TAXONOMY, GUILD STRUCTURE AND DUNG SPECIFICITY OF DUNG BEETLES (COLEOPTERA: SCARABAEIDAE: SCARABAEINAE) IN A COFFEE PLANTATION BELT IN SOUTH WAYANAD

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DOCTOR OF PHILOSOPHY IN ZOOLOGY

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Declaration

I do hereby declare that the thesis entitled "Taxonomy, guild structure and dung specificity of Dung Beetles (Coleoptera: Scarabaeidae: Scarabaeinae) in a coffee plantation belt in south Wayanad" submitted to the University of Calicut for the award of degree of Doctor of Philosophy in Zoology has not been formed the basis for the award of any other Degree, Diploma, Associateship, Fellowship and represents the original work done by me.

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Dedicated to my parents and teachers....

CONTENTS

Chapter 1

INTRODUCTION

An important biotic component of most terrestrial ecosystems is the community of beetles belonging to the subfamily Scarabaeinae, commonly known as dung beetles, characterized by their use of dung and organic debris at both the adult and larval stages (Hanski & Cambefort 1991). Worldwide distributions of dung beetles are strongly influenced by the diversity of mammal dung and climate (Davis *et al.,* 2002) with the tropical region having a high diversity of the Scarabaeinae (Halffter & Matthews 1966; Hanski & Cambefort 1991). Scarabaeid dung beetles (Scarabaeoidea) belong to three distinct taxonomic groups: Scarabaeinae, Geotrupinae and Aphodiinae (Baraud 1985). Within the subfamilies, Scarabaeinae is the only group which is predominantly coprophagous (feces eating) while the majority of Aphodiinae and Geotrupinae are saprophagous (eaters of decaying organic matter), not true dung beetles (Halffter & Matthews 1966; Scheffler 2002).

Dung beetle species, largely coprophagous, feed on the microorganism-rich liquid component of mammalian dung and use the more fibrous material to brood their larvae (Halffter & Edmonds 1982; Halffter & Matthews 1966). They play a key role in the forest and agricultural ecosystem as they remove feces from the environment (Tyndale-Biscoe 1994), soil fertilization and aeration (Bornemissa & Williams 1970), recycle nitrogen, organic carbon and other nutrients (Rougon & Rougon 1991), protect seeds from predation (Andresen 2001; Estrada & Coates-Estrada 1991; Feer 1999), seed dispersal (Anderson 2006) and reducing populations of disease-causing organisms such as flies, hookworms by competing for food (faecal) resources and destroying eggs and larvae (Hanski 1991; Miller 1954; Smith 2004) and serve as food for many birds and mammals (Ratcliffe 1991). The activity of dung burial proved not only important for increasing soil fertility but also has several other advantages such as enhancing total nutrients to plants as well as its yield, improving plant regeneration through dung-seed dispersal activity, and increasing plant palatability by reducing plants fouled with dung (Nichols *et al.*, 2008; Shahabuddin 2011). Therefore, in natural ecosystems the reduction of dung beetle populations most likely has cascading and long-term effects throughout the ecosystem (Klein 1989; Larsen *et al.*, 2005; Shahabuddin 2011). Some of these ecological functions can be considered to be ecosystem services, because of their potentially large economic importance and positive impacts on human well-being (Halffter & Matthews 1966). This large quantity of ecological functions arises because many dung beetle species have the habit of burying countless sources of food resources such as feces, carcasses, etc (Halffter & Halffter 2009). Dung represents perhaps one of the most nutritionally rich resources available to any animal, but it is usually limited, spatially patchy, and ephemeral (Hanski 1991; Philips *et al.*, 2004).

Almost all species of the Scarabaeinae family are restricted to areas where precipitation exceeds 250 mm per year, with an average annual temperature of 15^0C and within 45^0 latitudinal limits, so distributed in all continents except in Antarctica (Halffter 1991). Scarabaeinae ranges in size from 2-60 mm. Some species are brightly coloured and many have horns or conspicuous protuberances on the head or thorax (Ratcliffe 1991). The head of adult beetles have a well-developed broad clypeus overhanging the mouth, capable of shovelling earth and dung (Arrow 1931). The mouth parts in adult is adapted to feed on liquid and colloidal content of more or less fresh dung (microorganisms and undigested food molecules) whereas in larvae, it is of typical chewing type adapted to feed on solid contents of partially dried dung, several weeks or months old. Dung beetles have low fecundity which is directly related to the high degree of brood care involved and their larval development is shorter owing to the perishable nature of the food on which the larva subsists. The extraordinarily long and coiled intestine of the adult when compared to the larvae is an adaptation to this special type of microphagous coprophagy (Halffter & Mathews 1966). The legs, especially the fore legs are useful digging implements with well-developed muscles. In ball rolling genera, the four posterior legs are slender for rolling dung balls and for making shallow burrows in loose soil (Arrow 1931). In Scarabaeinae, the middle coxae are widely separated and the hind pair of legs are attached far back to the greatly developed metasternum. A considerable mass of dung can thus be held between the legs and compressed into globular shape (Arrow 1931).

According to Cambefort (1991), the Scarabaeinae evolved from saprophagous ancestors, which lived in Afrotropical forests at the Mesozoic-Cenozoic boundary (~ 65 million years ago). Phillips (2011) reviewed current understanding of the phylogenetic history of the dung beetles, which seem to have appeared during the Mesozoic era (around 145 million years ago), in the region of Gondwana that would later become Southern Africa. Their high global diversification seems to have followed the increase in mammal dung types during the Cenozoic, which would have influenced the high specialization of the group to coprophagy (Cambefort 1991; Monaghan *et al.,* 2007; Philips 2011).

1.1. TAXONOMY OF DUNG BEETLES

Arrow (1931), Janssens (1949) and Balthasar (1963) were the major contributors of dung beetle taxonomy. Arrow (1931) in his publication 'Fauna of British India' devoted to Coprinae (Scarabaeinae) studied 352 species of dung beetles from different parts of India and adjacent countries. Arrow (1931) placed dung beetles in four divisions (=tribes): Scarabaeini, Sisyphini, Coprini and Panelini which he placed under the subfamily Coprinae with which he considered the Scarabaeinae synonymous. Janssens (1949) subdivided Scarabaeinae into six tribes: Coprini, Eurysternini, Oniticellini, Onitini, Onthophagini and Scarabaeini. Later monographic works on the subfamilies Aphodiinae and Scarabaeinae of the Palaearctic and Oriental region were made by Balthasar (1963, 1964). Balthasar (1963) ranked the dung beetles into two distinct subfamilies: Coprinae and Scarabaeinae. The former subfamily included the tribes Coprini, Dichotomini, Phanaeini, Oniticellini, Onitini, and Onthophagini whereas the latter subfamily included the tribes Eucraniini, Eurysternini, Canthonini, Gymnopleurini, Scarabaeini and Sisyphini. Lawrence & Newton (1995) classified dung beetles into 12 tribes which included Coprini, Dichotomini, Phanaeini, Oniticellini, Onitini, Onthophagini, Eucraniini, Eurysternini, Canthonini, Gymnopleurini, Scarabaeini and Sisyphini and included them in the subfamily Scarabaeinae with which he considered the Coprinae synonymous. New phylogenic studies based on 200 internal and external morphological characters support this classification (Philips *et al.,* 2004) and indicate that the subdivision of dung beetles into two subfamilies- Scarabaeinae and Coprinae (Balthasar 1963), is not supportable as ball-rolling taxa are polyphyletic.

Species composition, distribution patterns and endemism are outlined for the dung beetles in the ecoregions of the western slopes of the moist South Western Ghats, South India (Sabu *et al.,* 2011a). Mittal & Jain (2015) reviewed the taxonomy of the Indian dung beetle fauna and known species until now were collated, listed and reallocated among the nine tribes now recognized for Indian fauna. New accepted names for many genera have also been included assigning them to their respective taxa. By excluding about 70 odd species (from the total of 354 species) reported in 'Fauna of British India' from other areas (i.e., Pakistan, Afghanistan, Sri Lanka, Myanmar, Indonesia, etc.) outside the present Indian region, the final record from India is 420 species in 38 genera.

1.2. GUILD STRUCTURE

Functional guild: Functional differentiation and differences in activity period generally allow dung beetles to minimize competition for limited resources (Hanski & Cambefort 1991; Bogoni & Hernandez 2014). The dung beetle community are divided into guilds according to its strategy of resources relocation (Cambefort & Hanski 1991). Cambefort & Hanski (1991) classified dung beetles into three basic nest building categories; namely, tunnelers (paracoprid nesters), dwellers (endocoprid nesters) and rollers (telecoprid nesters). Tunnelers make underground vertical chambers in close proximity to the dung pat and construct their nest using the dung from pat while rollers form balls from a dung pat which are rolled away and buried in the ground for feeding and breeding where as dwellers breed in dung pats itself (Cambefort & Hanski 1991; Halffter & Edmonds 1982; Holter *et al.*, 2002). A number of species use dung that has been buried by others. They have been termed kleptocoprids (Doube *et al.*, 1988; Doube 1990; Horgan 2005). This functional stratification allows dung beetles to minimize the intense competition for limited food and space and also to protect the food from adverse environmental conditions such as heat and excessive dryness (Halffter & Edmonds 1982; Cambefort & Hanski 1991; Scheffler 2002).

Many species of Scarabaeidae feed and reproduce in the excrement of mammals, especially on Bovidae and man, both in their larval and adult stages (Halffter & Mathews 1966). They use this substrate in different ways for feeding and breeding based on their reproductive and nest building behaviours (Doube *et al.*, 1988; Doube 1990). The dung beetles most likely developed their dung burying behaviour to avoid competition from flies or other dung-utilizing organisms and to protect the dung resource from drying out and losing its nutritional value. By locating the dung quickly, and either rolling the dung away or burying it, the resources will be fully utilized without competition or waste (Scholtz *et al.*, 2009).

Numerous reports are available on resource competition between dwellers, tunnelers and rollers as entire droppings can be removed or shredded by beetles within a limited time (Hanski & Cambefort 1991c). Tunnelers are the most important functional group in maintaining the ecosystem functions of dung and seed removal, particularly nocturnal tunnelers (Slade *et al.,* 2007). Other groups functionally appear to be unable to compensate for the loss of this group in the short term. Studies also found that rollers are less efficient than tunnelers at dung and seed removal (Estrada & Coates-Estrada 1991; Slade *et al.,* 2007). In Scarabaeinae, dung rolling is associated with tribes Scarabaeini, Gymnopleurini, Sisyphini and Canthonini, dwelling with tribe Oniticellini and tunnelling with tribes Coprini, Onitini and Onthophagini (Hanski & Cambefort 1991b). Regarding the morphological differences between the functional groups, the rollers generally have long hind legs. The rollers roll the dung ball with their back legs, rolling with their head down, making long legs preferred for this type of work. The tunnelling dung beetles have relatively shorter hind legs and the front legs are well adapted for digging. The presence of horns is common in the tunnelling dung beetles (Hanski & Cambefort 1991; Scholtz *et al.,* 2009).

Temporal Guild: Because dung is a scarce and ephemeral resource in tropical habitats, inter- and intra-specific competitions are common in dung beetle assemblages (Hanski & Cambefort 1991), but the fine-scale coexistence of different species is possible because of ecological segregation through different niche dimensions. These include feeding habits; body size, resource relocation behavior and daily activity (Feer & Pinceboure 2005; Villada-Bedoya *et al.,* 2017). Thus, some degree of niche partitioning (ecological, temporal or spatial) is expected to be important in promoting species coexistence within a guild (Janzen 1983; Gill 1991; Hirschberger 1998). Dung beetles are grouped readily into distinct functional groups based on the method of dung exploitation, size and diel activity (Doube 1990; Vulinec 2000; Feer & Pincebourde 2005). Based on the seasonal and diel activity of dung beetles two major guilds, viz., a nocturnal and a diurnal guild is distinguishable (Cambefort 1991; Doube 1991; Janzen 1983). It is a widespread mechanism to avoid competition between closely related species or phylogenetically distant groups.

Bioindicators: A bioindicator is a species or a species group that reflects some aspect of the state of the environment within which it is found (McGeoch 2013). Dung beetles (Scarabaeidae: Scarabaeinae) are a diverse, abundant group of insects that have been extensively used as a cost-effective indicator taxon, particularly for studies focusing on the consequences of habitat disturbance (Spector 2006; Gardner *et al.,* 2008). Species have various ecological requirements and their reactions to environmental variation are different from one another. So, some species are better indicators than others (Dufrêne & Legendre 1997; New 1998). Klein (1989) and Aydin & Kozak (2010) reported coprophagous scarabaeoid beetles are more responsive to environmental changes such as habitat fragmentation and therefore can be effective indicators providing early warnings to the ecological consequences of fragmentation due to spending most of their life cycles in the soil surface layer. The potential of dung beetles as indicators for disturbance have been reviewed (Halffter & Favila 1993; Jankielsohn *et al.,* 2001).

Dung beetles do not disperse long distances to find food and have a stenotopic distribution in relation to vegetation type (Hanski & Cambefort 1991), hence they are sensitive to environmental changes and considered as well suited bioindicators (Howden & Nealis 1975; Klein 1989; Halffter & Favila 1993). They are widely used as bioindicator of habitat disturbance in many studies (Gardner *et al.,* 2008; McGeoch *et al.,* 2002; Nichols *et al.,* 2007; Spector 2006; Shahabuddin 2011). Since environmental perturbations or disturbances promote changes in dung beetle community composition and abundance (Jankielsohn *et al.,* 2001), the potential for using them as suitable biological indicators is justified.

Dung beetles in Coffee Plantations: The distribution of dung beetles is strongly influenced by vegetation cover, soil type and the physical structure of the vegetation (Davis *et al.,* 2001). Many studies from Neotropical region have demonstrated that coffee agro-ecosystems with complex forest-like vegetation structure (shaded) harbor significantly high biodiversity (Greenberg *et al.,* 1997a; Johnson 2000; Perfecto *et al.,* 2003; Perfecto & Armbrecht 2003;

Somarriba *et al.,* 2004), particularly dung beetle diversity (Moron 1987; Pineda *et al.,* 2005; Horgan 2005).

The Western Ghats, a biodiversity hotspot in Southern India, is strewn with plantations that were once tropical rain forests (Dolia *et al.,* 2008). During the last century, these forests have witnessed severe fragmentation due to large-scale conversions to plantations of tea, coffee, rubber and cardamom (Daniels 1992; Daniels *et al.,* 1990) and considerable biodiversity loss in the South Western Ghats (Nair 1991). Studies on biodiversity in coffee plantations of the Western Ghats have recorded high biodiversity in the shaded coffee belts for birds, mammals and butterflies (Bali *et al.,* 2007; Dolia *et al.,* 2008; Anand *et al.,* 2008). So it is hypothesised that the shaded coffee plantations in the Western Ghats sustain a high diversity of dung beetles.

1.3. DUNG SPECIFICITY

Dung beetle communities are correlated with dung producing vertebrates and mammals (Hanski & Cambefort 1991). The diversity of dung beetles was highly related to the population of vertebrates due to their dependency on animal wastes as their primary food source (Muhaimin *et al.,* 2015). Dung, mainly mammalian dung, is one of the resources used by the Scarabaeinae as a food for larvae and adults and as a substrate for oviposition (Halffter & Matthews 1966), so their diversity is tightly linked to mammal dung diversity (Hanski & Cambefort 1991). A large and diverse mammal fauna is crucial for maintenance of diverse dung beetle fauna (Klein 1989; Hanski & Cambefort

1991; Estrada *et al.,* 1998). Decline in mammal abundance or richness is followed by restructured dung beetle communities with reduced species richness (Hanski & Cambefort 1991; Carpaneto *et al.,* 2005; Muhaimin *et al.,* 2015). Three aspects of mammalian species richness have direct consequences for dung beetles, the general abundance of mammals determines the level of availability of resources for dung beetles, range of different kinds of mammals determines the range of dung types available and the size of mammals is important to large species of dung beetles which are dependent on large droppings for breeding (Hanski & Cambefort 1991).

Dung beetles are generally opportunistic with respect to the exploitation of feces and thus utilize a wide variety of dung types (Hanski & Cambefort 1991; Bogoni & Hernandez 2014). Thus, the partitioning of dung beetles into assemblages based on trophic habits also depends on the capacity of the insect to detect and select the different types of resources when available (Dormont *et al.,* 2004). Feces texture and water content may also have an influence on resource choice because these factors affect desiccation rate and extent of odor emission, the latter being an important aspect of resource localization by beetles (Halffter & Edmonds 1982). Most dung beetle species compete for scarce and short-lived resources including feces of vertebrates, primarily of mammals. These resources are utilized for food and nesting by adults and larvae. Because the dung beetle life cycle involves complete metamorphosis, the development of the adult depends mainly on the quantity and quality of resources consumed during the larval period (Halffter

& Edmonds 1982). The droppings of mammals represent a relatively scarce and patchy microhabitat in most ecosystems. It is thus reasonable to expect polyphagous insects to be more efficient in locating and exploiting dung resources than would be insects specialized for a particular dung type (Dormont *et al.,* 2007). Polyphagy is the predominant feature of dung beetles feeding patterns (Hanski & Cambefort 1991).

Dung beetles partition their food and breeding resource according to its physico-chemical attributes. These include odour profile, water content, fibre size, dropping size, and nutritional quality (Halftter & Matthews 1966; Hanski & Cambefort 1991; Dormont *et al.,* 2004). Adult beetles are commonly supposed to rely heavily on dung odours to locate dung pats (Dormont *et al.,* 2004). The feces of vertebrates have a high degree of diversity in chemical composition (Nibaruta *et al.,* 1980). Therefore, volatile compounds released by the food source are important components in determining the dung beetle niche and this can vary depending on the vegetation structure of a given habitat (Correa *et al.,* 2016). For example, in forest-ecosystems, odours generated by these food sources are dispersed more slowly in the presence of barriers such as herbaceous vegetation and trees. Moreover, moisture content and quality of dung are maintained for a longer period under the shade which enables better colonization of dung beetles (Escobar *et al.,* 2007; Horgan 2005). All these characteristics affect the dung insect communities colonizing the dung (Edwards 1991; Hanski & Cambefort 1991; Scholtz *et al.,* 2009).

Significance of the study: Dung beetles are relatively short-lived, their life cycle is dependent on ephemeral resources (dung or carrion) and populations are sensitive to environmental alterations (Villada-Bedoya *et al.,* 2017). Biological diversity conservation within natural reserves has been prioritized, but conservation efforts outside protected areas (where most human activities take place) have been very little considered (Avendaño-Mendoza *et al.,* 2005). Forest disturbance and landscape modification generally reduce the diversity and abundance of most insect taxa (Muhaimin *et al.,* 2015). Halffter & Favila (1993), suggested that the dung beetles communities are excellent models to evaluate and to monitor what degree the changes in the vegetation alter the animal communities (Lopes *et al.,* 2006). According to Camberfort (1991), a reduction in the number of large mammals occurred parallel to a reduction of dung beetles, influenced by the food source for these scarab species. Dung beetle communities are correlated with dung producing vertebrates and mammals (Hanski & Cambefort 1991), as well as being particularly vulnerable to habitat changes like deforestation and fragmentation (Hanski & Cambefort 1991; Horgan 2005). Dung beetles are one such useful 'indicator' group as they are known to be influenced strongly by vegetation cover and soil type (Nealis 1977; Doube 1983) and the physical structure of the forest appears to be an important determining factor in the structure and distribution of dung beetle communities (Davis 1993; Davis & Sutton 1998; Davis *et al.,* 2000). Habitat loss and fragmentation are especially heavy in the Wayanad region. Cold wet conditions in the region lead to the establishment of plantations during the colonial period and replacement of natural forests. Extensive forest working, conversion of forests to monoculture tree plantations like teak and eucalyptus and cash crop plantations like tea, coffee, pepper, and clearance of forests for settlements have destroyed most of the forests of Wayanad, except along the eastern edge in Tamil Nadu and Karnataka and along the western outer slopes of Kerala (Nair 1991; WWF 2001). No efforts have been undertaken to identify dung beetle diversity from the plantation belts that will enable assessment of the variations in the biodiversity from shaded coffee plantations in the Western Ghats which unlike a natural habitat is always under threat from degradation by human activities.

No taxonomic or ecological data is available on Scarabaeinae (dung beetles) from coffee plantation belts from Nilgiri Biosphere Reserve (NBR) of Western Ghats region, hence present study focus on the modified taxonomic key from modified habitat. Community structure of dung beetles from the tropical ecoregions of India in general and the Western Ghats in specific, have not received enough attention as their African, Neotropical and Indo-Malayan/southeast Asian counterparts (Vinod 2009). Literature reveals that dung specificity of dung beetles towards different dung types is virtually non-existent from agrilbelts from the Western Ghats, so sampled coprophagous scarabaeoid beetle communities using different dung types as baits, which include omnivore dung (pig); fine fibered dung of ruminant herbivores dropped as pads (cattle); pellets of ruminant herbivores (goat) by pitfall traps in a shaded coffee plantation belt in south Wayanad of South Western Ghats. This study will give more precise information on the community structure and trophic preference of dung beetles especially in plantations.

Objectives:

1. Taxonomy,
2. Guild structure (functional and temporal) and
3. Dung specificity of dung beetles in a coffee plantation in South Wayanad.

Chapter 2

REVIEW OF LITERATURE

2.1. TAXONOMY OF DUNG BEETLES

Taxonomy of dung beetles of the world:

Taxonomy of dung beetles is fairly well studied and listed below are the important highlights of the major taxonomic works. The dung beetles now classified under subfamily Scarabaeinae and members of the suborder Lamellicornia were included by Linnaéus (1758) under a single genus, the *Scarabaeus.* Fourcroy (1785) separated the dung beetles from the Linnean *Scarabaeus* and constituted a new genus *Copris*. Latreille (1796) separated the species with 11-jointed antennae under the name *Geotrupes*. Illiger (1798) introduced two new genera *Oryctes* and *Aphodius* Fabricius (1798) separated genus *Onitis* from genus *Copris.* Creutzer (1799) proposed the name *Actinophorus* for the ball rolling beetles now included in the genera *Scarabaeus* and *Gymnopleurus*.

The name *Ateuchus* for *Scarabaeus sacer* and its congeners introduced by Weber (1801). Latreille (1802) introduced the largest dung beetle genus, *Onthophagus.* The genus *Gymnopleurus* was established by Illiger (1803). Latreille (1807) introduced the genus *Sisyphus.* Serville (1825) introduced the genus *Oniticellus*. *Drepanocerus* was introduced by Kirby (1828). Hope (1837) introduced two new genera, *Catharsius* and *Heliocopris* comprising large dung beetles. Thomson (1863) established the genus *Caccobius*. The genus *Liatongus* was introduced by Reitter (1892) and *Tiniocellus* by Péringuey (1900). Boucomont (1914) established the genus *Phacosoma.* Due to homonymy, Vaz-de-Mello (2003) renamed the genus *Phacosoma* as

Ochicanthon. The genus *Tibiodrepanus* was described by Krikken (2009) which is previously assigned to the genus *Drepanocerus* Kirby 1828.

Discarding the classification system proposed by Lacordaire (1856), Arrow (1931) placed dung beetles in four divisions (=tribes) namely; Scarabaeini, Sisyphini, Coprini and Panelini under the subfamily Coprinae with which he considered the Scarabaeinae synonymous. Janssens (1949) subdivided Scarabaeinae into six tribes: Coprini, Eurysternini, Oniticellini, Onitini, Onthophagini and Scarabaeini. Balthasar (1959) described *Digitonthophagus* as a subgenus of *Onthophagus* Latreille.

Later, Balthasar (1963) ranked the dung beetles as a family comprising two behaviourally distinct subfamilies: Coprinae and Scarabaeinae. Subfamily Coprinae included the tribes Coprini, Dichotomini, Phanaeini, Oniticellini, Onitini, and Onthophagini and the subfamily Scarabaeinae included the tribes Eucraniini, Eurysternini, Canthonini, Gymnopleurini, Scarabaeini and Sisyphini. Compared with the classification of Janssens (1949), Balthasar's classification had the advantage as the family is divided into two equivalent taxa, which correspond to the biological groups of rollers (subfamily Scarabaeinae) and tunnelers (subfamily Coprinae).

Zunino (1981) raised *Digitonthophagus* to genus level. Phylogeny of Zunino (1983) based on relatively few aedeagal characters, showed a basal split with one lineage comprising tribes primarily with tunnelling habits and the other dominated by ball-rolling tribes, supporting Balthasar's system of classification. New genus *Cleptocaccobius* introduced by Cambefort (1984) was added to the tribe Onthophagini. The comparative analysis of the male and female genitalia of subfamily Scarabaeinae, disputed the monophyly of the tribes Onitini, Coprini and Dichotomini (Zunino 1984). Cambefort (1985) provided the revision of the oriental species of *Cleptocaccobius* and four new species *C. arrowi*, *C. khatimae*, *C. durantoni* and *C. boucomonti* together with a new subspecies *C. simplex meridionalis* were added. Larval and adult characters were used to study the phylogenetic relationships within the most speciose tribe Onthophagini (Zunino 1979; Martin-Piera & Zunino 1983, 1986; Palestrini 1985; Martin-Piera 1986, 2000; Lumaret & Kim 1989).

Lawrence & Newton (1995) placed all 12 tribes in the subfamily Scarabaeinae with which they considered the Coprinae synonymous. Browne & Scholtz (1995, 1998) studied the phylogeny of Scarabaeidae based on the characters and evolution of hind wing articulation and wing base. Montreuil (1998) confirmed the monophyly of Coprini and Dichotomini. Recent and complete phylogeny of the Onthophagini was based on 12 external and internal morphological traits (Martin-Piera 2000).

New phylogenic studies of Philips *et al.,* (2004) based on 200 internal and external morphological characters support this classification. Krikken (2009) revised and discussed the taxonomic and biogeographic status of genus *Drepanocerus* Kirby and the related genera and split the genus into five new subgenera namely, *Afrodrepanus, Clypeodrepanus, Latodrepanus, Sulcodrepanus* and *Tibiodrepanus*.

Regional lists of dung beetles are available from South Africa (Péringuey 1900), African Tropical region (Gillet 1908, 1911), Sumatra (Gillet 1924), China (Gillet 1935; Nakane & Shirahata 1957), Southwest Arabia (Paulian 1938), Mexico, Central America, the West Indies and South America (Blackwelder 1944), Afganistan (Balthasar 1955), Japan (Nakane & Tsukamoto 1956), Florida (Woodruff 1973), Panama and Costa Rica (Howden & Young 1981; Howden & Gill 1987; González-Maya & Mata-Lorenzen 2008), Nebraska (Ratcliffe 1991), Europe (Baraud 1992), Colombia (Lopera 1996), Nearctic Realm (Smith 2003) and Palaearctic region (Löbl & Smetana 2006). Check list of dung beetles of the world were prepared by Krajcik (2006) and Schoolmeesters (2011). Vaz-de-mello *et al.*, (2011) gave a multilingual key to the genera and subgenera of the subfamily Scarabaeinae of the New World. Siddiqui *et al.*, (2014) gave an annotated list of scarabs collected from localities of Pakistan with the faunal composition. Taxonomic composition of Scarabaeinae dung beetles inhabiting fluvial islands in the Southern Brazilian Amazon given by Rafael *et al.*, (2014). Pokorny & Zídek (2014) provided "Review of the genus *Paragymnopleurus* Shipp belonging to Gymnopleurini (Coleoptera: Scarabaeidae: Scarabaeinae). González-Alvarado & Vaz-de-Mello (2014) did a taxonomic review of the subgenus Hybomidium Shipp 1897 (Coleoptera: Scarabaeidae: Scarabaeinae: Deltochilum). Daniel *et al.*, (2014) updated the first checklist of dung beetles from Brazilian Shield-Chacoan

Depression Border, Brazil published over a century ago. Checklist and key to species of the tribe Phanaeini (Coleoptera: Scarabaeidae: Scarabaeinae) from Roraima state, Northern Brazil was given by Pacheco & Vaz-de-Mello (2015).

Taxonomy of dung beetles of the Indian region:

Scarabaeinae globally supposed to include members of 13 tribes represented by over 5,000 described species in 234 genera (Ratcliffe & Jameson 2013; Sarkar *et al.*, 2015). Indian coprine species are now considered within the tribes Scarabaeini and Coprini. Even though informations on the new world species are largely available; our knowledge with the members of the old world is still scanty and is limited to the monographic works of Arrow (1931) and Balthasar (1963).

Biswas (1978a) studied on scarab beetles (Coleoptera: Scarabaeidae) of north-east India and given notes on other Indian species of subgenus *Strandius*, genus *Onthophagus*. Biswas (1978b) described three new species namely, *Onthophagus* (*Strandius*) *subansiriensis*, *Onthophagus* (*Strandius*) *gagates* Hope and *Onthophagus* (*Strandius*) *hingstoni* from north-east India. Biswas & Chatterjee (1985) reported seven new species namely, *Oniticellus namdaphensis*, *O. subhendui*, *O. gayeni*, *Onthophagus tirapensis*, *O. arunachalensis*, *O. songsokensis* and *O. royi* from Namdapha Wildlife Sanctuary. Newton and Malcolm (1985) reported 22 species from the Kanha Tiger Reserve. Male genitalia of three Indian genera, *Catharsius* (Sewak, 1985), *Onthophagus* (Sewak, 1986) and *Oniticellus* (Sewak, 1988) and taxonomic importance were studied. Chandra (1988) studied the pleurostict

Scarabaeidae (Coleoptera) of northwestern India and 108 species pertaining to four subfamilies were reported. Sewak & Yadva (1991) recorded 36 species from Western Uttar Pradesh. Veenakumari & Veeresh (1996a) reported 33 first reports among 61 species of Scarabaeinae belonging to three tribes from Bangalore in the Deccan region; Biswas *et al.,* (1997) recorded three species from Delhi; Mittal (1999) published an annotated list of the scarab fauna of Western Uttar Pradesh and recorded 151 species of these beetles belonging to 41 genera and 12 subfamilies; Chatterjee & Biswas (2000) recorded 27 species from Tripura State.

Chandra (2000) published an inventory of 96 species of scarab beetle s and its distribution from the protected areas of the Madhya Pradesh state. An account of scarabaeid beetles of Himachal Pradesh was also published by Chandra (2004) and a total 167 species under eight subfamilies were reported, which included only 30 species of Scarabaeidae from Kulu district. Chandra & Rajan (2004) reported *Onthophagus cervus* (Fabricius) from Mount Harriett National Park, South Andaman. Chandra & Singh (2004) recorded 10 dung beetles from Pachmarhi Biosphere Reserve, Madhya Pradesh. Forty-nine species were reported from Gujarat (Sewak 2004). Chandra & Ahirwar (2005) identified 44 species of 24 genera under 8 subfamilies. Thirty-five species are recorded for the first time from Bhandavgarh National Park and Umaria district. Of these five species are new records to the fauna of Madhya Pradesh. Sewak (2006) recorded 73 species under 14 genera from the Arunachal Pradesh. Chandra & Ahirwar

(2007) gave a comprehensive account of the scarab beetles of Chhattisgarh and Madhya Pradesh and recorded 124 species/subspecies belonging to 45 genera under 11 subfamilies, including 81 species of dung beetles.

Sewak (2009) provided a taxonomic key for the tribes, genera and species of the subfamily Coprinae, as well as a systematic account and synonyms for all 12 genera and 85 species and their distributions in the Thar Desert. Twenty two species of scarab beetles belonging to 11 genera from Achanakamar Wildlife Sanctuary, Chhattisgarh reported by Chandra & Singh (2010). Chatterjee (2010) reported 44 species belonging to 16 genera and 3 subfamilies from Uttarakhand.

Chandra & Gupta (2012b) presented a new record of five species of genus *Onthophagus* namely, *Onthophagus abacus* Boucomont, *O. armatus* Blanchard, *O. rudis* Sharp, *O. gratus* Arrow and *O. amplexus* Sharp from Central India. Chandra & Gupta (2013) gave taxonomic account of 52 species of dung beetles belonging to 22 genera, 12 tribes and 04 subtribes from Chhattisgarh. The genera namely, *Caccobius*, *Copris*, *Tibidrepanus*, *Phalops*, *Sisyphus*, *Tiniocellus*, *Oniticellus*, and *Onitis* are first time studied, illustrated and keyed from the state.

Gupta *et al.,* (2014) updated checklist of 61 species of Scarabaeoid beetles (Coleoptera: Scarabaeoidea) belonging to 30 genera and 19 tribes (Scarabaeidae) from Pench Tiger Reserve, Madhya Pradesh for the first time. Chandra & Gupta (2014) described male genitalia and sexual dimorphism of seven species except for *Gymnopleurus (Metagymnopleurus) parvus* MacLeay and illustrated for the first time. Also provided, an identification key for all *Gymnopleurini* species that occur in Madhya Pradesh and Chhattisgarh. Sarkar *et al.*, (2015) devoted to the systematics of 19 Scarabaeinae species under 6 genera recorded from Buxa Tiger Reserve, West Bengal.

Since the systematic studies on the dung beetles from the region by Arrow (1931), very few studies have assessed the taxonomy of dung beetles in the Western Ghats. Though Arrow (1931) reported 48 species of dung beetles from the western slopes of the South Western Ghats, it is unable to decipher the habitats from which the beetles were collected as locality details were not provided along with site descriptions. Paulian (1980) reported five new species of Canthonines from South India namely, *Phacosoma nitidus, P. loebli, Panelus mussardi*, *P. besucheti*, and *P. keralai*. Biswas & Chatterjee (1986) reported 3 new species namely *Onthophagus keralicus*, *O. sahai* and *O. taruni* and recorded 16 species from the Silent Valley National Park.

Biswas & Mulay (2001) recorded 71 species from Nilgiri Biosphere Reserve. Mathew (2004) recorded 37 species from Kerala as part of the biodiversity documentation programme by Kerala Forest Research Institute. A new species, *Onthophagus devagiriensis* from a moist deciduous forest in the Wayanad region of Kerala State was recorded (Schoolmeesters & Sabu 2006). Anu (2006) prepared a checklist of 29 species from a wet evergreen forest in the Wayanad region of Nilgiri Biosphere Reserve. Priyadarsanan (2006) reported dung beetles from the Bilgiri Rangaswamy Temple Sanctuary (BRT) of Karnataka in which 7 tribes, 13 genera and 87 species were recorded. Vinod (2009) prepared a checklist of 58 species, comprising 13 genera and 7 tribes of the Wayanad region. Seven new synonyms within the genus *Onthophagus* (Coleoptera: Scarabaeidae) from the oriental region including the synonymisation of *Onthophagus anamalaiensis* with *O. vladimiri* was reported (Tarasov 2010). Seven new synonyms within the genus *Onthophagus* (Coleoptera: Scarabaeidae) from the Oriental region was provided in which *Onthophagus anamalaiensis* was synonymised with *O. vladimiri* by Tarasov (2010).

Revision of taxonomic status of the Scarabaeinae genus *Ochicanthon* Vaz-de-Mello (Coleoptera: Scarabaeidae) and an identification key to the species with notes on distribution and flightlessness from the Indian subcontinent was provided by Latha *et al.,* (2011). *Ochicanthon* species from the region is increased to 15 in number, eight of which are new: *O. besucheti* Cuccodoro sp. nov., *O. ceylonicus* Cuccodoro sp. nov., *O. devagiriensis* Sabu & Latha sp. nov., *O. ernei* Cuccodoro sp. nov., *O. gauricola* Cuccodoro sp. nov., *O. murthyi* Vinod & Sabu sp. nov., *O. mussardi* Cuccodoro sp. nov. and *O. vazdemelloi* Latha & Sabu sp. nov. Discovery of four wingless species from the upper montane cloud forests raised the number of wingless species of *Ochicanthon* to five. Sabu *et al.,* (2011a) prepared a checklist of 142 species from the moist South Western

Ghats including five new dung beetles species from the moist South Western Ghats. Seena & Priyadarsanan (2013) presented a comprehensive list of 145 species of dung beetles belonging to 9 tribes and 23 genera reported so far from Karnataka. Sabu (2015) gave first time data on the community structure and species composition of Scarabaeinae in the forests and agribelts from the dry eastern slopes of the Western Ghats. Sathiandran *et al.,* (2015) presented an illustrated checklist of 36 species of dung beetles (Coleoptera: Scarabaeinae) from the Periyar Tiger Reserve in the southern Western Ghats. Mittal & Jain (2015) reviewed the taxonomy of the Indian dung beetle fauna and listed among the nine tribes. By excluding about 70 odd species (from the total of 354 species) reported in 'Fauna of British India' from other areas (i.e., Pakistan, Afghanistan, Sri Lanka, Myanmar, Indonesia, etc.) outside the present Indian region, the final record from India was around 420 species in 38 genera. Recently, Seena & Priyadharsanan (2016) reported three species *Onthophagus jwalae* (Kerala), *O. pithankithae* (Karnataka) *and O. tharalithae* (Assam) that are new to science.

2.2. GUILD STRUCTURE

Functional guild: Studies in functional guild composition of dung beetle assemblages of different habitats across the world includes studies done in forests of Colombia (Howden & Nealis 1975; Escobar 2000), forest pasture ecotones of Amazonia (Klein 1989; Vulinec 2002), moist forest of Ivory Coast in Africa (Cambefort & Walter 1991), Australia (Howden *et al.,* 1991), Panama (Gill 1991), forest pasture ecotones of Mexico (Estrada *et al.*, 1998, 1999), rain forests in Malaysia (Davis *et al.*, 2000), Guyana (Feer 2000), Brazil (Andresen 2002), forest savannah ecotone in Bolivia (Spector & Ayzama 2003), in natural and anthropogenic habitats of montane region of Colombia (Escobar 2004), in mountain grasslands of southern Alps (Errouissi *et al.*, 2004), in Afrotropical region (Krell-Westerwalbesloh *et al.*, 2004), agriculture field in Guatemala (Avendaño-Mendoza *et al.*, 2005), Indonesia (Shahabuddin *et al.*, 2005), agriculture field of Wayanad (Sabu & Vinod 2005), in elephant and bison dung of moist forests in South Western Ghats (Sabu *et al.*, 2006; Vinod & Sabu 2007), in fragmented tropical rain forest of Veracruz, Mexico (Halffter *et al.*, 2007), in continuous forests, forest fragments and cattle pastures of Chiapas, Mexico (Navarrete & Halffter 2008), in forest, monoculture plantation and agriculture field of Wayanad (Vinod 2009), in shaded cacao and forest in Indonesia (Shahabuddin 2010), in semi-urban fragmented agricultural land in the Malabar coast in Southern India (Simi *et al.*, 2012), in the Nelliampathi region of South Western Ghats, India (Latha 2011), in Atlantic forest fragments in southern Brazil (Campos & Hernández 2013), in a thorny forest in the south Western Ghats, India (Sobhana 2014), in different vegetational types in the Brazilian Shield–Chacoan Depression Border (Daniel *et al.*, 2014), in Atlantic forest fragments adjacent to transgenic maize crops (Campos & Hernández 2015), in the Guanacaste National Park of Belize (Latha *et al.*, 2016a) and in the Central Belize Corridor region of Belize (Latha *et al.*, 2016b).

Dominant guild in most assemblages was the tunnelers (Cambefort & Walter 1991; Hanski & Cambefort 1991; Halffter *et al.,* 1992; Escobar 2004; Navarrete & Halffter 2008). Tunnelers were the dominant guild in Southern India (Sabu *et al.,* 2006; Vinod 2009; Sabu 2011; Latha 2011; Sobhana 2014). Tunneler guild dominance is a characteristic of Neotropical forests and is related to their superior competitive nature (Campos & Hernandez 2013; Latha *et al.,* 2016b) but in habitats with anthropogenic disturbance and modifications an increase in roller dung beetles have been observed (Latha *et al.,* 2016a).

Krell *et al.,* (2003) found that the abundance of rollers and their kleptoparasites were positively correlated with the temperature of feces and soil, whereas the number of dwellers increases with decreasing temperature during the exposure period. Rollers were the second dominant guild preceded by tunnelers in the assemblages of Mexico (Estrada *et al.,* 1998) and Tanzania (Nielson 2007). Rollers were not recorded in the agroecosystems of North India (Mittal & Vadhera 1998). In the Neotropics (Mexico, Central, South America) the vast majority of dung beetles are rollers or tunnellers (Gill 1991; Horgon 2005).

Moist forests of Ivory Coast (Cambefort & Walter 1991) and Wayanad (Vinod 2009) were the only exceptions where the dominant species were distributed between tunneler and dweller guilds. Dwellers were found to be associated with large undisturbed herbivore dung pats (Hanski & Cambefort 1991; Krell *et al.,* 2003; Krell-Westerwalbesloh *et al.,* 2004). Dwellers were the least common functional group in most studies (Halffter *et al.*, 1992; Feer 2000; Scheffler 2005; Hernández & Vaz-de Mello 2009). Surface crust formation in dung pats was found to reduce dweller abundance in summer (Doube 1991; Hanski 1991; Sowig & Wassmer 1994; Horgan 2001; Vinod 2009). Dwellers were the most abundant guild followed by tunnelers and rollers (Simi *et al.*, 2012). Dweller functional group was more representative in Atlantic forest fragments near transgenic maize crops (Campos & Hernández 2015).

Temporal guild: In tropical forests, temporal differentiation appears particularly relevant where high rates of exploitation of carrion and dung occur especially because the resource is presumably limited (Peck & Forsyth 1982; Klein 1989; Feer 1999). Dung beetle species success is determined by their early arrival at the resource (Hanski 1990). So diel activity of species is an important parameter determining their success. Many studies recorded diel resource partitioning within dung beetle assemblages (Fincher *et al.,* 1971; Peck & Forsyth 1982; Janzen 1983; Walter 1985; Hanski 1986; Cambefort 1991; Cambefort & Walter 1991; Gill 1991; Caveney *et al.,* 1995; Krell-Westerwalbesloh *et al.,* 2004; Feer & Pincebourde 2005). Diel separation between guilds has only once been quantitatively examined (Doube 1991). Krell *et al.,* 2003 found that guild structures of beetle assemblages in buffalo dung differ between day and night.

In tropical ecosystems, species compositions of diurnal and nocturnal dung beetle assemblages were clearly different (Hanski & Cambefort 1991), particularly in open habitats (Cambefort & Walter 1991). Dung beetles were generally found to show an abundance peak at dusk and around mid-day (Peck & Forsyth 1982; Walter 1985; Fincher *et al.,* 1986; Davis 1996a; Feer 2000). Light intensity was found several times to be responsible for the onset of flight of crepuscular dung beetles (Carne 1956; Houston & McIntyre 1985). In Africa, Walter (1985) distinguished various temporal patterns among diurnal and nocturnal species. In Panama, diurnal species display several distinctive patterns of flight activity and some species are possibly auroral/crepuscular (Howden & Young 1981; Gill 1991) or active both by night and day. A similar grouping of species by temporal activity seems to prevail also in French Guiana (Feer 2000). Hernández (2002) determined the daily activity pattern of dung beetles species of the Neotropical region and the association between activity pattern and colouration of the species was assessed. Krell-Westerwalbesloh *et al.,* (2004) reported different patterns of guild structure during the day, with time of day and temperature influencing the presence of guilds.

Diurnal species tend to be smaller than nocturnal and crepuscular species and nocturnal species are black or dark in body colour whereas diurnal species show colour patterns (Feer & Pincebourde 2005). Diurnal species were more numerous than nocturnal species in several studies (Hanski 1989; Gill 1991; Andresen 2000; Feer & Pincebourde 2005) but equal or higher numbers of nocturnal species exist in other forests (Cambefort 1984; Walter 1985; Howden *et al.,* 1991; Halffter *et al.,* 1992; Escobar & Chacon de Ulloa 2000). Navarrete & Halffter (2008) reported that large-bodied, nocturnal species with specific requirements of soil temperature and compaction are more sensitive to anthropogenic changes.

Quintero & Halffter (2009) studied temporal changes in a community of dung beetles (Insecta: Coleoptera: Scarabaeinae) resulting from the modification and fragmentation of tropical rain forest, Brazil. Diurnal guild dominated the assemblage of semiurban agricultural land in the Malabar Coast of southern India (Simi *et al.,* 2012). Medina & Lopes (2014) reported higher species richness during the day and greater abundance during the night in a Caatinga Fragment, Brazil.

Bioindicators: Dung beetles have been used as bioindicators due to their sensitivity to environmental changes (McGeoch *et al.,* 2002; Gardner *et al.,* 2008; McGeoch 2013). *Indval* method (Dufrêne & Legendre 1997; Siddig *et al.,* 2016) was used to find indicator species. Many studies reported coprophagous scarabaeoid beetles are more responsive to environmental changes and considered as well suited bioindicators (Howden & Nealis 1975; Klein 1989; McGeoch & Chown 1998; Aydin & Kozak 2010). Halffter & Favila (1993) has reviewed the potential of dung beetles as indicators for disturbance. They are widely used as bioindicator of habitat disturbance in many studies (van Rensburg *et al.,* 1999; McGeoch *et al.,* 2002; Spector 2006; Nichols *et al.,* 2007; Tshikae *et al.,* 2008; Shahabuddin 2011). Rodrigues *et al.,* (2013) reported dung beetles as bioindicators of species diversity in agricultural or natural environments. Effectiveness of dung beetles as bioindicators of environmental changes in land-use gradient in Sulawesi, Indonesia was checked by Shahabuddin *et al* (2013).

Dung beetles in Coffee Plantations: Many studies from Neotropical region (Greenberg *et al.,* 1997a; Johnson 2000; Perfecto *et al.,* 2003; Perfecto & Armbrecht 2003; Somarriba *et al.*, 2004) have demonstrated that shaded coffee agro-ecosystems harbor significantly high biodiversity particularly dung beetle diversity (Moron 1987; Pineda *et al.,* 2005; Horgan 2005). Many studies also reported forest species of dung beetles from shaded coffee plantations (Perfecto *et al.,* 1996; Moguel & Toledo 1999; Arellano *et al.*, 2005). Arellano *et al.,* (2005) and Pineda *et al.,* (2005) also reported species composition of Scarabaeinae from coffee agrosystems of Mexico. Perfecto *et al.,* (1997) report drastic declines in beetle and ant species richness from well-shaded coffee agroforestry systems to zero-shade coffee. Philpott *et al.,* (2006) reported coffee management intensification (reduction or removal of shade trees) reduced the diversity of arthropod predators (ground-foraging ants). Recent study reported sun-grown coffee habitat acts a barrier to forest species and the agricultural matrix has its own assemblage of species, which increases diversity at the landscape scale (Villada-Bedoya *et al.,* 2017).

Studies on biodiversity in coffee plantations of the Western Ghats have examined bird, mammal, butterfly and recorded high biodiversity in the shaded coffee belts (Bali *et al.,* 2007; Dolia *et al.,* 2008; Anand *et al.,* 2008). Shahabuddin (2010) reported, shaded coffee agro-ecosystems with vegetation structure resembling like natural forest proved to be inhabited by a dung beetle fauna which is similar to the one found at forest sites. Maintaining high dung beetle diversity in coffee plantations is highly beneficial because biodiversity loss may lead to decreasing in ecological functions and environmental services, such as nutrient cycling and seed dispersal (Nichols *et al.,* 2008; Slade *et al.,* 2011; Gray *et al.*, 2014; Batista *et al.*, 2016).

2.3. DUNG SPECIFICITY

Many studies from forests and plantation ecosystems in the Tropical region used various baits such as cattle dung (Doube 1983; Horgan 2002, 2007; Shahabuddin *et al.*, 2005, 2010, 2013; Andresen 2005, 2008; Vinod 2009; Simi *et al.,* 2012; Latha 2011), human feces (Hanski 1983; Klein 1989; Nummelin & Hanski 1989; Hanski & Krikken 1991; Holloway *et al.,* 1992; Kikuta *et al.,* 1997; Davis 2000a; Davis *et al.,* 2000, 2001; Halffter & Arellano 2002, Feer & Hingrat 2005; Scheffler 2005; Horgan 2005; Gardner *et al.*, 2008), boar dung (Boonrotpong *et al.,* 2004), other dungs such as monkey, horse, dog, wallaby, coati, elephant, gaur, deer etc (Howden & Nealis 1975; Estrada *et al.,* 1993, 1998; Hill 1996; McGeoch *et al.,* 2002; Estrada & Coates-Estrada 2002; Andresen 2003; Vieira *et al.,* 2008; Sabu 2012). Studies from Palaearctic agriculture fields showed differences in the abundance of beetles among various herbivorous dung types (Lumaret & Iborra 1996; Martin-Piera & Lobo 1996; Galante & Cartagena 1999; Finn & Giller 2002). Studies evaluating the food preference of dung beetles among a greater variety of feces types have shown that the greatest number of individuals was attracted to omnivorous mammals (Estrada *et al.,* 1993; Sabu 2012; Noriega 2012). Many studies recorded distinct trophic preference for omnivorous mammal feces in Neotropical (Estrada *et al.*, 1993; Filgueiras *et al.*, 2009; Marsh *et al.*, 2013), Australian (Hill 1996; Vernes *et al.*, 2005), African (Davis 1994; Tshikae *et al.*, 2008; Davis *et al.*, 2010) and south Asian regions (India: Western Ghats) (Sabu 2012).

Dung beetle communities are strongly influenced by dung type and their species composition, abundance and guild structure change in relation to the available dung types (Krell *et al.*, 2003; Dormont *et al.*, 2004; Tshikae *et al.*, 2008; Shahabuddin *et al.*, 2010; Ueda *et al.*, 2015). Davis *et al.*, (2010) assessed dung beetle assemblage in various vegetation communities and dung types in Tswalu Kalahari Reserve, South Africa. In Brazil, the efficiency of bait for dung beetle sampling, documented in forested ecosystems (Silva *et al.*, 2012b). Puker *et al.*, (2013) compared dung of human and rodent, concluded an average number of individuals and species captured by the traps baited with human feces was greater. Medina & Lopes (2014) studied food preference of Scarabaeinae community in a Caatinga fragment (dry forest), Brazil. Also attractiveness of baits to dung beetles in Brazilian savanna and exotic pasturelands studied by Correa *et al.*, (2016).

Chapter 3

MATERIALS AND METHODS

3.1. STUDY REGION

The study was carried out in a coffee plantation at Ambalavayal in the Cherambadi belt of South Wayanad (Plate 1) in the Nilgiri Biosphere Reserve (NBR). South Wayand is peculiar for its geographical placement on the western slopes of Nilgiris and Vellarimala mountains (Nair 1991) in the South Western Ghats. Wayanad (11^{0} 30' N - 11^{0} 58' N and 75 ^{0} 45' E - 76 ^{0} 28' E), is a northern district of Kerala state comprising a geographical area of 2,126sq.kms and it is bounded on the east by the Nilgiris (Tamil Nadu) and Mysore (Karnataka) and in the north by Kodagu (Karnataka) district. It has Malapuram on the south and Kozhikode and Kannur constitute its western borders (Nair 1991). The altitude ranges from 700 to 2100 meters above sea level.

3.2. SAMPLING METHODOLOGY

Dung beetles were collected using dung baited pitfall traps (Lobo *et al.,* 1988; Veiga *et al.*, 1989), during the 2014-2015 period. Pitfall traps provide a cheaper, quick and relatively unbiased method for obtaining data on species diversity and abundance distributions (Spector & Forsyth 1998). Pit fall traps were made of plastic basins, 10 cm in diameter and 15 cm deep and a solution of mild detergent (to reduce surface tension and facilitate rapid drowning of the beetles) and salt (to reduce deterioration of the specimens) were used as a preservative (Spector & Ayzama 2003). The basins were buried with their rim in level with the soil and each trap was topped with a plastic plate supported on iron bars to prevent desiccation on warm days and flooding on rainy days.

Two hundred grams of fresh dung was placed on a strip of wire grid at the top of the basin as bait. Thirty traps spaced at 50 m interval between traps were placed with pig, cattle and goat dung types (ten traps with each dung) to minimize trap interference (Larsen & Forsyth, 2005). The trap contents were collected at 12 h interval (6:00-18:00 h and 18:00-6:00 h) to separate diurnal and nocturnal species because flight activity of dung beetles differs strongly between day and night (Krell *et al.,* 2003). The traps were emptied into a fine nylon gauze (0.5 mm mesh size), to concentrate the catches from the traps. An ethanol filled wash bottle was used to wash the catch into the bottles that already contains an appropriate label.

3.3 IDENTIFICATION AND DATA ANALYSIS

Collected beetles were preserved in 70% alcohol and identified to species level using the taxonomic keys available in Arrow (1931) and Balthasar (1963) and by comparing with type specimens available in the research centre and with Zoological Survey of India, Western Ghats regional station, Calicut. Once identified to the species level, the specimens were separated and kept in small vials containing 70% alcohol, appropriately labelled with information on site, trapping date, taxon name, trap type and number. Specimens were curated in the insect collections of Tamil Nadu Agricultural University (TNAU), Coimbatore and allotypes of 1 new and 2 rare specimens were deposited in the museum of Zoological Survey of India, Western Ghats regional station, Calicut.

Species were sorted into three functional guilds *viz.*, dwellers (endocoprids), rollers (telecoprids) and tunnelers (paracoprids) following Cambefort & Hanski (1991) and Sabu *et al.*, (2006, 2007). Number of species and the number of individuals collected from each dung were tabulated on a pre–printed tally sheet that also had the locality, date and trap code entered onto it. Capture data from three dung types were pooled so that 90 samples were available for subsequent analysis.

To identify temporal guilds namely, diurnal, nocturnal (Cambefort & Hanski 1991) and generalists, data was obtained by pooling diurnal and nocturnal collections separately for three dung types. Species collected only in diurnal traps or nocturnal traps were designated as diurnal or nocturnal. For those that were collected in diurnal and nocturnal collections, significant levels of variation in species abundance between diurnal and nocturnal collections were calculated. Species showed no variation in nocturnal and diurnal collections was considered as generalists and for those species showed significant variation, their abundance was used to determine whether they were diurnal or nocturnal. All the informations were entered into Microsoft Excel work sheet.

Checklist and Pictorial Key:

Checklist was prepared on the species collected during the present study. Pictorial key was drafted based on Arrow (1931), Balthasar (1963). Photographs were taken using Leica stereozoom microscope. The images were finalized in JPEG format using free Adobe Photoshop 7.0.

Diversity analysis:

To understand the diversity patterns, alpha diversity indices (richness, evenness, diversity), taxonomic diversity, rank abundance plot and beta diversity index (Bray Curtis similarity index) were considered.

For analyzing species richness, **Margalef's index (d)** (Clifford & Stephenson 1975; Magurran 2004) was calculated by using the following formula.

$$d = S - 1 / \log(N)$$

S = total number of species

N = total number of individuals

Shannon-Weaver diversity index (Shannon & Weaver 1949) is the most commonly used among diversity indices because it incorporates both species richness and evenness components and can provide heterogeneity of information (Rosenstock 1998; Cheng 1999). Also, it is possible to test the differences between two communities using a Shannon *t*-test/ANOVA (Cheng 1999; Magurran 2004).

$$H' = -\Sigma_i P_i (\log (P_i)$$

Where P_i is the proportion of the total count arising from the i^{th} species ($\log_e$ was used in its formulation).

Simpson's dominance index (λ) (Simpson 1949) gave the probability of any two individuals drawn at random from an infinitely large community belonging to the same species, its largest value corresponds to assemblages whose total abundance is dominated by one, or a very few of the species present

$$\lambda = \Sigma\, p_i^2$$

Where p_i is the proportion of the total count arising from the i th species

Evenness expressed as **Simpson's evenness index (1-λ)**, addresses equitability of the species (Simpson 1949).

$$\lambda = 1 - \Sigma\, p_i^2$$

Although there are many possible indices which can be used to portray diversity, each with strengths and weaknesses, these four are chosen because they are familiar to and readily interpretable for most ecologists.

Bray-Curtis similarity coefficient (Bray & Curtis 1957) was used to quantify and compare the similarity of dung beetle species composition among dung types. This index is calculated as

$$BC_{jk} = 100\left\{1 - \frac{\sum_{i=1}^{p}\left|y_{ij} - y_{ik}\right|}{\sum_{i=1}^{p}\left(y_{ij} + y_{ik}\right)}\right\}$$

Where BC_{jk} is the similarity between the j^{th} and k^{th} dung type and y_{ij} represents the abundance for the i^{th} species in the j^{th} dung type.

A triangular matrix of similarity coefficients was computed between every dung type. To measure the similarity coefficients between various dung types, a data matrix with p rows (dung beetle species) and n columns (dung types), filled with entries of abundance counts of each dung beetle species for each dung type was first constructed. Similarity based on the Bray-Curtis coefficient was calculated between every pair of dung types and a similarity matrix of abundance was then constructed. Bray-Curtis similarity coefficient, rated often as a satisfactory coefficient for biological data on community structure is selected. Although there are several indices of similarity, Bray Curtis similarity Index most accurately reflects changes in the communities (Clarke & Warwick 1994; Magurran 2004). This index ranges from 0 (no shared species) to 100 (no difference in species composition). Furthermore, to reduce the large disparities in counts between species and to validate statistical assumptions for parametric techniques, square root transformation were applied to the original abundance counts of insect order before computing the Bray-Curtis coefficient.

Patterns in species composition of the dung beetle assemblages were analyzed by constructing **rank-abundance plot** for each of the dung types. Rank-abundance plot was plotted with relative abundance of each order against the rank of species for the dung types (Whittaker 1965). **Rare species** were classified as those represented by a single or double individuals (singletons or doubletons) (Novotny & Basset 2000).

Indicator species value (ISV) using the **Indicator Value Method (*Indval*)** (Dufrene & Legendre 1997) was calculated for all the species captured from habitat, to assess the value of particular species as indicators of habitat change. The indicator species value incorporates two components: species specificity (species unique to sites in a group of sites) and species fidelity (species abundant and widespread within a group of sites). Thus, the ISV of a species shows the degree (0–100%) to which the species expresses specificity and fidelity. Species with high indicator values make reliable indicator species not only because they are specific to a locality, but also because they have a high probability of being sampled in that locality during monitoring and assessment (McGeoch & Chown 1998). ISV's were calculated for each species 'i' in each of the three dung types 'j' as

$$ISVij = Aij \cdot Bij \cdot 100$$

Where Aij is the mean number of species 'i' across the samples 'j' divided by the sum of the mean numbers of individuals of species 'i' over all dungs, and Bij is the number of samples in habitat 'j' where species 'i' is present, divided by the total number of dung samples in that habitat (Dufrêne & Legendre 1997; McGeoch & Chown 1998). Species with higher *Indval* values greater than 70% were regarded as bioindicator species for that particular habitat type and species with *Indval* between 50% to less than 70% was categorized as the detector species which will indicate the direction in which ecological change was taking place and species with *Indval* between 5% and 50% were generalists occurring in a wide range of habitats ((McGeoch *et al.*, 2002). Species with very low abundance (overall abundance >5 individuals) were excluded from *Indval* analysis.

Statistical Analysis

All the data used for statistical analysis were tested for normality with Anderson-Darling test. Since all the data were not normally distributed non parametric statistics, Kruskal-Wallis H tests was used to test the significance levels of variation in abundance (Sachs 1992). Differences with a p-value <0.05 was compared using Wilcoxon-Mann/ Whitney Test. The data includes the abundance of individual species of dung beetles; abundance of individual species of dung beetles in each dung type; variations in functional guild and temporal guild abundance in each dung type. All statistical analyses were performed using Megastat version 10.0 (Orris 2005).

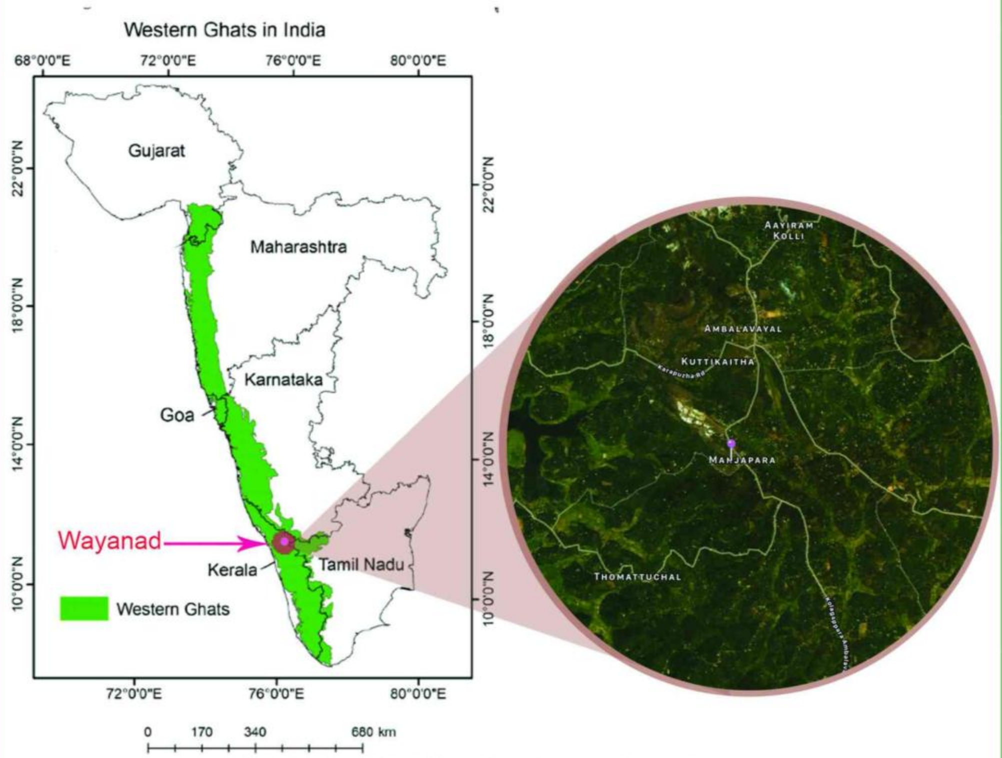


Plate 1 : (A) *Map showing study region*

(B) *Study site (Coffee Plantation)*

Chapter 4

RESULTS

4.1. TAXONOMY OF DUNG BEETLES

Checklist of dung beetle fauna from a coffee plantation belt in South Wayanad region reveals the presence of 38 species, comprising 10 genera- *Caccobius*, *Catharsius*, *Copris*, *Paracopris, Drepanocerus, Ochicanthon, Oniticellus*, *Onitis*, *Onthophagus* and *Sisyphus* and six tribes Onthophagini, Coprini, Onitini, Oniticellini, Canthonini and Sisyphini. *Onthophagus* is the most speciose genus with 23 species. Of the 38 species reported, *Onthophagus lilliputanus* Lansberge, 1883 is a first record from the moist South Western Ghats; 8 are endemic species to the Western Ghats namely *Ochicanthon laetus*, *Ochicanthon tristis*, *Onthophagus andrewesi*, *O. amphicoma*, *O. bronzeus*, *O. devagiriensis, O. tnai* and *Paracopris davisoni.* Among endemic species *Ochicanthon tristis*, *Onthophagus devagiriensis* and *O. tnai* are local endemics being specific to Nilgiri Biosphere Reserve. Primitive and rare *Ochicanthon* genus belonging to old world tribe Canthonini and two species, *Onthophagus truncaticornis* and *Onthophagus discedens* which were recorded as extirpated, also reported from coffee plantation.

Check list of dung beetles in a coffee plantation of South Wayanad region:

Superscripts provided to species furnishes the following details @ first report from moist part of south Western Ghats, # endemic to Nilgiri Biosphere Reserve, *endemic to Western Ghats

SCARABAEINAE

SISYPHINI

***Sisyphus* Latreille, 1807**

Sisyphus Latreille, 1807, Gen. Crust. et Ins. II: 79; Gory, 1833, Monogr. Du genre Sisyphe:1-15; Lacordaire, 1856, Gen. Col. III: 72; Reitter, 1892 (1893): 158, 164; Péringuey, 1900 (1901): 22, 94-103, 897, 898; Arrow, 1927a: 456-465; Arrow, 1931: 67; Balthasar, 1935: 52; Haaf, 1955: 341 ff.; Balthasar, 1963, I: 233.

1. *Sisyphus* (s. str.) *longipes* Olivier, 1789

Sisyphus (s. str.) *longipes* Olivier, 1789, Entom. I, 3: 164, Tf. XIX, Fg. 177 (*Scarabaeus*); Arrow, 1927a: 457; Arrow, 1931: 71; Haaf, 1955: 347, 355; Balthasar, 1963, I: 239-240.

-*minutus* Fabricius, 1792, Ent. Syst. I: 70; Gory, 1833, Monogr.: 15.

-*helwigi* Fabricius, 1798, Ent. Syst. Suppl.: 35.

Distribution: Sri Lanka, Myanmar, Thailand, India (W.Bengal; Orissa; Maharashtra; Karnataka; Tamil Nadu: Ooty, Nilgiri Hills).

CANTHONINI

***Ochicanthon* Vaz-de-Mello, 2003**

Ochicanthon Vaz-de-Mello, 2003, Coleop. Bull. 57(1): 25-26; Boucomont, 1914, Ann. Soc. Ent. Fr. 83: 249 (*Phacosoma*); Arrow, 1931: 354; Paulian, 1945: 56; Balthasar, 1963, I: 269.

2. *Ochicanthon laetus*[*] Arrow, 1931

Ochicanthon laetus Arrow, 1931, Fauna Brit. India, Lamellicornia III: 356; Balthasar, 1963, I: 271-272; Vaz-de-Mello, 2003, Coleop. Bull. 57(1): 25-26.

Distribution: Thailand, India (Karnataka; Tamil Nadu: Nilgiri Hills; Kerala: Wayanad).

3. *Ochicanthon tristis*[#] Arrow, 1931

Ochicanthon tristis Arrow, 1931, Fauna Brit. India, Lamellicornia III: 355; Balthasar, 1963, I: 273; Vaz-de-Mello, 2003, Coleop. Bull. 57(1): 25-26.

Distribution: India (Tamil Nadu: Nilgiri Hills).

COPRINI

Catharsius Hope, 1837

Catharsius Hope, 1837, Col. Man. I: 21; Burmeister, 1846, Gen. Ins. X, No. 27; Péringuey, 1900 (1901): 109, 323; Boucomont and Gillet, 1921:7; Arrow, 1931: 92; Balthasar, 1935: 62; Paulian, 1945: 68; Balthasar, 1963, I: 304.

4. *Catharsius* (s.str.) *molossus* Linnaéus, 1758

Catharsius (s.str.) *molossus* Linnaéus, 1758, Syst. Nat. Ed. X: 347 (*Scarabaeus*); Harold, 1877, 44; Boucomont and Gillet, 1921: 8; Arrow, 1931: 94; Balthasar, 1935: 65; Paulian, 1945: 69; Balthasar, 1963, I: 307-309.

-*abbreviatus* Herbst, 1789, Käfer II: 53.

-*berbiceus* Herbst, I. c.: 227.

-*janus* Olivier, 1789, Entom. I. Scarab.: 101.

-*ursus* Fabricius, 1801, Syst. Eleuth. I: 43.

-*borneensis* Paulian, 1936, Treubia 15: 396.

-*dubius* Paulian, 1. c.

-*dayacus* Lansberge, 1886, Tijdschr. Entom. XXIX: 6 (syn. n.).

-*timorensis* Lansberge, 1879, Ann. Soc. Ent. Belg. XXII, C. r.: 148 (syn. n.).

-*kangeanus* Paulian, 1. c.: 395 (syn. n.).

Distribution: India (Andaman Island; Arunachal Pradesh; Assam; Bihar; Chhattisgarh; Harynana; Himachal Pradesh; Madhya Pradesh; Meghalaya; Odisha; Sikkim; Uttar Pradesh; Uttaranchal; West Bengal; Karnataka; Kerala: Wayanad, Nelliyampathy, Thekkady) Afghanistan, Cambodia, China, Nepal, Pakistan, Sri Lanka, Thailand, Malaysia, Vietnam.

5. *Catharsius* (s.str.) *sagax* Quenstedt, 1806

Catharsius (s.str.) *sagax* Quenstedt, 1806, Schönh. Syn. Ins. I: 43; Boucomont and Gillet, 1921:8; Arrow, 1931:96; Balthasar, 1935:65; Balthasar, 1963, I: 309-310.

Distribution: Bhutan, India (Chhattisgarh; Haryana; Uttar Pradesh; W.Bengal; Bihar; Punjab; Maharashtra; Madhya Pradesh; Andhra Pradesh; Tamil Nadu: Nilgiri Hills, Palani Hills; Kerala: Peerumedu, Travancore, Wayanad)

***Copris* Geoffroy, 1762**

Copris Geoffroy, 1762, Ins. Env. De Paris I:87; Burmeister, 1846, Genera Ins. Heft 10, Col. No. 27; Reitter, 1892 (1893): 39, 93; Péringuey, 1900 (1901): 110, 342; Boucomont and Gillet, 1921: 10; Arrow, 1931: 102; Balthasar, 1933: 263; Balthasar, 1935: 66; Janssens, 1939: 40; Paulian, 1945: 71; Balthasar, 1963, I: 317–319.

6. *Copris* (s.str.) *repertus* Walker, 1858

Copris (s.str.) *repertus* Walker, 1858, Ann. Mag. Nat. Hist. (3) II: 208; Gillet, 1911: 290; Arrow, 1931:116; Balthasar, 1933: 272; Balthasar, 1935: 78; 1963, I: 351-352.

-*claudius* Harold, 1877, Ann. Mus. Civ. Genova X: 48.

Distribution: China, Sri Lanka, Thailand, India (Bihar; Mumbai; Chattisgarh; Maharashtra; Madhya Pradesh; Karnataka; Tamil Nadu : Nilgiri Hills, Anaimalai Hills; Kerala: Palghat, Malabar, Wayanad)

***Paracopris* Balthasar, 1939**

Paracopris Balthasar, 1939, XXV: 2; Paulian, 1945: 72; Balthasar 1958: 473–474, Balthasar, 1963, I: 329–331.

7. *Paracopris davisoni*[*] Waterhouse, 1891

Paracopris davisoni Waterhouse, 1891, Ann. Mag. Nat. Hist. (6), VII: 520; Arrow, 1931: 132; Balthasar, 1963, I: 373.

Distribution: India (Maharashtra: Mumbai; Karnataka; Tamil Nadu: Palni hills; Kerala: Nelliyampathy, Nilgiri hills, Peerumade, North Malabar, Thekkady, Travancore, Wayanad).

ONTHOPHAGINI

***Caccobius* Thomson, 1863**

Caccobius Thomson, 1863, Skand. Col. V: 34; Harold, 1867, Col. Hefte I: 5; Harold, 1867, 1.c.II: 1; Mulsant, 1871: 75; Jekel, 1872, Rev. Mag. Zool.: 405; Waterhouse, 1875, Trans. Ent. Soc. London: 73; Reitter, 1892 (1893): 39, 91; d'Orbigny, 1898; 127; Péringuey, 1900 (1901): 275; Péringuey, 1908: 565; d'Orbigny, 1913: 17; Boucomont and Gillet, 1921: 27; Arrow, 1931: 141; Portevin, 1931: 39; Porta, 1932: 412; Matsumura, 1936: 61; Paulian, 1945: 81; Balthasar, 1949: 1; Balthasar, 1963, II: 113.

-subg. *Caccophilus* Jekel, 1872, 1.c.: 410; d'Orbigny, 1898: 130; d'Orbigny, 1913: 21; Balthasar, 1935e: 183; Balthasar, 1949: 7.

8. *Caccobius* (*Caccophilus*) *meridionalis* Boucomont, 1914

Caccobius (*Caccophilus*) *meridionalis* Boucomont, 1914, Ann. Mus. Civ. Genova VI (XLVI): 239; Arrow, 1931: 142, 148; Balthasar, 1949: 8, 36; Balthasar, 1963, II: 138.

Distribution: Sri Lanka, India (Maharashtra; Karnataka; Tamil Nadu: Nilgiri Hills, Anaimalai Hills; Kerala: Mahe, Wayanad).

9. *Caccobius* (*Caccophilus*) *ultor* Sharp, 1875

Caccobius (*Caccophilus*) *ultor* Sharp, 1875, Col. Hefte, xiii, 1875: 50, Balthasar, 1963, II: 135.

Distribution: India (Maharashtra: Bombay, Khandesh; Punjab, Rajasthan, Uttar Pradesh Haryana: Kanneri; Karnataka: Budipadaga; Kerala: Nelliampathi, Ranipuram).

10. *Caccobius* (*Caccophilus*) *unicornis* Fabricius, 1798

Caccobius (*Caccophilus*) *unicornis* Fabricius, 1798, Ent. Syst. Suppl.: 33 (*Copris*); Boucomont, 1914: 236 (*Onthophagus*); Arrow, 1931: 142, 145; Balthasar, 1933d: 51; Paulian, 1945: 83; Balthasar, 1949: 10, 44; Balthasar, 1963, II: 142-143.

-*nitidiceps* Fairmaire, 1893, Ann. Soc. Ent. Belg. XXXVII: 304; Boucomont, 1914: 313, 314; Boucumont and Gillet, 1921: 34, 59.

-*yamauchii* Matsumura, 1936, Ins. Matsumurana XI: 66.

Distribution: China, Taiwan, Korea, Japan, Myanmar, North Vietnam, Philippines, Sumatra, Java, Borneo, Malaysia, Thailand, Sri Lanka, India (Assam; W. Bengal; Kerala: Wayanad).

***Onthophagus* Latreille, 1802**

Onthophagus Latreille, 1802, Hist. Nat. Crust. Ins. III: 141; Mulsant, 1842: 102; Erichson, 1848. III: 762; Lacordaire, 1856. Gen. Col. III: 107; Mulsant-rey, 1871: 78; Reitter, 1892 (1893): 47; d'Oribgny, 1898: 132; d'Oribgny, 1900: 289; Peringuey, 1900 (1901): 168; Peringuey, 1908: 560; Reitter, 1909: 325; Bedel, 1911; 25; d'Oribgny, 1913: 49;1915: 378 (Suppl.); Boucomont, 1914: 238; Boucomont and Gillet, 1921: 1; Boucomont, 1924a: 669; Arrow, 1930: 159; Portevin, 1931:42; Porta, 1932: 408; Balthasar, 1935d: 303; Savcenko, 1938; 46, 136; Paulian, 1941:66; Paulian, 1945: 85; Endrödi, 1956:94; Tesař, 1957: 127; Balthasar, 1963, II: 153.

-*Monapus* Erichson, 1848, Naturg. Ins. Deutschl. Col. III: 763.

-*Psilax* Erichson, 1848, 1.c..

-*Matashia* Matsumura, 1938, Ins. Matsum. XII: 63.

-subg. *Proagoderus* Lansberge, 1883, Not. Leyd. Mus. V: 14; d'Oribgny, 1913: 493; Boucomont, 1914: 261; Marcus, 1917,A (1919): 1; Marcus, 1920, D. Ent. Zeitschr.: 177, 1921, ibid. 163; Balthasar, 1963, II: 158.

-*Tauronthophagus* Shipp, 1895, Entomologist XXVIII: 179.

-subg. *Serrophorus* Balthasar, 1935, Fol. Zool. Hydrob. VIII: 306; Paulian, 1945: 86; Balthasar, 1963, II: 160.

-subg. *Colobonthophagus* Balthasar, 1935, 1.c.: 308; Paulian, 1945, 87; Balthasar, 1963, II: 164.

-subg. *Digitonthophagus* Balthasar, 1959, 1.c.: 464; Balthasar, 1963, II: 159.

-subg. *Paraphanaeomorphus* Balthasar, 1959,1.c.: 465; Balthasar, 1963, II: 162.

11. *Onthophagus* (s.str.) *amphicoma Boucomont, 1914**

Onthophagus (s.str.) *amphicoma* Boucomont, 1914, Ann. Mus. Civ. Genova, 3, VI (XLVI):239; Arrow, 1931:262; Balthasar, 1963, II: 269.

Distribution: India (Kerala: Mahe, Malabar, Nelliampathi, Travancore; Tamil Nadu: Nilgiri Hills).

12. *Onthophagus* (s.str.) *andrewesi Arrow, 1931**

Onthophagus (s.str.) *andrewesi* Arrow, 1931, Fauna Brit. India, Lamell. III: 321, 324; Balthasar, 1963, II: 273-274.

Distribution: India (Karnataka; Tamil Nadu: Nilgiri Hills, Anamalai Hills; Kerala: Wayanad).

13. *Onthophagus* (*Paraphanaeomorphus*) *bifasciatus* Fabricius, 1781

Onthophagus (*Paraphanaeomorphus*) *bifasciatus* Fabricius, 1781, Spec. Ins. I: 25 (*Scarabaeus*); Arrow, 1931; 327, 339; Balthasar, 1963, II: 292-293.

-*birmanicus* Harold, 1879, Col. Hefte XVI: 226; Arrow, 1931: 339.

Distribution: Myanmar, India (Assam; Sikkim; W.Bengal; Bihar; Tamil Nadu: Nilgiri Hills; Kerala: Wayanad).

14. *Onthophagus* (s.str.) *bronzeus Arrow, 1907**

Onthophagus (s.str.) *bronzeus* Arrow, 1907, Ann. Mag. Nat. Hist. (7), XIX: 429; Arrow, 1931: 184, 192; Balthasar, 1963, II: 299.

Distribution: India (Bombay; Karnataka; Tamil Nadu: Nilgiri Hills; Kerala: Wayanad).

15. *Onthophagus* (s.str.) *cervus* Fabricius, 1798

Onthophagus (s.str.) *cervus* Fabricius, 1798, Ent. Syst. Suppl.: 31(*Copris*); d'Orbigny, 1898: 214; Boucomont, 1914a: 227; Arrow, 1931: 328, 348; Balthasar, 1963, II: 307.

-*nuchidens* Fabricius, 1798, 1. c.: 31.

-*ceylonicus* Harold, 1877, Ann. Mus. Civ. Genova, X: 61; Boucomont, 1914a: 225.

Distribution: Sri Lanka, India (W.Bengal; Uttaranchal; Madhya Pradesh; Maharashtra; Puducherry; Karnataka; Tamil Nadu: Nilgiri Hills, Coimbatore; Kerala: Calicut, Wayanad)

16. *Onthophagus* (*Colobonthophagus*) *dama* (Fabricius, 1798)

Onthophagus (*Colobonthophagus*) *dama* Fabricius, 1798, Syst. Suppl.: 32 (*Copris*); d'Oribgny, 1898: 217; Arrow, 1931: 279, 280; Balthasar, 1963, II: 325-326 (s.str); (*Colobonthophagus)* Lobl and Smetana, 2006:163.

-*aeneus* Olivier, 1789, Ent. I.3: 131.

-*zubači* Balthasar, 1932, Stett. Ent. Zeit., 93: 151; Arrow, 1933: 422.

Distribution: Nepal, Bhutan, Sri Lanka, India (Sikkim; W.Bengal; Bihar; Uttaranchal; Maharashtra; Karnataka; Tamil Nadu: Anamalai Hills, Nilgiri Hills; Kerala: Nilambur, Wayanad, Thekkady)

17. *Onthophagus* (s.str.) *devagiriensis*# Schoolmeesters and Thomas, 2006

Onthophagus (s.str.) *devagiriensis* Schoolmeesters and Thomas, 2006, Phegea 34(2): 73-75.

Distribution: India (Kerala: Wayanad).

18. *Onthophagus discedens* Sharp, 1914

Onthophagus discedens Sharp 1914, Col. Hefte, xiv, 1875, p. 49; Bouc., Ann. Soc. Ent. Fr. 1914, p. 270; Arrow, 1931: 259, 260.

Distribution: India (Bengal; Sikkim; Dehradun; Tamil Nadu: Nilgiri Hills) Indo China, Malay Peninsula, Burma, Borneo.

19. *Onthophagus* (*Gibbonthophagus*) *duporti* Boucomont, 1914

Onthophagus (*Gibbonthophagus*) *duporti* Boucomont, 1914, Ann. Mus. Civ. Genova XLVI: 228; Boucomont & Gillet, 1921: 58; Arrow, 1931: 328, 353; Balthasar, 1935d: 346; Paulian, 1945: 123; Balthasar, 1963, II: 337–338 (s.str); *Palaeonthophagus,* Löbl & Smetana 2006: 167*; Gibbonthophagus,* Kabakov & Shokhin 2014: 50.

Distribution: India (Arunachal Pradesh; Bihar; West Bengal; Karnataka; Tamil Nadu: Nilgiri Hills; Kerala: Thekkady), Laos, Myanmar, Tonkin.

20. *Onthophagus* (s.str.) *fasciatus* Boucomont, 1914

Onthophagus (s.str.) *fasciatus* Boucomont, 1914, Ann. Mus. Civ. Genova, XLVI: 231; Arrow, 1931: 310, 311; Balthasar, 1963, II: 347.

Distribution: India (Uttaranchal; Madhya Pradesh; W.Bengal; Mumbai; Karnataka; Tamil Nadu: Nilgiri Hills, Anaimalai hills, Madhura; Kerala: Wayanad).

21. *Onthophagus* (s.str.) *favrei* Boucomont, 1914

Onthophagus (s.str.) *favrei* Boucomont, 1914, Ann. Mus. Civ. Genova, XLVI: 225; Arrow, 1931: 311, 315; Balthasar, 1963, II: 347-348.

Distribution: Sri Lanka, India (Karnataka; Tamil Nadu: Nilgiri Hills, Coimbatore; Kerala: Wayanad).

22. *Onthophagus* (s.str.) *furcillifer* Bates, 1891

Onthophagus (s.str.) *furcillifer* Bates, 1891, Entomologist XIV, Suppl.: 11; Arrow, 1931: 270, 273; Balthasar, 1963, II: 360.

Distribution: India (Assam; Kashmir; Punjab; Uttaranchal; Kerala: Wayanad).

23. *Onthophagus* (s.str.) *insignicollis* Frey, 1954

Onthophagus (s.str.) *insignicollis* Frey, 1954, Arb. Mus. Frey, 5:744; Balthasar, 1963, II: 393-394.

Distribution: India (Bihar; Kerala: Wayanad, Nelliampathi, Ranipuram).

24. *Onthophagus* (s.str.) *kchatriya* Boucomont, 1914

Onthophagus (s.str.) *kchatriya* Boucomont, 1914, Ann. Mus. Civ. Genova XLVI: 233; Arrow, 1931:252,255; Balthasar, 1963, II: 401-402 (s.str).

Distribution: India (Karnataka; Tamil Nadu: Anamalai Hills, Nilgiri Hills, Yercaud; Kerala: Nilambur, Thekkady)

25. *Onthophagus lilliputanus*[@] Lansberge, 1883

Onthophagus lilliputanus Lansberge, 1883, Notes Leyd. Mus.V: 69; Boucomont, 1921, Bull. Soc. Ent. France, 46; Arrow 1931: 263, 264.

Distribution: India (Kashmir; Bengal; Punjab; Bombay; Madras; Coimbatore), Burma, Java, Borneo, Philippine.

26. *Onthophagus* (s. str.) *ludio* Boucomont, 1914

Onthophagus (s. str.) *ludio* Boucomont, 1914, XLVI: 218; Arrow, 1931: 328, 346; Balthasar, 1963, II: 422–423.

Distribution: India (Maharashtra: Belgaum, Bombay, Nagpur; Kerala: Nilgiri hills) Sri Lanka.

27. *Onthophagus* (s.str.) *pacificus* Lansberge, 1885

Onthophagus (s.str.) *pacificus* Lansberge, 1885, not. Leyden Mus. VII: 17; Boucomont, 1914: 280; Boucomont and Gillet, 1921: 34, 53; Arrow, 1931: 171, 172.

Distribution: China, Vietnam, Bangladesh, Assam, Myanmar, Malaysia, Sunda Islands, Sumatra, Java, Borneo, Thailand, Laos, India (Uttaranchal; Assam; W.Bengal; Karnataka; Tamil Nadu: Nilgiri Hills; Kerala: Wayanad).

28. *Onthophagus socialis* Arrow, 1931

Onthophagus socialis Arrow, Fauna Brit. India, Lamell. III: 321: 325.

Distribution: India (Bombay; South India: Nilgiri Hills, Coorg).

29. *Onthophagus* (s.str.) *tnai*[#] Nithya and Sabu, 2012

Onthophagus (s.str.) *tnai* Nithya and Sabu, 2012 Zootaxa 3526: 53-58.

Distribution: India (Kerala: South Western Ghats montane rain forests ecoregion: Silent Valley, Ranipuram).

30. *Onthophagus truncaticornis* Schaller, 1783

Onthophagus truncaticornis Schaller, 1783, I: 240 (*Scarabaeus*); Fabricius, 1792: 49; Arrow, 1931: 321, 322.

Distribution: India (Bombay; South India: Nilgiri Hills, Mangalore).

31. *Onthophagus* (s.str.) *turbatus* Walker, 1858

Onthophagus (s.str.) *turbatus* Walker, 1858, Ann. Mag. Nat. Hist. (3), II: 209; Boucomont, 1914a: 222; Boucomont and Gillet, 1921: 54; Arrow, 1931: 327, 329; Balthasar, 1963, II: 569.

Distribution: Sri Lanka, India (Maharashtra; Puducherry; Karnataka; Tamil Nadu: Nilgiri Hills; Kerala: Mahe, Malabar).

32. *Onthophagus* (s. str.) *unifasciatus* Schaller, 1783

Onthophagus unifasciatus Schaller, 1783, I: 240 (*Scarabaeus*); Fabricius, 1792: 49; Arrow, 1931: 327, 341. Balthasar, 1963, II-571-572.

-*prolixus* Walker, 1858: 208; Harold, 1869, IV: 1038.

Distribution: India (Bengal; Bihar; Kerala: Nilgiri Hills; Maharashtra: Bombay; Tamil Nadu: Coimbatore, Madras), Sri Lanka (Colombo, Kandy).

33. *Onthophagus* (*Colobonthophagus*) *urellus* Boucomont, 1919

Onthophagus (*Colobonthophagus*) *urellus* Boucomont, 1919, Ann. Soc. Ent. France LXXXVIII: 310; Boucomont and Gillet, 1921: 46; Arrow, 1931: 280, 297; Balthasar, 1963, II: 572-573.

Distribution: Myanmar, India (Tamil Nadu: Nilgiri Hills; Kerala: Wayanad).

ONITINI

***Onitis* Fabricius, 1798**

Onitis Fabricius, 1798, Suppl. Ent. Syst.: 2; Fabricius, 1801, Syst. Eleuth. I: 26; Castelnau, 1840: 88; Lacordaire, 1856, Gen. Coleopt. III: 103;

Lansberge, 1875: 14, 49; Bedel, 1892, Abeille XXVII: 251; Reitter, 1892 (1893): 96; Peringuey, 1900 (1901): 108, 118; Arrow, 1931: 386; Balthasar, 1935: 87; Janssens, 1937: 15; Paulian, 1945: 140; Balthasar, 1963, II: 26.

34. *Onitis falcatus* Wulfen, 1786

Onitis falcatus Wulfen, 1786, Descrip. Cap. Ins.: 14, Tf.2, Fg. 17 m# (*sub Scarabaeus*); Lansberge, 1875: 126; Boucomont and Gillet, 1921: 17, 19; Arrow, 1931: 392; Balthasar, 1935: 93; Janssens, 1937: 44; Paulian, 1945: 142; Balthasar, 1963, II: 33-34.

-*hymalajicus* Redtenbacher, 1848, apud Hügel, Kashmir, IV, 2: 518.

-*sphinx* Herbst (nec Fabricius), 1789, Käfer II: 186.

Distribution: China, Tonkin, Taiwan, Philippines, Laos, Myanmar, Thailand, India (W.Bengal; Uttaranchal; Karnataka; Kerala: Mahe, Malabar).

35. *Onitis subopacus* Arrow, 1931

Onitis subopacus Arrow, 1931, Fauna Brit. India, Copr.: 395; Balthasar, 1935: 94; Janssens, 1937: 51; Balthasar, 1963, II: 38-39.

-*philemon* Lansberge (nec Fabricius), 1875, Ann. Soc. Ent. Belg. XVIII: 133; Boucomont, 1914: 336; Boucomont and Gillet, 1921: 19.

Distribution: China, Afghanistan, Nepal, Vietnam, Sri Lanka, Myanmar, Thailand, Sunda Islands, India (Kashmir; Assam; W.Bengal; Bihar; Uttaranchal; Madhya Pradesh; Tamil Nadu: Anamalai Hills, Kerala: Wayanad).

36. *Onitis virens* Lansberge, 1975

Onitis virens Lansberge, 1975, Ann. Soc. Ent. Belg. XVIII: 135; Boucomont and Gillet, 1921: 19; Arrow, 1931: 396; Balthasar, 1935: 52; Paulian, 1945: 144; Balthasar, 1963, II: 40.

-*amplectens* Lansberge, 1.c.: 136.

Distribution: China, Myanmar, North Vietnam, Laos, Thailand, India (Bihar; W.Bengal; Uttaranchal; Maharashtra; Karnataka; Tamil Nadu: Nilgiri Hills, Anamalai Hills; Kerala: Peerumedu, Travancore, Wayanad).

ONITICELLINI

***Drepanocerus* Kirby, 1828**

Drepanocerus Kirby, 1828, Zool. Journ. III: 521; Castelnau, 1840: 92; Lacordaire, 1856, Gen. Col. II: 105, III; Péringuey, 1900 (1901): 108, 110; Boucomont and Gillet 1921: 19; Boucomont, 1921b: 200; Arrow, 1931: 380; Balthasar, 1935: 97; Paulian, 1945: 50, 137; Janssens, 1953: 9. 12; Balthasar, 1963, II: 61.

-*Ixodina* Roth, 1851, Arch. Naturg. XVII, I: 128.

-*Cyptochirus* Lesne, 1900, apud Ch. Michel, Vers Fachoda: 499.

-*Drepanochirus* Peringuey, 1900 (1901), Trans. S. Afr. Phil. Soc. XII: 17; Boucomont, 1921b: 199.

37. *Tibiodrepanus setosus* Wiedemann, 1823

Drepanocerus setosus Wiedemann, 1823, Zool. Mag. II, 1: 19 (*Copris*); Arrow, 1931: 381; Janssens, 1953: 19, 31; Balthasar, 1963, II: 68-69.

-*setosa* Motschulsky, 1863, Bull. Soc. Nat. Moscou, XXXVI, II: 459 (*Ixodina*).

Distribution: Sri Lanka, India (Uttaranchal; Madhya Pradesh; Maharashtra; Kerala: Nilambur, Wayanad).

***Oniticellus* Serville, 1825**

Oniticellus Serville, 1825, Encycl. Mèthod. X: 356; Lacordaire, 1856, Gen. Col. III: 110; Reitter, 1892 (1893): 38, 44; Péringuey, 1900 (1901): 160; Boucomont and Gillet, 1921: 21; Boucomont, 1921b: 207; Arrow, 1931: 79, 375; Portevin, 1931: 39, 41; Porta, 1932: 407, 408; Balthasar, 1935: 25, 99; Paulian, 1941: 63; Paulian, 1945: 129; Janssens, 1953: 105.

38. ***Oniticellus* (s. str.) *cinctus* Fabricius, 1775**

Oniticellus (s. str.) *cinctus* Fabricius, 1775, Syst. Ent.: 30 (*Scarabaeus*); Boucomont, 1914: 255; Boucomont and Gillet, 1921: 23; Arrow, 1931: 375, 379; Balthasar, 1935: 103; Paulian, 1945: 130; Janssens, 1953: 107, 110; Balthasar, 1963, II: 77.

-*serratipes* Drury, 1770, III. Exot. Ins. I: 79, Tf. 36, Fg. 8, 9.

Distribution: Malaysia, Java, South China, Thailand, India (Uttaranchal; Madhya Pradesh; Maharashtra; W.Bengal; Karnataka; Tamil Nadu: Nilgiri Hills; Kerala: Wayanad).

Dung Beetles collected from a coffee plantation belt in South Wayanad

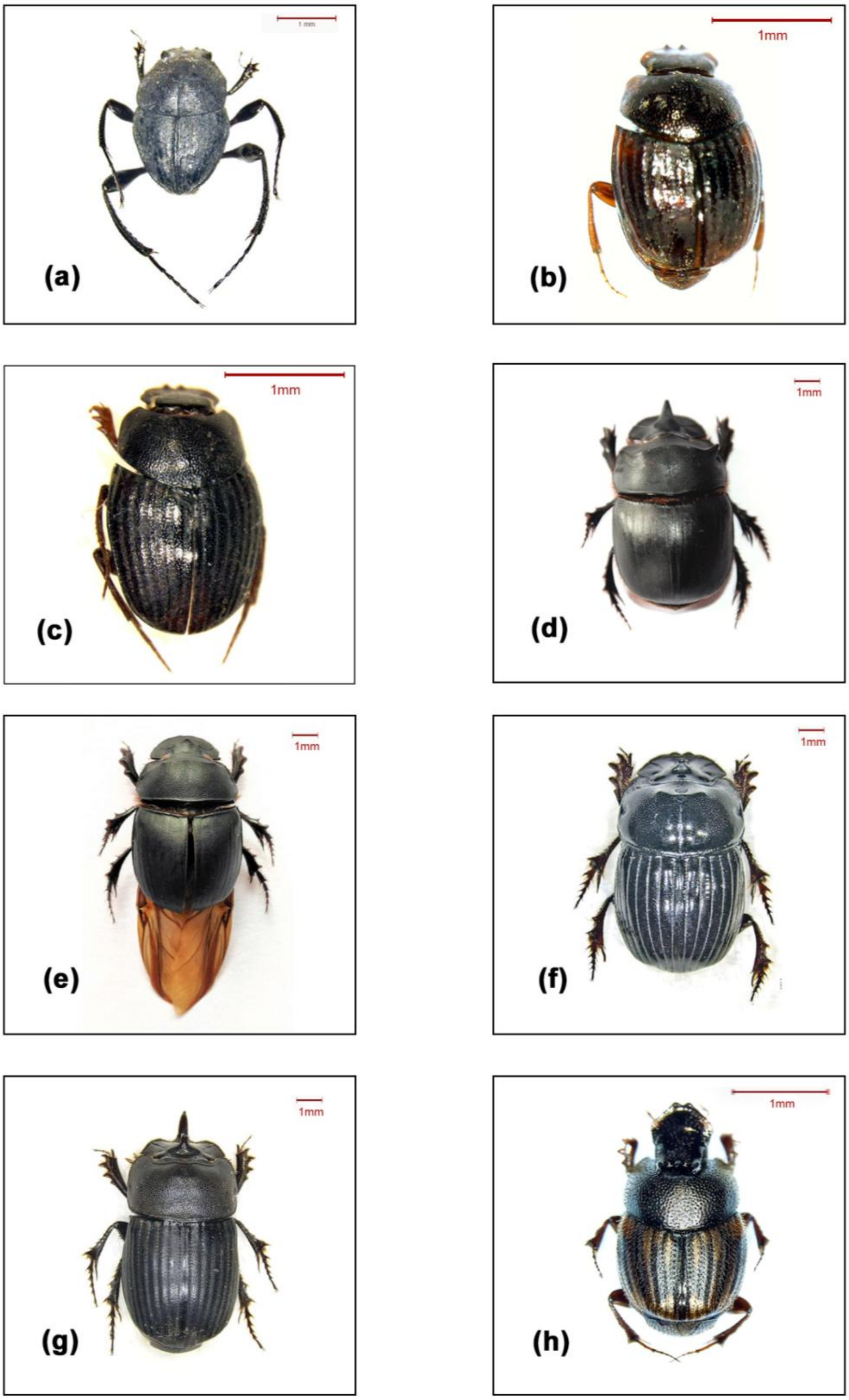


Plate 2: *a) Sisyphus longipes* *b) Ochicanthon laetus* *c) Ochicanthon tristis* *d) Catharsius molossus* *e) Catharsius sagax* *f) Copris repertus* *g) Paracopris davisoni* *h) Caccobius meridionalis*

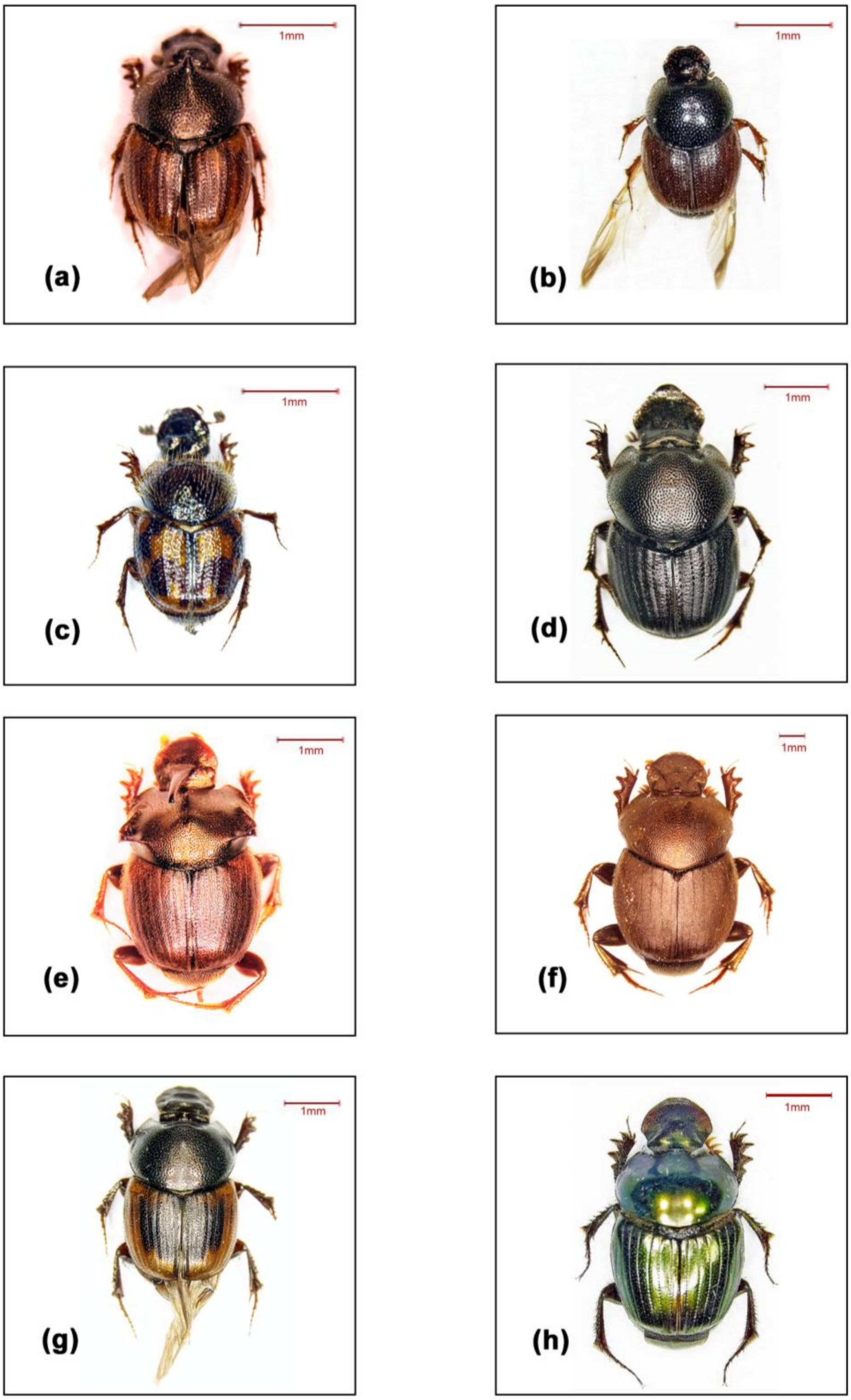


Plate 3: *a) C. ultor* *b) C. unicornis* *c) Onthophagus amphicoma*
d) O. andrewesi *e) O. bifasciatus* *f) O. bronzeus*
g) O. cervus *h) O. dama*

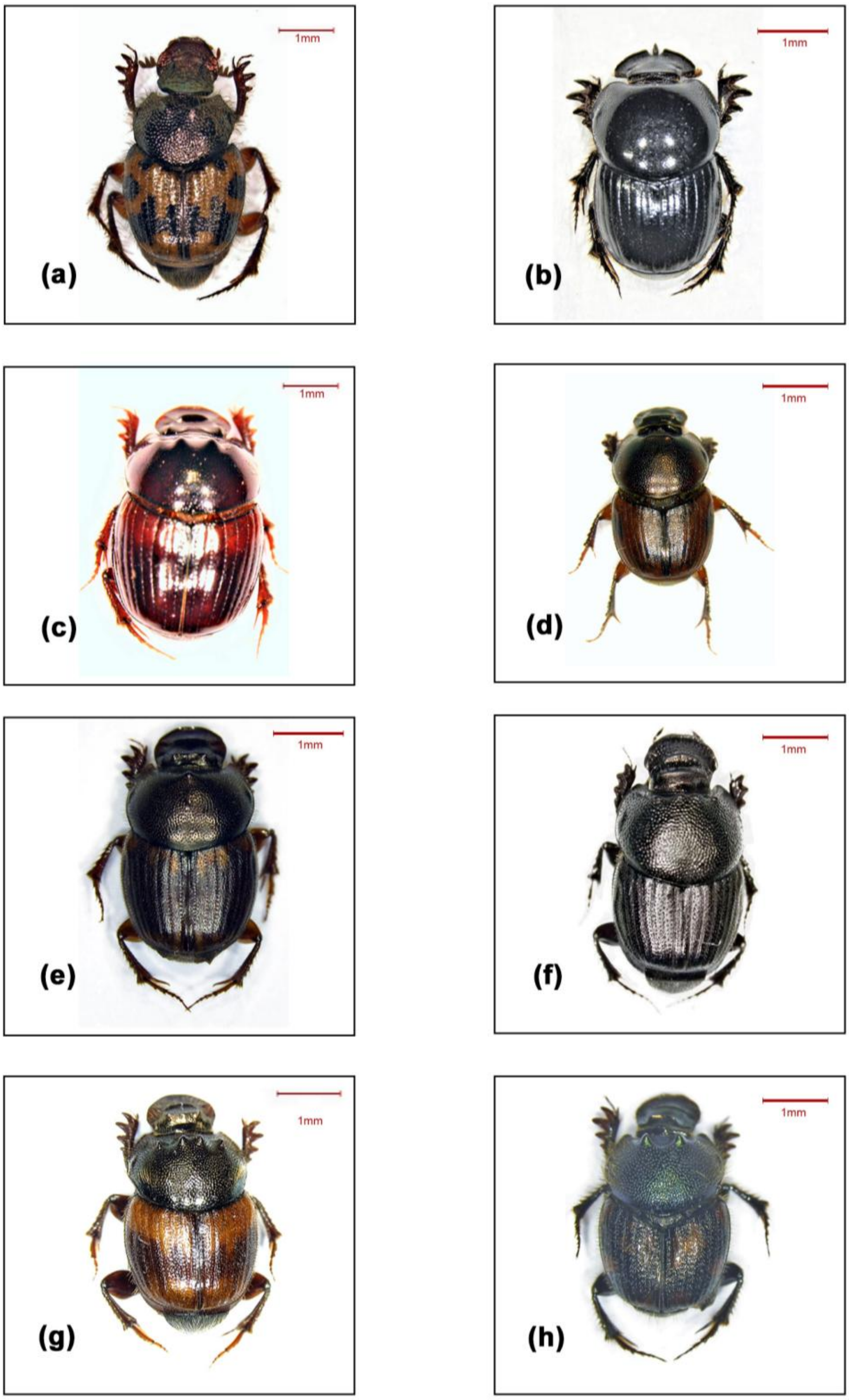


Plate 4: *a) O. devagiriensis* *b) O. discedens* *c) O. duporti*
d) O. fasciatus *e) O. faveri* *f) O. furcilifer*
g) O. insignicollis *h) O. kchatriya*

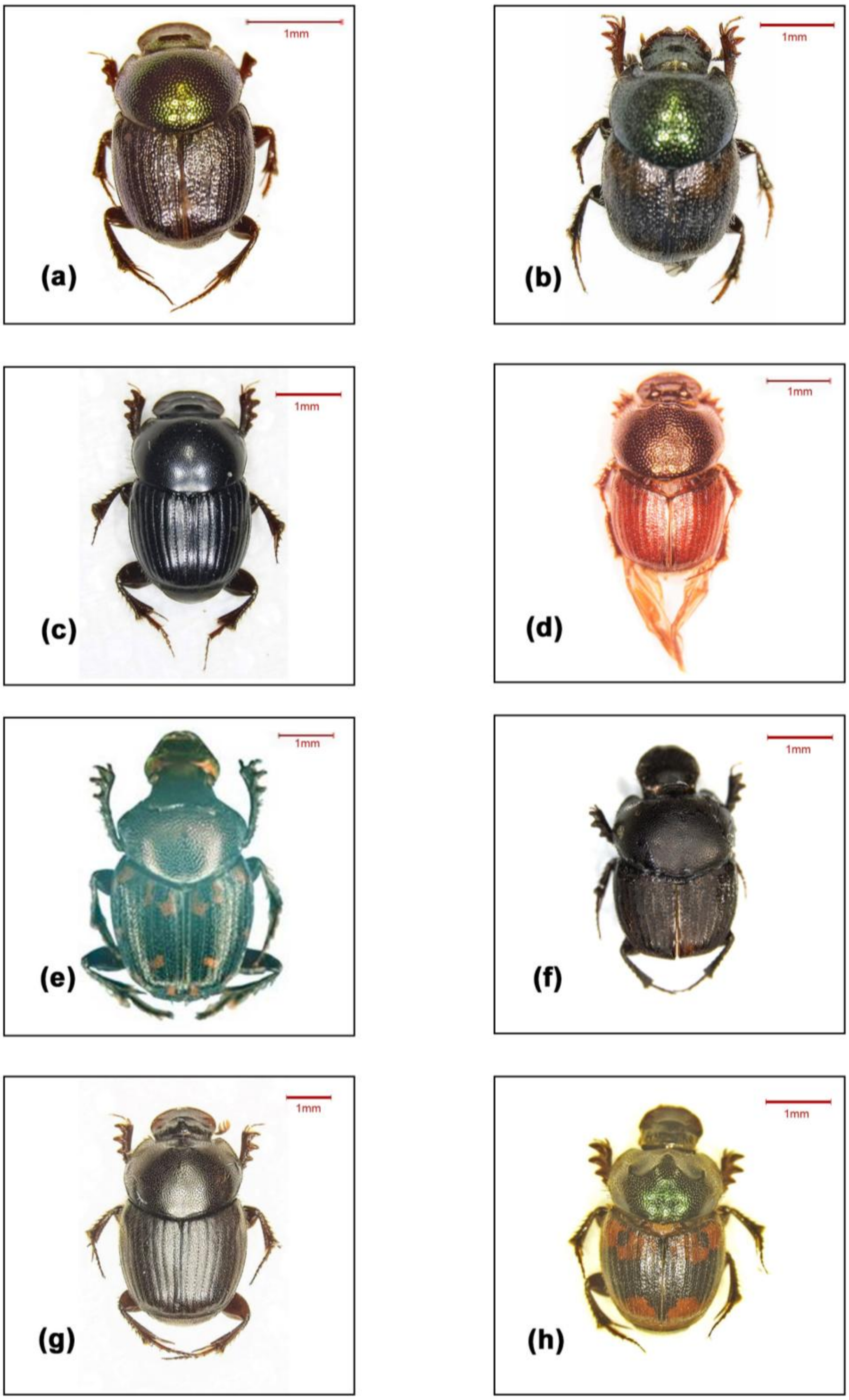


Plate 5: *a) O. lilliputanus* *b) O. ludio* *c) O. pacificus*
d) O. socialis *e) O. tnai* *f) O. truncaticornis*
g) O. turbatus *h) O. unifasciatus*

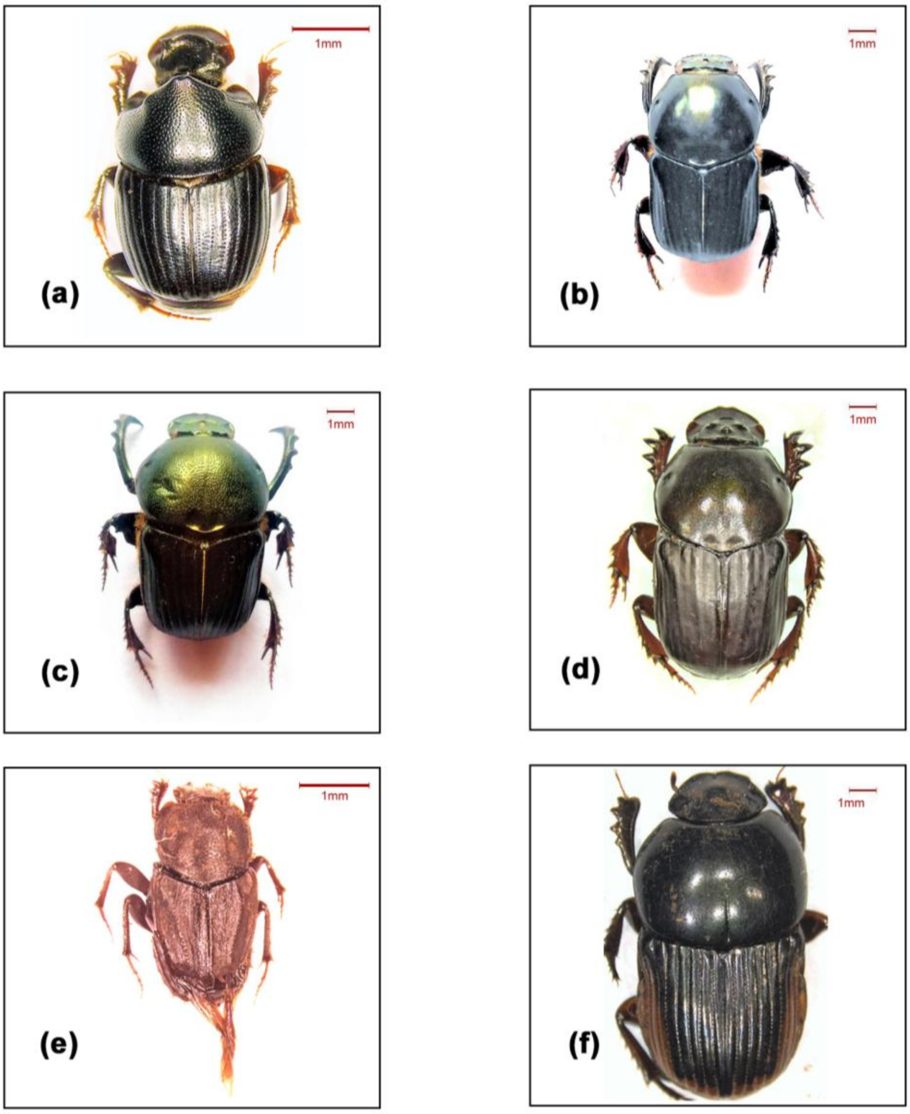
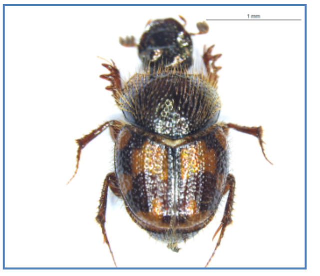


Plate 6: *a) O. urellus* *b) Onitis falcatus* *c) O. subopacus*
d) O. virens *e) Tibiodrepanus setosus* *f) Oniticellus cinctus*

KEY TO THE TRIBES AND SUBTRIBES OF SUBFAMILY SCARABAEINAE

1(4) Middle and hind tibia elongate, slender, not or very little widened towards the apex



2(3) Middle and hind legs remarkably long and slender and the hind tibia more or less strongly curved- **Sisyphini**

3(2) Middle and hind legs not remarkably long, occasionally the hind tibia short- **Canthonini**

4(1) Middle and hind tibia short, widened towards the apex and triangular

5(6) Second segment of labiail palp shorter than the first, third well developed- **Coprini**

6(5) Second segment of labial palp longer that the first , third very rudimentary or absent

7(8) Antennae 8-segmented- **Oniticellini**

i(ii) Upper surface smooth or with fine hairs- subtribe **Oniticellina**

ii(i) Upper surface with coarse erect hairs- subtribe **Drepanocerina**

8(7) Antennae 9- segmented

9(10) Pronotum with two basal impressions near the middle- **Onitini**

10(9) Pronotum without two basal impressions near the middle- **Onthophagini**

KEY TO THE GENERA

Sisyphini

Body strongly curved, posteriorly pointed, laterally compressed- ***Sisyphus* Latreille**

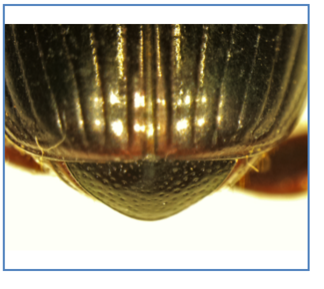
Canthonini

Elytra flat with six dorsal striae- ***Ochicanthon* Vaz-de-Mello**

Coprini

1(2) Elytra with two lateral carina- ***Catharsius* Hope**

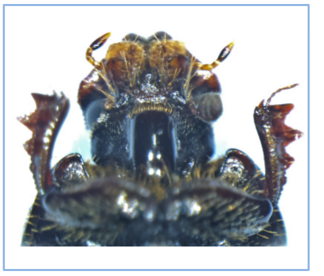
2(1) Elytra with one lateral carina



3(4) Punctures at the apex and sides of the elytra are without hairs- ***Copris* Geoffroy**

4(3) Punctures of the apex and sides of the elytra bearing short stiff hairs- ***Paracopris* Balthasar**

Onthophagini



1(2) Terminal margin of the from tibia at right angles to the inner margin and anterior angles of the prothorax hollowed beneath- ***Caccobius*** **Thomas**

2(1) These characters not both, and usually neither present- ***Onthophagus*** **Latreille**

Onitini

Scutellum very minute , front tarsi absent- ***Onitis*** **Fabricius**

Oniticellini

1(2) Sides of the abdomen exposed above- ***Oniticellus*** **Serville**

2(1) Sides of the abdomen not exposed above- ***Tibiodrepanus*** **Krikken**

KEY TO THE SPECIES

Sisyphus

Single species recorded- ***S. longipes* Olivier**

Ochicanthon

1(2) Body predominantly black with distinct orange- yellow humeral spot on each elytron- ***O. laetus* Arrow**

2(1) Body predominantly black without distinct orange- yellow humeral spot on each elytron- ***O. tristis* Arrow**

Catharsius

1(2) Head with a small smooth area adjoining each eye- *C. **molossus*** **Linnaeus**

2(1) Head without a smooth area adjoining each eye- ***C. sagax* Quenstedt**

Copris

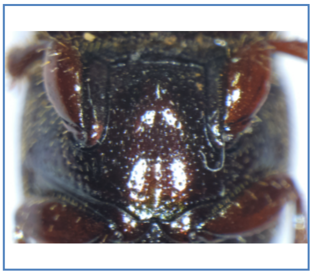
Single species recorded- *C. **repertus*** **Walker**

Paracopris

Single species recorded- ***P. davisoni*** **Waterhouse**

Caccobius

1(2) Metasternum not punctured in the middle; male with a cephalic horn- ***C. unicornis*** **Fabricius**



2(1) Metasternum well punctures; male not horned

3(4) Elytra brown , variegated- ***C. meridionalis*** **Boucomont**

4(3) Elytra entirely black- ***C. ultor*** **Sharp**

Onthophagus

1(2) Hind tibia extremely short, triangular, as broad at the end as metatarsus is long- ***O. pacificus*** **Lansberge**

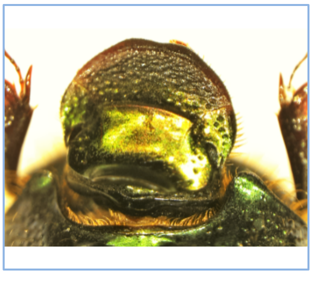
2(1) Hind tibia not extremely short, triangular, not as broad at the end as metatarsus is long

3(8) Pronotum wholly or partly granular or rugose

4(5) Pronotum entirely granular or rugose without distinct punctures- ***O. bronzeus* Arrow**

5(4) Pronotum partly granular or rugose with some punctures or smooth areas

6(7) Clypeal margin not tridendate- ***O. kchatriya* Boucomont**

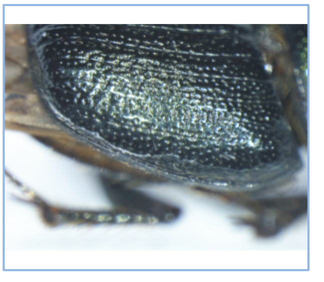


7(6) Clypeal margin tridendate- ***O. discedens* Sharp**

8(4) Pronotum punctured without granules, asperities or rugosity

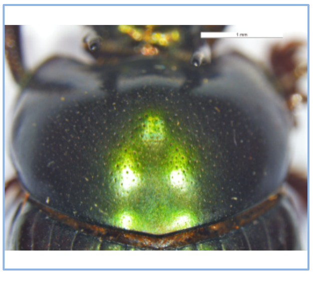
9(10) 7th Elytral stria indistinct- ***O. amphicoma* Boucomont**

10(9) 7th Elytral stria distinct- ***O. lilliputanus* Lansberge**



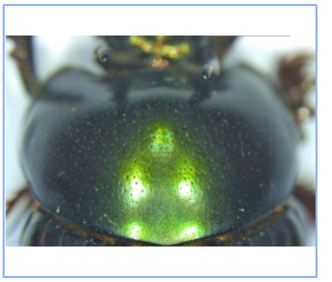
11(12) Puntures of pronotum large, close and umbilicate- ***O. furcilifer* Bates**

12(11) Puntures of pronotum not large, close and umbilicate



13(16) Upper surface without hairs, smooth or with only very minute, scanty and inconspicuous setae

14(15) Pronotum finely and rather sparsely punctured- ***O. dama* Fabricius**



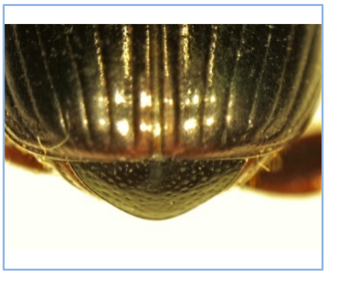
15(14) Pronotum well , not sparsely punctured- ***O. urellus* Boucomont**

16(13) Upper surface distinctly hairy or setose

17(18) Base, apex and sides of the elytra pale- ***O. fasciatus* Boucomont**

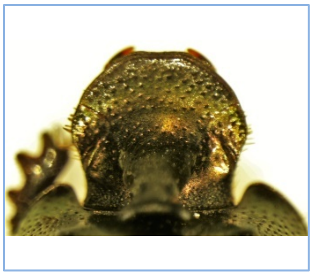
18(17) Elytra dark, except at the base and apex- ***O. faveri* Boucomont**

19(24) Pygidium without a basal ridge



20(23) Pronotum closely punctured

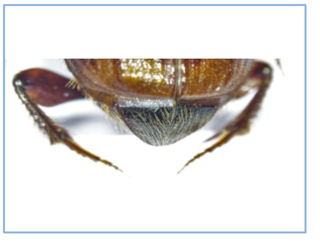
21(22) Clypeus truncate or excised in front- ***O. truncaticornis*** **Schaller**



22(21) Clypeus produced or round in front-
O. andrewesi **Arrow**

23(20) Pronotum not closely punctured- ***O. socialis*** **Arrow**

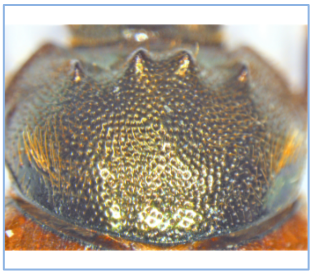
24(19) Pygidium with a basal ridge



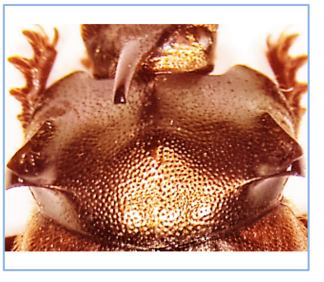
25(32) Pronotum evenly and uniformly punctured

26(27) Pronotum finely and closely punctured- ***O. turbatus*** **Walker**

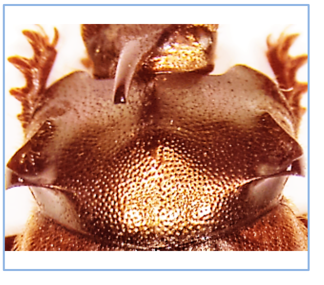
27(26) Pronotum not finely and closely punctured



28(31) Thoracic elevation not longitudinally impressed



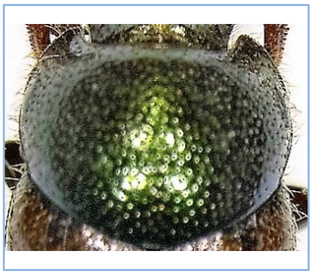
29(30) Pronotum with a median longitudinal groove- ***O. bifasciatus*** **Fabricius**



30(29) Pronotum without a median longitudinal groove- ***O. insignicollis*** **Frey**

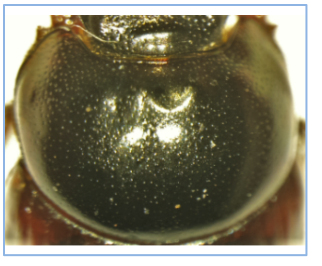
31(28) Thoracic elevation longitudinally impressed- ***O. unifasciatus*** **Schaller**

32(25) Pronotum unequally and unevenly punctured- ***O. ludio*** **Boucomont**



33(34) Pronotum with a broad anterior prominence- ***O. cervus*** **Fabricius**

34(33) Pronotum with a sharp anterior process- ***O. duporti*** **Boucomont**

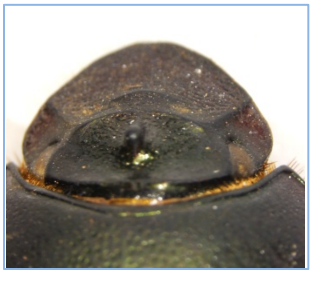


Onitis

1 Clypeo-frontal carina interrupted and with a tubercle in the middle- ***O. falcatus*** **Wulfen**

2 Clypeo-frontal carina broadly interrupted- ***O. subopacus*** **Arrow**

3 Clypeo-frontal carina narrowly interrupted- ***O. virens*** **Lansberge**



Oniticellus

Single species recorded- ***O. cinctus*** **Fabricius**

Tibiodrepanus

Single species recorded- ***T. setosus*** **Wiedemann**

4.2. GUILD STRUCTURE

Functional guild: All the three functional guilds (dwellers, rollers and tunnelers) were recorded from the coffee agroecosystem (Table 3, 7, 11). Tunnelers showed significant variation in abundance (tunnerlers> rollers> dwellers) (Table 4, 8, 12). Tunnelers were the dominant guild found in all the three dung types with 33 species (99.50 of total abundance). Roller guild represented by genus *Ochicanthon* and *Sisyphus* were present in pig and cattle dung. Genus *Sisyphus* was a strict omnivore dung roller guild. No rollers were recorded in goat dung. Dweller guild was represented by genus *Tibiodrepanus* and *Oniticellus* reported in cattle and goat dung respectively. *Onthophagus fasciatus* was the dominant tunneler guild. Abundance of tunnelers was in the order of pig> cattle> goat; rollers in the order of pig>cattle and dwellers in the order of cattle>goat.

Temporal guild: All the three temporal guilds were present in all the three dung types. Generalists were the dominant guild found in all the three dung types. Generalists showed significant variation in abundance (generalist> nocturnal> diurnal) (Table 4, 8, 12). Diurnal guild was represented by *Onthophagus fasciatus, O. andrewesi* and *O. devagiriensis,* in all the dung types; *Onitis falcatus* and *O. virens* in both cattle and goat dung; *Onthophagus furcilifer* and *O. urellus* in pig dung only. Nocturnal guild was represented by *Onthophagus turbatus* and *O. dama* in all the dung types; *Catharsius molossus* in cattle and pig dung; *Onitis subopacus* in cattle and goat dung. *Onitis subopacus* was a strict herbivore nocturnal guild. Abundance of generalists was in the order of pig> cattle>goat; diurnal guild was in the order of pig= cattle= goat and nocturnal guild in the order of cattle> pig= goat (Table 1, 5, 9). *Paracopris davisoni* was the dominant generalist guild. *Onthophagus fasciatus* was the dominant diurnal and *Onthophagus turbatus* was the dominant nocturnal guild.

Bioindicators: Based on *Indval* analysis, five species namely *Onthophagus fasciatus, O. turbatus, O. faveri, Caccobius meridionalis and Paracopris davisoni* were identified as characteristic or bioindicator species of coffee plantation with *Indval* value < 70%. Detector species with *Indval* between 50% to less than 70% were *Copris repertus*, *Onthophagus andrewesi and O.dama.* Thirteen species namely *Caccobius unicornis, Catharsius molossus, Catharsius sagax, Onitis subopacus, Onitis virens, Onthophagus amphicoma, O. bifasciatus, O. bronzeus, O. devagiriensis, O. insignicollis, O. unifasciatus, O. urellus* and *Tibiodrepanus setosus* were recorded as generalists with *Indval* value between 5 and 50% (Table 14). Among the characteristic species *Onthophagus fasciatus* and *O. turbatus* recorded highest *Indval* score above 95%. All characteristics species and one detector species, *Onthophagus dama* were under the category of major species and all the rest of the species were minor species. All characteristic and detector species were tunnelers. Dweller guild was represented by one generalist species, *Tibiodrepanus setosus.* No rollers were identified as bioindicator/detector/generalist species from the study site.

Species Composition, Abundance and Diversity: Thirty eight species belonging to 10 genera namely, *Caccobius*, *Catharsius*, *Copris, Paracopris, Tibiodrepanus, Ochicanthon, Oniticellus, Onitis, Onthophagus* and *Sisyphus* and six tribes Onthophagini, Coprini, Onitini, Oniticellini, Canthonini and Sisyphini, were captured. (Table 13). *Onthophagini* and *Coprini* were the most speciose tribes in all the three dung types.

Eight species endemic to the Western Ghats were collected namely, *Ochicanthon laetus, O. tristis, Onthophagus amphicoma, O. andrewesi, O. bronzeus, O. devagiriensis O. tnai* and *Paracopris davisoni. Onthophagus fasciatus* (23.08%) was the dominant species in the assemblage followed by *Paracopris davisoni* (17.46%), *Onthophagus turbatus* (9.17), *O. dama* (8.28), *O. faveri* (7.77%) and *Caccobius meridionalis* (7.54%). These six species together constituted 73.30% of total abundance and are major species. Thirty two species accounted for less than 1% of the total abundance of which *Caccobius ultor, Ochicanthon laetus, O. tristis, Oniticellus cinctus, Onthophagus socialis, O. tnai* and *Sisyphus longipes* were represented by one individual each (0.01% abundance) and *Onthophagus cervus, O. kchatriya, O. lilliputanus, O. ludio* and *O. truncaticornis* by two individuals (0.02% abundance). Small species (represented by 30 species; 72.97% of total abundance) dominated the assemblage compared to large species (represented by 8 species; 27.03% of total abundance). Diversity of dung beetles in the coffee plantation was H' (Shannon diversity index) = 2.547, Margalef's species richness value (d) was 13.66, Simpson's dominance index (λ) was 0.1 and evenness index (1-λ) was 0.8.

4.3. DUNG SPECIFICITY

Based on the *Indval* value, that takes into account both incidence and abundance of dung beetles in samples, two categories of dung beetles namely, specialists and generalists were recorded. Three species namely, *Onthophagus fasciatus, O. turbatus* and *O. faveri* were specialists with a score of >70 and they were strict specialists in omnivore dung type. No specialists were recorded in cattle and goat dung (herbivore). *Onthophagus turbatus* was specialist in pig dung and generalist in goat dung.

Common generalist species (*Indval* score between 5-50) shared by three dung types (pig, cattle, goat) include *Catharsius sagax, Copris repertus, Onthophagus amphicoma, O. devagiriensis.* Other generalist species include *Caccobius unicornis, Catharsius molossus, O. bifasciatus, O. bronzeus, O. cervus, O. furcilifer, O. insignicollis, O. kchatriya, O. ludio* and *O. urellus* in pig dung and *Catharsius molossus, Tibiodrepanus setosus, Onitis falcatus, O. andrewesi, O. bifasciatus, O. dama, O. faveri, O. insignicollis, O. pacificus* and *O. truncaticornis* in cattle dung and *Caccobius meridionalis, Paracopris davisoni, Onitis subopacus, Onitis virens, O. andrewesi, O. dama, O. decendens, O. faveri* and *O. turbatus* in goat dung (Table 15).

Sixteen species exhibited strong dung associations. *Caccobius ultor*, *C. unicornis*, *Ochicanthon laetus*, *Onthophagus cervus*, *O. duporti*, *O. furcilifer*, *O. kchatriya*, *O. ludio*, *O. socialis*, *O. urellus* and *Sisyphus longipes* were recorded only from pig dung. *Ochicanthon tristis*, *Onthophagus tnai*, *O. truncaticornis* and *Tibiodrepanus setosus* were recorded only from cattle dung and *Onitcellus cinctus* only from goat dung. Thirteen species were present in more than one dung type. Nine species namely, *Catharsius molossus*, *Onthophagus bifasciatus*, *O. bronzeus*, *O. dama*, *O. devagiriensis*, *O. insignicollis*, *O. lilliputanus*, *O. pacificus* and *O. unifasciatus* were shared between pig and cattle dung types. *Onitis falcatus*, *O. subopacus* and *O. virens* were shared between cattle and goat dung; only one species was shared between pig and goat. Based on the presence or absence, eleven species present in all the dung types include *Caccobius meridionalis*, *Catharsius sagax*, *Paracopris davisoni*, *Copris repertus*, *Onthophagus amphicoma*, *O. andrewesi*, *O. dama*, *O. devagiriensis*, *O. fasciatus*, *O. faveri* and *O. turbatus.*

Highest incidence of endemic species (seven species) was in the cattle dung. *Ochicanthon laetus*, *Onthophagus amphicoma*, *O. andrewesi*, *O. bronzeus*, *O. devagiriensis* and *Paracopris davisoni* were collected from pig dung. *Ochicanthon tristis*, *Onthophagus amphicoma*, *O. andrewesi*, *O. bronzeus*, *O. devagiriensis*, *O. tnai* and *Paracopris davisoni* were collected from cattle dung. *Onthophagus amphicoma*, *O. andrewesi*, *O. devagiriensis* and *Paracopris davisoni* were collected from goat dung type. Two rare species to Western Ghats namely, *Onthophagus truncaticornis* and *O. discedens* were also reported from the region. *Onthophagus discedens* were reported from the pig and goat dung. *Onthophagus truncaticornis* were reported only from the cattle dung.

The abundance of small species was more in pig (26 species, 75.27%) compared to cattle (18 species, 72.39%) and goat (10 species, 65.47%) dungs. Abundance of large species was more in goat dung (34.53%) compared to cattle (27.61%) and pig (24.73%) dung (Table 2, 6, 10). As per the Bray Curtis similarity coefficient values, highest similarity was between the dung beetle assemblages of pig and cattle dung types followed by cow and goat dung types and least similarity was between pig and goat dung types (Table: 16).

Table 1: Abundance (Mean±SD), percentage composition and temporal guild of dung beetle assemblage attracted to the pig dung in a coffee plantation belt in South Wayanad during 2014-15 period. (G-generalist; D-diurnal; N-nocturnal)

Sl No.	Species	Mean ± SD	Percentage	Temporal Guild
1	*Caccobius meridionalis*	1.53 ±2.34	6.35	G
2	*Caccobius ultor*	0.03 ±0.18	0.14	G
3	*Caccobius unicornis*	0.47 ±1.17	1.93	G
4	*Catharsius molossus*	1.23 ±1.87	5.11	N
5	*Catharsius sagax*	0.40 ±0.67	1.66	G
6	*Paracopris davisoni*	3.80 ±6.17	15.75	G
7	*Copris repertus*	0.53 ±0.82	2.21	G
8	*Ochicanthon laetus*	0.03 ±0.18	0.14	G
9	*Onthophagus amphicoma*	0.23 ±0.50	0.97	G
10	*Onthophagus andrewesi*	1.07 ±1.17	4.42	D
11	*Onthophagus bifasciatus*	0.23 ±0.50	0.97	G
12	*Onthophagus bronzeus*	0.50 ±0.97	2.07	G
13	*Onthophagus cervus*	0.07 ±0.25	0.28	G
14	*Onthophagus dama*	2.30 ±2.59	9.53	N
15	*Onthophagus devagiriensis*	0.10 ±0.40	0.41	D
16	*Onthophagus discedens*	0.03 ±0.18	0.14	G
17	*Onthophagus duporti*	0.10 ±0.55	0.41	G
18	*Onthophagus fasciatus*	4.40 ±3.60	18.23	D
19	*Onthophagus faveri*	2.37 ±2.36	9.81	G
20	*Onthophagus furcilifur*	0.17 ±0.46	0.69	D
21	*Onthophagus insignicollis*	0.83 ±1.18	3.45	G
22	*Onthophagus kchatriya*	0.07 ±0.25	0.28	G
23	*Onthophagus lilliputanus*	0.03 ±0.18	0.14	G
24	*Onthophagus ludio*	0.07 ±0.25	0.28	G
25	*Onthophagus pacificus*	0.03 ±0.18	0.14	G
26	*Onthophagus socialis*	0.03 ±0.18	0.14	G
27	*Onthophagus turbatus*	2.77 ±2.47	11.46	N
28	*Onthophagus unifasciatus*	0.43 ±0.77	1.80	G
29	*Onthophagus urellus*	0.23±0.68	0.97	D
30	*Sisyphus longipes*	0.03±0.18	0.14	G

Table 2: Abundance of small and large dung beetle species associated with pig dung in a coffee plantation belt in South Wayanad region during 2014-15 period. (S=small; L=large)

Sl No.	Species	Mean ± SD	Percentage	Size
Small species				
1	*Caccobius meridionalis*	1.53 ±2.34	6.35	S
2	*Caccobius ultor*	0.03 ±0.18	0.14	S
3	*Caccobius unicornis*	0.47 ±1.17	1.93	S
4	*Ochicanthon laetus*	0.03 ±0.18	0.14	S
5	*Onthophagus amphicoma*	0.23 ±0.50	0.97	S
6	*Onthophagus andrewesi*	1.07 ±1.17	4.42	S
7	*Onthophagus bifasciatus*	0.23 ±0.50	0.97	S
8	*Onthophagus bronzeus*	0.50 ±0.97	2.07	S
9	*Onthophagus cervus*	0.07 ±0.25	0.28	S
10	*Onthophagus dama*	2.30 ±2.59	9.53	S
11	*Onthophagus devagiriensis*	0.10 ±0.40	0.41	S
12	*Onthophagus discedens*	0.03 ±0.18	0.14	S
13	*Onthophagus duporti*	0.10 ±0.55	0.41	S
14	*Onthophagus fasciatus*	4.40 ±3.60	18.23	S
15	*Onthophagus faveri*	2.37 ±2.36	9.81	S
16	*Onthophagus furcilifur*	0.17 ±0.46	0.69	S
17	*Onthophagus insignicollis*	0.83 ±1.18	3.45	S
18	*Onthophagus kchatriya*	0.07 ±0.25	0.28	S
19	*Onthophagus lilliputanus*	0.03 ±0.18	0.14	S
20	*Onthophagus ludio*	0.07 ±0.25	0.28	S
21	*Onthophagus pacificus*	0.03 ±0.18	0.14	S
22	*Onthophagus socialis*	0.03 ±0.18	0.14	S
23	*Onthophagus turbatus*	2.77 ±2.47	11.46	S
24	*Onthophagus unifasciatus*	0.43 ±0.77	1.80	S
25	*Onthophagus urellus*	0.23±0.68	0.97	S
26	*Sisyphus longipes*	0.03±0.18	0.14	S
	Total		**75.27**	
Large species				
27	*Catharsius molossus*	1.23 ±1.87	5.11	L
28	*Catharsius sagax*	0.40 ±0.67	1.66	L
29	*Paracopris davisoni*	3.80 ±6.17	15.75	L
30	*Copris repertus*	0.53 ±0.82	2.21	L
	Total		**24.73**	

Table 3: Functional guild composition of dung beetles associated with pig dung in a coffee plantation belt in South Wayanad during 2014-15 period.

Sl No.	Species	Mean ± SD	Percentage
	Tunnelers		
1	*Caccobius meridionalis*	1.53 ±2.34	6.35
2	*Caccobius ultor*	0.03 ±0.18	0.14
3	*Caccobius unicornis*	0.47 ±1.17	1.93
4	*Catharsius molossus*	1.23 ±1.87	5.11
5	*Catharsius sagax*	0.40 ±0.67	1.66
6	*Paracopris davisoni*	3.80 ±6.17	15.75
7	*Copris repertus*	0.53 ±0.82	2.21
8	*Onthophagus amphicoma*	0.23 ±0.50	0.97
9	*Onthophagus andrewesi*	1.07 ±1.17	4.42
10	*Onthophagus bifasciatus*	0.23 ±0.50	0.97
11	*Onthophagus bronzeus*	0.50 ±0.97	2.07
12	*Onthophagus cervus*	0.07 ±0.25	0.28
13	*Onthophagus dama*	2.30 ±2.59	9.53
14	*Onthophagus devagiriensis*	0.10 ±0.40	0.41
15	*Onthophagus discedens*	0.03 ±0.18	0.14
16	*Onthophagus duporti*	0.10 ±0.55	0.41
17	*Onthophagus fasciatus*	4.40 ±3.60	18.23
18	*Onthophagus faveri*	2.37 ±2.36	9.81
19	*Onthophagus furcilifur*	0.17 ±0.46	0.69
20	*Onthophagus insignicollis*	0.83 ±1.18	3.45
21	*Onthophagus kchatriya*	0.07 ±0.25	0.28
22	*Onthophagus lilliputanus*	0.03 ±0.18	0.14
23	*Onthophagus ludio*	0.07 ±0.25	0.28
24	*Onthophagus pacificus*	0.03 ±0.18	0.14
25	*Onthophagus socialis*	0.03 ±0.18	0.14
26	*Onthophagus turbatus*	2.77 ±2.47	11.46
27	*Onthophagus unifasciatus*	0.43 ±0.77	1.80
28	*Onthophagus urellus*	0.23±0.68	0.97
	Total		**99.72**
	Rollers		
1	*Ochicanthon laetus*	0.03 ±0.18	0.14
2	*Sisyphus longipes*	0.03±0.18	0.14
	Total		**0.28**

Table 4: Statistical analysis of functional and temporal guild composition of dung beetle species associated with pig dung from a coffee plantation belt in South Wayanad during 2014-15 study period. (T= Tunneler; R= Roller; Dw= Dweller)

Parameters	**Kruskal-Wallis H test**			**Wilcoxon-Mann/Whitney Test (*P* value)**		
	H	**DF**	***P***	**T-R**	**R-Dw**	**T-Dw**
Functional guild	81.17	2	<0.05	<0.05	<0.05	<0.05
	H	**DF**	***P***	**Di-N**	**N-G**	**Di-G**
Temporal guild	8.92	2	<0.05	<0.05	<0.05	<0.05

Table 5: Abundance (Mean±SD), percentage composition and temporal guild of dung beetle assemblage attracted to the cattle dung in a coffee plantation belt during 2014-15 period. (G-generalist; D-diurnal; N-nocturnal)

Sl No.	**Species**	**Mean ± SD**	**%**	**Temporal Guild**
1	*Caccobius meridionalis*	1.20 ± 1.40	8.35	G
2	*Catharsius molossus*	0.33 ± 0.71	2.32	N
3	*Catharsius sagax*	0.40 ± 0.62	2.78	G
4	*Paracopris davisoni*	2.57 ± 3.07	17.87	G
5	*Copris repertus*	0.50 ± 0.73	3.48	G
6	*Drepanocerus setosus*	0.10 ± 0.31	0.70	G
7	*Ochicanthon tristis*	0.03 ± 0.18	0.23	G
8	*Onitis falcatus*	0.10 ± 0.31	0.70	D
9	*Onitis subopacus*	0.03 ± 0.18	0.23	N
10	*Onitis virens*	0.03 ± 0.18	0.23	D
11	*Onthophagus amphicoma*	0.17 ± 0.46	1.16	G
12	*Onthophagus andrewesi*	1.17 ± 1.70	8.12	D
13	*Onthophagus bifasciatus*	0.20 ± 0.41	1.39	G
14	*Onthophagus bronzeus*	0.03 ± 0.18	0.23	G
15	*Onthophagus dama*	1.33 ± 2.14	9.28	N
16	*Onthophagus devagiriensis*	0.10 ± 0.40	0.70	D
17	*Onthophagus fasciatus*	4.03 ± 3.97	28.07	D
18	*Onthophagus faveri*	0.57 ± 0.97	3.94	G
19	*Onthophagus insignicollis*	0.07 ± 0.25	0.46	G
20	*Onthophagus lilliputanus*	0.03 ± 0.18	0.23	G
21	*Onthophagus pacificus*	0.10 ± 0.31	0.70	G
22	*Onthophagus tnai*	0.03 ± 0.18	0.23	G
23	*Onthophagus truncaticornis*	0.07± 0.25	0.46	G
24	*Onthophagus turbatus*	1.13 ± 1.07	7.89	N
25	*Onthophagus unifasciatus*	0.03 ± 0.18	0.23	G

Table 6: Abundance of small and large dung beetle species associated with cattle dung in a coffee plantation belt in South Wayanad region during 2014-15 period. (S=small; L=large)

Sl No.	Species	Mean ± SD	Percentage	Size
	Small species			
1	*Caccobius meridionalis*	1.20 ± 1.40	8.35	S
2	*Tibiodrepanus setosus*	0.10 ± 0.31	0.70	S
3	*Ochicanthon tristis*	0.03 ± 0.18	0.23	S
4	*Onthophagus amphicoma*	0.17 ± 0.46	1.16	S
5	*Onthophagus andrewesi*	1.17 ± 1.70	8.12	S
6	*Onthophagus bifasciatus*	0.20 ± 0.41	1.39	S
7	*Onthophagus bronzeus*	0.03 ± 0.18	0.23	S
8	*Onthophagus dama*	1.33 ± 2.14	9.28	S
9	*Onthophagus devagiriensis*	0.10 ± 0.40	0.70	S
10	*Onthophagus fasciatus*	4.03 ± 3.97	28.07	S
11	*Onthophagus faveri*	0.57 ± 0.97	3.94	S
12	*Onthophagus insignicollis*	0.07 ± 0.25	0.46	S
13	*Onthophagus lilliputanus*	0.03 ± 0.18	0.23	S
14	*Onthophagus pacificus*	0.10 ± 0.31	0.70	S
15	*Onthophagus tnai*	0.03 ± 0.18	0.23	S
16	*Onthophagus truncaticornis*	0.07± 0.25	0.46	S
17	*Onthophagus turbatus*	1.13 ± 1.07	7.89	S
18	*Onthophagus unifasciatus*	0.03 ± 0.18	0.23	S
	Total		**72.39**	
	Large species			
19	*Catharsius molossus*	0.33 ± 0.71	2.32	L
20	*Catharsius sagax*	0.40 ± 0.62	2.78	L
21	*Paracopris davisoni*	2.57 ± 3.07	17.87	L
22	*Copris repertus*	0.50 ± 0.73	3.48	L
23	*Onitis falcatus*	0.10 ± 0.31	0.70	L
24	*Onitis subopacus*	0.03 ± 0.18	0.23	L
25	*Onitis virens*	0.03 ± 0.18	0.23	L
	Total		**27.61**	

Table 7: Functional guild composition of dung beetles associated with pig dung in a coffee plantation belt in South Wayanad during 2014-15 period.

Sl No.	Species	Mean ± SD	Percentage
	Tunnelers		
1	*Caccobius meridionalis*	1.20 ± 1.40	8.35
2	*Catharsius molossus*	0.33 ± 0.71	2.32
3	*Catharsius sagax*	0.40 ± 0.62	2.78
4	*Paracopris davisoni*	2.57 ± 3.07	17.87
5	*Copris repertus*	0.50 ± 0.73	3.48
6	*Onitis falcatus*	0.10 ± 0.31	0.70
7	*Onitis subopacus*	0.03 ± 0.18	0.23
8	*Onitis virens*	0.03 ± 0.18	0.23
9	*Onthophagus amphicoma*	0.17 ± 0.46	1.16
10	*Onthophagus andrewesi*	1.17 ± 1.70	8.12
11	*Onthophagus bifasciatus*	0.20 ± 0.41	1.39
12	*Onthophagus bronzeus*	0.03 ± 0.18	0.23
13	*Onthophagus dama*	1.33 ± 2.14	9.28
14	*Onthophagus devagiriensis*	0.10 ± 0.40	0.70
15	*Onthophagus fasciatus*	4.03 ± 3.97	28.07
16	*Onthophagus faveri*	0.57 ± 0.97	3.94
17	*Onthophagus insignicollis*	0.07 ± 0.25	0.46
18	*Onthophagus lilliputanus*	0.03 ± 0.18	0.23
19	*Onthophagus pacificus*	0.10 ± 0.31	0.70
20	*Onthophagus tnai*	0.03 ± 0.18	0.23
21	*Onthophagus truncaticornis*	0.07± 0.25	0.46
22	*Onthophagus turbatus*	1.13 ± 1.07	7.89
23	*Onthophagus unifasciatus*	0.03 ± 0.18	0.23
	Total		**99.07**
	Dwellers		
1	*Tibiodrepanus setosus*	0.10 ± 0.31	0.70
	Rollers		
1	*Ochicanthon tristis*	0.03 ± 0.18	0.23

Table 8: Statistical analysis of functional and temporal guild composition of dung beetle species associated with cattle dung from a coffee plantation belt of South Wayanad during 2014-15 study period. (T= Tunneler; R= Roller; Dw= Dweller)

Parameters	**Kruskal-Wallis H test**			**Wilcoxon-Mann/Whitney Test (*P* value)**		
	H	**DF**	***P***	**T-R**	**R-Dw**	**T-Dw**
Functional guild	78.32	2	<0.05	<0.05	<0.05	<0.05
	H	**DF**	***P***	**Di-N**	**N-G**	**Di-G**
Temporal guild	7.88	2	<0.05	<0.05	<0.05	<0.05

Table 9: Abundance (Mean±SD), percentage composition and temporal guild of dung beetle assemblage attracted to the goat dung in a coffee plantation belt during 2014-15 period. (G-generalist; D-diurnal; N-nocturnal)

Sl No.	**Species**	**Mean ± SD**	**Percentage**	**Temporal guild**
1	*Caccobius meridionalis*	0.67 ±0.96	10.15	G
2	*Catharsius sagax*	0.17± 0.38	2.54	G
3	*Paracopris davisoni*	1.50±2.03	22.84	G
4	*Copris repertus*	0.07±0.25	1.02	G
5	*Oniticellus cinctus*	0.03± 0.18	0.51	G
6	*Onitis falcatus*	0.03± 0.18	0.51	D
7	*Onitis subopacus*	0.27± 0.69	4.06	N
8	*Onitis virens*	0.20±0.61	3.05	D
9	*Onthophagus amphicoma*	0.13±0.35	2.03	G
10	*Onthophagus andrewesi*	0.43±0.86	6.60	D
11	*Onthophagus dama*	0.10± 0.40	1.52	N
12	*Onthophagus devagiriensis*	0.13±0.43	2.03	D
13	*Onthophagus discedens*	0.07±0.25	1.02	G
14	*Onthophagus fasciatus*	1.97±2.59	29.95	D
15	*Onthophagus faveri*	0.57±0.86	8.63	G
16	*Onthophagus turbatus*	0.23±0.50	3.55	N

Table 10: Abundance of small and large dung beetle species associated with goat dung in a coffee plantation belt in South Wayanad region during 2014-15 period. (S-small; L-large)

Sl No.	**Species**	**Mean ± SD**	**Percentage**	**Size**
	Small species			
1	*Caccobius meridionalis*	0.67 ±0.96	10.15	S
2	*Onthophagus amphicoma*	0.13±0.35	2.03	S
3	*Onthophagus andrewesi*	0.43±0.86	6.60	S
4	*Onthophagus dama*	0.10± 0.40	1.52	S
5	*Onthophagus devagiriensis*	0.13±0.43	2.03	S
6	*Onthophagus discedens*	0.07±0.25	1.02	S
7	*Onthophagus fasciatus*	1.97±2.59	29.95	S
8	*Onthophagus faveri*	0.57±0.86	8.63	S
9	*Onthophagus turbatus*	0.23±0.50	3.55	S
	Total		**65.47**	
	Large species			
2	*Catharsius sagax*	0.17± 0.38	2.54	L
3	*Paracopris davisoni*	1.50±2.03	22.84	L
4	*Copris repertus*	0.07±0.25	1.02	L
5	*Oniticellus cinctus*	0.03± 0.18	0.51	L
6	*Onitis falcatus*	0.03± 0.18	0.51	L
7	*Onitis subopacus*	0.27± 0.69	4.06	L
8	*Onitis virens*	0.20±0.61	3.05	L
	Total		**34.53**	

Table 11: Functional guild composition of dung beetles associated with goat dung in a coffee plantation belt in South Wayanad during 2014-15 period.

Sl No.	Species	Mean ± SD	Percentage
	Tunnerlers		
1	*Caccobius meridionalis*	0.67 ±0.96	10.15
2	*Catharsius sagax*	0.17± 0.38	2.54
3	*Paracopris davisoni*	1.50±2.03	22.84
4	*Copris repertus*	0.07±0.25	1.02
5	*Onitis falcatus*	0.03± 0.18	0.51
6	*Onitis subopacus*	0.27± 0.69	4.06
7	*Onitis virens*	0.20±0.61	3.05
8	*Onthophagus amphicoma*	0.13±0.35	2.03
9	*Onthophagus andrewesi*	0.43±0.86	6.60
10	*Onthophagus dama*	0.10± 0.40	1.52
11	*Onthophagus devagiriensis*	0.13±0.43	2.03
12	*Onthophagus discedens*	0.07±0.25	1.02
13	*Onthophagus fasciatus*	1.97±2.59	29.95
14	*Onthophagus faveri*	0.57±0.86	8.63
15	*Onthophagus turbatus*	0.23±0.50	3.55
	Total		**99.49**
	Dwellers		
1	*Oniticellus cinctus*	0.03± 0.18	0.51

Table 12: Statistical analysis of functional and temporal guild composition of dung beetle species associated with goat dung from coffee plantation belt of south Wayanad during 2014-15 study period. (T= Tunneler; R= Roller; Dw= Dweller)

Parameters	**Kruskal-Wallis H test**			**Wilcoxon-Mann/Whitney Test (*P* value)**		
	H	**DF**	***P***	**T-R**	**R-Dw**	**T-Dw**
Functional guild	82.71	2	<0.05	<0.05	<0.05	<0.05
	H	**DF**	***P***	**Di-N**	**N-G**	**Di-G**
Temporal guild	34.76	2	<0.05	<0.05	<0.05	<0.05

Table 13: Overall abundance (Mean±SD), percentage composition, temporal and functional guild of dung beetle assemblage in a coffee plantation belt in South Wayanad during 2014-15 period. (M- Major; m-Minor; r-Rare; Dw- Dweller; R-Roller; T-Tunneler *-Endemic; $-Rare to Western Ghats)

Sl.No	**Species**	**Mean±SD**	**%**	**Temporal Guild**	**Functional guild**
1	*Onthophagus fasciatus*[M] (Boucomont, 1914)	3.47±3.56	23.07	D	T
2	*Paracopris davisoni**[M] (Waterhouse, 1891)	2.62±4.21	17.45	G	T
3	*Onthophagus turbatus*[M] (Walker, 1858)	1.38±1.89	9.17	N	T
4	*Onthophagus dama*[M] (Fabricius, 1798)	1.24±2.13	8.28	N	T
5	*Onthophagus faveri*[M] (Boucomont, 1914)	1.17±1.76	7.76	G	T
6	*Caccobius meridionalis*[M] (Boucomont, 1914)	1.13±1.69	7.54	G	T
7	*Onthophagus andrewesi*[*m] (Arrow, 1931)	0.89±1.32	5.91	D	T
8	*Catharsius molossus*[m] (Linnaeus, 1758)	0.52±1.26	3.47	N	T
9	*Copris repertus*[m] (Walker, 1858)	0.37±0.68	2.44	G	T
10	*Catharsius sagax*[m] (Quenstedt, 1806)	0.32±0.58	2.14	G	T
11	*Onthophagus insignicollis*[m] (Frey, 1954)	0.30±0.79	1.99	G	T
12	*Onthophagus amphicoma*[*m] (Boucomont,1914)	0.18±0.44	1.18	G	T
13	*Onthophagus bronzeus*[*m] (Arrow,1907)	0.18±0.61	1.18	G	T
14	*Caccobius unicornis*[m] (Fabricius, 1798)	0.16±0.70	1.03	G	T
15	*Onthophagus unifasciatus*[m] (Schaller,1783)	0.16±0.50	1.03	G	T

16	*Onthophagus bifasciatus*[m] (Fabricius, 1781)	0.14±0.38	0.96	G	T
17	*Onthophagus devagiriensis*[*m] (Schoolmeesters & Thomas, 2006)	0.11±0.41	0.73	D	T
18	*Onitis subopacus*[m] (Arrow, 1931)	0.10±0.43	0.66	N	T
19	*Onitis virens*[m] (Lansberge, 1975)	0.08±0.37	0.51	D	T
20	*Onthophagus urellus*[m] (Boucomont, 1919)	0.08±0.40	0.51	D	T
21	*Onthophagus furcilifer*[m] (Bates, 1891)	0.06±0.27	0.36	D	T
22	*Onthophagus pacificus*[m] (Lansberge, 1885)	0.04±0.21	0.29	G	T
23	*Onitis falcatus*[m] (Wulfen, 1786)	0.04±0.21	0.29	D	T
24	*Tibiodrepanus setosus*[m] (Wiedemann, 1823)	0.03±0.18	0.22	G	Dw
25	*Onthophagus discedens*[$m] Boucomont, 1914)	0.03±0.18	0.22	G	T
26	*Onthophagus duporti*[m] (Boucomont 1914)	0.03±0.32	0.22	G	T
27	*Onthophagus cervus*[r] (fabricius, 1798)	0.02±0.15	0.14	G	T
28	*Onthophagus kchatriya*[r] (Boucomont, 1914)	0.02±0.15	0.14	G	T
29	*Onthophagus lilliputanus*[r] (Lansberge, 1883)	0.02±0.15	0.14	G	T
30	*Onthophagus ludio*[r] (Boucomont, 1914)	0.02±0.15	0.14	G	T
31	*Onthophagus truncaticornis*[$r] (Schaller, 1783)	0.02±0.15	0.14	G	T
32	*Caccobius ultor*[r] (Sharp, 1875)	0.01±0.11	0.07	G	T
33	*Ochicanthon laetus*[*r] (Arrow, 1931)	0.01±0.11	0.07	G	R
34	*Ochicanthon tristis*[*r] (Arrow, 1931)	0.01±0.11	0.07	G	R
35	*Oniticellus cinctus*[r] (Fabricius, 1775)	0.01±0.11	0.07	G	Dw
36	*Onthophagus socialis*[r] (Arrow, 1931)	0.01±0.11	0.07	G	T
37	*Onthophagus tnai*[*r] (Nithya & sabu, 2012)	0.01±0.11	0.07	G	T
38	*Sisyphus longipes*[r] (Olivier, 1789)	0.01±0.11	0.07	G	R

Table 14**:** *Indval* scores of dung beetle assemblage in a shaded coffee plantation in South Wayanad during 2014-15 period. (B=Bioindicator; D= detector; G= generalist; T=tunneler; Dw=dweller)

Sl.no	**Species**	***Indval* value (%)**	**Species Category**	**Functional Guild**
1.	*Caccobius meridionalis*	83.33	B	T
2.	*Paracopris davisoni*	80	B	T
3.	*Onthophagus fasciatus*	96.67	B	T
4.	*Onthophagus faveri*	86.67	B	T
5.	*Onthophagus turbatus*	96.67	B	T
6.	*Copris repertus*	60	D	T
7.	*Onthophagus andrewesi*	70	D	T
8.	*Onthophagus dama*	66.67	D	T
9.	*Caccobius unicornis*	23.33	G	T
10.	*Catharsius molossus*	46.67	G	T
11.	*Catharsius sagax*	46.67	G	T
12.	*Onitis subopacus*	16.67	G	T
13.	*Onitis virens*	13.33	G	T
14.	*Onthophagus amphicoma*	40.00	G	T
15.	*Onthophagus bifasciatus*	30.00	G	T
16.	*Onthophagus bronzeus*	30.00	G	T
17.	*Onthophagus devagiriensis*	23.33	G	T
18.	*Onthophagus insignicollis*	46.67	G	T
19.	*Onthophagus unifasciatus*	33.33	G	T
20.	*Onthophagus urellus*	13.33	G	T
21.	*Tibiodrepanus setosus*	10	G	Dw

Table 15: Indicator value (%) of dung species attracted to pig, cattle and goat dung in a coffee plantation belt in the South Wayanad region during 2014-2015 period.

Sl.No	**Species**	**Pig *Indval* value (%)**	**Cattle *Indval* value (%)**	**Goat *Indval* value (%)**
1	*Caccobius meridionalis*	53.33	56.67	43.33
2	*Caccobius ultor*	3.33	0	0
3	*Caccobius unicornis*	23.33	0	0
4	*Catharsius molossus*	46.67	23.33	0
5	*Catharsius sagax*	30	33.33	16.67
6	*Paracopris davisoni*	63.33	63.33	46.67
7	*Copris repertus*	36.67	40	6.67
8	*Tibiodrepanus setosus*	0	10	0
9	*Ochicanthon laetus*	3.33	0	0
10	*Ochicanthon tristis*	0	3.33	0
11	*Oniticellus cinctus*	0	0	3.33
12	*Onitis falcatus*	0	10	3.33
13	*Onitis subopacus*	0	3.33	13.33
14	*Onitis virens*	0	3.33	13.33
15	*Onthophagus amphicoma*	20	13.33	13.33
16	*Onthophagus andrewesi*	56.67	43.33	30
17	*Onthophagus bifasciatus*	20	20	0
18	*Onthophagus bronzeus*	26.67	3.33	0
19	*Onthophagus cervus*	6.67	0	0
20	*Onthophagus dama*	63.33	46.67	6.67
21	*Onthophagus devagiriensis*	6.67	6.67	10
22	*Onthophagus discedens*	3.33	0	6.67
23	*Onthophagus duporti*	3.33	0	0
24	*Onthophagus fasciatus*	83.33	70	60
25	*Onthophagus faveri*	80	33.33	40
26	*Onthophagus furcilifur*	13.33	0	0
27	*Onthophagus insignicollis*	46.67	6.67	0
28	*Onthophagus kchatriya*	6.67	0	0
29	*Onthophagus lilliputanus*	3.33	3.33	0
30	*Onthophagus ludio*	6.67	0	0
31	*Onthophagus pacificus*	3.33	10	0
32	*Onthophagus socialis*	3.33	0	0
33	*Onthophagus tnai*	0	3.33	0
34	*Onthophagus truncaticornis*	0	6.67	0
35	*Onthophagus turbatus*	83.33	70	20
36	*Onthophagus unifasciatus*	30	3.33	0
37	*Onthophagus urellus*	13.33	0	0
38	*Sisyphus longipes*	3.33	0	0

Table 16: Bray Curtis similarity coefficient values of dung beetle assemblage associated with pig, cattle and goat dung types in a coffee plantation belt in South Wayanad during 2014-15 period.

	PIG	**CATTLE**	**GOAT**
PIG			
CATTLE	71.88		
GOAT	48.53	64.97	

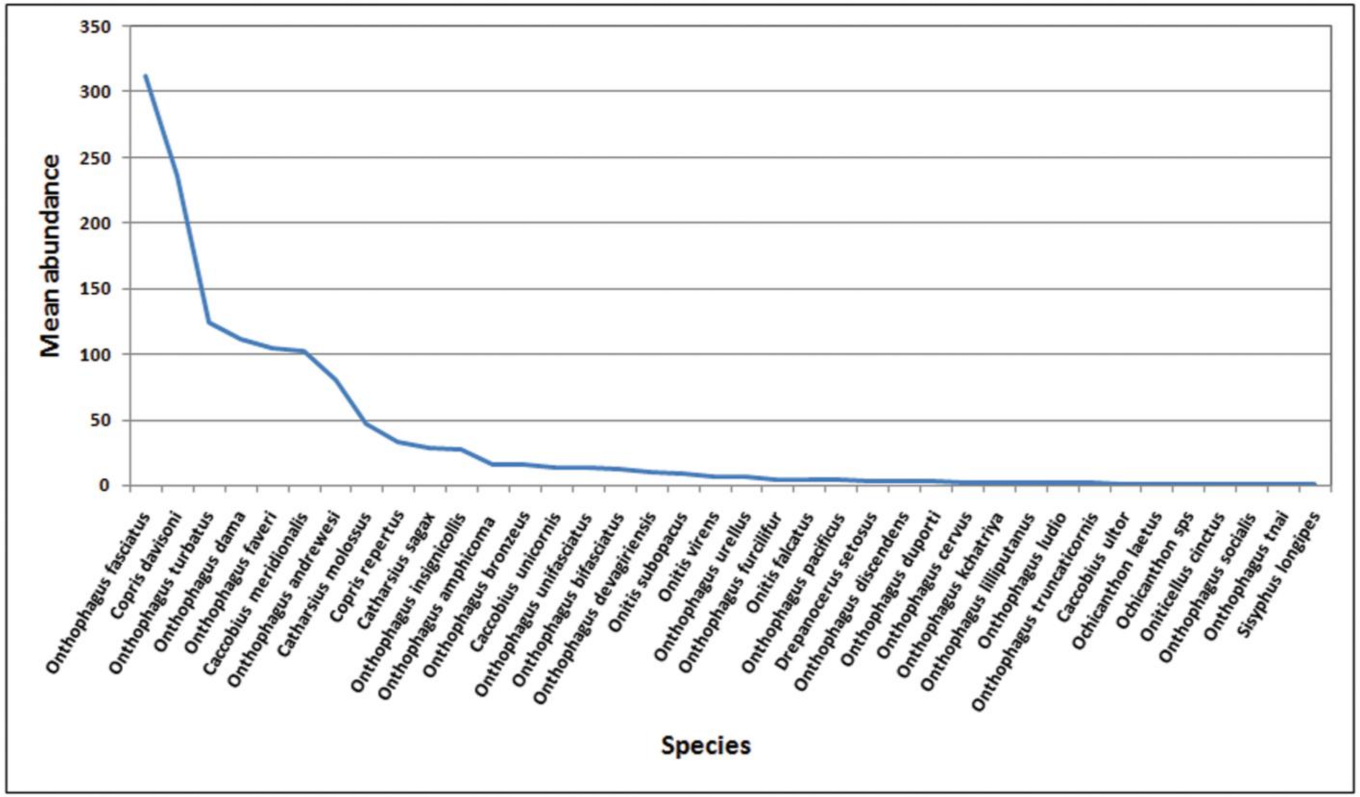


Figure 1: Overall rank abundance plot of dung beetles in a coffee plantation of South Wayanad during 2014-2015 period.

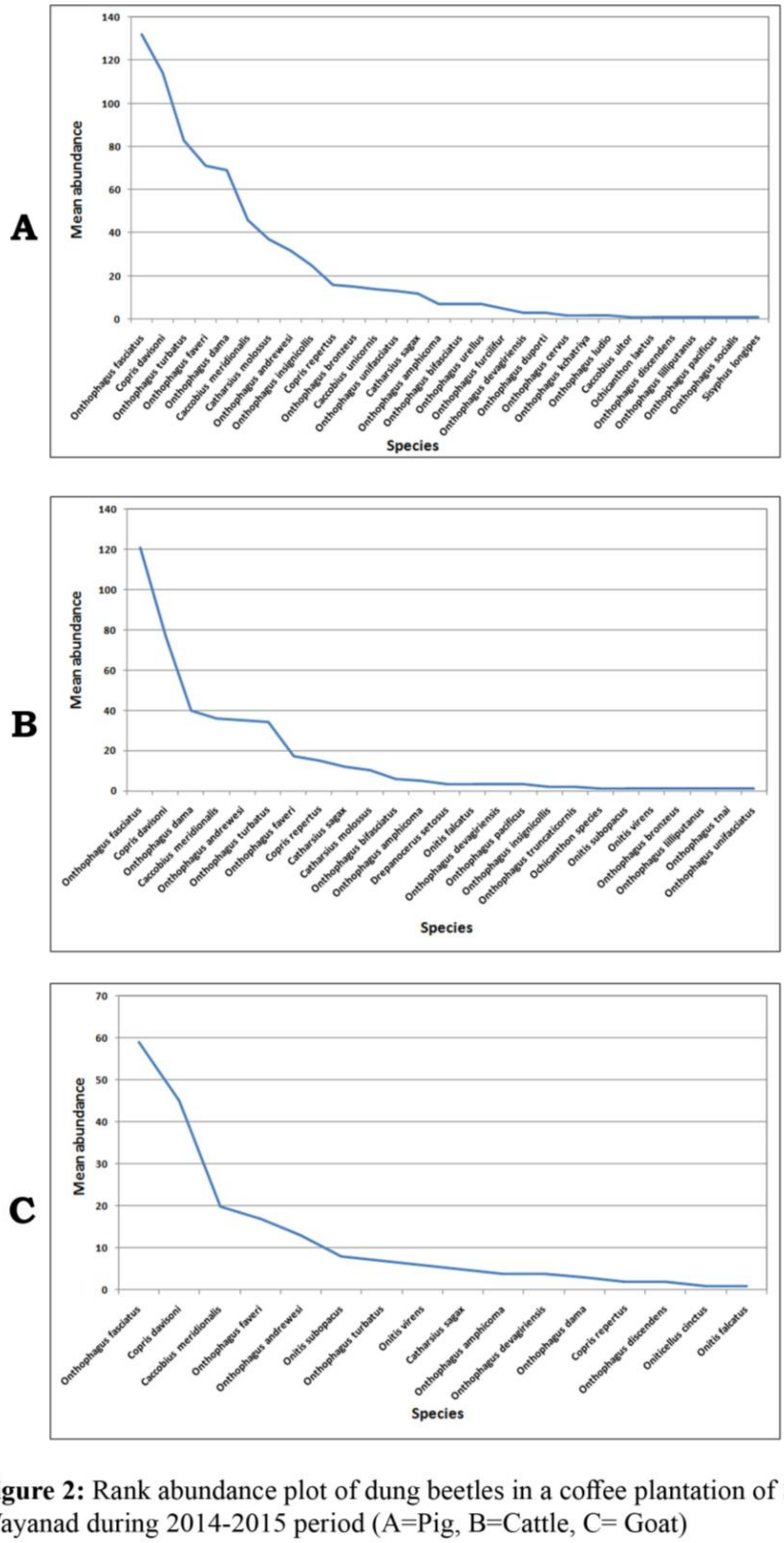


Figure 2: Rank abundance plot of dung beetles in a coffee plantation of South Wayanad during 2014-2015 period (A=Pig, B=Cattle, C= Goat)

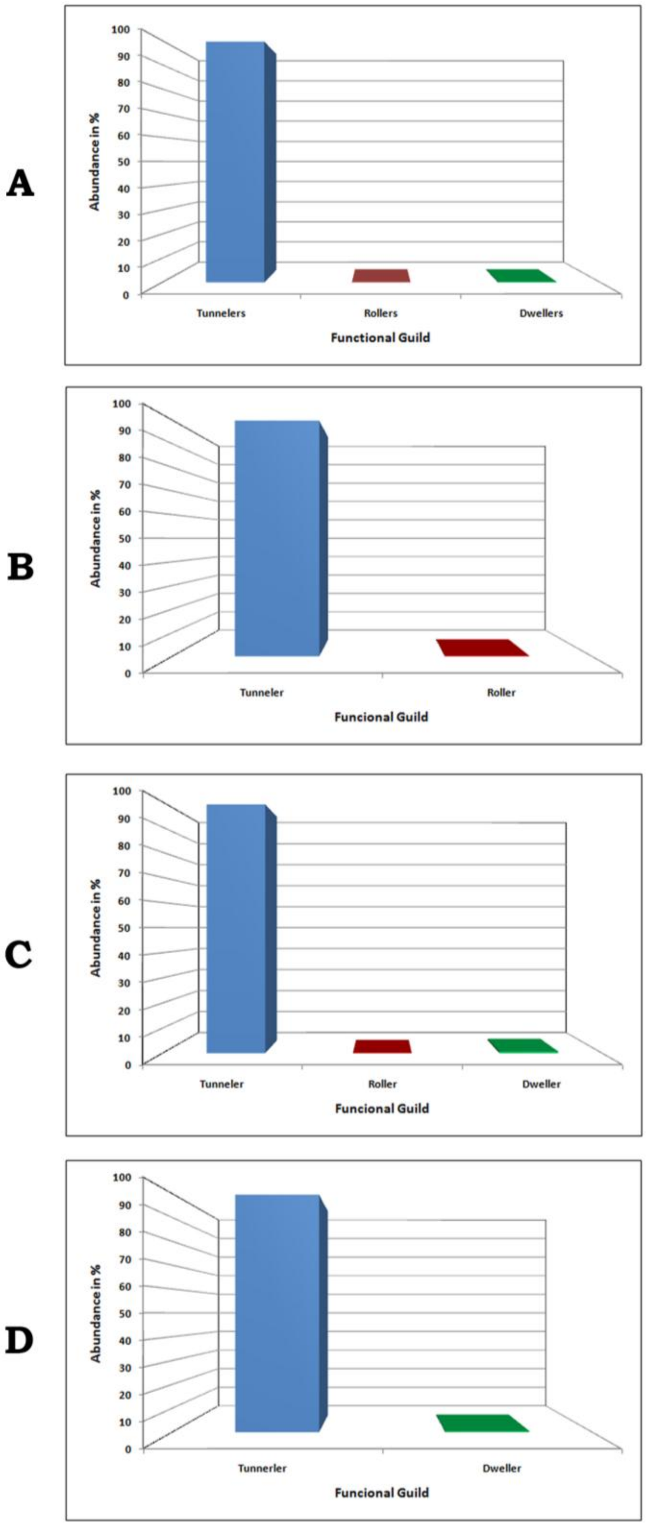


Figure 3: Functional guild composition and abundance of dung beetles in a coffee plantation of South Wayanad during 2014-2015 period (A=Overall, B=Pig, C=Cattle, D=Goat).

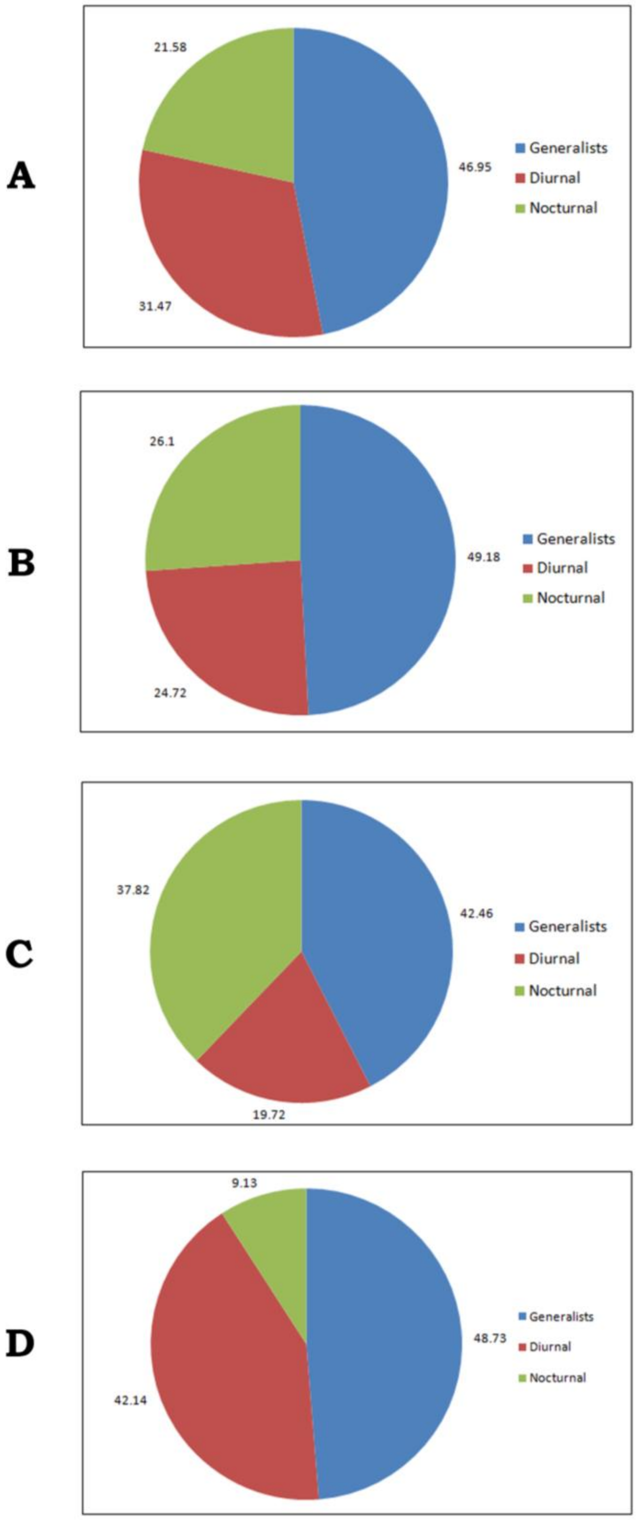


Figure 4: Temporal guild composition and abundance of dung beetles in a coffee plantation of South Wayanad during 2014-2015 period (A=Overall, B=Pig, C=Cattle, D=Goat)

Chapter 5

DISCUSSION

5.1. TAXONOMY

First report of *Onthophagus lilliputanus* from the moist South Western Ghats indicates that further studies from these plantation regions of South Wayanad may disclose new additions to the species list of the Nilgiri Biosphere Reserve of South Western Ghats. Record of eight species endemic to the Western Ghats region namely, *Ochicanthon laetus, Ochicanthon tristis, Onthophagus andrewesi, O. amphicoma, O. bronzeus, O. devagiriensis, O. tnai* and *Paracopris davisoni* and two rare species to Western Ghats namely, *Onthophagus truncaticornis* and *O. discedens* highlights the importance of shaded coffee plantation as a region of conservation priority and requirement of long term studies.

Checklist prepared provides baseline information on the composition of dung beetle fauna of the coffee plantation belt of NBR of South Western Ghats. Similar collection efforts done in Wayanad (Vinod 2009), Nelliampathi (Latha 2011), Thekkady (Nithya 2012), North Malabar (Simi 2014), Chinnar (Shobana 2014) will provide comprehensive list of dung beetles of the Western Ghats region of Kerala, as no such studies have been done in the region since the work of Arrow (1931).

5.2. GUILD STRUCTURE

Functional guild: Presence of all the 3 guilds is a signal that the community structure of dung beetles and the soil profile in the agroecosystems in the region are not intensively disturbed (Subha & Sabu 2017). Comparative assessment of the functional guild composition of the dung beetle assemblages associated with other agroecosystem of Wayanad (Vinod 2009) indicated similarity with tunnelers being the dominant guild followed by rollers and dwellers. Same pattern of assemblage was found in the agro-ecosystems of Mexico (Estrada *et al.,* 1998) and Tanzania (Nielson 2007). Prevalence of tunneler guild with lower abundance of dweller guild in all the coffee plantation belts (Latha 2011; Simi 2014) and also in other plantations (Vinod 2009; Sabu 2011) in the South Western Ghats indicates that, it is a uniform pattern in the less disturbed agriculture belts in the South Western Ghats (Subha & Sabu 2017) and entire tropical region (Shahabuddin *et al.,* 2005; Nielson 2007). Aggressive and superior competitive nature of tunnelers in utilizing the dung resource most rapidly (Doube 1991; Krell-Westerwalbesloh *et al.,* 2004) and easier digging the wet and soft soil due to high moisture in coffee plantations soils contributed to their success and dominance in the various habitats (Scholtz *et al.,* 2006).

Aasland (2015) reported tree cover may prevent sunlight from entering the ground level which may affect the composition of dung beetles in forests. Low abundance of rollers in the coffee plantation is attributed to the vegetation structure with tree cover (shaded), which imposes difficulties to the rolling of resource balls. Rollers which exploit the resource more quickly require specific environmental conditions, such as higher dung and soil temperature (Lopes *et al.,* 2006).

Low abundance of dwellers is attributed to the limited availability of undisturbed dung pads and dung removal for agricultural practices and scattering of dung pats by domestic fowls and other native birds in the study region. Same pattern and reasons were found to be affecting dweller guilds in other region of the South Western Ghats (Vinod 2009; Simi 2014). Undisturbed dung pads are essential for feeding and breeding of dwellers (Krell *et al.,* 2003; Krell-Westerwalbesloh *et al.,* 2004; Simi 2014). Also dwellers are strongly associated with undisturbed larger herbivore dung pats and show little competition from competitively superior tunnelers and rollers (Hanski & Cambefort 1991c; Krell *et al.*, 2003; Krell-Westerwalbesloh *et al.*, 2004; Vinod 2009; Nithya 2012).

Temporal guild: Generalists dominated the assemblage followed by diurnal and nocturnal temporal guilds. Same pattern of generalist dominance was recorded from the coffee plantation in North Malabar (Simi 2014). It is attributed to the the cool and shaded environmental conditions in coffee plantations that lead to uniformity in the habitat conditions enabling better conditions for generalist species during day and night.

Bioindicators: Based on the abundance and occurrence in the samples, five major species (*Onthophagus fasciatus, O. turbatus, O. faveri, Caccobius meridionalis* and *Paracopris davisoni)* were the bioindicator species, three species (*Copris repertus, Onthophagus andrewesi* and *O. dama*) were the detector species and thirteen species are generalists (low specificity species) in the shaded coffee plantation. As bioindicator species have strong habitat specificity, their abundance may decline rapidly under changing environmental conditions and may disappear rapidly (McGeoch *et al.,* 2002) with no further value for monitoring thereafter. Hence monitoring the populations of characteristic species are useful in understanding whether drastic habitat changes have taken place in the coffee plantation belts. Among these five indicator species*, Onthophagus fasciatus* and *O. turbatus* with highest *Indval* score are the most vulnerable species. These two species were recorded from various plantation belts in the Western Ghats with high *Indval* values (Vinod 2009; Latha 2011; Simi 2014). Hence tracking the abundance pattern of these two species will enable to understand whether further monitoring is required. Their lower presence in the region will indicate that the habitat under consideration might have already deteriorated and urgent corrective steps should be taken to improve the habitat quality by identifying and arresting the activities that lead to degradation.

Detector species have a range of ecological states (i.e. do not have high specificity) and are useful indicators of direction of change than the highly specific species restricted to a single state (McGeoch & Chown 1998; McGeoch *et al.,* 2002; Shahabuddin *et al.,* 2013). This is due to their different degrees of preference for different ecological states and relative changes in their abundance across ecological states indicative of the direction in which change is occurring. Furthermore, detector species are less likely to become vulnerable than indicator species because a variety of habitats or ecological states, provide suitable resources for them rather than only a single one (Mc Geoch *et al.*, 2002). Accordingly, these three detector species, *Copris repertus, Onthophagus andrewesi* and *O. dama* will be useful for long-term monitoring of habitat changes in the shaded coffee plantation belts in the NBR region of the Western Ghats and in other plantation belts in the region. Thirteen generalist species discovered are low specificity species which are unlikely to respond very rapidly to changing habitat conditions (Tshikae *et al.,* 2008; McGeoch *et al.,* 2002).

Species Composition, Abundance and Diversity: The assemblage consisted of thirty eight species which is low when compared to the 60 species recorded from the agriculture belts of moist South Western Ghats (Sabu 2011), but high in comparison with twenty eight species recorded from agriculture belt of Wayanad (Vinod 2009), 26 species recorded from semiurban agricultural land in the Malabar Coast (Simi *et al.,* 2012), 25 species from agriculture belt of Nelliampathi (Latha 2011), 31 species recorded from the agriculture field of North Malabar (Simi 2014) and 10 species from agriculture fields of North India (Mittal & Vadhera 1998). At global level, these numbers are very high compared to 22 species from agriculture belt in Mexico (Estrada *et al.,* 1998), 10 species from cropland in Columbia (Escobar 2004), nine species from shaded coffee plantation of Mexico (Arellano *et al.,* 2005), 12 species from agroecosystems of Guatemala (Avendano-Mendoza *et al.,* 2005), 16 species coffee agrosystems of Veracruz, Mexico (Pineda *et al.,* 2005), 13 species from agriculture field in Sulawesi, Indonesia (Shahabuddin *et al.,* 2005), 10 and 16 species from cacao and oil palm plantation of Southwest Ghana (Davis & Philips 2005), 17 species from agriland of Indonesia (Shahabuddin *et al.*, 2010). However, dung beetle assemblages of the African agroecosystems hold a high species richness of 55 species (Nielson 2007).

Present study showed that diversity, species richness and functional guild structure of dung beetles in the shaded coffee plantation has no major differences with that of the nearby natural forest. The assemblage consisted of 38 species, which is not low in comparison with the 46 species recorded from a larger forest region in the Wayanad (Vinod 2009). Harvey *et al.,* (2006) indicated that indigenous agroforestry systems maintain an intermediate level of biodiversity (which is less than that of the original forest but significantly greater than that of monocultures) and provide suitable habitat for a number of forest-dependent species. Dung beetles can use plantations to some extent but their densities may be lower than in forest, probably due to the structure of the understory and availability of resources (Medina *et al.*, 2002). Many studies also reported shaded coffee plantations are refuges for forest species of dung beetles (Perfecto *et al.,* 1996; Moguel & Toledo 1999; Arellano *et al.*, 2005). Also majority of forest species have strong preference for shade and may require shade for reproduction or during specific life-stages (Horgan 2007). Similarities in diversity, species richness and functional guild is attributed to the maintenance of temperature and humidity conditions similar to that in forest interior, that is favourable for dung beetle presence and activity (Moron 1987). Moisture content and quality of dung is maintained for a longer period under the shade which enables better colonization of dung beetles than in the open (Horgan 2002; Horgan 2005; Subha & Sabu 2017). Excrement of people working in the plantations and that of domestic animals provides a considerable amount of dung that may contribute to the maintenance of the high dung beetle diversity recorded in coffee plantations (Escobar 2004; Pineda *et al.,* 2005; Villada-Bedoya *et al.,* 2017). Even though species abundance and dominance pattern varied from the forest region, all other genera except the genus *Liantogus* reported from the nearby forest belts exists in the shaded coffee plantation. Non-record of the genus *Liantogus* belonging to the dweller guild was attributed to its requirement of undisturbed large dung pads of mega-herbivores like elephant and gaur for dwellers in general (Vinod & Sabu 2007; Vinod 2009). Many studies from Neotropical region have demonstrated that coffee agro-ecosystems with complex forest-like vegetation structure (shaded) harbor significantly high biodiversity (Greenberg *et al.,* 1997a; Johnson 2000; Perfecto *et al.,* 2003; Perfecto & Armbrecht 2003; Somarriba *et al.,* 2004), particularly dung beetle diversity (Moron 1987; Pineda *et al.,* 2005; Horgan 2005).

Reports from the present study is in agreement with the findings from the coffee and cocoa plantation belts in Neotropical and south east Asian regions with surprisingly little reduction in diversity of dung beetles despite the great anthropogenic habitat transformation in plantations (Moron 1987; Estrada *et al.,* 1998; Estrada & Coates-Estrada 2002; Pineda *et al.,* 2005; Escobar 2004; Horgan 2005; Shahabuddin *et al.,* 2005; Shahabuddin *et al.,* 2010;

Shahabuddin *et al.,* 2013). This closer association between dung beetle groups registered at forest and agriculture belt sites shows the high similarity of some habitat parameters like vegetation structure and microclimate between both habitat types (Shahabuddin 2010).

Record of two species of genus *Ochicanthon* [*O. tristis* (Arrow 1931) and *O. laetus* (Arrow 1931)] from the study site is significant since *Ochicanthon* is a rare primitive old world dung beetle species recorded from only moist forest patches (Krikken & Huijbregts 2007; Latha *et al.,* 2011). Presence of *Ochicanthon* indicates that the recent habitat modifications in the Western Ghats have not wiped out the relict old world dung beetles (primitive groups) from the agrilands. Dominance of genus *Onthophagus* belonging to the dung-pad-preferring younger modern tribe, Onthophagini (Sabu *et al.,* 2011b) was seen in the coffee plantation and is attributed to the cosmopolitan status of the genus (Medina *et al.,* 2002) and its wider food selection habits (Cambefort & Hanski 1991).

Small species of dung beetles (72.97%) dominated the assemblage in coffee plantation compared to large species (27.03%). Same pattern was observed from the agriculture belts of North Malabar (Simi 2014) and Nelliampathi (Latha 2011). Capacity of small beetles to utilize small dung resources (Nealis 1977) and their ability to use greater range of microhabitats and food resources (Jankielsohn *et al.,* 2001) might have led to their high abundance (Latha 2011; Simi 2014). Despite the loss of species richness and biomass in agroforestry, the large number of small individuals in these systems suggests that density compensation is occurring which is similar to secondary forests (Slade *et al.,* 2011; Braga *et al.,* 2012). Lower abundance of large dung beetles is attributed to the low abundance of large dung producers in the plantations and the habitat disturbance arising from agricultural activities like farm land weed removal and loosening the soil for fertilizer application. Body size of dung beetles may be an important factor interacting with habitat type and may be related to the presence of large mammals (Hanski & Cambefort 1991; Shahabuddin *et al.,* 2005) and smaller dung beetle species are more abundant and less habitat specific (Hanski & Cambefort 1991; Shahabuddin *et al.,* 2005). Moreover large species tend to have small populations due to low fecundity (Hanski & Cambefort 1991), reproductive rate (clutch size) and long life span (Cardillo *et al.*, 2005) and this could be another reason for their low abundance (Latha 2011). Studies also have shown that large bodied beetles are more susceptible to habitat disturbance than small bodied beetles (Nealis 1977; Gardner *et al.,* 2008). Large beetles require larger quantities of dung for nesting (Peck & Howden 1984; Doube 1990) and are affected by decline in dung availability (Holter & Scholtz, 2007; Nichols *et al.*, 2009). Forest fragmentation (Nealis 1977; Larsen *et al.*, 2005), conversion to agriculture (Gardner *et al.,* 2008; Shahabuddin 2010) and deforestation (Scheffler 2005) are all found to affect large dung beetles by altering physical factors like temperature and sunlight exposure and declining dung diversity and availability.

Lesser abundance of *Catharsius* and the non-record of *Heliocopris* are attributed to the lesser availability of dung pads in agriculture belts and also to the possible of destruction of their deep tunnels and burrows during farm preparation activities (Sabu 2011). Andresen (2003) also reported mean beetle size increased with increasing forest area. Also larger bodied beetles may be more prone to microclimatic changes as they dissipate heat slower and are vulnerable to over-heating and desiccation (Verdu *et al.,* 2006). *Heliocopris* species occur only when large mammals are present in the sites, with a positive correlation between the dropping's size and the size of beetles (Cambefort 1991; Errouissi *et al.*, 2004).

5.3. DUNG SPECIFICITY

Very few specialists and more generalists are seen in the studied coffee agroecosystem. Hence dung specificity is less in the plantation belts. This is different from the trends in forests where specialists and detectors are more in number (Sabu 2012). As feces are relatively scarce and difficult to locate, the low abundance of specialists with a diet restricted to one kind of dung is understandable. *Onthophagus fasciatus, O. faveri* and *O. turbatus* with highest *Indval* score identified as dung beetle specialists, were recorded only from pig dung from shaded coffee plantation belt in South Wayanad. Their high specialist status towards pig dung makes them as vulnerable species in the coffee system. It is possible that they need pig or omnivore dung type to attain the high abundance. Though in the absence of pig dung, they will sustain on other dung types, whether their reproductive potential on other dung types will be same or not and how it may affect their abundance, needs analysis of life cycle on different dung types. Such data on the reproductive performance of prominent dung beetle species are needed to reach at conclusions. *Onthophagus fasciatus* dominates the agriculture belts when compared to the forests in the South Western Ghats (Sabu 2011). Strong habitat association makes, *O. fasciatus* a good indicator species for the agriculture belt in Wayanad (Vinod 2009) and Nelliampathi (Latha 2011). Their distribution records from the subcontinent disclose that they are widespread species all over India (Arrow 1931). They are well adapted species capable of surviving in variety of habitats including disturbed habitats like crop fields and may produce several broods per year as common in small tunnelers (Cambefort & Hanski 1991) which led to their high abundance (Latha 2011). *Onthophagus turbatus* was also recorded from various plantation belts in the Western Ghats (Vinod 2009; Latha 2011; Simi 2014) and *Onthophagus faveri* was reported as rare in forest and common in agricultural belts (Sabu 2011; Simi 2014).

Present study showed high abundance of generalists or species with no preference towards any dung type. These generalist species (*Catharsius sagax, Copris repertus, Onthophagus amphicoma* and *O. devagiriensis*) are low specificity species which are unlikely to respond very rapidly to changing habitat conditions (Tshikae *et al.,* 2008) or can be concluded as opportunists. Because of the scarcity of the dung resource, extreme specialization is considered unlikely to occur in coprophagous insects (Hanski & Cambefort 1991; Finn & Giller 2002; Dormont *et al.,* 2004). High abundance and their generalist nature indicate that they are capable of exploiting a wide variety of dung types and are the most adapted and successful generalists in the coffee plantation.

The rare beetle species (*Caccobius ultor, Ochicanthon laetus, O. tristis, Oniticellus cinctus, Onitis falcatus, Onthophagus cervus, O. discedens, O .duporti, O. furcilifer, O. kchatriya, O. lilliputanus, O. ludio, O. pacificuss, O. socialis, O. tnai, O. truncaticornis, Tibiodrepanus setosus* and *Sisyphus longipes***)** whose *Indval* values and dung preferences cannot be determined are the less prominent dung beetles in the agrilandscapes (Sabu 2011) or tourist species. Braga *et al.*, (2013) reported that agricultural areas have many tourist species (50% of all species in agriculture are singletons) which increase total species number. So in terms of dung beetle community attributes and dung removal, agriculture sites were more similar to agroforests and secondary forests than to pasture sites (Braga *et al.*, 2013). Among rare species *Onthophagus discedens* and *O. truncaticornis* are the two species recorded as extirpated and *O. lilliputanus* is reported for the first time from the moist South Western Ghats (Sabu *et al.*, 2011a). Less of specialists and more of generalists exist in the plantation site. This pattern is arising from the unpredictable conditions in the agriculture belts where dung resources are always scarce due to the low abundance of dung producers and demand for dung for agriculture uses.

The present study recorded more species and abundance in omnivore dung (pig) than herbivore dung types. This clearly indicates that feeding preferences occur in dung beetles and greatest number of individuals was attracted to feces of omnivorous mammals when a greater diversity of dung types is considered. Pig dung remains uniquely different because of high species richness and the presence of rare species. This preference is possibly due to the fact that omnivores have a greater variety of food items in their diet, in addition to substantial seasonal variation (Uchoa & Moura-Britto 2004; Rocha-Mendes *et al.,* 2010). High attraction towards pig dung is attributed to the variation in dung physico-chemical characteristics, most importantly fibre type, volatile compounds (odour), water content and resource type which vary according to animal digestive system (Noriega 2012). Also omnivore dung is more nutritious than megaherbivore dung therefore a smaller quantity is required to attract beetles (Davis *et al.,* 2000). The mobile adults opt for more nitrogen rich omnivore dung or carcass for their nutritional requirements while they provide their brood with more abundant, carbohydrate rich herbivore dung (Hanski & Cambefort 1991; Halffter & Matthews 1966; Seena & Priyadharsanan 2016).

Dung beetle preference for feces of omnivores corroborates the notion that the feces of omnivores are the principal resource for food and nesting (Halffter & Matthews 1966; Halffter & Edmonds 1982; Hanski & Cambefort 1991; Bogoni & Hernandez 2014). Other studies evaluating the food preference of dung beetles among a greater variety of feces types have also shown that the greatest number of individuals was attracted to feces of omnivorous mammals (Estrada *et al.,* 1993; Filgueiras *et al.,* 2009; Noriega 2012; Marsh *et al.,* 2013;

Bogoni & Hernandez 2014; Whipple & Hoback 2012; Aasland 2015). Davis *et al.,* (2010) reported more species in pig dung type (omnivore) than pads or pellets of ruminant herbivores represented by cattle and sheep or coarse-fibered monogastric herbivore dung (elephant). Many studies recorded distinct trophic preference for omnivorous mammal feces in Neotropical (Estrada *et al.,* 1993; Filgueiras *et al.,* 2009; Marsh *et al.,* 2013), Australian (Hill 1996; Vernes *et al.,* 2005), African (Davis 1994; Tshikae *et al.,* 2008; Davis *et al.,* 2010) and south Asian regions (Sabu 2012).

Sixteen species which exhibited strong associations with pig dung namely, *Caccobius ultor, C. unicornis, Ochicanthon laetus, Onthophagus cervus, O. duporti, O. furcilifer, O. kchatriya, O. ludio, O. socialis, O. urellus* and *Sisyphus longipes* showed the importance of omnivore dung in agriculture belts. Non-occurrence of pig or omnivore dung in agriculteur belts may affect the specialists or the ones with high nutrient requirements. In conclusion, despite opportunism remaining common, dung beetles seem to be more attracted to omnivorous mammalian feces than to feces types from mammals of other trophic guilds.

Chapter 6

CONCLUSIONS

Taxonomy, guild structure and dung specificity of dung beetles in a coffee plantation belt in Nilgiri Biosphere Reserve of South Western Ghats region were analysed. Thirty eight dung beetle species belonging to 10 genera and 6 tribes were listed. First report of *Onthophagus lilliputanus* from the moist part of South Western Ghats and two rare species *Onthophagus truncaticornis* and *O. discedens* and eight endemic species from the Western Ghats namely, *Ochicanthon laetus, Ochicanthon tristis, Onthophagus andrewesi, O. amphicoma, O. bronzeus, O. devagiriensis, O. tnai* and *Paracopris davisoni* were recorded.

All the 3 functional guilds, tunnelers, rollers and dwellers were recorded from the shaded coffee plantation with less habitat destruction. Tunnelers were the dominant guild and *Onthophagus fasciatus, O. turbatus and Paracopris davisoni* were the dominant tunnelers in the coffee plantation. Rollers were the second dominant and dwellers were the least dominant guild in the coffee plantation.

Generalists dominated the assemblage with twenty seven species followed by diurnal and nocturnal temporal guilds. Dominance of generalists is attributed to the high dung resource availability during the day and low abundance of more competitively superior diurnal and nocturnal beetles. *Paracopris davisoni, Onthophagus faveri* and *Caccobius meridionalis* were the dominant generalists. *Onthophagus fasciatus* was the most abundant diurnal guild and *Onthophagus turbatus*, the most abundant nocturnal guild.

Small dung beetles species dominated the assemblage in the coffee plantation compared to large species. Study showed bait type affects both the abundance of individuals and the species captured and dung beetles were more attracted to omnivorous pig dung than to herbivore (cattle and goat) dung. Three speceis, *Onthophagus fasciatus*, *O. faveri* and *O. turbatus* are specialists in omnivore dung indicating that they are with high nutrient requirements and the non-availability of omnivore dung may affect such specialists which may lead to their low abundance. High abundance of generalists which are species with no preference towards any dung type indicates that the coffee plantation is dominated by an assemblage capable of exploiting a wide variety of dung types and less of specialists.

Record of the rare primitive old world dung beetle genus *Ochicanthon* recorded only from moist forest patches indicates that the habitat modifications in the Western Ghats have not wiped out the relict old world dung beetles from the shaded coffee plantations. Shaded coffee agro-ecosystem is inhabited by a dung beetle assemblage similar to the one found at nearby forest site indicating that shaded coffee agro-ecosystems have no significant impact on dung beetle diversity.

Chapter 7

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LIST OF SYMBOLS AND ABBREVIATIONS

'@'= First report from moist South Western Ghats

'$'= rare to Western Ghats

'*'= endemic to the Western Ghats

Di= diurnal

N= nocturnal

G= generalist

Dw= dweller

R= roller

T= tunneler

S= small beetles

L= large beetles

NBR= Nilgiri Biosphere Reserve