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Original Article

An experimental study on bioturbation and dung removal activities of *Catharsius molossus* (Linnaeus, 1758) (Coleoptera: Scarabaeidae) in the Greater Himalaya

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A B S T R A C T

In this artice, we studied the bioturbation and dung removal activity of dung beetle *Catharsius molossus* (Linnaeus, 1758) (Coleoptera: Scarabaeidae: Scarabaeinae) in different elevations in the Great Himalayan National Park Conservation Area for the first time to understand the capability of the species in providing such ecosystem services with an experimental approach in six different elevations in the area. We found that the weight of dung buried and bioturbation had significant difference between the elevations, and they had significant linear relationship with the elevations. Differences in such activities along the elevation can cause a low amount of nutrient transfer from the dung to the soil which can adversely affect the surrounding habitats.

Introduction

The beneficial functions and goods that humans obtain from ecosystems that support directly or indirectly their quality of life are called ecosystem services (Harrington et al 2010; Díaz et al 2015). For human welfare, these ecosystem services are critical (Daily et al 2000) because these services include, the provision of food, fiber, and water, the regulation of floods, diseases and climate, the control of organic matter decomposition and nutrient cycling, the suppression of pests, and the cultural services such as recreation or education (Millennium Ecosystem Assessment 2003; Díaz et al 2015). Insects play a key role in the regulation and dynamics of many ecosystem services (Noriega et al 2018) which include the provisioning services (material or energy outputs from the ecosystems), supporting services (maintenance of other ecosystem services), regulating services (regulation of the magnitude and directionality of ecosystem processes), and cultural services (educational, spiritual, and/or esthetic values) (GEO4 2007, Prather et al 2012).

The coleopteran insects (beetles) belonging to the subfamilies Aphodiinae and Scarabaeinae under the family Scarabaeidae are commonly called dung beetles as they feed primarily on mammalian dung and also use it for providing nesting and food for their larvae (Singh et al 2019). Dung beetles play a key role in dung decomposition in both temperate (Gittings et al 1994) and tropical (Barragan et al 2011) regions of the world. Through manipulating feces during the feeding process, both adults and larvae of dung beetles instigate a series of ecosystem functions such as nutrient cycling, bioturbation, soil fertilization, plant growth enhancement, secondary seed dispersal, and biological pest control, and owing to their functional importance, they have been described as key “ecosystem service providers” (Nichols et al 2008).

Bioturbation is the displacement and mixing of sediment particles by animals or plants which influence soil biota and plant productivity by increasing soil aeration and water porosity (Nichols et al 2008). Paracoprid dung beetles play a major role in bioturbation by their tunneling strategies through transportation of deep soil from earth ground to the surface (Mittal 1993). But this role of insects as ecosystem providers is often assumed, with limited or no experimental quantification of its real value, and our current knowledge on the ecosystem service provided by insects is relatively scarce and biased and show gaps in the least studied functional and taxonomic groups (Noriega et al 2018). The experimental studies of biodiversity function examine communities

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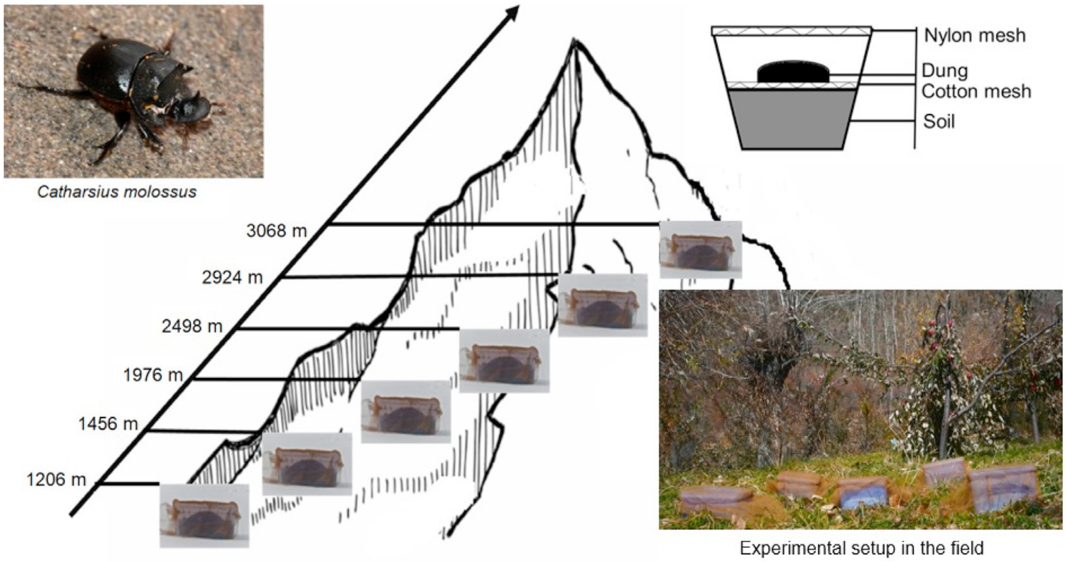

Figure 1. Systematic representation of experimental setup across the elevational gradient in the Great Himalayan National Park Conservation Area.

whose structures often differ markedly from those providing services in real landscapes (Kremen 2005), and it is an established fact that dung beetles are ecosystem service providers, but, so far, there are no studies had been carried out to understand the bioturbation by dung beetles in the Himalayan region in the field level.

With this background, in the present work, for the first time, we evaluated the bioturbation and dung removal or dung burring activities of dung beetle in different elevations using the species *Catharsius molossus* (Linnaeus 1758) (Coleoptera: Scarabaeidae: Scarabaeinae) in the Himalayan region—one of the most fragile and vulnerable ecosystems of the world. For the work, we hypothesized that there would be significant difference present in the dung buried and bioturbation in different elevation.

Material and methods

We performed the field experiment in the last two weeks of August 2018 in the Great Himalayan National Park Conservation Area at six different locations with different elevations: 1206 m (31.7691°N, 77.2974°E), 1456 m (31.6419°N, 77.4055°E), 1976 m (31.6442°N, 77.4508°E), 2498 m (31.6542°N, 77.4659°E), 2924 m (31.6431°N, 77.4685°E), and 3068 m (31.64152778°N, 77.4710°E).

As we used herbivores' dung for the study and the study was also performed at night, we chose the dung beetle *Catharsius molossus* (Linnaeus, 1758) (Coleoptera: Scarabaeidae: Scarabaeinae) for the study as it is a large nocturnal tunneler and specialist of herbivores' dung (Ong et al 2013) and well abundant in the study area. The species is characterized by its highly convex and broadly oval large size body, black-colored body covered with reddish hair beneath, entirely opaque elytra, presence of a small smooth area adjoining each eye, pronotum covered by granules, obtuse hind angles, and fringed metasternal shield (Biswas et al 1999). We took five plastic boxes with the dimension of 24 cm length × 20 cm breadth × 18 cm height. We filled each of the boxes with the soil of that particular location up to 12 cm height of the box. Then, we placed a thin cotton mesh (which can be easily torn by the beetle) over the soil so that the buried soil can be separated out properly from the surface. Then, we applied 150 gm of fresh organic cattle dung (collected from the local cattle sheds of *Bos indicus*) over the mesh. Then, we placed only male individual in each box. We chose to place single specimen in each box because we wanted to measure weight of dung buried (the amount of dung inserted into the tunnel) and bioturbation (amount of the soil made out of the tunnel) at individual level, and we chose only male because male is a more active burrower than female. Then, we covered each of the boxes with the nylon mesh to prevent the escape of the beetle. Then, we kept boxes in each location for 24 hours (2:00 pm to 2:00 pm of next day). After the period of 24 hours, we removed gently the remaining dung from the boxes and took weight of the remaining dung and the soil which was made out of the tunnel. We measured the weight of the dung and soil by Kerro laboratory analytical balance (accuracy 0.01gm) (Mxrady Lab solutions Pvt. Ltd.). We followed the same procedure in each elevation range with different individuals (Figure 1).

We conducted non-parametric Kruskal–Wallis rank sum tests to find out significant difference present in the mean ranks of the groups followed by pairwise comparisons using Wilcoxon rank sum exact test to find out which group pair had significant difference for mean weights of dung buried and bioturbation. We draw a linear regression model between the weight of dung buried and bioturbation in different elevations. We compared the slope of six regression models of between six elevations by the Tukey method in the package "lsmeans" (Lenth 2016). Before analysis, we log transformed the data. We performed analysis in free statistical software PAST (Hammer et al 2001) and R language and environment for statistical computing (R Core Team 2020).

Results

We observed that there was a decline in dung buried by the beetle with increase in elevation: 18.4 ± 0.687 gm at 1206 m, 13.6 ± 0.963 gm at 1456 m, 10.3 ± 0.590 gm at 1976 m, 9.58 ± 0.527 gm at 2498 m, 7.95 ± 0.413 gm at 2924 m, and 6.82 ± 0.331 gm at 3068 m (Figure 2B). We observed that there was a decline in bioturbation by the beetle with increase in elevation—at18.4 ± 0.687 gm at 1206 m, 13.6 ± 0.963 gm at 1456 m, 10.3 ± 0.590 gm at 1976 m, 119 9.58 ±

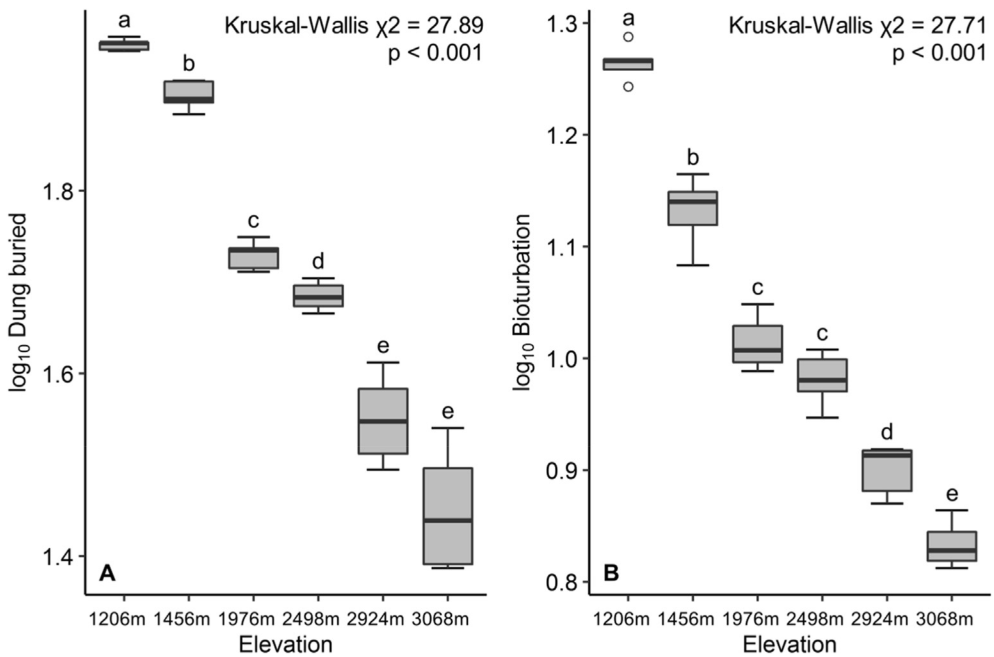

Figure 2. Boxplots showing comparison of dung buried (A) and bioturbation (B) between 6 different elevations. Different letters are differentiating between different ranks of the groups, and the same letter is representing no difference in ranks between the groups.

0.527 gm at 2498 m, 7.95 ± 0.413 gm at 2924 m, and 6.82 ± 0.331 gm at 3068 m (Figure 2B). By using the Kruskal–Wallis rank sum test, we found that mean ranks of the groups were significantly different for dung buried (Kruskal–Wallis $\chi^2 = 27.89$, df = 5, $p < 0.001$) (Figure 2A) and for bioturbation (Kruskal–Wallis $\chi^2 = 27.71$, df = 5, $p < 0.001$) (Figure 2B). For pairwise comparisons by using Wilcoxon rank sum exact tests, we found that significant differences ($p < 0.05$) were present between the groups except 2924 m and 3068 m ($p > 0.05$) for dung buried (Figure 2A) and significant differences ($p < 0.05$) were present between the groups except 1976 m and 2498 m ($p > 0.05$) for bioturbation (Figure 2B). We found significant ($p < 0.05$) linear relationship between the weight of dung buried and bioturbation in all six elevations (Figure 3). By comparing the slope of six regression models of between six elevations, we found significant ($p < 0.05$) difference in the slopes present between 3068 m–2498 m (estimate = -1.190, p = 0.007), 3068 m–1456 m (estimate = -1.556, p = 0.0004), 3068 m–1976 m (estimate = -1.140, p = 0.008), 2498 m–2924 m (estimate = 1.067, p = 0.019),1456 m–2498 m (estimate = 1.433, p = 0.001), and 1976 m–2498 m (estimate = 1.017, p = 0.026) (Table 1). We found that the weight of dung buried and bioturbation had significant ($p<0.05$) linear relationship with elevation (Figures 4A and 4B).

Discussion

Community structure and ecosystem processes often vary along elevational gradients because increasing elevation is associated with decline in temperature, decline in land area, decline in total atmospheric pressure, increase in total radiation and UV-B radiation, and changes in other abiotic factors such as precipitation, wind velocity, seasonality, geological substrates, soil formation processes, disturbance history, and nitrogen (N) deposition (Pickett 1989; Körner 2007; Sundqvist et al 2013). These abiotic factors act as drivers of not only changes of biodiversity but also changes in the activity pattern of a species across elevational gradients.

In the present study, we found a significant difference in the weight of dung buried and bioturbation by *Catharsius molossus* in different elevations, and these were significantly decreased with increase of elevation in the study area. These differences came from differential activity of this species, very likely driven by changes of abiotic factors at different elevations.

Carvalho et al (2020) suggested that dung removal may not always be a good indicator for other dung beetle mediation functions such as seed dispersal because these functions vary with environmental conditions. Nondecomposition of the dung may adversely affect the surrounding habitat by various reasons, as paracoprid beetles (tunnelers) bury dung deep into the soil for breeding and feeding purpose just under the dung pat, by digging long tunnels (Camberfort and Hanski 1991) which leads to nutrient cycling and enhance the productivity of ecosystem (Bornemissza 1960; Fincher 1981, 1990; Halffter et al 1982; Hanski and Cambefort 1991); thus, they are acting as a viaduct between soil fertility and dung disruption (Nakamura 1975). As it has already proven that dung burying directly affects the herbage growth (Gillard 1967; Yokoyama et al 1991; Yokoyama and Kai 1993), disruption in the ecosystem services along the elevation gradient in the Greater Himalayas can put their negative effect on the herbage growth. Dung beetles have also a negative effect on dung breeding flies, nematodes, and protozoa owing to their nesting and feeding habits (Nichols et al 2008). The inhibition of these basic services of dung removal also causes diseases to the surrounding flora and fauna, as these services put its positive impact on the livestock, wildlife, as well as on the human well-being (Byford et al 1992; Miller 1954)

As far our best knowledge, there has been no research work done on the change in the bioturbation activity of dung beetles in the highlands with the change in altitude. As such, our work can be considered as the first study in this field. We acknowledge

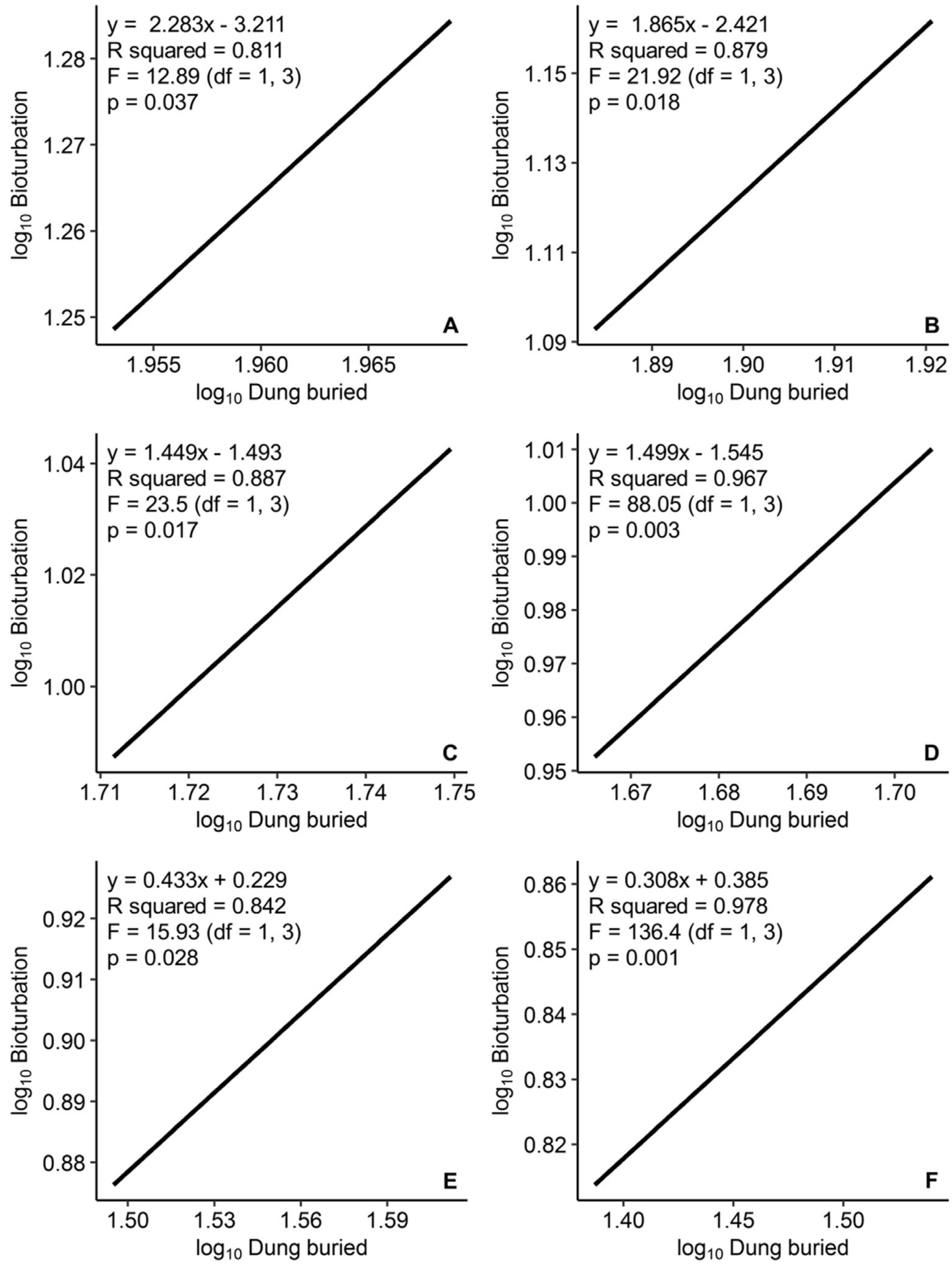

Figure 3. Linear relationship between log bioturbation and log dung buried in six elevations (A = 1206 m, B = 1456 m, C = 1976 m, D = 2498 m, E = 2924 m, and F = 3068) by *Catharsius molossus*.

Table 1. Pairwise comparison (Tukey method) between the slopes of the regression.

	1206 m	1456 m	1976 m	2498 m	3068 m
1456 m	-0.419 (p = 0.992)				
1976 m	-0.834 (p = 0.866)	0.416 (p = 0.889)			
2498 m	-0.785 (p = 0.893)	-0.366 (p = 0.933)	0.049 (p = 1)		
2924 m	-1.851 (p = 0.133)	1.433* (p = 0.001)	1.017* (p = 0.026)	1.067* (p = 0.019)	
3068 m	-1.975 (p = 0.094)	-1.556* (p = 0.0004)	-1.140* (p = 0.009)	-1.190* (p = 0.007)	-0.124 (p = 0.874)

The * marks indicate significant ($p < 0.05$) values.

that we had performed the work at only six elevations with single species, so that, through this work, we can only make a preliminary idea about bioturbation and dung removal activities of dung beetles in different elevations. A comprehensive understanding of the functioning of different ecosystems of the world, including the Himalayas, requires a comprehensive understanding of the ecosystem services provided by the plants and animals living there. To truly evaluate the contribution of nature to humans, we urge researchers to work on ecosystem services with multiple species in different ecosystems of the world. The knowledge we gain from this will enable us to make contributions to the conservation, management, and restoration of ecosystems for better future.

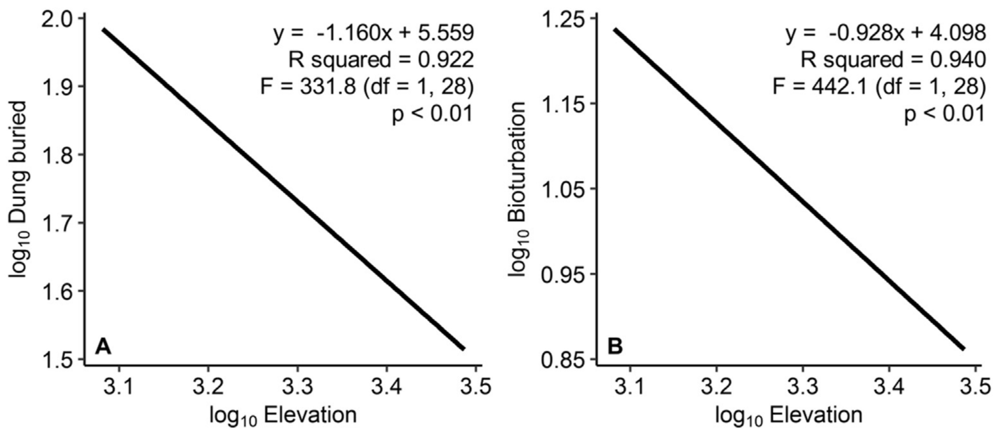

Figure 4. Pearson's product moment correlation and linear relationship between (A) log dung buried and log elevation and between (B) log bioturbation and log elevation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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