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ACKNOWLEDGEMENTS. We thank Prof. Mustaq Ali (GKVK Bangalore) for determining the ants collected in the study to the species. P.B.U. thanks Kerala State Council for Science Technology and Environment (KSCSTE) for a Ph D fellowship; The project was supported by National Geographic Society's Conservation Research and Exploration award to P.A.S. He also thanks the University Grants Commission's start-up grant for funding the research. We also thank two anonymous reviewers for their constructive comments on the manuscript, which helped improve the overall style of the manuscript.

Received 20 May 2016; revised accepted 17 February 2017

doi: 10.18520/cs/v113/i02/317-322

Species diversity of white grubs (Coleoptera: Scarabaeidae) in the sub-Himalayan and northern plains of India

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White grubs belonging to subfamilies Melolonthinae and Rutelinae of Scarabaeidae (Coleoptera) are ubiquitous pests. Studies during 2013 and 2014 document the species diversity of white grubs in the sub-Himalayan and northern plains of India. Surveys conducted in four states, viz. Himachal Pradesh, Uttarakhand, Uttar Pradesh and Rajasthan revealed high species diversity representing 65 species under 16 genera. The species richness, evenness and composition varied among the states. Higher species diversity was recorded in Uttarakhand and Himachal Pradesh of the sub-Himalayan region when compared to Uttar Pradesh and Rajasthan of the northern plains. The species abundance distribution followed log normal distribution in all places except Uttarakhand, where the curve skewed to the left due to overweight of species with low abundance. The species dominance and abundance patterns in different regions are presented. The new distributional records, *Anomala pictipes* Arrow and *Popillia macclellandi* Hope from Uttarakhand, *Anomala propinqua* Arrow and *Popillia marginicollis* Hope from Himachal Pradesh and *Anomala stenodera* Arrow from Uttar Pradesh are provided.

Keywords: Abundance models, Melolonthinae, Rutelinae, species diversity, white grub.

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WHITE grubs (Coleoptera: Scarabaeidae) are polyphagous herbivores that constitute one of the most widespread and devastating pest groups. Due to the magnitude of economic impact, white grub is considered a national pest. Scarabaeidae comprises about 27,800 species worldwide[1] and includes Laprosticti and Pleurosticti beetles, in which the former includes dung feeders and the latter phytophagous. Of the four major subfamilies of Pleurosticti Scarabaeidae in India, Melolonthinae and Rutelinae, include the so-called 'May' or 'June beetles' and 'shining leaf chafers', which are popularly known as white grubs. Amongst all, Melolonthinae is the largest subfamily with 750 genera and 11,000 species present in the world and 75 genera with 932 species occurring in India[2].

The life cycle of white grubs ranges usually from 1 to 2 years, depending on climatic conditions[3]. Certain species have two generations in a year. The sericine beetle, *Maladera* spp., was reported to have two generations annually in Israel[4] and India[5]. The average longevity of adults, usually lasts for a month[3]. The adults of white grubs emerge generally during May–June from the soil, in the night, and settle on the nearby trees like neem, ber, moringa, *Prosopis*, *Acacia*, apple and plants like wild rose, *Polygonum*, etc. for feeding and mating[5]. The beetles return to the soil in the morning for oviposition. Incubation period ranges from 4 to 12 days depending on the species. On hatching, larvae dwell in the soil and feed on roots, rootlets and underground stems of plants. The larval period invariably lasts for 3–6 months in annual species and still longer in others. This being the longest and most destructive stage, the infestation leads to initial yellowing, stunted growth and subsequent drying and wilting of plants[6]. Pupation takes place in the soil and as soon as the adult emerges, these inhabit the soil for considerable time, and swarm in large numbers after first showers.

The damage is extensive in several economic crops like sugarcane, groundnut, cereals, millets, pulses, vegetables and plantation crops[7]. Many of these species cause serious damage all over the country from Himalaya to Kerala and Gujarat to north eastern regions[8]. The damage is more pronounced in sugarcane[9] and groundnut[10], resulting in huge losses to the tune of 25–100% and 80.56% respectively. Species delineation is important for strategizing the management options. Earlier reports provide an annotated list of scarab fauna in western Uttar Pradesh (UP)[11] and Uttarakhand[12], however, detailed distribution patterns of pest species of Melolonthinae and Rutelinae are yet to be addressed. Geographical variations coupled with cropping pattern differences contribute to the composition of species complex of a region. Hence in the present study, we document the white grub species diversity and distribution in the northern plains and sub-Himalayan regions of India.

Surveys were conducted in four states, viz. Rajasthan, UP, Uttarakhand and Himachal Pradesh (HP) in India during 2013 and 2014. Three districts, viz. Bhakrota, Jaipur (26°91′N; 75°79′E), Gang do Gadi, Dausa (26°52′N; 76°20′E) and Khejrauli, Khejrauli (27°33′N; 75°69′E) in Rajasthan; Pursi, Ghaziabad (28°40′N; 77°28′E), Jallopur, Amroha (28°54′N; 78°31′E), Jakhwala, Saharanpur (29°42′N; 77°43′E) in Uttar Pradesh; Pantnagar (29°02′N; 79°48′E), Almora (29°61′N; 79°67′E) and Ranichauri (30°32′N; 78°41′E) in Uttarakhand; Kheradhar, Sirmour (30°56′N; 77°47′E), Kufri, Shimla (31°10′N; 77°27′E) and Palampur, Kangra (32°11′N; 76°53′E) in HP were selected for the study. At four locations in each district, light traps with black light (wavelength 365 nm) were installed. The adults of white grubs were collected during the second fortnight of May to first fortnight of August. Adults attracted into a funnel trap were sorted, killed using ethyl acetate, cleaned, relaxed, dried, pinned and labelled. These adults were grouped based on similarities and identified by comparison with the keys[13–15]. The voucher specimens were deposited with the National Pusa Collection, Division of Entomology, Indian Agricultural Research Institute, New Delhi. The collections were documented for associated data on the distribution and subjected to diversity (species richness and evenness) and abundance analyses. Rank/abundance plot depicts the contrasting patterns of species richness, especially in the case of relatively few species as compared to histogram, where it would be inefficiently displayed[16]. Further, rank/abundance plots enable the differences in species evenness to be clearly visible amongst assemblages[17,18]. Hence, the distribution of species abundance was worked out by Whittaker's rank/abundance plot and $\log x$ frequency distribution (Preston plot), wherein the number of species in each abundance category was plotted in the latter.

The Shannon–Wiener's, Simpson's[19] and Pielou's evenness indices were used to determine the species richness and evenness. The Shannon–Wiener index was used for calculating alpha diversity as it is most important for the major species when compared to the rare species. In taxonomic or ecological research, similarity indices provide quantitative bases of assessment in comparing species composition or biodiversity of two or more assemblages[16]. Hence, the similarity index between states was calculated by Jaccard's similarity coefficient[20,21], Sorenson's similarity coefficient and Bray-Curtis distance index[22].

A total of 65 species represented by 16 genera belonging to Melolonthinae and Rutelinae were documented from the surveyed areas of four states, viz. HP, Uttarakhand, UP and Rajasthan during 2013 and 2014 (Table 1). Fauna of Melolonthinae was abundant with 35 species represented by 12 genera while Rutelinae was represented by 29 species under 4 genera. The species richness was high in HP (34 species under 11 genera) followed by Uttarakhand (31 species under 9 genera) of the sub-Himalayan region. When compared to the above

Table 1. White grub species diversity in four northern states of India

Species	Relative abundance (%)			
	Himachal Pradesh	Uttarakhand	Uttar Pradesh	Rajasthan
Holotrichia nagpurensis Khan and Ghai	0.00	0.00	23.51	1.85
H. serrata (F.)	0.00	0.00	13.98	2.93
H. consanguinea (Blanchard)	0.00	0.00	15.70	53.09
H. longipennis (Blanchard)	14.91	5.19	0.00	0.00
H. sikkimensis Brenske	10.81	0.00	0.00	0.00
H. seticollis Moser	0.00	4.40	0.00	0.00
H. rosettae Frey	0.00	2.59	0.00	0.00
H. sculpticollis (Blanchard)	0.00	2.43	0.00	0.00
H. akolana Khan and Ghai	0.00	0.00	0.86	0.00
H. problematica Brenske	0.14	0.00	0.00	0.00
Lepidiota mansueta (Burmeister)	0.00	5.81	10.07	0.00
L. stigma (F.)	0.00	2.80	0.00	0.00
L. sticticopetra Blanchard	0.00	0.88	0.00	0.00
Brahmina coriacea (Hope)	28.78	3.06	0.00	0.00
B. flavosericea (Brenske)	4.50	0.30	0.00	0.00
B. crinicollis Burmeister	2.19	0.00	0.00	0.00
Melolontha cuprescens Blanchard	4.40	0.00	0.00	0.00
M. nepalensis (Blanchard)	1.29	0.42	0.00	0.00
M. indica (Hope)	1.09	0.22	0.00	0.00
M. furcicauda Ancey	0.00	3.72	0.00	0.00
Maladera insanabilis (Brenske)	1.51	3.08	6.61	17.25
M. carinata Khan and Ghai	0.08	0.00	0.00	0.00
M. simlana (Brenske)	0.22	0.00	0.00	0.03
M. perpendicularis Khan and Ghai	0.08	0.00	0.25	1.16
Serica sp.	0.98	0.00	0.00	0.00
Microserica sp.	0.96	0.00	0.00	0.47
Microtrichia cotesi Brenske	0.68	0.00	0.00	0.00
Schizonycha ruficollis (F.)	1.97	0.00	1.17	5.86
Schizonycha sp.	0.00	0.00	0.14	0.00
Apogonia ferruginea F.	0.00	0.00	0.39	1.91
Apogonia sp.	0.00	0.00	0.00	1.47
Brahmina sp.	0.00	0.00	0.08	0.00
Sophrops sp.	0.30	5.53	0.00	0.00
Cyphonoxia sp.	0.00	0.00	0.00	0.08
Anomala bengalensis (Blanchard)	0.10	0.10	4.23	0.00
A. polita Blanchard	0.00	0.10	0.43	0.00
A. dimidiata (Hope)	0.18	20.96	13.28	13.41
A. lineatopennis Blanchard	8.48	4.24	0.00	0.00
A. cantori (Hope)	0.00	10.34	0.00	0.00
A. propinqua Arrow	7.28	0.00	0.00	0.00
A. rufiventris Kollar and Redtenbacher	2.63	3.86	0.00	0.00
A. dorsalis (F.)	0.06	0.64	2.31	0.00
A. tristis Arrow	0.00	1.94	0.00	0.00
A. ruficapilla Burmeister	0.00	0.00	1.30	0.00
A. varicolor (Gyllenhal)	0.00	1.35	1.05	0.00
A. nilgirensis Arrow	0.00	0.06	0.00	0.00
A. stenodera Arrow	0.00	0.00	0.02	0.00
A. rugosa Arrow	0.12	4.08	0.00	0.00
A. chlorosoma Arrow	0.00	1.25	0.00	0.00
A. marginata Schilsky	0.02	0.54	0.00	0.00
A. pictipes Arrow	0.00	0.18	0.00	0.00
Adoretus flavus Arrow	0.28	0.00	1.67	0.00
A. lasiopygus Burmeister	0.04	0.00	0.43	0.00
A. versutus Harold	0.00	0.00	0.72	0.00
A. duvauceli Blanchard	0.00	0.00	1.48	0.19
A. excisus Ohaus	0.00	0.00	0.31	0.00
Adoretus sp.	0.02	0.00	0.00	0.30
Mimela fulgidivittata Blanchard	0.00	5.85	0.00	0.00
M. pectoralis Blanchard	1.45	0.00	0.00	0.00
Popillia cyanea Hope	0.56	2.30	0.00	0.00
P. marginicollis Hope	1.19	0.00	0.00	0.00
P. cupricollis Hope	2.07	0.00	0.00	0.00
P. macclellandi Hope	0.00	1.75	0.00	0.00
P. nasuta Newman	0.52	0.00	0.00	0.00
Popillia sp.	0.10	0.00	0.00	0.00

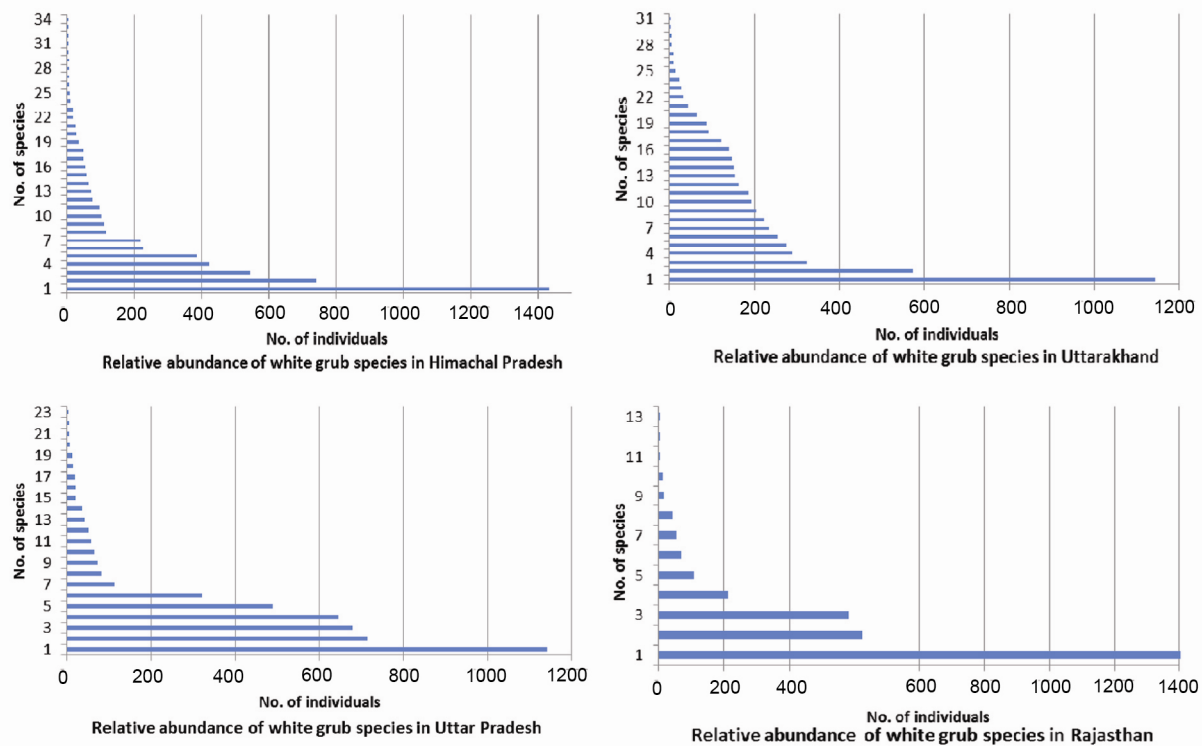

Figure 1. Fisher plots – frequency of white grub species in relation to abundance.

abundances, in the northern plains, lesser species richness was observed. In UP, 23 species under 8 genera and in Rajasthan, 14 species under 8 genera were recorded (Table 1).

The Fisher plot and Whittaker's rank abundance curve in the four states exhibited a hollow curve distribution indicating few common and more rare species (Figures 1 and 2 *a*). The shape and slope of the curve varied among the states; it was less steep in Uttarakhand and HP compared to UP and Rajasthan, indicating high species diversity in terms of richness and evenness. The species diversity revealed a few predominant species of Melolonthinae and Rutelinae in respective regions. In HP, *Brahmina coriacea* (Hope) (29%) followed by *Holotrichia longipennis* (Blanchard) (15%) and *H. sikkimensis* (Brenske) (11%) constituted 55% of the total population. In Uttarakhand, *Anomala dimidiata* (Hope) was predominant (21%) followed by *A. cantori* (Hope) (10%), while it was *H. nagpurensis* Khan and Ghai (24%) followed by *H. consanguinea* Blanchard (16%), *H. serrata* (F.) (15%) and *A. dimidiata* (14%) in UP. *Holotrichia consanguinea* was the most predominant species in Rajasthan constituting nearly 53% followed by *Maladera insanabilis* (Brenske) (17%) and *A. dimidiata* (13%) (Table 1 and Figure 3).

The alpha diversity was high in Uttarakhand (H = 1.271; D = 0.904 and E = 0.852) followed by HP (H = 1.074; D = 0.864 and E = 0.702) and UP (H = 0.960; D = 0.855 and E = 0.706) as evidenced by Shannon and Simpson diversity indices (Table 2). The diversity was observed to be low in Rajasthan (H = 0.652; D = 0.687 and E = 0.585) (Table 2) in terms of species richness and evenness, as it is skewed towards the three common species to the extent of 84%.

The species *Anomala pictipes* Arrow and *Popillia macclellandi* Hope (Scarabaeidae: Rutelinae) are reported for the first time from Uttarakhand. Similarly, *Anomala propinqua* Arrow and *Popillia marginicollis* Hope from HP and *Anomala stenodera* Arrow (Scarabaeidae: Rutelinae) from UP are new distributional records reported.

The relative abundance, which depicts the commonness and rarity, revealed few common species compared to rare ones. The Jaccard and Sorenson similarity indices, which compare two assemblages based on species incidence revealed that HP and Uttarakhand exhibited comparatively greater similarity (0.21; 0.34). UP showed similarity with Rajasthan (0.16; 0.28) and Uttarakhand (0.15; 0.26) (Table 3). HP and Uttarakhand showed high dissimilarity with Rajasthan as evidenced by Bray–Curtis distance index (0.965 and 0.826 respectively). UP and Himachal Pradesh also exhibited high dissimilarity (0.951) in white grub species diversity (Table 4).

The white grub endemic areas surveyed in the four states, viz. HP, Uttarakhand, UP and Rajasthan revealed variations in the species richness and abundance. Both these observations are important in representing changes in diversity[23]. The species belonging to Melolonthinae were abundant in surveyed areas of Rajasthan, UP and HP while Rutelinae were abundant in Uttarakhand.

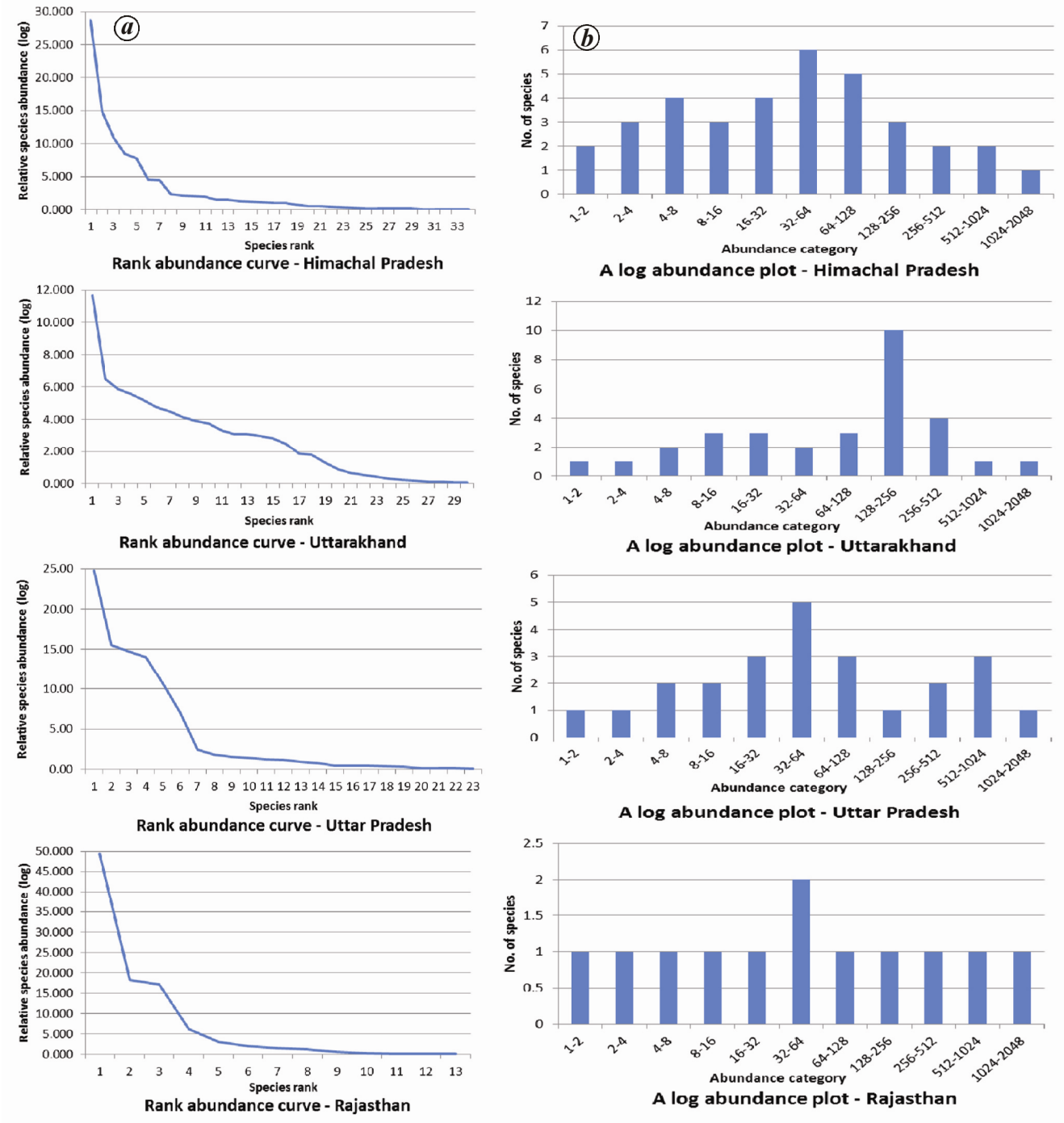

Figure 2. ***a***, Whittaker's white grub species rank abundance curve. ***b***, Preston's log abundance plot of white grub species.

The communities in each region, by and large, are stable with fewer common species than rare species, which conforms to the fact that most individuals belong to few common species in a typical community[24]. The hollow curve depicted by Fisher plot (that depicts the relation between the number of species and the number of individuals in a random sample of a population[25]) (Figure 1), also supported by Whittaker's rank abundance curve, showed variations in the slope among the states that are functional to the community. This is justified, because the relative abundance in the four states varied with regard to the percentage of common species. The most abundant three species in HP and UP constituted nearly 50–60% of the total white grub population, while three species occupied 37% in Uttarakhand and one species alone occupied 50% in Rajasthan. This is also supported by the species abundance models expressed as rank abundance curve, which showed a steep slope for Rajasthan indicating less

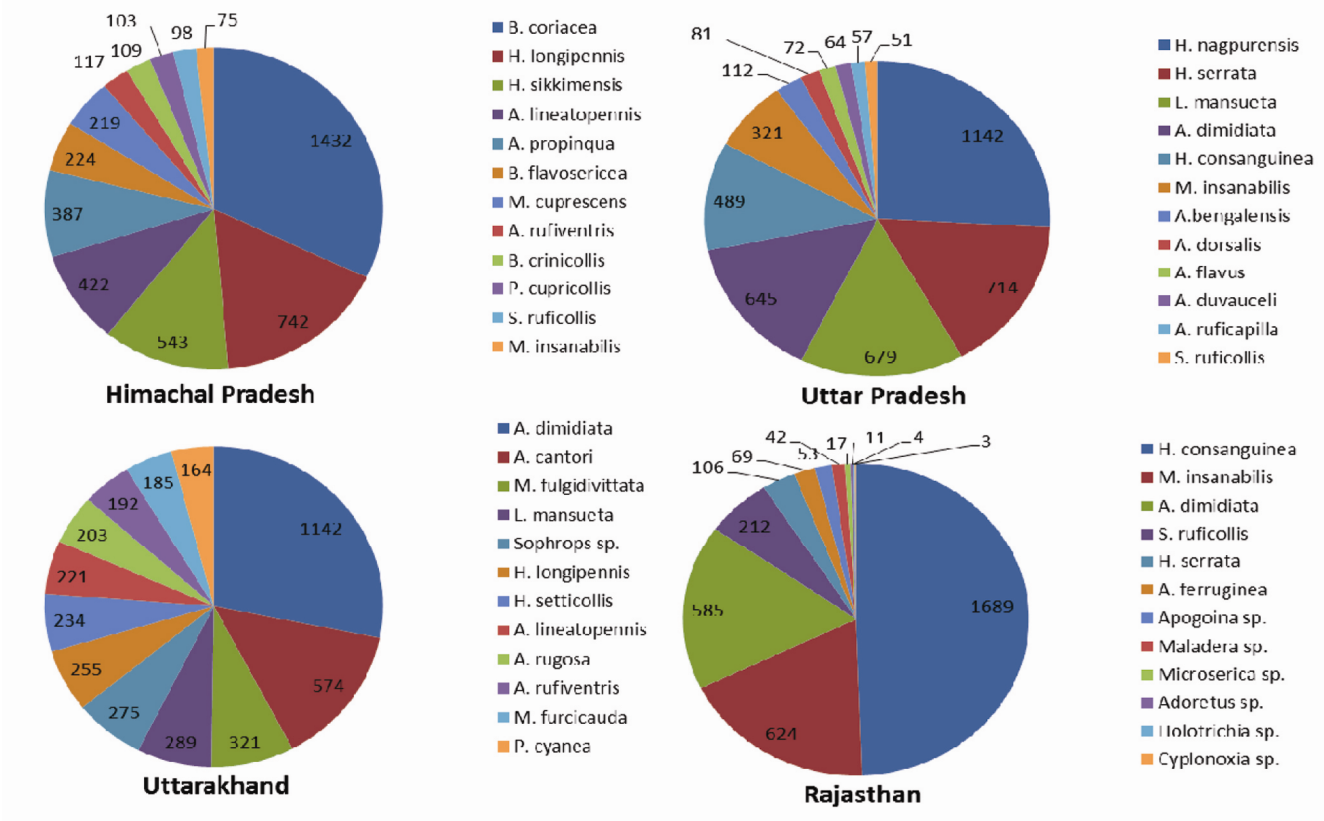

Figure 3. Species composition of white grubs (major twelve).

Table 2. Diversity indices of white grub species in North India

State	Shannon's diversity index (H')	Simpson's diversity index (D)	Pielou's evenness index (E)
Himachal Pradesh	1.074	0.864	0.702
Uttarakhand	1.271	0.904	0.852
Uttar Pradesh	0.960	0.855	0.706
Rajasthan	0.652	0.687	0.585

species richness and evenness (Figure 2 *a*), moderate in HP and UP and comparatively high in Uttarakhand. On the whole, 1–5 species occupied nearly 50% of the population with 13 to 31 species constituting the remaining 50% in the surveyed regions of the four states. This pattern of relative species abundance is an expression of the momentary balance set-up within the community, resulting from past and/or present competition for resources, and population dynamic processes[26].

The predominance of *B. coriacea* followed by *H. longipennis*, *H. sikkimensis* and *Anomala lineatopennis* Blanchard in HP could be attributed to the latitudinal and altitudinal range that influences the kind of vegetation. The cropping pattern is also one of the main factors, as these are mainly associated with potato causing nearly 50% damage in endemic pockets[27]. Similarly, in UP, the dominant species *H. nagpurensis*, *H. consanguinea*, *H. serrata*, *A. dimidiata* and *Lepidiota mansueta* (Burmeister) are mainly associated with sugarcane. In Rajasthan, *H. consanguinea* and *M. insanabilis*, the predominant species are serious pests of groundnut, jowar and maize. The species predominance may be correlated to the cropping pattern to a large extent. The relative abundance patterns may vary within a community through time and among communities in both time and space[23] and the abundance of species is independent of one another[28,29]. The spatial and resource partitioning of white grub species was evident among the surveyed areas of the four states, thus avoiding competition and emerging as tough candidates in their respective areas warranting their containment. The predominance of species in the surveyed areas can be attributed largely to two factors, crop and altitude. The only species unaffected by altitude and crop is *A. dimidiata*, which was found in plains, mid- and high-altitudes and is associated with sugarcane, groundnut, maize, potato and other forest plants.

Table 3. Jaccard's and Sorenson's similarity coefficient in relation to white grub species in North India

	Uttarakhand		Uttar Pradesh		Rajasthan	
	Jaccard	Sorenson	Jaccard	Sorenson	Jaccard	Sorenson
Himachal Pradesh	0.21	0.34	0.11	0.20	0.10	0.18
Uttarakhand	0.00	0.00	0.15	0.26	0.06	0.11
Uttar Pradesh			0.00	0.00	0.16	0.28

Table 4. Bray–Curtis distance index in relation to white grub species distribution

	Himachal Pradesh	Uttarakhand	Uttar Pradesh	Rajasthan
Himachal Pradesh	0.000	0.715	0.951	0.965
Uttarakhand		0.000	0.753	0.826
Uttar Pradesh			0.000	0.607
Rajasthan				0.000

In general, species abundance distribution (SAD) varies between the log–normal and the logarithmic series[30]. The log abundance[31] deduced in the present study showed more or less normal distribution in HP, UP and Rajasthan with the highest number of species occurring in the frequency class 32–64, while in Uttarakhand, the highest number was in the octave, 128–256 showing skewness to the left side of the curve (Figure 2 *b*). The SAD patterns sometimes do not follow a log normal distribution due to overweight of species with low abundances[32]. The interacting and non-interacting groups of the community lead to closer log-normal pattern, but skewed to the left, which is usually interpreted as a result of the excess of rare species[33]. In Uttarakhand, the ratio of common species to rare was observed to be 1 : 4, indicating more species with low abundances. Rarity of species is valuable in the context of biological conservation[34], and thus Uttarakhand followed by HP in the sub-Himalayan region could be viewed as biodiversity spots.

The diversity was relatively high in Uttarakhand, where one species occupied 31% and the remaining 29 species occupied 69%. Of the 29 species, the number below 2% was 12%, 2–4% was 10 and 4–6% was 7 indicating high evenness. In HP and UP, 5 species that are abundant occupied nearly 70–77% with 29 and 18 species occupying the remaining 30% and 23% respectively. The diversity was low in Rajasthan where only three species constituted nearly 84%.

The species diversity exhibited differences among the surveyed states with distinct species composition (Figure 3). Comparative high similarity between HP and Uttarakhand can be attributed to similarity in topography, weather and vegetation in the Himalayan ranges. Similarly, the high dissimilarity between these two hill states and Rajasthan could be attributed to differences in topography and crops grown. UP also showed dissimilarity with HP in sharing the species, as the diversity of plains differs from that of hill regions. UP and neighbouring Uttarakhand shared a few species which can be attributed to migration of the species and topography (plains in both states adjacent to each other).

In the present study, 65 species of white grubs belonging to Melolonthinae and Rutelinae were recorded in surveyed areas of four states namely HP, Uttarakhand, UP and Rajasthan of North India. Species distribution followed hollow curve indicating few common and more rare species. The most predominant species were *Brahmina coriacea*, *A. dimidiata*, *H. nagpurensis*/*H. serrata* and *H. consanguinea* in HP, Uttarakhand, UP and Rajasthan respectively. The species diversity was high in HP and Uttarakhand, sub-Himalayan range compared to plains of UP and Rajasthan. Five Rutelinae species are reported for the first time from Uttarakhand, HP and UP of northern India.

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ACKNOWLEDGEMENTS. We thank Dr V. V. Ramamurthy, Principal Scientist (Retd.), Division of Entomology, IARI, New Delhi, India for constant guidance and support during the studies. We also thank the Director, Joint Director (Res.), IARI, Head, Division of Entomology, IARI, New Delhi for facilitating the study. We acknowledge the help extended by the Jaipur, Palampur and Almora centres of AINP on Soil Arthropod Pests, FARMER (NGO), Ghaziabad, UP, State Agricultural Universities, Department officials and local farmers of the four states in facilitating the sampling of white grubs.

Received 28 December 2014; revised accepted 6 March 2017

doi: 10.18520/cs/v113/i02/322-329

Influence of astronomical (lunar)/meteorological factors on the onset of dawn song chorus in the Pied Bush Chat (*Saxicola caprata*)

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Climatic factors which prevail during the breeding season of avian species in spring and early summer may trigger the onset of singing behaviour in songbirds. To understand the effect of climatic variables on the onset of dawn song chorus, we conducted a study in the natural habitats of a tropical songbird, the Pied Bush Chat *Saxicola caprata* in Haridwar, Himalayan foothills, India during early spring. The results indicated that the onset time of dawn chorus depends on a number of environmental factors. The song bout length depended on daily temperature, rainfall rate, wind direction, photoperiod, lunar phase, indices of apparent temperature, dew point, sunrise timing and day length, whereas the song rate depended on daily temperature, photoperiod, indices of apparent temperatures, dew point, sunrise timing and day length. Further, stepwise multiple regression revealed that onset time of dawn chorus was dependent on photoperiod and lunar phase, while song bout length and song rate were influenced by day length and sunrise timing respectively.

Keywords: Onset of dawn song, Pied Bush Chat, tropical songbird.

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