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RESEARCH ARTICLE

Darkling beetles (Coleoptera: Tenebrionidae) of forest sites and agricultural fields in the south Western Ghats (South India)

Chuliath Arunraj[1] Joseph P. Vineesh[2] Thomas K. Sabu[3]

[1,2,3]*PG & Research Department of Zoology, St. Joseph's College, Devagiri, Calicut 673008, Kerala, India; e-mails: [1]rajcarun@gmail.com; [2]vineeshpj@gmail.com; [3]sabukthomas@gmail.com*

Abstract: Data on the abundance, feeding guilds, flightlessness and endemic status of darkling beetles from selected forest sites and agriculture fields in the moist south Western Ghats in south India are provided. Overall abundance, diversity and evenness were higher in agriculture fields than in forest. *Luprops tristis* was the major species in agriculture field and *Gonocephalum bilineatum* in forest. Mycetophagous and detritivorous guilds were reported from the agriculture fields and detritivorous guild alone from the forests. Epigean, subterranean, corticolous, dung associated and mycetophagous darkling beetles were present in agriculture fields in contrast to the record of epigean and subterranean forms in forests. Higher abundance of flightless platynotine genus *Menearchus,* endemic to the Indian subcontinent in the agricultural field is attributed to the decaying organic matter availability in the open, dry environment conditions in agriculture field.

Key words: Darkling beetles, the Western Ghats, feeding guilds, Endemism.

Introduction

The coleopteran family Tenebrionidae, popularly known as darkling beetles, is the fifth largest beetle family following Curculionidae, Staphylinidae, Chrysomelidae and Scarabaeidae, including more than 20,000 species belonging to 96 tribes and 10 subfamilies (Bouchard *et al*. 2005). Though predominantly distributed in semi-arid areas, tenebrionids occur in many terrestrial ecosystems, where they can be found under stones or bark (Tezcan *et al*. 2012). Though tenebrionids are predominantly detritivores, many are herbivorous, mycetophagous and omnivorous (Borror 1996; Matthews & Bouchard 2008).

A few Tenebrionidae are of some direct economic importance as pests since certain species in larval stage, known as false wireworms, attack roots and young crop shoots

(*Pterohelaeus*, *Celibe*, *Isopteron*, *Mesomorphus* and *Gonocephalum*); others, known as mealworms, occur as pests in stored grains (*Tenebrio*, *Alphitobius* and the flour beetle *Tribolium*) (Matthews & Bouchard 2008).

Data on the feeding habits and ecology of tenebrionids in the Indian subcontinent are mostly confined to the biology of pest species such as *Tribolium castaneum* and *Alphitobius diaperinus* (Battu & Dhaliwal 1975), including a report of infestation of *A. diaperinus* by *Subulura brumpti* in poultry houses (Karunamoorthy *et al*. 1994) and association of *A. diaperinus* and *T. castaneum* with bird nests (Bhattacharyya 1995), bionomics and host plant preference of the home invading nuisance pest *Luprops tristis* in rubber plantation belts (Sabu *et al*. 2007, 2008), efficacy of the protein-enriched flour of pea (*Pisum sativum*) against *Tribolium castaneum* (Pretheep-Kumar *et al*. 2007) and comparison of diversity of tenebrionid populations in agroforest, ragi field and grasslands in Karnataka (Gowda 2010). Apart this latter study (Gowda 2010), there is no data on the ecology of tenebrionids in south India and in particular from the Western Ghats, a global hotspot of biodiversity. The present study provides data on the feeding guilds, habitat preference and pest status of the tenebrionid beetles from the moist south Western Ghats in south India.

Material and methods

Study site: Beetles were collected from four forest areas [Sholayar (10° 18' 34.98" N; 76° 43' 47.60" E; Evergreen; 1200 masl), Vazhachal (10° 17' 55.38" N; 76° 34' 6.05" E; Evergreen; 1300 masl), Idukki (10° 6' 20.70" N; 76° 42' 39.41" E; Evergreen; 1700 masl) and Thekkady (09° 26.699' N; 77° 05.170' E; Evergreen; 1450 masl)] and four agriculture fields [Omassery (11° 22.170' N; 75° 56.409' E; 52 masl), Ponoor (11° 28.138' N; 75° 55.476' E; 50 masl), Chemperi (12° 05.737' N; 75° 32.822' E; 60 masl) and Thamarassery (11° 24.568' N; 75° 56.118' E; 50 masl)] in the moist south Western Ghats (Fig. 1).

Beetles were collected by using pitfall traps from September 2009 to May 2010. Each trap consisted of a plastic jar (210 mm diameter, 150 mm deep), buried in the ground with its rim at surface level, filled with a mixture of water and propylene glycol, and covered with a square shaped plastic sheet supported on iron rods to restrict desiccation on warm days and flooding on rainy days. Twenty pitfall traps were used in each sampling site. Pitfall traps were disposed in a line transect, 25 meters equidistant from each other. Habitat preference of tenebrionid species is based on Lawrence *et al*. (1999). Feeding guild type is based on Borror *et al*. (1996).

Data analysis: Shannon diversity (H') and Buzas and Gibson's evenness ($e^{H/S}$) were estimated for both agriculture and forest habitats. Normality of data was tested using Jarque-Bera test. Variation in species abundance was analysed with ANOVA followed by paired Tukey test. Significance level was set at $P < 0.05$. Species richness was predicted with the Chao1 non-parametric estimator by using EstimateS software (Colwell 2000). All other diversity and statistical analyses were done with PAST version 2.17c Software (Hammer *et al*. 2001).

Results

Abundance and Diversity: Six tenebrionid beetle species belonging to five genera and four tribes were recorded from the forest habitat and 22 species belonging to 14 genera and eight tribes from the agriculture field (Figs 2-4). Overall faunal abundance and species richness was higher in the agriculture field than in the forest habitat: Chao1 for forest = 5.5 (bias = 0.1); Chao1 for agriculture field = 22 (bias = 0). Species abundance of the most abundant species in the agriculture field decreased as follows: *Luprops tristis* > *Gonocephalum bilineatum* > *Menearchus balteatus* > *Mesomorphus villiger* > *Alphitobius diaperinus* (Table 1). In the agriculture filed, the most abundant species were *Gonocephalum bilineatum* (Fig. 2F) and *Menearchus balteatus* (Fig. 3C) in forest (Table 1). Diversity was greater in the agriculture field (H' = 6.5) than in the forest habitat (H' = 5.4) (p-value for difference tested with bootstrap analysis p = 0.001). The two habitats did not differ for evenness ($e^{\wedge H/S}$ = 0.7 for forests; $e^{\wedge H/S}$ = 0.7 for agriculture; p-value for difference tested with bootstrap analysis p = 1.0).

Feeding Guilds: Twenty detritivorous species and two mycetophagous species were recorded from the agriculture field. Abundance of detritivorous species was higher in the agriculture field than in the forest. Only detritivorous species namely, *Alphitobius laevigatus* (Fig 2B), *Gonocephalum bilineatum* (Fig 2F), *Luprops devagiriensis, L. tristis* (Fig. 3B), *Menearchus balteatus* (Fig. 3C) and *Mesomorphus villiger* (Fig. 3H) were recorded from forest habitat (Table 1).

Habitats: Epigean, subterranean, corticolous, dung associated and mycetophagous species were recorded from the agriculture field. By contrast, only epigean and subterranean species were recorded in the forest. Epigean and subterranean species dominated in both agriculture field and forest habitats (Tables 2 and 3).

Flightlessness and Endemism: Members of the flightless genus *Menearchus* (Fig. 3C-D), endemic to the Indian subcontinent were collected in both the agriculture field and forest habitats with higher richness in the agriculture field. Higher abundance of flightless beetles were recorded in the agriculture field ($t = 11.2$; $p<0.000$) (Table 1).

Pest species: Six pest species [*Alphitobius diaperinus* (Fig. 2A), *Gonocephalum bilineatum* (Fig. 2F), *G. depressum* (Fig. 2G), *G. oblongum* (Fig. 2H), *Luprops tristis* (Fig. 3B), and *Mesomorphus villiger* (Fig. 3H)] were collected from the agriculture field and three pest species [*G. bilineatum* (Fig. 2F), *L. tristis* (Fig. 3B), and *M. villiger* (Fig. 3H)] in the forest habitat, respectively. Abundance of pests was higher in the agricultural field ($t = 13.92$; $p<0.000$) (Table 1).

Discussion

Abundance and richness: Higher abundance and richness of Tenebrionidae in the agricultural field than in the forest habitat is arising from the high abundance of three pest species, *Luprops tristis* (Sabu *et al*. 2008), *Mesomorphus villiger* (Sitaramaiah *et al*. 1999) and *Alphitobius diaperinus* (Karunamoorthy *et al*. 1994). *Luprops tristis*, known as Mupli beetle, is a serious home invading nuisance pest (Sabu *et al*. 2007) and *Alphitobius diaperinus* is a pest of stored and spilled grains and poultry (Dunford & Kaufman 2006). *Mesomorphus villiger,* known as ‘tobacco ground beetle’, is a pest of tobacco seedlings (Sitaramaiah *et al*. 1999). Agricultural fields in the region are mostly composed of monoculture plantations and the dry habitat conditions, with fallen litter prevailing in the monoculture plantation floor during pre-summer and summer, make them an ideal habitat for tenebrionids (Sabu & Vinod 2009; Carpaneto & Fattorini 2001). Tenebrionidae include many thermophilic species, often adapted to arid environments (Fattorini & Fowles 2005; Fattorini 2008). Low habitat preference of thermophilic tenebrionids towards the cool, moist conditions in forests with dense vegetation cover, as well as the presence of the strong root mass of perennial trees in forests that impedes the movement of tenebrionids over ground (Carpaneto & Fattorini 2001; for more details), may explain their lower abundance in the forest habitat. The more open and drier habitat conditions typical of agriculture fields in the study region, along with the availability of resources in the form of fallen litter, may explain the higher diversity of Tenebrionidae in the agriculture fields than in the moist forests.

Feeding guilds: High abundance of detritivorous species (namely, *L. tristis*, *G. bilineatum*, *M. balteatus*, *M. villiger* and *A. diaperinus*) in the agriculture fields contribute towards the dominance of detritivores. Lesser availability of the specific habitats, namely the fruiting bodies of bracket fungus *Ganoderma applanatum* on which the mycetophagous species *Byrsax cornutus* (Arunraj *et al*. 2013a) and *Cryphaeus tenuis* (Arunraj & Sabu 2012) dwell, could be the reason for low abundance and species richness of mycetophagous tenebrionids in the agriculture fields. Further, it could be the inadequacy of pit fall traps that could not collect the tenebrionids possibly present on the fallen and standing dead trees that led to their low abundance in forests.

Habitats: Tenebrionidae are predominantly epigean and subterranean (Matthews & Bouchard 2008). High abundance of epigean and subterranean species, such as *L. tristis*, *G. bilineatum*, *M. balteatus* and *M. villiger*, in the agricultural fields is the reason for dominance of species associated with epigean and subterranean habitat types. Abundance of dung dwelling forms is attributed to the presence of *Alphitobius diaperinus* in the dung imported from poultry belts in Tamil Nadu (Arunraj *et al*. 2013b). No records of corticolous, dung dwelling and fungus dwelling species and the low abundance of subterranean and epigean species in the forest habitat lead to the following conclusions. The strong competition for dung resources from highly abundant dung beetles, presence of other mycetophagous and corticolous groups better adapted to persist in the moist forests, the moist conditions prevailing in the corticolous habitat (bark) and in forest floor, and the root mass of perennial trees that impedes the movement of tenebrionids over ground (Carpaneto & Fattorini 2001) probably make the forest habitat less favourable for tenebrionids compared to the open and dry agricultural fields.

Flightlessness and endemism: Evolution of endemism usually requires the presence of some physical barrier that prevents a species to disperse and the origin of a flightless species requires an isolation in a protected, resource-rich environment and a reduced necessity of wings (Roff 1990; Matthews & Bouchard 2008). Subterranean habits of living in small burrows under large stones, protection by odoriferous defensive gland secretions and rich resource availability might have allowed flightlessness to evolve in Asian genera of Platynotini as in the case of island tenebrionids (Fattorini 2009). Thus, the availability of copious amount of detritus, the subterranean habit and the presence of defensive glands are key factors promoting the evolution of flightlessness and the abundance of platynotine genus *Menearchus*, endemic to the Indian subcontinent in the region.

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Correspondence: Sabu T. K. e-mail: *sabukthomas@gmail.com*
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Figure 1. Map of India showing location of Western Ghats (**A**); Kerala state and location of study sites (**B**).

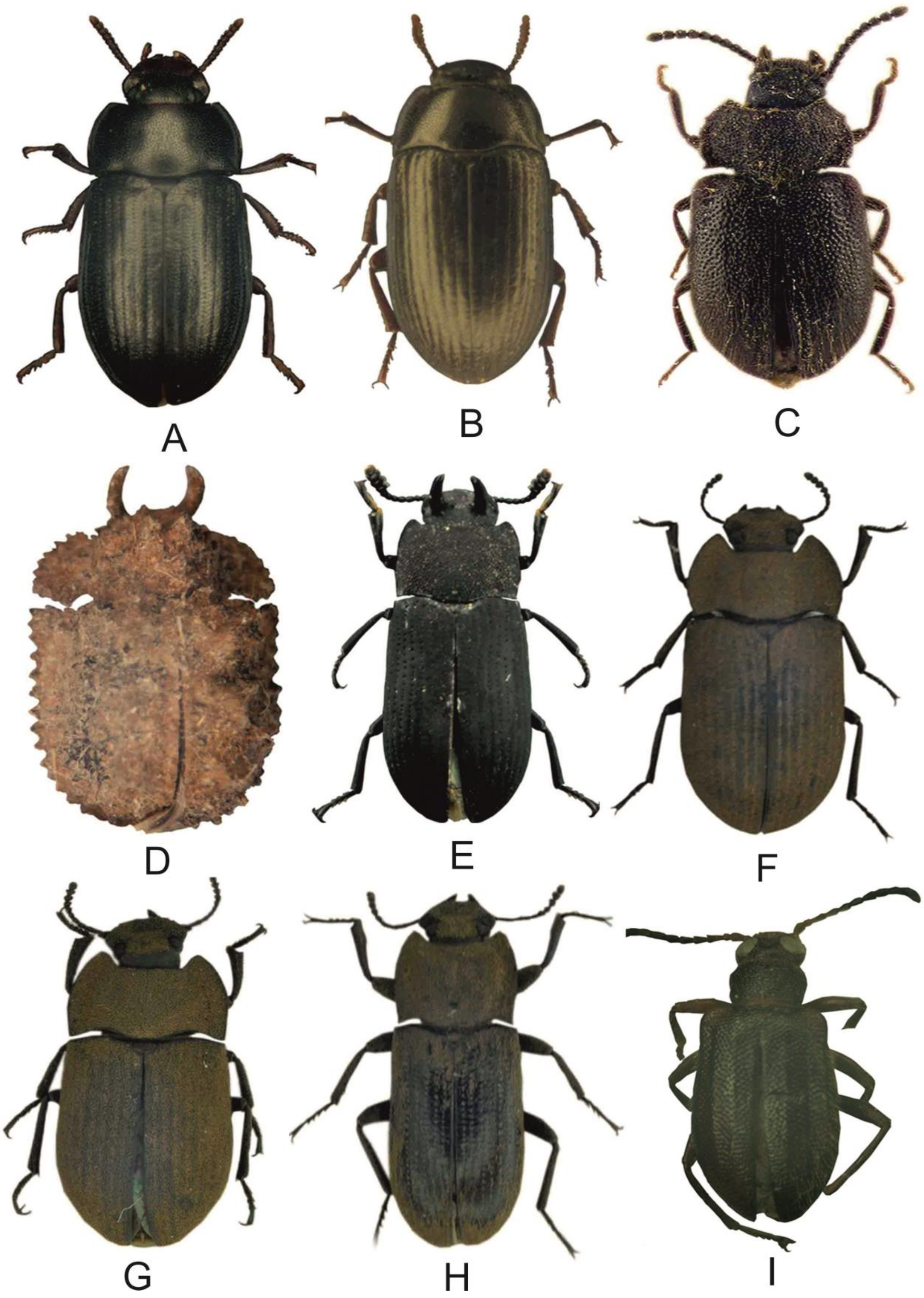

Figure 2. Tenebrionid beetles sampled in the Western Ghats. **A,** *Alphitobius diaperinus*; **B,** *A. laeigatus*; **C,** *Anaedus marginicollis*; **D,** *Byrsax cornutus*; **E,** *Cryphaeus tenuis*; **F,** *Gonocephalum bilineatum*; **G,** *G. depressum*; **H,** *G. oblongum*; **I,** *Lagria andrewesi*.

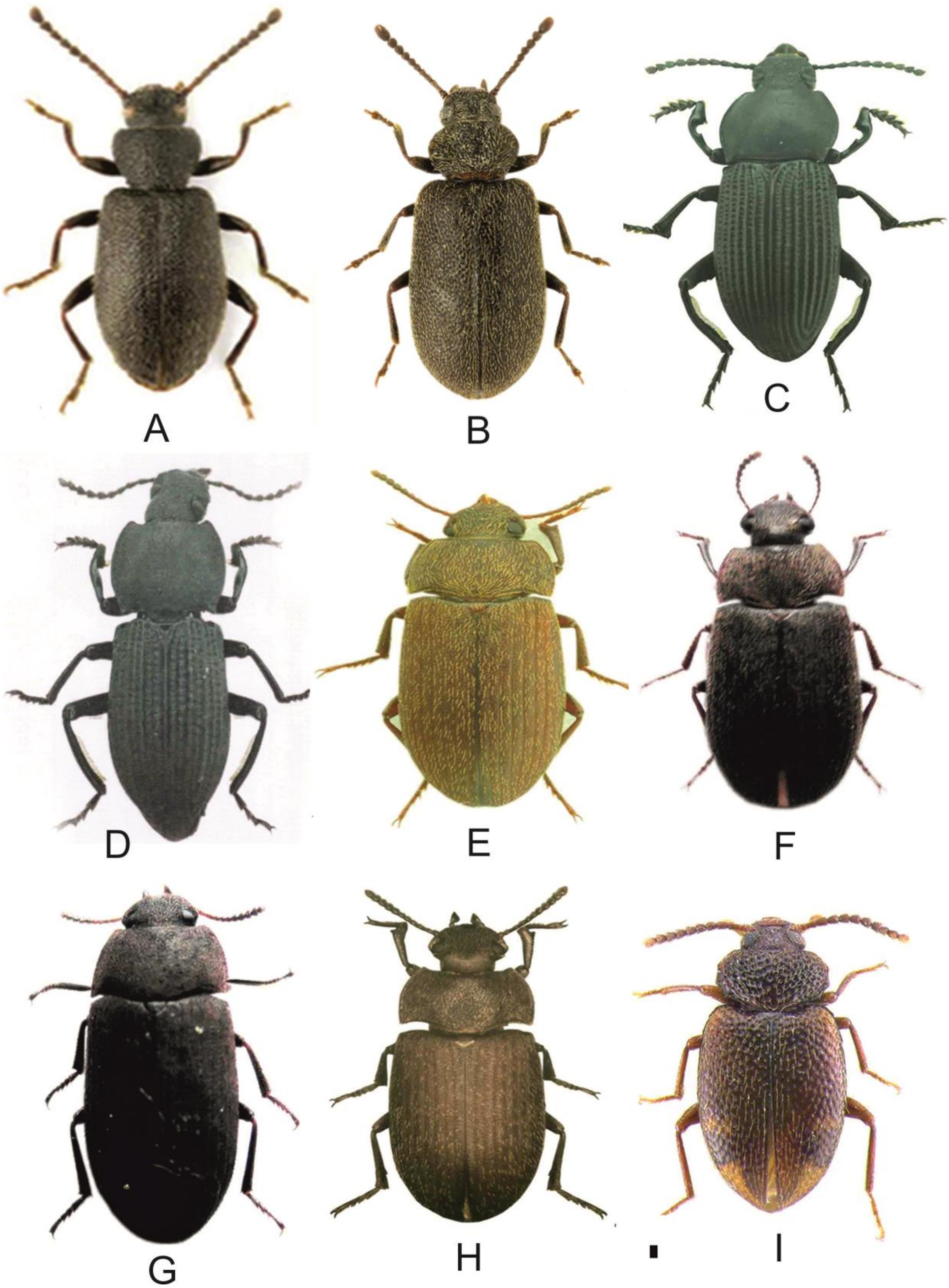

Figure 3. Tenebrionid beetles sampled in the Western Ghats. **A,** *Lagria gracilior*; **B,** *Luprops tristis*; **C,** *Menearchus balteatus*; **D,** *M .hirtipes*; **E,** *Mesomorphus gridelli*; **F,** *M. kulzeri*; **G,** *M. striolatus*; **H,** *M. villiger*; **I,** *Sphingocorse keralensis*.

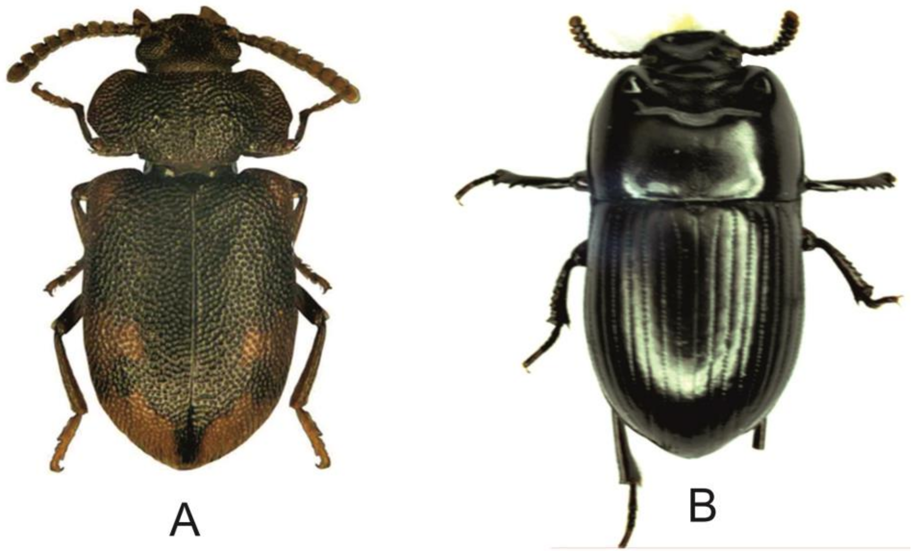

Figure 4. Tenebrionid beetles sampled in the Western Ghats. **A,** *Spinolyprops himalyicus*; **B,** *Uloma polita*.

Table 1. Abundance (Mean ± SD) of tenebrionid beetle species in forest and agricultural fields in the moist south Western Ghats (Abbreviations for habits: R- Rubber litter, LA- Light attracted, S- Under stones, L- Litter, B- Bark of trees, P- Under pumpkins, RB- Roof of buildings, PD- Poultry dung, G- Stored grains, GR- Garden refuse, C- Subcortical, FB- Fungal fruiting bodies, RW- Rotten wood; Abbreviations for guilds: D- Detritivore, M- Mycetophagous; Abbreviations for citations: a- Sabu *et al.* 2007, b- Watt 1992, c- Ferrer 2002, d- Dunford & Kaufman 2006, e- Matthews & Bouchard 2008; ***** Flightless).

Species	Habits	Guild	Forest	Agricultural field	t	p
Alphitobius diaperinus (Panzer, 1797)	PD, G (d) (b)	D(d)	0.00±0.00	0.79±1.84	6.63	***
Alphitobius laevigatus (Fabricius, 1781)	GR (d) , L	D(c)	0.62±1.83	0.00±0.00	5.18	***
Amarygmus tenuicornis Motschulsky, 1863	**C** (b)]	D(b)	0.00±0.00	0.03±0.16	2.48	*
Anaedus marginicollis (Fairmaire, 1896)	R	D	0.00±0.00	0.13±0.57	3.62	***
Byrsax cornutus Gebien, 1906	FB, LA, L	M	0.00±0.00	0.03±0.16	2.48	**
Cryphaeus tenuis Fairmaire, 1896	FB ,DW(e)	M	0.00±0.00	0.45±1.00	-7.03	***
Gonocephalum bilineatum Walker, 1858	L, S (b)	D(b)	1.65±2.86	3.03±3.41	4.80	***
Gonocephalum depressum Fabricius, 1801	S (b), L, LA	D(b)	0.00±0.00	0.03±3.4	0.60	N.S
Gonocephalum oblongum Fabricius, 1801	S, (b) L, LA	D(b)	0.00±0.00	1.27±1.15	17.23	***
Lagria andrewesi (Borchmann, 1925)	L	D	0.00±0.00	0.06±0.33	-2.93	**
Luprops devagiriensis Sabu et al. 2007	L (a)	D(a)	0.04±0.19	0.00±0.00	3.05	**
Luprops gracilior Fair-maire, 1896	L, S (a)	D(a)	0.00±0.00	0.39±1.27	4.72	***
Luprops tristis (Fabricius, 1801)	R; LA (a)	D(a)	0.15±0.46	4.00±5.70	3.40	***
Menearchus balteatus (Kaszab 1975) *****	S	D	0.91±1.45	2.75±2.59	10.28	***
Menearchus cirratus (Kaszab 1975) *****	S	D	0.00±0.00	0.08±0.38	3.05	**
Menearchus hirtipes Kaszab, 1975*****	S	D	0.00±0.00	0.04±0.19	3.05	**
Menearchus tibialis Kaszab, 1975*****	S	D	0.00±0.00	0.18±0.77	3.51	***
Mesomorphus gridellii Kaszab 1963	S and V(c)	D(c)	0.00±0.00	0.48±1.43	5.13	***
Mesomorphus kulzeri Kaszab 1963	S and L (c)	D(c)	0.00±0.00	0.16±0.8	3.15	**
Mesomorphus striolatus Fairmaire 1896	S (c)	D(c)	0.00±0.00	0.28±0.81	5.28	***
Mesomorphus villiger Blanchard, 1853	S, L, B, RB P (c)	D(c)	0.50±0.83	1.2±1.84	5.38	***
Sphingocorse keralensis Kaszab 1979	L	D	0.00±0.00	0.03±0.16	2.48	*
Spinolyprops himalyicus Kaszab 1965	L & S	D	0.00±0.00	0.48±1.40	7.18	***
Uloma polita (Wiedemann, 1821)	RW (b), L	D(b)	0.00±0.00	0.03±0.16	2.48	*
Overall abundance of detritivore guild			0.18±0.41	0.70±1.12		
Overall abundance of mycetophagous guild			0.00±0.00	0.24±0.30		

* p ≤ 0.05; ** p ≤ 0.01; *** p ≤0.001; N.S: not significant.

Table 2. Abundance (Mean ± SD) of tenebrionid beetle species belonging to five different habitat types in the forests and agricultural fields of moist south Western Ghats.

Habitat types	Forest	Agricultural field	t	p
Epigean	1.05 ± 2.3	15.5 ± 8.77	0.0959	N.S
Subterranean	11.6 ± 9.84	30.5 ± 12.73	-0.641	N.S
Corticolous	0.0 ± 0.0	0.05 ± 0.22	-1.762	N.S
Coprophagous	0.0 ± 0.0	2.1 ± 3.4	-4.866	***
Mycetophagous	0.0 ± 0.0	0.35 ± 0.67	-4.112	***

* p ≤ 0.05; ** p ≤ 0.01; *** p ≤0.001; N.S.: not significant.

Table 3. Statistical analysis of the abundance of the guilds of Tenerbrionidae in the agriculture and forest belts of the moist south Western Ghats [E- epigean, S - subterranean, C - corticolous, D- dung associated, M- mycetophagous].

Habitat Type		ANOVA		Tukey		
		F	***P*- value**	**Guild**	**t-value**	***P*- value**
Guild composition within each habitat	**Agricultural belts**	79.74	***	C-M	1.33	N.S
				C-D	6.11	***
				C-E	6.12	***
				C-S	16.09	***
				M-D	4.77	***
				M-E	4.78	***
				M-S	14.75	***
				D-E	0.01	N.S
				D-S	9.98	****
				E-S	9.97	****
	Forests	85.53	***	C-M	0.00	N.S
				C-D	0.00	N.S
				C-E	1.20	N.S
				C-S	14.88	***
				M-D	0.00	N.S
				M-E	1.20	N.S
				M-S	14.88	***
				D-E	1.20	N.S
				D-S	14.88	***
				E-S	13.68	***

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; N.S : not significant