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Seasonal distribution of Scarabs (Insecta: Coleoptera: Scarabaeidae) of a tropical dry deciduous forest in central India

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Abstract – Studies on scarab (Insecta: Coleoptera: Scarabaeidae) seasonality from central Indian province are sparse, particularly from tropical dry deciduous forests which comprise 38% of the forest cover in India. A study of seasonal distribution of scarabs in Bor forest, a tropical dry deciduous forest of central India, led to a collection of 72 species belonging to 35 genera under subfamilies, Aphodiinae, Cetoniinae, Dynastinae, Melolonthinae, Rutelinae, Scarabaeinae and Orphnini. Subfamily Scarabaeinae is found to be the most species-rich with 36 species under 14 genera. Genus *Onthophagus* is the most speciose genus with 15 species. Subfamily Orphninae was found to be the least diverse with a single species. Season and weather parameters shaped the scarab beetle assemblages in the tropical dry deciduous Bor forest. Scarab species richness is found to be positively and significantly related to the mean temperature (β=0.03±0.01 *SE*, p<0.05) and to the mean precipitation (β=0.03±0.01 *SE*, p<0.05). Constrained by logistics, we could not identify optimum temperature or precipitation values on which the scarab species richness can be highest for both the fitter models.

Keywords – scarabs, dung beetles, phytophagous, seasonal prevalence, coprophagous

Introduction – Continuous monitoring, documentation, and successional studies of insects are necessary in understanding ecological changes over time. Studies on seasonal prevalence of species across habitats aid in understanding the fauna better, thus helping develop effective control or conservation strategies. Little has been known about the seasonality of insects in tropical dry deciduous forest habitat comprising almost one-third forest cover in India. The behaviour and ecological interactions of insects across seasons, along with insights into their life history, can be known by observing and studying their community structure over a determined period. Our study group, Scarab beetles (Coleoptera: Insecta: Scarabaeidae), constitute one of the most prominent families in order Coleoptera with 35642 species under 25

subfamilies and 2580 genera (Schoolmeesters 2022). Despite their cosmopolitan occurrence, studies on their seasonal distribution across different habitat types are sparse. Beetles under the family Scarabaeidae are differentiated into two major groups, 'Laprosticti', which are saprophagous and 'Pleurosticti', which are phytophagous beetles (Ritcher 1958). The Pleurosticti beetles, composed of subfamilies Melolonthinae, Rutelinae, Dynastinae and Cetoniinae, are economically important as their larvae, 'white grubs,' are root feeders of crops and forest plants while the adults feed on the foliage of fruits, flowers and forest trees (Mehta et al. 2008). The Laprosticti beetles composed of the subfamilies Aphodiinae and Scarabaeinae are saprophagous or coprophagous in habit. These coprophagous dung beetles are ecologically important as they aid in nutrient recycling and control the parasitic fauna in dung (Halffter and Matthews 1966); Brown et al 2010; Slade et al. 2016). The dung beetles are indicators of environmental change (Davis et al. 2001) and are significant to evaluate the effect of anthropogenic habitat modification on biodiversity (Slade et al. 2016). Dung beetles are also recognized as helpful taxon for describing and monitoring spatial and temporal patterns of biodiversity (Davis et al. 2001; Favila and Halffter 1997). Understanding the ecology and documentation of occurrence data of scarabs is of utmost necessity due to their economic and ecological importance. Their seasonal patterns can be formulated by analysing the timing of the occurrence, the mean date, the median date, the pattern duration and the seasonal peak sensitivity. Study of which might give rise to various ecologically important phenomena. Through the mediation of temperature, humidity and/or day length, insects arrive and/or become active at the study site (Wolda 1988). The current study was planned for two consecutive years as considering tropical insects, the yearly data pattern is justified only if it repeats itself annually (Wolda 1988).

Earlier studies from India have revealed some interesting aspects of the community structure of scarabs (Sabu et al. 2006; Vinod and Sabu 2007; Pathania 2014; Aparna 2015). However, studies on scarab seasonality and activity from central Indian province are sparse, particularly from tropical dry deciduous forests which comprise 38% of the forest cover in India. Our goal was to analyse the seasonal distribution of scarabs from a dry deciduous forest. The current study was planned with two objectives, 1) to estimate the abundance and distribution of scarabs across seasons and 2) to understand the effect of rainfall and temperature on scarab beetle diversity in a dry deciduous forest in central India, Bor Wildlife Sanctuary. We recorded and analysed the scarab beetle abundance and distribution from the study area across three seasons, summer, winter and monsoon and compared it with the rainfall and temperature data. We hypothesized that, scarab beetles show maximum abundance and richness during and post monsoon months with least activity in summers.

Material and methods –

Study area Bor Wildlife Sactuary forest is south Deccan Plateau's dry deciduous forest, situated along the Southern boundary of Nagpur district and the Northern border of Wardha district of Maharashtra, India, at 20° 57' N and 78° 37' E latitude and longitude, respectively. Three sites in Bor forest, namely, Alesu, Degma and Dabha were chosen for the study. The study area is situated at an elevation of 460 m. The broadly-classified seasons of the sites are Summer (March to June), Monsoon (July to October) and Winter (November to February). The region's temperature varies from 7℃ in winter to 45℃ in summer, with an average rainfall of 1018 mm.

Sampling Scarab beetles were collected from June 2014 to May 2015 and June 2015 to May 2016. Sampling was done with the help of mercury vapour light trap and cattle dung-baited pitfall traps. Fortnight collections were done per month with the help of a mercury vapour lamp

of 165 Watts. The light trap was operated for 12 hours from 1800-0600 hrs in winter and monsoon, while at 1900-0700 hrs in summer months. The following morning, insects collected from the light trap were checked, and those other than beetles were released. For the pitfall trap collection, pitfall traps made of plastic were filled with a mild soap water solution to intensify the drowning of beetles. Three pitfall traps per transect, baited with 150 to 200g of fresh cattle dung, were installed for 24 hours per collection at three sites. Transect I is a typical grassland habitat, Transect II was placed near a water stream, and transect III was in a dense forest. The traps were covered with a plastic sheet to avoid leaves and other trash and also to protect the traps from rain. A minimum 50 m distance was maintained between each trap according to the established methodology (Larson and Forsyth 2005).

Collected beetles from traps were washed, labelled and preserved in alcohol. Scarabs were identified by conferring literature like Fauna of British India (Arrow 1910, 1917, 1931, 1949). For specimens where species-level identification is not possible, they were given codes as sp 1, sp 2 and so on. For example, *Onthophagus* sp 1, *Onthophagus* sp 2, etc. Beetle experts from Zoological Survey of India (ZSI) Kolkata were consulted for species identification.

Statistical analysis The species richness was represented by the Menhinick evaluation criterion, computed separately for each site of light and pitfall traps (Menhinick 1964).

$$d = \frac{S}{\sqrt{N}}$$

Where d= Species richness (Menhinick diversity); S= total number of species in a community; N= total number of individuals of all species in a community.

In total, we performed four generalized linear models (*glm*; two additive models [M_{L1} & M_{P1}] and two interactive models [M_{L2} & M_{P2}]) to evaluate the relationship between the species richness and climatic variables, *i.e.*, mean temperature (further written as "*temp*") and mean precipitation (further written as "*prec*"). The regression analyses were performed separately for both trapping methods, light traps (n=48) and pitfall traps (n=216). During regression analysis, species richness was considered the dependent variable and (Dogan and Dogan 2006) climatic variables as independent variables.

Performed generalized linear regression models are (Table 1):

1. $M_{L1} = \alpha + \beta_1 (temp) + \beta_2 (prec)$
2. $M_{L2} = \alpha + \beta_1 (temp) + \beta_2 (prec) + \beta_3 (temp\ X\ prec)$
3. $M_{P1} = \alpha + \beta_1 (temp) + \beta_2 (prec)$
4. $M_{P2} = \alpha + \beta_1 (temp) + \beta_2 (prec) + \beta_3 (temp\ X\ prec)$

Where M_L represents the *glm* for light trap datasets, and M_P stands for the *glm* of pitfall trap datasets. α and β indicate the values of intercept and Beta coefficient, respectively.

Models M_{L2} and M_{P2} proceeded as interactive models, so we can know if there is any significant relationship between the species richness and the interaction of temperature and precipitation simultaneously.

*AIC*s of the models mentioned above were compared within their sibling models. The model with lower *AIC* opted as a better fit model for describing the relationship between species richness of Scarabs and local climatic variables (Burnham and Anderson 2002).

Results and discussion –

A. *Overall collection* -

Relative abundance and species richness The study led to a collection of a total of 3249 specimens of 72 species belonging to 35 genera of scarabs under subfamilies Aphodiinae,

Cetoniinae, Dynastinae, Melolonthinae, Rutelinae, Scarabaeinae and Orphnini. Subfamily Scarabaeinae is the most species-rich group with 36 species under 14 genera (Fig. 1). Genus *Onthophagus* is the most species-rich genus with 15 species. Subfamily Orphninae is found to be the least diverse, encountering only a single species. Subfamilies Aphodiinae, Melolonthinae and Rutelinae contributed nine species each. Subfamilies Cetoniinae and Dynastinae contributed six species and two species, respectively.

Scarabaeinae, a species-rich subfamily, is often found to share more than 50 % of the overall scarab fauna collected from different parts of India (Biswas and Chatterjee 1986; Chandra and Gupta 2012a, 2012b). Similarly, in our study, coprophagous subfamilies, Aphodiinae and Scarabaeinae, dominated the collection, contributing to 62.5 % of the entire collection. The rest of the phytophagous subfamilies contributed 37.5 %. Genus *Onthophagus* is found to be the species-rich genus with 15 species, followed by *Aphodius*, *Holotrichia* and *Anomala*. In all, 24 genera were represented by a single species. Six genera contributed two species each (Fig. 2).

B. Light trap catches 2014-16

Distribution Light trap catches over the years 2014-15 and 2015-16 yielded a collection of 2308 scarab beetles belonging to 51 species and 23 genera under 7 subfamilies. The most abundant subfamily is calculated to be Aphodiinae (50.52%), followed by Scarabaeinae (26.04%), while the least abundant subfamilies were Cetoniinae (1.00%) and Orphninae (0.22%). Though Aphodiinae contributed the maximum in species abundance, and species richness is maximum in Scarabaeinae (29.41%), followed by Aphodiinae, Rutelinae and Melolonthinae (17.65 %). Cetoniinae contributed 11.76%, followed by Dynastinae (3.92%), while Orphninae (1.96%) contributed the least.

Rhyssemus sp1 is found to be most abundant with 42.89 % of the total collection, followed by *Digitonthophagus gazella* (19.02%), *Aphodius moestus* (4.16%) and *Phyllognathus dionysius* (2.86%). Forty-three species showed moderate abundance within a range of (0.09% to 2.38%). Three species contributed the least (0.04%) in terms of species abundance and were identified as Cetoniines, such as *Oxycetonia jucunda* and *Clinteria klugi*. It might entirely be a chance event to get them caught in the light trap as cetoniines are diurnal scarabs. These species appeared only once during the entire collection period.

Seasonality of scarabs For 2014-15, species richness and abundance were maximum in July (18.06% and 18.71%) and September (18.71% and 20.83%) and least from January to May. Moderate abundance and richness were calculated in June, August, October, November and December. Though the richness and abundance were high in July and September, the Shannon diversity index was constant from June to November with a range of (H= 1.96 to 2.28) and further decreased from December onwards till May. Shannon diversity was highest in June (H= 2.28) and least in February and April (H= 0.63) (Fig. 3).

For 2015-16, Maximum richness and abundance were observed in June (21.55% and 29.83%, respectively). Richness was least in February, March and April (1.66%), while Abundance was least in April (0.32%). Shannon diversity values were moderate from June to September, with a maximum in July (H= 2.41). Shannon diversity was least in April (H= 0.32) (Fig. 4).

C. Pitfall trap catches 2014-16

Distribution Pitfall trap catches yielded a collection of 941 specimens of dung beetles belonging to 45 species from 16 genera under 2 subfamilies, *i.e.*, Scaranaeinae and Aphodiinae. Scarabaeinae showed maximum richness (80%), while in comparison, Aphodiinae showed the maximum abundance (55.79%) (Fig. 5). *Rhyssemus sp1* was the most abundant contributing 43.57 % of the total collection, followed by *Tibiodrepanus setosus*, *Aphodius moestus*, *Digitonthophagus gazella*, and *Tiniocellus spinipes* (Fig. 6). Six species contributed least (0.11

%) and are identified as *Onthophagus sp1, Onthophagus sp2, Onthophagus sp3, Onthophagus sp5, Onthophagus sp6, Onthophagus sp8, Caccobius sp3, Scarabaeinae sp1* and *Aphodius sp4*.

Seasonality For 2014-15, Species abundance was maximum in July (28.5%) and least in November (8.75%). Species richness and abundance were high in September (25.29% and 21.25%). Irrespective of the richness and abundance, Shannon diversity values showed moderate diversity from June to October, with the maximum in September (H= 2.40) and the least in November (H= 0.82) (Fig. 7).

For 2015-16, species richness and abundance were high in June (22.95% and 25.69%), while least richness and abundance were recorded in November (6.56% and 9.61%). Irrespective of richness and abundance, Shannon diversity was highest in July (H= 3.02) while least in November (H= 0.89). July to October period showed moderate richness, abundance and Shannon diversity. Shannon diversity index values ranged from (H= 0.89 to 3.02) (Fig. 8).

D. Factors affecting activity of scarabs It was found that Season and weather parameters shaped the scarab beetle assemblages in the tropical dry deciduous Bor forest. Assessing the impact of temperature and precipitation, for the light trap models, model M_{L1} (*AIC*=59.9) opted as a better fit model than M_{L2} (*AIC*=61.17). The model M_{L1} informed that the Scarab species richness is positively and significantly related to the mean temperature (β=0.03±0.01 *SE*, p<0.05; Table 2) and also to the mean precipitation (β=0.03±0.01 *SE*, p<0.05; Table 2).

Model M_{L1} found suggesting:

$$M_{L1} = 0.7 + 0.03\ (temp) + 0.03\ (prec)$$

For pitfall trap models, out of two models, M_{T2} opted as a better-fit model with a lower *AIC* 92.8. This model suggested a positive relationship between species richness and average temperature (β=0.1±0.02 *SE*, p<0.05; Table 3) and found similar with average precipitation (β=0.17±0.09 *SE*, p=0.05; Table 3).

Model M_{P2} found suggesting:

$$M_{P2} = -0.9 + 0.17\ (prec) + 0.1\ (temp) - 0.005\ (prec\ X\ temp)$$

Though we found model M_{T2} better than M_{T1}, the relationship between the species richness and interaction between precipitation and temperature is not significantly affecting Scarab species richness, but temperature and precipitation were found to be substantially related to the species richness separately.

Hence both fitter models M_{L1} and M_{P2} suggest the positive relationship between the species richness of Scarab with temperature and precipitation. Since we were constrained by logistics, we could not identify optimum temperature or precipitation values on which the Scarab species richness can be highest for both the fitter models. There is a need to collect similar datasets on diversified spatial and temporal scales.

Table 1: Four performed generalized linear models with their respective AIC and type of model

S.No.	Model	Type of model	AIC
1	$M_{L1} = \alpha + \beta_1\ (temp) + \beta_2\ (prec)$	Additive	59.9*
2	$M_{L2} = \alpha + \beta_1\ (temp) + \beta_2\ (prec) + \beta_3\ (temp\ X\ prec)$	Interactive	61.166
3	$M_{P1} = \alpha + \beta_1\ (temp) + \beta_2\ (prec)$	Additive	93.532
4	$M_{P2} = \alpha + \beta_1\ (temp) + \beta_2\ (prec) + \beta_3\ (temp\ X\ prec)$	Interactive	92.797*

**Represent a better fit regression model*

Table 2: Responses of the predictor variable for assessing the relationship with scarab species richness (light trap method) $M_{L1} = \alpha + \beta_1 (temp) + \beta_2 (prec)$; AIC=59.9

$M_{L1} = \alpha + \beta_1 (temp) + \beta_2 (prec)$	β estimate	SE	t value	p value
Intercept	0.7	0.356	1.967	0.05*
Prec	0.026	0.009	2.934	0.005*
Temp	0.026	0.013	2.021	0.04*

*Represents the significant relationship between the respective predictor variable and scarab species richness

Table 3: Responses of the predictor variable for assessing the relationship with scarab species richness (pitfall trap method) $M_{P2} = \alpha + \beta_1 (temp) + \beta_2 (prec) + \beta_3 (temp \times prec)$; AIC=92.797

$M_{P2} = \alpha + \beta_1 (temp) + \beta_2 (prec) + \beta_3 (temp \times prec)$	β estimate	SE	t value	p value
Intercept	-0.94	0.499	-1.876	0.06
Prec	0.17	0.087	1.982	0.05
Temp	0.1	0.017	5.728	2.62^{e-07}
prec X *temp*	-0.005	0.003	-1.622	0.11

*Represents the significant relationship between the respective predictor variable and scarab species richness

Results of this study reveal that season, along with temperature and rainfall, shapes the activity of the scarab community in the tropical dry deciduous Bor forest of central India. Temperature and precipitation were found to be significantly related to the species richness separately. Scarabs showed maximum activity immediately after the start of the monsoon, in the months of June and July. Results of this study align with the studies on the ecology of coprophagous subfamilies Aphodiinae and Scarabaeinae across North India and South India where environmental factors work collectively and affect the efficacy of dung, resulting in variation in dung beetle community composition (Sabu et al. 2006; Kakkar, 2010). For phytophagous and anthophagous subfamilies, beetle community structure is found to be shaped by the availability of host plants and seasonality. The occurrence and abundance of dung beetles change with weather conditions over short periods (Kakkar 2010).

Though the difference between AIC is not much, this can be relatively justified that activities of dung beetles are regulated by physical factors such as temperature, humidity, soil type and vegetation cover (Halffter et al. 1992). Dung beetle diversity is reported more during the moist than the dry season (Doube 1991). In a number of species, the activity is known to be influenced by rainfall than other weather parameters (Vernes et al. 2005).

Conclusion –

Season and weather parameters shaped the scarab beetle assemblages in the tropical dry deciduous Bor forest of central India. Scarab species richness is positively and significantly related to the mean temperature (β=0.03±0.01 *SE*, p<0.05) and to the mean precipitation (β=0.03±0.01 *SE*, p<0.05). Scarabs showed maximum activity immediately after the start of the monsoon, in the months of June and July. Genus *Onthophagus* is found to be the most species rich. Some genera such as *Orphnus* were represented by a single species. Studies across different spatial and temporal scales give insights about the species activity and also add to the knowledge about rare species and singletons. Further research on the seasonality and activity of scarabs across different locations in central India would help understand the life history of these neglected yet influential groups of insects.

Declaration of interest – None.

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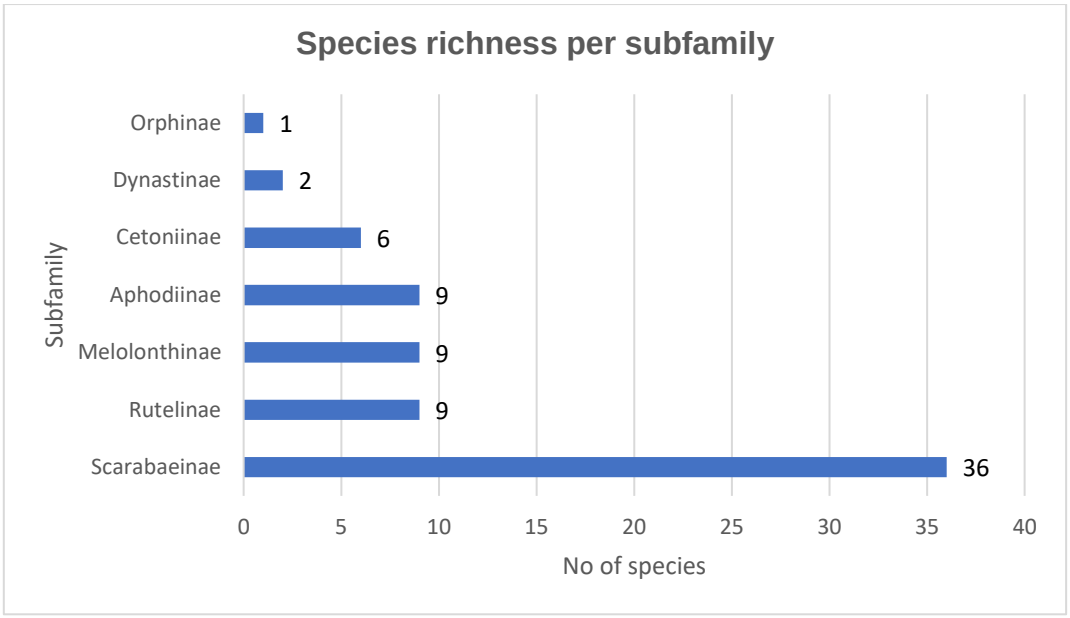

Figure 1: Overall relative species richness of scarabs per subfamily collected around Bor Wildlife Sanctuary for 2014-2016. Subfamily Scarabaeinae contributed 36 species followed by Aphodiinae, Melolonthinae and Rutelinae with nine species each. Subfamily Orphninae is represented by a single species.

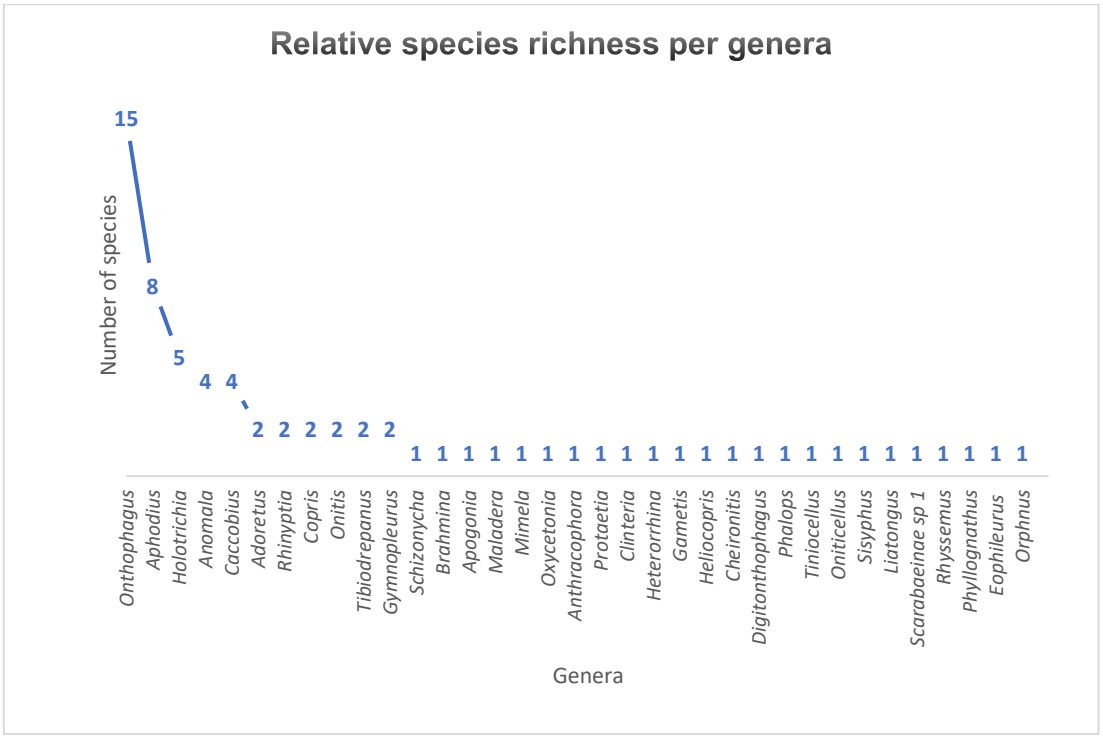

Figure 2: Overall relative species richness per genera collected around Bor Wildlife Sanctuary for 2014-2016. Genus *Onthophagus* is found to be the most species rich with 15 species followed by genus *Aphodius* with eight species.

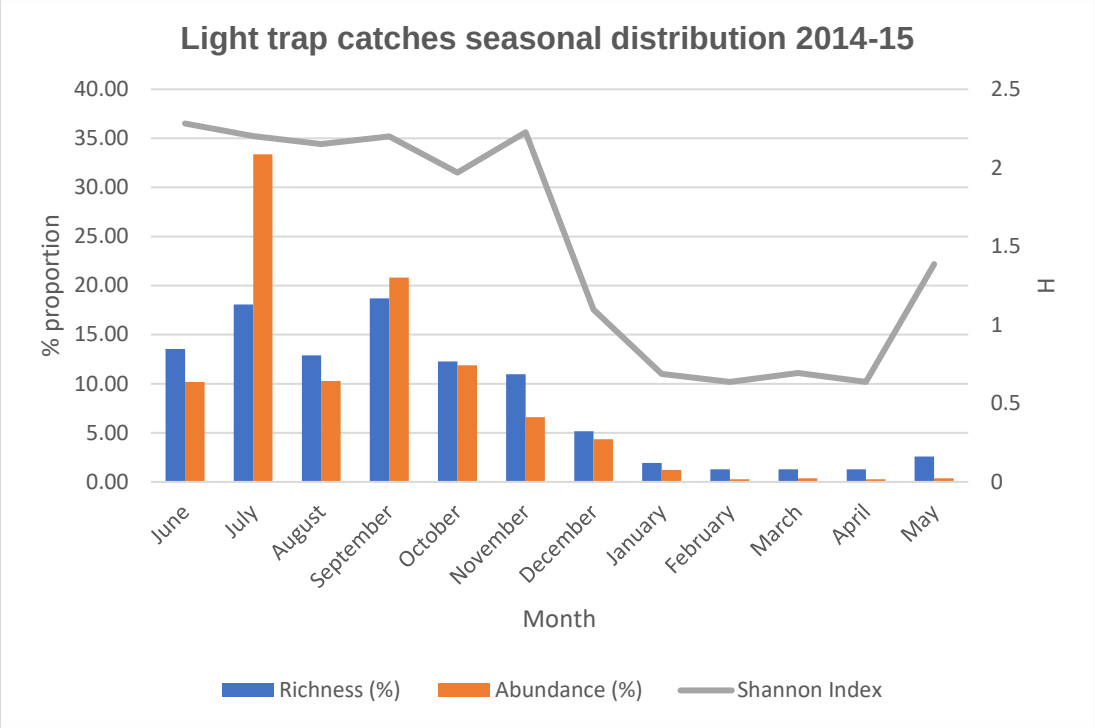

Figure 3: Seasonal distribution of scarab beetles collected by Light Trap for the year 2014-15.

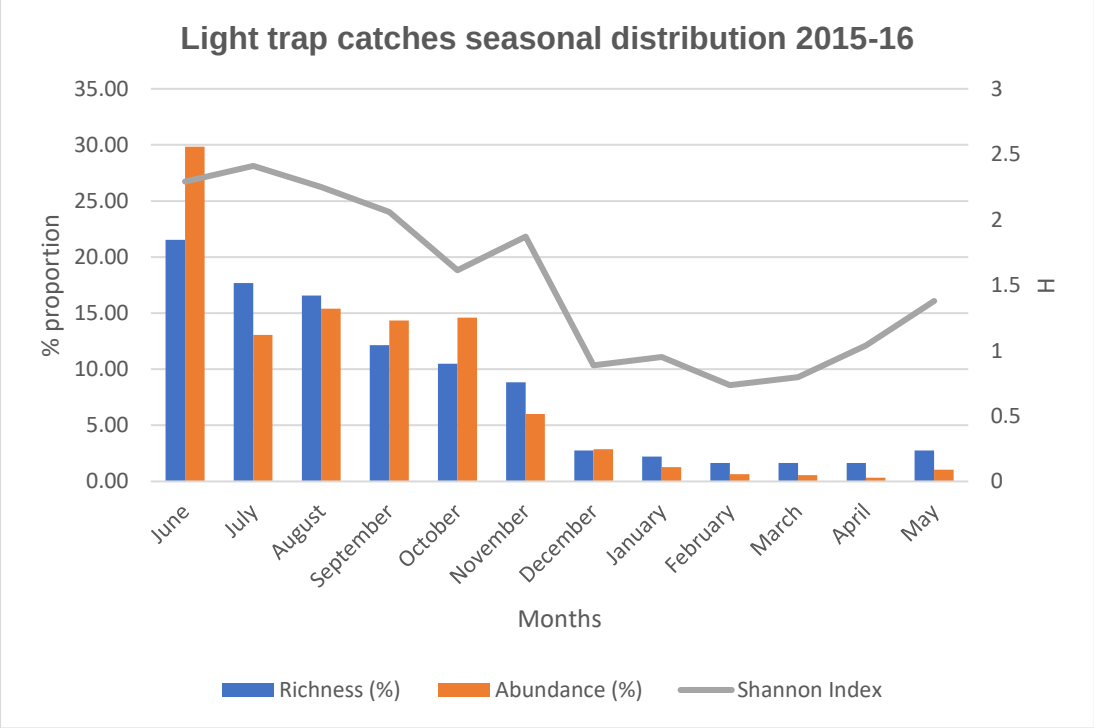

Figure 4: Seasonal distribution of scarab beetles collected by Light Trap for the year 2015-16

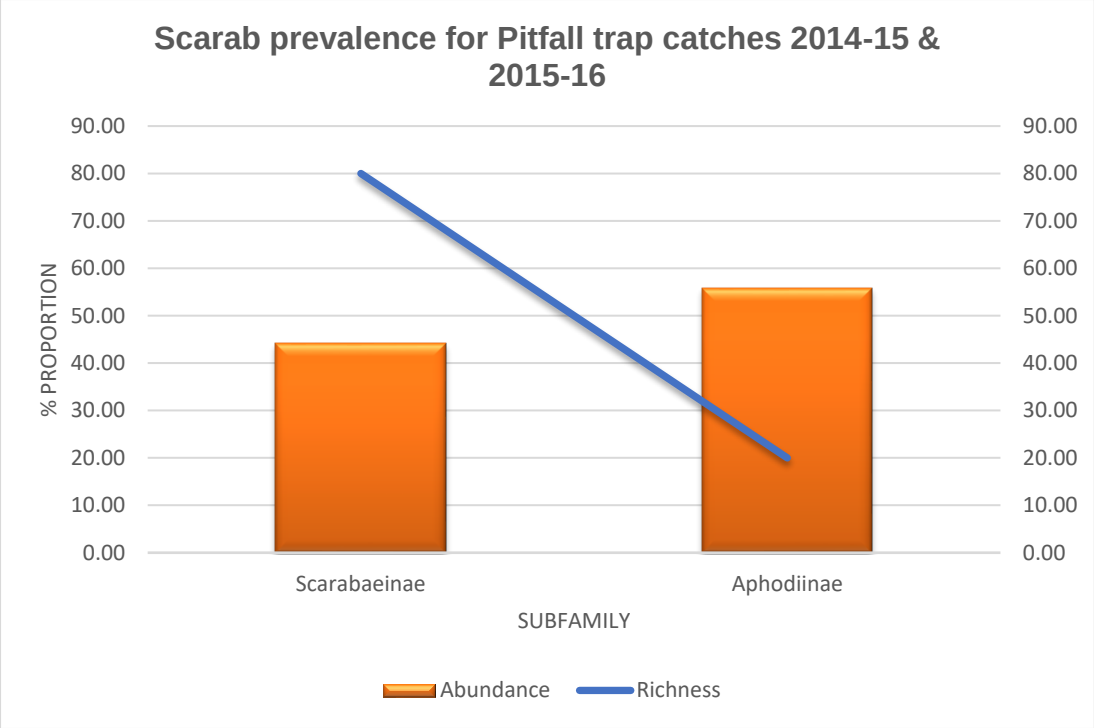

Figure 5: Scarab prevalence for Pitfall Trap catches 2014-15 & 2015-16. Subfamily Aphodiinae is found to be the most abundant followed by subfamily Scarabaeinae.

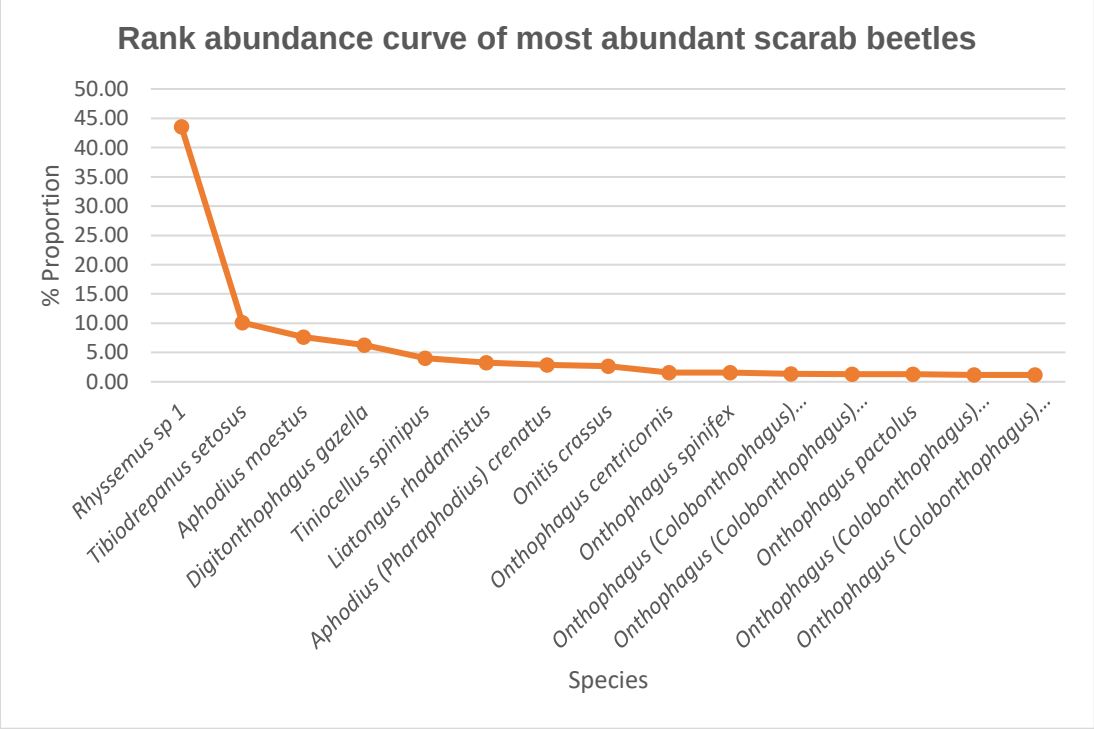

Figure 6: Rank abundance curve for most abundant scarab beetles collected with Pitfall Trap for the years 2014-15 and 2015-16. *Rhyssemus sp.* dominated the collection.

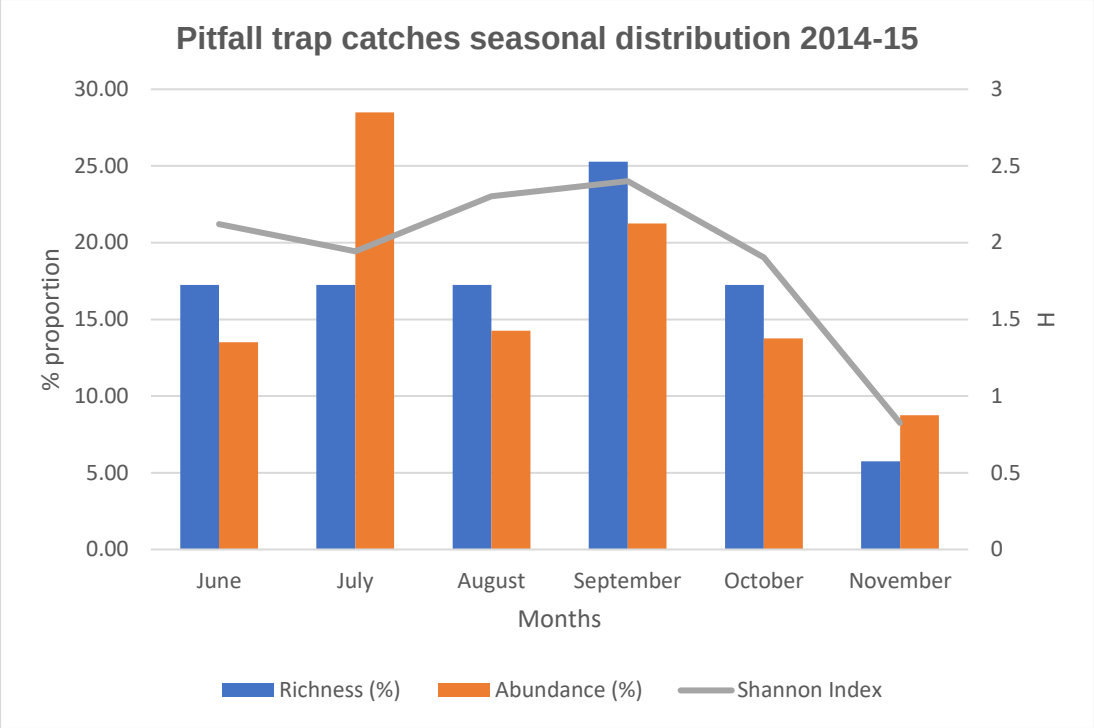

Figure 7: Seasonal distribution of scarab beetles collected by Pitfall Trap for the year 2014-15

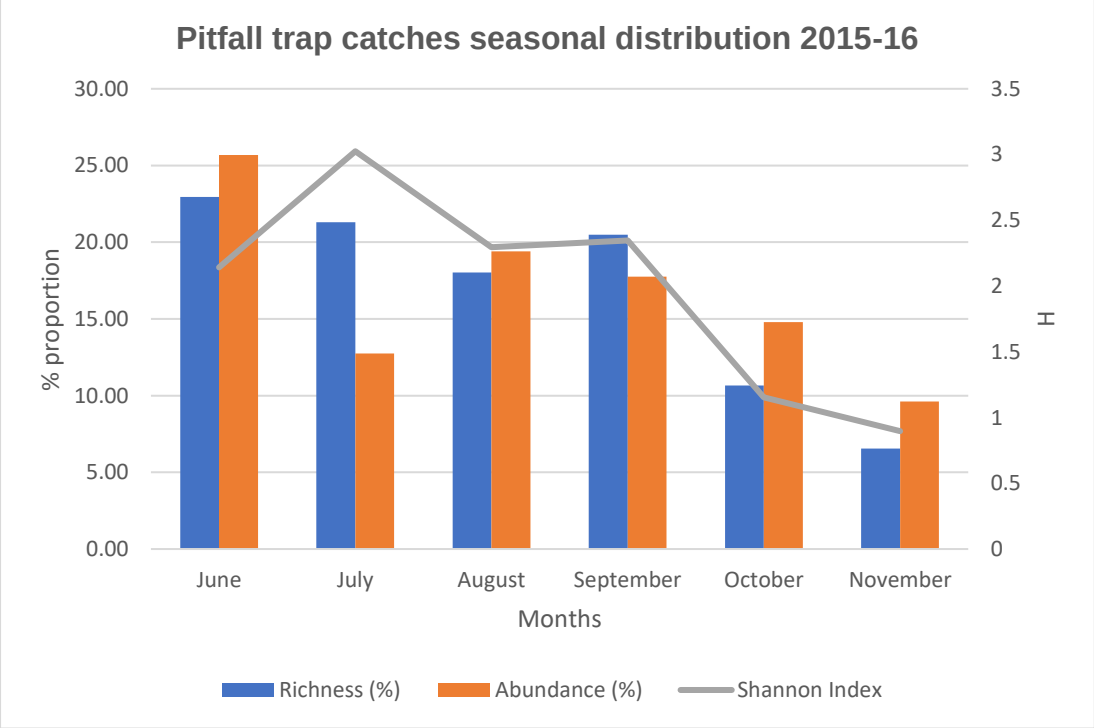

Figure 8: Seasonal distribution of scarab beetles collected by Pitfall Trap for the year 2015-16