

Short term response of dung beetle communities to disturbance by road construction in the Ecuadorian Amazon

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Abstract. In the tropics, human disturbance continuously challenges initiatives for habitat conservation. In these regions, as economical budgets for conservation shrink, conservation planning requires precise information on when and how different kinds of disturbance may affect natural populations, but also on adequate experimental designs to monitor them. Due to their high diversity, ecological role, stable taxonomy and facilities to sample, dung beetles are used in biodiversity surveys for conservation purposes worldwide. Here we studied the short-term effects of dung beetle communities to an important and widespread ecological disturbance due to road construction in the Amazon basin. We surveyed the dung-beetle community in a spatio-temporal context, i.e. in transects located at 10, 50 and 100-m from a newly constructed, 10-m wide, paved road. The sampling periods took place 1, 3 and 6 months after the construction. During the survey, we collected 4895 specimens that belong to 69 species in 19 dung beetle genera. Six dung beetle species (*Canthon aequinoctialis*, *C. luteicolis*, *Dichotomius fortetstriatus*, *Eurystemus caribaeus*, *E. confusus* and *Onthophagus haematopus*) accounted for 55% of all individuals collected. Both species diversity and abundance tended to decrease during the 6 months after the opening of the road, but not with distance from the road. Accordingly, an NMDS analysis revealed clear differences in dung beetle community composition and biomass among the three sampling periods, but not with respect to transect location. However, the number of rare species tended to increase toward the forest interior. A detailed analysis of dung beetle species among transects revealed that 5 species (*Sylvicanthon bridarollii*, *Canthidium* sp. 2, *C. sp. 6*, *C. sp. 7* and *Ontherus diabolicus*) were more abundant when getting further from the road. On the contrary 6 species (*Eurystemus hamaticollis*, *E. velutinus*, *E. confusus*, *E. caribaeus*, *Deltochilum oberbengeri* and *D. orbiculare*) increased in abundance in the transect next to the road. Our study therefore confirmed that while overall community metrics did not respond to road construction, several rare dung beetle species did, within an incredibly rapid time frame. While pattern based descriptions of dung beetle responses to anthropogenic activities are common in the literature, our findings suggest that effect of roads is certainly under emphasized.

Résumé. Réponse à court terme des communautés de bousiers aux perturbations induites par la constructions de routes dans l'Amazonie Equatorienne. Dans les zones tropicales, les activités humaines sont une menace constante pour la conservation des habitats. Les budgets alloués aux efforts de conservation étant réduits dans ces régions, l'établissement de plans de gestion requiert des informations précises sur la manière dont différents types de perturbations affectent les populations naturelles et sur les protocoles expérimentaux adéquats pour suivre l'évolution de ces populations. En raison de leur diversité, de leur rôle écologique clé, de leur facilité d'échantillonnage et de leur taxonomie relativement bien connue, les coléoptères bousiers sont largement utilisés comme indicateurs dans les programmes de conservation dans le monde entier. L'objectif de ce travail est d'étudier les effets à court terme de la construction d'une route sur les communautés de bousiers en forêt amazonienne. Nous avons réalisé une étude spatio-temporelle des communautés de bousiers le long d'un transect composé de site d'échantillonnages localisés à 10, 50 et 100 m de distance d'une route, après 1, 3 et 6 mois de construction. Durant cette étude 4 895 individus appartenant à 69 espèces et 19 genres de bousiers ont été collectés. Six espèces (*Canthon aequinoctialis*, *C. luteicolis*, *Dichotomius fortetstriatus*, *Eurystemus caribaeus*, *E. confusus* and *Onthophagus haematopus*) représentaient 55% de tous les individus collectés. Nos résultats ont montré que la diversité spécifique, l'abondance et la composition des communautés de bousiers variaient significativement en fonction du mois de collecte, mais pas en fonction de la distance à la route. Cependant, le nombre d'espèces rares de bousiers tendaient à augmenter en s'éloignant de la route. Par ailleurs, une analyse au niveau spécifique a révélé que cinq espèces (*Sylvicanthon bridarollii*, *Canthidium* sp. 2, *C. sp. 6*, *C. sp. 7* and *Ontherus diabolicus*) étaient significativement plus abondantes en s'éloignant de la route. Au contraire, l'abondance de six espèces (*Eurystemus hamaticollis*, *E. velutinus*, *E. confusus*, *E. caribaeus*, *Deltochilum oberbengeri* and *D. orbiculare*) augmentait en se rapprochant de la route. L'utilisation des bousiers comme indicateurs de perturbation à court terme, telle qu'elle est réalisée dans de nombreux pays tropicaux est discutée dans un contexte général de conservation des milieux soumis à des perturbations anthropiques.

Keywords: Human disturbance, Ecuador, Scarabaeinae, Tropical rainforest, NMDS.

Like many other South American countries, Ecuador faces important habitat conservation challenges throughout its territory. These place serious pressure on the survival of many species, and the maintenance of biodiversity and ecosystem function (Dangles *et al.* this issue). Although insect biodiversity is crucial for maintaining ecosystem function, our understanding of the overall response of insects to human activity remains limited. Dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) are relevant candidates to assess interactions between anthropogenic disturbances and community composition (Nichols *et al.* 2007). These insects perform key roles in many ecosystems around the world as they provide a suite of vital ecosystem services such as recycling of dead tissue, fecal material, and the dispersal of seeds (Andresen & Feer 2005, Nichols *et al.* 2008). Dung beetles also represent a large proportion of insect biomass, are easily attracted to baits, and have a relatively well-known taxonomy, at least for some groups (Hanski & Cambefort 1991). For these reasons, numerous studies have investigated the impact of habitat disturbance on dung beetle communities in various tropical regions including Eastern Asia (Boonrotpong *et al.* 2004, Shahabuddin *et al.* 2005), Africa (Davis & Philips 2005) and Latin America (Klein 1989, Forsyth *et al.* 1998, Quintero & Roslin 2005, Scheffler 2005, Gardner *et al.* 2008) (see Nichols *et al.* 2007 for a review). Some of these authors have stressed the potential use of dung beetles as bio-indicators for mammal population densities (as many species rely directly on mammal excrement for food and nesting while others are carrion feeders) and environmental changes (e.g., Nichols *et al.* 2009). In Ecuador, environmental monitoring programs have been developed with dung beetles as the focal group (Celi & Davalos 2001).

Road construction is the main factor leading to forest fragmentation in the Amazon basin (Perz *et al.* 2008). Forest fragmentation has negative ecological consequences such as stream network degradation, spread of exotic invasive species, wildlife mortality and species loss from ecosystems (Trombulak & Frissell 2000; Forman *et al.* 2003), which implies that the Amazon in the near future may become more vulnerable to global change than climate models assume (Perz *et al.* 2008). Roads can affect species by reducing available habitat, affecting patterns of movement, and extending edge microclimatic conditions into forests, further reducing existing habitat (see Dunn & Danoff-Burg 2007 and references therein). In spite of great advances in our understanding of road ecology, much remains to be known about the effects of road construction on ecosystems in the short and long-term (Forman *et al.* 2003).

Recent literature has outlined several long-term effects, both positive and negative, on the structure and function of invertebrate communities along the road-forest continuum (see Dunn & Danoff-Burg 2007). Obviously long-term effects are the most relevant in an ecological perspective. However, most environmental impact studies related to road construction in developing countries are performed at short temporal and spatial scales. In most cases, the objective of these impact studies has been to assess the degree of local perturbations in view of authorizing the further use of the road. Because of limited funding, these impact studies have been limited to several months up to a few years in the best case. Finding biological indicators that can rapidly respond to anthropogenic perturbation is an important issue for environmental assessment. Dung beetle communities are potential candidates as biological indicators, known to show a graded and rapid response to environmental degradation (Larsen & Forsyth 2005).

This study examines how insect communities responded to the perturbation of road construction using dung beetles as an indicator group (Halffter & Favilla 1993, Forsyth *et al.* 1998, Davis *et al.* 2001). We studied dung beetle communities in a spatio-temporal context, i.e. at different distances from the road and at different times after road opening. Although overall community composition metrics were not sensitive to these changes, our study found rapid responses of several rare dung beetle species to road construction.

Material and methods

Study site

The study site was near the “Chiruisla Station” on the south rim of the Napo River in Sucumbíos Province close to the Chiruisla Village of the Quichua Territory, Ecuador. We selected a 12600 m² study area (140 × 90 m) around a central point located at the coordinate 00° 38' 39.2" S, 75° 54' 45.4" W (Fig. 1). This site ranges from 180–250 m in altitude. The climate is tropical and humid. Rainfall and temperature are aseasonal with an annual mean precipitation of 2400 mm. No month receives less than 100 mm (Valencia *et al.* 2004) of rain but December and January are generally slightly drier than the rest of the year. Temperatures range from 22–32 °C and humidity from 56–96%. The whole area is a young landform classified as “western sedimentary uplands,” which are fluvial deposits (red clays, brown or gray alluvium) (*sensu* Tuomisto *et al.* 2003). The area has been reported to contain important populations of large mammals with no record of species extirpation (Peres & Dolman 2000).

The Chiruisla Station was controlled by the Petrobras Oil Company. The study plot was located 2 km inside a mature forest south of the Napo River, on a west side of a recently (< 1 month) opened road for oil extraction activities. The road was 12.5 km long and 10 m wide and ended at river. Every 1000 m,

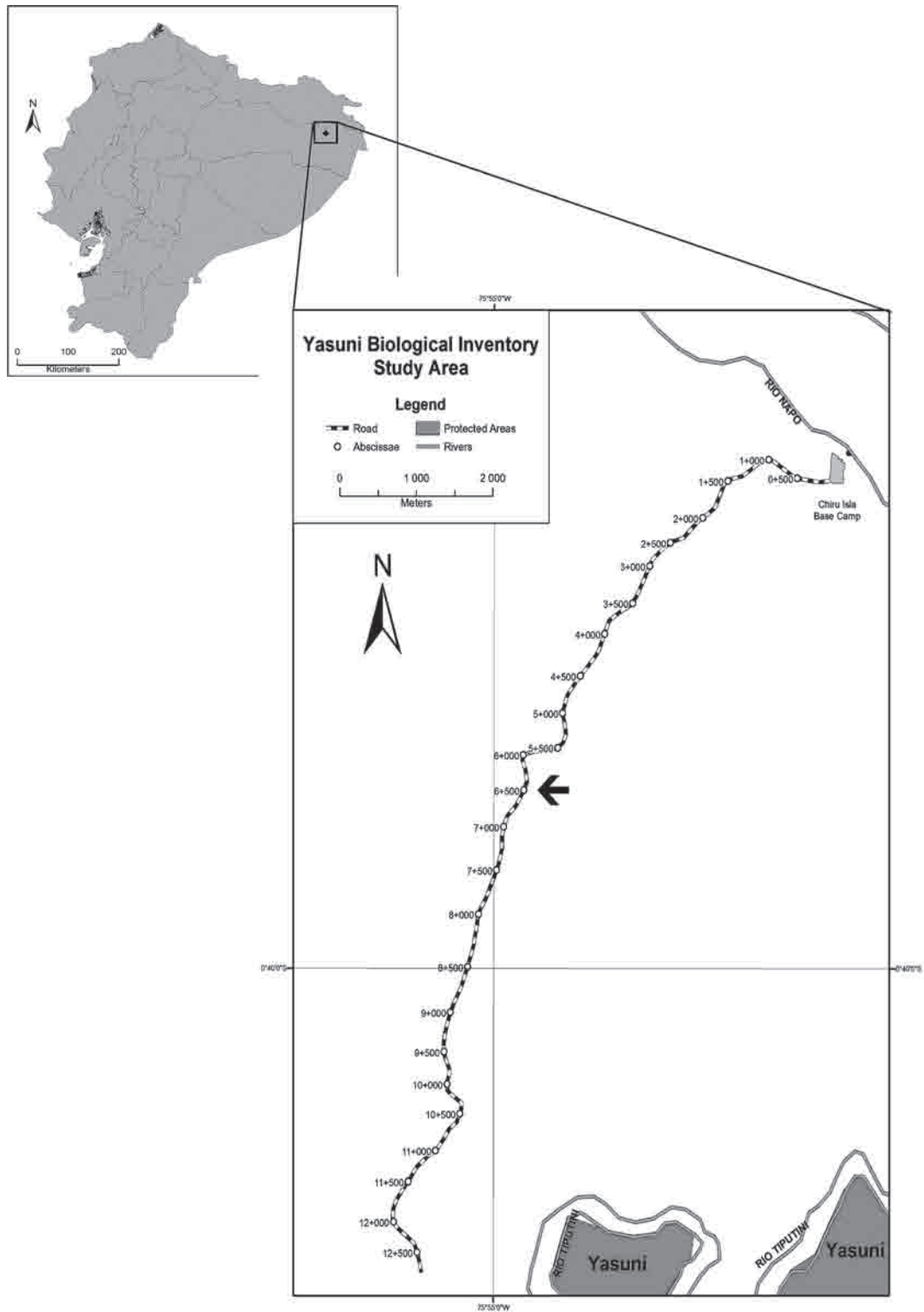


Figure 1
Location of the study region in Ecuador (insert) and map of the study area showing the location dung beetle sampling transect (black arrow) along the recently constructed road in Chiruisla.



Figure 2
A, photograph of the paved road in Chiruisla (2005). **B**, schematic drawing of the sampling design used to collect dung beetle communities in Chiruisla.

the road was partly covered by canopy segments thanks to the presence of canopy bridges. These bridges consisted in 40-meter-long sections where the working row of the road was narrowed to seven meters to preserve canopy connections. Before road construction, the forest was considered a primary forest, except for some local disturbances originating from indigenous groups who clear the forest for agriculture. This is an evergreen lowland wet forest that has a canopy mostly 15–30 m high, with some emergent trees reaching 50 m. It was dominated by species of the families Arecaeae (*Iriartea deltoidea*), Euphorbiaceae (*Margaritaria nobilis*), Rubiaceae (*Duroia hirsuta*), Lecythidaceae (*Grias neuberthii*) and Mimosaceae (*Parkia multijuga*).

Sampling design

From September 2005 to February 2006, we surveyed the study area on three occasions at one, three and six months (September, November and February, respectively) after the opening of the road. Although we tried to control for rain and seasonal differences by limiting our sampling to the early and mid-rainy season we are aware that seasonal effects can still be significant as abundance of dung beetles is sometimes higher at the beginning of the rainy season than in mid-rainy season. For logistic reasons, we were unable to sample the plot before the opening of the road and thus data on the original dung beetle community composition are not available. On each occasion, we surveyed the dung beetle fauna on three transects located at 10, 50 and 100 m inside the forest (L10, L50, L100, respectively, fig. 2). Each transect was composed of 8 traps (T1, T2, ..., T8), separated by a distance of 20 m. Trap placement and collection was randomized across transects to control for sampling time effect. Dung beetle communities were sampled using pitfall traps consisting of two stacked 0.5 L plastic cups buried in the ground so that the top rim was aligned with the soil surface (Spector & Forsyth 1998). Two cups were used so that the top cup could be easily removed and replaced again after each collection (Larsen & Forsyth 2005). The top cup was half-filled with water and a small amount of soap to reduce surface tension. Two types of baits, human dung and tuna fish were used in an alternating spatial configuration (fig. 2B). For both bait types, 50 g of bait material was wrapped in nylon mesh (1 mm²) and tied with plastic thread to a 30-cm wooden stick. This quantity of bait was sufficient to attract the largest dung beetles at the sites (Peck & Howden 1984). The bait was suspended above the cups which were covered with large leaves positioned at least 20-cm over the trap to protect it from rain and sun. In each sample interval, traps were baited for 6 complete days and beetles were collected daily. Baits were replaced every two days to avoid desiccation (Spector & Ayzama 2003). All insects were preserved in 70% ethanol and returned to the lab for identification.

Identification of Scarabaeinae

We identified the species of Scarabaeinae using taxonomic keys (Howden & Young 1981, Jessop 1985, Edmonds 1994, Génier 1996, Arnaud, 1997, Cook 1998, Medina & Lopera 2001), unpublished species lists and collections of the QCAZ Museum (PUCE), and assistance of W. D. Edmonds, Marfa, Texas. Where specific identification was not possible, specimens were identified to genus and then assigned to a morphospecies. In total, morphospecies represented 52% of the total collected Scarabaeinae, which is within the range of morphospecies proportions found in other studies in South

America: 42.0% (Ecuador, Celi *et al.* 2004), 43.0% (Peru, Larsen *et al.* 2006), 45.4% (Brazil, Durães *et al.* 2005), 45.6% (Bolivia, Vidaurre *et al.* 2008), and 61.0% (Brazil, Andresen 2002). In all these studies, *Canthidium* and *Dichotomius* were the most problematic genera to identify to the species level. All specimens were deposited at the museum of Invertebrates at QCAZ Museum of the Pontificia Universidad Católica del Ecuador, Quito, Ecuador.

Dung beetle biomass estimation

We used linear measurement of elytra length + pronotum length as an estimator of dung beetle biomass. Linear measurements are easier to obtain on dry specimens and there is a highly significant relationship between the log values of these two variables (Radtke & Williamson 2005, $R = 0.964$, $p < 0.001$). When possible, linear measurements were made on at least 5 individuals for each species using a caliper accurate to 0.1 mm. Dung beetle species biomass was estimated from linear measurements according to the equation ($P < 0.01$, $R = 0.93$) used by Radtke & Williamson (2005) in their figure 1. The estimated biomass of each species in each site was calculated by multiplying the mean estimated biomass by the total abundance for that species (see Gardner *et al.* 2008 for further details).

Data analysis

To determine the degree of completeness of our samples, we calculated species accumulation curves and estimated the true species richness for each sample/day with the Chao 1 estimate using the software EstimateS (Colwell 2006). We then compared quantitatively the differences in community structure of dung beetles between the three distances (10, 50, and 100 m from the road) and three sampling dates (1, 3, and 6 months after the road opening). The number of species, the abundance of individuals and the Shannon Index were calculated for each trap level. We also estimated richness at a transect scale to make comparisons of the total number of species potentially found at each distance from the road. For these analyses, we estimated the Chao1 overall richness using EstimateS (Colwell 2006). Species density, species abundance, and Shannon index per trap were compared among treatments using a two-way ANOVA with distance from road (10, 50, and 100 m), time after road opening (1 month, 3 months, 6 months), and the interaction term as factors. By considering traps as independent units in the ANOVA analysis, we were aware that our analysis may suffer from pseudoreplication (Hurlbert 1984). However, the large differences in dung beetle fauna found between neighboring pitfall traps with similar bait (40-m distance) suggested that the independence hypothesis of adjacent trap was likely true. Because rare taxa (singletons, doubletons, and tripletons) are an important feature of rainforest invertebrate samples (Novotny & Basset 2000), we also compared the presence of rare taxa between the three distances from the road.

We then carried out a non-metric multidimensional scaling (NMDS) analysis to examine patterns of biological similarity in dung beetle assemblages among distance and date. This ordination technique represents samples as points in low-dimensional space, such that the relative distances of all points are in the same rank order as the relative similarities of the samples (Gucht *et al.*, 2005). The Bray-Curtis method was used as a measure of similarity. Samples from the same transect or the same dates were grouped with convex hulls. The NMDS goodness of fit was estimated with a stress function (which ranges

from 0 to 1) with values close to zero indicating a good fit. The difference in composition of the dung beetle community between the three transects and the three dates were tested using an analysis of similarities (ANOSIM). This method has been widely used for testing hypotheses about spatial differ-

ences in plant and animal assemblages, in particular for detecting environmental impacts (Chapman & Underwood 1999). ANOSIM tested the null hypothesis that the within-sites similarity was equal to the between-sites similarity. ANOSIM generates a statistical parameter R which is indicative of the degree

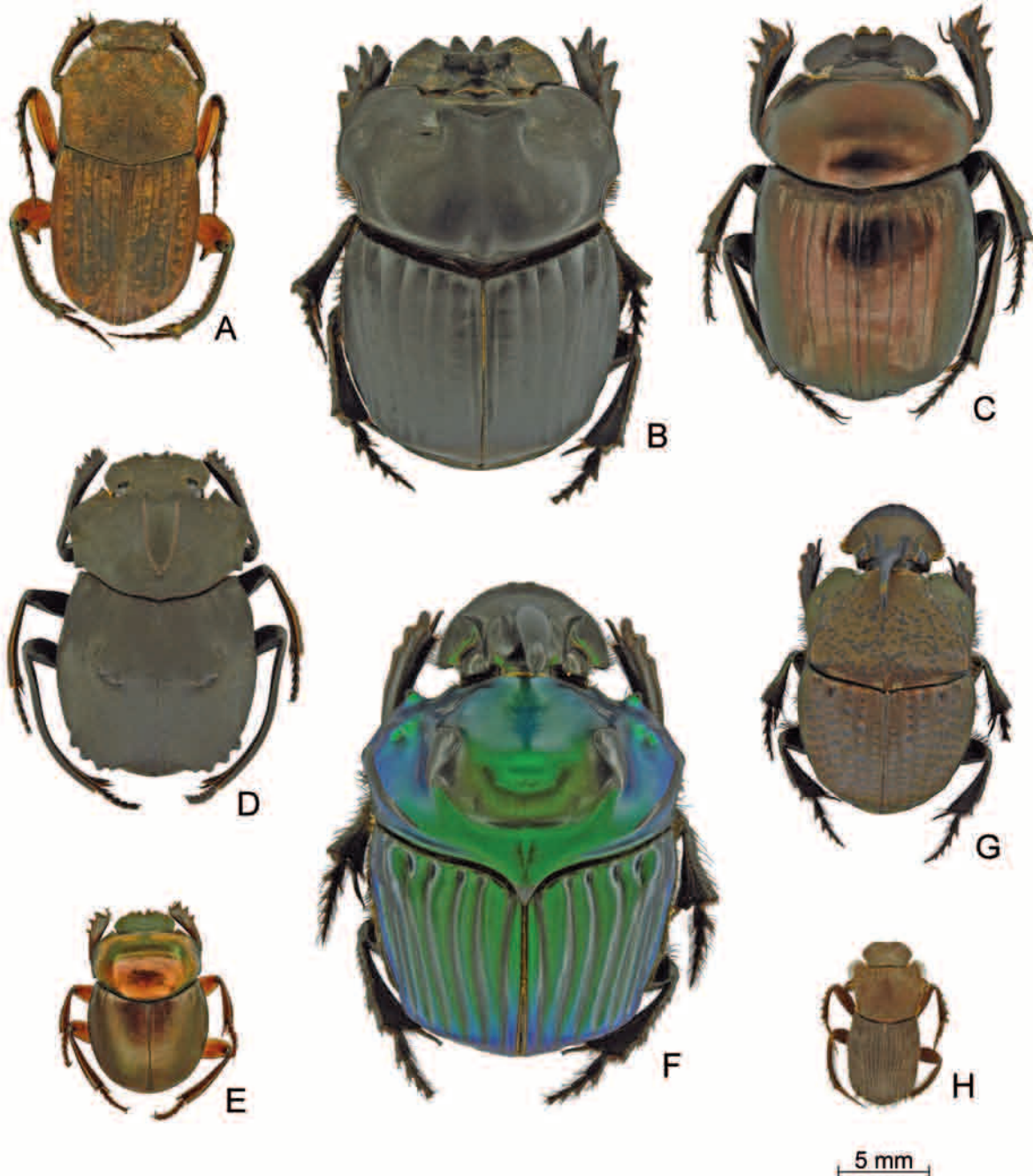


Figure 3

Photographs of several species of dung beetles collected during the study period in Chiruisla (Amazonia, Ecuador). **A**, *Eurysternus caribaeus* (Herbst 1789); **B**, *Coprophanaeus telamon* (Erichson 1847); **C**, *Malagoniella astyanax* (Olivier 1789); **D**, *Deltochilum carinatum* (Westwood 1837); **E**, *Canthon luteicollis* (Erichson 1847); **F**, *Oxysternon conspicillatum* (Weber 1801); **G**, *Phanaeus chalcomelas* (Perty 1830); **H**, *Eurysternus confusus* (Jessop 1985).

of separation between groups; a score of 1 indicates complete separation and a score of 0 indicates no separation (Gucht *et al.* 2005). Monte-Carlo randomization of the group labels was used to generate null distributions in order to test the hypothesis that within-group similarities were higher than would be expected by chance alone. Finally, we determined which dung beetle species contributed most to distinguish transects at different distances from the road by performing a SIMPER analysis on density data for all Scarabeinae taxa. All analyses were performed using PAST (Paleontological statistics, version 1.79) on $\ln(X + 1)$ transformed data. This procedure is commonly applied to invertebrate assemblage data to reduce the importance of occasional large abundance values (Clarke, 1993).

Finally, we plotted the percentage values for abundance vs. biomass data to detect differences in the analytical weight of individual species in discriminating patterns of dung beetle community structure at the three distances from the road.

Results

Patterns in species diversity and abundance

A total of 4895 individuals of 69 species and morphospecies belonging to 5 tribes (Ateuchini,

Table 1. Results of the two-way ANOVA analysis on dung beetle community richness.

(A), abundance (B) and Shannon Index (C) at three distance from the road (10, 50 and 100 m) and three sampling dates (at one, three and six months after road opening).

A. Richness

Source	Sum of Squares	Df	Mean Square	F	P
Date	932.583	2	466.292	4.590	0.014
Distance	63.000	2	31.500	0.310	0.734
Date * distance	137.667	4	34.417	0.339	0.851
Error	6399.625	63	101.581		
Total	26643.000	72			

B. Abundance

Source	Sum of Squares	Df	Mean Square	F	P
Date	129.104	2	64.552	3.874	0.026
Distance	0.487	2	0.244	0.015	0.985
Date * distance	11.258	4	2.814	0.169	0.953
Error	1049.673	63	16.661		
Total	4806.000	72			

C. Shannon Index

Source	Sum of Squares	Df	Mean Square	F	P
Date	2.422	2	1.211	4.428	0.016
Distance	0.274	2	0.137	0.501	0.608
Date * distance	1.083	4	0.271	0.990	0.420
Error	17.232	63	0.274		
Total	367.444	72			

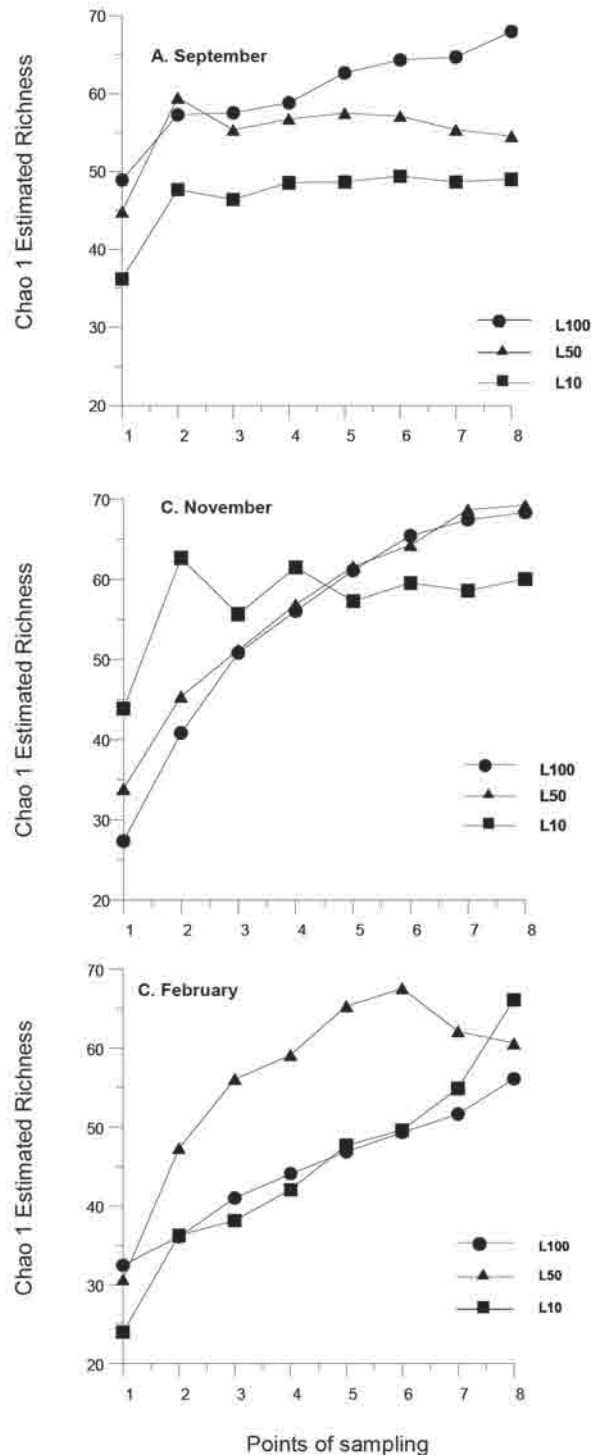


Figure 4 Accumulation curves of Chao1 estimates of dung beetle species richness for each transect (L10, L50, L100) and each sampling date (A: 1 month, B: 3 months and C: 6 months after road opening). Capture units express total sampling effort at one site. Each curve represents 500 randomizations using the program EstimateS (Colwell 2006).

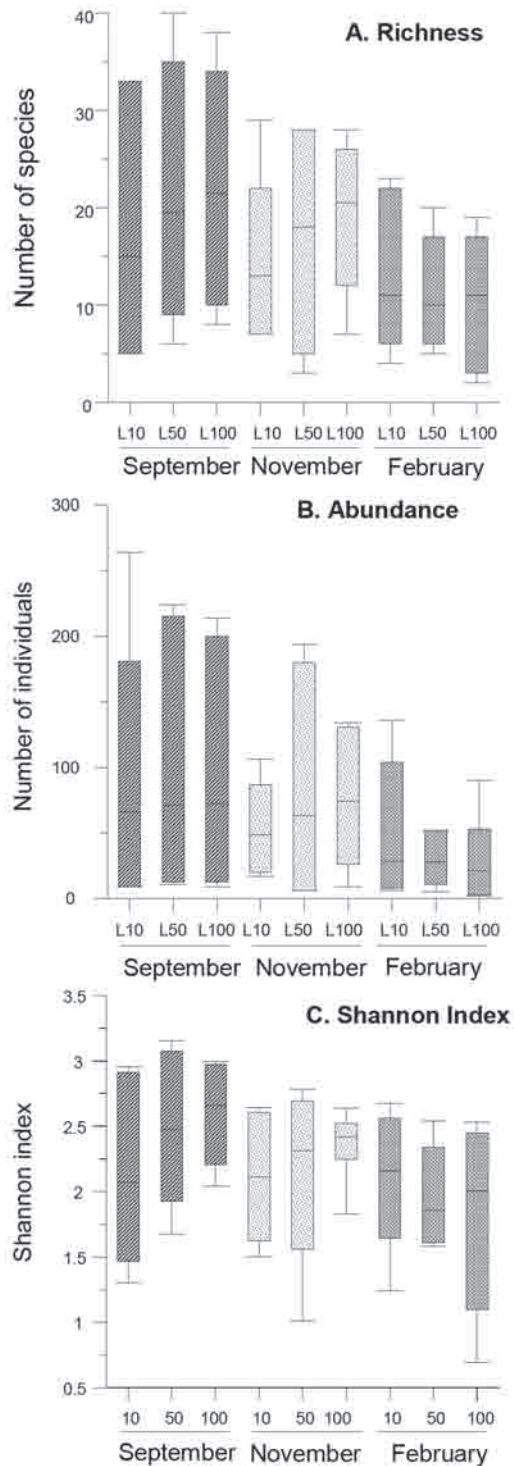


Figure 5
Impact of road construction on the dung beetle community richness (A), abundance (B), and Shannon Index (C) at three distances from the road (L10, L50 and L100), during the study period from 1 to 6 months after road opening. For box-whisker plots, the outer edges of the box define the interquartile range, the center line is the median and the bars indicate 1.5 times the interquartile range.

Canthonini, Dichotomiini, Onthophagini, and Phanaeini) of Scarabaeinae, were recorded over the study period, 432 trap-days (see Figure 3 and Appendix 1). Six species (*Canthon aequinoctialis*, *C. luteicollis*, *Dichotomius fortistriatus*, *Eurysternus caribaeus*, *E. confusus* and *Onthophagus haematopus*) accounted for 55% of all individuals collected. The species accumulation curves accounted for 83.4 % of the variance in sampling performance at all sites ($P < 0.001$, fig. 4). We estimated that we collected 93.5 % of the true species richness.

Box-whisker plots of species diversity, abundance and Shannon index at the trap level revealed large inter-trap variability for these parameters at the three sampling dates (fig. 5). Median species richness values ranged from 10 (L50, 6 months) to 22 species (L100, 1 month) per trap. Median abundance values ranged from 22 (L100, 6 months) to 75 individuals (L100, 1 month) per trap. Both species richness and abundance tended to decrease during the 6 months after road opening. We found that at the trap level, patterns of species density, abundance, and Shannon index varied significantly from beginning to later in the rainy season (two-way ANOVA, $F > 3.8$, $p < 0.005$, Table 1), but not with the distance from the road (two-way ANOVA, $F < 0.51$, $p > 0.6$, Table 1) or the interaction term (two-way ANOVA, $F < 1.0$, $p > 0.4$, Table 1). One month after road opening, species accumulation curves showed differences in total richness between the three distances with a gradual increase in estimated richness when going further from the road (fig. 4A). However, this pattern was not observed in the two other sampling dates (fig. 4B, C). As a general pattern, the diversity of rare taxa was generally higher in L50 and L100 than in

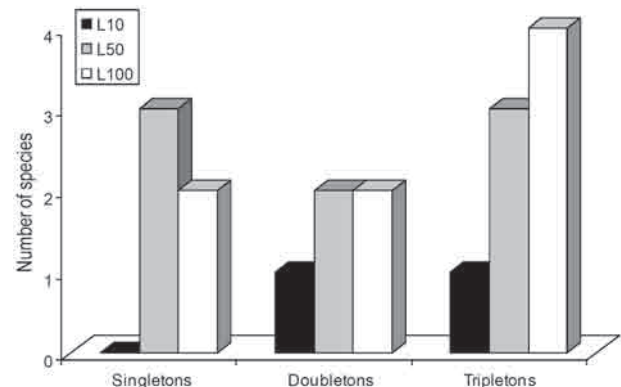


Figure 6
Total number of rare dung beetle species (singletons, doubletons, tripletons) found at the three distances from the road (L10, L50, L100) over the study period (from 1 to 6 month after road opening).

L10 (fig. 6). Eleven (*Bdelyrus* sp. 1, *Canthidium* sp. 1, *Canthidium* sp. 8, *Canthon* sp. 2, *Deltochilum orbiculare*, *Deltochilum* sp. 3, *Malagoniella astyanax*, *Onthophagus* sp. 7, *Scatimus strandi*, *Scatimus* sp. 2, *Trichilum* sp. 1) out of the 13 rare species/morphospecies found over the study period, were absent in the transect located 10 m from the road.

Community composition and biomass

The NMDS analysis revealed clear differences in dung beetle community composition (both richness and abundance) among the three sampling periods (fig. 7A and C). Stress was low (0.01) indicating a high degree of fit. The ANOSIM significantly separated

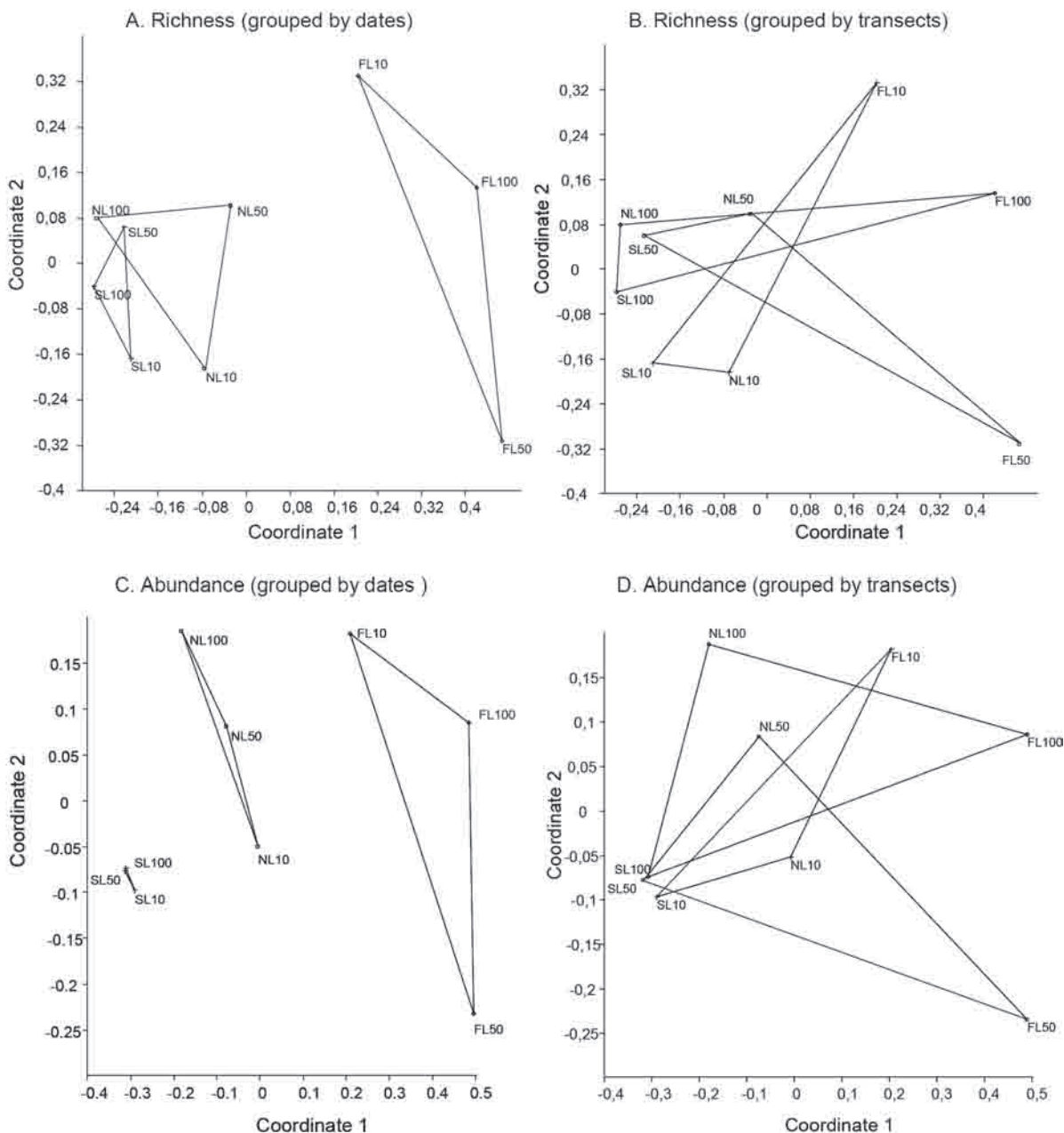


Figure 7
 Nonmetric multidimensional scaling (NMDS) analysis of dung beetle communities (A-B richness, C-D abundance) at the three distances from the road (L10, L50, and L100) and the three sampling dates after road opening (1 month, 3 month, 5 months). Triangles show the convex hull (smallest convex polygon containing all points) in each group (A-C sampling date, B-D sampling distance). S: September, N: November, F: February.

the three different sampling periods presented in the NMDS (ANOSIM, $R = 0.44$; $p = 0.023$ for richness, $R = 0.66$, $p = 0.004$ for abundance; see convex hulls in Figure 7A and C). Contrastingly, the NMDS showed no significant differences in community composition (both richness and abundance) among transects lines (ANOSIM, $|R| < 0.2$, $p > 0.900$, fig. 7B and D). Despite the absence of significant differences for the whole dung beetle communities between transect lines, SIMPER analysis indicated that several changes occurred for some species (Table 2). Of the 22 most discriminatory dung beetle species among transects, 5 species (*Sylvicanthon bridarollii*, *Canthidium* sp. 2, *C.* sp. 6, *C.* sp. 7, *Ontherus diabolicus*) were gradually more abundant when getting further from the road (Table 2). On the contrary 6 species (*Eurysternus hamaticollis*, *E. velutinus*, *E. confusus*, *E. caribaeus*, *Deltochilum obenbergeri*, *D. orbiculare*,) increased in abundance in the transect next to the road (Table 2).

Community analyses based upon species abundance and estimated species biomass data produced superficially similar patterns between transects (fig. 8, see also fig. 3 for a visualization of some differences

in size among species). In all cases both large- and intermediate-bodied species contributed the most to patterns based on biomass and abundance data (see the top right corner of each panel). However, these patterns were driven by distinct sets of species. Whereas the top 3 weighted species (*Canthon aequinoctialis*, *Dichotomius fortetristatus*, and *Onthophagus haematopus*) were the same in all transects, they accounted for 47.5% of total estimated biomass at L100 and only for 31.3 % and 29.2% at L50 and L10, respectively. In particular, total estimated biomass of *Dichotomius fortetristatus* decreased by 64% between L100 and L10.

Discussion

Dung beetle diversity and composition in the Ecuadorian Amazon

The total number of species found in the study area ($n = 69$) was within the range of dung beetle diversity recorded in other Amazonian regions: 60 species in Leticia, Colombia (Howden & Nealis 1975); 74 species in Tambopata (Spector & Forsyth 1998), Peru and 97 species in Parque Nacional Noel Kempff,

Table 2. Results of SIMPER analysis for 22 dung beetle species at three transect lines (L10, L50 and L100).

Log-transformed abundance data provide the percent contribution of each species to average dissimilarity between the three transects. Only species that contributed up to a total of 50% to the separation of transects are listed. Arrows indicate the trend in species abundance with increasing distance from the road.

Taxon	Contribution	Cumulative %	L10	L50	L100	Trend
<i>Canthidium</i> sp. 4	1	5	1.55	2.07	1.34	
<i>Sylvicanthon bridarollii</i>	0.82	9	1.19	1.5	1.84	↑
<i>Phanaeus chalcomelas</i>	0.75	12.06	2.71	1.36	1.73	
<i>Canthidium</i> sp. 7	0.72	14.57	1.32	1.44	1.87	↑
<i>Eurysternus hamaticollis</i>	0.72	17.06	2.78	2.51	1.99	↓
<i>Eurysternus velutinus</i>	0.71	19.52	3.4	2.93	2.07	↓
<i>Onthophagus</i> sp. 5	0.70	21.93	1.39	0.462	1.3	
<i>Dichotomius lucasi</i>	0.69	24.32	2.73	2.83	1.99	
<i>Ateuchus murrayi</i>	0.68	26.7	1.43	0.732	1.17	
<i>Eurysternus confusus</i>	0.66	29	4.04	3.37	2.72	↓
<i>Deltochilum obenbergeri</i>	0.61	31.12	3.22	3.12	2.14	↓
<i>Canthidium</i> sp. 6	0.58	33.14	0.693	1.26	1.36	↑
<i>Oxysternon conspicillatum</i>	0.56	35.08	2	2.59	2.49	
<i>Ontherus diabolicus</i>	0.55	37	0.903	1.73	2.16	↑
<i>Onthophagus</i> sp. 6	0.54	38.88	0.366	1.23	0.903	
<i>Deltochilum orbiculare</i>	0.52	40.67	0.924	0.462	0	↓
<i>Onthophagus</i> sp. 1	0.51	42.46	0.903	0.999	0.88	
<i>Canthidium</i> sp. 2	0.48	44.14	0.597	0.999	1.34	↑
<i>Eurysternus caribaeus</i>	0.48	45.8	3.42	3.36	3.04	↓
<i>Canthidium haroldi</i>	0.48	47.46	0.924	0.462	0.999	
<i>Dichotomius ohausi</i>	0.47	49.12	2.82	2.05	2.39	
<i>Uroxys</i> sp. 1	0.47	50.75	0.231	1.06	0.903	

Bolivia (Forsyth *et al.* 1998). Dung beetle species richness and abundance were variable among samples (fig. 5), a feature that was also reported by Radtke *et al.* (2007) in the Ecuadorian Amazon. Both richness and abundance significantly decreased from one to six months after road opening for the three transects, which is probably due to slightly more rainy conditions in the second part of the survey. Rain, temperature, and seasonal conditions in general can greatly influence dung beetle populations, causing surges and declines of particular species from one week to the next (Hanski & Cambefort 1991).

Impact of road construction on dung beetle communities

Although habitat edges can have profound effects on the spatial distribution of many species (e.g. Lovejoy *et al.* 1986, Murcia 1995, Ries *et al.* 2004, Laurance *et al.* 2007) including beetles (Ewers & Didham 2008), our study provides no clear evidence of short term impact of road opening on dung beetle communities in Chiruisla. In general, diversity, abundance and community composition did not differ significantly among transects located at various distance from the road. Potential explanations for the lack of an impact of the road on dung beetle populations concerns the limited width of the road (10 m) and the absence of further clear-cuts by colonizing people, as access to Chiruisla is controlled by the oil company. Dunn & Danoff-Burg (2007) found that the most important effect of roads on carrion beetle assemblages appeared to be due to road width rather than road type (paved or dirt). A parallel study on the impact of road construction on vegetation revealed that in areas that were not directly disturbed during construction, the road had little effect on the original vegetation composition (J. Jaramillo comm. pers.). This explanation would agree with Halffter & Arellano (2002) who showed that tree cover was the most influential factor determining dung beetle community composition in the neotropics.

Another explanation could be that we did not sample deep enough into the rainforest to get much

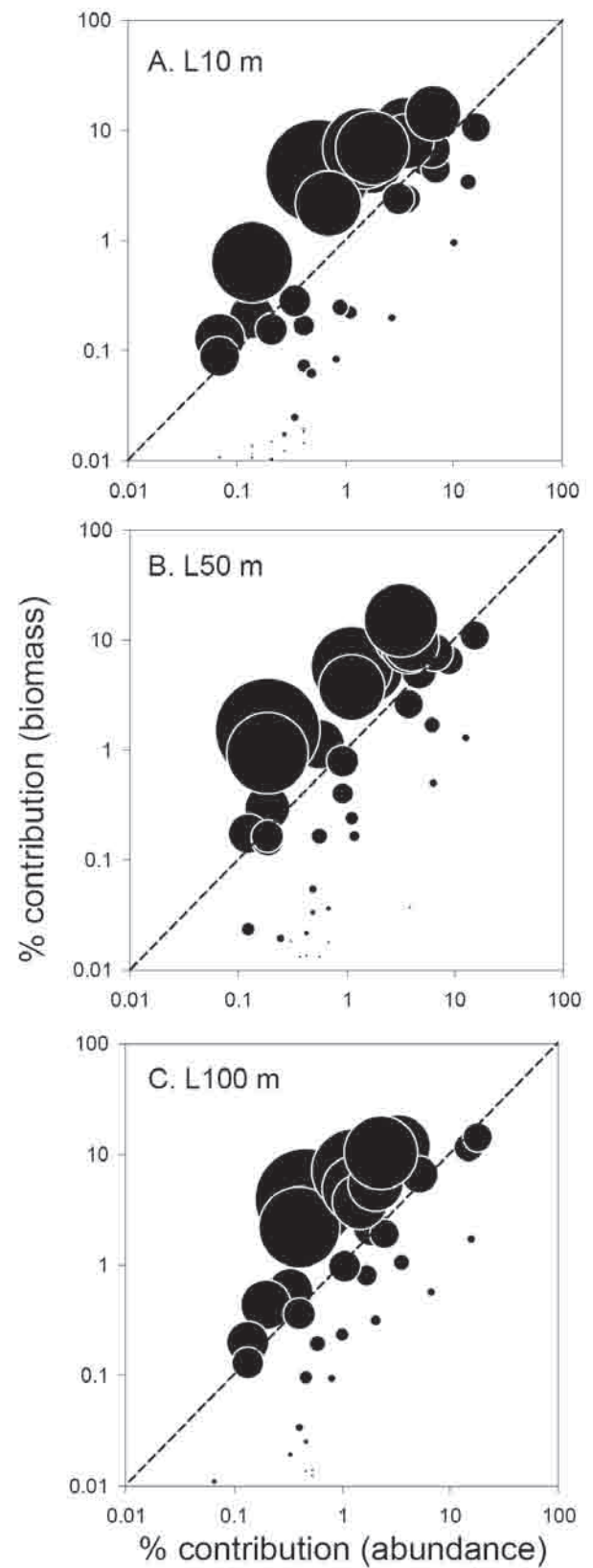


Figure 8

Percentage contributions, based separately on abundance and biomass data, of individual dung beetle species at the three distances from the road (L10, L50, L100) over the study period (from 1 to 6 months after road opening). Species are represented by black circles, which are scaled by differences in average body mass. Both axes are log-transformed so the species in the top right corner of each panel contribute the most towards the patterns. The diagonal dashed line identifies the position of species that contribute equal weights to analyses based on both data sets. Large-bodied species clearly contributed the most to patterns based on biomass data.

beyond the edge effects, or that our sampling effort was not sufficient (see the spatial extent in the study by Dunn & Danoff-Burg 2007 on carrion beetles). The great olfactory powers of dung beetles in locating feces may also have obscure local population differences over 100 m distances. In a large scale study in the Southern Alps in New Zealand, Ewers & Didham (2008) found that beetle communities differed in species richness and composition from the deep forest interior up to 1 km inside forest. The edge effects recorded in the study were much stronger than in our case, making this explanation improbable.

Theoretically we would have expected opposite responses of dung and carrion beetle community to the road, the former being negatively affected by the road while the later being attracted by the carrion produced by the road. However, additional analyses revealed no significant differences between these two guilds at the community level, in their response to road construction. Dung beetle richness and abundance were rather constant among transects, ranging from 42–44 species and 480–580 individuals, respectively. Carrion beetles varied from 14–20 taxa and 50–58 individuals depending on date and transects, but with no evident increase when getting closer to the road. For the two guilds, NMDS analyses revealed no differences among transects on both species richness and abundance ($R < 0.2$, $P > 0.67$).

Our analyses revealed two signs of potential effects by road opening. First the number of rare species was greatly reduced in the transect nearest to the road, through time. Rare taxa have proven to be useful indicators of human disturbance (Hecnar & M'closkey 1996, Maurer *et al.*, 1999). Because rare species by definition represent a small number of individuals, sampling for them requires extensive field work to generate well-supported conclusions. Second the estimated biomass of the three dominant dung beetle species decreased with distance to the road. This pattern was mainly due the decrease in abundance of only one species, the two other large-bodied species showed no similar trend. Dung beetle biomass response to perturbation is however debated. On one hand, larger insect species may be more susceptible to local extinction in disturbed areas because they usually have more stochastic population dynamics (Baumgartner 1998). Alternatively, microclimate conditions are likely to be altered at forest edges (e.g. increasing temperature extremes and moisture loss, Williams-Linera *et al.* 1998) and larger body size may confer greater resistance to desiccation (see Grimbacher *et al.* 2008 for a discussion).

Insights for planning environmental studies in Ecuador

The Amazon region exhibits exceptionally high biodiversity (Myers *et al.* 2000), which makes capacity building for environmental governance in the region particularly important. In this context the search for relevant bioindicators of the degree of human disturbance is a priority for all developing nations that contain Amazon forest. Our study gave poor support for the use of dung beetles as indicators of short term-response (from 1 to 6 months) to road construction. However, although road construction might not negatively affect dung beetle diversity and abundance in microlandscapes over short time scales, these conclusions cannot be extrapolated directly to the much larger scales of landscapes and decades (see the MAP initiative concerning the inter-oceanic highway in the Southwestern Amazon ([http://www.map-amazonia.net./](http://www.map-amazonia.net/)) for further discussion; Perz *et al.* 2008). For example, a study of road impacts on a cloud forest in Puerto Rico 35 years after opening, showed that although there was limited impact on vegetation structure and composition, the recovery of soil resource levels to those of mature forests was extremely slow (Olander *et al.* 1998). After opening, roads foster access to natural resources and facilitate market access for rural producers, which in turn may generate habitat fragmentation and degradation (Perz *et al.* 2008). Developing a sustainable plan for road corridors in the Amazon would require long-term programs proceeded by coordinated data collection and long-term monitoring. This would allow formulation of likely scenarios of long-term road impact, which then could serve as a basis for participatory planning not only with government agencies at national, provincial, and local levels but also with local communities.

Finally, to conclude this last article of the special session of “*Entomology in Ecuador*”, we would like to stress that, in the light of this study, appropriate environmental assessment requires a good taxonomic basis. Limitations in taxonomy expertise represent a great challenge for the use of dung beetles as bioindicators in the megadiverse rainforest of the Ecuadorian Amazon. Further studies should reveal whether coarser taxonomic data or data on particular dung beetle taxa could be used to detect ecosystem changes with sensitivity. However, in a study on tropical beetles, Grimbacher *et al.* (2008) showed that species data had the greatest sensitivity to environmental change and cautioned against the use of higher taxonomic levels as a standard procedure for the study of environmental change in invertebrate assemblages. Investing resources in insect taxonomy likely represents a critical requirement for measuring the

conservation status of highly endangered Neotropical ecosystems.

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Appendix 1.

List of total number of individuals of the dung beetle (Coleoptera: Scarabeinae) species and morpho-species captured in excrement- and tuna fish-baited pitfall traps during the study period (1 month, 3 month and 6 months after road building).

Tribes	Species	Sept 2005	Nov 2005	Feb 2006	
Ateuchini	<i>Ateuchus murrayi</i> (Harold 1868)	26	5	1	
	<i>Ateuchus scatimoides</i> (Balthasar 1939)	15	4	3	
	<i>Ateuchus</i> sp.1	5	10	0	
	<i>Ateuchus</i> sp.2	9	3	2	
	<i>Ateuchus</i> sp.3	3	3	0	
	<i>Canthidium haroldi</i> (Preudhomme de Borre 1886)	5	7	3	
	<i>Canthidium</i> sp.1	0	1	0	
	<i>Canthidium</i> sp.2	12	6	2	
	<i>Canthidium</i> sp.3	9	2	0	
	<i>Canthidium</i> sp.4	107	12	0	
	<i>Canthidium</i> sp.5	10	2	0	
	<i>Canthidium</i> sp.6	22	5	2	
	<i>Canthidium</i> sp.7	49	8	3	
	<i>Canthidium</i> sp.8	3	0	0	
	<i>Trichilum</i> sp.1	0	0	2	
	<i>Uroxys</i> sp.1	2	6	5	
	Canthonini	<i>Canthon aequinoctialis</i> (Harold 1868)	248	278	180
		<i>Canthon luteicollis</i> (Erichson 1847)	153	78	12
		<i>Canthon brunneus</i> (Schmidt 1922)	2	1	1
<i>Canthon</i> sp.1		5	3	1	
<i>Canthon</i> sp.2		0	1	0	
<i>Deltochilum carinatum</i> (Westwood 1837)		9	2	2	
<i>Deltochilum amazonicum</i> (Bates 1887)		3	6	9	
<i>Deltochilum orbiculare</i> (Lansberge 1874)		0	1	10	
<i>Deltochilum obenbergeri</i> (Balthasar 1939)		95	65	25	
<i>Deltochilum</i> sp.1		8	1	2	
<i>Deltochilum</i> sp.2		1	2	2	
<i>Deltochilum</i> sp.3		19	21	12	
<i>Malagoniella astyanax</i> (Olivier 1789)		0	0	1	
<i>Sinapisoma</i> sp.1		0	0	3	
<i>Scybalocanthon</i> sp.1		20	3	9	
<i>Scybalocanthon pygidialis</i> (Schmidt 1922)		3	0	0	
<i>Sylvicanthon bridarollii</i> (Martinez 1949)		21	36	2	
<i>Sylvicanthon</i> sp. 1		0	4	3	
Dichotomiini		<i>Bdeleyrus</i> sp.1	0	1	0
	<i>Dichotomius fortistriatus</i> (Luederwaldt 1923)	210	201	115	
	<i>Dichotomius globulus</i> (Felsche 1901)	5	2	5	
	<i>Dichotomius lucasi</i>	112	18	27	
	<i>Dichotomius prietoi</i> (Martínez & Martínez 1982)	29	15	14	
	<i>Dichotomius mamillatus</i> (Felsche 1901)	80	45	35	
	<i>Dichotomius ohausi</i> (Luederwaldt 1922)	63	26	25	
	<i>Dichotomius</i> sp.1	20	19	9	
	<i>Ontherus diabolicus</i> (Genier 1996)	26	15	7	
	<i>Scatimus strandi</i> (Balthasar 1939)	0	4	0	
	<i>Scatimus</i> sp.1	2	5	0	
	<i>Scatimus</i> sp.2	1	0	1	
	Eurysternini	<i>Eurysternus caribaeus</i> (Herbst 1789)	152	74	51
		<i>Eurysternus confusus</i> (Jessop 1985)	194	105	50
		<i>Eurysternus hamaticollis</i> (Balthasar 1939)	78	42	15
<i>Eurysternus inflexus</i> (Germar 1824)		8	1	0	
<i>Eurysternus vastiorum</i> (Martinez 1988)		10	2	1	
<i>Eurysternus velutinus</i> (Bates 1887)		103	51	38	
Onthophagini		<i>Onthophagus haematopus</i> (Harold 1875)	219	282	89
	<i>Onthophagus acuminatus</i> (Harold 1880)	5	12	3	
	<i>Onthophagus</i> sp.1	14	6	0	
	<i>Onthophagus</i> sp.2	6	9	3	
	<i>Onthophagus</i> sp.3	10	8	4	
	<i>Onthophagus</i> sp.4	19	11	0	
	<i>Onthophagus</i> sp.5	15	2	2	
	<i>Onthophagus</i> sp.6	1	1	0	
	<i>Onthophagus</i> sp.7	1	0	0	
	<i>Onthophagus</i> sp.8	2	1	1	
	<i>Onthophagus</i> sp.9	3	2	4	
	<i>Onthophagus</i> sp.10	11	7	1	
	Phanaeini	<i>Coprophanaeus telamon</i> (Erichson 1847)	23	40	22
<i>Coprophanaeus callegarii</i> (Arnaud 2002)		1	7	2	
<i>Oxysternon conspicillatum</i> (Weber 1801)		63	33	15	
<i>Oxysternon silenus</i> (Castelnau 1840)		8	2	0	
<i>Phanaeus chalconelas</i> (Perty 1830)		26	40	10	