites* associated with the remnant and edge habitats showed greater diurnal activity than those associated with the soybean field; *C. seximpressus* was most active diurnally in the remnant, and *Harpalus pensylvanicus* (DeGeer) showed the greatest nocturnal activity in the remnant and edge habitats. We found significant temporal and habitat-related variation in diel activity among carabid species inhabiting agricultural areas in west-central Illinois.

INTRODUCTION

The ground beetles and tiger beetles (Coleoptera: Carabidae) constitute one of the most diverse insect families, with over 40,000 described species (Lövei and Sunderland 1996). Carabids are important predators in many terrestrial ecosystems, and can help suppress pest insect populations in agroecosystems (Cárcamo and Spence 1994, Thomas et al. 1998, Carmona and Landis 1999, Crist and Ahern 1999, Landis et al. 2000, French et al. 2004). Because carabids are often closely associated with factors such as soil type, vegetation cover and microclimate, they can also be useful indicators of habitat conditions (Thiele 1977, Niemelä et al. 1992, Ings and Hartley 1999, Villa-Castillo and Wagner 2002, McCravy and Willand 2005). Microhabitat conditions and diel activity patterns may play a role in interspecific segregation and species richness, at least in tropical tiger beetles (Zerm and Adis 2001). In the Midwestern United States, the landscape is dominated by a mosaic of agricultural lands interspersed with patches of alternative habitats. In west-central Illinois, coal mine remnants (hereafter referred to as "remnants") are one source of alternative habitat. These remnants are the remains of shaft mines that flourished during the late 1800s and early 1900s, but were abandoned and filled by 1960 (Monteith 1976, Hallwas 1984, Murray 1998). Secondary succession produced a diversity of herbaceous and woody vegetation, resulting in habitat "islands" within agricultural fields. These remnants are inhabited by over 40 carabid species that represent an assemblage distinct from that of the surrounding soybean fields (McCravy and Willand 2005). These remnants, therefore, provide an opportunity to study the diel activity of a diverse assemblage of carabids in

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field, edge, and wooded habitats. The objective of this study was to investigate potential habitat-related and temporal variation in diel activity patterns of a carabid assemblage.

METHODS AND MATERIALS

The study was conducted on a remnant and surrounding soybean field near Colchester, Illinois from June through October 2002. The remnant was located at N 40° 25' 21" W 90° 49' 6". Remnant dimensions were as follows: circumference - 237 m, maximum length - 78 m, maximum width - 27 m and maximum canopy height - 17 m. Remnant vegetation was composed primarily of black cherry (*Prunus serotina* Ehrhart), slippery elm (*Ulmus rubra* Muhl.), honeylocust (*Gleditsia triacanthos* L.), bramble (*Rubus* spp.), poison ivy [*Toxicodendron radicans* (L.) Kuntze], and grasses. All plant nomenclature follows that of Gleason and Cronquist (1991). Mean percent ground cover (± SE) in the remnant, as measured by visual estimation in 20 0.5-m^2 plots, was 61.8 ± 6.3%. Mean percent canopy cover (± SE) in the remnant, measured at 20 sample points with a vertical densitometer (Geographic Resource Solutions, Arcada, CA), was 39.0 ± 7.5%. Soybeans (*Glycine max* (L.) Merr.) were planted in the surrounding fields in early June.

Pitfall traps were used to capture carabids. Each trap consisted of two 473 ml plastic cups (Solo®, Urbana, IL) one nested inside the other so that the inner cup could be removed during collections and replaced with a fresh one with minimal disturbance to the trap site. The diameter of the cup opening was 9.3 cm. Traps were placed so the trap rim was flush with the ground, and efforts were made to return surrounding soil and litter to former conditions. Thirty-six traps were used, as follows: 20 in the remnant, 8 in the soybean field, and 8 along the edge of the remnant. The remnant and field traps were deployed in a line through the coal mine remnant and extending 20 m into the soybean field on each end. Traps were placed 4 m apart within the remnant and 5 m apart in the soybean field. The edge traps were placed 30 m apart along the edge of the remnant at the remnant/field interface. Traps were filled with approximately 150 ml of a 50/50 mixture of propylene glycol and water, which acted as a killing agent and preservative. Traps were operated continuously for one 6-day period each month (20-25 June, 14-19 July, 19-24 August, 22-27 September and 13-18 October). Traps were set at dusk of the first day of each trapping period, and were serviced and replaced each day at dawn to collect nocturnally active carabids and at dusk to collect diurnally active carabids. The last collection for each trapping period was at dusk of the last day.

Associations between carabid captures and time of capture (diurnal vs. nocturnal) were analyzed using the single classification chi-square test, with expected frequencies based on the extrinsic hypothesis of a 50:50 ratio of diurnal and nocturnal captures. The more conservative continuity correction was used for species that produced between 25 and 200 total captures. For species with sample sizes between 10 and 25, the exact probabilities of the expected binomial distribution (two-tailed) were used (Sokal and Rohlf 1995). Associations between captures and time of capture were not analyzed for species that produced less than 10 captures. Associations of time of capture (diurnal vs. nocturnal) with month, habitat, and beetle sex were analyzed using two-way contingency tables and the chi-square test. The level of statistical significance was set at $P = 0.05$ for all tests.

RESULTS

A total of 1,402 carabids representing 29 species and 17 genera were collected (Table 1). The three most abundant species [*Poecilus chalcites* (Say), *Pterostichus permundus* (Say), and *Cyclotrachelus seximpressus* (LeConte)] comprised 85.4% of the total. Overall, carabids showed more diurnal activity than expected by chance ($\chi^2 = 53.54$, df = 1, $P < 0.001$), due primarily to the predominantly diurnal activity of *P. chalcites*. When *P. chalcites* was excluded from analysis, the remaining carabids showed more nocturnal activity than expected by chance ($\chi^2 = 49.38$, df = 1, $P < 0.001$). Sample sizes were sufficiently large to allow statistical analyses of associations between sex and time of capture for the five most commonly collected species. Only *P. chalcites* showed a statistically significant association; 79.7% of male vs. 73.4% of female captures were diurnal ($\chi^2 = 4.49$, df = 1, $P = 0.034$).

About 93% of *P. chalcites* were captured in the soybean field (Table 1). This species showed more diurnal activity than expected by chance ($\chi^2 = 229.38$, df = 1, $P < 0.001$). There was a significant association between *P. chalcites* activity patterns and month of collection ($\chi^2 = 151.46$, df = 4, $P < 0.001$). Nocturnal and diurnal activity were roughly equal in June, whereas activity was predominantly diurnal during the remaining months (Fig. 1). There was also a significant association between *P. chalcites* activity and habitat ($\chi^2 = 8.69$, df = 2, $P = 0.013$). In the remnant and edge, 87.5% and 94.3% of *P. chalcites* were captured diurnally, whereas only 74.9% were trapped diurnally in the soybean field (Fig. 2). When *P. chalcites* was excluded from analysis, there was a significant association between time of capture and habitat for all other carabids combined ($\chi^2 = 9.229$, df = 2, $P = 0.010$). Among these carabids, 41.6% of those captured in the remnant were diurnal, whereas 27.0% and 32.7% of those captured in the edge and field, respectively, were diurnal.

Of the remaining species producing greater than ten captures, four species showed significant nocturnal activity (Table 1): *P. permundus* ($\chi^2 = 13.41$, df = 1, $P < 0.001$), *C. seximpressus* ($\chi^2 = 20.31$, df = 1, $P < 0.001$), *Amara obesa* (Say) ($\chi^2 = 15.75$, df = 1, $P < 0.001$), and *Scarites quadriceps* Chaudoir ($P < 0.001$, two-tailed binomial probability). A significant association between time of capture and habitat was found for *C. seximpressus* ($\chi^2 = 18.38$; df = 2; $P < 0.001$), with 51.6% of captures being diurnal in the remnant, but only 21.7% and 17.3% being diurnal in the edge and field habitats, respectively (Fig. 2). No association between time of capture and habitat was found for *P. permundus* ($\chi^2 = 4.06$, df = 2, $P > 0.05$; Fig. 2). Small expected values for contingency table cells precluded statistical testing for *A. obesa* and *S. quadriceps*.

Neither *Harpalus compar* LeConte ($\chi^2 = 1.64$, df = 1, $P > 0.05$), *Harpalus pensylvanicus* (DeGeer) ($\chi^2 = 0.43$, df = 1, $P > 0.05$), *Cyclotrachelus sodalis sodalis* (LeConte) ($P > 0.05$, two-tailed binomial probability), nor *Patrobus longicornis* (Say) ($P > 0.05$, two-tailed binomial probability) showed statistically significant diel activity patterns overall (Table 1). Contingency table cell sample sizes allowed testing for an association between time of capture and habitat for *H. pensylvanicus*, which was significant ($\chi^2 = 12.45$, df = 2, $P = 0.002$). Interior and edge habitats produced only 10.0% and 30.8% diurnal captures, respectively whereas the field produced 78.6% diurnal captures (Fig. 2).

DISCUSSION

Most carabid species showed primarily nocturnal activity in our study (Table 1). These findings are consistent with those of other studies (Luff 1978, Lövei and Sunderland 1996). In the United Kingdom, 60% of species are nocturnal and 20% are diurnal (Luff 1978). In our study, 4 of 5 species showing statistically significant activity patterns were nocturnal, with only *P. chalcites* having significant diurnal activity (Table 1). Larochelle and Larivière (2003) describe *P. chalcites* as mostly nocturnal, and Ellsbury et al. (2005) found *P. chalcites* to be most active around midnight in the northern corn belt of the midwestern United States. However, our results suggest that the behavior of this species includes a strong diurnal component that can vary significantly both seasonally and in relation to habitat (Figs. 1 and 2). Nocturnal activity of

Table 1. Number of carabid beetles captured in pitfall traps in three habitats [coal mine remnant (20 traps), field edge (8 traps), and soybean field (8 traps)] in west-central Illinois during June-October 2002, percent of beetles that were diurnal (captured during dawn to dusk), and for species where more than 10 individuals were captured, the results of chi-square analyses (two-tailed binomial for *C. sodalis sodalis*, *P. longicornis*, and *S. quadriceps*). Analyses were based on the extrinsic hypothesis of a 50:50 ratio diurnal to nocturnal capture rate.

Species	**Remnant**	**Edge**	**Field**	**% Diurnal**	***P*-values**
Poecilus chalcites (Say)	24	35	785	76.1%	< 0.001
Pterostichus permundus (Say)	96	33	65	36.6%	< 0.001
Cyclotrachelus seximpressus (LeConte)	62	46	52	31.9%	< 0.001
Harpalus compar LeConte	14	24	1	38.5%	> 0.05
Harpalus pensylvanicus (DeGeer)	10	13	14	43.2%	> 0.05
Amara obesa (Say)	10	18	0	10.7%	< 0.001
Cyclotrachelus sodalis sodalis (LeConte)	9	4	2	46.7%	> 0.05
Patrobus longicornis (Say)	4	0	8	33.3%	> 0.05
Scarites quadriceps Chaudoir	0	1	10	0.0%	< 0.001
Anisodactylus caenus (Say)	9	0	0	22.2%	
Amphasia sericea (T.W. Harris)	6	0	2	75.0%	
Calathus opaculus LeConte	8	0	0	50.0%	
Anisodactylus ovularis (Casey)	1	2	3	83.3%	
Clivina bipustulata (Fabricius)	3	0	2	20.0%	
Cicindela punctulata Olivier	0	2	3	100.0%	
Anisodactylus carbonarius (Say)	2	1	0	0.0%	
Harpalus caliginosus (Fabricius)	1	2	0	33.3%	
Harpalus protractus Casey	2	1	0	33.3%	
Chlaenius emarginatus Say	1	1	0	0.0%	
Agonum punctiforme (Say)	0	0	1	0.0%	
Amara littoralis Mannerheim	1	0	0	100.0%	
Anisodactylus agricola (Say)	1	0	0	0.0%	
Anisodactylus furvus LeConte	1	0	0	0.0%	
Clivina impressefrons LeConte	0	0	1	100.0%	
Dicaelus elongatus Bonelli	1	0	0	0.0%	
Galerita janus (Fabricius)	1	0	0	100.0%	
Lebia analis Dejean	1	0	0	0.0%	
Poecilus lucublandus (Say)	0	0	1	0.0%	
Pterostichus praetermissus Chaudoir	1	0	0	100.0%	
TOTAL	269	183	950	59.8%	

P. chalcites was greatest in June. This pattern could be related to density of canopy cover. In June the soybeans were recently planted and provided little cover and concealment for the carabids. By July, the soybeans provided denser cover. Honek (1988) and Carmona and Landis (1999) suggested that carabid abundance increased under dense crop cover due to increased humidity and prey availability. Carmona and Landis (1999) also found that cover crops helped to decrease predation upon carabids by providing shelter. Activity peaks of carabids can vary depending on the agroecosystem (Ellsburg et al. 2005). The increase in diurnal activity after June in our study could reflect some combination of more favorable daytime microclimate, increased prey availability, and increased protection from diurnal visual predators such as birds. Catbirds, crows, kingbirds, starlings, thrushes, and woodpeckers are known predators of *P. chalcites* (Larochelle and Larivière 2003). Lower night temperatures in

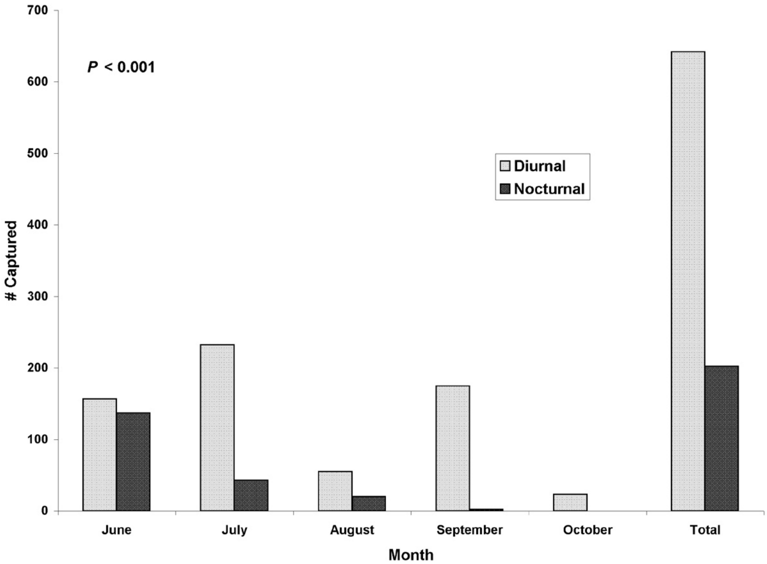

Figure 1. Diel activity of *Poecilus chalcites* (N = 844 individuals) captured in pitfall traps in three habitats [coal mine remnant (20 traps), field edge (8 traps), and soybean field (8 traps)] in west-central Illinois by month in 2002: diurnal = collected during dawn to dusk, nocturnal = collected during dusk to dawn.

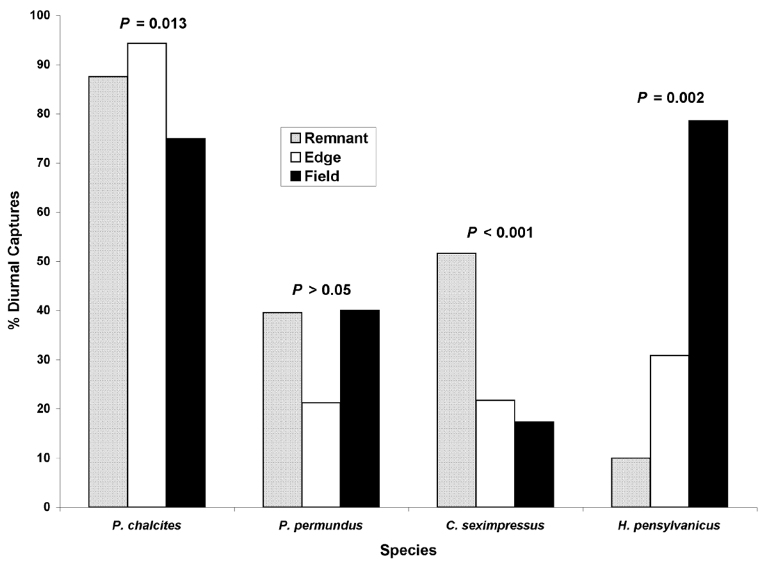

Figure 2. Diurnal activity (i.e., collected during dawn to dusk) of four species of carabid beetles by habitat (coal mine remnant, field edge, and soybean field) in west-central Illinois in 2002 based on captures in pitfall traps: *Poecilus chalcites* (N = 844 individuals), *Pterostichus permundus* (N = 194), *Cyclotrachelus seximpressus* (N = 160), and *Harpalus pensylvanicus* (N = 37).

September and October may have limited nocturnal activity during those collection periods compared with earlier months. Mean minimum daily temperatures (in °C ± SE, based on climatic data obtained from the La Harpe, IL weather station, ca. 25 km NW of the study site) for the trapping periods were 18.8 ± 0.6 in June, 16.8 ± 1.1 in July, 17.4 ± 1.2 in August, 4.4 ± 1.2 in September, and -1.0 ± 0.5 in October. Seasonal changes in diel activity have also been found in *Pterostichus melanarius* (Illiger), which tends to be nocturnal in June and July, but more diurnal in August (Desender et al. 1985).

Poecilus chalcites is a relatively small, dark green, iridescent beetle, and is strongly associated with agricultural fields at our study location (Table 1; McCravy and Willand 2005). Kegel (1990) found that diurnal carabids tend to be small and iridescent, whereas nocturnal species tend to be large and dull black. The four species that showed significant nocturnal activity in our study (*P. permundus*, *C. seximpressus*, *A. obesa*, and *S. quadriceps*) are all larger, dull black carabids. Kegel (1990) and Greenslade (1963) also found that forest carabids are generally nocturnal and field or grassland species diurnal. Excluding *P. chalcites*, carabids in our study tended to be more diurnal in the remnant overall. Of the three species in our study that had statistically significant associations between diel activity and habitat (Fig. 2), only *H. pensylvanicus* showed more nocturnal activity in the remnant than in the field. It may be that the relatively young age and open canopy of the remnant (mean percent canopy cover (± SE) = 39.0 ± 7.5) did not produce environmental conditions conducive to nocturnal activity for most species.

Carabid species of west-central Illinois coal mine remnants can vary substantially in diel activity patterns, and this variation is, to an extent, associated with season and habitat. This variation could result in species-specific responses to habitat and agroecosytem management practices, and these responses may vary temporally. Knowledge of these patterns is important in understanding the ecology and pest management roles of these beetles.

ACKNOWLEDGMENTS

We thank Seán E. Jenkins, Thomas C. Dunstan, Richard V. Anderson (all of Western Illinois University), and Tara A. Beveroth (Illinois Natural History Survey) for their valuable support and advice. We also gratefully acknowledge Janet Hunt (Colchester, IL) for granting us access to the study site located on her property, and Robert L. Davidson (Carnegie Museum of Natural History) for identifying the carabids collected during the study. Finally, we thank Therese Poland and Robert Haack for their valuable editorial comments, and an anonymous reviewer for many helpful suggestions.

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