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ORIGINAL RESEARCH ARTICLE

Comparative effect of forest cutting and mammal hunting on dung beetle assemblages in Chocó Biogeographic forests in Colombia

J. P. Correa-Cuadros[1,2] · A. Gómez-Cifuentes[3] · J. A. Noriega[4]

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Abstract
Anthropic activities usually affect the diversity, structure, and functionality of communities. The tropical rain forests from Chocó Biogeographic in Colombia are one of the world's biodiversity hotspots. However, very few studies evaluate the impact of anthropic activities on areas surrounding human populations. The structure of dung beetle assemblages was studied to compare a forest exposed to hunting activities (FH) and a forest intervened by cutting and thinning trees (FC). Two samplings were carried out in March and October 2009 using 64 pitfall traps distributed in four transects. We captured 678 individuals belonging to 18 species and nine genera. FH had 227 individuals and 12 species, and FC had 451 individuals and 16 species. The diversity index did not show statistical differences in the dung beetle assemblages between forests. Also, diversity profiles did not present differences between forests by richness (q0) and abundance (q1 and q2). Both forests shared the same species (ANOSIM: $p < 0.01$), while FH showed a lower dissimilarity in the species composition (ANOVA: $F = 9.83$). FH showed an absence of several species and the loss of some functional traits. FC has three times more roller beetles and almost twice as many small-medium tunneller beetles than FH, while there was a critical absence of large species in both forests. In conclusion, our results showed that hunting and cutting disturbances in these forests could similarly impact dung beetles' diversity and functional structure. However, it is important to continue evaluating the anthropogenic effect on nearby forests to establish conservation strategies for dung beetles.

Keywords Anthropic disturbance · Bioindicators · Functional groups · Intermediate disturbance hypothesis · Dung beetles

Introduction

Biodiversity is affected negatively by anthropic disturbances such as agricultural expansion, livestock, or mining frontiers, generating a reduction in species richness, abundance, biomass, functional groups, and their composition (Braga et al. 2013; Kenyon et al. 2016; Cardoso et al. 2020). The Chocó Biogeographic in Colombia is one of the most important hotspots worldwide, with the highest species richness per square meter, making it relevant to conservation measures and policies (Myers et al. 2000; Jha and Bawa 2006; Hrdina and Romporti 2017). Chocó has a high affinity with Central America, sharing several species and becoming a biological corridor into South America (Hernández et al. 1992). Still, Chocó is one of the most under-sampled areas with very few published works (Neita et al. 2003; Pardo-Locarno 2007; Arias-Buriticá et al. 2011; Neita-Moreno 2011; Neita and Escobar 2012; Davies et al. 2020).

Chocó Biogeographic has been affected by anthropic disturbance for a long time, but the hotspot has few evaluations of the impact of the anthropic disturbances on its fauna and flora assemblages (Mittermeier et al. 2011; Davies et al. 2020). Forest areas have two critical disturbances: i) cutting down and thinning of trees, and ii) hunting of large mammals (Nichols et al. 2007; Andresen and Laurence 2007; Gardner

✉ J. A. Noriega
jnorieg@hotmail.com

J. P. Correa-Cuadros
jpcorrea4@uc.cl

A. Gómez-Cifuentes
agomezc33@gmail.com

1 Biological Science Faculty, Ecology Department, Pontificia Universidad Católica de Chile, Santiago, Chile

2 Center of Applied Ecology and Sustainability (CAPES), Santiago, Chile

3 Institute of Subtropical Biology (IBS), Universidad Nacional de Misiones -CONICET, Puerto Iguazú, Misiones, Argentina

4 Laboratory of Zoology and Aquatic Ecology - LAZOEA, University of Los Andes, Bogotá, Colombia

et al. 2008; Culot et al. 2013; França et al. 2018). Deforestation affects the function and structure of the ecosystems and causes the loss of their services (Mosquera-Andrade 2014; Noriega et al. 2021). Chocó lost 29.951 hectares of forest at a loss rate of 0,003% per year between 1990 and 2010 (González et al. 2011). In 20 years, it went from having 3.412.441 hectares to 3.382.490 hectares. Then, Chocó has the largest deforested area corresponding to 18% of the national total. For example, Acandí, a municipality in the Chocó area, lost 1.240 hectares of humid primary forest cover from 2000 to 2019, equivalent to a 2,9% decrease in tree cover (Global Forest Watch 2020). Likewise, hunting large mammals could have a negative effect in food webs and their ecosystems because mammal disappearance could change the abundance and distribution of other species (Barbar and Lambertucci 2018).

One of the most relevant insect groups to evaluate the ecological services and human impacts is the dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae), which feed mainly on vertebrate excrements (omnivores and herbivores) and play a crucial role in ecosystems as recyclers of manure, nutrient cycling processes, secondary dispersal of seeds, control of fly and nematode populations, and improving soil conditions (Nichols et al. 2007; Slade et al. 2011; Nervo et al. 2017; Noriega et al. 2021). Usually, dung beetles are used to carry out biodiversity, conservation, and environmental impact studies due to their well-known biology, presence in a wide variety of habitats, well-known taxonomy, short generational cycles, and high sensitivity to anthropogenic disturbances due to high specificity of habitat (Halffter and Favila 1993; McGeoch et al. 2002; Spector 2006; Nichols et al. 2007; Noriega et al. 2007; Nichols et al. 2009; Otavo et al. 2013; Manning et al. 2016). Globally, there are approximately 8000 species and 300 genera, while in Colombia, there are 305 species of 40 genera (Noriega et al. 2015; Schoolmeesters 2020). However, the state of knowledge of this group in Colombia is not complete, and several regions of the country need local and regional studies, such as the Chocó Biogeographic (Noriega et al. 2015).

The disturbance of forests affects the diversity of dung beetle, which could severely affect their ecological processes. Deforestation affects the canopy cover that regulates extreme temperatures and humidity conditions, which could modulate the flight of dung beetles and change the dung paths altering the beetle's behaviour (Gómez et al. 2018). Likewise, the microclimatic conditions could affect the dung beetle activity because they are highly sensitive to physiological restrictions (Verdú and Lobo 2008; Dortel et al. 2013). For example, tree shade reduces excrement desiccation, keeping the interior fresh for long periods and thus improving its quality (Lobo et al. 1988; Gill 1991; Louzada and Carvalho e Silva 2009; Cardinale et al. 2012; Laurance et al. 2014). Another forest disturbance is hunting some mammals because the human population considers them dangerous for them or their subsistence resources (Rodríguez-Mahecha et al. 2008). The changes in their composition could affect the trophic guild of dung beetles because they are closely associated with these vertebrates by feeding on their faeces (Rodríguez-Mahecha et al. 2008).

Based on the above, we evaluate the anthropic disturbance effect on the taxonomic and functional diversity of dung beetle assemblages in the Chocó Biogeographic of Colombia. This study assessed patterns of taxonomic and functional diversity of dung beetles among two forests in Chocó, providing information on their diversity, functional groups, traits, and the anthropic perturbation impact on dung beetles. We compared a forest with cutting and thinning trees and a forest with hunting activities. We hypothesize that the cutting and thinning of trees disturbance affects the diversity and functional structure of dung beetles more than a forest with hunting activities. This first disturbance modifies the vegetation cover, niches, habitats, microclimates, and fauna diversity on a higher level compared to hunting activities.

Materials and methods

Study area

The fieldwork was carried out in Capurganá in the municipality of Acandí, department of Chocó, Colombia, located in the Gulf of Urabá near the Atrato River and the Caribbean Sea (8°37'N–77°21'W, 90 m a.s.l.; Fig. 1). Capurganá has a mean annual temperature of 27° C and 2296 mm of annual precipitation. The primary ecosystem is a tropical moist forest with bimodal weather (April and October are the wettest months) (García-Valencia 2007). Soil types are inceptisol, entisol, alfisol, and vertisol with clay-dominated texture, deep and well-drained (IGAC 2004). We selected two forests with different anthropic interventions: i) a forest in a regeneration process after an effect of cutting and thinning trees in the last 20 years (FC) and ii) a forest used as a source of illegal hunting activities (FH) to analyse the anthropic effect on dung beetle assemblages. We tried to sample a primary forest as a control in our design, but it was impossible to find a forest without any anthropic disturbance. All the forest in the region has suffered from anthropogenic disturbance processes at different scales, from ancestral hunting and thinning to total forest clearing.

Dung beetles sampling

Two samplings were carried out corresponding to March and October of 2009 to collect dung beetle species in dry (March) and wet (October) seasons. Each season, four parallel transects (separated by 150 m) were located (FC and FH).

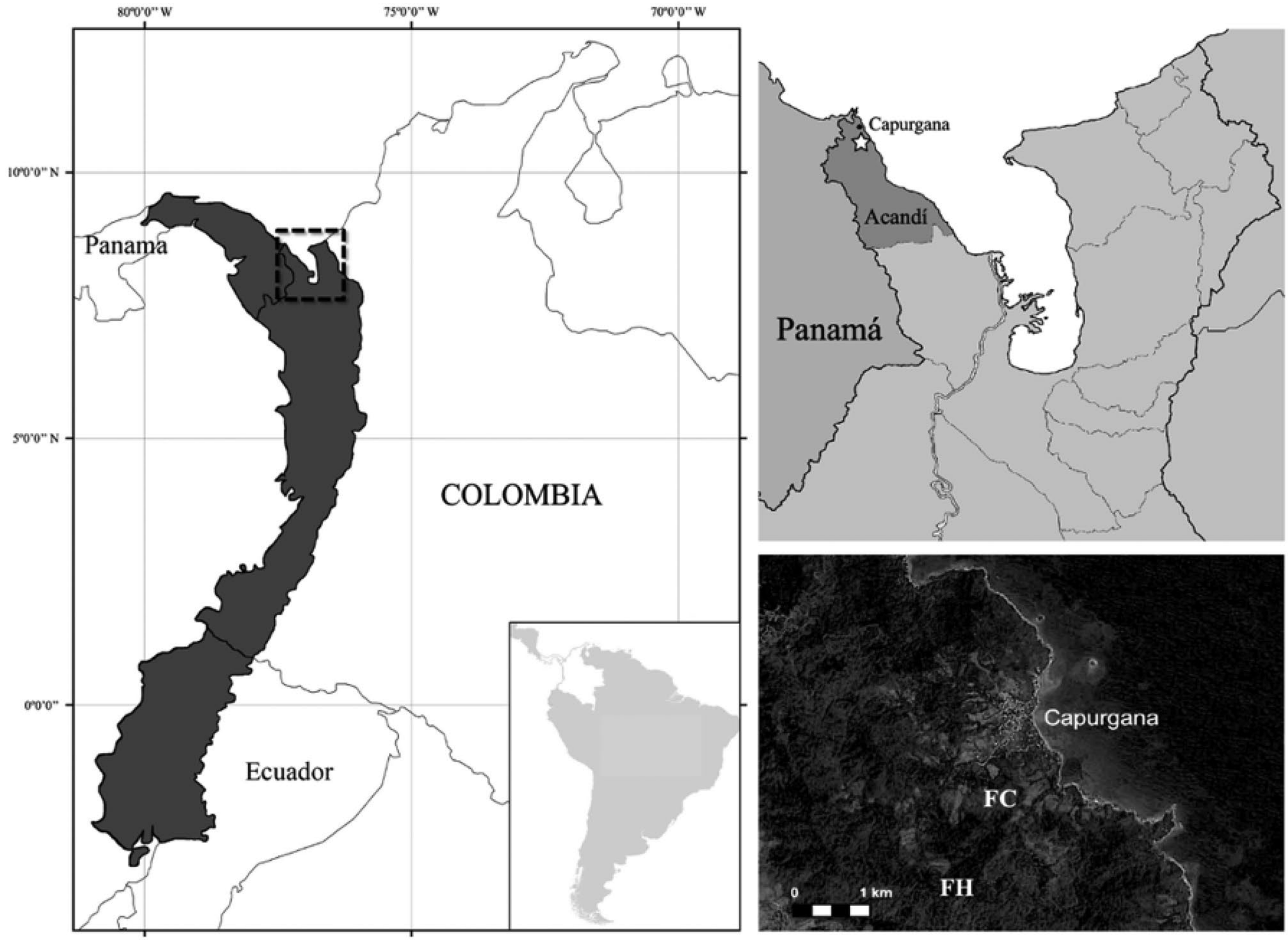

Fig. 1 Location of the forest with hunting (FH) and forest with cutting (FC) in the strip of the Chocó Biogeographic region (Panamá, Colombia, and Ecuador), department of Chocó in the vicinity of Capurganá

Transects (replicates) had four pitfalls installed 50 m from each other and baited with fresh human excrement (30 g) in each ecosystem to be the most effective resources to attract dung beetles in Colombia (Lobo et al. 1988; Gill 1991; Noriega and Fagua 2009; Bourg et al. 2016). Pitfall traps (64 total traps, sample unit) consisted of a plastic container (12 cm in diameter and depth) filled with a preservative solution (water, salt, and detergent) to prevent dung beetles from decomposing (Beiroz et al. 2018). After collecting the samples, this solution was changed by alcohol 75%. The traps remained active for 72 h. The collected specimens were identified at the species level using different taxonomic keys (Howden and Young 1981; Kohlmann 1997; Kohlmann and Solis 1997, 2001, 2006; González et al. 2009; Camero 2010; Vaz-de-Mello et al. 2011), the comparison with material from collections, and the help of experts in some groups. Specimens were deposited in the Pontificia Universidad Javeriana (Colombia)'s entomological collection with respective labels, mentioning the collection place, date, type of trap, and identified species.

Estimation of ecological and functional diversity

We performed sampling completeness analysis to evaluate the efficiency of the sampling effort and the representation of dung beetle assemblages in each forest (FH and FC). The analysis compared the sampling sites, considering the number of missing species, their average abundances, and detailed and "fair" inferences about the sampled assemblages (Moreno 2001). We carried out diversity profiles of order q, based on the Hill series, to describe and compare the taxonomic diversity of dung beetle between the hunting forest (FH) and the cutting forest (FC) (Hill 1973). Diversity profiles represent the number of species (q0, richness) and the number of equally common species weighted by their relative abundance (q1: rare and common species and q2: dominant species) (Moreno et al. 2011).

The functional diversity of dung beetles was estimated by combining different traits into functional groups related to several ecosystem services such as burial activity, secondary seed dispersal, and nutrient cycling. Those functional traits

(Petchey et al. 2009) were the food relocation strategy (tunneller, roller, and dweller species) and the beetle size (small, medium, and large species) (Doube 1990). Food relocation strategies were obtained from previous studies (Halffter and Edmonds 1982; Doube 1990; Hanski and Cambefort 1991). The average beetle body size was measured as the total length from the external border of the clypeus to the pygidium for each species, and they were assigned to three size categories: small (< 10 mm), medium (10–18 mm), and large (> 18 mm).

Data analysis

Simpson (D) and Shannon–Wiener (H) indices were estimated in a matrix of species captured in each forest (FC and FH). The Simpson index established the probability that two individuals are drawn randomly from a sample to the same species, considering the best-represented species. The Shannon–Wiener index assumes that all species are in the samples and indicates the species distribution's uniformity (evenness), number of species (richness), and the relative number of individuals (abundance) (Moreno et al. 2011; Majeed et al. 2020; Ramzan et al. 2021). Simpson and Shannon–Wiener indexes were compared through a chi-square test (X^2). We used the BioDiversity Pro program for indices and EstimateS (Colwell 2013) to estimate each forest's species accumulation curves.

The diversity profiles were compared through overlapping confidence intervals (5–95%) (Hill series: q0, q1 and q2). The C.hat and alpha diversity were estimated using the R-based interactive online version of the software iNEXT (Chao et al. 2016). Beta diversity components were evaluated using the indices βsim (Simpson dissimilarity–spatial turnover), βnes (nestedness dissimilarity), and βsor (Sorensen dissimilarity–total Beta diversity) performed within forest sites, employing pair.beta function of the betapart package (Baselga et al. 2018). The dissimilarity measures were additive fractions (βsor = βsim + βnes), and the indices values were compared through Anova and DGC (Di Rienzo, Guzmán, Casanoves). Non-metric multidimensional scaling analysis (NMDS) was used to explore the species composition, using the isoMDS function in the MASS package (Venables and Ripley 2002). We also use ANOSIM to test differences in species composition based on the NMDS analysis. Finally, the HDS.test function was used from the agricolae package for the posthoc comparisons because of controlled type I error (Di Rienzo et al. 2002; Mendiburu 2017).

Functional diversity was evaluated using the functional traits of dung beetles: i) grouping species into functional groups, and ii) comparing the total and proportional abundance of each functional trait. In the first case, a dissimilarity analysis was performed to group species into functional groups using the Gower distance with the gower.dist function of StatMatch package (D'Orazio 2019). This measure computes the distances between pairs of variables over two data sets and combines those distances into a single value. In the second case, the total abundance of each functional trait was compared by the Kruskal–Wallis test using the posthoc.kruskal.nemenyi from the PMCMR package (Pohlert 2014). The proportional abundance of functional traits of each forest (FH and FC) was compared using the Friedman test (friedman.test) from the stats package (R Core Team 2018). Statistical analyses were performed using R software (R Core Team 2018).

Results

A total of 678 individuals belonging to 18 species and nine genera were collected (Table 1). The estimator of sampling coverage showed that sampling effort was enough to capture most of the species present in FH and FC forests (C. hat > 99%), which means that amount of pitfall was enough for the monitoring. The forest with hunting activities (FH) had 227 individuals distributed among seven genera and 12 species. The forest with cutting and thinning activities (FC) had 451 individuals distributed among nine genera and 16 species (Table 1). Shannon–Wiener index (J) and Simpson index (D) showed similar species diversity values in both forests (Shannon: FH = 0.72 and FC = 0.639 and Simpson: FH = 0.243 and FC = 0.239, Table 1). We did not find statistically significant differences by comparing these values through a chi-square test (X^2). *Dichotomius favi* (Kohlmann and Solis 1997) and *Sylvicanthon aequinoctialis* (Harold 1868) were the most abundant species ($n > 100$) (Table 1). The similarity analysis showed close values with high equality between the species of FH and FC. The diversity profiles did not present any differences between forests in diversity measured by richness (q0) and abundance (q1 and q2). However, according to the upper confidence intervals, FC could maintain twice as many species (q0) as FH (Fig. 2). For example, FC showed a higher hypervolume compared to FH; both forests share the same species (ANOSIM: $p < 0.01$, Fig. 3A), and FH demonstrated a lower dissimilarity in the species composition with the Jaccard index (ANOVA: F = 9.83, $p = 0.01$, Fig. 3B). Finally, changes in both forests were probably for a higher species turnover (addition) than nestedness patterns (Fig. 3B).

Functional groups and trait diversity (paracoprids, telecoprids, endocoprids, small < 10 mm, medium 10 to 18 mm, large > 18 mm) identified five groups from 18 species associated with the tropical moist forest of Chocó Biogeographic of Colombia (Gower: cutline = 0.4) (Fig. 4A, B). FG1 - *Deltochillum gibbosum* (Fabricius 1775) and FG4 - *Dichotomius satanas* (Harold 1867) were composed by a single species (Fig. 4B). Three species constituted the FG2 and FG3, and the FG5 was compounded by half

Table 1 Number of individuals and species of dung beetles in the forest with hunting (FH) and forest with cutting (FC). Length (L; average in mm); Functional groups (FG): Paracoprids (P), Telecoprids (T), and Endocoprids (E); and size of the individuals - small (s; < 10 mm), medium (m; 10 to 18 mm), and large (l; > 18 mm)

Tribe - Species	L	FG	FH	FC	Total
Ateuchini					
Agamopus lampros (Bates 1887)	3.5	Ps	0	13	13
Ateuchus candezei (Harold 1868)	6.1	Ps	29	51	80
Ateuchus sp. 1	6.9	Ps	3	3	6
Coprini					
Canthidium aurifex (Bates 1887)	4.8	Ps	8	11	19
Canthidium centrale (Boucomont 1928)	9.7	Ps	1	0	1
Dichotomius favi (Kohlmann and Solis 1997)	11.4	Pm	101	167	268
Dichotomius satanas (Harold 1867)	23.2	Pl	2	1	3
Deltochilini					
Canthon cyanellus (LeConte 1859)	7.8	Ts	0	4	4
Deltochilum gibbosum (Fabricius 1775)	24.4	Tl	0	1	1
Deltochilum pseudoparile (Paulian 1938)	13.7	Tm	7	6	13
Sylvicanthon aequinoctialis (Harold 1868)	11.2	Tm	36	127	157
Oniticellini					
Eurysternus foedus (Guérin-Méneville 1844)	16.3	Em	0	1	1
Eurysternus impresicollis (Castelnau 1840)	8.5	Es	9	12	21
Eurysternus plebejus (Harold 1880)	7.9	Es	10	12	22
Onthophagini					
Onthophagus acuminatus (Harold 1880)	7.2	Ps	1	0	1
Onthophagus coscineus (Bates 1887)	4.2	Ps	20	40	60
Onthophagus marginicollis (Harold 1880)	6.3	Ps	0	1	1
Onthophagus praecellens (Bates 1887)	7.1	Ps	0	1	1
Abundance			227	451	678
Richness			12	16	18
Shannon index (J)			0.720	0.639	
Simpson index (D)			0.243	0.239	
Sample coverage (C.hat)			0.991	0.989	

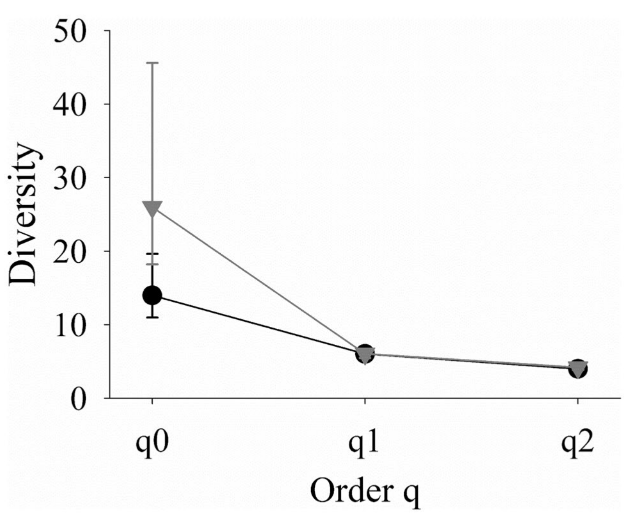

Fig. 2 Diversity profiles (and confidence intervals 95%) in two tropical moist forests (circles: FH, forest with hunting and triangles: FC, forest with cutting) of Chocó Biogeographic of Colombia. q0, species richness; q1 and q2, effective species numbers based on the relative abundance of rare and common species, and dominant species, respectively

of the total species captured in this study (Fig. 4B). The results of the functional groups in FH showed an absence of several species and the loss of some functional traits (Fig. 4A). Mainly, the loss of rollers and large beetles was observed (*D. gibbosum*), implying the loss of FG1 (Fig. 4A). In addition, dwellers and medium beetles were also lost (*Eurysternus foedus,* Guérin-Méneville 1844) (Fig. 4A). The absence of two species (tunneller and small beetles) belonging to FG5 was observed in FC (Fig. 4B). Although we do not observe statistical differences in total abundances of functional traits between FH and FC forests (Table 2), there seems to be a tendency between them. FC has three times more roller beetles and almost twice as many small, medium, and tunneller beetles than the FH (Table S1). Also, there was a critical absence of large species in both forests (Table S1). We found twice as many tunneller beetles than roller species in FH (Fig. 5 A), while FC had almost the same proportion of both functional traits (Fig. 5B). Regarding body size, both forests had a higher proportional abundance of medium beetles compared with small and large species (Fig. 5).

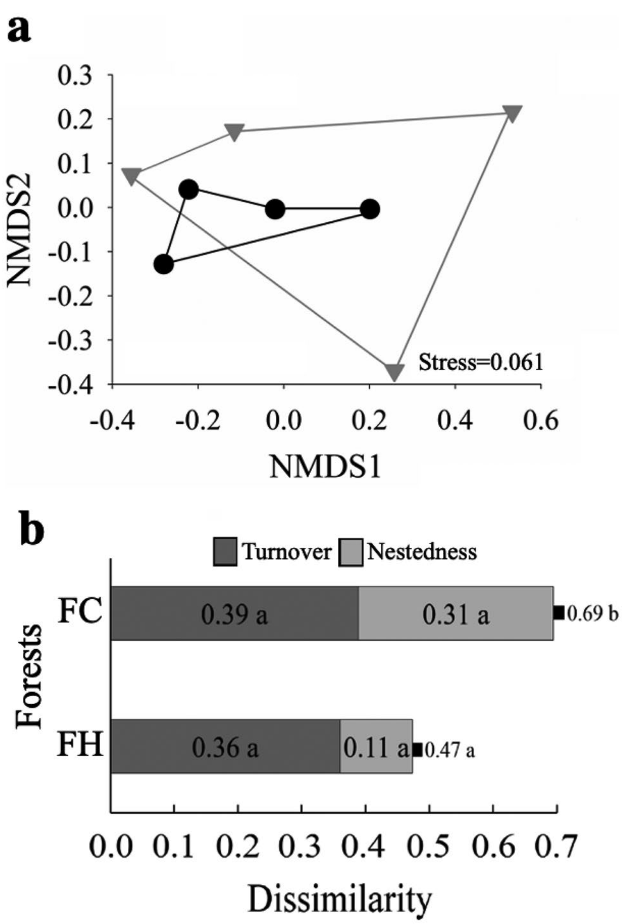

Fig. 3 **a** Changes in species composition based on a non-metric multidimensional model (NMDS). **b** Jaccard dissimilarity analysis of dung beetle assemblages in two tropical rain forests of the Chocó Biogeographic of Colombia. Circles: FH, forest with hunting and triangles: FC, forest with cutting. Dark grey bar: species turnover (βsim) and light grey bar: species nestedness (βnes). Anova and DGC post-hoc comparisons. Different letters indicate statistical differences

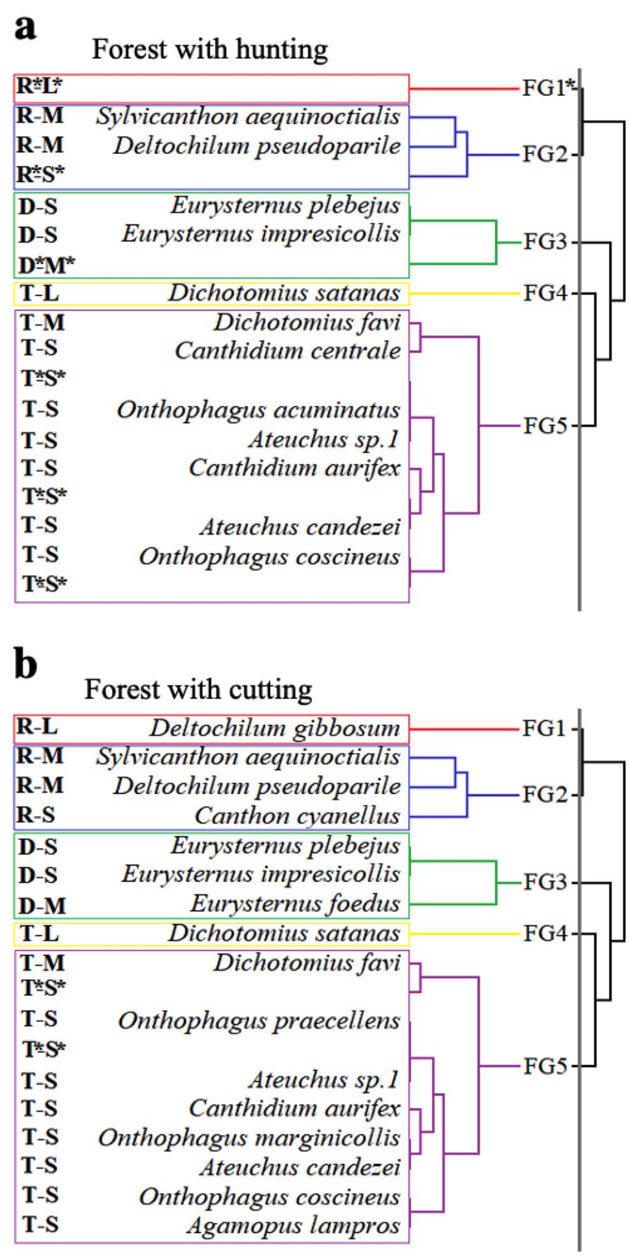

Fig. 4 Species composition and traits associated with the functional groups (FG) of dung beetle assemblages. **a** Forest with hunting (FH). **b** Forest with cutting (FC) of Chocó Biogeographic of Colombia. FG were built at the Gower distance of 0.4 (total distance = 0.8). Letters that compose the FG belong to the following functional traits: R: Rollers, T: Tunnellers, and D: Dwellers and S: Small, M: Medium, and L: Large. (*) Asterisks indicate the absence of a trait/functional species

Discussion

Our study hypothesis was that the cutting and thinning of trees affect the diversity and functional structure of dung beetle communities more than the hunting activities. However, our results do not support the initial hypothesis because we observed a uniform tendency in dung beetles' assemblages in both forests (FC-cutting and FH-hunting), which implies that both perturbations have a similar effect on the diversity and functional structure of dung beetle assemblages. Diversity estimators and profiles showed a similar diversity and a loss of functional traits and groups between forests, and beta diversity estimators showed a lower dissimilarity in the species composition within sites, observing a higher abundance and richness of dung beetles in FC and a higher abundance of tunneller, roller, and beetles of medium size in both forests. These results are similar to recent studies by Davies et al. (2020) and López-Bedoya et al. (2022), where taxonomic and functional diversity of dung beetle species are higher and could be recovered in secondary forests in comparison to open or highly perturbated habitats (*e.g.*, pastures) in different regions around the world.

Table 2 Changes in functional traits of dung beetle assemblages between two tropical moist forests of Chocó Biogeographic of Colombia

Functional trait	Category	FH	FC	Statistic	*p-value*
Food relocation	Roller	10.5 a	23.0 a	4.08	0.06
	Tunneller	41.5 a	66.0 a	0.00	0.99
	Dweller	5.0 a	3.0 a	0.33	0.66
Beetle size	Small	20.5 a	25.0 a	0.08	0.89
	Medium	36.5 a	88.5 a	1.33	0.34
	Large	0.5 a	0.0 a	0.08	0.99

FH forest with hunting, *FC* forest with cutting

*Nonparametric data: Kruskal–Wallis test and post hoc comparisons. Different letters indicate statistical differences

Disturbance pressures on dung beetles could explain the similar patterns in FH and FC. The decrease of mammals by hunting activities is mainly associated with a loss of medium-size mammals, which usually are the abundant species (Nichols et al. 2009; Feer and Boissier 2015; Guerra et al. 2019). Then, if the mammal populations are reduced by hunting, the food resources for dung beetles will decrease, unleashing an impact on their diversity (Culot et al. 2013). Also, a lower heterogeneity of available resources could imply a lower diversity and a decrease in the richness and abundance of dung beetle populations, seeming to be negatively correlated with this disturbance (Gardner et al. 2008; Da Silva and Hernández 2016; Gómez et al. 2018). Deforestation of the tree canopy by cutting activities could modify the entrance of light, temperature, and humidity, affecting the ecological role of dung beetles, which are susceptible to microclimatic changes because they affect their nests and food resource (Hanski and Cambefort 1991; Damborsky et al. 2015). For example, a lower humidity of the excrements and changes in soil conditions due to high evaporation and low humidity can reduce the availability of resources for the dung beetles (Holter and Scholtz 2007). Also, cutting activities changes critical factors in the air level, such as temperatures (high) and humidity (low), causing a limitation in the thermoregulation, a crucial process for dung beetles to fly and disperse (Verdú et al. 2006; Verdú and Lobo 2008; Dortel et al. 2013). Cutting activities cause tree coverage changes that affect the fauna species, which are the primary producers of dung beetle food supply (Bourg et al. 2016).

Our results showed a similar diversity pattern among FC and FH forests, despite our initial hypothesis that FH could have higher diversity and composition in dung beetle populations due to its more heterogeneity, niches, and richness in comparison with FC. Perhaps, the intermediate disturbance hypothesis and abundant food supply offer could explain the similar diversity between FH and FC forests (Correa et al. 2019). The intermediate disturbance hypothesis mentions that rare or frequent ecological disturbances could maximize an ecosystem's diversity (Connell 1978). Diversity could be highest when disturbances are intermediate in intensity or size and lower when perturbations are extreme. The secondary forest (FC) in Chocó in 2009 had not yet been intervened by an intense cutting of trees compared to the current annual deforestation rate of humid tropical forests (Achard et al. 2002; Global Forest Watch 2020). Then, intermediate disturbances could make it possible to maintain species richness

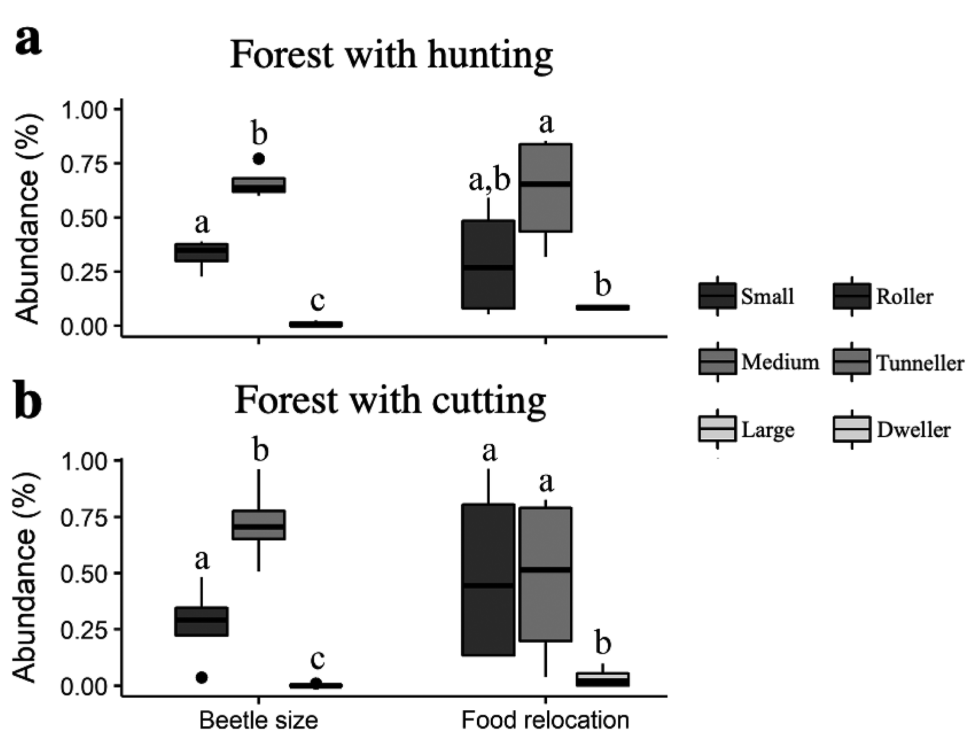

Fig. 5 Proportional abundance of the food relocation strategy and the body size of dung beetle communities. **a** Forest with hunting (FH). **b** Forest with cutting (FC) of the Chocó Biogeographic of Colombia. Black points represent extreme values. Non-parametric data: Friedman test and posthoc comparisons. Different letters indicate statistical differences

and biodiversity levels similar to FH. Gómez-Cifuentes et al. (2017) observed high diversity of dung beetles in land with continuous anthropic activities (cutting and logging) compared to land with few anthropic events (pastures for livestock or old pine plantations).

Additionally, cutting activities in FC could be compensated through high offer resources to dung beetles because the FC is closer to the human population. An increase in resource supply over a long and constant time makes dung beetles adapt quickly to modified environments, explaining their high diversity in FC (Rodrigues et al. 2013; Correa et al. 2019). Humans are omnivorous, and this makes the excrement more attractive for dung beetles due to the high concentration of nitrogen and phosphorus, which are essential nutrients for immature adults to complete the development of their muscular system and for females to complete the maturation of their eggs (Hanski 1991; Gómez-Cifuentes et al. 2015). Also, an important part of the diet of dung beetles is made up of bacteria that are found in large quantities in the excrement of omnivores, which is essential for the metabolism of these insects (Filgueiras et al. 2009). Perhaps, for these reasons, FC has three times more roller beetles and almost twice as many small, medium, and tunneller beetles than FH.

The species composition evidenced a higher dominance in both forests, observing that *D. favi* represented 45% of FH captured species. In comparison, *D. favi* and *S. aequinoctialis* represented 65% of the individuals in FC. We suggest that the similarity in the composition between forests can be attributed to the proximity in space (< 2 km), which would be evidence of a strong influence of high spatial mobility in the region despite differences in the type of anthropic disturbance (Beiroz et al. 2018). In general, we observed a higher presence of tunnellers and small beetles in both forests, grouped in one functional group (FG5). In contrast, we observed two functional groups with one unique species and the absence of several species and traits in most FH functional groups, while FC was the opposite.

The disturbances on FH imply the absence of the unique roller and large species (*D. gibbosum*) and dweller and medium species (*E. foedus*). The lack of medium and large species had several adverse effects on the forest function because these species bury higher portions of organic matter in the soil compared to small species (Slade et al. 2007; Shahabuddin et al. 2008; Dangles et al. 2012). The absence of roller and dweller species probably can be explained by the higher presence of tunneller beetles and could be associated with a competition mechanism for overlapping niches (Hanski and Cambefort 1991; Simmons and Ridsdill-Smith 2011). Finally, the Phanaeini tribe's absence, medium, and large tunneller species, in both forests show their susceptibility to anthropogenic disturbance due to the lack of large mammal communities (Edmonds and Zídek 2010; Noriega et al. 2020).

Implications for dung beetles' conservation

The anthropic pressure in FH with frequent hunting events could disappear large mammals and their faeces, affecting dung beetles by the absence of food resources. At the same time, cutting activities in FC could modify the vegetation cover structure, entrance of light, temperature, and humidity, affecting the ecological role of dung beetles. Although deforestation strongly impacts fauna and flora by destroying dung beetles' niches, habitats, and resources. The human communities and their domestic fauna near secondary forests could benefit from dung beetles' diversity in FC, which would provide a higher resource offer and explain the similarities between these two disturbance effects.

Conclusions

Hunting and cutting activities in the sampled forests of Chocó Biogeographic similarly influence dung beetles' diversity and functional structure. This study shows that, despite conserving the vegetation cover, if the mammals existing in a forest disappear, the diversity and structure of the assemblage of dung beetles would be as harmful as the effect of cutting and thinning trees. In this context, it becomes evident that it is necessary to conserve both the vegetation cover and the mammalian fauna to maintain taxonomic and functional diversity. In conclusion, cutting and hunting disturbances had similar impacts on dung beetle communities. However, it is important to continue evaluating the anthropogenic effect on nearby forests of unique regions like Chocó Biogeographic to establish conservation strategies for dung beetles, including undisturbed forests.

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Author contribution JPCC and JAN contributed to the study conception and design. JPCC performed data collection and laboratory identification. JAN performed laboratory identification and trait measurements. AG and JAN performed data analyses. JPCC and JAN wrote the first draft of the manuscript, and all authors commented on previous versions. All authors read and approved the final version of the manuscript.

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