Final Report: Diversity of Ground Beetles (Coleoptera: Carabidae) in Relation to Forest Stand Characteristics and Prescribed Burning
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Introduction

The ground beetles (Coleoptera: Carabidae) comprise one of the most diverse insect families, containing more than 40,000 described species (Lövei and Sunderland 1996). Most species are exclusively carnivorous although a few are phytophagous or omnivorous (Larochelle 1990). Carabids are voracious feeders, and can consume close to their own body mass of food daily (Thiele 1977). Because of their abundance and ravenous feeding habits, carabids are an important component of food chains in many terrestrial ecosystems. Their importance as regulators of invertebrate prey populations is indicated by their ability to suppress pest insect outbreaks, and prolong the period between outbreaks (Southwood and Comins 1976). In turn, carabids are an important component of vertebrate diets, with literally hundreds of vertebrate species preying on them (Larochelle 1975a, 1975b, 1980). In addition to their importance in ecological food chains, ground beetles are becoming increasingly important as ecological indicator organisms. They have been used in assessments of environmental pollution and in classification of habitats for potential protection (Luff et al. 1992). Furthermore, they are being increasingly recognized as effective indicators of biodiversity. To prioritize areas for conservation, natural resource managers need information on species diversity in specific habitats. However, resources and manpower available for such inventories are severely limited, and quicker ways to estimate biodiversity are needed. Critical assessments of the usefulness of ground beetles as biodiversity indicators are needed (Lövei and Sunderland 1996). In particular, there is a lack of information on the effects of variation in vegetation structure and accompanying microclimatic variation on the diversity of forest ground beetle faunas.

Western Illinois University's Alice L. Kibbe Life Science Research Station and adjacent Illinois Department of Natural Resources lands (the "Kibbe macrosite") offer outstanding opportunities for examining ground beetle/habitat relationships. These lands encompass over 1600 acres with a diversity of habitat types, including riparian and upland deciduous forest, early successional forest, hill barrens and prairies, and xeric sand prairies. These habitats vary substantially in vegetation type and cover, slope, aspect, soil type, soil moisture, and drainage. In addition, prescribed burning is done at Kibbe, offering opportunities for examination of the effects of fire disturbance on ground beetle diversity. Prescribed burning is a management tool that is commonly used to remove invasive plant species while retaining native vegetation (Artman et al., 2003). Prescribed burning is also important for clearing the understory of excessive dead vegetation, releasing stored nutrients and stabilizing the composition of forest communities. In many parts of the Midwest the original composition of fire-tolerant oak-hickory forests is being replaced by fire-intolerant species such as maple and beech (Artman et al. 2003). This process is occurring because shade tolerant species can thrive in the understory of large oaks and hickories, replacing the overstory trees as they die. Prescribed burning has been implemented in Illinois to maintain the structure of oak-hickory savannas (Artman et al. 2003). However, little is known about the effects of prescribed burning on forest arthropod communities.

The overall goal of this proposed study was to evaluate the habitat associations of ground beetle species assemblages in a natural area containing a mosaic of habitat types. Meeting this goal would clarify the usefulness of ground beetles as indicator species, and also shed light on the effects of habitat management practices on ground beetle diversity.

Project Objectives

The specific objectives of this study were to: 1) describe specific ground beetle/habitat associations in West-Central Illinois, 2) investigate possible associations between microclimatic conditions, stand characteristics, prescribed fire, and ground beetle diversity, and 3) document the ground beetle diversity of the Kibbe macrosite.

Materials and Methods

This study was done at the Kibbe macrosite in Hancock Co., Illinois. Four forest habitats and two prairie habitats, representing a variety of microclimatic conditions and vegetation structure, were included in this study. These habitats were 1) restored prairie that had undergone prescribed burning in Spring 2005, hereafter referred to as "BP" (40° 22.0' N, 91° 24.3' W), 2) restored prairie that had not been burned for three years ("UP" – 40° 21.8' N, 91° 24.3' W), 3) an unburned early successional forest dominated by black locust ("ESF" – 40° 21.9' N, 91° 24.3' W), 4) an upland, old-growth hardwood forest burned in Spring 2006 (“BF-06” – 40° 21.8' N, 91° 24.1' W), 5) an upland, old-growth hardwood forest burned in Spring 2005 (“BF-05” – 40° 22.0' N, 91° 24.5' W), and 6) an upland, old-growth hardwood forest that hadn’t been burned for at least five years (“UF” – 40° 21.8' N, 91° 24.2' W). Within each habitat, three study plots were established. Each plot consisted of a grid of nine pitfall traps, placed 5 m apart, and constructed of 16 oz. plastic cups partially filled with a 50/50 mixture of propylene glycol antifreeze to act as a killing agent and preservative. Trapping was conducted for 7 consecutive days each month from May through October 2006. Captured ground beetles were pinned and identified to species. Difficult specimens were identified by Robert Davidson (Carnegie Museum of Natural History), an authority on ground beetle taxonomy and identification.

Hobo® dataloggers were placed in each habitat and operated throughout the study. The dataloggers were set to record temperature and humidity at 15 minute intervals. In addition, a 0.5 m^2 plot was established around each trap. Percent leaf litter cover was estimated in these plots, and understory plant species were identified as well.

Comparisons of ground beetle species diversity between habitats were done using multi-response permutation procedures (MRPP), a nonparametric statistical technique for testing the hypothesis of no difference in overall species composition between two or more habitats. MRPP *A*-values provide a measure of the similarity in species composition between two habitats. *A*-values can range from 0 to 1, with higher values reflecting greater dissimilarity. An *A*-value greater than 0.3 is considered relatively high (McCune and Grace 2002). Indicator species analysis (ISA), was used to detect and describe the value of individual species for indicating environmental conditions. ISA measures the extent to which individual ground beetle species are *exclusive* (never occurring elsewhere) and *faithful* (always present) to particular habitats (McCune and Grace 2002). ISA produces an indicator value for each species and habitat, and can range from 0 to 100. An indicator value of 100 for a given species would mean that the species is present in every plot in a given habitat, but never present in any other habitat. Simpson's index was used to obtain a measure of the ground beetle species diversity of each habitat. This index considers the number of species in a habitat, as well as the number of individuals and the proportion of the total number that occurs in each species. The index ranges from 0 to 1, with higher numbers representing higher diversity. The index is an expression of the number of times one would have to take pairs of individuals at random to find a pair from the same species (Brower et al. 1998). Single classification analysis of variance was used to compare percent leaf litter cover and plant species richness between habitats.

Results

A total of 630 ground beetles, representing 25 species and 20 genera, were collected during this study (Table 1). The four most common species, which accounted for almost 70% of all specimens collected, were *Chlaenius platyderus*, *Cicindela sexguttata*, *Cyclotrachelus sodalis*, and *Platynus decentis*. Forest habitats produced the greatest numbers of captures, ranging from 98 beetles in the UF to 162 in BF-06. The prairie habitats produced fewer captures, with the BP and UP yielding 65 and 36 beetles, respectively. The ESF and BF-06 produced the greatest species richness, with 17 and 16 species respectively, whereas the UP and BF-05 had only 10 and 9 species respectively (Table 2). The overall species diversity for the six habitats, based on Simpson's index, was 0.82. The two prairie habitats, as well as the ESF and BF-06, had relatively high diversity, with indices ranging from 0.83 to 0.89. The UF and BF-05 had lower diversity, with values of 0.70 and 0.57, respectively.

MRPP *A*-values (Table 3) showed that the two prairie habitats had very similar ground beetle species composition, as reflected in the very low *A*-value of 0.06, which was statistically nonsignificant (P = 0.07). The BP had species composition very different from all forest habitats, with *A*-values ranging from 0.34 to 0.41. Species composition in the UP was also quite different from the forest habitats, although less so than the BP. Among the forest habitats, there was generally more dissimilarity in ground beetle species composition than occurred between prairie habitats, with the ESF and BF-05 being most dissimilar (Table 3).

ISA showed that there were several species of ground beetles that were strongly associated with particular habitats (Figs. 1-3). *Megacephala virginica* (P = 0.005), *Notiophilus novemstriatus* (P = 0.02), and *Scaphinotus elevatus* (P = 0.03) were all significantly associated with the BP (Fig. 1). However, several other species were associated with forest habitats, and were rare or absent in prairies. Four species – *Amara cupreolata* (P = 0.02), *Chlaenius emarginatus* (P = 0.01), *Galerita janus* (P = 0.01), and *Poecilus leucoblandus* (P = 0.005), were significantly associated with the ESF

(Fig. 2), and two species, *Platynus decentis* (P = 0.03) and *Pterostichus stygicus* (P = 0.05), were significantly associated with BF-06 (Fig. 3).

For the most part, mean temperatures were similar among the different habitats, with temperatures ranging from the mid-40s in October to the low and mid-80s in July (Table 4). The BP, however, was consistently warmer than the other habitats through the spring and summer months (May – August). Temperatures in both prairie habitats were more variable than in the forest habitats throughout the study, as shown by the higher SEMs in the prairie habitats. The SEMs also show that October had the greatest variation in temperatures in all habitats. Relative humidity was highest in the ESF during May through July (Table 5). During September and October, however, all forest habitats had relatively low humidity compared to the prairie habitats.

There was statistically significant variation in leaf litter cover (Table 6) among the four forest habitats, based on analysis of variance (F = 30.31, df = 3, 104, P < 0.00001). The ESF had the greatest amount of litter cover. Among the three mature hardwood forests, mean percent leaf litter cover increased with length of time since the last prescribed burn. Mean number of understory plant species also varied significantly among the forest habitats (F = 6.13, df = 3, 104, P = 0.0007), with the ESF having the lowest number of species per plot and BF-05 having the highest. Common plant species found in the forest understory included Virginia creeper (*Parthenocissus quinquefolia*), white snakeroot (*Ageratina altissima*), cluster-leaf tick-trefoil (*Desmodium glutinosum*), and Alleghany blackberry (*Rubus allegheniensis*), with substantial amounts of garlic mustard (*Alliaria petiolata*) in the ESF.

Discussion

Our results show that the diverse habitats of the Kibbe macrosite harbor a diverse assemblage of ground beetle species. Among the mature hardwood forest habitats, the BF-06 had the highest ground beetle species richness, diversity, and total number of captures (Tables 1 and 2). This suggests that burning alters the habitat in some way that is conducive to high ground beetle numbers, activity, or both. It is possible that the small amount of leaf litter in this habitat may produce conditions more advantageous to active hunting predators such as most ground beetles. Some ground beetle species are attracted to recently burned forests (Holliday 1984, Larsen and Williams 1999). Two species in particular were strongly associated with BF-06: *Platynus decentis* and *Pterostichus stygicus* (Fig. 3). *Platynus decentis* is a caterpillar hunter that may be an important biological control agent; it is thought to play an important role in control of spruce budworm in spruce-fir forests (Larochelle and Larivière 2003). *Pterostichus stygicus* is a flightless ground beetle (Larochelle and Larivière 2003). It is possible that the sparse leaf litter of BF-06 (Table 6) may enhance the level of activity of this beetle by providing more open ground for running.

The ESF had the highest species richness and diversity among the forest habitats, and also had several indicator species (Table 2, Fig. 2). This habitat had a great deal of leaf litter cover (Table 6) and high relative humidity (Table 5), perhaps due to the relatively low canopy that helps to keep moisture close to the ground. This combination of environmental characteristics may provide ecological niches for ground beetle species that prefer more enclosed microhabitats with a lot of crevices and shelter, and that prefer higher humidity environments that increase retention of water and decrease the possibility of dehydration. The high diversity and large number of indicator species in this habitat was an interesting finding, since these early successional locust forests are often considered to be undesirable “weedy” habitats. Our results suggest that these stands could be valuable from a biological diversity perspective.

Both prairie habitats had relatively high species diversity despite low total captures (Tables 1 and 2). The two habitats had very similar ground beetle species assemblages, based on MRPP analyses (Table 3). While it is likely that burning affects prairie ground beetles, our results suggest that any effects are short-lived, with regard to the ground beetle assemblage as a whole. However, there were three species that were strongly associated with the BP (Fig. 1). Mean temperatures were slightly but consistently higher in the BP that in the UP (Table 4), suggesting that even a year after burning slight differences in microclimate and microhabitats may exist that can affect certain beetle species. For instance, *Megacephala virginica* is a tiger beetle. Tiger beetles are highly visual, fast running predators that actively pursue prey based on their memory of the prey’s shape and location (Pearson and Vogler 2001). A slight, residual reduction in ground level vegetation from a previous year’s burn could enhance the ability of this species to locate and capture prey. Both prairie habitats had ground beetle assemblages substantially different from the forest habitats, indicating that, with regard to ground beetles, even small remnant prairies provide unique habitat relative to the surrounding forests.

In conclusion, the habitat mosaic of the Kibbe macrosite provides a variety of environments that support a diverse ground beetle fauna. These habitats provide diversity of vegetation structure and microclimate that, in some cases, are important in maintaining a diversity of ground beetle assemblages. In addition, 36% (9 of 25) of ground beetle species were found to be strongly associated with particular habitats. Management practices that maintain this diversity of habitats will result in high diversity of these ecologically important insects.

Summary

Ground beetles are ecological important insects that can be closely associated with particular environmental conditions. We studied the diversity and habitat associations of ground beetles inhabiting the Kibbe macrosite in Hancock Co., Illinois, using pitfall traps to collect ground beetles in six habitats. We collected 630 ground beetles representing 25 species and 20 genera. Ground beetle diversity was highest in prairie habitats, early successional forest, and mature hardwood forest subjected to prescribed burning in the same season. Prairie and forest ground beetle assemblages were substantially different. Nine species of ground beetles were found to be indicator species of particular habitats, three in prairie, four in early successional forest, and two in mature hardwood forest burned the same season. Differences in such environmental variables as microclimate, vegetation, and amount of leaf litter could be important factors affecting ground beetle diversity. These results suggest that management practices that maintain habitat diversity also help to increase ground beetle diversity.

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Table 1. Ground beetles collected in six habitats at the Kibbe macrosite.

Species	BP	UP	ESF	BF-06	BF-05	UF	Total
Amara cupreolata	2	1	10				13
Amphasia interstitialis			1	1			2
Anisodactylus furvus		2					2
Bembidion affine		2	3	2			7
Calathus opaculus	1	1		4		5	11
Chlaenius emarginatus			18	3			21
Chlaenius platyderus	14	10	17	21	3	3	68
Cicindela sexguttata	7	2	6	20	19	8	62
Clivina bipustulata			1			1	2
Cyclotrachelus sodalis	6	8	49	50	71	51	235
Cymindus americanus						1	1
Dicaelus dilatatus			1	1			2
Dicaelus elongatus	5	2	1	3		1	12
Dicaelus purpuratus	1		1	2		1	5
Galerita janus			9	3	2		14
Harpalus compar					1		1
Megacephala virginica	7						7
Notiophilus novemstriatus	10			3	6	4	23
Platynus decentis			22	29	8	13	72
Poecilus chalcites	2						2
Poecilus leucoblandus			9			1	10
Pterostichus permundus	5	5	2	1	1		14
Pterostichus stygicus			4	17	2	7	30
Scaphinotus elevatus	5	3					8
Trichotichnus fulgens			2	2		2	6
TOTAL	65	36	156	162	113	98	630

Table 2. Ground beetle specie richness and diversity in six habitats at the Kibbe macrosite.

	BP	UP	ESF	BF-06	BF-05	UF	All Habitats
Species Richness	12	10	17	16	9	13	25
Simpson's Index	0.89	0.86	0.85	0.83	0.57	0.70	0.82

Table 3. Results of MRPP comparisons of six habitats at the Kibbe macrosite.

Habitat Comparison	*A*-value	*P*-value
BP vs. UP	0.06	0.07
BP vs. ESF	0.39	0.02
BP vs. BF-06	0.34	0.02
BP vs. BF-05	0.37	0.02
BP vs. UF	0.41	0.02
UP vs. ESF	0.22	0.02
UP vs. BF-06	0.20	0.02
UP vs. BF-05	0.24	0.02
UP vs. UF	0.24	0.02
ESF vs. BF-06	0.09	0.08
ESF vs. BF-05	0.21	0.02
ESF vs. UF	0.16	0.04
BF-06 vs. BF-05	0.12	0.06
BF-06 vs. UF	0.11	0.13
BF-05 vs. UF	0.05	0.18

Table 4. Mean temperature (°F ± SEM) during monthly trapping periods in six habitats at the Kibbe macrosite.

Date	BP	UP	ESF	BF-06	BF-05	UF
May	54.7±0.39	53.7±0.43	53.9±0.30	54.1±0.27	54.0±0.28	54.1±0.28
Jun	70.7±0.49	68.3±0.50	66.5±0.28	67.2±0.28	66.9±0.30	67.6±0.30
Jul	84.1±0.53	81.1±0.47	80.3±0.30	80.0±0.26	80.3±0.30	80.4±0.28
Aug	75.4±0.44	72.6±0.38	73.3±0.27	72.4±0.20	72.9±0.24	72.8±0.23
Sep	61.8±0.49	60.4±0.48	62.6±0.40	61.5±0.35	62.4±0.39	61.8±0.36
Oct	47.6±0.50	46.1±0.51	48.8±0.49	49.2±0.38	49.2±0.40	49.3±0.40

Table 5. Mean relative humidity (± SEM) during monthly trapping periods in six habitats at the Kibbe macrosite.

Date	BP	UP	ESF	BF-06	BF-05	UF
May	79.4±0.82	80.5±0.82	89.4±0.41	78.8±0.67	80.8±0.67	76.2±0.71
Jun	81.1±0.87	78.9±0.82	89.3±0.33	79.0±0.47	81.7±0.52	76.1±0.55
Jul	79.2±0.88	80.1±0.73	85.6±0.53	83.3±0.50	83.2±0.58	80.4±0.56
Aug	86.6±0.83	86.8±0.68	89.9±0.58	90.5±0.45	90.7±0.50	88.1±0.49
Sep	81.2±0.83	80.7±0.75	78.3±0.68	77.7±0.58	76.7±0.64	76.1±0.59
Oct	72.7±0.94	74.4±0.88	69.9±0.89	62.8±0.73	64.5±0.77	63.2±0.76

Table 6. Mean percent leaf litter cover and mean number of plant species (± SEM) in forest habitats at the Kibbe macrosite.

Habitat	Mean % Leaf Litter Cover (± SEM)	Mean # of Species (± SEM)
ESF	52.6 ± 3.63	4.3 ± 0.23
BF-06	9.8 ± 1.08	5.4 ± 0.25
BF-05	30.2 ± 3.83	5.9 ± 0.32
UF	47.0 ± 4.46	5.4 ± 0.27

Figure 1. Indicator values for ground beetle species strongly associated with restored prairie burned in spring 2005 at the Kibbe macrosite.

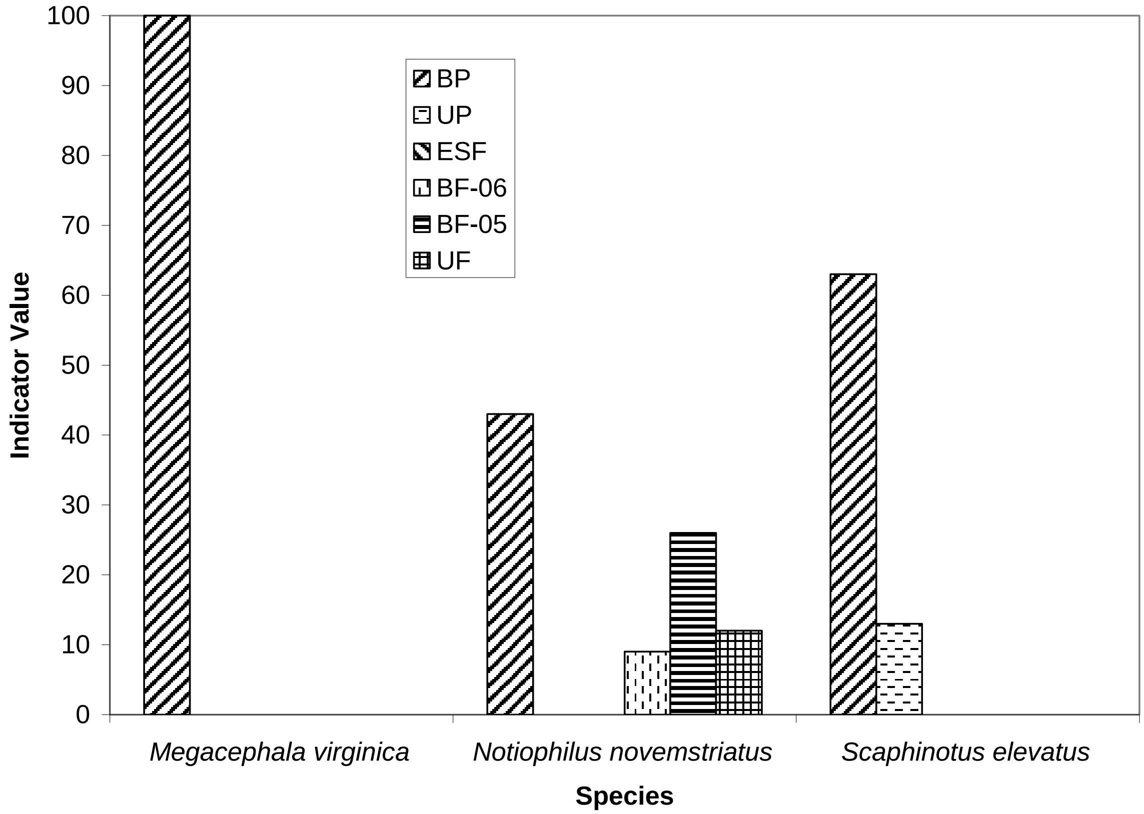


Figure 2. Indicator values for ground beetle species strongly associated with early successional forest at the Kibbe macrosite.

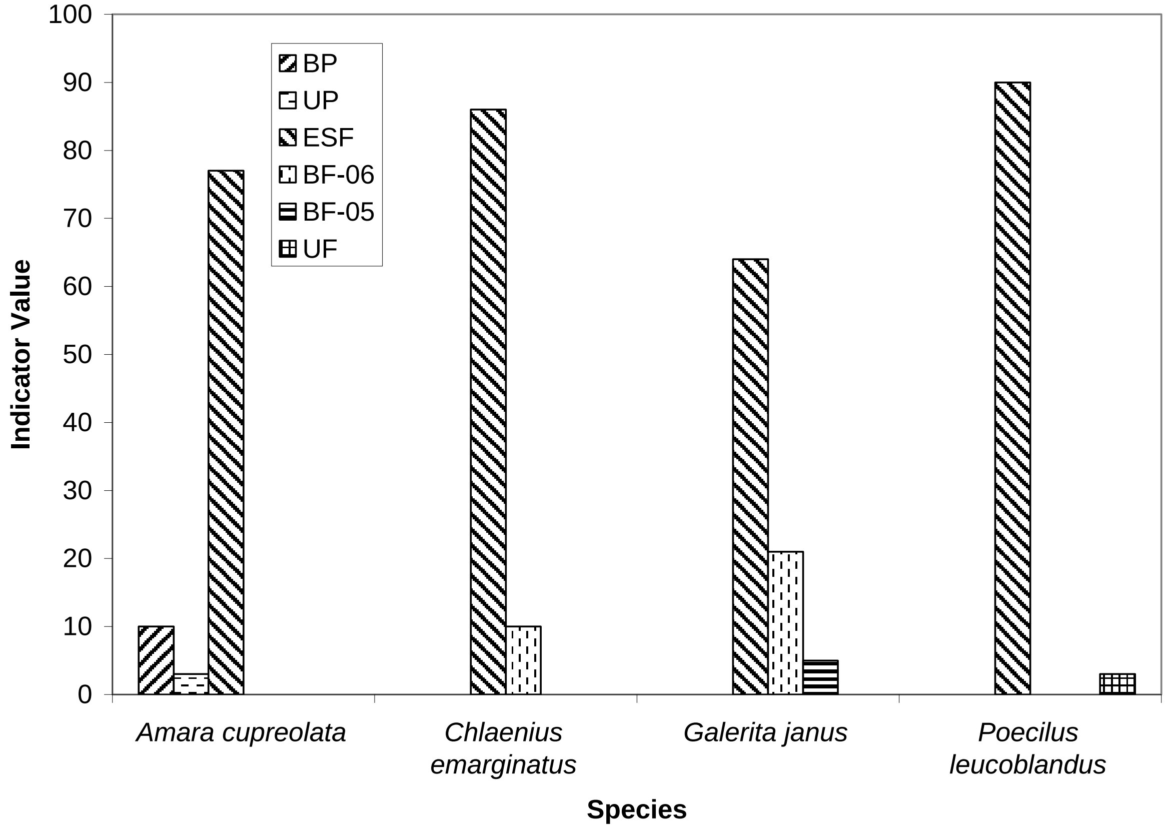
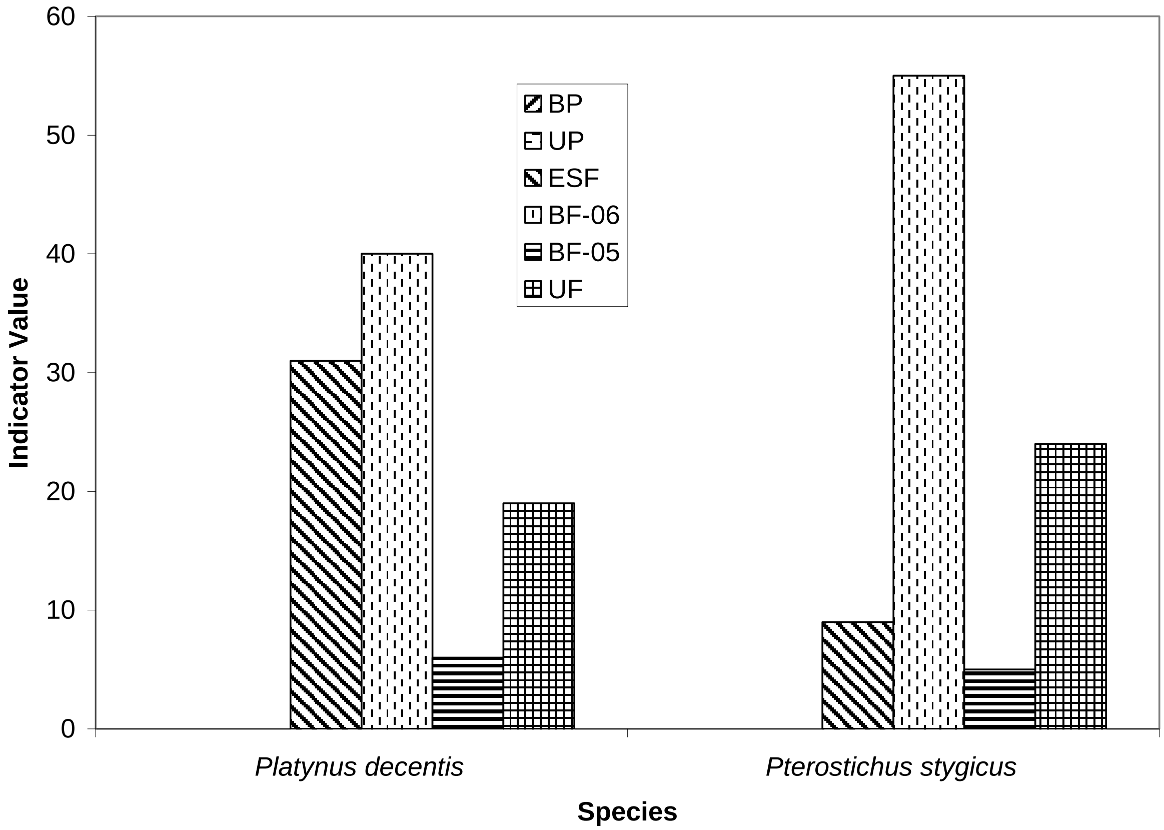


Figure 3. Indicator values for ground beetle species strongly associated with hardwood forest burned in spring 2006 at the Kibbe macrosite.



Digital Image Legends

1. A pitfall trap.
2. A Hobo® data logger with rain cover.
3. Restored prairie after prescribed burning in spring 2005.
4. Restored prairie unburned for several years.
5. Early successional forest understory.
6. *Cyclotrachelus sodalis*, the most common ground beetle in our study.

Project Expenditures

Description	Expenditure
Graduate Assistantship	$2,608
Undergraduate Student Assistant	$1,911
Commodities (Antifreeze, plastic cups, insect boxes & pins)	$284
Travel to and from study site	$700
Contractual (Payment to Robert Davidson for beetle identifications)	$275
Indirect Costs	$550
TOTAL	$6,328