Article

Diversity and population dynamics of phytophagous scarabaeid beetles (Coleoptera: Scarabaeidae) in different landscapes of Himachal Pradesh, India

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Abstract

Scarabaeid beetles constitute a major group of defoliators of cultivated and wild plants. Therefore, it is important to understand their diversity, abundance and distribution for planning effective pest management programmes. We surveyed scarabaeid beetles from 8 landscapes from different zones in Himachal Pradesh (N 32^o 29' and E 75^o 10'), India. In 2011 and 2012, surveys were conducted during 4 months period (May-August) by using UV light traps. A total of 13,569 scarabaeid adults of 20 genera and 56 species belonging to subfamilies Melolonthinae, Rutelinae, Cetoniinae and Dynastinae were recorded. The five most common species were *Brahmina coriacea*, *Adoretus lasiopygus*, *Anomala lineatopennis, Maladera insanabilis* and *Holotrichia longipennis*. They comprised 9.88-10.05, 7.18-7.76, 7.13-7.27, 6.80-7.62 and 5.22-5.30% during 2011-12, respectively. *Anomala* (10 species) was the most dominant genus in the present study, whereas Melolonthinae was the most dominant subfamily accounting 53.23% of total scarabs collected from the study sites. Among different landscapes, Palampur had maximum diversity and abundance, while Shillaroo had least diversity but more abundance of single species *B. coriacea*. The value of alpha diversity indices *viz.* Shannon index was maximum (H'=3.01-3.03) at Palampur. This indicates maximum evenness and abundance of species at Palampur. Shillaroo had lowest Shannon index (H'=1.12-1.17) and Pielou’s evenness index (J'=0.46-0.49). This showed least species diversity and higher unevenness of scarabaeid beetles at Shillaroo. The results of beta diversity analysis revealed poor similarity of scarabaeid species between different sites confirming that the scarabaeid community in the north western Himalayan regions is much diverse.

Keywords abundance; biodiversity; Coleoptera; Himachal Pradesh; India; richness; Scarabaeid beetles.

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1 Introduction

Scarabaeidae is the second largest family within the order Coleoptera, and is cosmopolitan in distribution (Ritcher, 1958). Scarabaeidae falls into two main groups, one group including Coprinae, Aphodiinae, Geotrupinae and Troginae which are either saprophagous or fungus feeders and form a separate group 'Laprosticti'. The second group includes the subfamilies Melolonthinae, Rutelinae, Dynastinae and Cetoniinae which are strictly phytophagous forming 'Pleurosticti' (Ritcher, 1958). The world fauna of scarabaeids exceeds 30,000 species (Mittal, 2000; Jameson and Ratcliffe, 2001). Maximum numbers occur in the tropical areas of the world, particularly in the African and Oriental regions. The family Scarabaeidae represents about 2,500 species from the Indian sub-continent to which the majority of the phytophagous scarabs belong to and the economically most important sub families include Melolonthinae, Rutelinae, Dynastinae and Cetoniinae (Ali, 2001). The scarabaeid beetles and their larvae cause extensive damage to both cultivated and forest plants. The adult beetles become active during May-June and feed on the foliage of different fruit and forest trees (Mehta et al., 2008). Adults of the sub-family Melolonthinae and Rutelinae are pre-eminently leaf feeders (Arrow, 1917), whereas the adults of Cetoniinae feed on flowers and fruits, and are popularly referred to as flower beetles. However, the larvae of scarabaeids commonly known as whitegrubs, cause extensive damage to the roots of cereals, legumes, small fruit plants, shrubs and trees in many parts of the world. In India, whitegrubs are pests of national importance and cause extensive damage to field crops and fruit trees (Mehta et al., 2010). Among the soil macro fauna, whitegrubs form a major component both in number of species and diversity of habits (Veeresh, 1988).The scarab fauna is quite diverse, but in Indian sub-continent it is yet to be fully explored (Mishra and Singh, 1999). Scarabaeid beetles are serious pests of many field crops and fruit and forest trees (Lawrence et al., 2000). Loss in biodiversity and degradation of natural habitats due to climate change and human interference in natural ecosystem has necessitated the need to have an inventory of species richness in an ecosystem.

Sampling is the basis of documenting the spatial distribution of species or assessing changes in ecosystem structure, composition and function (Kremen et al., 1993; Heywood, 1995; Humphries et al., 1995; Stork and Samways, 1995; Yoccoz et al., 2001; Coscaron et al., 2009; Zhang, 2011). It is important to use simple and most effective methods to obtain an estimate of diversity and relative abundance of species (Southwood and Henderson, 2000). Different methods have been used for collecting beetles for research purposes, and for preparing inventories depending on their biology and host range (Lobo et al., 1988; White et al., 1990; Hayes, 2000; Falach and Shani, 2000; McIntosh et al., 2001; Missa et al., 2009).

Insects as a class respond to electromagnetic radiations from approximately 2537 A^0-7000 A^0, i.e., from ultraviolet to the infrared. At the long range end of the spectrum, the most effective wavelength for insects is of the order of 6500 A^0 (Detheir, 1953). Based on light as an attractant, a variety of insect traps have been developed and used to monitor long term changes in population of nocturnal insects. Light trap also provide information on time of arrival of a particular species insect in a particular locality (Saini and Verma, 1991).

Many studies have been focused focus on sampling methods for analyzing and assessing the diversity of scarabaeid beetles in different ecosystems (cultivated or forest ecosystem) by using different types of light traps (Sanders and Fracker, 1916; Morofsky, 1933; Stearns, 1937; Gruner, 1975; Forschler and Gardner, 1991; Kard and Hain, 1990; Rodriguez Jimenez et al., 2002; Zahoor et al., 2003; Pardo et al., 2005; Dhoj et al., 2009; Khanal et al., 2012; Kishimota et al., 2011; Gracia et al., 2008; Petty, 1977; Stewart and Lam, 1968; Cho et al., 1989; Freitas et al., 2002). In India, several studies have been conducted in different regions to explore the scarab fauna, their diversity and bioecology by using different light sources for reporting and conservation of species (Pal, 1977; Nath et al., 1978; Bakhetia and Sohi, 1982; Tripathi and Gupta, 1985; Vora and Rama Krishnan, 1991; Chandramohan and Nanjan, 1991; Mishra and Singh, 1996; Mishra and Singh, 1997; Mishra and Singh, 1999; Patel and Patel, 1999; Bhat et al., 2005; Thakare and Zade, 2012; Chandra and Gupta, 2012; Dhasad et al., 2008; Bhawne et al., 2012; Viraktamath and Kumar, 2005; Chenchaiah, 2006; Devi et al., 1994; Bhagat and Kashyap,1997).

The scarabaeid beetles and whitegrubs are widely distributed throughout the cultivated and forest areas of Himachal Pradesh (Arrow, 1917; Bhalla and Pawar, 1977; Chandra, 2005; Sharma and Bhalla, 1964; Sharma et al., 1969, 1971, 2004; Chandel et al., 1994; Kumar et al., 1996). However, little information is available on species diversity, emergence pattern, richness and relative abundance in different agroecological regions of Himalayan regions. This poses a basic problem in developing effective integrated pest management schedules against these pests. To combat the burgeoning problem of whitegrubs, it is imperative to understand the species distribution in different regions, so to develop a strategy for their management, and conservation in wild habitats to maintain the ecological balance. Keeping these points in view, we studied the diversity and relative abundance of scarabaeid beetles at 8 locations of Himachal Pradesh, India by using UV light traps between May-August during 2011 and 2012.

2 Methods

2.1 Field sites

Populations of scarabaeid beetles were monitored through UV light traps installed in six districts in zone I (sub-tropical, sub-mountane and low hills), zone II (sub-temperate, sub humid mid hills), zone III (wet-temperate high hills) and zone IV (dry-temperate high hills and cold deserts) of Himachal Pradesh, in the northwestern Himalayan region, India in 2011 and 2012 lying between N 32^0, 05 to N 31^0, 12 Latitude and E 76^0, 32 to E 77^0, 25 Longitude with Altitude ranging from 1222-2479 m amsl (Fig. 1). The entire light traps installed were either in fruit orchards or farmlands with different cropping patterns, which were grouped on the basis of terrain and vegetation characteristics. The details of study sites are given in Table 1.

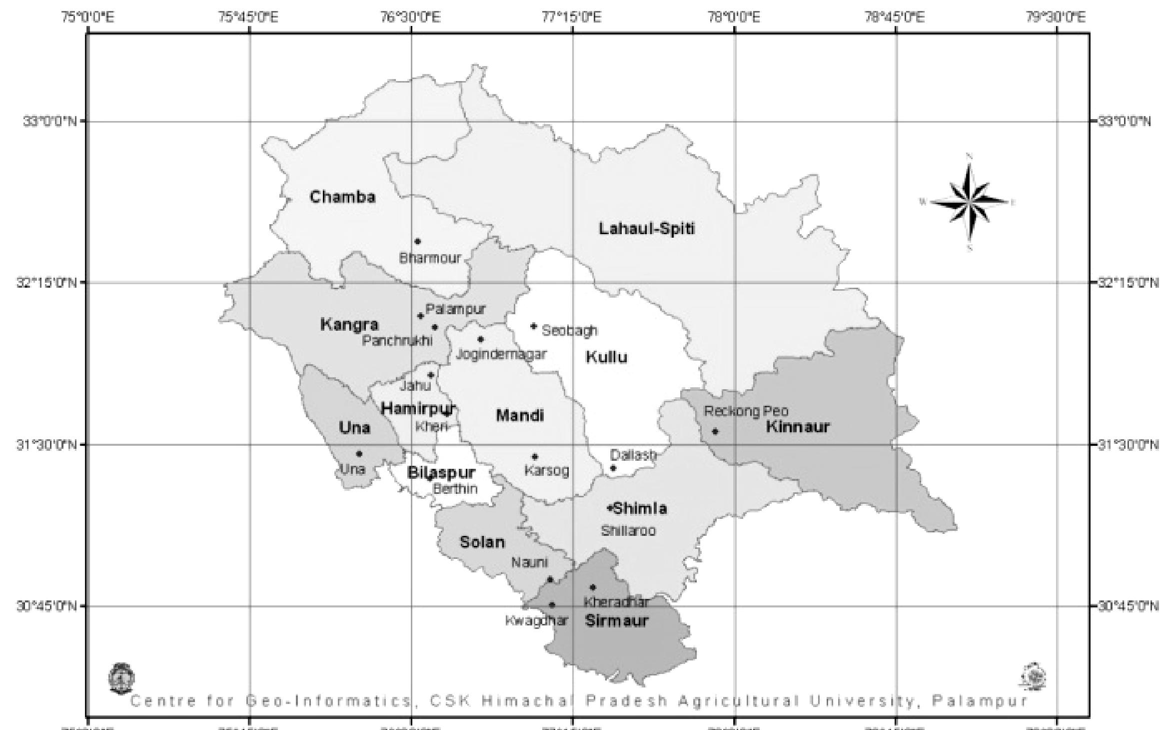


Fig.1 Map showing sites for sampling of scarab beetle populations in Himachal Pradesh, India.

Table 1 Location of light traps in Himachal Pradesh, 2011 and 2012.

District	Location	Zone	Latitude	Longitude	Altitude (m)	Crop habitat	Soil type
Kangra	Palampur	II	N 32^0, 05.666′	E 76^0, 32.781′	1222	*Toon*, peach, pear, grasslands	Silty clay loam
Kullu	Seobagh	II	N 32^0, 02.958′	E 76^0, 37.533′	1327	Apple , pear, peach, grassland	Clay loam
	Dallash	III	N 31^0, 23.036′	E 77^0, 26.024′	2020	Apple, pear, apricot, potato, peas	Clay loam
Sirmaur	Kwagdhar	III	N 30^0, 45.409′	E 77^0, 09.235′	1774	Apple, pear, peach, wildrose, grassland	Sandy loam/ clay loam
	Kheradhar	III	N 30^0, 50.035′	E 77^0, 20.634′	2032	Apple, walnut, pear, potato	Sandy loam/ clay loam
Shimla	Shillaroo	III	N 31^0, 12.409′	E 77^0, 25.462′	2479	Apple, walnut, pear, potato, grassland	Sandy loam/ clay loam
Kinnaur	Reckong Peo	IV	N 31^0, 31.348′	E 77^0, 47.856′	2117	Apple, pear, walnut, apricot, potato, rajmash	Gravelly loamy sand
Chamba	Bharmour	IV	N 32^0, 26.505′	E 76^0, 31.949′	2169	Apple, pear, apricot, potato, rajmash, grassland	Sandy loam

2.2 Collection of adult beetles from light trap

Light traps were used for four months, and the beetle populations monitored regularly. The light traps were installed at 8 locations and there was one trap at each location. The light traps (Plate 1) were placed in the centre of the fields at a height of about 3 metre above the ground and operated between 7:00 PM to 11:00 PM to attract the scarabaeid beetles which are positively heliotactic in nature. The trapped beetles were collected and separated species-wise and the cumulative count of each species was determined at each location. These beetles were grouped on the basis of relative abundance and frequency for accessing the relative importance of different species. The diversity of scarab beetles depends on the availability of food for larvae and adult, weather conditions and soil type. Therefore, to reduce the seasonal effects, the beetles sampled between May-June (2011 and 2012) which is the major activity period of all the scarabaeids were used for assessing the species diversity. Beetles collected using light trap were pinned and preserved in the insect museum.

The light trap (Plate 1) was made of red coloured PVC plastic. The plastic funnel was 25 cm in height, and in diameter of 30 cm. The bottom diameter of the funnel was 5 cm. The rain shed cone for protecting the bulb was fixed at 17 cm above the funnel with the help of three white metal sheets. The diameter of the rain shed cone was 20 cm. The light trap had three baffles (30 cm x 10 cm), placed at a uniform distance of 10 cm around the circumference of funnel. The baffles were fixed to emit light uniformly in all directions without any interference, when the beetles are attracted to light they collide with baffles and fall into the trap. A nylon bag was attached to the bottom of this funnel. The light source consisted of hard glass bulb with copper wire choke. The capacity of bulb was 120 Watts with UV radiation in the visible spectrum range having bluish light (Plate 2).

The scarab adults collected during the surveys and the adults emerging from larvae collected from different locations were identified to the species level based on the keys and characters listed by Veeresh (1977), Mittal and Pajni (1977), Khan and Ghai (1982) and Ahrens (2005). The identity of adult beetles was confirmed by Dr. V.V. Ramamurthy, Indian Agriculture Research Institute, New Delhi, India. Some of the samples were compared with scarabaeid collection available in Museum of Forest Research Institute, Dehradun, India.


a


b

Plate 1 UV light trap at Palampur (a), and at Kwagdhar (b).

2.3 Data analysis

2.3.1 Alpha diversity

The numbers of species recorded per site were considered as alpha diversity. Richness (number of species), abundance (number of individuals) and four indices were used to access species diversity. The diversity indices assume that individuals are randomly sampled from an infinitely large population. The Shannon index (H') explains the evenness of the abundance of species, while the Simpson's index of diversity (D) is less sensitive to species richness, but more sensitive to the most abundant species (Price, 2004; Hill, 1973; Oksanen, 2013; Wilson and Peter, 1988; Whittaker, 1960, 1965; Chao, 2004). Pielou's evenness index (J') explains the evenness of allotment of individuals among the species (McDonald et al., 2010). The diversity indices were based on all the information recorded during study period at each site by using the following indices (Krebs, 2001).

i) Shannon index

$$H' = -\sum_{i=1}^{S} (p_i)\ (\log_2 p_i)$$

ii) Simpson's index of diversity

$$D = 1-\sum_{i=1}^{s} (p_i)^2$$

iii) Simpson's reciprocal index= 1/D

iv) Pielou's evenness index (J')

$$J' = H'/ H_{max}$$

where

H'= Shannon diversity index

p_i= Proportion of total sample belonging to the ith species.

S= Number of species.

∑= Sum from species 1 to species S

D= Simpson's index of diversity.

N= Total percentage cover or total number of organisms.

n= Percentage cover of a species or number of organisms of a species

J'= Evenness of allotment of individuals among the species.

H_{max}= Maximum species diversity (H') = Log_2S

Diversity dominance plots were drawn to assess the changes in abundance in each species at each locality. The properties and merit of each index, and the appropriateness of each index has been discussed extensively by Kempton (1979); Routledge (1979); Koeleff et al. (2003); Magurran (1988, 2004). A combination of indices, which measure species richness, diversity and evenness are more appropriate for the purpose (McDonald et al., 2010).

2.3.2 Beta diversity

Bray-Curtis index to estimate species similarity between two habitats was calculated as follows (Chandra and Gupta, 2012; Koleff et al., 2003).

$$C_N = 2jN/(Na+Nb)$$

where

Na = the total number individuals in site Aj

Nb = the total number of individuals in site Bj

2jN = the sum of the lower of the two abundance for species found in both sites. The index value ranges from one (or 100) when two samples are identical, 0 when there are no shared species between them. The index is selected because it reflects differences in total abundance rather than relative abundance (Magurran, 2004).

Sorensens similarity index is a simple measure of beta diversity

$$ß=2C/(C+S_1+S_2)$$

where C= no. of shared species between different landscapes

S_1= no. of species in site 1

S_2= no. of species present in site 2.

Jaccard similarity index was calculated according to Jaccard (1912) by using the following formula.

$$S=a/(a+b+c)$$

where

a= No. of shared species between different landscapes

b= No. of species in site 1

c= No. of species present in site 2.

3 Results

3.1 Species composition

Information in relation to the topography, climate, soil, and vegetation are given in Table 1. A total of 13,569 scarabaeid beetles were collected in the light traps from 8 landscapes in Himachal Pradesh with an average of 316.75 individuals per trap per month. The total scarabaeid fauna represented 20 genera and 56 species during the period. The collected beetles belonged to four sub-families, Melolonthinae (51.79%), Rutelinae (33.93%), Cetoniinae (10.71%) and Dynastinae (3.57%). The light trap catches from 8 locations completed at 29 (Fig. 2) Melolonthinae species in 10 genera (Fig. 3), 19 Rutelinae species in 5 genera, 6 Cetoniinae species in 4 genera, and 2 Dynastinae species. Maximum species belonged to Melolonthinae (52.95 and 53.5% during 2011 and 2012, respectively (Fig. 4) followed by Rutelinae (42.66% in 2011 and 42.37% in 2012).The species belonged to Cetoniinae and Dynastinae were least abundant in terms of total number of individuals trapped during the study period (Fig. 4). The maximum number of scarabs across years and locations (Fig. 5) were caught in June (50.79%). The average trap catch during July, May and August was 29.81, 12.92 and 6.46%, respectively (Fig. 5). Species belonged to Melolonthinae and Rutelinae were the most abundant species of whitegrubs in Himachal Pradesh. However, the species belonged to these subfamilies are quite different in behavior and period of activity. Activity of Melolonthids was low in May (38.59%), but a sharp increase was observed in the activity of beetles of the subfamily with the onset of monsoon rains and it became most dominant group in June (87.84% of total catch) (Fig. 5). The activity of rutelinids was maximum during the hot summer in May (68.41%) and their number declined afterwards (Fig. 5).

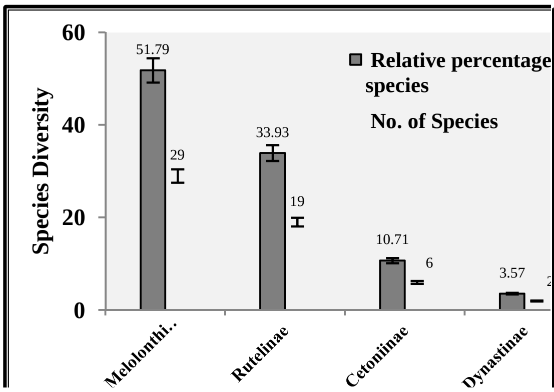


Fig. 2 Subfamily-wise distribution of scarabaeid species on light traps in Himachal Pradesh.

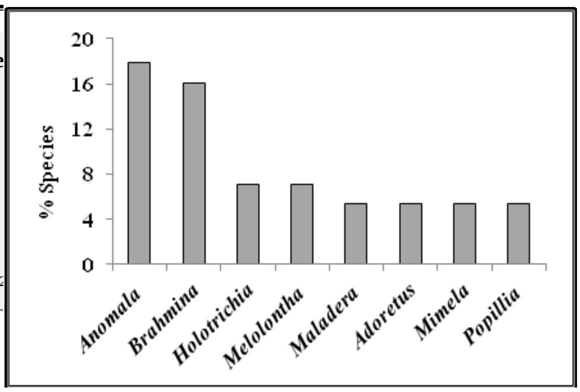


Fig. 3 Genus wise dominance of scarabaeids in light traps in Himachal Pradesh.

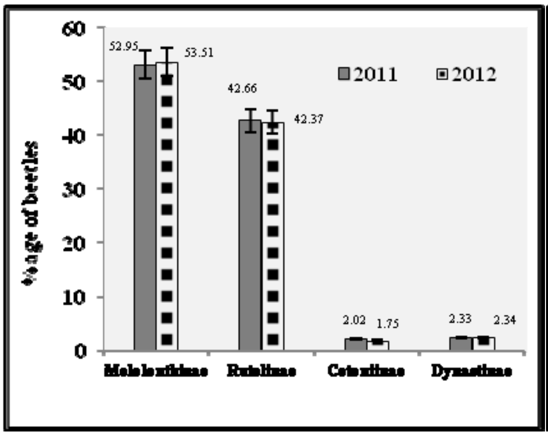


Fig. 4 Subfamily-wise distribution of number of individuals of scarabaeids caught in light traps in Himachal Pradesh.

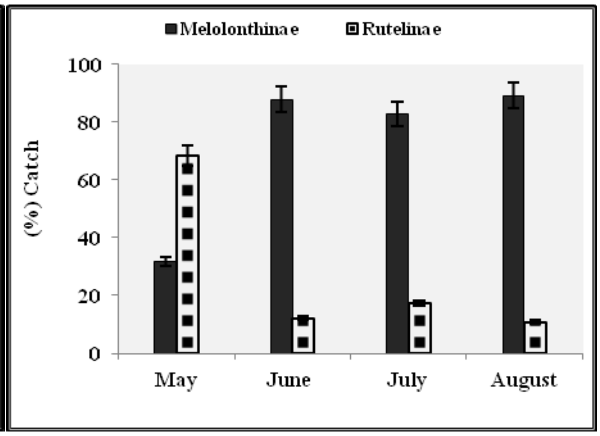


Fig. 5 Month-wise catch of beetles belonging to different subfamilies from Himachal Pradesh (in 2011 and 2012).

3.2 Distribution and abundance

Maximum diversity was recorded in genus *Anomala* with 11 species (Tables 2 and 3) followed by 9 in *Brahmina* and 4 in *Holotrichia*. The genera *Maladera, Melolontha, Adoretus, Mimela, Popillia* and *Protaetia* were represented by 3 species each (Tables 2 and 3).

Dominance diversity plots for 2011 and 2012 showed differences in populations of different species between the habitats (Fig. 6). The relative abundance of the scarabaeid adults was quite variable across habitats but number of some species showing high abundance when correlated with other less abundant species. *B. coriacea* was the most abundant species followed by *A. lasiopygus, A. lineatopennis, M. insanabilis* and *H. longipennis*. They accounted for 37.11% of total individuals collected (Fig. 7). *B. coriacea* (676 beetles/trap) accounted for 9.96% of the total number of scarabaeid beetles collected, followed by *A. lasiopygus* (506.5 beetles/trap) accounting for 7.47% of the total catch. The relative abundance of *M. insanabilis* and *A. lineatopennis* was 7.21 and 7.20%, with an average catch of 489.5 and 488.5 beetles/trap, respectively.

Table 2 Scarabaeid beetle species collected in UV light traps at different locations in Himachal Pradesh (May - August, 2011).

Species	Palampur		Kullu		Dallash		Shillaroo		Kheradhar		Kwagdhar		Bharmour		Reckong		Total no. of beetles	% Dominance
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%		
Apogonia carinata Barlow	8	0.67															8	0.12
Apogonia ferruginea Fab.			3	0.38													3	0.04
Apogonia villosella Bl.	40	3.33	30	3.75													70	1.04
Autoserica phthisica Br.	43	3.57	97	12.13													140	2.09
Brahmina bilobus Fab.			16	2.00									22	2.89	27	3.34	65	0.97
Brahmina coriacea (Hope)	4	0.33	103	12.88	72	6.77	25	70.5	14	21.2	78	7.75	77	10.1	10	12.3	838	12.50
Brahmina crinicollis Burm.			2	0.25							4	0.40	58	7.62	43	5.32	107	1.60
Brahmina flavosericea Br.	6	0.50			29	2.73	27	7.44			49	4.87	41	5.39	77	9.53	229	3.42
Brahmina kuluensis Moser													25	3.29			25	0.37
Brahmina sp. 1			17	2.13													17	0.25
Brahmina sp. 2							5	1.38									5	0.07
Brahmina sp. 3													3	0.39			3	0.04
Brahmina sp. 4															8	0.99	8	0.12
Holotrichia longipennis Bl.	89	7.40	87	10.88	85	7.99	28	7.71	61	8.75	63	6.26	41	5.39	60	7.43	514	7.67
Holotrichia nigricollis Br.	51	4.24															51	0.76
Holotrichia problematica Br.							8	2.20									8	0.12
Holotrichia sikkimensis Br.	54	4.49	42	5.25	57	5.36			22	3.16							175	2.61
Lepidiota stigma (Fab.)			5	0.63													5	0.07
Maladera insanabilis (Br.)	148	12.30	62	7.75	87	8.18					89	8.84			13	16.3	518	7.73
Maladera irridescens Bl.	27	2.24	4	0.50													31	0.46
Maladera piluda	15	1.25									8	0.79					23	0.34
Melolontha cuprescens Bl.			21	2.63	34	3.20			23	3.30			63	8.28	47	5.82	188	2.80
Melolontha furcicauda Ancy	33	2.74	27	3.38	43	4.04			32	4.59			73	9.59			208	3.10
Melolontha indica Hope	38	3.16			41	3.85											79	1.18
Melolontha virescens Br.	5	0.42															5	0.07
Microtrichia cotesi Br.	16	1.33															16	0.24
Schizonycha sp. 1			4	0.50	26	2.44					6	0.60	57	7.49	97	12.0	190	2.83
Schizonycha sp. 2							6	1.65									6	0.09
Trichoserica umbrinella (Br.)	8	0.67											9	1.18			17	0.25
Adoretus bimarginatus Ohaus					121	11.3			95	13.6							216	3.22
Adoretus lasiopygus Burm.	94	7.81			119	11.1			99	14.2			97	12.7	11	13.7	520	7.76
Adoretus pallens Bl.	81	6.73									168	16.6					249	3.71
Anomala comma Arrow	9	0.75															9	0.13
Anomala dimidiata Hope	39	3.24	59	7.38	72	6.77											170	2.54
Aomala lineatopennis Bl.	94	7.81			88	8.27					296	29.3					478	7.13
Anomala pellucida Arrow	15	1.25															15	0.22
Anomala polita Bl.			18	2.25													18	0.27
Anomala rufiventris Redt.	44	3.66	83	10.38	52	4.89			63	9.04			10	13.9			348	5.19
Anomala rugosa Arrow	19	1.58							46	6.60							65	0.97
Anomala singularis Arrow	22	1.83	20	2.50													42	0.63
Anomala stoliezkoe Hope															50	6.19	50	0.75
Anomala varicolor (Gyll.)	85	7.07			78	7.33					243	24.1					406	6.06
Mimela fulgidivittata Bl.	54	4.49			60	5.64											114	1.70
Mimela passerinii Hope							20	5.51	42	6.03			40	5.26	15	1.86	117	1.75
Mimela pectoralis Bl.									42	6.03							42	0.63
Popillia cyanea Hope							4	1.10									4	0.06
Popillia nasuate Newman							5	1.38									5	0.07
Popillia virescens									2	0.29							2	0.03
Clinteria spilota (Hope)											1	0.10					1	0.01
Heterorrhina nigritarsis Hope							4	1.10									4	0.06
Protaetia coensa (West.)	6	0.50							4	0.57							10	0.15
Protaetia impavida Jan.															4	0.50	4	0.06
Protaetia neglecta Hope									18	2.58			49	6.44	37	4.58	104	1.55
Oxycetonia albopunctata (Fab.)											2	0.20					2	0.03
Heteronychus lioderes (Fabricius)	56	4.66	78	9.75													134	2.00
Phyllognathus dionysius Redt.			22	2.75													22	0.33
Total	**1203**		**800**		**1064**		**36**		**69**		**1007**		**76**		**80**		**6703**	

Table 3 Scarabaeid beetle species collected in UV light traps at different locations in Himachal Pradesh (May - August, 2012).

Species	Palampur		Kullu		Dallash		Shillaroo		Kheradhar		Kwagdhar		Bharmour		Reckong		Total no. of beetles	% Dominance
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%		
Apogonia carinata Barlow	8	0.60															8	0.12
Apogonia ferruginea Fab.			4	0.51													4	0.06
Apogonia villosella Bl.	35	2.63	31	3.98													66	0.96
Autoserica phthisica Br.	58	4.35	111	14.25													169	2.46
Brahmina bilobus Fab.			13	1.67									26	3.12	19	2.49	58	0.84
Brahmina coriacea (Hope)	5	0.38	98	12.58	60	5.56	291	72.39	130	19.23	64	6.39	92	11.03	88	11.55	828	12.06
Brahmina crinicollis Burm.			1	0.13							7	0.70	70	8.39	57	7.48	135	1.97
Brahmina flavosericea Br.	9	0.68			29	2.69	20	4.98			42	4.20	50	6.00	87	11.42	237	3.45
Brahmina kuluensis Moser													18	2.16			18	0.26
Brahmina sp. 1			22	2.82													22	0.32
Brahmina sp. 2							3	0.75									3	0.04
Brahmina sp. 3													5	0.60			5	0.07
Brahmina sp. 4															5	0.66	5	0.07
Holotrichia longipennis Bl.	99	7.43	51	6.55	107	9.91	30	7.46	60	8.88	66	6.59	43	5.16	63	8.27	519	7.56
Holotrichia nigricollis Br.	62	4.65															62	0.90
Holotrichia problematica Br.							11	2.74									11	0.16
Holotrichia sikkimensis Br.	53	3.98	58	7.45	59	5.46			29	4.29							199	2.90
Lepidiota stigma (Fab.)			3	0.39													3	0.04
Maladera insanabilis (Br.)	182	13.66	53	6.80	89	8.24					98	9.79			148	19.42	570	8.30
Maladera irridescens Bl.	35	2.63	7	0.90													42	0.61
Maladera piluda	10	0.75									4	0.40					14	0.20
Melolontha cuprescens Bl.			24	3.08	40	3.70			20	2.96			66	7.91	36	4.72	186	2.71
Melolontha furcicauda Ancy	28	2.10	22	2.82	45	4.17			32	4.73			81	9.71			208	3.03
Melolontha indica Hope	33	2.48			45	4.17											78	1.14
Melolontha virescens Br.	7	0.53															7	0.10
Microtrichia cotesi Br.	17	1.28															17	0.25
Schizonycha sp. 1			2	0.26	28	2.59					10	1.00	66	7.91	75	9.84	181	2.64
Schizonycha sp. 2							8	1.99									8	0.12
Trichoserica umbrinella (Br.)	3	0.23											9	1.08			12	0.17
Adoretus bimarginatus Ohaus					103	9.54			90	13.31							193	2.81
Adoretus lasiopygus Burm.	112	8.41			109	10.09			88	13.02			99	11.87	98	12.86	506	7.37
Adoretus pallens Bl.	77	5.78									184	18.38					261	3.80
Anomala comma Arrow	12	0.90															12	0.17
Anomala dimidiata Hope	39	2.93	54	6.93	77	7.13											170	2.48
Aomala lineatopennis Bl.	99	7.43			77	7.13					284	28.37					460	6.70
Anomala pellucida Arrow	24	1.80															24	0.35
Anomala polita Bl.			21	2.70													21	0.31
Anomala rufiventris Redt.	40	3.00	86	11.04	54	5.00			73	10.80			117	14.03			370	5.39
Anomala rugosa Arrow	38	2.85							41	6.07							79	1.15
Anomala singularis Arrow	23	1.73	26	3.34													49	0.71
Anomala stoliezkoe Hope															46	6.04	46	0.67
Anomala varicolor (Gyll.)	84	6.31			95	8.80					239	23.88					418	6.09
Mimela fulgidivittata Bl.	73	5.48			63	5.83											136	1.98
Mimela passerinii Hope							24	5.97	42	6.21			49	5.88	8	1.05	123	1.79
Mimela pectoralis Bl.									41	6.07							41	0.60
Popillia cyanea Hope							3	0.75									3	0.04
Popillia nasuate Newman							5	1.24									5	0.07
Popillia virescens									3	0.44							3	0.04
Clinteria spilota (Hope)											2	0.20					2	0.03
Heterorrhina nigritarsis Hope																	0	0.00
Protaetia coensa (West.)	5	0.38							3	0.44							8	0.12
Protaetia impavida Jan.															2	0.26	2	0.03
Protaetia neglecta Hope									24	3.55			43	5.16	30	3.94	97	1.41
Oxycetonia albopunctata (Fab.)											1	0.10					1	0.01
Heteronychus lioderes (Fab.)	62	4.65	67	8.60			7	1.74									136	1.98
Phyllognathus dionysius Redt.			25	3.21													25	0.36
Total	**1332**		**779**		**1080**		**402**		**676**		**1001**		**834**		**762**		**6866**	

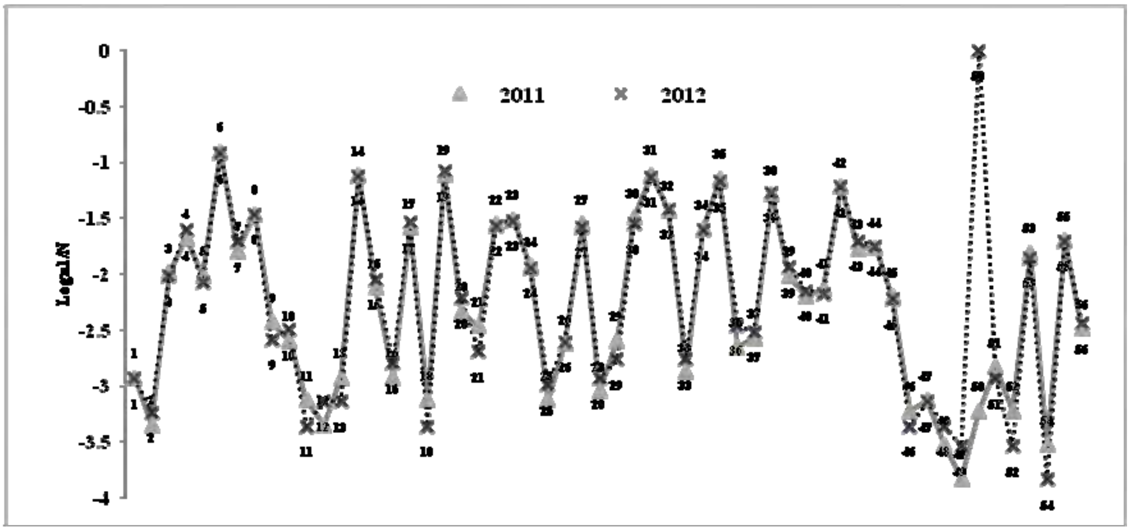


Fig. 6 Dominance diversity plot, numeric code for each species corresponds to those in Tables 2 and 3.

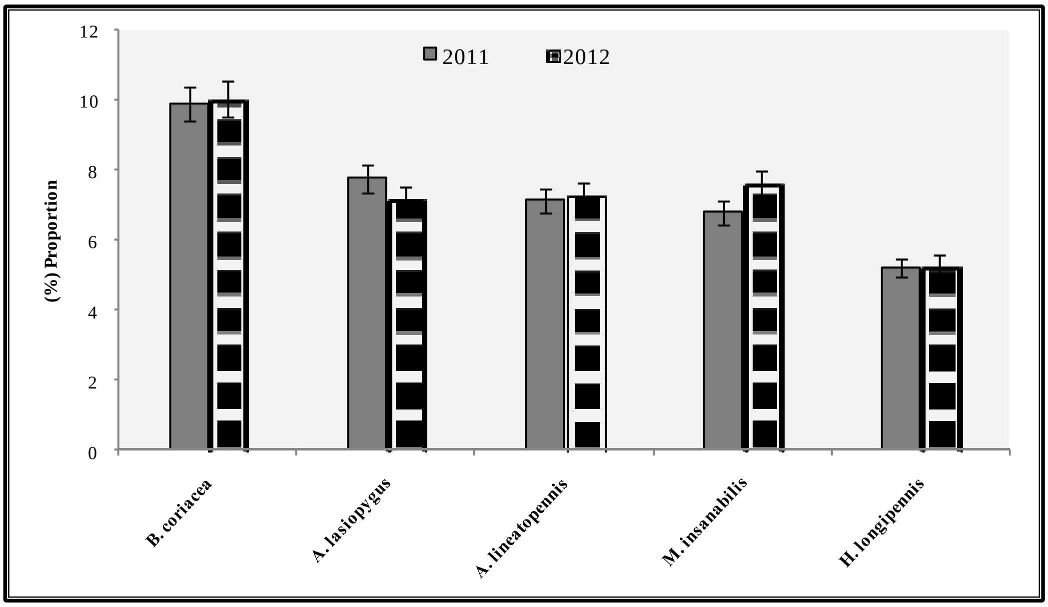


Fig. 7 Dominant species of scarabaeid beetles caught in light trap in Himachal Pradesh.

Chandel et al. (1994) reported that *B. coriacea* constituted 13.4-18.9% of total beetle catch on light trap at Nauni in Solan, Himachal Pradesh. In Kullu valley, *B. coriacea* comprised up to 26.87% of total catch in light trap (Kumar et al., 2007). This is the most abundant species in Shimla hills constituting 96.38% of total beetle catch at Shillaroo. At Kheradhar, *B. coriacea* accounted to 84.95% of total catch (Gupta, 2012). Kumar et al. (1996) reported that *M. insanabilis* was the most predominant species in Kullu valley and comprised of 16.04 - 29.58% of the total beetle catch in the light trap. *Anomala lineatopennis* was the predominant species at Palampur (Chandel et al., 2010) and Kwagdhar (Anon, 2010). *Holotrichia longipennis* (357 beetles/trap) constituted 5.26% of the total scarabaeid beetles collected in light trap during 2011-12. It accounted for 11.2-13.7% of the total beetle catch at Nauni (Chandel et al., 1994), 10.66-18.43% in Kullu valley (Kumar et al., 2007) and 5.05% at Palampur (Mehta et al., 2010). According to Sushil et al. (2006), *H. longipennis* is the most abundant species in Uttrakhand (8.15-10.41% of total beetle catch). Five species *viz., O. albopunctata, C. spilota, P. impavida, P. cynea* and *A. ferruginea* were least abundant species in Himachal Pradesh and were region specific (Tables 2 and 3). The species *H. nigritarsis* was observed only during 2011. The scarabaeid beetles were quite abundant in the Himalayan region, India. The average light trap catch per month was 257.13 beetles/trap and maximum numbers were recorded in Zone II. In zone III and IV, the average trap per month was 196.56 and 197.81 beetles/trap, respectively. Maximum species diversity was recorded in the mid hills (zone I and II), where 38 species were recorded.

Table 4 Data matrix with beta diversity values obtained through Sorensen similarity index, Jaccard similarity index and Bray Curtis index with number of species per site and number of shared species for 2011-12.

Site I*	Site II*	No. of species at site 1	No. of species at site II	Shared species	Sorensen index	Jaccard index	Bray Curtis index
1	2	29	21	11	0.3607	0.1803	0.4573
1	3	29	16	10	0.3636	0.1818	0.5867
1	4	29	10	3	0.1429	0.0714	0.0485
1	5	29	12	7	0.2917	0.1458	0.2947
1	6	29	14	8	0.3137	0.1569	0.3891
1	7	29	15	8	0.3077	0.1538	0.2342
1	8	29	14	5	0.2083	0.1042	0.2944
2	3	21	16	10	0.4255	0.2128	0.4549
2	4	21	10	2	0.1212	0.0606	0.2253
2	5	21	12	6	0.3077	0.1538	0.3968
2	6	21	14	4	0.2051	0.1026	0.2313
2	7	21	15	9	0.4000	0.2000	0.3472
2	8	21	14	7	0.3333	0.1667	0.3296
3	4	16	10	3	0.2069	0.1034	0.1780
3	5	16	12	8	0.4444	0.2222	0.5179
3	6	16	14	7	0.3784	0.1892	0.4085
3	7	16	15	8	0.4103	0.2051	0.4449
3	8	16	14	7	0.3784	0.1892	0.4476
4	5	10	12	3	0.2400	0.1200	0.4113
4	6	10	14	3	0.2222	0.1111	0.1942
4	7	10	15	4	0.2759	0.1379	0.3185
4	8	10	14	4	0.2857	0.1429	0.2647
5	6	12	14	2	0.1429	0.0714	0.1631
5	7	12	15	7	0.4118	0.2059	0.5364
5	8	12	14	6	0.3750	0.1875	0.4186
6	7	14	15	5	0.2941	0.1471	0.1912
6	8	14	14	6	0.3529	0.1765	0.3152
7	8	15	14	10	0.5128	0.2564	0.6080

***1 = Palampur, 2 = Kullu, 3 = Dallash, 4 = Shillaroo, 5 = Kwagdhar, 6 = Kheradhar, 7 = Bharmour, 8 = Reckong Peo**

3.3 Species diversity across locations

A large variation was observed in diversity and abundance of species across locations. Abundance of scarabaeid beetles was three times greater at Palampur (1203 adults during 2011 and 1332 in 2012) with 29 species from 13 genera, comprising 18.68% of the total scarabaeid species during 2011-2012 as compared to Shillaroo (363 adults during 2011 and 402 in 2012), constituting 5.63% of total catch during 2011-12 with 10 species belonging to 7 genera (Tables 2 and 3). Abundance and diversity of scarabaeid beetles was significantly and negatively correlated with altitude ($p<0.01$ or $p<0.05= -0.697$). At Dallash, 1,064 and 1,080 beetles from 16 species belonging to 10 genera were collected during 2011 and 2012, respectively, which constituted 15.80% of the total catch. The highest numbers of beetles were collected in Kwagdhar and Dallash, which belonged to subfamily Rutelinae. At other sites most of the beetles belonged to Melolonthinae in terms of numbers of adults collected (Tables 2 and 3). At Kwagdhar, Kheradhar, Reckong Peo, Bharmour and Kullu, the number of species ranged from 12-21 (Fig. 8a) constituting 14.80, 10.12, 11.57, 11.75 and 11.64% of the total catch during 2011-12, respectively. No beetles of the subfamily Dynastinae were collected during the study period from Dallash, Kheradhar, Kwagdhar, Bharmour and Reckong Peo. Similarly, from Dallash, no species belonged to subfamily Cetoniinae were recorded. The general diversity of scarab beetles at each site is shown in Tables 2 and 3.

3.4 Emergence pattern and activity period

To study the beetle's emergence pattern and peak activity period at different locations, data were recorded for four months, i.e., May-August. Adult emergence starts in May at all the locations comprising 3.86-12.97% of the total catch in Shillaroo, Kheradhar, Kullu, Bharmour, Palampur and Dallash, respectively, during 2011 (Fig. 9). A similar trend was observed during 2012 at all the locations (Fig. 10). However, the scarab catch was maximum in Kwagdhar during the month of May (36.54%) because of the high abundance of rutelinids, especially *A. lineatopennis* and *A. varicolor* suggesting that May is the peak activity period for rutelinids (Figs. 9 and 10). At Reckong Peo, no scarab activity was recorded during May (Figs. 9 and 10). Total beetle catch was maximum in June at all the locations which coincided with onset of monsoon rains except at Reckong Peo, where the beetle catch was highest in July 2011 (55.32% of total beetle catch at Reckong Peo). Reckong Peo is located in the dry temperate zone of Himalayas and monsoon rains starts in late July. There was a direct relationship with occurrence of pre-monsoon rains and peak activity of scarabaeids. By the end of the August the scarab activity began to decline, with minimum catch at all the locations (Figs. 9 and 10).

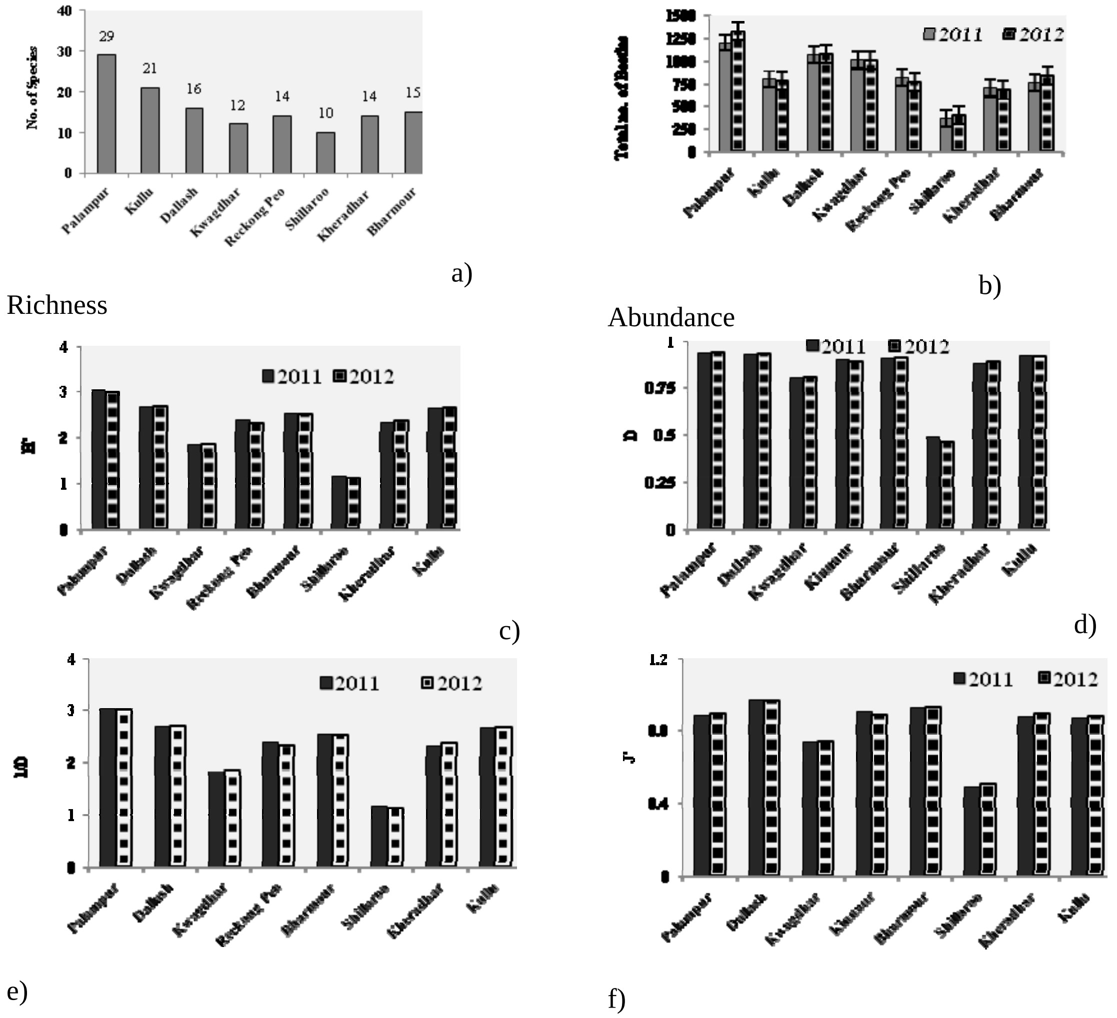


Fig. 8 Scarabaeid beetle diversity at eight study sites in Himachal Pradesh. a) Number of Species, b) Total number of beetle specimen, c) Shannon index (H'), d) Simpson's index of diversity (D), e) Simpson's reciprocal index (1/D), and f) Pielou's evenness index (J').

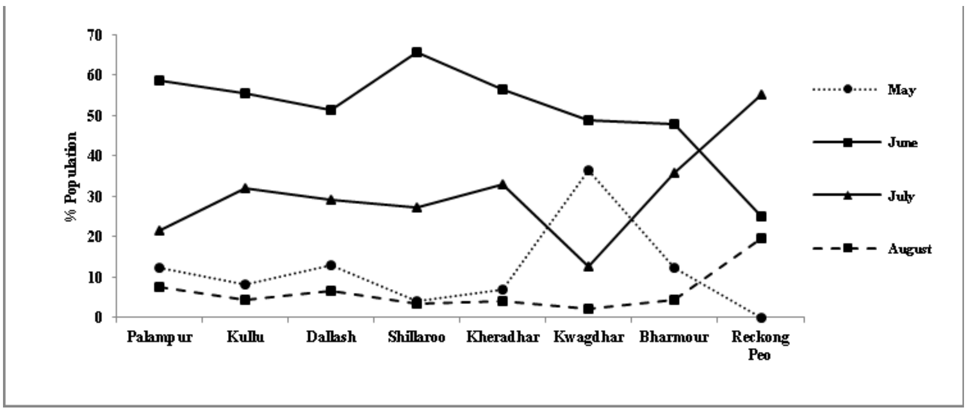


Fig. 9 Monthwise catch of scarabaeid beetles in light traps during 2011.

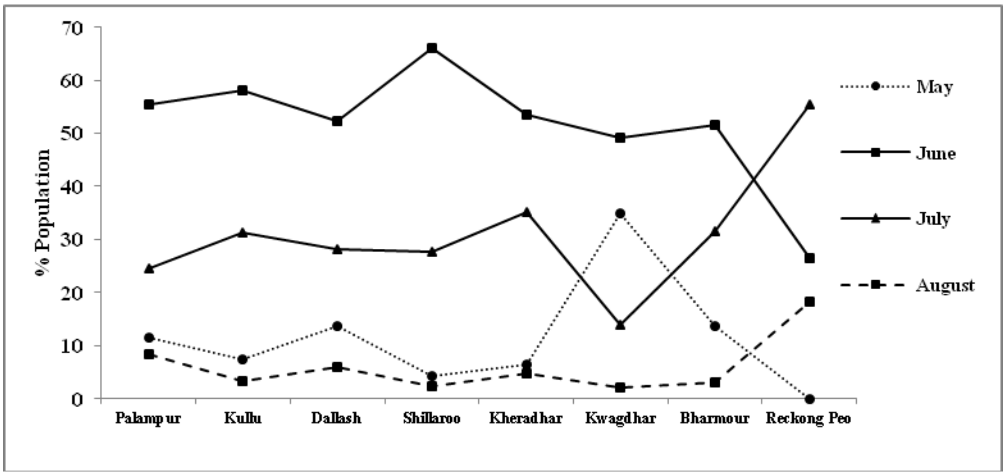


Fig. 10 Monthwise catch of scarabaeid beetles in light traps during 2012.

3.5 Diversity analysis

The overall diversity of scarabaeid beetles in Himachal Pradesh, as revealed by light trap catches, is depicted in Fig. 8. The Simpson's index (D) was ≥ 0.90 at Palampur, Dallash, Reckong Peo, Bharmour and Kullu during 2011 and at Palampur, Dallash, Bharmour and Kullu in 2012. At Palampur, the Simpson's index of diversity (D = 0.94) was highest followed by Dallash (D = 0.93). At Kwagdhar, Simpson's index was 0.81. At Shillaroo, it was lowest (D = 0.46 - 0.49). The Simpson's reciprocal index was maximum at Shillaroo (1/D = 2.04 - 2.17) and minimum at Palampur (1/D = 1.06). The maximum Simpson's index and minimum Simpson's reciprocal index at Palampur indicated that scarabaeid community at Palampur consisted of maximum number of species (Fig. 8) with more or less similar abundance. Similar trend was observed at Dallash, Reckong Peo, Bharmour, and Kullu. At Kwagdhar, the species richness was low, and with greater variation in abundance of different species. At Shillaroo, the species richness was lower than at Kwagdhar. Shillaroo had the lowest Shannon index (H' = 1.12 - 1.17) and Pielou's evenness index (J' = 0.49 - 0.51) during 2011 and 2012, respectively (Fig. 8). These values for Shannon index and Pielou's evenness index showed poor species richness, with least evenness in relative abundance of different species. The beetle community at Shillaroo was least diverse. This unevenness of scarabaeid community was mainly due to the dominance of *B. coriacea*, which comprised of more than 70% of total beetle catch.

The Shannon index was maximum (H' = 3.01 - 3.03) at Palampur and Pielou's evenness index ranged 0.89 - 0.90 (Fig. 8) suggesting maximum abundance of scarabaeid beetles species at Palampur. There exists a local variation among the scarabaeid beetles, but the evenness was high. Since Shannon index was > 3, there was no dominance of any particular species at Palampur (Fig. 8). A community dominated by few species is considered to be less diverse than one with a high species richness and evenness (Dhoj et al. 2009). There was considerable variation in the diversity of scarabaeid beetles across locations an observation reported by several workers in the past (Chandel et al., 1994; Anon, 2008, 2009, 2010). Variation in beetle diversity might be due to variation in vegetation, crops grown, and altitude and soil types.

Beta diversity was also calculated for different locations, which is one of most important measure to compare abundance, richness and diversity within sites. Diversity within the sites by using Bray-Curtis index, Sorensen's similarity index and Jaccard index was calculated by pooling the data for 2011-2012. The shared species statistics between different landscapes of Himachal Pradesh is given in Table 4. The Bray-Curtis index indicated 60.80% similarity between Bharmour and Reckong Peo. Jaccard index and Sorensens index also indicated a similar pattern with 25.64 and 51.28% similarity, respectively, between Bharmour and Reckong

Peo which had the highest similarity across locations. The Bray-Curtis index was minimum (0.0485) between Palampur and Shillaroo which indicating that these two sites have poor similarity in terms of diversity, richness and abundance.

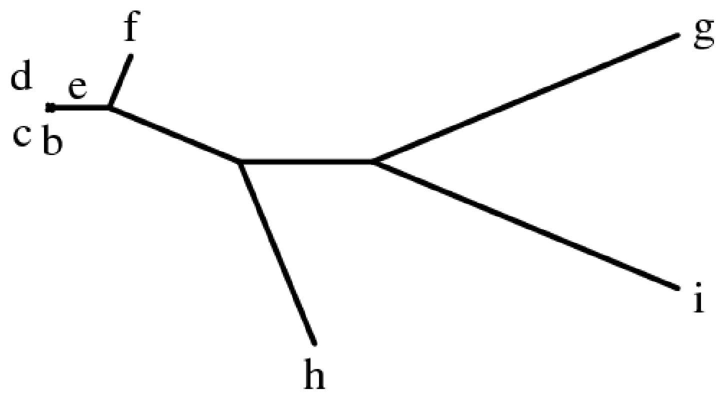
3.6 Species turnover comparison across the locations

Jaccard similarity coefficient matrix was used to find out the differences in species composition between the locations. Dendrogram prepared by using Jaccard similarity matrix for clustering of habitats with similar diversity is given in Fig. 11. Clustering was measured on the basis of similarity, richness and abundance of the scarab taxa. Palampur, Kullu, Dallash and Shillaroo were in a single cluster while Kheradhar and Reckong Peo in another cluster. Kwagdhar and Bharmour were placed in separate clusters. The composition and population structure of scarabs species were similar between Palampur, Kullu and Dallash whereas, Bharmour area was completely different from these clusters.

4 Discussion and Conclusions

In the present study, 56 species belonging to subfamilies Melolonthinae, Rutelinae, Cetoniinae and Dynastinae were recorded from the eight locations in the northwestern Himalayan region of Himachal Pradesh. More than 50% of the species found in Palampur and Kullu which have one of most important and diverse scarab fauna in India (Chandra, 2005; Kumar et al., 2007; Chandel et al., 1994). These habitats had a diverse scarabs beetle fauna, because they are rich in vegetation for feeding, mating and nesting (Cherty et al., 2008; Dhoj et al., 2009; Bhalla and Pawar, 1964; Kumar et al., 1996, 2005). These agroecological regions have a high scarab diversity for historical, geographical and landscape reasons. There is a long history of fruit and vegetable cultivation in these regions which serve as important adult and larval food, for conserving the scarab fauna. The surveyed landscapes are located in sub-tropical and dry temperate latitudinal region (N 30^0, 45.409'-32^0, 05.666' (Table 1)), with a broad altitude range (1222 - 2479 m amsl; Table 1, Fig. 1), which facilitated the diversity of scarab fauna in different habitats. Most of the landscapes are surrounded by natural vegetation, which might contribute to greater diversity of scarab fauna in the region (Dhoj et al., 2009; Khanal et al., 2012; Chandra and Gupta, 2012). *B. coriacea* was the dominant species in high hills and dry temperate zones, whereas *H. longipennis* was dominant in the mid hills.

There was a large variation in beetle abundance in different landscapes across years 2011 and 2012 (Tables 2 and 3). The abundance and diversity decreased with an increase in altitude. Species richness was significantly and negatively correlated with altitude. The possible reason may be low temperatures of high altitudes which limits the growth and development of scarabs. A similar relationship has been observed in the Iberian mountains of Spain (Martin-Piera et al., 1992; Romero-Alcaraz and Avila, 2000) and, the central region of mainland Japan (Imura et al., 2010). The species richness at Palampur and Kullu was exceptionally high as compared to the other landscapes. This might be due surrounding uncultivated wild habitats, which served as a source of scarab beetles. The broad leaved deciduous forests and pastures increase species richness, whereas artificial coniferous forests decrease species richness (Imura et al., 2011). A positive relationship between local abundance and the distribution range of species is a ubiquitously observed phenomenon in taxonomic assemblages (Hanski, 1982; Brown, 1984; Lawton, 1993, and Gaston, 1996). In the present study, all the species exhibited such a relationship. These findings are in conformity with the earlier studies by Chandra (2005), Chandra and Gupta (2012), Dhoj et al. (2009), Hanski and Koskela (1978) and Romero-Alcaraz and Avila (2000). A positive distribution-abundance relationship is significant in conservation and the species with restricted host range and small populations are more vulnerable to human activities, risk of extinction and likely emergence of new pests or secondary pest problems in managed ecosystems (Lawton, 1996). The results of the present study also stressed the need for continuous large scale monitoring to assess the distribution and abundance of scarab beetles for effective conservation of species, as well as to study their movements/shifts from forests to cultivated crops of agricultural and horticultural importance.



(Jaccard similarity matrix-abundance)

Fig. 11 Dendrogram comparing different sites for scarabaeid beetle species assemblage (b = Palampur, c = Kullu, d = Dallash, e = Shillaroo, f = Kwagdhar, g = Kheradhar, h = Bharmour, I = Reckong Peo).

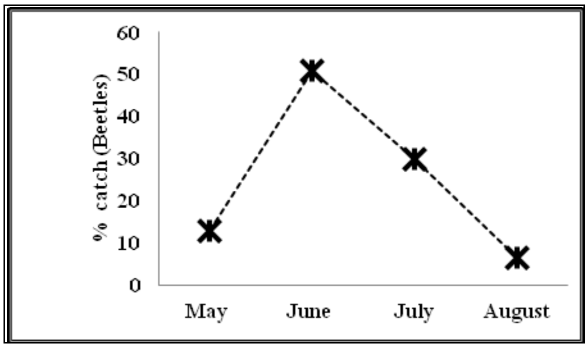


Fig. 12 Overall emergence pattern of scarabaeid adults in Himachal Pradesh, India (2011-2012).

In the present study 13,569 adults of scarabaeid beetles belonging to 56 species of 4 subfamilies were recorded from different landscapes. The five most dominating species were *B. coriacea*, *A. lasiopygus, A. lineatopennis, M. insanabilis* and *H. longipennis*. Melolonthinae was most dominant with 29 species, comprising 51.79% (Fig. 4) of the total species followed by Rutelinae with 19 species (33.93%). *Anomala* was the most dominant genus with 17.86% of total species followed by *Brahmina* (16.07% of total species). Chandra (2005) collected 89 species of phytophagous scarabs in Himachal Pradesh, belonging to 33 genera. He reported 34 species in subfamily Melolonthinae, and recorded maximum diversity (13 species) under the genus *Anomala*. Mehta et al. (2010) reviewed the status of whitegrubs in north western Himalaya and listed 116 species belonging to 43 genera, with maximum diversity in the genus *Anomala* (19 species). Maximum species diversity in the present study was in genus *Anomala*. June was the most critical month for planning management and conservation strategies for the scarab beetles, as 50.80% (Fig. 12) of the total scarab beetles were trapped in June followed by July. Among the collected species, *B. coriacea*, *B. flavosericea, B. crinicollis*, *H. longipennis, H. sikkimensis, A. lineatopennis, A. dimidiata, A. varicolor, M. indica, M. furcicauda, M. cuprescens, Schizonycha* spp., *M. insanabilis, M. cotesi, H. lioderes, P. dionysius, Popillia* spp.and *C. spilota* has been reported to be of agricultural and horticultural pests.

The structure of the organism's diversity at the landscape scale can be analyzed by using within community (α diversity) and between community (β diversity) (Whittaker, 1972; Magurran, 1988; Southwood and Herderson, 2000). To understand the structure and functioning of the ecosystem, it is important to specify how species composition and distribution are determined. Beta diversity indicates that species composition over large areas, which fluctuates in a random (Legendre et al. 2005). The present study supported second and third hypotheses as Beta diversity was observed to be <50% between the locations except Bharmour and Reckong Peo (60.80% similarity) and Kwagdhar and Bharmour (53.64% similarity) and Dallash and Kwagdhar (51.79% similarity). The overall results of beta diversity analysis indicated that Himachal Pradesh has a rich diversity of scarabaeid beetles and shared species between the landscapes were very low. This may be because of differences in cropping patterns and the surrounding wild habitats. Differences in climatic, edaphic and landscape management may be responsible for the observed differences in beta diversity of beetle communities in the Himalayan regions.

Biodiversity surveys play a crucial role in providing information for conservation, justification for the protected areas as well as designing and development of pest management plans (Spector and Forsyth, 1998). Mid hill regions in Himachal Pradesh were rich in diversity of scarab beetles. The information on species diversity, abundance, richness and dominance will be helpful for planning strategies for conservation of ecosystems and biological health of natural habitats. This information can be utilized to solve the increasing menace of scarab beetles in field crops and fruit trees in the Himalayan regions in Himachal Pradesh.

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