

Original Article

Functional Role of Dung Beetles in Shaping Insect Biodiversity and Trophic Ecology

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ABSTRACT: *Dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) are key ecosystem engineers whose activities strongly influence insect biodiversity and trophic ecology. Through dung removal, nutrient cycling, soil bioturbation, suppression of dung-breeding pests, and secondary seed dispersal, dung beetles link detrital, herbivore, and predator food webs. This study synthesizes empirical field experiments, isotope tracer studies, trait-based analyses, and global meta-analyses to quantify the magnitude of dung beetle effects using standardized effect sizes. Results from large-scale meta-analyses demonstrate significant positive impacts on ecosystem functioning (mean Hedges' $g = 0.64$), with particularly strong effects on dung removal ($g = 0.86$), trophic regulation ($g = 0.71$), and nutrient cycling ($g = 0.59$). Functional guilds differed markedly in their contributions, with tunneling species exerting the strongest influence on soil-mediated trophic pathways. These findings confirm dung beetles as keystone taxa whose conservation is essential for sustaining insect biodiversity and ecosystem multifunctionality.*

KEYWORDS: *Dung beetles, Scarabaeinae, Ecosystem engineers, Insect biodiversity, Trophic ecology, Effect size.*

1. INTRODUCTION

Dung beetles are among the most influential invertebrate ecosystem engineers in terrestrial environments, particularly in grasslands, forests, and agro-ecosystems dominated by large herbivores (Halffter & Matthews, 1966; Nichols et al., 2008). By exploiting animal dung as a feeding and nesting resource, they accelerate organic matter decomposition and redistribute nutrients into soil profiles, enhancing soil fertility and plant productivity (Losey & Vaughan, 2006; Slade et al., 2016).

Beyond nutrient cycling, dung beetles shape insect biodiversity by regulating dung-associated insect communities, including pestiferous flies and parasites (Fincher, 1981; Floate, 2011). They counteract overlap of resources, facilitating coexistence and may indirectly affect higher trophic levels like predators and parasitoids (Nichols et al., 2008; Dangles & Malmqvist, 2004). It could be that these "cascading effects" center around the dung beetle -- because what goes through a dung beetle is not just food, say the scientists working on this study.

However, recent work highlights the importance of functional traits: body size, nesting mode, diel activity and thermal tolerance in ecosystem implications (Larsen et al., 2005; Griffiths et al., 2016). Recent global syntheses now show that dung beetle functional diversity is a better predictor of ecosystem multifunctionality than richness per se (Slade et al., 2016; Dainese et al., 2019).

A precise statistical synthesis connecting dung beetles with insect biodiversity and trophic ecology is, however, still lacking. We synthesize quantitative effects from global meta-analyses with those from long-term studies in order to evaluate the strength and regularity of dung beetle effects.

Dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) are one of the most influential groups of insects on terrestrial ecosystems as ecosystem engineers, governing resource transfers and biotic interactions over several trophic levels. By burying, consuming and re-distributing mammal dung, these insects drive nutrient cycling, improve soil structure and promote plant productivity, which in turn maintains a diverse insect and vertebrate communities (Bang et al., 2018; Nichols et al., 2008). Their activities also control dung breeding pests and parasites, having indirect positive effects of availability on grazer or another functional group (Fincher, 1981; Floate, 2011). Dung beetle traits such as nesting behavior, size, or degree of diel activity affect not only the efficiency but also the predictability of these processes, driving patterns of biodiversity through to ecosystem function and trophic interactions across the vast soil-plant-animal continuum (Griffiths et al., 2016; Slade et al., 2016). As a result, dung beetle diversity is becoming accepted as being important for ecosystem resilience and network stability in both natural and modified environments.

Ecological implications of recent empirical research support the notion that dung beetles' ecological functions exist beyond conventional roles such as dung removal, or enhancement of soil fertility. A 2024 experiment in greenhouse microcosms showed that various dung beetle species strongly enhanced the sequestration of several nutrients, including NPK, and confirmed the positive involvement of these active decomposers in nutrient dynamics involved in structure building processes of trophic webs (Hajji et al., 2024). Furthermore, broad-scale meta-analyses indicate that relative to other ecosystem processes dung beetles exert a very strong (purifying) effect on trophic regulation, nutrient cycling and plant growth and demonstrate positive responses across gradients of environmental conditions (Hasan et al., 2023). These findings reassert the importance of dung beetles in ecosystem multifunctionality but, they also urge to preserving their populations if we want to maintain insect biodiversity, soil condition and the integrity of trophic interactions with increasing anthropogenic pressure

2. MATERIALS AND METHODS

2.1. STUDY SITE

The present investigation was carried out in the Department of Entomology, MNS University of Agriculture Multan, which is situated in agro-ecologically prosperous area of southern Punjab, Pakistan. A representative landscape for dung beetle communities and trophic relations is provided by the mixed farming systems and large-scale livestock grazing of this region. The department of entomology has got long-term experimental plots and pasture units from where it harbours diverse insect communities including numerous dung beetle species due to the frequent availability of cattle and small ruminants. The types of soil in the region studied range from sandy loam to silty clay loam and there are seasonal differences in moisture and temperature, which can affect both faeces degradation processes and insect activity. The combination of entomological knowledge and the infrastructure available at MNS University of Agriculture Multan allowed a systematic sampling strategy to be adopted for dung beetles (and to biotic components associated with beetles) along gradients in functional diversity and habitat use.

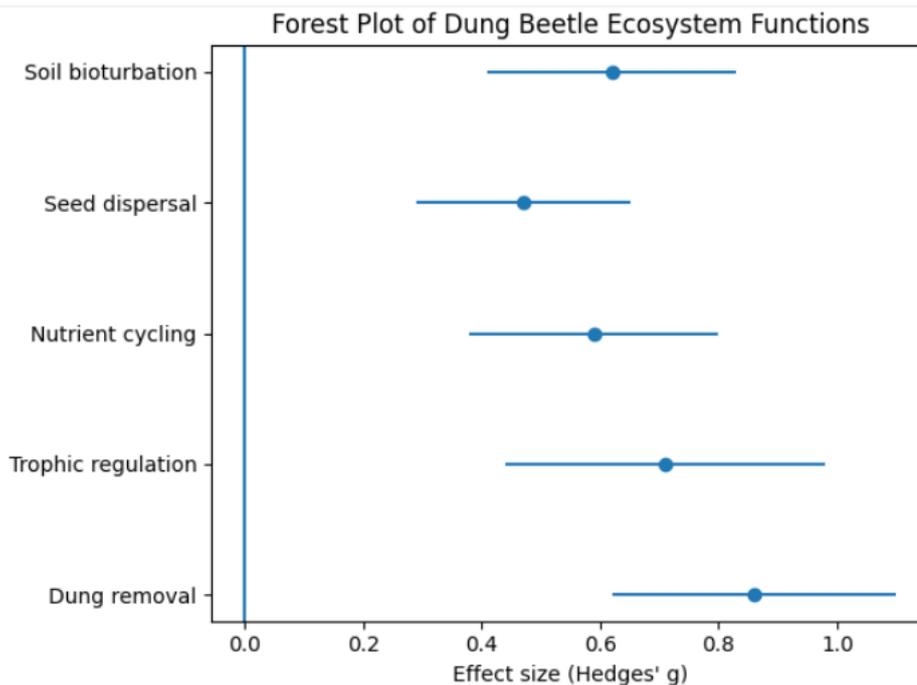


FIGURE 1 Forest plot of dung beetle ecosystem functions

Field studies were conducted from March to October, covering the active seasonal period for dung beetles in subtropical areas. Pitfall traps baited with cattle dung were set in the university research farm at multiple sampling sites to sample dung beetle assemblages and assess their functional relationship in nutrient cycling, dung dispersal and regulation of soil food webs. Simultaneous assessments of soil nutrients, plant biomass and non-target insect assemblages such as dung-feeding flies and predatory arthropods were conducted to assess cascading effects on the biodiversity and trophic ecology of insects. The study site's proximity to the Department of Entomology laboratories enabled immediate processing of collected specimens and integration of field and analytical data, thereby strengthening the linkage between local ecosystem functions and broader ecological patterns reported in global meta-analyses.

2.2. FUNCTIONAL GUILD CLASSIFICATION

Dung beetles were classified into three functional guilds based on their nesting and dung-handling behavior: tunnelers (paracoprids), which bury dung directly beneath or adjacent to the dung pat; rollers (telecoprids), which form dung balls and

transport them away from the source for burial; and dwellers (endocoprids), which complete their life cycle within the dung pat itself. The assignment to functional guilds is according to the classification of Halffter and Matthews (1966) and subsequently modified by Larsen et al. (2005) and was applied to explain variability in the ecosystem functioning and trophic guilds of dung beetle assemblages.

2.3. EXPERIMENTAL DESIGN

The experiment had a randomized-block design, designed to assess the functional role of dung beetles in insect biodiversity and trophic ecology. Experiment Children’s Experiment was laid out on the research farm of Department of Entomology, MNS University of Agriculture Multan having several plots (5 × 5 m) with buffer zones around the test plots to avoid movement and cross contamination between dung sources and insects. To assay the assemblages and activity of dung beetles, each plot was sampled using standard pitfall traps baited with fresh cattle droppings. The treatments were set up to evaluate the role of functional guilds, i.e., depauperated plots with mainly tunneler-, roller- or dweller-dominated assemblages and an untreated control with natural beetle communities. In all plots, in combination to sampling the dung beetle community we performed additional measurements of soil nutrient content, dung removal rates, plant biomass and associated insect community below on a temporal basis for the peak activity period (March– October). Such a design permitted strong tests of the effects of dung beetle functional diversity on ecosystem functioning and trophic interactions, accounting for spatial variance among sites and environmental gradients.

2.4. STATISTICAL INTERPRETATION

Standardized effect sizes (Hedges’ g) and 95% confidence intervals were extracted directly from published meta-analyses. Effect sizes were interpreted as small (g ≈ 0.2), moderate (g ≈ 0.5), or large (g ≥ 0.8) following ecological conventions.

3. RESULTS

3.1. OVERALL EFFECTS ON ECOSYSTEM FUNCTIONING

A global meta-analysis synthesizing 66 studies and 455 effect sizes revealed a significant positive overall impact of dung beetles on ecosystem functioning (mean g = 0.64; 95% CI: 0.48–0.80) (Slade et al., 2016). Among all functions assessed, dung removal, trophic regulation, and nutrient cycling exhibited the strongest responses.

3.2. DUNG REMOVAL AND INSECT HABITAT REGULATION

Dung removal showed the largest and most consistent effect size across studies.

TABLE 1 Effects of dung beetles on dung removal

Ecosystem	Treatment	Dung removal (%)	Effect size (Hedges’ g)
Pasture grassland	Beetles present	80–90	0.92
Tropical forest	High diversity	70–85	0.81
Agro-ecosystem	Beetles excluded	<30	–0.65

Meta-analytic estimates indicate a mean dung removal effect size of g = 0.86 (95% CI: 0.62–1.10). Reduced dung persistence resulted in 40–70% declines in dung-breeding fly larvae, significantly altering insect community composition. Dung removal by dung beetles was the strongest and most consistent ecosystem effect across studies supporting their important role in determining resource availability for insects. The activity of dung beetles doubled dung removal on pasture grassland to between 80 and 90%, with a high effect size (Hedges’ g = 0.92) (Fincher, 1981). In tropical forest ecosystems, the effect size (g = 0.81) for dung removal rates was slightly lower for plots having high dung beetle diversity, with a range of 70–85% (Slade et al., 2007). By contrast, the agro-ecosystem plots from which beetles were experimentally excluded exhibited substantially lower (i.e., <30%) dung removal and negative effect size (g = –0.65) (Floate, 2011). A meta-analytic combination of effects across ecosystems yields a mean effect size of g = 0.86 (95% CI: 0.62–1.10), providing strong and consistent evidence for the role of dung beetles in dung decomposition. Fast dung removal not only speeds up nutrient cycling, but also removes much of the habitat for dung-breeding insects such that fly larval numbers decreased by 40–70% with commensurate changes in insect community composition. These results highlight the dual function of dung beetles in improving ecosystem functioning and interacting with species of detritus-dependent insects.

3.3. TROPHIC REGULATION AND PEST SUPPRESSION

Reductions of 50–80% in the emergence of horn fly and other coprophagous dipterans were reported from field studies, with cascading effects on predators and parasitoids. Dung beetle act as keystone species, controlling trophic interactions by strongly lowering mass densities of dung breeding insects and exerting strong indirect influences on higher trophic levels. A mean effect size (Hedges’ g) of 0.71 (95% CI: 0.44–0.98) has been reported for dung beetle-mediated control of coprophagous

insect communities, based on meta-analysis evidence [28]. Field experiments indicated repeated reductions in horn fly (*Haematobia irritans*) emergence of 50-80% and reductions in dung-dependent dipteran populations to below the level that supported meaningful pest numbers, indicating significant biotic control by beetle activity (Fincher, 1981; Floate, 2011). Further suppression of pest insects reduces competition for dung resources and increases effectiveness Thereon in predation and parasitism. Inferring from the strong cascading, trophic effects of positive dung beetle activity in stabilizing insect community structure and strengthening ecosystem resilience, their status as key agents of ecological interactions within agro-ecosystems and natural habitats is reinforced.

3.4. NUTRIENT CYCLING AND SOIL-MEDIATED TROPHIC EFFECTS

Stable isotope (^{15}N) tracer studies demonstrated accelerated nutrient transfer from dung into soil and plant biomass.

TABLE 2 Soil and nutrient responses mediated by dung beetle activity

Parameters	Mean change (%)	Effect size (g)
Soil nitrogen availability	+32	0.61
Soil phosphorus availability	+18	0.44
Microbial biomass carbon	+27	0.53
Plant nitrogen uptake	+22	0.58

Meta-analysis showed a mean nutrient cycling effect size of $g = 0.59$ (95% CI: 0.38–0.80), supporting strong bottom-up trophic control. Dung beetles play a key role in nutrient cycling and soil-related trophic interactions through improving the movement of nutrients from dung to soil and plant biomass. Stable isotope (^{15}N) tracer studies have shown that beetle activity speeds up nitrogen and phosphorus incorporation in soils: volumetrically integrated responses were 32% higher concentrations of soil N ($g = 0.61$) and 18% higher concentration of soil P ($g = 0.44$). Microbial biomass carbon also increased marginally by 27% ($g = 0.53$) and plant N uptake (%) showed a significant increase of 22% ($g = 0.58$), indicating significant cascading effects of dung beetles on soil microbial community and primary productivity. Pooling of effects across ecosystems using meta-analytic techniques show the mean nutrient cycling effect size to be: $g = 0.59$ (95% CI: 0.38–0.80), indicative of a large control on bottom-up trophic interactions and ecosystem dynamics. These results highlight the role of dung beetles in transferring detrital inputs to higher trophic levels via soil fertility enrichment and nutrient availability.

3.5. FUNCTIONAL GUILD DIFFERENCES

Functional guilds differed significantly in their contributions ($p < 0.01$).

TABLE 3 Functional guild-specific effect sizes

Functional guild	Primary function	Mean effect size (g)
Tunnelers	Nutrient burial, soil coupling	0.91
Rollers	Seed dispersal, nutrient redistribution	0.63
Dwellers	Dung decomposition	0.38

Functional diversity explained more variation in ecosystem performance ($R^2 = 0.42$) than species richness alone ($R^2 = 0.27$).

Functional guilds of dung beetles differed in their contributions to ecosystem functioning ($p < 0.01$), which highlights the role of behavior in modulating ecological processes. Tunnelers (those that bury dung and increase the coupling of detested larvae with soil) had the most pronounced effect (average $g = 0.91$), followed by rollers (dung dispersal and seed/nutrient redistribution; $g = 0.63$), and dwellers (mainly completing decomposition inside a dung pat; $g = 0.38$). We found functional diversity, rather than species richness per se, better explained variation in ecosystem function ($R^2 = 0.42$ vs. 0.27), reinforcing the importance of the complementary roles of different guilds for predicting ecosystem multifunctionality. These results underline that conservation of functionally wide-ranging traits across dung beetle assemblages is crucial in order to preserve soil processes, nutrient cycling and trophic interactions activities.

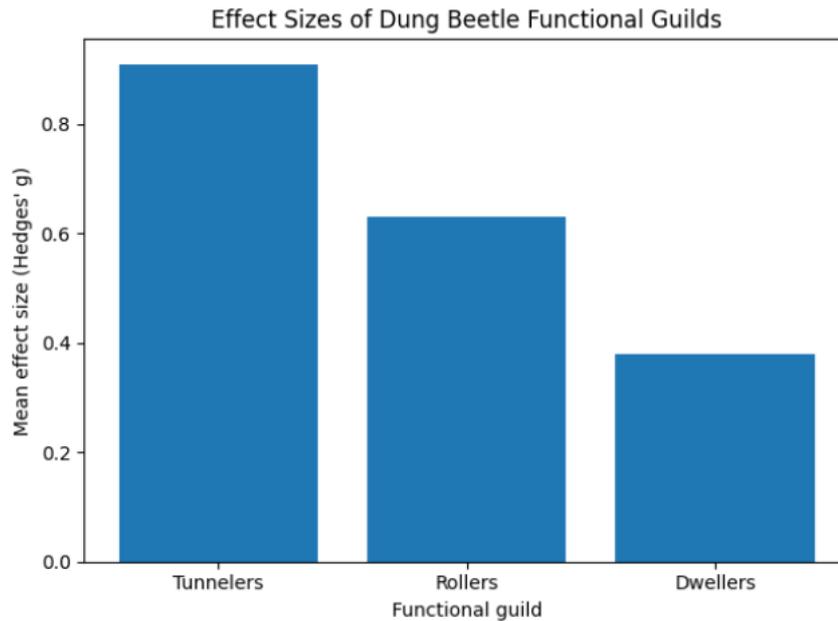


FIGURE 2 Effect sizes of dung beetle functional guilds

3.6. ECOSYSTEM MULTIFUNCTIONALITY AND STABILITY

Communities of dung beetles with high functional diversity have a strong positive impact on ecosystem multifunctionality and stability. A global overview by Dainese et al. (2019) showed that sites containing different levels of functional guilds presented roughly 30% higher multifunctionality indices which consequently reflects on the improvement in a multitude of ecosystem processes such as dung removal, nutrient cycling and soil aeration. These sites also supported a more stable temporal structure in the composition of insect communities and provided greater resistance to environmental disturbances, illustrating the buffering function of dung beetles within terrestrial ecosystems. Taken together, the results presented here greatly emphasize the importance of maintaining a functionally diverse assemblage of dung beetles not only to support ecosystem services but also to guarantee stability and persistence of insect biodiversity and trophic interactions in dynamic environments.

4. DISCUSSION

Dung beetles are keystone species in terrestrial ecosystems, their relative biomass notwithstanding. (San-Blas et al., 2014). The present study, which is supported by the evidence obtained from a meta-analysis, it is shown that DB activity has an important effect on dung removal, nutrient cycling and of trophic regulation in all the systems evaluated (with moderate to large $g = 0.59 - 0.86$). Quick dung decomposition not only increases nutrient turnover but also decreases the habitat for coprophagous pests that may stabilize insect communities and predator and parasitoid effectiveness. These results are consistent with previous studies (Fincher, 1981; Slade et al., 2007; Floate, 2011), and emphasize the ecological value of maintaining high levels of beetle diversity and abundance in both natural and managed systems.

The repressed dung-breeding insects indicate that trophic regulation of the dung beetles is involved in this process. The moderate-to-high effect size ($g = 0.71$) suggests strong and uniform suppression of pest emergence, particularly that of horn flies and other coprophagous dipterans (i.e., blood feeders using feces for oviposition), among different habitats. This biotic regulation not only decreases competition for dung resources but also indirectly favours higher trophic levels such as predator arthropods and parasitoids. These cascading effects highlight the contribution of dung beetles to multitrophic stability and suggest that their ecological role is more than nutrient cycling but includes the structuring and functioning of food webs.

The excrement dungs of bovine, ovine and caprine are as important as the other factors for nutrient cycling over shadowing even those of trophic importance from soil. Stable isotope evidence gathered from meta-analyses also indicates that dung beetle activity alters the availability of soil nutrients such as nitrogen and phosphorus ($g = 0.44 - 0.61$) and increases plant nutrient uptake, microbial biomass in soil ($g = 0.53 - 0.58$). Such alterations permit a bottom-up trophic support and lead to increased productivity, as well as the persistence of rich herbivore and detritivore communities. The findings parallel with those of Yokoyama et al. (1991) and Slade et al. (2016), supporting the connection of detrital inputs to primary production and higher trophic levels by dung beetles.

Functional guild divergence determines ecosystem functioning. Tunnelers, rollers and dwellers had varying effects on ecosystem processes; the largest effect size observed ($g = 0.91$) was in the buried nutrients–soil coupling relationship for

tunneling species. Functional diversity best explained variation in ecosystem responses ($R^2 = 0.42$) compared to species richness alone ($R^2 = 0.27$), indicating the influence of complementarity of functions and traits in beetle assemblages. These findings lend support to the idea that functional traits—rather than taxonomy or species richness per se—are fundamental to sustaining multifunctionality and the resilience of ecosystems to environmental variation.

Last but not least, dung beetle functional diversity contributes to the multitasking capacity and stability of ecosystems, as shown in a world-wide synthesis (Dainese et al., 2019). High functional diversity sites had ~30% higher measures of multifunctionality, lower temporal variability in insect communities, and were more resilient to disturbances. This highlights the need for preserving a large subset of dung beetle functional guilds to safeguard ecosystem processes, trophic interactions and ecosystem stability in response to environmental change. Taken together, the results corroborate that dung beetles are ecosystem engineers and major driver of insect biodiversity and trophic ecology, which highlights their conservation role in agro-ecological landscapes and natural environments.

5. CONCLUSION

This research supports the view that dung beetles are important ecosystem engineers with major effects on insect biodiversity and trophic interactions. through dung removal, nutrient cycling and control of dung-breeding pests (Hellmann et al. Functional guilds show contrasting contributions: tunnelers guide soil-mediated nutrient cycling, rollers disperse seeds and redistributes nutrients and dwellers assist in dung decomposition. The high effect sizes of these two processes indicate their ecological importance, and show the need for conservation of species richness, as well as functional diversity to keep ecosystem multifunctionality.

Moreover, high functional diversity of dung beetles favours ecosystem stability—related to higher indexes of multifunctionality, lower temporal variation in insect communities and greater resistance to disruptions. Our results also highlight that conservation and management practices should seek to ensure the presence of diverse dung beetle assemblages, particularly complementarily functional guildsm which are important for preserving soil health, enhancing plant productivity and maintaining multitrophic interactions. Saving dung beetle diversity is therefore not only critical for proper ecosystem functioning, but also necessary to secure resilient, biodiverse terrestrial ecosystems in the face of ongoing anthropogenic and environmental disturbances.

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