

## Dung Beetle (Coleoptera: Scarabaeoidea) Community Response to Clear-cutting in the Missouri Ozarks

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Dung beetles (Scarabaeoidea) show a mixed response to forest alteration (Davis *et al.*, 2001; Scheffler, 2005). In some studies, community attributes are negatively affected by anthropogenic forest disturbance, not only reducing beetle abundance and their species richness and diversity (e.g., Colombian Amazon: Howden and Nealis (1975), but also limiting their movement between undisturbed forest patches (Klein, 1989). In other studies, however, logging may reduce species richness only after extreme alteration of the landscape. For example, species richness did not differ between virgin forest and selectively logged forest in Uganda (Nummelin and Hanski, 1989) and between undisturbed forest, mosaics of forest, and several types of cultivars, including cacao, citrus, banana, avocado, pineapple, and papaya in Mexico (Estrada and Coates-Estrada, 2002). Thus, global generalizations about the impacts of forest disturbance, and logging in particular, would be premature at the this time given the variability in results seen in available studies and the general lack of studies in the temperate zone.

In the present study we document the local effects of clear-cutting on the dung beetle community in a Missouri Ozark forest by contrasting community attributes between adjacent clear-cuts and uncut, closed canopy forests. We chose dung beetles because they are easily sampled and taxonomically well known, particularly in the temperate zone. In addition, dung beetles perform important ecological functions. Beetle-mediated dung burial increases the rate of nutrient cycling which in turn increases the available nitrogen and phosphorous for plants (Halffter and Mathews, 1966; Mittal, 1993). Dung beetles also are responsible for secondary dispersal of seeds, influencing forest succession (Estrada and Coates-Estrada, 1991). Finally, despite the depth of taxonomical knowledge of temperate Scarabaeoidea, to the best of our knowledge there are no published studies on the effects of anthropogenic forest disturbance on communities of dung beetles in temperate North America. We conducted our study in the context of the Missouri Ozark Forest Ecosystem Project (MOFEP), a large-scale, long-term, replicated before-after/control-impact experiment designed to determine the effects of even-aged (i.e., clear-cutting) and uneven-aged (i.e., thinning) management on multiple forest flora and fauna (Brookshire *et al.*, 1997; Gram *et al.*, 2001).

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## Materials and Methods

The MOFEP study area is located in Shannon, Reynolds, and Carter Counties in southeastern Missouri within the Current River Hills Subsection of the Ozark Highlands (Kabrick *et al.*, 2000). The forests of this area are primarily oak-hickory and oak-pine communities, and the landscape is 84% forested (Kurzejeski *et al.*, 1993). Prior to 1880 these forests were dominated by *Pinus echinata* and oak savannas (Batek *et al.*, 1999).

The MOFEP experimental design consists of nine treatment sites ranging in size from 314–516 ha. Three timber management treatments were organized into three blocks, each block randomly receiving one each of the uneven-aged management (UAM), even-aged management (EAM), and no harvest management (NHM) treatments. Sites are divided into stands ca. 4 ha in area, defined by slope aspect, soil type, and vegetation composition.

The first and only round of timber extraction thus far in the MOFEP sites took place from May to October 1996. In this study we are concerned only with the three EAM sites. For further description of the UAM and control sites see Brookshire and Dey (2000). Two harvest types were employed in the EAM sites, clear-cuts and intermediate-cuts. Clear-cut harvests completely remove canopy cover while an intermediate cut, also called thinning, removes some mature trees and undesirable immature sawtimber and poles but does not completely clear-cut the stand. In the first harvest approximately 130 ha were harvested from clear-cut stands and 166 ha were thinned per site, with the size of each clear-cut stand averaging five hectares, while the thinned stands averaged three hectares at each site (Kabrick *et al.*, 2002).

To compare dung beetle communities between clear-cut and adjacent un-treated (closed canopy forest) areas, we established a series of transects in the three EAM sites. We chose three clear-cuts in each of the three EAM sites such that the topography of the clear-cut and adjacent un-harvested forest stand was similar. From the edge of the clear-cut we measured 60 m to either side (clear-cut and closed canopy forest) and set a trap every 20 m. An additional trap was set at 0 m (edge). We sampled each transect twice during August 2003, resulting in 126 samples total.

Traps consisted of deli plastic containers ( $\pm 10$  cm deep and 11.5 cm in diameter) set flush with the ground; a plastic disposable spoon to hold the bait over the cup with the wide end of the spoon loosely wrapped with tin foil to prevent the bait from being rolled into the container by making a wider and deeper platform for the bait. The spoon was anchored to the ground with a rock placed on the handle, with the wide end placed over the cup. We covered each trap with a plastic plate (ca. 16 cm in diameter) held about 10 cm above the ground by 4 pieces of 12 cm long bamboo skewer to prevent rain and debris from flooding the trap. We used ca. 150 ml of 70% EtOH as the killing and preserving agent inside the deli cup. Traps were baited with a spoon-full of fresh human dung early in the morning and left open for 24–28 hr. We collected the samples in pre-labeled Whirl-Pak® bags. In the laboratory we cleaned the samples, recorded the number of each morphospecies, and pinned a long series of each for identification and vouchering. Species were identified according to Ratcliffe (1991) and by visual comparison with identified specimens at the Enns Entomology Museum, University of Missouri-Columbia. Paul Lago (University of Mississippi) and Federico Ocampo (University of Nebraska State Museum)

confirmed our identifications. Voucher samples reside at these museums and at the University of Missouri-St. Louis.

We calculated observed species richness as the number of observed species per trap at each sampling distance class (edge, 20 m, 40 m, and 60 m in either direction from the edge into closed canopy forests and clear-cuts) on the 120 m long transects. We used ANOVA (PROC GLM, SAS Institute, 1989) followed by Tukey's means comparison (HDS) to analyze mean beetle abundance and species richness (square root transformed values) at each distance class and site. Site was considered to be a random variable, with the effects of distance tested over the site  $\times$  distance interaction. We also estimated the effects of cutting on species richness using rarefied species richness (Coleman curves) calculated analytically with the software EstimateS Version 7 (Colwell, 2004). Values used were those based on pooling across sites to augment sample size. Species richness values of cut and uncut areas also were compared using rarefaction on values pooled across all transects and sites.

To compare diversity among distances classes, we calculated the reciprocal of Simpson's Index ( $1/D$ ) also using EstimateS, but sampling with replacement and randomizing 500 times. For evenness we divided the reciprocal of Simpson's index by the number of species in the sample (Magurran, 2004). We also tested individual species abundances for the eight most abundant species ( $N > 40$ ) at different distance classes along transects using ANOVA. Values analyzed were those based on pooling at the site level because un-pooled data were neither normal nor homogeneous in variance.

We used non-metric multidimensional scaling (NMS) with the eight most common species to quantify the effects of clear-cuts on the dung beetle community structure, using PC-ORD (version 4, MJM Software Design, Gleneden Beach, Oregon). NMS is an iterative ordination method, which uses ranked distances between samples to test for ordination of samples by community composition (McCune and Grace, 2002). We first pooled data for each distance class of the three transects per site to obtain one sample per distance class per site. Then, following McCune and Grace (2002), we adjusted data by relativizing by column (species) maximum. This procedure assigns a value of 1.0 to the most abundant sample and equalizes the weights among abundant and less abundant species. To lower skew and the coefficient of variation we omitted less common species ( $N < 40$ ). An outlier analysis of the data revealed no outliers. We ran the NMS using the autopilot program set to 'slow and thorough' analysis option and the default settings in the PC-ORD program.

We also tested the hypothesis of no difference in community composition among the different distance classes on transects with a multi-response permutation procedure (MRPP). This nonparametric method allows testing group differences ( $H_0$  = no difference between groups) without requiring the assumptions of parametric tests (McCune and Grace, 2002). A low  $P$ -value ( $< 0.05$ ) signifies that the differences found between groups are greater than would be expected by chance assignment to groups. To compare similarity in species composition among clear-cut site and adjacent uncut areas in EAM sites (beta diversity), we calculated the Renkonen (percentage) similarity index (Krebs, 1999) for each transect on each site with pooled values for the three distances classes on either side of the edge.

Table 1. Dung beetle abundance, richness, and Simpson index.

Species	Clearcut			Edge	Forest			Total by species
	60 m	40 m	20 m	Edge (0 m)	20 m	40 m	60 m	
<i>Canthon viridis</i> (Palisot de Beauvois)	40	37	49	64	18	13	5	226
<i>Deltochillum gibbosum</i> (Fabricius)	4	0	2	11	27	32	34	110
<i>Onthophagus hecate</i> (Panzer)	21	10	12	19	18	12	15	107
<i>Onthophagus taurus</i> (Schreber)	2	2	1	14	20	24	37	100
<i>Ateuchus histeroides</i> Weber	14	8	8	24	16	7	16	93
<i>Canthon chalcites</i> Haldeman	5	1	1	13	20	14	18	72
<i>Onthophagus pennsylvanicus</i> Harold	8	4	10	17	11	3	8	53
<i>Dialytes truncatus</i> Melsheimer	0	9	4	0	13	11	9	46
<i>Onthophagus striatulus</i> (Palisot de Beauvois)	2	0	2	1	0	1	0	14
<i>Copris minutus</i> (Drury)	1	2	2	1	0	0	1	7
<i>Onthophagus orpheus</i> Howden and Cartwright	2	2	3	0	0	0	0	7
<i>Aphodius stercorosus</i> Melsheimer	0	0	0	0	0	0	1	1
<i>Geotrupes splendidus</i> (Fabricius)*	0	0	1	0	0	1	1	3
<i>Trox hamatus</i> Robinson**	1	0	0	0	0	0	0	1
Total number of individuals	100	75	95	164	143	118	145	840
Species richness	11	9	12	9	8	10	11	
Simpson Index (1/D)	4.13	3.51	3.40	4.53	7.13	6.08	5.91	
(±95% C.I)	(1.58)	(1.72)	(1.56)	(1.58)	(1.39)	(1.31)	(1.47)	
Evenness (1/D)/S	0.37	0.39	0.28	0.50	0.89	0.61	0.54	

\* Geotrupidae.

\*\* Trogidae.

## Results

During the two August 2003 censuses we collected 840 individuals representing 14 species (Table 1). Five species comprised 75% of the abundance of all beetles captured, with *Canthon viridis* (Palisot de Beauvois) the most abundant (26.0%), followed by *Deltochillum gibbosum* (Fab.) (13.1%), *Onthophagus hecate* (Panzer) (12.7%), *O. taurus* (Schreber) (11.9%), and *Ateuchus histeroides* Weber (11.1%).

There was a marginally significant difference in total dung beetle abundance among sites ( $F_{2,12} = 2.86$ ,  $P = 0.06$ ), and among clear-cuts, edge and forest interior sampling locations, with a trend for greater abundance at the edge and in the forest locations ( $F_{6,12} = 2.6$ ,  $P = 0.07$ ) (Fig. 1a). Distance along the transect ( $F_{6,12} = 4.72$ ,  $P = 0.02$ ) and site ( $F_{2,12} = 11.43$ ,  $P = 0.001$ ) also significantly affected observed species richness, with a greater number of species at the edge and in the forest than in the clear-cut (Fig. 1a). Only richness at the 40 m location in the clear-cut was significantly different from the other sampling locations along the transect (Tukey analysis, Fig. 1a).

Rarefaction curves rarely reached asymptotes indicating that sampling was not sufficiently complete to estimate the true number of species at a given transect position. At  $N = 75$  we found no specific trend in expected species richness between

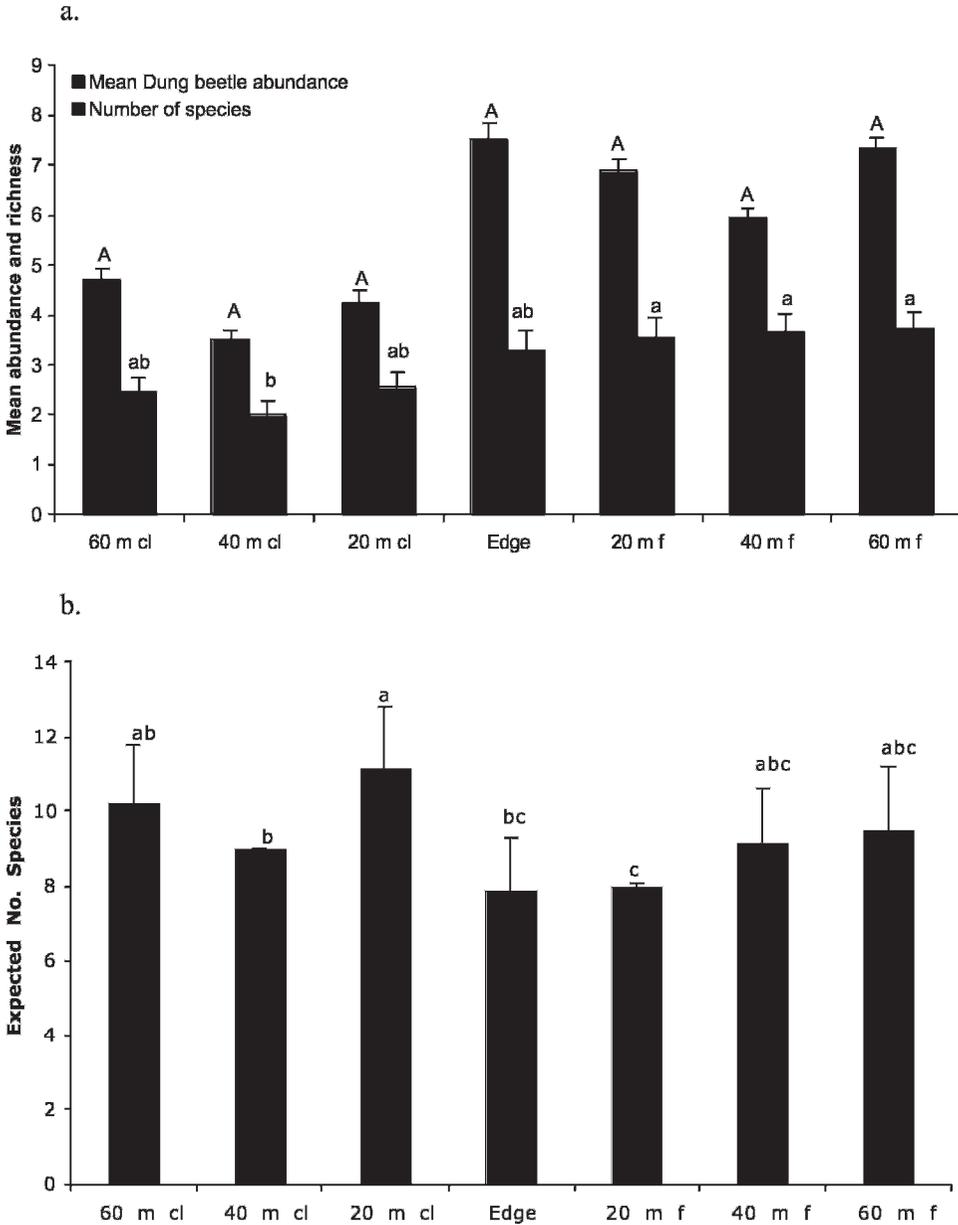


Fig. 1. (a) Abundance and species richness, (b) rarefied species richness. Abundance and species richness of dung beetles at each 20 m distance interval along the transect from clear-cut (cl) to forest (f) with (a) as mean abundance ( $\pm$  SE) and mean species richness ( $\pm$  SE) and (b) as rarefied species richness at  $N=75$  with 95% C.I. Bars associated with a given variable that do not share the same letter are significantly different at  $P < 0.05$ .

forest and clear-cut sampling locations. Some sampling locations were significantly different from each other (no overlap between 95% C.I.), but there was no relationship with canopy cover (Fig. 1b). Furthermore, rarefaction based on pooling all samples for each of the cut and uncut areas across all three sites showed that at  $N$

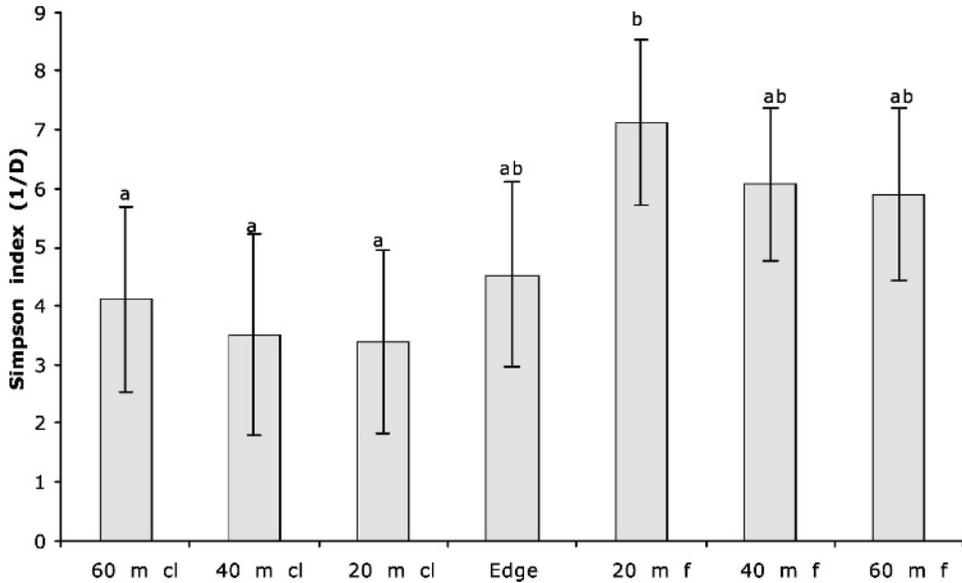


Fig. 2. Diversity estimated by the reciprocal of Simpson's Index ( $1/D$ ) with 95% C.I. for each sampling distance. Samples with the same letter are not significantly different.

= 175 expected richness was not different. Diversity, expressed as the reciprocal of the Simpson Index, tended to be higher in the forested sites and peaked at 20 m from the edge into the forest (Table 1; Fig. 2). This trend is also noticeable for the evenness estimator (Table 1).

Comparisons of individual species were made for the eight most abundant species ( $N > 40$ ), three of which showed significant differences along transects. Both *Deltochillum gibbosum* ( $F_{6,12} = 12.48$ ,  $P = 0.0002$ ) and *Onthophagus taurus* ( $F_{6,12} = 15.84$ ,  $P = 0.0001$ ) were more abundant on the forested side of the transect, but did not differ within the distance classes. *Canthon viridis* was most abundant in the clear-cuts but peaked at the edge ( $F_{6,12} = 6.63$ ,  $P = 0.002$ ). Two other species, *Canthon chalcites* Haldeman and *Dialytes truncates* Melsheimer, showed marginally significant differences ( $F_{6,12} = 2.49$ ,  $P = 0.07$ ;  $F_{6,12} = 2.46$ ,  $P = 0.07$  respectively), and appeared to be more abundant in the uncut forest.

Non-metric multidimensional scaling analysis revealed clear differences in the composition of dung beetles sampled from the clear-cut, edge, and forest (Fig. 3). NMS partitioned 90% of the variation in the data set among the first three ordination axes, with axes 2 and 3 explaining 87%. MRPP analysis showed significant differences among the different sampling locations ( $P < 0.001$ ). Overall, the mean percent similarity of species composition (beta diversity) between clear-cut and adjacent forested sites was 37%.

### Discussion

In this study the clearest effect of timber harvest on the dung beetle community was on community composition, with reduced abundance (Fig. 1a) and diversity (Fig. 2) in clear-cuts compared to forests. These effects were due to the association of the most common species with either the closed forest or the clear-cuts (Fig. 3). Of



mammal activity (Martin *et al.*, 1951; Fantz and Renken, 2002). In this study, the abundance of *Canthon viridis* was statistically higher in clear-cuts, but in fact, its abundance peaked at the edge. *Deltochilum gibbosum*, the largest species collected, may use turkey feathers to make its egg-ball (Howden and Ritcher, 1952); wild turkeys do not tolerate complete forest loss (James, 2004) and are not likely to be found in clear-cuts.

Third, the dung resource itself might be influenced by the microhabitat changes (Jankielsohn *et al.*, 2001). Dung in clear-cuts is expected to lose moisture and harden faster than dung in the uncut forest, and this may affect the reproductive success of dung beetles (Vessby, 2001). Halffter and Arellano (2002) found that the number of dung beetle captures from cow pats in direct sunlight was significantly lower than cow pats in shade. Moreover, desiccation of larvae can be an important source of dung beetle mortality as suggested by Fincher (1973), further reducing the abundance of beetles in clear-cuts.

Finally, soil characteristics have been reported to influence the incidence and abundance of dung beetles (Nealis, 1977; Lumaret and Kirk, 1991; Vessby and Wikteliuss, 2003). Soils in clear-cuts, although unstudied here, are likely to be much drier and harder than soils under the uncut forest due to higher temperatures experienced in clear-cuts, perhaps limiting the burrowing ability of dung beetles.

This study provides initial evidence that dung beetle community composition changes in response to complete removal of the forest canopy in the Missouri Ozark region. It suggests that both diversity and the abundance of forest species would decline, putting local populations in danger of extinction. Given that maintenance of biodiversity is a goal of MOFEP and ecosystem management in general, this study provides preliminary support for timber harvesting regimens that temporally stagger the harvest of neighboring sites, so that large tracts of adjacent forest are never cut simultaneously. Future studies should sample throughout the growing season, as well as across multiple years, and couple this sampling with manipulative experiments to determine the robustness of our results and the mechanisms for observed changes.

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