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Original Research

Studies on the Preliminary Ecology of Invasive Phytophagous Indian Scarabaeidae of North Western Himalaya

Mandeep Pathania[1,2*], Chandel R.S[1], Verma K.S [1] and Mehta P.K [1]

[1]Department of Entomology, College of Agriculture, Chaudhary Sarvan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India

[2]Punjab Agricultural University, Regional Research Station, Abohar, Punjab, India

Abstract

The present study deals with comprehensive list and preliminary ecology of invasive scarabaeid species of North western Himalayan region with background information on diversity, distribution pattern, abundance and nativity. A total of 85 invasive species of phytophagous scarabaeids under 25 genera, belonging to 5 subfamilies of family Scarabaeidae have been recorded. Among these, 55 species were recorded on light trap and 78 species occurred on host trees. Melolonthinae being most dominated subfamily representing 13 genera and 51 species, Rutelinae represents 24 species belonged to 4 genera. *B. coriacea*, *H. longipennis*, *A. phthisica*, *M. insanabilis* and *Schizonycha* sp. 1 were recorded as the leading species of north western Indian hills. *B. coriacea* and *H. longipennis* were the most dominant and very common species in terms of number and damage potential. The scarabaeid species composition (richness and diversity) was significantly higher in the mid hill areas of Himachal Pradesh as compared to higher hills. Palampur area situated in the mid hills with long rainy seasons had the maximum Shannon Weiner index (3.03) with 39 species recorded from the region. The richness pattern also shows a positive trend with an increase in altitudinal gradient. During the study 24 species were recorded for the first time from Himachal Pradesh. Furthermore, a better planning is needed for early detection to control and reporting of infestations of spread of these invasive species.

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***Corresponding Author:**
Mandeep Pathania

E-mail:
mandeeppathania999@gmail.com
mpathania@pau.edu

INTRODUCTION

Scarabaeid beetles are the most common leaf chafers, whereas the larvae are among the most destructive soil pests. They have been a favourite group for insect collectors for their versatile habitats, marvelous coloration and sculpture as well as for their economic importance as they are polyphagous in nature and cause losses to many crops worldwide. The major ecological impact of scarabaeid beetles results from their damage potential to green plants, their contribution to breakdown of plant and animal debris and their predatory activities. Scarabaeidae is second largest family within the order Coleoptera and is cosmopolitan in distribution. The larvae of family Scarabaeidae are recognized as pests of planted crops in many parts of the world and are almost universally known as 'whitegrubs'. Among the soil macro fauna, the whitegrubs form a major component both in number of species and diversity of habits in Indian sub-continent (Veeresh, 1988). The world fauna of whitegrubs exceed 30,000 species (Mittal, 2000), and the maximum number occurs in the tropical areas of the world, particularly in the African and oriental regions. Indian sub-region is well known for richness of scarabaeid fauna, but it is yet to be fully explored (Mishra and Singh, 1999). Ali (2001) reported that the family Scarabaeidae represents about 2500 species from the Indian sub-region.

Scarabaeids are polyphagous pest both in the grub and adult stage inflicting heavy damage on various fruit/ forest trees, their nurseries, vegetables, lawns and field crops (Chandel and Kashyap, 1997). Studies on the diversity and abundance of coleopteran insects in the Himalayan regions have been carried out by Mani (1956), Singh (1963), Mishra (2001), Sushil *et al.* (2004, 2006), Kumar *et al.* (2007), and Chandra *et al.* (2012). Similarly, others workers have also studied the species composition and abundance in different parts of the world (Lenski 1982; Kruger and McGavin 1997; Gutierez and Menendez 1997; Weslein and Schroeder 1999; Martikainen *et al.,* 2000; Stork *et al.,* 2001, Jukes *et al.,* 2002, Chandel *et al.,* 2003 and Magagula 2009, Kishimota *et al.,* 2011). In India whitegrubs are pest of national importance and their economic importance is primarily due to feeding activity of third instar grubs (Mehta *et al.,* 2010). Grubs of scarabaeidae prefer to feed on fibrous roots for normal growth and the crops with tap root system suffer more as compared to adventitious root system (Yadava and Vijayvergia, 2000).

Studies on the species diversity of coleopteran insects have been carried out by Forschler and Gardner (1991), Hutcheson and Jones (1999), Romero-Alcaraz and Avila (2000), Rodriguez Jimenez *et al.* (2002), Zahoor *et al.,* (2003), and Aland *et al.* (2010) in the different parts of the world. In addition, several studies conducted to evaluate the relationship between insect populations in the different parts of the world by various workers (Alexander and Hillard 1969; Wolda, 1987; Pardo *et al.,* 2005; Joshi and Arya, 2007, Gracia *et al.,* 2008, Joshi *et al.,* 2008 and Dhoj *et al.,* 2009). Similarly, many other workers have also studied the fluctuation in population density of coleopterans (Kaushal and Vats, 1987; Joshi, 1996; Joshi and Sharma, 1997 and Arya and Joshi, 2011). In entire north western Himalaya, the grubs of *B. coriacea*, *H. longipennis* and *Melolontha* spp. cause wide spread damage to potato, vegetables, groundnut, sugarcane, maize, pearlmillet, sorghum, cowpea, pigeonpea, green grass, cluster bean, soybean rajmash, ginger, pea, rice, strawberry etc. , whereas the adults of these species are the defoliators of pome and stone fruits. In forest nurseries, up to 30 per cent infestation due to grubs of *B. coriacea* have been reported in mid hills of Himachal Pradesh (Chandel *et al.,* 2009). More than 100 species of phytophagous whitegrubs have been reported to occur in north western Himalaya, however, large number of species is still unidentified and there exists lot of variation in their behaviour and biology and no systematic attempt has been made so far to identify phytophagous scarabaeid beetles in the Himachal Pradesh, India. This poses problem in the development of effective integrated pest management schedules against these pests. Keeping this in view, we explored north western Himalayan region to assess ecological aspects such as abundance, diversity, habitat preference of phytophagous Scarabaeidae.

MATERIALS AND METHODS

Study Environment: The study was conducted in the north western Himalaya covering eleven districts in 4 agroclimatic zones (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, India. The survey was conducted during the two successive years 2011 and 2012 within the altitude range from 393-2479 m amsl and the longitude and latitude varied from N 31^0,27.301’, E 76^0,15.541’ to N 31^0, 12.409′, E 77^0, 25.462′, respectively (Table 1 and Figure 1).

Table 1: Description of locations surveyed for studying scarabaeid diversity during 2011 and 2012

District	Area surveyed	Zone	Latitude	Longitude	Altitude (masl)	Soil type	Host crops surveyed
Kangra	Palampur	II	N 32^0,05.666′	E 76^0,32.781′	1222	Silty clay loam	*Toon*, pear, peach, apple, walnut, poplar, *khirak*
	Panchrukhi	II	N 32^0,06.350′	E 76^0,57.980′	1078	Silty clay loam	citrus, poplar, *toon, khirak*,
Kullu	Seobagh	II	N 32^0,02.958′	E 76^0, 37.533′	1327	Clay loam	Apple, pear, pear, plum, *ficus*, pomegranate, wildrose, appricot
	Dallash	III	N 31^0,23.036′	E 77^0, 26.024′	2020	Clay loam	Apple, pear, peach, plum, apricot, pomegranate, *toon*, robinia, poplar
Shimla	Shillaroo	III	N 31^0,12.409′	E 77^0, 25.462′	2479	Sandy loam/ clay loam	Apple, walnut, pear, apricot, berberris, *indigofera*, grasses
Kinnaur	Reckong Peo	IV	N 31^0,31.348′	E 77^0, 47.856′	2117	Gravelly loamy sand	Apple, pear, peach, apricot, wildrose, almond, grass
Solan	Nauni	III	N 30^0,51.818′	E 77^0, 09.105′	1255	Sandy loam/ clay loam	Apple, pear, pear, plum, walnut, apricot, *toon*, robinia, *kachnaar*
Sirmaur	Kwagdhar	III	N 30^0,45.409′	E 77^0, 09.235′	1774	Sandy loam/ clay loam	Apple, pear, peach, walnut, wildrose
	Kheradhar	III	N 30^0,50.035′	E 77, 20.634′	2032	Sandy loam/ clay loam	Apple, apricot, rubus, berberris, *indigofera*, grasses
Chamba	Bharmour	IV	N 32^0,26.505′	E 76^0, 31.949′	2169	Sandy loam	Apple, pear, plum, apricot, walnut
Bilaspur	Berthin	I	N 31^0,12.310′	E 76^0,23.458′	461	Deep loamy-skeletal soils	Guawa, *Grewia*
Hamirpur	Kheri	I	N 31^0,53.299′	E 76^0, 35.759′	456	Sandy loam	*Grewia*, *taali*
	Jahu (Bhararei)	I	N 31^0,38.630′	E 76^0,41.062′	838	Loamy skeletal soils	*Grewia*
Mandi	Jogindernagar	II	N 31^0,59.248′	E 76^0,49.362′	1465	Clay loam	Paddy, grasses
	Karsog	II	N 31^0,26.599′	E 77^0,04.599′	1860	Clay loam	Apple, pear
Una	Rampur	I	N 31^0,27.301’	E 076^0,15.541’	393	Sandy loam/ clay loam	Guava

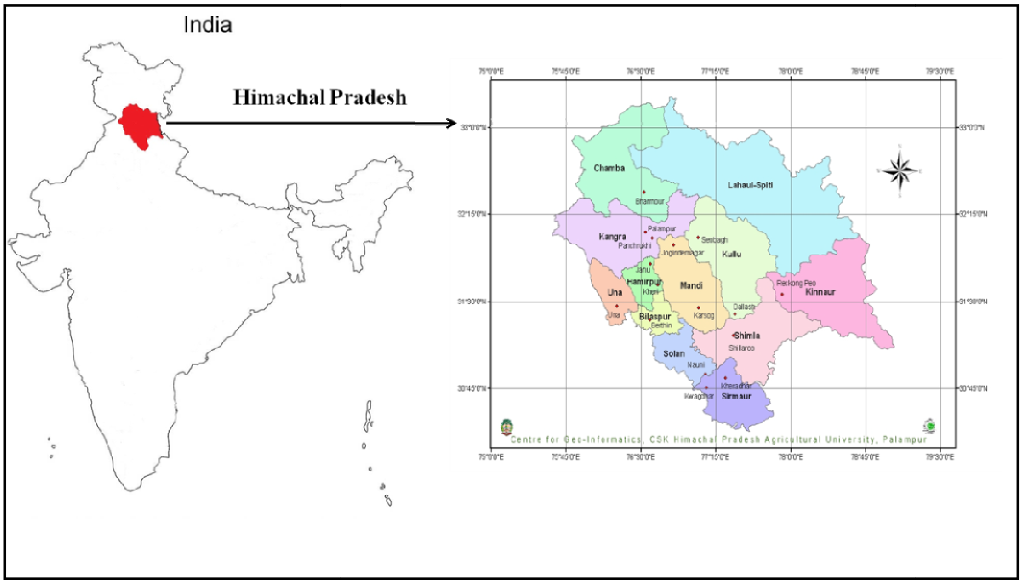


Figure 1: Study area (Himachal Pradesh in north western Himalayas, India)

Light Trap Catches: The monitoring of scarabaeids' adult population was carried out over two consecutive years in 2011 and 2012. The light traps utilized for the study was fitted with a bulb of 120 watt with UV radiation with visible spectrum having bluish light. The light traps were used for about seven months from March - September and beetles were monitored regularly. These light traps were installed at 9 different locations and there was one trap at each location. The light trap was placed in the centre of the field at a height of about 10 feet and operated from 7:00 PM to 11:00 PM to attract the adults of scarabaeid beetles. The trapped beetles were collected daily and segregated species- wise and cumulative count of each species at each location was taken.

Host Tree Catches: Adult surveys to determine the occurrence and relative abundance of scarabaeid adults to different host plants were conducted in the nine important fruit growing areas of Himachal Pradesh, India starting from March-September during the two consecutive years in 2011 and 2012 and also roving survey to other areas was conducted (Table 1). Generally the scarabaeid beetles are nocturnal in behaviour and come out of soil at dusk. Chandel *et al.* (1995) reported that beetles come out of soil around 7:50 PM at light intensity of 3 lux and settle on host trees for mating and feeding. Therefore, it was ensured to reach at the collection site by 7:30 PM on the day of collection and trees 3-5m high were commonly selected. Five plants were marked at random in each orchard/farm in all the surveyed localities and three branches of almost equal length were selected. The beetles were collected between 18:30-20:30 hours using a powerful flash light. This collection was done during the activity period of beetles from March-September for different species by fortnightly observations. A simple umbrella method was used for collecting beetles from trees as suggested by Chandel *et al.* (1997). All the collected beetles were brought into the laboratory for identification and preservation. For the purpose of this survey, any tree on which scarabaeid adults could be collected feeding and/or mating was considered to be a host tree. Trees in and around a selected location were sampled in a semi-systematic manner ensuring that all the tree species at the locality were examined. Also the roving surveys were conducted to some new areas of the northwestern Himalaya except the regular visited sites.

Identification

The scarabaeid adults collected during the surveys 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 beetles were compared with samples available in the Museum of Forest Research Institute, Dehradun, India.

Data Analysis

Abundance status was assessed on an arbitrary frequency scale as suggested by Davidar *et al.* (1996) as very common (VC), collected more than in eight spots from the nine areas; common (C), collected from four to seven spots from the nine areas; uncommon (UC), collected from two or three spots from the nine areas and rare (Ra), collected from one spot from the nine areas.

Species Diversity

Survey of diversity is essential for understanding the distribution of the forms. The Shannon index (H') explains the evenness of the abundance of species, but more sensitive to the most abundant species (Whittaker, 1960; Whittaker, 1965). The species diversity index was based on all the information recorded during study period at each site by using the following indices (Krebs, 2001). The species diversity in the present study was calculated by using "Shannon Wiener Index (1963)", which is defined as,

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

Where,
H'= Shannon diversity index
p_i= Proportion of total sample belonging to the i^{th} species.
S= Number of species.
∑= Sum from species 1 to species S

RESULTS

Species Composition

The detailed list of the collected scarabaeid beetles (Coleoptera: Scarabaeidae) from different farming areas in north western Himalaya in India is summarized in table 2. There exists lot of biodiversity among phytophagous scarabs in Himachal Pradesh and this diversity of insect composition results from diversity in the topography, climate and soil in north western Himalaya. A total 46,536 individuals of phytophagous scarabaeid beetles *i.e.* 13,569 on light traps and 32967 on host trees belonging to 85 species within 5 subfamilies were recorded during the study period (Table 2). Out of the total recorded species 67 were identified completely and 18 were up to genus level. On the basis of number of identified species, Melolonthinae was the most dominant subfamily with 51 species (Figure 2), followed by Rutelinae (24), Cetoniinae (7), Dynastinae (2) and Dynamopodinae (1). Per cent contribution of relative number of species and individuals of different families of beetles collected from study area are presented in (Figure 2). Subfamily Melolonthinae was the most dominant subfamily of Scarabaeidae, which constituted 60.0% of the total collected phytophagous scarabaeids. Rutelinae was the second most dominant subfamily with 28.24% of the total collected phytophagous scarabaeids followed by Cetoniinae (8.24%) and Dynastinae (2.35%). Subfamily Dynamopodinae was reported for the first time from Himachal Pradesh represented by one species (Table 2). The presence - absence data of the recorded scarabaeid species are given in table 2. There were 25 genera of phytophagous scarabaeids have been documented out of which subfamily Melolonthinae being most predominant with 13 genera's followed by Rutelinae representing 4 genera (Figure 3). Among different documented genera, *Brahmina* was highly diverse genus with 15 species (Figure 4) and closely followed by *Anomala* (14 species) and *Holotrichia* (9 species). However, thirteen genera in the present study were represented by a single species each (Figure 4). *Brahmina coriacea* Hope was the most dominant species which constituted 48.4% of total individuals, followed by *H. longipennis* (9.70%), *A. phthisica* (5.19%), *M. insanabilis* (4.95%), *Schizonycha* sp. 1 (3.88%).

Table 2: Checklist and ecological data of phytophagous scarabaeids of different sites of Himachal Pradesh

No	Species	Palampur	Kullu	Dallash	Shillaroo	Kheradhar	Kwagdhar	Bharmour	Reckong Peo	Solan	Collected on	Abundance	Months of Dominance
	Family: Scarabaeidae												
	Subfamily: Melolonthinae												
1.	*Apogonia carinata* Barlow	+									Light trap	Rare	June - Sep
2.	*Apogonia ferruginea* Fabricius		+								Light and host	Rare	June - Sep
3.	*Apogonia proxima* Waterhouse									+	Host trees	Rare	June - Sep
4.	*Apogonia villosella* Blanchard	+	+								Light and host	Uncommon	June - Sep
5.	*Autoserica phthisica* Brenske	+	+								Light and host	Uncommon	June - Sep
6.	*Aserica* sp.										Host trees	Rare	May - Aug
7.	*Brahmina bilobus* Fabricius		+					+	+		Light and host	Uncommon	May - Aug
8.	*Brahmina coriacea* (Hope)	+	+	+	+	+	+	+	+	+	Light and host	Very common	June - Aug
9.	*Brahmina comata* Blanchard			Collected from Karsog							Host trees	Rare	June - Aug
10.	*Brahmina crinicollis* Burmeister		+				+	+	+		Light and host	Common	June - Aug
11.	*Brahmina flavosericea* Brenske	+		+	+		+	+	+	+	Light and host	Common	June - Aug
12.	*Brahmina kuluensis* Moser							+			Light and host	Rare	April - June
13.	*Brahmina poonensis* Frey		+								Host trees	Rare	June - Sep
14.	*Brahmina* sp. 1		+				+				Light and host	Uncommon	June - Aug
15.	*Brahmina* sp. 2				+			+			Light and host	Uncommon	June - Aug
16.	*Brahmina* sp. 3							+			Light and host	Rare	June - Aug
17.	*Brahmina* sp. 4							+	+		Light and host	Rare	July - Sep
18.	*Brahmina* sp. 5								+		Host trees	Rare	July - Sep
19.	*Brahmina* sp. 6								+		Host trees	Rare	July - Sep
20.	*Brahmina* sp. 7								+		Host trees	Rare	July - Sep
21.	*Brahmina* sp. 8								+		Host trees	Rare	July - Sep
22.	*Holotrichia insularis* Brenske									+	Host trees	Rare	July - Aug
23.	*Holotrichia longipennis* Blanchard	+	+	+	+	+	+	+	+	+	Light and host	Very common	June - Sep
24.	*Holotrichia nigricollis* Brenske	+									Light and host	Rare	June - Sep
25.	*Holotrichia problematica* Brenske				+						Light and host	Rare	June - Sep
26.	*Holotrichia serrata* Fabricius									+	Host trees	Rare	July - Aug
27.	*Holotrichia setticollis* Moser									+	Host trees	Rare	July - Aug
28.	*Holotrichia sikkimensis* Brenske	+	+	+		+				+	Light and host	Common	July - Aug
29.	*Holotrichia* sp. 1									+	Light and host	Rare	July - Aug
30.	*Holotrichia* sp. 2			Collected from Una							Host trees	Rare	July - Aug
31.	*Lepidiota stigma* (Fabricius)		+								Light and host	Rare	July - Aug
32.	*Maladera bimaculata* Hope	+									Host trees	Rare	July - Aug

33.	*Maladera carinata* Khan & Ghai						+				Host trees	Rare	July - Aug
34.	*Maladera insanabilis* (Brenske)	+	+	+			+		+		Light and host	Common	July - Aug
35.	*Maladera irridescens* Blanchard	+	+								Light and host	Uncommon	July - Aug
36.	*Maladera perpendicularis* Khan & Ghai	+									Host trees	Rare	July - Aug
37.	*Maladera piluda*	+					+				Light and host	Uncommon	July - Aug
38.	*Maladera simlana* Brenske	+		+						+	Host trees	Uncommon	July - Aug
39.	*Maladera* sp.							+			Host trees	Rare	July - Aug
40.	*Melolontha cuprescens* Blanchard		+	+		+		+	+		Light and host	Common	July - Aug
41.	*Melolontha furcicauda* Ancy	+	+	+		+		+			Light and host	Common	July - Aug
42.	*Melolontha indica* Hope	+		+							Light and host	Uncommon	July - Aug
43.	*Melolontha virescens* Brenske	+									Light and host	Rare	July - Aug
44.	*Microtrichia cotesi* Brenske	+									Light and host	Rare	July - Aug
45.	*Schizonycha* sp. 1		+	+	+		+	+	+		Light and host	Common	July - Sep
46.	*Schizonycha* sp. 2				+	+					Host trees	Uncommon	July - Sep
47.	*Sophrops* sp. 1	+					+				Light and host	Uncommon	July - Aug
48.	*Sophrops* sp. 2				Collected from Una						Host trees	Rare	July - Aug
49.	*Sophrops* sp. 3				Collected from Una						Host trees	Rare	July - Aug
50.	*Trichoserica umbrinella* (Brenske)	+						+			Light and host	Uncommon	July - Sep
51.	*Meloserica* sp.	+									Host trees	Rare	July - Aug
Subfamily: Rutelinae													
52.	*Adoretus bimarginatus* Ohaus			+		+				+	Light and host	Uncommon	May - Aug
53.	*Adoretus lasiopygus* Burmeister	+		+		+		+	+	+	Light and host	Common	May - Aug
54.	*Adoretus pallens* Blanchard	+					+			+	Light and host	Uncommon	May - Aug
55.	*Anomala chlorocarpa* Arrow	+									Host trees	Rare	May - Aug
56.	*Anomala comma* Arrow	+									Light and host	Rare	May - Aug
57.	*Anomala elata* Olivier		+								Light and host	Rare	May - Aug
58.	*Anomala dimidiata* Hope	+	+	+							Light and host	Uncommon	May - Aug
59.	*Aomala lineatopennis* Blanchard	+		+			+			+	Light and host	Common	May - Aug
60.	*Anomala pellucida* Arrow	+								+	Light trap	Rare	May - Aug
61.	*Anomala polita* Blanchard		+								Light and host	Rare	May - Aug
62.	*Anomala ruficapilla* Burmeister	+					+				Light and host	Uncommon	May - Aug
63.	*Anomala rufiventris* Redtenbacher	+	+	+		+		+			Light and host	Common	May - Aug
64.	*Anomala rugosa* Arrow	+				+	+				Light and host	Uncommon	May - Aug
65.	*Anomala singularis* Arrow	+	+							+	Light and host	Uncommon	May - Aug
66.	*Anomala stoliezkoe* Hope								+		Light and host	Rare	May - Aug
67.	*Anomala tristis* Arrow	+					+				Host trees	Uncommon	May - Aug
68.	*Anomala varicolor* (Gyllenhal)	+		+			+			+	Light and host	Common	May - Aug
69.	*Mimela fulgidivittata* Blanchard	+		+							Light and host	Uncommon	July - Sep
70.	*Mimela passerinii* Hope				+	+		+	+		Light and host	Common	July - Sep
71.	*Mimela pectoralis* Blanchard					+					Light and host	Rare	July - Sep
72.	*Popillia cyanea* Hope	+			+					+	Light and host	Uncommon	July - Sep
73.	*Popillia pilosa* Arrow				+						Light and host	Rare	July - Sep
74.	*Popillia nasuate* Newman				+						Light and host	Rare	July - Sep
75.	*Popillia virescens*					+					Light trap	Rare	July - Sep
Subfamily: Cetoniinae													
76.	*Chiloloba acuta* (Weidemann)	+									Host trees	Rare	July - Sep
77.	*Clinteria spilota* (Hope)						+			+	Light and host	Uncommon	July - Sep
78.	*Heterorrhina nigritarsis* Hope				+						Light and host	Rare	July - Sep
79.	*Protaetia coensa* (Westwood)	+				+					Light trap	Uncommon	July - Sep
80.	*Protaetia impavida* Janson								+	+	Light and host	Uncommon	July - Sep
81.	*Protaetia neglecta* Hope					+		+	+		Light and host	Uncommon	July - Sep
82.	*Oxycetonia albopunctata* (Fabricius)						+				Light and host	Rare	July - Sep
Subfamily: Dynastinae													
83.	*Heteronychus lioderes* (Fabricius)	+	+								Host trees	Uncommon	July - Sep
84.	*Phyllognathus dionysius* Redtenbacher		+							+	Light and host	Uncommon	July - Sep
Subfamily: Dynamopodinae													
85.	*Dynamopus athleta*									+	Host trees	Rare	July - Sep

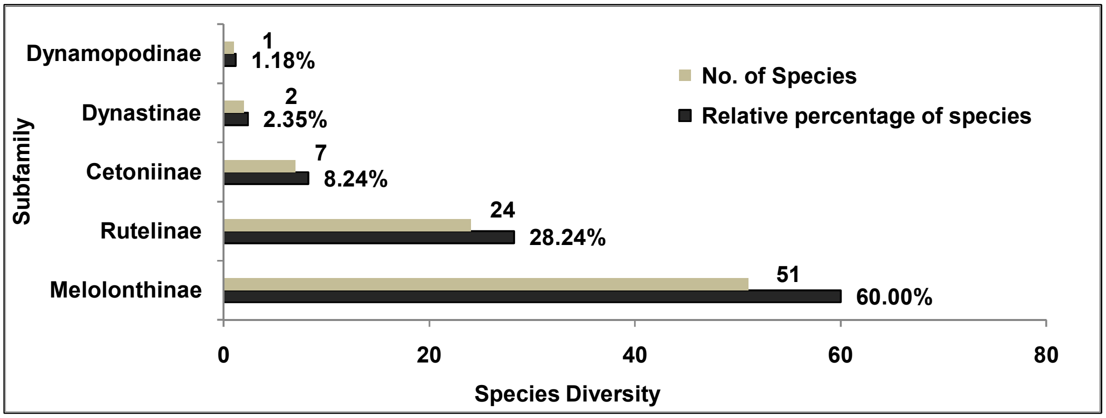


Figure 2: Subfamily-wise share of scarabaeid beetles in Himachal Pradesh

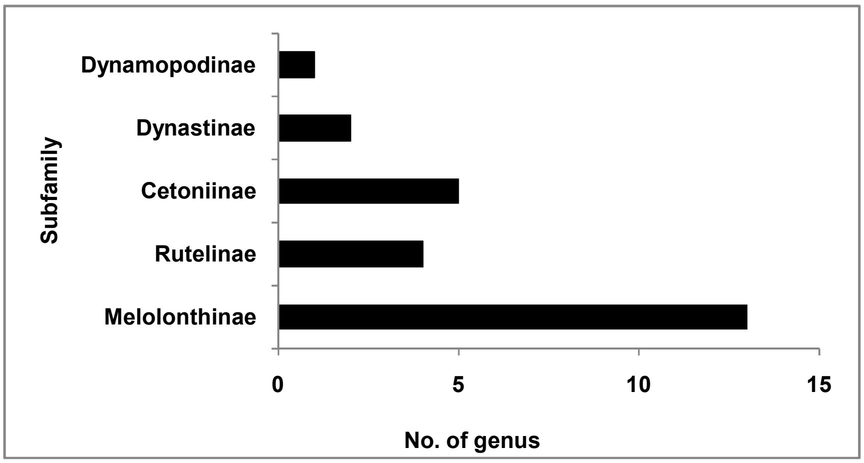


Figure 3: Genus wise distribution of scarabaeid species to different subfamilies

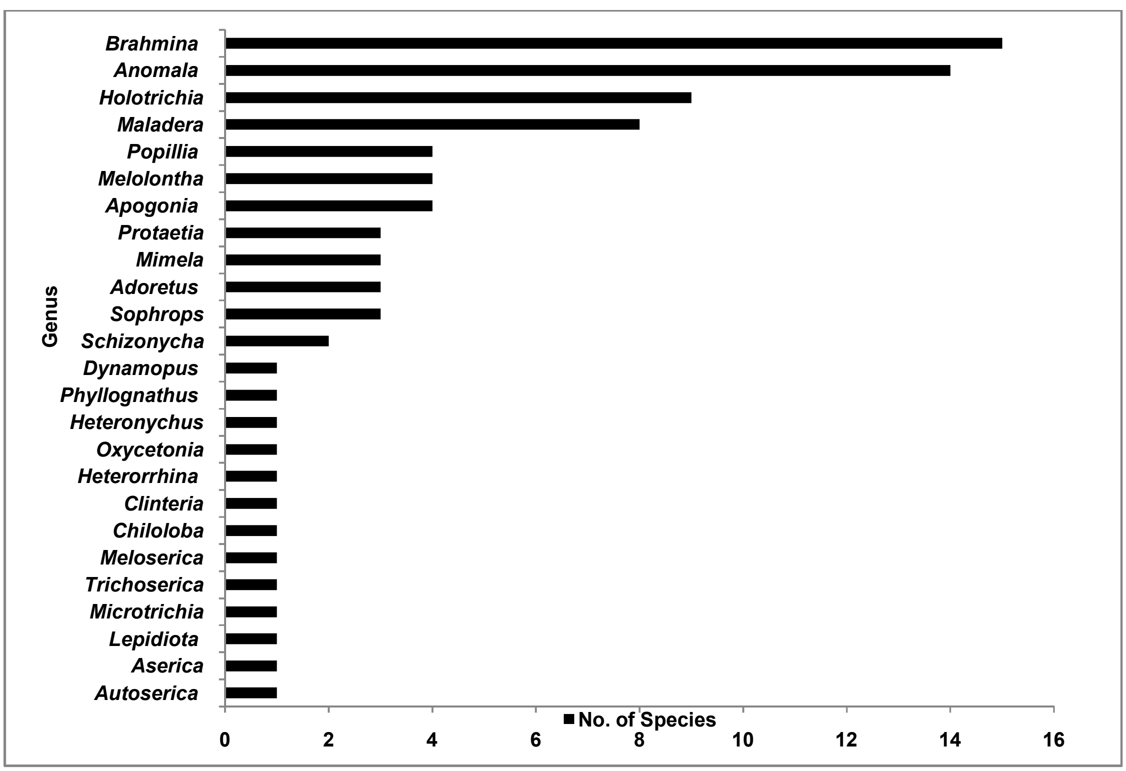
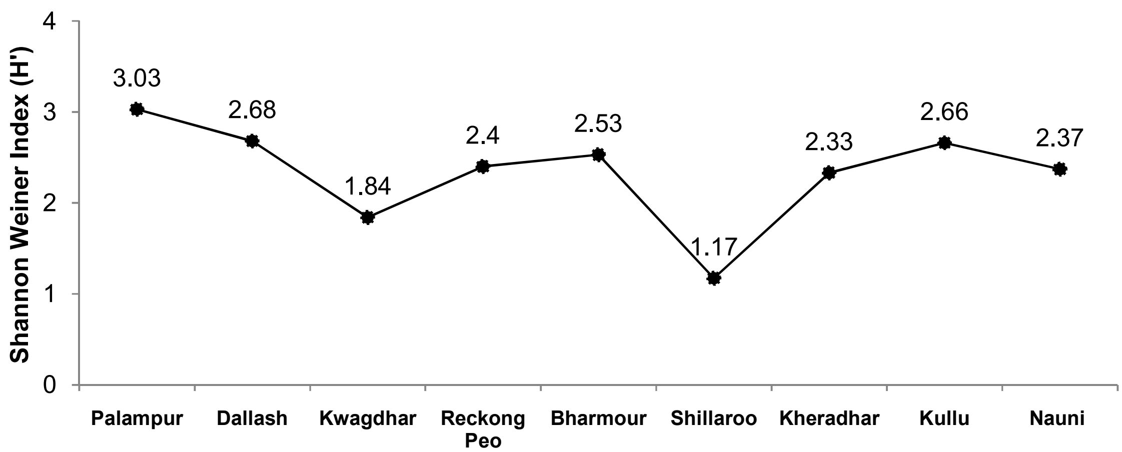


Figure 4: Genus wise distribution of scarabaeid species collected from different sites of Himachal Pradesh

Species Diversity

Overall diversity of phytophagous scarabaeidae of the study area was recorded to be 21.01 indicating richness and evenness of abundance of species in the north western Himalaya. Among different sites, Palampur had a highest value of Shannon index (H') during 2011-12 (H'=3.03) and at Dallash, Kullu, Bharmour, Reckong Peo, Kheradhar, Nauni and Kwagdhar the value of Shannon index (H') was moderately higher ranging from 2.68-1.84, respectively (Figure 5). During both the years of study, Palampur area with higher altitude and longest rainy season had the highest Shannon-Wiener diversity Index. The highest value of Shannon-Wiener diversity Index at Palampur represents higher diversity and evenness of abundance of species. The Shannon index was lowest at Shillaroo (H'=1.17) suggesting complete unevenness of abundance of species at Shillaroo during the study period (Figure 5) which was due to the reason that this region was dominated by only *B. coriacea* which constituted 97.33% of total population of the collected species.



1=Palampur, 2=Dallash, 3=Kwagdhar, 4=Kinnaur, 5=Bharmour, 6=Shillaroo, 7=Kheradhar, 8=Kullu and 9=Nauni

Figure 5: Diversity index for phytophagous scarabaeid assemblage along 9 locations

Abundance

In the present study, Palampur supported maximum diversity (39 species) representing 17 genera belonged to 4 subfamilies, followed by Kullu with 23 species (Figure 6). However, number of species documented in rest of the locations ranged from 12-22 (Figure 6). In all the studied locations, Melolonthinae was the most dominant subfamily and its per cent share of total population count across locations ranged from 77.80-43.75% in Bharmour to Kheradhar, respectively. Rutelinae ranked second in diversity and the rutelinids constituted 41.18-8.33% among different surveyed areas (Table 3). There were no dynastids documented from Kullu, Dallash, Kheradhar, Kwagdhar, Bharmour and Reckong Peo. This is because of the reason that the members of Dynastinae are mostly found in low hill areas (Table 2 and 3). During the study period *Dynamopus athleta* member of subfamily Dynamopodinae was recorded for the first time in Himachal Pradesh from Nauni area (Table 3).

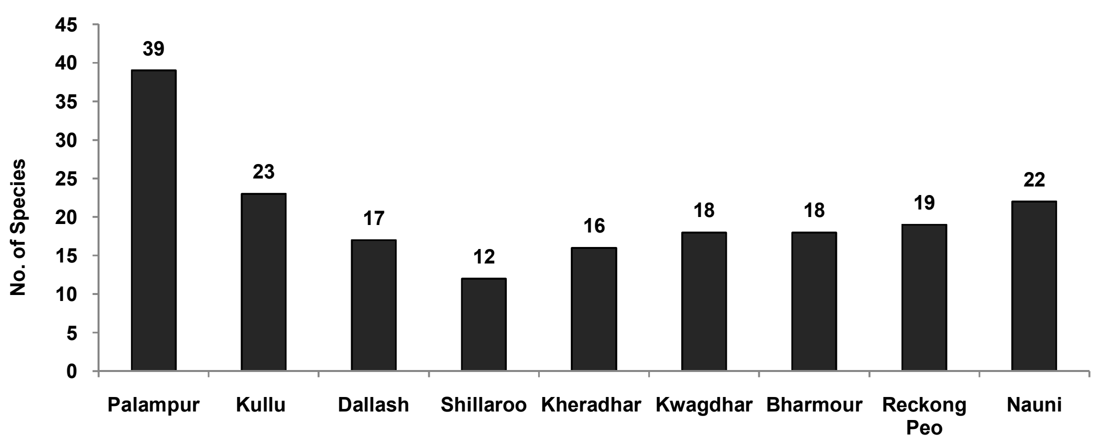


Figure 6: Phytophagous Scarabaeid species diversity at different study sites of Himachal Pradesh

Table 3: Diversity of phytophagous scarabaeidae across different locations of Himachal Pradesh during 2011-12

S. No.	Locations Surveyed	Number of species				
		Melolonthinae	Rutelinae	Cetoniinae	Dynastinae	Dynamopodinae
1.	Palampur	21 (53.85%)	14 (35.90)	3 (7.69)	1 (2.56)	0.00
2.	Kullu	16 (69.57)	5 (21.74)	2 (8.70)	0.00	0.00
3.	Dallash	10 (58.82)	7 (41.18)	0.00	0.00	0.00
4.	Shillaroo	7 (58.33)	1 (8.33)	3 (25.0)	1 (8.33)	0.00
5.	Kheradhar	7 (43.75)	6 (37.50)	3 (18.75)	0.00	0.00
6.	Kwagdhar	10 (55.55)	6 (33.33)	2 (11.11)	0.00	0.00
7.	Bharmour	14 (77.80)	3 (16.67)	1 (5.60)	0.00	0.00
8.	Reckong Peo	14 (73.68)	3 (15.79)	2 (10.53)	0.00	0.00
9.	Nauni	10 (45.45)	8 (36.36)	2 (9.09)	1 (4.54)	1 (4.54)

Values in parentheses are the per cent share of different subfamilies

Altitudinal Gradient and Scarabaeid Species Assemblage

The empirical species richness exhibit a mid elevation peak for the alpha diversity. The altitudinal assemblage of scarabaeidae showed richness and diversity in north western Himalayan region with different peaks corresponding to elevation gradient (Figure 7). The elevation zone 1000-1500 m was found richest in scarabaeid species assemblage representing 31.76% (Figure 7) of total species. Twenty four species of scarabaeids showed broad activity zone with in the elevation rage of 1000-2500 m, however, 4.71% species were confined only to low lying areas *i.e.* below 1000m (Figure 7). In the present study, 23.53% species were recorded within the range of 2000 m and above. The results of the survey revealed that the scarab fauna of north western Himalaya is highly diverse and speciation also changed along with altitudinal gradient.

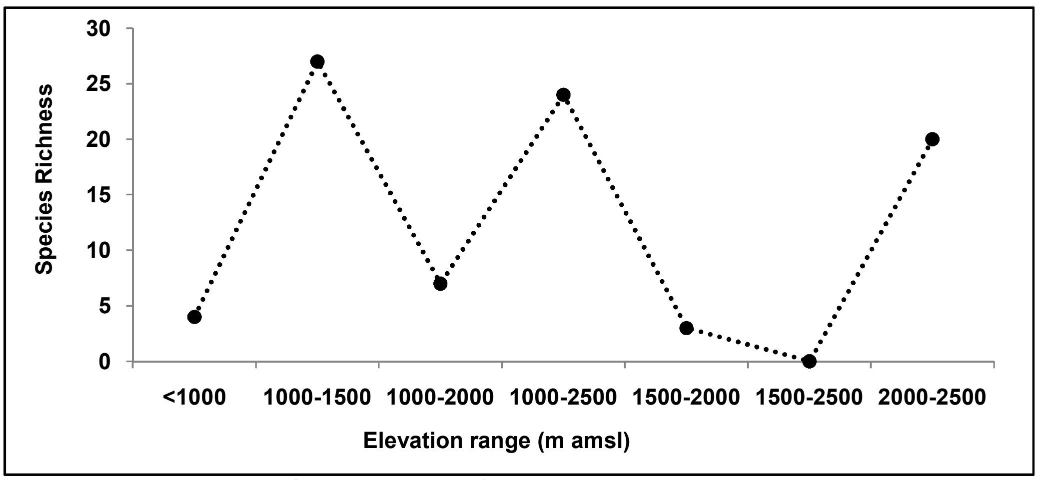


Figure 7: Species richness of scarabaeidae along 7 elevation ranges

Response of Scarabaeids to Light

A total of 85 species were recorded on light trap and host trees in Himachal Pradesh. Out of these, 5.88% species (Figure 8) were recorded only on light trap and 30.59% species occurred on host trees (Figure 8). Moreover, 63.53% species of phytophagous scarabaeids were collected on light and host trees both (Figure 8). Out of 85 species recorded from Himachal Pradesh, 26 species (*A. proxima, B. poonensis, B. comata, Brahmina* sp. 5, *Brahmina* sp. 6, *Brahmina* sp. 7, *Brahmina* sp. 8, *H. insularis, H. serrata, H. setticolis, Holotrichia* sp., *M. bimaculata, M. carinata, M. perpendicularis, M. simlana, Maladera* sp., *Meloserica* sp., *A. tristis, H. nigritarsis, P. virescens, D. athleta, Sophrops* sp. 2, *Sophrops* sp. 3, *Aserica* sp., *A. chlorocarpa* and *C. acuta*) were found only on host trees and not recorded on light trap. On the other hand, five species *viz. H. nigricollis, A. carinata, A. pellucida, P. virescens* and *P. coensa* were recorded only on light trap and not recorded on host trees. *B. coriacea*, *A. lasiopygus*, *A. lineatopennis, M. insanabilis* and *H. longipennis* were the most predominant species on light trap. On host trees, *B. coriacea*, *H. longipennis*, *A. phthisica*, *M. insanabilis* and *Schizonycha* sp. 1 were the leading species. *B. coriacea* and *H. longipennis* were found to be less phototactic in nature, whereas *M. insanabilis*, *A. lineatopennis*, and *A. lasiopygus* are more heliotactic in nature. Maximum emergence of beetles was recorded in the month of June during both the years, indicating that June month is most critical period requiring definite intervention to control whitegrubs in endemic areas.

First Reports

Twenty four species *viz. D. athleta, A. carinata, A. proxima, A. villosella, Sophrops* sp. 1, *Sophrops* sp. 2, *sophrops* sp. 3, *M. carinata, M. bimaculata, M. perpendicularis, M. piluda, M. simlana, T. umbrinella, A. comma, A. singularis, A. tristis, A. elata, A. pallens, A. lasiopygus, A. bimarginatus, A. pellucida, H. nigricollis, P. virescens* and *O. albopunctata* were recorded for the first time from Himachal Pradesh.

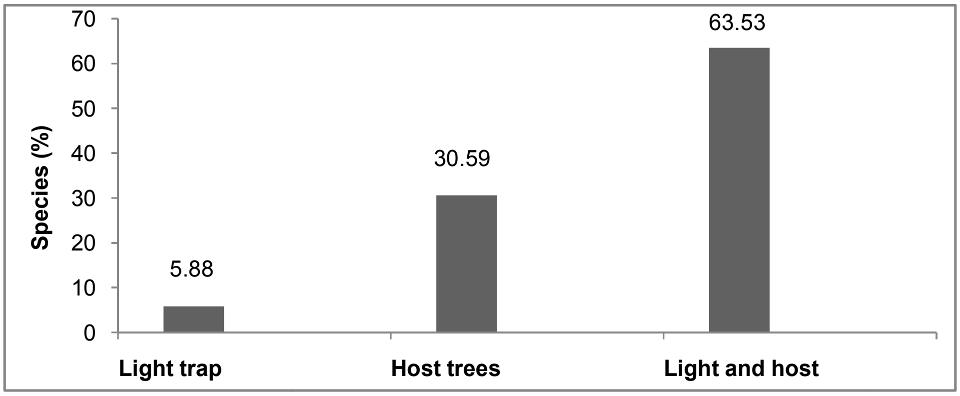
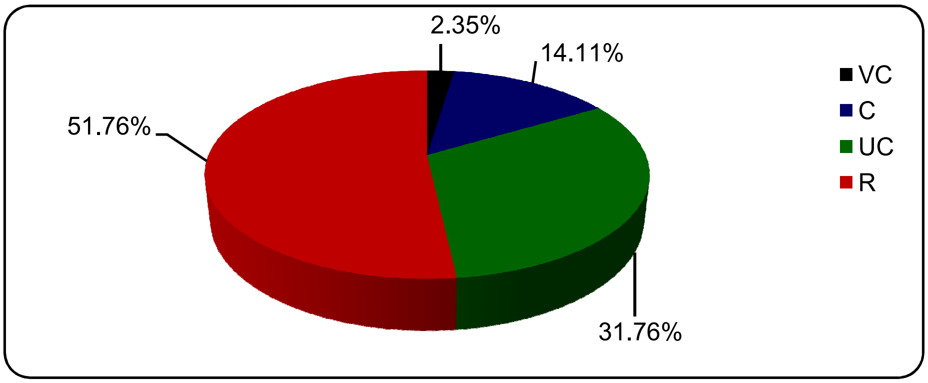


Figure 8: Occurrence of scarabaeid adults on light trap and host trees in north western Himalaya



VC: very common; C: common; UC: Uncommon and R: Rare

Figure 9: Frequency of scarabaeid occurrence in n western Himalaya, India

DISCUSSION

This paper provides comprehensive information on the diversity, distribution pattern, abundance and nativity of phytophagous scarabaeidae in Himachal Pradesh. In the north western Himalaya, Himachal Pradesh lies between 30' 22' 40" North to 33' 12' 40" North latitude and its longitudinal extent is 75' 45' 55" East to 79' 04' 20" East and supports rich fauna of phytophagous scarabaeidae with a total of 85 species. Out of these, 80% (68) species were identified up to species level and remaining 20% (17) species were identified up to genus level. Amongst collected pleurosticti, subfamily Melolonthinae was the most dominant represented with 51 species, followed by Rutelinae (24), Cetoniinae (7), Dynastinae (2) and Dynamopodinae (1). According to Ali (2001), the family Scarabaeidae represents nearly 2500 species from the Indian sub- region and the subfamily Melolonthinae comprised 78.32% of the beetles, followed by Rutelinae (16.48%), Cetoniinae (9.8%) and Dynastinae (1.84%). Yadava and Sharma (1995) also reported that most of the destructive whitegrub species in India belong to subfamily Melolonthinae. Mehta *et al.* (2010) reviewed the status of whitegrubs in north western Himalaya which states that 116 species of scarabaeid beetles are known to occur in north western Himalaya and the subfamily Melolonthinae represents 82% of the total scarabaeid fauna. Chandra (2005) conducted extensive survey in Himachal Pradesh using light trap and collected 88 species of phytophagous scarabs with 34 species belonging to subfamily Melolonthinae. The present records are in accordance with the previous reports thereby substantiating our results.

Maximum numbers of species were observed from March to September and maximum abundance of species was recorded during the period from end of May to August with few exceptions. There was no activity of these beetles from November to February. Earlier surveys in mid hill areas of north western Himalaya revealed the activity of scarabaeid beetles from late February - early September in olive orchards. On pome and stone fruits, these beetles were recorded from first week of April - first week of September (Chandel *et al.,* 1997). In the present study, the main beetle activity was recorded from April to July, however, peak beetle emergence was recorded in the month of June. Irrespective of species, 52.93% of the total number of scarabaeid beetles was collected in June. The beetles from subfamily Rutelinae outnumbered Melolonthinae in the month of May comprising 69.35% of total beetle catch. The total catch for melolonthids was about 7.22 times higher as compared to rutelinids in June. Earlier workers in HP have also reported that rutelinid beetles predominate in the month of May and melolonthids are numerically higher in June (Anon. 2007) Maximum abundance of scarabaeids in particular periods of the year (May - June) is related to seasonal variations and atmospheric temperature. Gharty Chetry *et al.* (2008) also observed that in Nepal the scarabaeid beetle species diversity and abundance varied highly with location and with seasons. Chandel *et al.* (1997) found positive correlation of temperature and rainfall with beetle catch in Himachal Pradesh. In multiple regression analysis, they reported that temperature and rainfall jointly contributes to about 30% of beetle catch. It means other factors are of much greater significance which regulates beetle emergence. It seems that a critical moisture level is required to soften the otherwise hard earthen cells and for escape of beetles from these cells. Thus heavy rainfall in early summer may result in a condition equivalent to flooding, thereby forcing the adult beetles to come out of soil and the mild rainfall may not be of much significance. In north western Himalaya, the pre monsoon showers begin in May-June with high summer temperature triggers the emergence of scarabaeid beetles from soil. During monsoon period from July to September, there is increased growth of various type of vegetation, especially the broad leaves plants. Hence, during this period the abundance of scarabaeids is maximum and they damage many fruit and forest trees by defoliating their leaves.

In this study it was revealed that maximum diversity and abundance was present in the north western Himalaya. The north western hills had a diverse scarab beetle fauna, because they are rich in vegetation for feeding, mating and nesting (Dhoj *et al.,* 2009; Bhalla and Pawar 1977; Kumar *et al.,* 1996; Kumar *et al.,* 2005). Veeresh (1988) also reported that adult food is the chief environmental factor affecting the beeltes' behavior and is one of the important considerations in the distribution of both beetles and grubs. Mehta *et al.,* (2010) reported that vast Shimla hills in Pir Panjal ranges of north western Himalaya are highly favourable for multiplication of whitegrubs because plenty of fruit orchards exist on the slopes of Shimla hills. The scarabaeid beetles exhibit distinct preference for feeding on foliage of pome and stone fruits (Chandel *et al.,* 1997). Palampur situated in mid hill zone of Himachal Pradesh harbor maximum diversity of phytophagous scarabaeidae with 39 species belonged to 4 subfamilies. Kullu and Nauni areas supported more than 20 species each. Similar observations were made in previous studies on diversity and habitat preference of scarabaeid beetles in various parts of India (Kumar *et al.,* 2007; Mehta *et al.,* 2010; Chandra and Gupta 2012; and Chandra *et al.,* 2012). However, higher altitude areas including Shillaroo, Reckong Peo, Kheradhar and Kwagdhar supported lesser species diversity in the present study (Figure 7). This variation in the beetle species might be due to variation of hosts, vegetations, crops grown and soil types. In addition, the variation of other competing species or natural enemies might also have caused variation in the species diversity of the scarabaeid beetles. It was revealed from the results that with increase in altitude above 1500 m amsl diversity and abundance decreasing but the speciation of high altitude areas is entirely different from lower hill areas which adds up in richness of Himalayan region. Several workers have observed that in Himalayan region the scarabaeids diversity and abundance varied highly with locations (Chandel *et al.,* 1994). The impact of altitude is clearly evident as the maximum number of species and individuals were recorded from mid hill areas (below 1500 m). The observation of Chandel *et al.* (2008) also vindicates this fact that the number of species and abundance of insects found at the mid hills is much higher as compared to the higher elevation sites. Thus, it was clear from the present study that the higher hills are rich in diversity and the speciation of higher hills is entirely different from those of low and mid hill zone areas. Different ecosystems of the world harbor different species composition with varying numbers. Lenski (1982) has reported 43 species of Coleoptera: Carabidae from the Blue Ridge Mountain forest of North Carolina. Kruger and McGavin (1997) reported 113 species of Coleoptera from Mkomazi Game Reserve, North-East Tanzania. Scarabaeids show distinct patterns of habitat utilization. The nature of vegetation is an important factor which determines the dependence and survival of a species on a particular habitat. The impact of altitude is clearly evident as the maximum number of species and individuals were recorded from mid hill zone, (1000-1500 m) supporting the observation of Joshi and Arya (2008) that the number of species and abundance of insects found at the lower elevation is higher as compared to the higher elevation site. During the two year survey, 24 species were recorded from the study area for the first time.

When relative abundance of these species was studied it was found that of these 85 species, 2 were found to be very common, 12 common, 27 uncommon and 44 were rare (Figure 9). The results indicated that the phytophagous scarabaeids are sporadic in nature and speciation changes with altitude, topography, soil and geology. Several species of these phytophagous scarabaeidae have unpredicted potential of damage to agricultural and horticultural crops grown in the region. *B. coriacea*, *H. longipennis*, *A. phthisica*, *M. insanabilis* and *Schizonycha* sp. 1 were the leading species in terms of abundance in the study area. The diversity indices indicate maximum species richness with more evenness in scarab communities at Palampur, Dallash, Nauni and Kwagdhar. Alexander and Hillard (1969) have reported that the maximum species diversity of insects occurs at lower altitudes (1530 m) in comparison of high altitudes (4265 m) because of the longer seasons at lower altitudes. In Shillaroo area poor species diversity and complete unevenness of abundance in scarab community recorded with only *B. coriacea* constituting about 97% of total scarabaeid population. Dhoj *et al.* (2009) also reported that a community dominated by few species is considered to be less diverse than one with a high species richness and evenness.

CONCLUSIONS

Richness in abundance of species and individuals of phytophagous scarabaeidae in the northwestern Indian Himalaya than what has been reported by some earlier workers in different ecosystems of the world indicate the availability of sufficient food plants, adaptability of scarabaeids to the ecological factors prevailing in the study area reveals that these areas are main centers of insect diversity. Furthermore for effective management of insect-pests of a particular area, knowledge about the ecology, morphology, phenology, reproductive biology and physiology of that insect species is essential. Monitoring of invasion can be done through qualitative approach like species inventory (seasonally) and quantitative approach using phytosociological methods and mapping of diversity using ground-based methods (GPS). A better planning is needed for early detection and reporting of infestations/ spread of new pest species by establishing communication links between taxonomists, ecologists and local farmers to monitor and control.

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Conflict of Interest

Conflict of Interest none declared.

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