DIVERSITY AND FIRE INDUCED BEHAVIOURAL DYNAMICS OF SHORT - HORNED GRASSHOPPERS (INSECTA: ORTHOPTERA: CAELIFERA) IN ERAVIKULAM NATIONAL PARK AND PARAMBIKULAM TIGER RESERVE, WESTERN GHATS

Thesis submitted to the
University of Calicut in partial fulfilment of the
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By

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CERTIFICATE

This is to certify that the thesis entitled "**Diversity and Fire Induced Behavioural Dynamics of Short-Horned Grasshoppers (Insecta: Orthoptera: Caelifera) in Eravikulam National Park and Parambikulam Tiger Reserve, Western Ghats**" is an authentic record of research work carried out by **Mr Dhaneesh Bhaskar** under my supervision and guidance in KSCSTE- Kerala Forest Research Institute in partial-fulfilment of the requirements for the degree of Doctor of Philosophy of the University of Calicut. The work has not been previously submitted for the award of any degree, diploma, associateship or other similar titles to any candidate of any university.

Dr. P.S. Easa

Thrissur
September 29, 2020

DECLARATION

I, Dhaneesh Bhaskar do hereby declare that the thesis entitled **"Diversity and Fire Induced Behavioural Dynamics of Short-Horned Grasshoppers (Insecta: Orthoptera: Caelifera) in Eravikulam National Park and Parambikulam Tiger Reserve, Western Ghats"** is an authentic record of the research work carried out by me in KSCSTE - Kerala Forest Research Institute, under the guidance of **Dr P. S. Easa.** I further declare that no part of this thesis has been submitted previously for any other degree or diploma of this or any other university.

Dhaneesh Bhaskar

Thrissur
September 29, 2020

To my Father

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DHANEESH BHASKAR

ABSTRACT

The grasshopper of Protected Areas of the Western Ghats is one of the least explored insect groups. Conservation activities and understanding of the population biology and community ecology of the insect fauna are significant in an ecological system. The grasshopper studies were mostly restricted to the agricultural fields and the human-inhabited regions. Grasshoppers can range from being rare curiosities to abundant menaces. Accurate information on these taxa can suggest proper management strategies in different habitat conditions. An understanding of the population biology and community ecology of the insect could help formulate strategies for conservation of the natural habitats.

Studies on insect diversity of Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR) are comparatively few. Butterflies and dragonflies are the only major group of insects that received greater attention from the researchers. Since both the Protected Areas are having unique environmental conditions, Orthoptera diversity was also expected to be interesting as that of butterflies. The grasshopper of PKMTR was never documented whereas there had been some effort by Zoological Survey of India in ENP. There had been no comparative study on the diversity and ecology of Orthoptera in the different habitats and altitudes of ENP and PKMTR. The present study was aimed to generate information on the diversity, distribution and ecology of Orthoptera in relation to altitudinal variations, different ecosystems and fire regimes of ENP and PKMTR.

Eravikulam National Park is unique with its extensive grasslands and the high altitude shola forests with very few scattered shrub land. Parambikulam Tiger Reserve is more complex in vegetation with evergreen, semi-evergreen and moist deciduous forests

with grasslands in the higher reaches. The marshy swamps called vayals are distributed in the middle of these vegetation types and the teak and eucalypts plantations.

The grasshoppers were studied from January 2015 to May 2018. The richness and abundance of grasshoppers were sampled by visual count (direct observation) and hand searching on randomly plotted transects in every habitat of ENP and PKMTR. Fifty eight species were documented, 18 of which are endemic to India. Fifty-five grasshopper species were recorded in PKMTR and 18 in ENP, with 15 species common to both the areas. Thirty-nine species were exclusively found in PKMTR, but only three in ENP. A new pygmy grasshopper species of the genus *Tettilobus* (Orthoptera: Tetrigidae) from the shola forests of ENP was described and named it as *Tettilobus trishula sp. nov*. A rare Catantopinae species *Mopla guttata* was rediscovered since its description in 1940, representing the first male collected for this species. The discovery of *Euparatettix personatus* and *Deltonotus subcucullatus* from PKMTR is the first record to India.

The distribution of grasshoppers across different elevation gradients in ENP and PKMTR was documented across 23 elevation bands of 100 m. In PKMTR, the elevational ranges from 400 to 1429 m were divided into 11 elevation bands and in ENP from 1500 to 2700 m were divided into 12 elevation bands. Sampling transects of 50 m were laid on each elevation band and the number of transects in each gradient band varied based on the area-composition. A hump-shaped species richness pattern was observed across elevation gradients of ENP and PKMTR. The grasshopper species distribution was found to be very much associated with increased number of niches, habitat complexity and geographical area across elevation gradients. The grasshoppers of ENP exhibited higher species richness across its mid-elevation ranges where the area is also found to be larger. In the case of PKMTR, a monotonic decreasing trend in grasshopper richness with increasing elevation was observed. Lower elevations of PKMTR with mosaic habitats and larger area support more grasshopper species.

Habitat management strategies across the globe are often focusing on flagship species, such as large threatened mammals. This is also true for most of the Protected Areas of India, where large mammals such as the Tiger or Asian Elephant represent focal species of conservation management. However, a shift towards other species groups can be observed in recent times. Prescribed burning is a controversially debated method to manage open habitat types. This method has been in practice in ENP as a tool to manage the habitat of the endangered Nilgiri tahr, *Nilgiritragus hylocrius* (an endemic goat) at a large scale (50 ha grids). However, the impact of prescribed burning on other biota of this unique environment in a global biodiversity hotspot has not been studied. The impact of large-scale prescribed burning on grasshopper abundances in Eravikulam National Park was compared with small-scale burning in Parambikulam Tiger Reserve from 2015 to 2018, to assess the impact of the different fire management practices of these reserves on this species-rich insect group. A negative response of grasshoppers to burning of larger contiguous areas in terms of their recovery after fire events was observed. Burning small patches in a mosaic pattern facilitated the rapid recovery of grasshopper communities. The results suggest that burning management can be optimized to benefit both the flagship vertebrate species as well as species-rich invertebrate communities.

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ACRONYMS

AMT - Annual Mean Temperature
APn - Annual Precipitation
BNHM - Natural History Museum, London
CWG - Central Western Ghats
ENP - Eravikulam National Park
ICZN - International Code of the Zoological Nomenclature
IUCN - International Union for Conservation of Nature
KFRI - Kerala Forest Research Institute
MDF - Moist Deciduous Forests
MHNG - Muséum d'histoire naturelle de la Ville de Genève
MNCN - Museo Nacional de Ciencias Naturales, Madrid
MNHN - Muséum National d'Histoire Naturelle, Paris
MTCM - Minimum Temperature of the Coldest Month
MTWM - Maximum Temperature of the Warmest Month
NDVI - Normalized Difference Vegetation Index
NHMUK - Natural History Museum, London, United Kingdom
NWG - Northern Western Ghats
OSF - Orthoptera Species File
PA - Protected Area
PAST - PAleontological STatistics
PCA - Principal Component Analysis
PKMTR - Parambikulam Tiger Reserve
SMTD - Museum für Tierkunde Dresden, Germany
SRTM - Shuttle Radar Topography Mission
SWG - Southern Western Ghats
WG - Western Ghats
ZSI - Zoological Survey of India

INTRODUCTION

The diverse tropical forest ecosystems are home for two-third of the fascinating terrestrial biodiversity on the Earth (Giam 2017). Such ecosystems with higher endemism and extensive viable habitats are often referred to as ‘‘hotspots’’ (Myers 1988). Relying on the high levels of plant endemism and habitat richness, Myers identified ten “tropical forest hotspots” during 1988 (Myers et al. 2000). On subsequent analysis, Mittermeier et al. (2011) defined the hotspots formally as bio-geographic regions. Redefining the boundaries of existing hotspots (Mittermeier et al. 2004) and adding new ones (Mittermeier et al. 2011) brought to a total of 36 hotspots (Williams 2011; Mittermeier et al. 2017). Although the hotspots possess most of the biodiversity on the earth, it is being challenged by the combined effects of climate change and land use (Riordan and Rundel 2014). Bellard et al. (2014) find that 19% of the insular biodiversity hotspots might be entirely submerged by the global sea level rise and an average loss of 31% of their area is predicted. The biodiversity of tropical forests is also being reduced by human impact and effect size varied by region, taxonomic group, metric and disturbance type (Gibson et al. 2011).

In the Indian subcontinent, four global biodiversity hotspots have been identified: Himalaya, Indo-Burma, Western Ghats and Sri Lanka and Sundaland (Myers et al. 2000; Mittermeier et al. 2017). The “Western Ghats and Sri Lanka” represents climatically and topographically heterogeneous landscapes of both India and Sir Lanka. The Western Ghats (WG) is a unique continuous chain of highlands (with one major break called Palakkad Gap) running along 1600 km of the south-western edge of peninsular India (Subramanyam and Nayar 1974; Ali and Ripley 1987). The history of WG is connected to the Gondwana landmass and extensive volcanic activities at the end of Cretaceous epoch, the biodiversity of these highlands are ecologically very significant (Joshi and Karanth, 2013). The vegetation structure and composition of the WG divides it as four different zones; (1) Northern WG (NWG), (2) Central WG (CWG), (3) Nilgiri or Blue Mountains, and (4) Southern WG (SWG) (Subramanyam and Nayar 1974). Among the four divisions, the SWG is identified as the most diverse zone with higher rate of endemicity (plant, amphibian, bird and fish) than the CWG and NWG (Pascal 1988; Gimaret-Carpentier et al. 2003; Dahanukar et al. 2004; Pascal et al. 2004; Davidar et al. 2007). Also in terms of endemicity and evolutionary history of carnivores, the WG belongs to the top five biodiversity hotspots (Mittermeier and Rylands 2017). The unique chain of Ghats originates from the south of Tapti River and extends up to Kanyakumari at southern tip of peninsular India. The WG covers six major states of India (Gujarat, Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala). The natural habitat of WG is being managed as different protected areas (PA) such as National Parks, Wildlife Sanctuaries, Tiger reserves and Community and Conservation Reserves. The WG is home for 137 species of mammals, 290 species of fresh water fishes, 181 species of amphibians, 203 species of reptiles, 508 species of Birds, 332 species of Butterflies, 174 species of Odonates and 5916 species of plants (Radhakrishnan and Rajmohana 2012). The highest rate of endemism is to be found among amphibians (78% of all Western Ghats species) followed by reptiles (62%), fishes (53%), mammals (12%), and birds (4%). The higher fauna of WG is well documented as it gains more conservation priority. The diversity of lower fauna (invertebrates) was never deeply explored except that of the butterflies. Most of the PAs have been declared with focus on large mammals that represent major priorities in conservation management and they are often used as flagship species in conservation planning (Bowen-Jones and Entwistle 2002).

Insect diversity of tropics has fascinated many explorers, naturalists and biologists. Insects of tropical forests were instrumental in contributions of Wallace and Darwin as they were developing the concepts of natural selection (Godfray et al 1999). Insecta accounts 66% (10, 20,007 species) of world's faunal diversity among which the order Coleoptera represents 38% (3, 87,100 species) of the insect species (Zhang 2011). With its geographical position and climatic conditions, India is very unique among the tropical forested countries. Systematic entomology expeditions of Indian tropical forests were initiated by the British colonials. Later on, the Indian insects were studied from its snow high mountains to sea coasts by many researchers. With about 65,000 -70,000 insects so far described, India contribute 7-10% of the world's insect diversity. Of these, more than twenty thousand are endemic to India (Gosh and Singh 2000). Being the most speciose fauna on the earth, functionally insect's interaction to other biotic and abiotic components are well known; as dominant prey (Floren et al. 2002), predators of seeds (Janzen 1971), herbivores (Coley and Barone 1996) and pollinators (Bawa 1990; Ollerton et al. 2011) and are very significant in dead organic matter decomposition (Simon 2002). The diversity and abundance of insects contributes to the functioning and resilience of tropical forest ecosystems (Ewers et al. 2015). Environmental sensitivity of functionally similar species and their loss and replacement with more robust ones predicts the functional resistance of an ecosystem (Walker 1992). With a combination of different functional roles, insects are very good indicators of environmental changes. The two major impediments to insect conservation, as Samways (1992) pointed out, are lack of taxonomic and ecological information (New 1995). This is true in the case of Indian insects also. Understanding the insects at taxonomic and ecological levels is very important in the field of entomology. Information about the functional role of insects and its response towards the environmental change is very crucial in predicting the health and dynamism of the ecosystem.

The insects under the order Orthoptera is considered to be a great indicator of diversity and ecosystem health (Belovsky 2000). **Orthoptera** (Greek word "**Ortho**=**Straight**" and "**Ptera**=**wings**") are straight winged, large and easily recognized group of insects that include grasshoppers, locusts, ground hoppers, crickets, bush crickets, mole crickets and camel crickets. It is less likely to confuse with other groups because of its generally straight winged body and enlarged hind femur (adapted for jumping). Spindle-shaped body narrows towards both the ends and narrowing anteriorly, posteriorly and laterally or dorso-ventrally compressed body. They are provided with strong mandibles and are exclusively categorized as herbivorous insects, except some crickets that consume other smaller insects including Orthopterans. The first and strong pair of straight wings is known as tegmina which are relatively thicker as that of elytra in Coleoptera (Beetles) while the hind wings are membranous with definite venation. Major distinguishing features of Orthoptera include the development of large excrescences (tubercles, ridges, crests, spines), particularly on the pronotum and legs.

Order **Orthoptera** is broadly divided into two suborders: **Ensifera** and **Caelifera**. Suborder **Caelifera** is also known as true grasshoppers with relatively short antennae (short-horned grasshoppers). More than 28,000 species of Orthoptera are known to science till now (Cigliano et al. 2019). India has 1750 species, which is almost 9% of the global Orthoptera diversity (Tandon and Hazra 1998). Out of 1750 species/subspecies belonging to 398 genera and 21 families, 563 species/subspecies under 19 families are endemic. The Indian subcontinent is still capable of contributing a lot to the order Orthoptera. It requires systematic and extensive studies across its protected and non-protected areas. Zoological Survey of India (ZSI) has generated some basic information on Indian Orthoptera; Shishodia et al. (2010) published checklist of Indian Orthoptera with 1033 species. In the Indian subcontinent, grasshoppers are still struggling to overcome its status as an agricultural pest. Orthoptera diversity of Tropical Asia-Indian subcontinent is well documented during the early nineties (Westwood 1839; Bolivar 1900, 1902 and 1914; Kirby 1914a and 1914b; Bolivar 1917 and 1930; Hebard 1930; Uvarov 1929; Henry 1937 and 1940; Chopard 1969; Vasanth 1991). All those studies were restricted mainly to the agricultural fields and human inhabited areas. Orthoptera diversity of Indian Protected Areas especially in the WG still remains untouched. Bhaskar et al. (2018) reported 130 species of Orthoptera from Kerala, the southern state of the Western Ghats.

Orthoptera are highly susceptible to environmental changes, including those resulting from the anthropogenic activity. Many of them have considerable capacity for long distance dispersal, enabling them to find and colonize isolated resources, such as locust swarm. Study on grasshoppers address both the elements of land use - agricultural production (Pest management) Biodiversity and its conservation. Grasshoppers enhance plant production by accelerating the nutrient cycle primarily by increasing the proportion of litter provided by faster decomposing plants. They also enhance the production of forage for larger herbivores. According to Belovsky (2000), grasshoppers actually stimulate forage production between years and this long-term enhancement exceeds annual losses as grasshoppers accelerate nutrient cycling in the grassland ecosystem more effectively than larger herbivores could. Controlling or any type of restrictions to the grasshoppers in grassland may actually reduce the ecosystem's long-term productivity. Grasshoppers have a special demand in vegetation and microclimate conditions (Sanger 1977, Ingrisch 1980) since only a very few monophagous species are known (Chapman 1990). Because of their relation to vegetation irrespective of species, grasshoppers are considered as an important species for environmental studies. Hochkirch (1996) mentioned the lack of confirmation of grasshoppers' role as a diversity indicator in tropics.

Diversity documentation of such an important and neglected group of insect is very significant. Grasshoppers can range from being rare curiosities to abundant menaces; proper information on these taxa only can suggest a management strategy since it represents two extremes. An understanding of the population biology and community ecology of the insect is required for formulating conservation strategies.

The motivation for this study is the lack of information about the grasshopper (Caelifera) diversity of Eravikulam National Park and Parambikulam Tiger Reserve. It was also considered interesting and appropriate to understand its response towards habitat management practices. The research objectives of the present study can be summarized as follows:

1. Document the diversity of short-horned grasshoppers (Orthoptera - Caelifera) in Eravikulam National Park and Parambikulam Tiger Reserve.
2. Record the distribution of short-horned grasshoppers (Orthoptera - Caelifera) in different altitudinal gradients.
3. Study the impact of prescribed fire practices on short-horned grasshoppers (Orthoptera - Caelifera).

REVIEW OF LITERATURE

2.1 INTRODUCTION

Orthopterans are the most recognizable and familiar insects in all the terrestrial habitats. The oligophagous and mixed feeding nature makes it the best fit for different habitats (Mulkern 1967). They are major primary consumers and contribute significantly to the nutrient cycling (Gandar 1980) and energy flow (Samways 1997). The local-level abundance can represent landscape or regional grasshopper abundance (Kemp et al. 1990; Samways and Sergeev 1997), and also they are indicators of land use (Bei-Bienko 1970; Lockwood 1997; Samways and Sergeev 1997). Even though they are not a perfect umbrella taxon for all aspects of biodiversity (Lawton et al. 1998; Kotze and Samways 1999) for certain ecosystems, they are important indicator species. They are considered as essential ground invertebrates in grassland ecosystem (Scott 1979; Risser et al. 1981). Grasshoppers are primary consumers and contribute significantly to the prey base of insectivorous birds (Curry 1994; Joern, 1986; Samways 1997). The role of grasshoppers in grasslands is comparatively better studied (Uvarov 1966; Mitchell and Pfadt 1974; Gangwere et al. 1997; Cigliano et al. 2000; Guo et al. 2006; Bhaskar et al. 2019). They contribute more than half of the total arthropod biomass in grasslands and play a significant role in nutrient cycling (Gillon 1983; Mitchell and Pfadt 1974; Belovsky and Slade 1993; Gangwere et al. 1997). Grasshoppers are good ecological indicators as they provide nutrition to both invertebrates and vertebrates (Joern et al. 2006; Gandar 1982; Song et al. 2018). Along with the grasslands, the grasshoppers are well associated with the tropical forests (Song et al. 2018).

Earlier, the grasshopper taxonomy was based on European, African, Eurasian, and North American specimens and thus formed the basis for the classification schemes (Rehn and Grant 1961; Bei-Bienko and Mishchenko 1963; Dirsh 1965). The Orthoptera in Southeast Asia and Australia have not been fully explored (Song et al. 2018).

2.2 Indian Orthoptera studies

The insect diversity of Indian mainland had been studied by many including the expeditions of Fabricius from 1745 to 1808, and the Systema Naturae (10th edition) of Carl Linnaeus' (1758). During 1847, Westwood came up with 'Cabinet of Oriental Insects' with some rare and endemic species of insects from India (Ananthakrishnan 2000). However, Orthopterans in India are comparatively least studied after the colonial researchers (Bhaskar et al. 2019). Kirby (1914a and 1914b) and Henry (1937 and 1940) provided the basic description for Indian Orthoptera through the Fauna of British India. Spanish entomologists (Bolivar 1900, 1902a, b and 1917; Bolívar 1914 and 1930) documented Orthoptera diversity of Indian subcontinent based on the specimens deposited in the natural history museum Madrid. Many scientists (Tandon and Shishodia 1977; Bhowmik 1985; Hancock 1913; Shishodia and Mandal 1990; Usmani and Shafee 1990; Shrinivasan and Muralirangan 1992; Hazra et al. 1993; Shishodia 1997, 1999, 2000a and 2008; Shishodia and Tandon 2000; Priya and Narendran 2003; Shishodia et al. 2003; Kulkarni and Shishodia 2004; Thakur et al. 2004; Ingrisch et al. 2004; Mathew 2004; Shishodia and Dey 2006 and 2007; Saini and Mehta 2007; Chandra et al. 2007 and 2010; Shishodia and Gupta 2009; Usmani et al. 2010; Senthilkumar 2010; Kumar and Usmani 2012; Sharma et al. 2004; Kumar and Usmani

2015) have made significant contributions to the taxonomy of Indian Caelifera. Chopard (1969) studied Indian Ensifera, which was then continued by Barman and Srivastava (1976), Ingrisch and Shishodia (2000), Shishodia (2000b), Barman (2003), Ingrisch and Muralirangan (2003), Kulkarni and Shishodia (2004), Senthilkumar et al. (2006), Chandra et al. (2007), Senthilkumar (2010), Srinivasan and Prabhakar (2012).

In recent years, researchers of the Northern part of India significantly contributed to the diversity documentation of Indian Orthoptera. The team of scientists with Chandra, Gupta and others contributed most to the knowledge of Orthoptera in the country. These include findings of *Schizodactylus monstrosus* (Schizodactylidae: Orthoptera) from Chhattisgarh, India (Chandra and Gupta 2005). Senthilkumar et al. (2006) documented Orthopteran fauna of Gibbon wildlife sanctuary in Assam (25 species). Chandra et al. (2007) reported 139 species of Orthoptera belonging to 12 families from Madhya Pradesh and Chhattisgarh. Gupta (2008) published new records of two short-horned grasshoppers from Central India. Shishodia and Gupta (2009) published a checklist of Orthoptera of Himachal Pradesh. Shishodia and Gupta (2009) recorded 165 species of grasshoppers under 16 families from Himachal Pradesh. Shishodia et al. (2010) published an annotated checklist of Orthoptera from India. Koli et al. (2010) contributed to Orthoptera fauna in Chandoli National park reporting 62 species belonging to eight families. Akhtar et al. (2012) recorded 26 species of grasshoppers belonging to two families in Uttar Pradesh. Usmani and Nayeem (2012) studied taxonomy and distribution of Acridoidea (Orthoptera) of Bihar and recorded 37 species. Desutter-Grandcolas and Jaiswara (2012) described Phalangopsidae (Grylloidea) crickets from India along with descriptions of new taxa. Jaiswara et al.

(2012) tested concordance in species boundaries using acoustic, morphological, and molecular data among the field cricket of genus *Itaropsis* (Orthoptera: Gryllidae) in India. Jaiswara et al. (2013) dealt with species identification of male field crickets based on the acoustics. Chandra and Gupta (2013) listed endemic Orthoptera (Insecta) of India. Waghmare et al. (2013) worked on species diversity of short-horned grasshopper in selected grasslands of Solapur district of Maharashtra and recorded seven species. Jaiswara and Desutter-Grandcolas (2014) revised the genus Pteroplistes in India, with the description of two new species *Pteroplistes kervasae* and *Pteroplistes masinagudi* (Orthoptera, Grylloidea, Pteroplistinae). Kumar and Usmani (2014) published taxonomic studies on Acrididae (Orthoptera: Acridoidea) from Rajasthan. Skejo and Gupta (2015) updated the specific status of *Hedotettix cristatus* (Tetrigidae: Tetriginae). Kumar and Usmani (2015) studied Acrididae from Haryana and recorded 36 species. Kumar and Usmani (2015a) described a new genus Mesophlaeoba (Orthoptera: Acrididae: Acridinae) from Himachal Pradesh. Kumar and Usmani (2015b) reviewed the genus Hieroglyphus (Acrididae: Hemiacridinae) from Uttar Pradesh. Gupta and Chandra (2016a) published a new species *Poekilocerus geniplanus* (Orthoptera: Pyrgomorphoidea) from Barnawapara Wildlife Sanctuary Chattisgarh, India. Gaikwad et al. (2016) studied Tettigoniidae of Protected Areas of Northern India. Gupta and Chandra (2016b) described a new species of the short-horned grasshopper of the genus *Heteropternis* (Orthoptera: Acrididae) from Central India. From Central India Gupta (2016a) described a new pygmy grasshopper (Tetrigidae). Gupta (2016b) described *Euparatettix dandakaranyensis* (Tetrigidae: Tetriginae) a new pygmy grasshopper species from Central India. Gupta et al. (2016) described *Hedotettix* *angulatus* (Orthoptera: Tetrigidae), a new pygmy grasshopper species from Barnawapara Wildlife Sanctuary, Chattisgarh, India. Kumar and Usmani (2016a) described a new genus and a species (Orthoptera: Acrididae: Oedipodinae) from Jammu and Kashmir. Kumar and Usmani (2016b) published taxonomic studies on Acrididae (Orthoptera: Acridoidea) from Gujarat. Gupta and Chandra (2017a) described a new genus (Orthoptera: Acrididae) and three species of short-horned grasshoppers from India. Gupta (2017a) published the first record of *Tarbinskiellus terrificus* (Grylloidea: Gryllidae) from Central India. Gupta (2017b) published the Orthoptera collection of Sitanadi-Udanthi Tiger Reserve of Chattisgarh. Gupta and Chandra (2017b) published a new species and a key to the genus *Coptotettix* (Orthoptera: Tetrigidae). Gupta and Chandra (2017c) described new species of raspy cricket genus *Gryllacris* (Orthoptera: Gryllacrididae) from Central India. Gupta and Chandra (2017d) described a new species of the genus *Epistaurus* (Orthoptera: Acrididae) from Central India. Gupta and Chandra (2017e) studied the taxonomy of pygmy-grasshoppers (Orthoptera Tetrigidae) from India with the description of a new species. Gupta et al. (2018a) described new species of genus *Thoradonta* (Orthoptera: Tetrigidae) from India. Gupta and Chandra (2018a) described a new species of genus *Euscelimena* (Orthoptera: Tetrigidae: Scelimeninae) from Central India which was then revised (Skejo et al. 2018) as the earlier description was a nymph inadvertently described as new species for a fourth time. Gupta and Chandra (2018b) described two new species of slant-faced grasshopper of the genus *Acrida* (Acrididae: Acridinae) from India. Gupta and Chandra (2018c) described two new species of the genus *Criotettix* (Orthoptera: Tetrigidae). Gupta et al. (2018b) published a new species of the genus

Tridactylus (Orthoptera: Tridactylidae) from India. Gupta et al. (2018) described *Brachyxenia subtruncata* (Orthoptera: Acrididae), a new short-horned grasshopper species from India. Kumar and Chandra (2018a) reviewed of the Indian species of genus Anaptygus (Orthoptera: Acrididae) and described a new species from the Himalayas. Kumar and Chandra (2018b) recorded genus Mesambria (Orthoptera: Acrididae: Catantopinae) first from India along with a new species description. Kumar and Chandra (2018c) described a new species of genus Oxytauchira (Orthoptera: Acrididae) from Himalaya. Kumar et al. (2018) published taxonomic notes on position of the genus Siruvania (Orthoptera: Acrididae). Jaiswara et al. (2019a) explained the phylogenetic relationships in the cricket tribe Xenogryllini (Orthoptera: Gryllidae: Eneopterinae) and described the genus *Indigryllus*. Jaiswara et al. (2019b) revised the genus *Xenogryllus* (Orthoptera: Grylloidea: Eneopterinae). Gupta and Chandra (2019) published two new species of *Hedotettix* (Orthoptera: Tetrigidae) pygmy grasshoppers from India. Gupta et al. (2019) compiled a checklist of the Indian species of the band-winged grasshopper genus *Sphingonotus* (Orthoptera: Acrididae) with the description of a new species. Skejo et al. (2019) published on oriental macropterous leaf-mimic pygmy grasshoppers of the genera *Oxyphyllum* and *Paraphyllum* (Orthoptera: Tetrigidae) and their taxonomic assignment. Chandra et al. (2019) reviewed the genus Sikkimiana (Orthoptera: Acrididae) with the description of a new species from Himalayas. Kumar and Chandra (2019a) described a new genus of subfamily Oxyinae (Orthoptera: Acrididae) from Himalayas. Kumar and Chandra (2019b) described a new species of Xestophrys (Orthoptera: Tettigoniidae; Conocephalinae) from Arunachal Pradesh. The first female of Letana mursinga (Orthoptera: Tettigoniidae;

Phaneropterinae; Letanini) was described by Kumar and Chandra (2019c) from Arunachal Pradesh. Kumar and Chandra (2020) reported first record of Orthelimaea himalayana (Orthoptera: Tettigoniidae: Phaneropterinae: Elimaeini) from Central Himalaya.

Although there had been several attempts to study Orthoptera of Northern and Central parts of India, the Southern part is not much covered. Prabhakar (2015) provided an updated checklist of Orthoptera of Tamil Nadu with new distributional records, which revealed 384 species. Bhaskar et al. (2018) provided a checklist to Orthopterans of Kerala, south India. Bhaskar et al. (2019) studied the impact of prescribed burning on grasshoppers in the Western Ghats. Bhaskar et al. (2020) rediscovered an extremely rare Catantopinae species from the Western Ghats.

2.3 Grasshoppers and Elevation gradient

The elevational gradients and associated environmental conditions are very significant in the field of ecology and evolutionary studies (Grinnel 1914). Biodiversity distribution and ecosystem functioning are influenced by various environmental conditions (Malhi et al. 2010). The environmental conditions associated with elevational ranges such as temperature, precipitation, plant community composition and growing season duration are important factors in species composition (Price 1981; Mani 1968; McCoy 1990). Variations in net primary productivity, temperature and precipitation across different elevational gradients can influence species richness and distribution (Sundqvist et al. 2013; Beck et al. 2016). High rate of primary productivity may lead to higher consumer richness and decreased extinction probabilities (Evans et al. 2005). Based on the productivity, two patterns of species richness have been documented so far. One is that the species richness increases monotonically with increased productivity (Hutchinson 1959; Preston 1962a, b; Connell and Orians 1964; Brown 1988; Brown and Lomolino 1998). The second pattern is that species richness increased with productivity and peaks at mid-levels of productivity, and then decreases at high productivities (Rosenzweig and Abramsky 1993).

Relationship between diversity and elevation has been explained by different hypothesis such as the mid-domain effect (Colwell and Lees 2000). According to this a mid-domain peak in species richness is generated when there is increasing overlap of species ranges toward the centre of the domain (Colwell and Hurtt 1994). Another hypothesis in relation with elevational gradients and diversity is a positive correlation between elevation and the species ranges. This is known as Rapoport's rule (Stevens 1992) or effect (Blackburn and Gaston 1996). Environmental heterogeneity and ecological gradients are well known cause to phenotypic variation among many organisms (Bai et al. 2016). Under certain conditions, such changes could increase fitness in organisms (Otaki et al. 2010; Valladares et al. 2014). The relationship of organisms with ecological gradients and environmental heterogeneity are described with ecogeographical rules such as Bergmann's rule, which explains a positive relationship between body size and latitude, as the smaller individuals distributed at lower latitudes with warmer climate (Bai et al. 2016). Many studies have stated that the body size of insects along environmental gradients fit Bergmann clines or converse-Bergmann clines. But some studies concluded that the Bergmann's rule does not fit to insects much (Mousseau 1997; Blanckenhorn and Demont 2004).

The role of elevation gradients on biodiversity, ecology, ecosystem functioning and the changes of biodiversity in the natural world with elevation was detailed during the nineteenth century by Darwin, Wallace and Humboldt (Lomolino 2001; McCain and Grytnes 2010). In these expeditions, they mentioned that the types of habitats and the species richness pattern varied across different elevation ranges (McCain and Grytnes 2010). Such predictable changes in plants and animal distribution pattern with elevation ranges have been considered as a major tool in the field of ecology and evolution.

Species distribution pattern across different elevation gradients is determined by various biotic and abiotic factors such as habitat heterogeneity, extent of area, temperature, precipitation, soil quality, air pressure and solar radiation (Grytnes and Vetaas 2002; McCain 2009). Elevational gradients can be considered as natural experiment tool for studying the community and ecosystem responses to long-term climate changes and to predict the future of biodiversity in a changing world (Fukami and Wardle 2005; McCain and Colwell 2011). The comparative study of species ecology along altitudinal or latitudinal transects/gradients have been used to study the response of species and communities to changing environmental conditions (Hodkinson 2005). The patterns of species richness along elevational gradients are also a tool to investigate the environmental causes of species distribution patterns (Beck et al. 2016). Different patterns of species richness modals such as decreasing and unimodal have often been reported across many taxonomic and functional groups of organisms (e.g. Rahbek 2005; McCain and Grytnes 2010; Kessler et al. 2011). It was Grinnell (1914), who first pointed out that elevation gradients can provide useful information to understand how the ranges of plant and animal species are restricted by environmental conditions. A positive relationship between habitat complexity and species diversity have been predicted in the spatial heterogeneity hypothesis; the more significant the heterogeneity of habitat, the higher the number of species in that habitat (Davidowitz and Michael 1998). Terborgh (1977) and his team's study is considered to be the first on tropical elevation gradient that examined bird communities in the Peruvian Andes.

The response rate of small organisms such as insects to the short term environmental fluctuations is higher than that of the populations of larger organisms (Belovsky and Slade 1995). Apart from the species richness and community structure, the development, survival, and distribution of insects are also being affected by elevational gradients and associated environmental factors such as temperature, precipitation and plant community composition (Price 1981; Mani 1968; McCoy 1990). Such adaptations of insects to elevational gradients include their higher cold-tolerance, colour, body size, including shorter wings (Mani 1968; Uvarov 1977; Gillis and Possai 1987; Somme 1989). Among several significant groups of insects, including ants and termites, appear to be low in species richness at 2,500m and above. Others such as Lepidoptera, Orthoptera, Diptera, Coleoptera, and Hymenoptera are less abundant at higher elevations. Primary consumers like grasshoppers are very much influenced by the changes in vegetation structure and composition with elevational gradients (Belovsky and Slade 1995). The grasshopper community composition varies across elevations within regions (Alexander 1951; Scoggan and Brusven 1973; Claridge and Singhrao 1978; Kemp et al. 1990). The monotonic decreasing pattern of species richness was reported among grasshoppers at different elevational ranges (Alexander and Hilliard 1969). Adaptations to different elevation gradients include tolerance to minimum temperature, cryptic colouration and morphological adaptations (Mani 1968; Uvarov 1977; Kingsolver 1985; Gillis and Possai 1987; Somme 1989) and the patterns of species richness with elevational gradients have not been tested properly with grasshoppers (Sirin et al., 2010). Grasshopper richness and distribution are reported to vary with elevation ranges and associated environmental factors (Alexander 1951; Scoggan and Brusven 1973; Claridge and Singhrao 1978; Kemp et al. 1990). Alexander and Hilliard (1969) reported that the grasshopper species diversity is higher at low elevations and diversity declined with increasing altitudes in the Rocky Mountains of North America. Similar observation was made by Claridge and Singhrao (1978) in the Western Mediterranean. Populations of lower organisms with short lifespan are sensitive to environmental variations (Belovsky and Slade 1995).

2.4 Fire and Grasshoppers

Conservation management strategies are largely focused on flagship species especially larger mammals (Bowen-Jones and Entwistle 2002). The red list status of the large mammals often favours their conservation priority (Williams et al. 2002). Larger herbivores are mainly associated with the open habitats such as grasslands (Swengel 2001). Major habitat management strategies include grazing, mowing or burning (e.g. Collins et al. 1998) grasslands. Fire is used as a habitat management tool in nature conservation (Whelan 1995; Hochkirch and Adorf 2007). The impact of fire on habitats is comparatively well studied (Warren et al. 1987; Swengel 1996, 2001; Hochkirch and Adorf 2007; Bhaskar et al. 2019). Prescribed burning is being practised frequently to manage vegetation dynamics and grassland health, which improves the forage value of pastures, reduce wildfire hazard (Valentine and Schwarzkopf 2009). Fire regimes can lead to major changes in community structure including the risk of extinction (Charrette et al. 2006; Fisher et al. 2009; Gill and Bradstock 1995). Fire and fire management are hence recognised as very important factor in biodiversity conservation and management (Driscoll et al. 2010). Research explains that fire responses in plants and invertebrates may be mediated by analogous traits such as their ability to survive and recover after fire and mobility (Moretti and Legg 2009).

The impact of fire varies between ecosystems, species and burning parameters (e.g. season, fire intensity and extent of burnt area) (Bhaskar et al. 2019). The habitat heterogeneity hypothesis (Tscharntke et al. 2002; Tews et al. 2004) explains that the small-scale burning is less detrimental to biodiversity than large-scale burning. The extent of area burnt may thus be an adequate strategy to minimize potential negative effects on species-rich insect communities (Bhaskar et al. 2019). The change in composition of fauna (birds, mammals and invertebrates) in post-fire habitat varies (Burrows, 2008). Effects of fire on biodiversity are well documented in Prairies, savannahs and coniferous forests (Hochkirch and Adorf 2007).

Prescribed burning and its impact studies are really scarce in tropics (Bhaskar et al. 2019). The use of fire as a tool to manage habitat is still a subject of debate (Bhaskar et al. 2019) particularly on its impact on invertebrates (Swengel 2001; Pullin 2002; Fredericken and Fredericken 2002). Effects of fire on invertebrates include the varying fire regimes, differing ecological pre- and post-fire conditions and the difference in the taxonomic groups (Moretti et al. 2004). The species richness and composition of invertebrates change after fire (e.g. Sgardelis and Margaris 1993; Yanovsky and Kiselev 1996; Orgeas and Andersen 2001; Simila et al. 2002) as a direct impact of fire (e.g. York 2000, Wikars 2001). The frequency of burning or fire incidences influence the species composition of flying insects, repeatedly burnt sites host more rare and endangered species than unburnt sites (Moretti et al. 2004). Fire and grazing in grasslands lead to changes in food quality and vegetation structure that may affect susceptibility to predation, or affect opportunities for thermoregulation of grasshopper (Joern, 2004). Post-fire recolonizations of grasshoppers are considered to be very important part of fire impact studies (Evans 1984). A prolonged rate of recolonization and higher abundance of grasshoppers at the edges of the burnt areas are observed than in the centre (Hochkirch and Adorf 2007). A decrease in grasshopper species richness and abundance from annually to triennially burnt experimental plots was observed (Chambers and Samways, 1998). Branson and Vermeire (2007) recorded the impact of fire intensity on the eggs of grasshoppers. There are reports of fire-related melanism among grasshoppers from Europe (Hochkirch et al. 2008; Gardiner 2014). Fire affects fecundity, survival, and dispersal of individual grasshoppers which ultimately determine population abundance (Joern 2004). Direct effects of fire on grasshoppers include burnt death (Bock and Bock 1991) and egg mortality due to increased soil temperatures (Branson and Vermeire 2007). Indirect effects include shifting of host plant or plant community composition (Porter and Redak 1996; Vermeire et al. 2004), changes in natural enemy abundance or behaviour (Branson et al. 2006) and post fire changes in soil moisture or temperature regimes affecting egg developmental phenology or mortality (Meyer et al. 2002). Grasshopper responses to fire can also be species specific and heavily dependent upon the timing and intensity of the burn (Joern 2004; Branson and Vermeire 2007). Density of grasshopper population is often found to be increasing with fire events in the tall grass prairie (Knutson and Campbell 1976; Meyer et al. 2002). The effects also vary with the frequency of fire incidences (Evans 1988a).

The foregoing discussions indicate lack of information on grasshoppers in the Western Ghats. This is especially true in relation to habitats and elevational gradients. The impacts of fire on invertebrates such as grasshoppers have not been a subject of study in any of the regions of Western Ghats. Hence, the present study investigates the diversity and ecology of grasshoppers in two protected areas of Southern Western Ghats.

STUDY AREA

The Protected Areas of Western Ghats are well known to their richness in faunal and floral components. The study area includes two Protected Areas of Southern Western Ghats; Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR) (Fig. 3.1). Both ENP and PKMTR are known mainly in terms of larger mammal diversity and distribution.

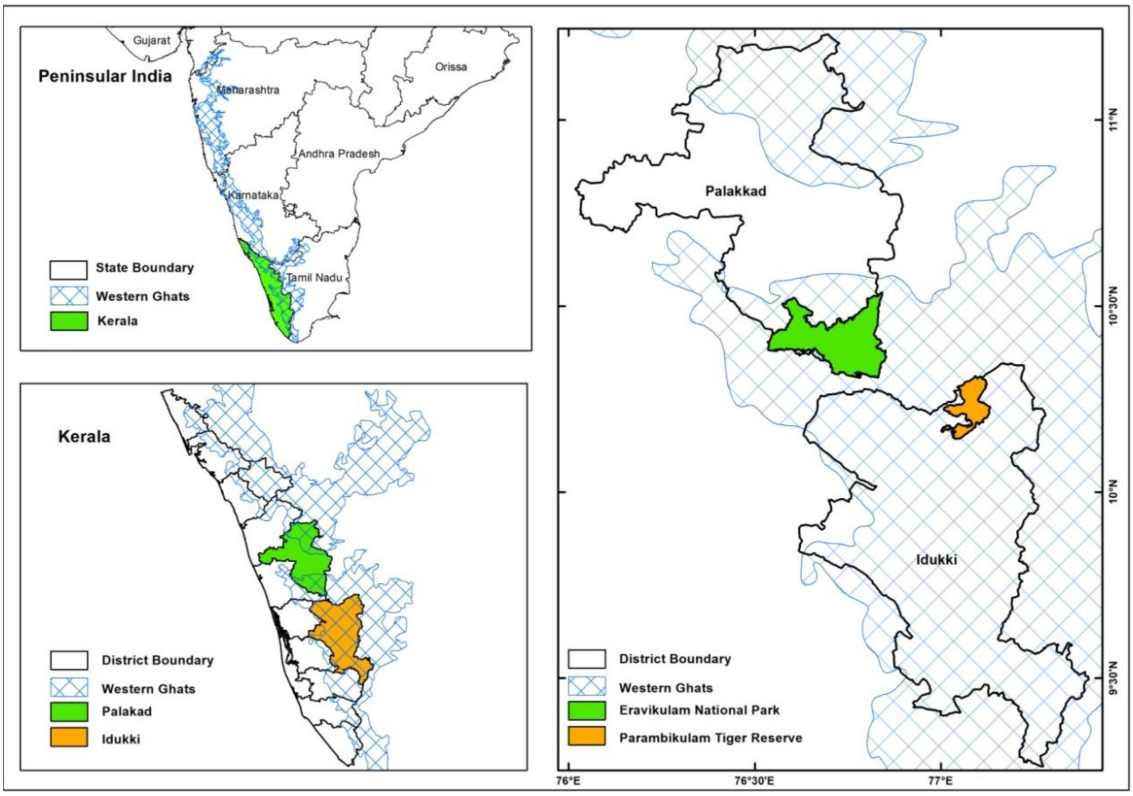


Fig. 3.1 Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR)

3.1 Eravikulam National Park

Eravikulam National Park (10°05’-10°20’N, 77°0’-77°10’ E) is located in the Kannan Devan Hills of Idukki district in Kerala. Initially declared as Eravikulam-Rajamala Wildlife

Sanctuary in 1975 for the protection of the Nilgiri tahr and its habitat, it was given the status of a National Park in 1978. The name “Eravikulam” represents a lake in the core area of the National Park. The 97 km^2 National Park consists of high altitude grasslands interspersed with sholas and shrubs. A high rolling plateau having a base elevation of ca. 2000 m asl comprises the main body of the Park.

3.1.1 Terrain

The Park is with an undulating terrain with a cover of high altitude grasslands interspersed with sholas (Southern montane wet temperate forest) and shrubs. The montane grasslands are distributed as mosaic across the rugged terrain. The elevated landscape of ENP are slopes (low to steep), flat mountain tops and valleys (water logged and well drained). The 97 km^2 high rolling plateau of ENP with a base elevation of ca. 2000 m asl possess hillocks of 100 to 300m peaks. The northwest and southwest plateau has the steep Turner’s valley. The sheer southern fringe is occupied by broken cliffs descending from Anamudi and Umayamala hillocks. The main land is less steep with cliffs often grading into rock slabs with numerous brakes of grasslands, shrubs or forests. The cliffs are usually not abrupt but rounded both horizontally and vertically.

3.1.2 Geology

The geological formation in the ENP is of Archaean igneous origin with granite, gneiss and minerals such as silica, feldspars, muscovite along with ferro-magnesium. The soil is rich with organic matter composition especially in the litter filled sholas. The soil composition involves; sand (79.43 – 94.14 %), silt (1.43 – 11.00 %), clay (2.71 – 5.57

%) and some gravel, altogether approximately 30-100 cm in depth. The soil is loamy, acidic (pH 5.2 – 5.6) with a high organic carbon (18% in grassland and 22.5% in shola) and total N (0.7% in grassland and 1.2% is shola) (Koshy 1970; Jose et al*.* 1994). The granular, friable, sandy loam interspersed with a little gravel soil. The thick soil cover is composed of different layers of black to dark gray in colour. Depth of soil varies in valleys, bogs and sholas (KFD 2012a).

3.1.3 Climate and Rainfall

The geographical advantage favours the tropical climatic conditions within the Park area. The South - West monsoon from June to August and the North - East monsoon from September to November dominates the annual weather cycle. Along with the two monsoon seasons, the winter (December to February) and summer (March to May) covers the four weather seasons. From June to November, the area will be mostly covered with mist of the monsoon seasons. The table top elevated hill ranges favours good microclimatic conditions to the flora and fauna resulting in high range of endemicity (KFD 2012a).

The pattern of rain is not continuous, occasional heavy showers lasts for less than an hour. The ENP itself doesn’t possess a weather station. It depends on the adjacent tea estate weather station for climatic data. An average of 60% of the annual rainfall in ENP is contributed by the South-West monsoon. The North-East monsoon from September accounts for nearly 30% of the total precipitation. The summer showers occur during February - April. The pattern of rainfall varies greatly across the Park (KFD 2012a). The temperature rises during January – May, which drops with arrival of monsoon. The minimum temperatures are during the winter months, leads to frost conditions during winter nights. The nights are clear and through radiant heat loss the surface temperature at times reaches freezing point. The day temperature during this period goes to 23 - 25^0 C. Humidity also varies with season. During monsoon, it is as high as 83–100% and during winter days as very low to 59-62% that further declines with high wind velocity. The dry winds blow from the east during February – March and low velocity winds occur during north – east monsoon and in the winter season.

3.1.4 Flora and Fauna

With unique bio-geographic conditions, ENP is home for many rare and endemic floral and faunal components. The mosaic habitats of shola and grasslands interspersed with shrubs are unique habitats in the Western Ghats. About 60% of the Park falls under Grasslands (southern montane wet temperate grass land), 25% by shola (southern montane wet temperate forest) forests and 7.5% constitute the shrubs (Menon 1997).

The flora of ENP includes 803 taxa including 727 Angiosperms and 76 Peridophytes that belongs to 332 genera representing 134 families. Dicotyledons dominate with 505 species belonging to 240 genera and 90 families. Monocotyledons are represented by 222 species under 92 genera and 16 families. Nearly 190 species are endemic to Western Ghats (KFD 2012a). The shola forests of ENP is a continuous canopy with evergreen tree species covered with lichens, orchids, mosses and many species of creepers. Major tree species in the Park include *Pithecellobium subcoriaceum*, *Ixora notoniana, Syzygium arnottianum, Ilex denticulata, Michaelia nilagirica, Elaeocarpus* *recurvatus, Microtropis ramiflora, Actinodaphne bourdellonii, and Symplocos pendula*. *Rhododendron arboretum* is commonly distributed across the edges of shola, lake and streams. Major herbs and shrubs include *Gaultheria fragrantissima, Moonia heterophylla, Jasminum bignoneacium, Smithia blanda* and *Valeriana hookeriana.* Among the shrubs, *Strobilanthes kunthinum* is well known with its unique blooming cycle of 12 years. The undergrowth of shola is represented by certain species of *Strobilanthes* and *Impatiens.* The creepers include *Piper schmidtii, Rubia cordifolia,* and *Connarus wightii* (KFD 2012a). The grass species such as *Andropogon lividus, Arundinella vaginata, Digitaria wallichiana* and *Arundinella mesophylla* and grass species of genus *Cymbopogon are* also frequent and dominant (Karunakaran et al. 1998).

The fauna of ENP includes 49 species of mammals among which 17 are endemic to Western Ghats (ZSI 2002; KFD 2012a). The Park is well known for its larger mammal population. The major carnivores include *Panthera tigris* (Tiger), *Panthera pardus* (Leopard), *Felis chaus* (Jungle Cat) and *Cuon alpinus* (wild dog). The omnivores such as *Melursus ursinus* (Sloth Bear), *Semnopithecus johnii* (Nilgiri langur), and *Sus scrofa* (Wild Boar) are found in the sholas and on the fringes. The grasslands and shola are inhabited by herbivores such as *Elephas maximus* (Asian Elephant), *Bos gaurus* (Gaur) and *Nilgiritragus hylocrius* (Nilgiri tahr). The Nilgiri tahr (*Nilgiritragus hylocrius*), a threatened mountain goat is an endemic species confined to the habitats of ENP and Southern Western Ghats (Easa and Alembath 2019). The Nilgiri tahr is an endangered species on the IUCN Red List (Alempath and Rice 2008). The other faunal components of ENP includes 13 species of reptiles, 132 species of birds, 20 species of amphibians and 101 species of butterflies (ZSI 2002; KFD 2012a).

3.2 Parambikulam Tiger Reserve

Parambikulam Tiger Reserve (PKMTR) is situated between Anamalai and Nelliyampathy hill ranges in Palakkad district in Kerala (10°20’-10°32’ N, 76°35’-76°5’ E) and was established as Tiger Reserve in February 2010. The Tiger Reserve has an area of 644 km^2 and an altitude range from 460 m to 1439 m. The major habitats of PKMTR are West coast tropical evergreen forests (IA/C4), West coast semi-evergreen forests (2A/C2), Southern moist mixed deciduous forest (3B/C2), Southern dry mixed deciduous forests (5A/C3), Moist bamboo brakes (2/E3) (Chandrasekharan 1962; Champion & Seth 1968). The habitat is represented by low altitude marshy grasslands (Vayals), Teak (*Tectona grandis*) plantations, thin crust of grasslands on the hilltops (Karimala and Pandaravara) and Riparian forests.

3.2.1 Terrain

The PKMTR exhibits hilly areas interspersed with undulating plains and marshy grasslands (Vayals). The hilltops of PKMTR part of Anamalai hills including Karimala (1439m), Vengoli (1120m) and Pandaravara (1290m) are covered with thin crust of grasslands. The northern boundary opens to the Nelliyampathy hills at an average elevation of 600m. The hill ridges have valleys and slopes that lead the streams to the plains. The major valleys of PKMTR are represented by the rivers and streams from the hilltops. From north to south, there are six major valleys; Thekkady-Keerapady valley (along the Thekkady river), Thunacadavu valley (along the Thunacadavu river), Parambikulam valley (along the Parambikulam river), Pulikkal valley (along the Pulikkal river), northern half of Karappara valley (along the Karappara river) and Thuvaiar valley (along the Thuvai river) (Karthikeyan and Thomas 2013).

3.2.2 Geology

The geological formation of PKMTR represents the Pre Cambrian (570 million years ago) era. The rock of the PKMTR and the Western Ghats as a whole is formed of charnockites (Karthikeyan and Thomas 2013). Hornblende biotite gneiss, garnetiferous biotite gneisses and charnockites, intruded by granitic orthoclasic gneisses and plagioclase porphorite dyke had been identified as the major formations in the PKMTR by Geological Survey of India (1963-64). Major geologic formations are metamorphic whereas the intruded ones are igneous in origin (KFD 2012b). Major minerals found in the rocks of PKMTR are quartz (SiO2), feldspars (Orthoclase) (KAlSi3O2), Biotite [Mica, H2K(Mg, Fe)8Al(SiO4)3], Hornblende [Ca(Mg, Fe)4Al(Si7Al)O22(OH,F)2] and Hypersthenes [(Mg,Fe)2SiO6]. The soil varies in their depth, texture, internal drainage, and degree of erosion. The properties of the soil are further influenced by the type of vegetation cover and the habitat conditions. The upper slopes of the Reserve possess shallow gravelly soil and deep filler textured soil to the lower slopes and in the valleys. Alluvial deposits are also found along the stream and riverbanks. The soil types include alluvial soil, laterite soil, red soil and forest – hill soil (KFD 2012b).

3.2.3 Climate and Rainfall

The physiographic nature of the Tiger Reserve strongly influences the climate. The hilly cliffs of PKMTR separate the moist windward valleys and hills from the north-eastern dry plains of Palghat gap and Pollachi plains. Major part of the sanctuary is along the windward region and receives high rainfall. The PKMTR exhibits tropical climatic conditions with temperature gradients from 15 ºC to 39 ºC. The South - West and the North - East monsoon from September to November dominates the annual weather cycle. The South – West monsoon contributes to the maximum precipitation. Beginning of the year is considered as the driest month (January) with a monthly average of just 3.24 mm rainfall. The pre-monsoon showers start from April and May. The month of June and July has been the wettest period with an average rainfall of 455.94 mm. The average rainfall within the reserve varies between 1400mm and 2300mm. Based on the monsoon, three seasons had been identified; dry season (January to May), wet season-I (June to September) and wet season-II (October to December) (KFD 2012b).

3.2.4 Flora and Fauna

The natural vegetation of PMTR have been classified into five major forest types; West coast tropical evergreen forests, West coast semi-evergreen forests, Southern moist mixed deciduous forest, Southern dry mixed deciduous forests and Moist bamboo brakes (Chandrasekharan 1962 and Champion and Seth 1968). The vegetation also includes low altitude marshy grasslands (Vayals), Teak (*Tectona grandis*) plantations and the thin crust of grasslands on the hilltops (Karimala and Pandaravara). The West coast tropical evergreen forests of PKMTR support luxuriant growth of trees and woody climbers with closed canopy. The high humidity, shade and sheltered conditions of the evergreen patches provide ideal habitat for epiphytic as well as terrestrial orchids, ferns, mosses and other herbaceous plants. The major tree species occupying the higher altitudes are Mesua-Cullenia-Calophyllum, Palaquium-Calophyllum, MesuaCullenia and Palaquium-Mesua and lower altitudes with Vateria-

Calophyllum, HopeaDiospyros, Dysoxylum malabaricum, VateriaCalophyllum, Palaquium-Mesua and Hopea-Diospyros-Mesua (Sasidharan 2002). The Moist Deciduous Forests (MDF) in the Reserve are well known for the valuable timbers like teak. The Kannimara Teak in the MDF is regarded as one of the largest and oldest teak in the world. The major dominant trees in MDF include, towards the eastern side, *Anogeissus latifolia, Cleistanthus collinus, Shorea roxburghii, Madhuca indica, Holoptelea integrifolia, Semecarpus anacardium, Lannea coromandelica, Cassine glauca* along with which thorny species like *Zizyphus* and *Catunaregam* as undergrowth (Sasidharan 2002). The moist bamboo brakes of *Bambusa bambos* are rich in Vengoli, Seechali and Padippara along the banks of rivers and reservoirs. Associated trees include *Terminalia elliptica, Tectona grandis* and *Albizia odoratissima* (Sasidharan 2002). The Southern dry mixed deciduous forests occupy comparatively very small area around Kuchimudi and along the eastern slopes of Pandaravarai. *Anogeissus latifolia* is the dominant tree along with *Tectona grandis, Givotia molucanna, Pterocarpus marsupium, Cleistanthus collinus, Strychnos potatorum, Premna tomentosa* (Sasidharan 2002). The thin crust of grasslands on the hilltops at Karimala, Vengoli and Pandaravarai are dominated by grasses, herbs and sub-shrubs. A palm *Phoenix loureirii* is common in the grasslands along with grasses inlcuding *Arundinella leptochloa, Chrysopogon hackelii, Cymbopogon flexuosus, Sacciolepis indica, Themeda triandra* and *Zenkeria elegans* (Sasidharan 2002). The low altitude marshy grasslands of PKMTR are also known as Vayals are with grasses and sedges. The common plant species are *Axonopus compressus, Paspalum* spp., *Eragrostis* spp., *Lipocarpha chinensis, Fuirena umbellata, Fimbristylis* spp., *Cyperus* spp. (Sasidharan 2002).

With heterogeneous habitat conditions, PKMTR is home for many rare and endemic fauna of Western Ghats. There are 39 species of mammals reported from the Tiger reserve (Easa and Balakrishnan 1990; Sreehari and Nameer 2016). Common primates are bonnet macaque (*Macaca radiata*), Nilgiri langur (*Presbytis johni*), lion tailed macaque (*Macaca silenus*), common langur (*Presbytis entellus*) and slender loris (*Loris tardigradus*). Three major cat species are tiger (*Panthera tigris*), leopard (*Panthera pardus*) and jungle cat (*Felis chaus*). Herbivorous mammals include Asian elephant (*Elephas maximus*), gaur (*Bos gaurus*), chital (*Axis axis*), sambar (*Cervus unicolor*), barking deer (*Muntiacus muntjak*) and mouse deer (*Tragulus meminna*). The omnivores such as *Melursus ursinus* (sloth bear) and Indian wild boar (*Sus scrofa*) are also common in PKMTR. Other than mammals, 52 species of reptiles, 24 species of amphibians, 274 species of birds, 47 species of fishes and 1049 species of insects have been recorded from PKMTR (KFD, 2012b).

Chapter IV

DIVERSITY OF SHORT-HORNED GRASSHOPPERS IN PARAMBIKULAM TIGER RESERVE AND ERAVIKULAM NATIONAL PARK

4.1 INTRODUCTION

4.1.1 Diversity studies on Grasshoppers

Grasshoppers (Orthoptera: Caelifera) are the most familiar and significant group of insects in terrestrial habitat on the earth (Uvarov 1966; Kevan 1982). They are dominant herbivores and key living component of grassland ecosystems in terms of nutrient cycling (Uvarov 1966; Mitchell and Pfadt 1974; Belovsky and Slade 1993; Gangwere et al. 1997; Cigliano et al. 2000; Guo et al. 2006). Functional roles of the Orthopterans in all the diverse ecosystems identified themselves as model organisms for studying anatomy, physiology, neurobiology, bioacoustics, chemical ecology, life-history traits, speciation research and evolutionary ecology (Song et al. 2015). Hence grasshoppers are very important group of organisms in the field of environmental studies. The Orthopterans are comparatively least explored among the group of insects in India. Some of the highly biodiversity rich areas of India such as the Western Ghats (WG) are never explored for grasshoppers after the colonial researchers. Most of the 1033 known Indian grasshopper species were described by Britishers or other researchers from abroad (Chandra et al. 2010).

The peak period of Indian Orthoptera research ended up by mid of the 20th century when the foreign researchers left the Indian subcontinent. It is mostly the researchers from Europe who pioneered the Indian Orthoptera expeditions.

Westwood (1839) described three species (one each from the subfamily Chorotypinae, Mecopodinae and Tripetalocerinae) from Kerala part of India. Ignacio Bolivar attempted to explore the Orthopterans of South India by the end of 19th century and the beginning of 20th century (Bhaskar et al. 2018). Bolivar (1887, 1900, 1902 and 1917) described 100 species in the suborders Ensifera and Caelifera from the southern states of India (Tamil Nadu and Kerala). Candido Bolivar took charge of the remaining part of the Indian expeditions from Ignacio Bolivar during the beginning of 20th century. Candido Bolívar described two species of Chorotypinae and one Mastacideinae from Karnataka state of India during 1914. Kirby (1914 a and b) described nine species from various part of Indian subcontinent. Uvarov (1929) described four of Acridinae; one each of Orthacridinae and Spathosterninae from Tamil Nadu and one of Oxyinae species from Karnataka. Candido Bolivar (1930) described three of Mastacideinae from Tamil Nadu and two from Karnataka; one each of Caliptaminae and Chorotypinae from Maharashtra and Tamil Nadu respectively. Hebard (1930) described five species of pygmy grasshoppers (Tetrigidae) from Tamil Nadu region. Henry (1933 and 1940) reported 16 new species from three southern states. During 1933, Henry described one species of Acridinae from Karnataka. Henry (1940) described eight Catantopinae (seven from Kerala and one from Tamil Nadu), two Gomphocerinae from Karnataka, one Phaneropterinae from Kerala, three Pseudophyllinae (two from Kerala and one from Tamil Nadu) and one Prionacanthinae from Kerala. The active species description era of Indian Orthoptera ended up by mid of 20th century. Later, Priya and Narendran (2003), Kulkarni and Shishodia (2004), Usmani and Nayeem (2012), Desutter-Grandcolas and Jaiswara (2012), Mandal (2014), Gupta (2016 a and b), Gupta and Chandra (2017 a and b), Bhaskar et al. (2018), Skejo et al. (2019), Bhaskar et al. (2019) and Bhaskar et al. (2020) contributed to the information on the diversity and ecology of Indian Orthoptera. Grasshoppers in India are so far not being considered as a biodiversity indicator. But most of the works were considering it as an agricultural pest (Bhaskar et al 2018). Hence, most of the Orthopteran research in India has been confined to the agricultural universities and regional pest research stations of India.

The Protected Areas of Western Ghats are highly significant in terms of its biological diversity. It is the significance of this chain of highlands marked it as one among the global biodiversity hotspot (Myers et al. 2000). The 1600 km chain of highlands covers five major states of South India (Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala). As mentioned above, all the pioneering Indian Orthoptera expeditions were centered on these southern states. Unfortunately, there were no scientific revisits for the grasshoppers of Western Ghats except for a few pest research expeditions in the agricultural areas. The forested areas of Western Ghats including the Protected Areas still remain untouched and unexplored in terms of the grasshopper diversity. The WG is very significant as it is the type locality for some of the endemic grasshoppers (Cigliano et al. 2018). Most of the 790 species mentioned in the ‘Faunal Diversity in India’ by Tandon and Hazra (1998) are known from biodiversity hotspots such as Western Ghats.

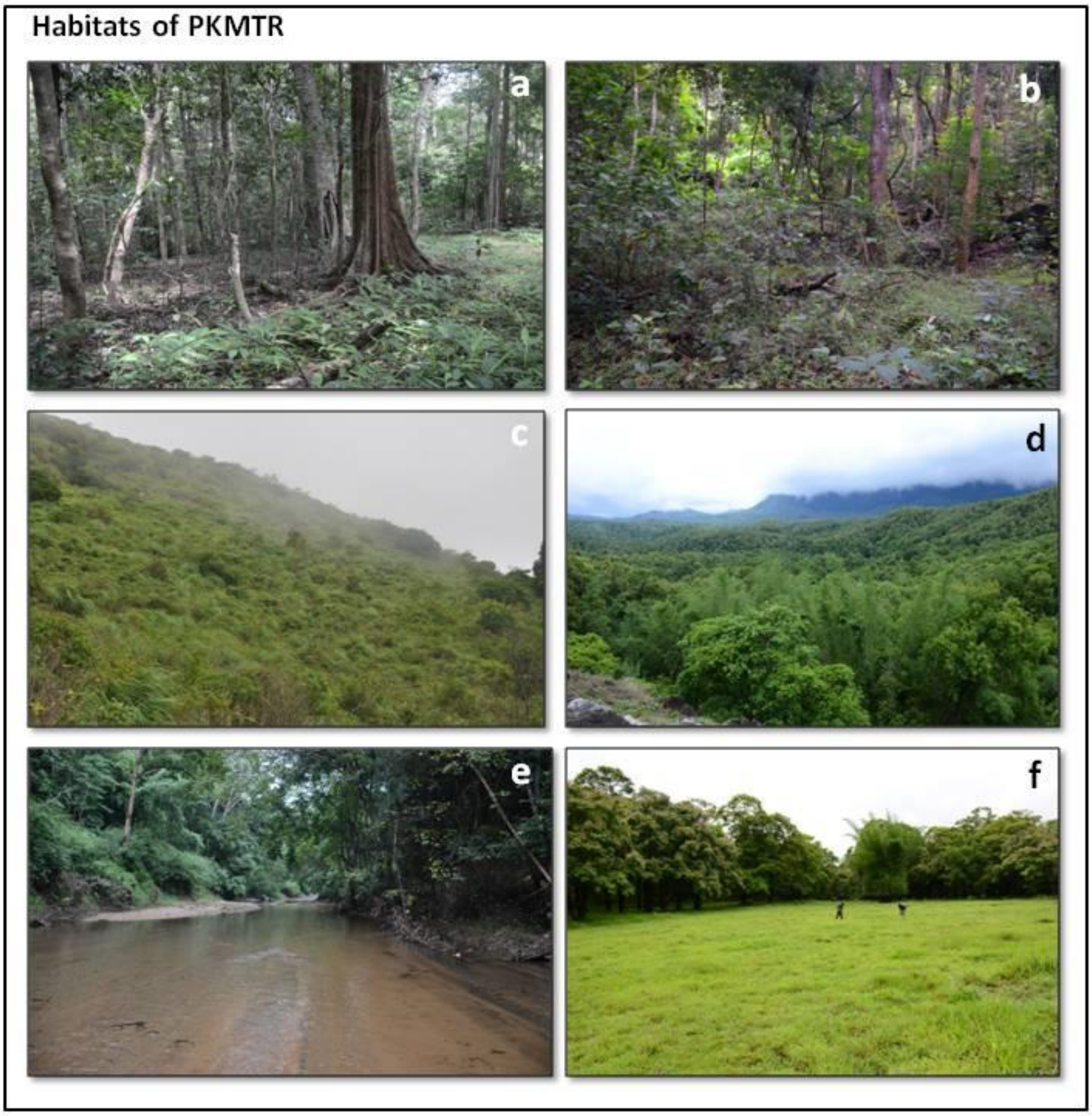
A checklist of Orthoptera in Kerala was compiled and published by Bhaskar et al. (2018) in which 130 species of Orthoptera was reported. Since the forested areas of the Kerala part of WG has been the real centre of exploration by earlier researchers, a study was carried out on the diversity of grasshoppers in different forest habitat types of WG. Two very significant Protected Areas of the southern Western Ghats *viz.* Eravikulam National Park and Parambikulam Tiger Reserve, Kerala were selected. Both the areas are highly heterogeneous in terms of its habitat complexity.

Eravikulam National Park (ENP) (Fig. 4.1 g to i) is a very unique Protected Area. The 97 km^2 National park consists of high altitude grasslands (southern montane wet temperate grassland) interspersed with shrubs and shola forests (southern montane wet temperate forest) with a base elevation of 2000 m asl. In ENP, 60% of the area is with grasslands, about 25% by shola forests and 7.5% constitute the shrubs (Menon 1997). A detailed description of the area is given under study area in Chapter III.

Parambikulam Tiger Reserve (PKMTR) (Fig. 4.1a to f) is one of the richest wildernesses in the Western Ghats. According to the revised classification of forest types of India (Chandrasekaran 1962; Champion and Seth 1968), the forested areas of PKMTR comes under five categories; West coast tropical evergreen forests (IA/C4), West coast semi-evergreen forests (2A/C2), southern moist mixed deciduous forest (3B/C2), southern dry mixed deciduous forests (5A/C3) and Moist bamboo brakes (2/E3). The forested areas of PKMTR covers more than 70% of the Reserve, with 36% evergreen forest, 17% Semi evergreen forest, 20% moist deciduous forest (Magesh 2014). Other than the categorised forest types, the vegetation of PKMTR is also represented by low altitude marshy grass lands (vayals), plantations of teak and eucalypts, thin-crust of grasslands on the hilltops (Karimala and Pandaravara) and river associated vegetation. Details of PKMTR are given under study area in Chapter III. Grasshopper diversity of these two areas are least explored but for Shishodia and Kulkarni (2002), who reported 12 species of Orthopterans in general from ENP. The grasshopper of PKMTR was never documented.

The eight Catantopinae (Orthoptera) species of Henry (1940) is an example of rarity of the Western Ghats endemic grasshoppers. For example, the genus Mopla (Henry 1940) is known only from the type specimens deposited in Natural History Museum London (BNHM). Henry struggled to get a single male specimen or even more than one female type. The two species (*Mopla guttata* and *Mopla rubra*) were described from a single female specimen. Henry (1940) mentioned the multiple failed attempts in search of male from the particular genus. Henry (1940) foresighted the possibilities of more rare endemic grasshoppers from Kerala part of the WG. Seventy six years later, the first male specimen of the genus *Mopla* was discovered from Parambikulam Tiger Reserve, Kerala (Bhaskar et al. 2020). The male specimen of *Mopla guttata* was collected from 3km of its type locality (Top slip station, Anamalai). The study also restarts the species description era of Orthoptera of southern India that ended up during the mid of 20th century with a new species from the shola forests of Eravikulam National Park, named as Siva’s pygmy trishula (*Tettilobus trishula* Skejo, Bhaskar et Stermšek sp. nov.).

As a part of the present investigation, diversity study across different habitats of ENP and PKMTR were studied for documenting the diversity, structure and composition and abundance of grasshoppers.


Habitats of PKMTR

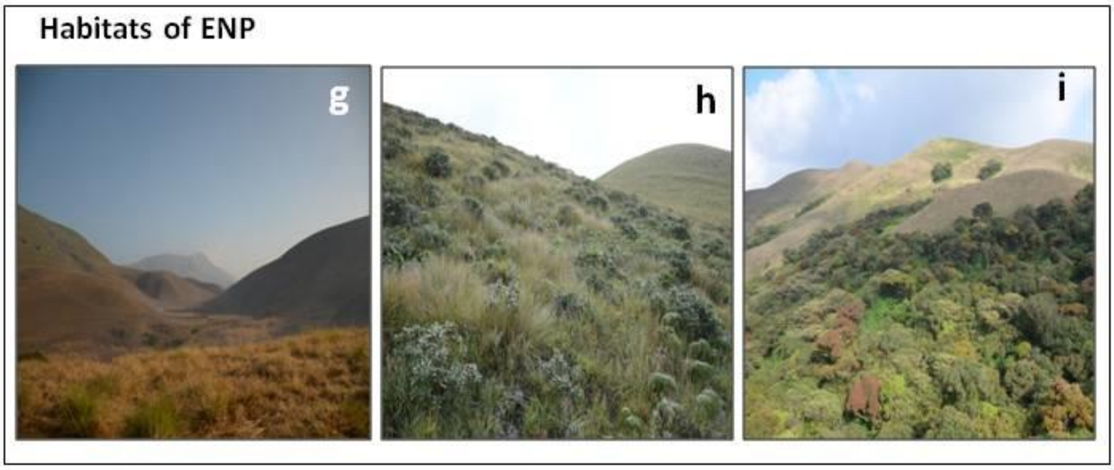

Habitats of ENP

Fig. 4.1. Habitats of PKMTR (a.evergreen, b.semi-evergreen, c.grasslands, d.moist deciduous forests, e.riparian and f.vayals) and in ENP (g.grasslands, h.shrubs and i.shola)

4.2 METHODS

4.2.1 Grasshopper sampling

Grasshopper diversity of PKMTR and ENP were documented by recording species richness and abundance in every habitat from January 2015 to May 2018 between 10.00 and 18.00 hrs. Since grasshopper activity is strongly dependent on the weather conditions, all the counts were performed during sunny and windless weather. Sweeping and suction sampling were not suitable for different habitats where vegetation is dense and with wet foliages. As grasshoppers always choose the open environment (in most cases they place themselves onto the surface of the vegetation), direct observation and hand picking are considered to be the most chosen technique by ecologists. Moreover, since transect visual count method is less influenced by the vegetation type, it is considered to be the effective way to achieve quantitative data on grasshopper abundance (Hochkirch and Adorf 2007). Accordingly, direct observation and hand searching along transects were used. Grasshopper richness and abundance were sampled by visual count (direct observation) and hand searching on randomly selected 25m transects in every habitat. Each transect was walked at a slow pace (2 km/h) and the number of grasshoppers flushed in a 0.5m strip in front of the observer counted (Isern-Vallverdu et al. 1993). Each transect walk took 10 min to complete, which included identifying and counting of grasshoppers. The secondary effect of the vegetation structure was never recorded systematically. However, the vegetation conditions along the transects were photographed.

The count was repeated thirty times on each transect in every habitats of both ENP and PKMTR for three consecutive years to account for the grasshopper richness and abundance. Since grasshoppers are highly specific to their microhabitat conditions such as vegetation structure, the habitats of PKMTR and ENP were categorised accordingly. Evergreen, semi-evergreen, grasslands, moist deciduous forests and riparian were sampled in PKMTR and grasslands, shola and shrubs in ENP. One hundred and eighty transects were covered for PKMTR (Evergreen – 30, Semi evergreen – 30, MDF – 30, Riparian – 30, Vayals – 30, Grasslands – 30) and 90 for ENP (Grasslands – 30, Shrubs – 30, Shola - 30). The three year survey from Jan 2015 to Jan 2018, each year 10 transects were sampled in every habitat of both the study areas. The areas were sampled every month except during the monsoon peak months (June and July). Time was also spent in the field for some exclusive species that are later described as new, rare and rediscovered species. A checklist of grasshoppers sighted during the present study was prepared for both ENP and PKMTR.

4.2.2 Grasshopper identification

After each sampling along the transect, the grasshoppers were photographed, quantified and identified. Collected voucher specimens were preserved and deposited in Kerala Forest Research Institute (KFRI) Entomology Museum (we were not permitted to collect all specimens captured in the sweep net in Protected Areas). Unidentified and taxonomically complex species were later identified using a variety of taxonomic literature (Westwood 1839; Bolívar 1900, 1902 a and b, 1914, 1930; Kirby 1914 a; Uvarov 1929; Chopard 1969; Henry 1937, 1940) and by consulting experts. The specimens were also compared with the type specimens in the British Natural History

Museum London (BNHM), Natural History Museum Madrid (MNCN), Natural History Museum Paris (MNHN) and Natural History Museum Geneva (MHNG). The taxonomy follows the latest version of the Orthoptera Species File (Cigliano et al. 2019).

4.2.3 Data analysis

EstimateS (Version 9.1.0) was used to estimate total species richness from the observed richness, and to plot species accumulation curves, non-parametric estimators namely Chao 2 and Jacknife 2 (Colwell 2013) were employed.

The software PAleontological STatistics (PAST) Version 3.25 was used to calculate different diversity indices and test for significant difference between different habitats of both ENP and PKMTR. Diversity indices such as Shannon, Simpsons, Fisher's alpha and Margalef were calculated for each habitat of ENP and PKMTR. Simpson index is one of the robust measures of diversity that indicates the variance of species abundance distributions (Magurran 2004). Fisher's alpha is a parametric measure of diversity, which has been widely applied to log-series abundance distribution patterns and is unaffected by sample size (Magurran 2004). Margalef index measures species richness (Gamito 2010). Equitability or evenness index measures the similarities of abundance distributions of different species (Magurran 2004). Equitability J index provides comparison of Shannon-Wiener index with the distribution of individuals in the observed species which would have the maximum diversity (Henderson and Seaby 2001).

Kruskal Wallis test was performed using PAST V 3.25 to find significant difference in total number of species and individuals per transect counts among the three habitats in ENP and six habitats in PKMTR. Mann-Whitney U test was used to detect significant difference of total number of species and individuals per transect count between different habitats. Rank abundance curves were plotted for habitats of ENP and PKMTR to display species abundance distributions and visualise difference in evenness among grasshopper assemblages. Assemblages with high dominance show steep curves while assemblages with more evenness show shallow slopes (Magurran 2004).The cluster analysis among different habitats of ENP and PKMTR was performed using PAST V 3. 25 to understand the similarities in species composition between habitats in both the study areas.

4.3 RESULTS

A total of 58 species were found in PKMTR and ENP, 18 of which are endemic to India. Fifty-five grasshopper species were recorded in PKMTR and 18 in ENP (Table 4.1), with 15 species common to both the areas. Thirty-nine species were exclusively found in PKMTR, but only three in ENP (Fig. 4.2). A new pygmy grasshopper species of the genus *Tettilobus* (Orthoptera: Tetrigidae) was described from the shola forests of ENP and named it as *Tettilobus trishula sp. nov*. In PKMTR, the Catantopinae species *Mopla guttata* was rediscovered for the first time since its description in 1940, representing also the first male collected for this species. In PKMTR, the record of *Euparatettix personatus* and *Deltonotus subcucullatus* of family Tetrigidae were the first record from India.

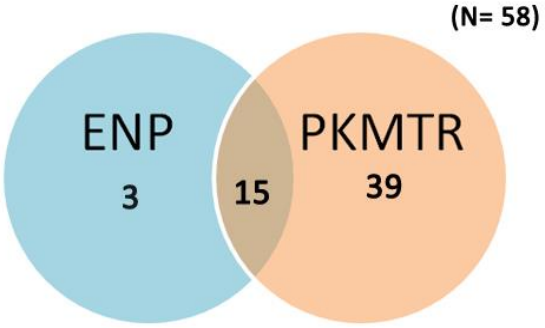


Fig. 4.2. Venn diagram of number of grasshopper species recorded from Eravikulam National Park and Parambikulam Tiger Reserve

Sr No.	Taxon	PKMTR	ENP	Distribution
INFRAORDER **ACRIDIDEA**				
FAMILY **ACRIDIDAE**				
Subfamily **ACRIDINAE**				
1.	*Acrida exaltata*	**+**	**-**	
2.	*Acrida gigantea*	**+**	**-**	
3.	*Carliola carinata*	**+**	**+**	*****
4.	*Phlaeoba antennata*	**+**	**-**	
5.	*Phlaeoba infumata*	**+**	**-**	
6.	*Phlaeoba panteli*	**+**	**-**	
7.	*Zygophlaeoba sinuatocollis*	**-**	**+**	
Subfamily **CATANTOPINAE**				
8.	*Bambusacris travancora*	**+**	**+**	*****
9.	*Choroedocus illustris*	**+**	**-**	*****
10.	*Diabolocatantops innotabilis*	**+**	**-**	
11.	*Naraikadua charmichaelae*	**+**	**-**	*****
12.	*Pachyacris vinosa*	**+**	**-**	
13.	*Palniacris maculatus*	**+**	**+**	*****
14.	*Siruvania dimorpha*	**+**	**+**	*****
15.	*Xenocatantops humilis*	**+**	**+**	
16.	*Oxyrrhepes obtusa*	**+**		
17.	*Mopla guttata*	**+**	**-**	*****
Subfamily **CYRTACANTHACRIDINAE**				
18.	*Chondracris rosea*	**+**	**-**	
19.	*Cyrtacanthacris tatarica tatarica*	**+**	**+**	
20.	*Patanga succincta*	**+**	**-**	
Subfamily **EYPREPOCNEMIDINAE**				
21.	*Tylotropidius varicornis*	**+**	**-**	

Subfamily **GOMPHOCERINAE**				
22.	*Aulacobothrus taeniatus*	**+**	**-**	
23.	*Aulacobothrus socius*	**+**	**-**	
Subfamily **HEMIACRIDINAE**				
24.	*Hieroglyphus banian*	**+**	**-**	
25.	*Leptacris filiformis*	**+**	**-**	*
Subfamily **OEDIPODINAE**				
26.	*Dittopternis venusta*	**+**	**+**	
27.	*Trilophidia annulata*	**+**	**-**	
Subfamily **OXYINAE**				
28.	*Gesonula punctifrons*	**+**	**-**	
29.	*Hygracris malabaricus*	**+**	**-**	*
30.	*Oxya hyla*	**+**	**+**	
31.	*Oxya japonica japonica*	**+**	**-**	
32.	*Oxya fuscovittata*	**+**	**-**	
Subfamily **SPATHOSTERNINAE**				
33.	*Spathosternum prasiniferum*	**+**	**-**	
Subfamily **TERATODINAE**				
34.	*Teratodes monticollis*	**+**	**+**	
FAMILY **CHOROTYPIDAE**				
Subfamily **CHOROTYPINAE**				
35.	*Phyllochoreia ramakrishnai*	**+**	**-**	*
36.	*Phyllochoreia unicolor*	**+**	**-**	*
37.	*Burrinia burri*	**+**	**-**	*
Subfamily **PRIONACANTHINAE**				
38.	*Prionacantha picta*	**-**	**+**	
FAMILY **MASTACIDEIDAE**				
Subfamily **MASTACIDEINAE**				
39.	*Paramastacides ramachendrai*	**+**	**+**	*
40.	*Mastacides nilgirisicus*	**+**	**-**	*

FAMILY **PYRGOMORPHIDAE**				
Subfamily **ORTHACRIDINAE**				
41.	*Neorthacris acuticeps acuticeps*	+	-	*
42.	*Neorthacris acuticeps nilgiriensis*	+	-	*
Subfamily **PYRGOMORPHINAE**				
43.	*Atractomorpha crenulata*	+	+	
44.	*Aularches miliaris miliaris*	+	-	
45.	*Chrotogonus oxypterus*	+	-	
46.	*Chrotogonus trachypterus*	+	-	
47.	*Poekilocerus pictus*	+	+	
FAMILY **TETRIGIDAE**				
Subfamily **CLADONOTINAE**				
48.	*Deltonotus subcucullatus.*	+	-	**New to India**
49.	*Deltonotus gibbiceps*	+	+	*
50.	*Tettilobus trishula sp. Nov*	-	+	**New Species**
Subfamily **TETRIGINAE**				
51.	*Euparatettix personatus*	+	-	**New to India**
Subfamily **SCELIMENINAE**				
52.	*Eucriotettix flavopictus*	+	+	
53.	*Euscelimena gavialis*	+	-	
54.	*Euscelimena harpago*	+	+	
Subfamily **METRODORINAE**				
55.	*Systolederus sp.*	+	-	
56.	*Indomiriatra provertex*	+	-	
INFRAORDER **TRIDACTYLIDEA**				
FAMILY **TRIDACTYLIDAE**				
Subfamily **DENTRIDACTYLINAE**				
57.	*Bruntridactylus saussurei*	+	-	
Subfamily **TRIDACTYLINAE**				
58.	*Xya castetsi*	+	-	

Table 4.1. Inventory of grasshopper species (Caelifera) of Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR) and their distributional status (+ present, - absent,*endemic to India)

4.3.1 Taxonomic composition

Grasshoppers of both ENP and PKMTR comprised of 6 families (Acrididae, Chorotypidae, Mastacideidae, Pyrgomorphidae, Tetrigidae and Tridactylidae) in two infraorders (Acrididea and Tridactylidea) of suborder Caelifera (Fig. 4.3). Acrididae with 34 species formed 59% of the total grasshoppers of ENP and PKMTR followed by Tetrigidae (16%) with 9 species, Pyrgomorphidae (12%) with 7 species, Chorotypidae (7%) with 4 species and with 2 species each of Mastacideidae (3%) and Tridactylidae (3%) (Table 4.2).

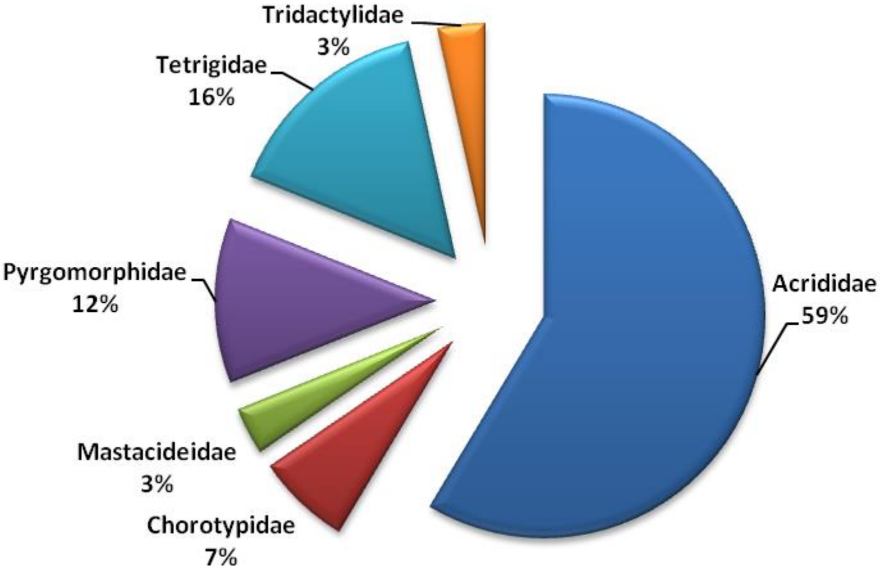


Fig. 4.3 Grasshopper family proportion in both ENP and PKMTR (N=58)

Sr No.	Family	Number of species	%
1	Acrididae	34	59
2	Tetrigidae	9	16
3	Pyrgomorphidae	7	12
4	Chorotypidae	4	7
5	Mastacideidae	2	3
6	Tridactylidae	2	3
		Total = 58	

Table 4.2. Number and proportion of Grasshoppers of ENP and PKMTR

In ENP, 18 species were recorded from five families (Acrididae, Chorotypidae, Mastacideidae, Pyrgomorphidae and Tetrigidae) (Fig. 4.4). Acrididae with 10 species contributed most (56%) followed by Tetrigidae with 4 species (22%) including one new species (*Tettilobus trishula sp. nov*). With 2 species, Pyrgomorphidae formed 11% and one species each from Mastacideidae and Chorotypidae (Table 4.3).

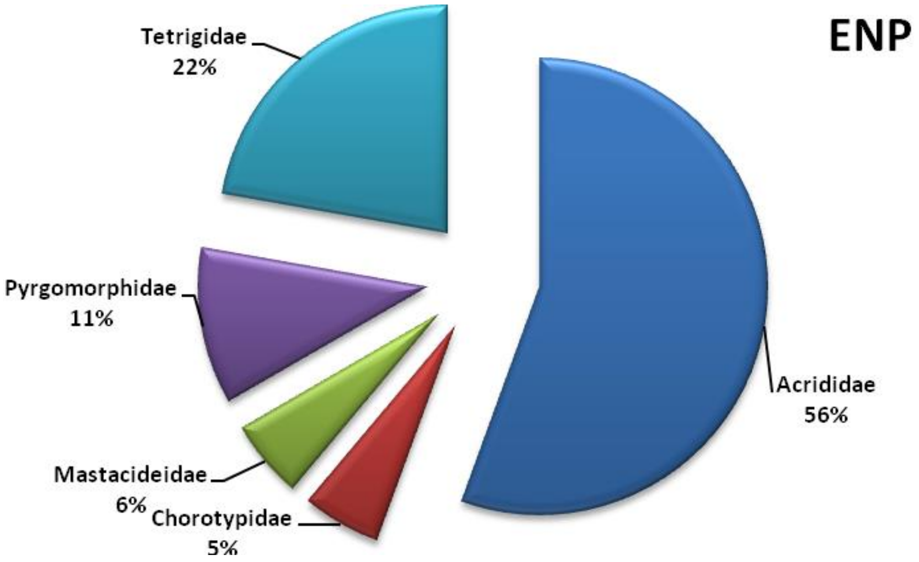


Fig. 4.4 Grasshopper family proportion in ENP (N=18)

Sr No.	Family	Number of species	%
1	Acrididae	10	56
2	Tetrigidae	4	22
3	Pyrgomorphidae	2	11
4	Chorotypidae	1	6
5	Mastacideidae	1	5
	Total = 18		

Table 4.3. Grasshopper families of ENP, number of species and proportion

In PKMTR, 55 species was recorded representing six families (Acrididae, Chorotypidae, Mastacideidae, Pyrgomorphidae, Tetrigidae and Tridactylidae) (Fig. 4.5). Acrididae with 33 species (60%) were the most diverse family followed by Tetrigidae with 8 species (14%). Pyrgomorphidae contributed 13% with 7 species, Chorotypidae (5%) with three species and two species each (4% each) from Mastacideidae and Tridactylidae (Table 4.4).

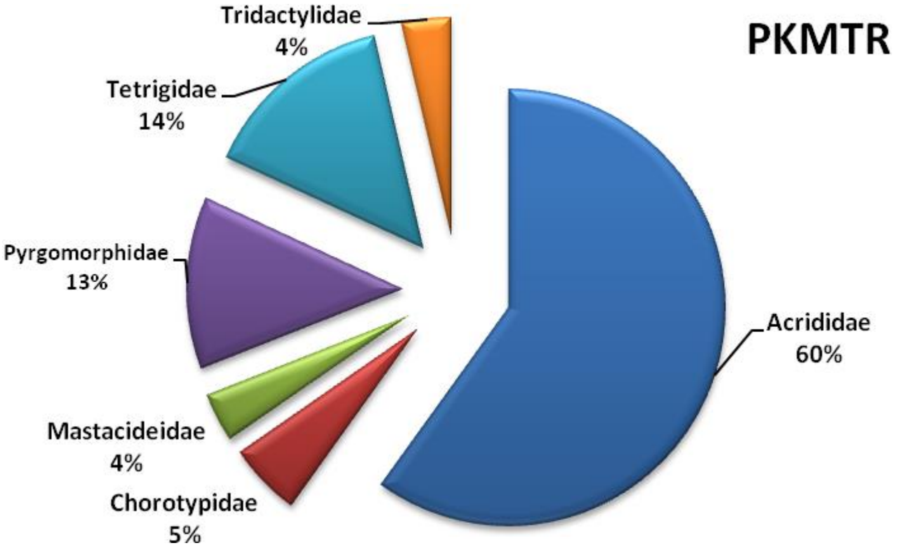


Fig. 4.5. Grasshopper family proportion in PKMTR (N=55)

Sr No.	Family	Number of species	%
1	Acrididae	33	60
2	Tetrigidae	8	14
3	Pyrgomorphidae	7	13
4	Chorotypidae	3	5
5	Mastacideidae	2	4
6	Tridactylidae	2	4
		Total = 55	

Table 4.4. Grasshopper families of PKMTR, number of species and proportion

4.3.2 Grasshopper Community structure

Diversity and composition of grasshopper species across different habitats of ENP showed slight variance among each other (Fig. 4.6). Out of the 18 species from three habitats, grasslands was the most species-rich (12 species). Shola and shrubs were equal in diversity with 9 species of grasshoppers. Only two species were common to the three habitats, six species were shared between grasslands and shrubs, four species between grasslands and shola while only three species were common to shola and shrubs (Fig. 4.6). A total of 844 individuals of 18 species were recorded from 90 transect counts 30 each to each habitats.

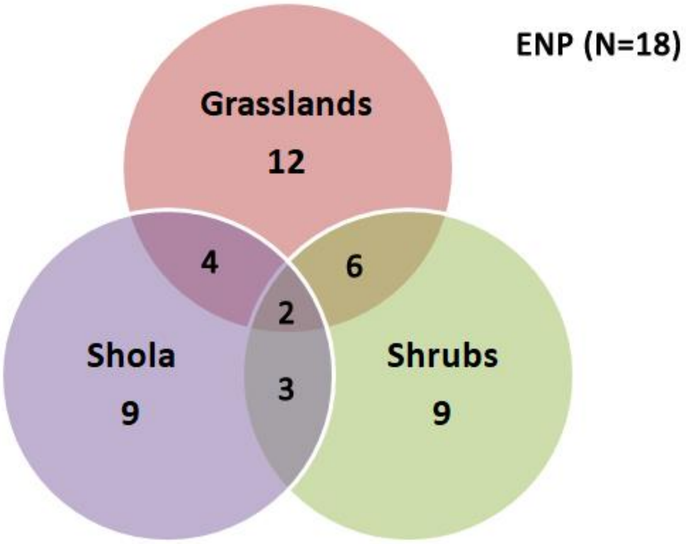


Fig. 4.6. Venn diagram of number of species recorded from three habitats (Grasslands, Shola and Shrubs) of ENP.

Grasshopper species diversity and composition of six different habitats of PKMTR varied prominently (Fig. 4.7). Among the total 55 species from six habitats, MDF were the most species-rich (29 species) followed by riparian and semi evergreen with 28 species each. Comparatively low number of species was seen in evergreens and vayals, 16 and 12 species respectively. Considering the species composition between habitats, MDF and semi evergreen shared highest number of grasshopper species (17 species) followed by semi evergreen and evergreen (12 species). MDF and grasslands shared 11 species, vayals and riparian 8 species and grasslands and vayals only 6 species. Only one species (*Atractomorpha crenulata*) was common to all six habitats of PKMTR (Fig. 4.7). A total of 3611 individuals of 55 species were recorded from 180 transect counts 30 each to each habitats.

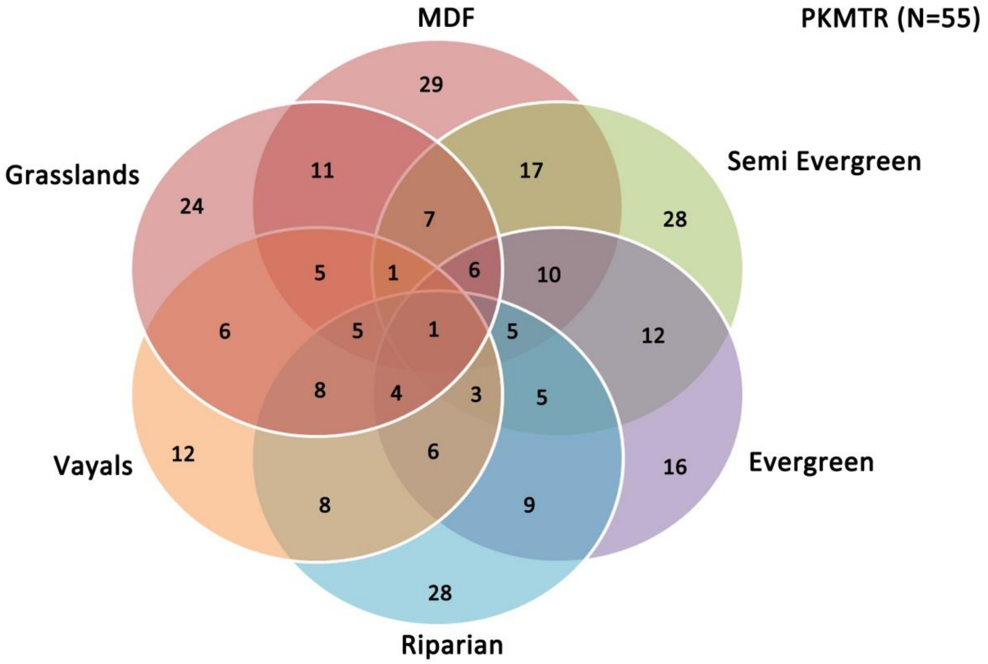


Fig. 4.7. Venn diagram of number of species recorded from six habitats (MDF, Semi Evergreen, Evergreen, Riparian, Vayals and Grasslands) of PKMTR

From a total 270 transect counts in both the study areas (90 ENP and 180 PKMTR), 4455 individuals of 58 grasshopper species were recorded. The MDF areas of PKMTR were found to be higher in species richness with 29 grasshopper species and the shola and shrub areas of ENP were the lowest species-rich habitat (9 species). With 30 transect counts each across grasslands of ENP and PKMTR, it is seen that the grasslands of PKMTR is home for largest number of grasshopper species (24 species) while the grasslands of ENP harbour only 12 species.

The abundance rate of grasshopper species of each habitat is plotted as bar graphs (Fig. 4.8 – 4.16). *Carliola carinata* was observed to be most abundant and dominant across the grasslands of ENP followed by *Zygophlaeoba sinuatocollis* and *Cyrtacanthacris tatarica tatarica,* the least abundant (Fig. 4.8). The grasslands of PKMTR had *Neorthacris acuticeps acuticeps* in abundance followed by *Oxya hyla* and *Carliola carinata* (Fig. 4.11). *Carliola carinata* and *Paramastacides ramachendrai* were the most abundant in the shrub dominated areas of ENP grasslands (Fig. 4.10). *Paramastacides ramachendrai* was found resting on and camouflaged with the invasive fern (Pteridium). The grasshopper species composition within the dense Shola habitats was observed to be different from the grasslands and shrubs of ENP. *Deltonotus gibbiceps,* a flightless pygmy grasshopper constituted the most abundant species in the shola (Fig. 4.9).

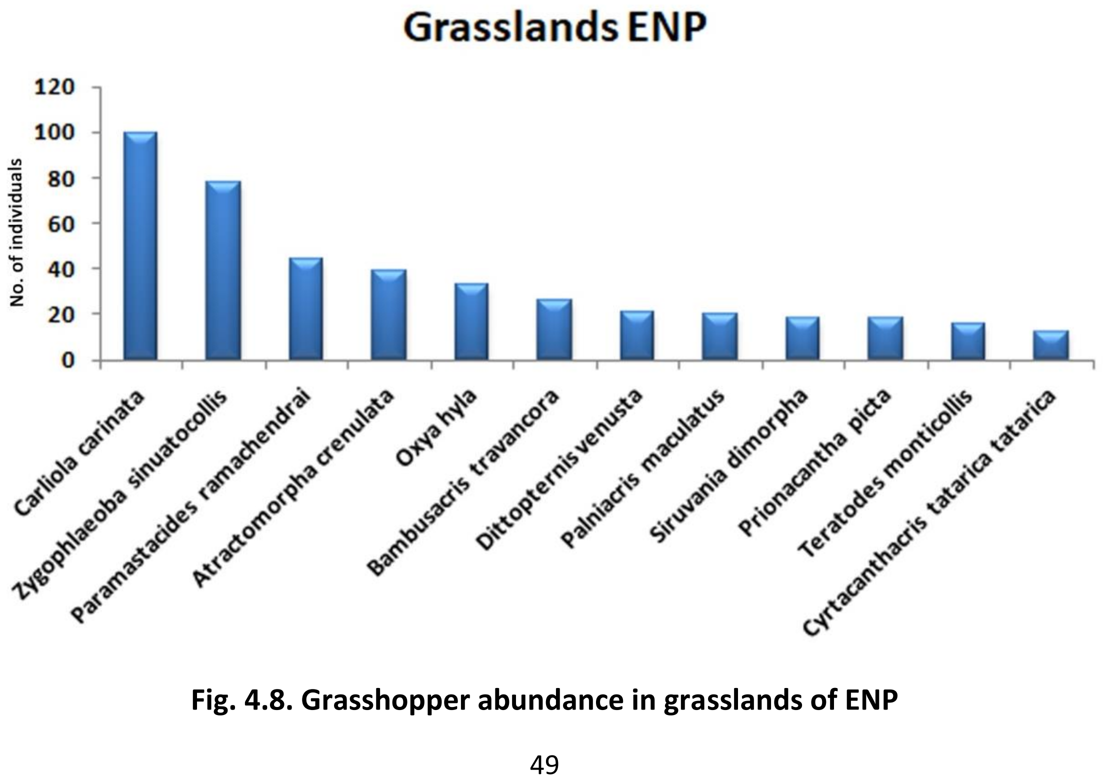


Fig. 4.8. Grasshopper abundance in grasslands of ENP

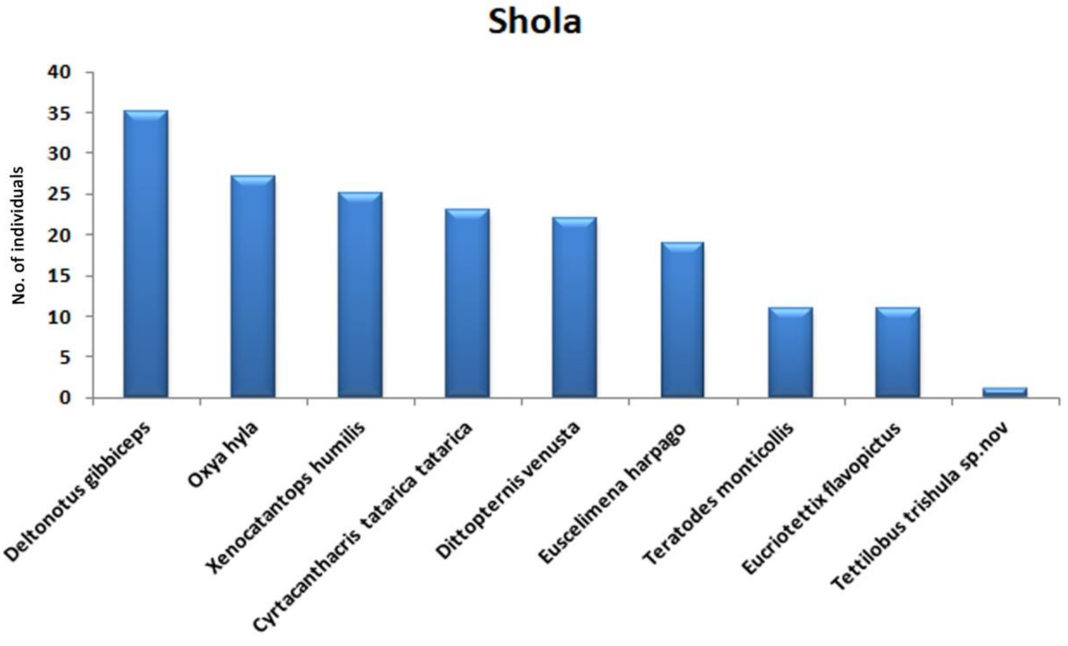


Fig. 4.9. Grasshopper abundance in shola habitat of ENP

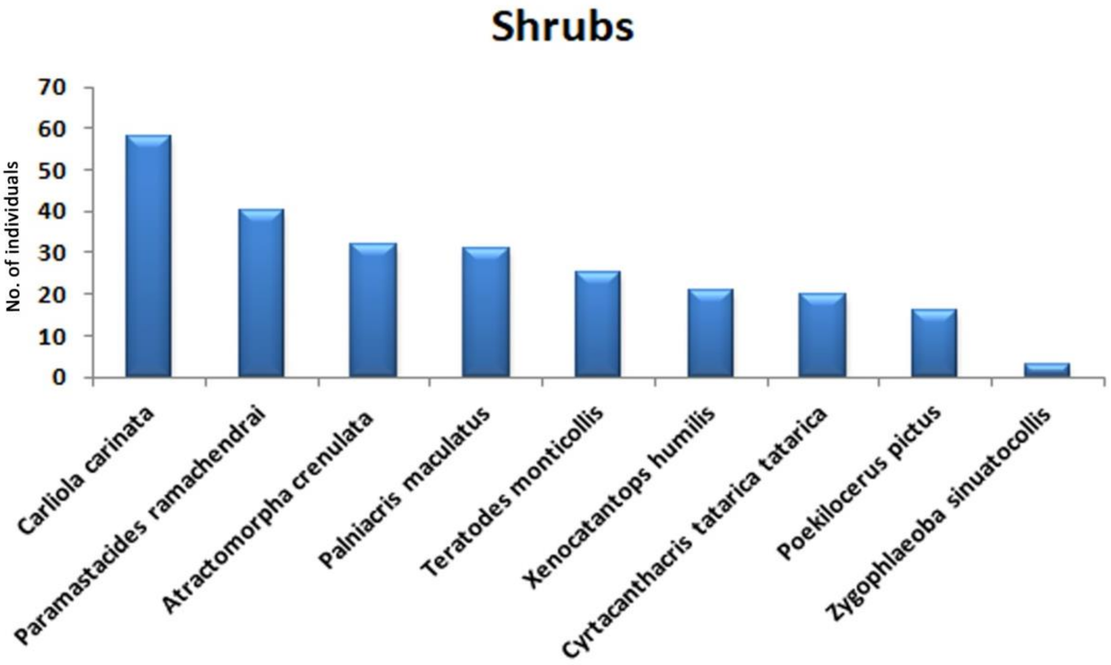


Fig. 4.10. Grasshopper abundance in shrubs habitat of ENP

The habitats of PKMTR are much diverse than that of ENP and is reflected in the grasshopper diversity. The grasslands of PKMTR possess 24 species with more than 5 highly abundant species. *Neorthacris acuticeps* was found to be most abundant in grasslands of PKMTR (Fig. 4.11). *Deltonotus subcucullatus* and *Deltonotus gibbiceps* were the most abundant grasshoppers in the evergreen habitats of PKMTR (Fig. 4.12). Both the *Deltonotus sp.* are ground dwelling evergreen-forest were seen within fallen leaves under shades of trees. *Deltonotus gibbiceps* was recorded to be most abundant in shola of ENP also. *Oxya japonica japonica* and *Oxya hyla* were highly abundant in the riparian habitats of PKMTR (Fig. 4.13). Within the semi evergreen habitats of PKMTR, *Deltonotus subcucullatus* and *Deltonotus gibbiceps* constituted the most abundant species (Fig. 4.14). *Phlaeoba antennata, Gesonula punctifrons* and *Patanga succincta* were exceptionally abundant in the MDF areas of PKMTR (Fig. 4.15). *Oxya hyla* and *Oxya japonica japonica* were highly abundant in the Vayals of PKMTR (Fig. 4.16).

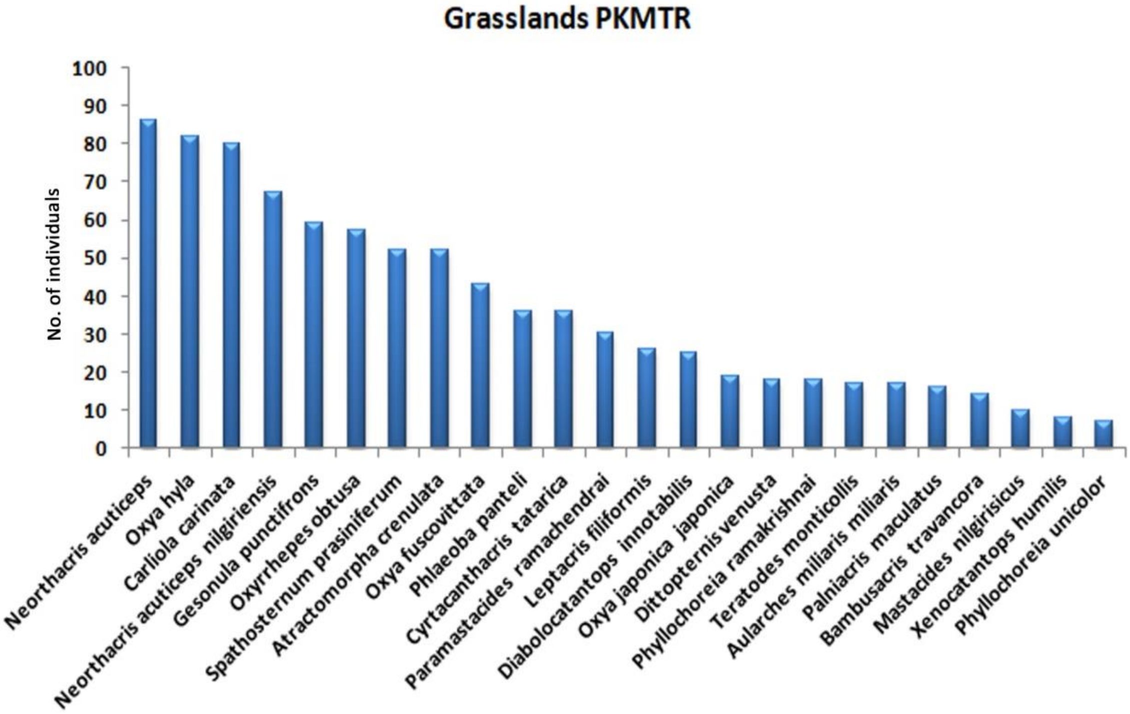


Fig. 4.11. Grasshopper abundance in grasslands of PKMTR

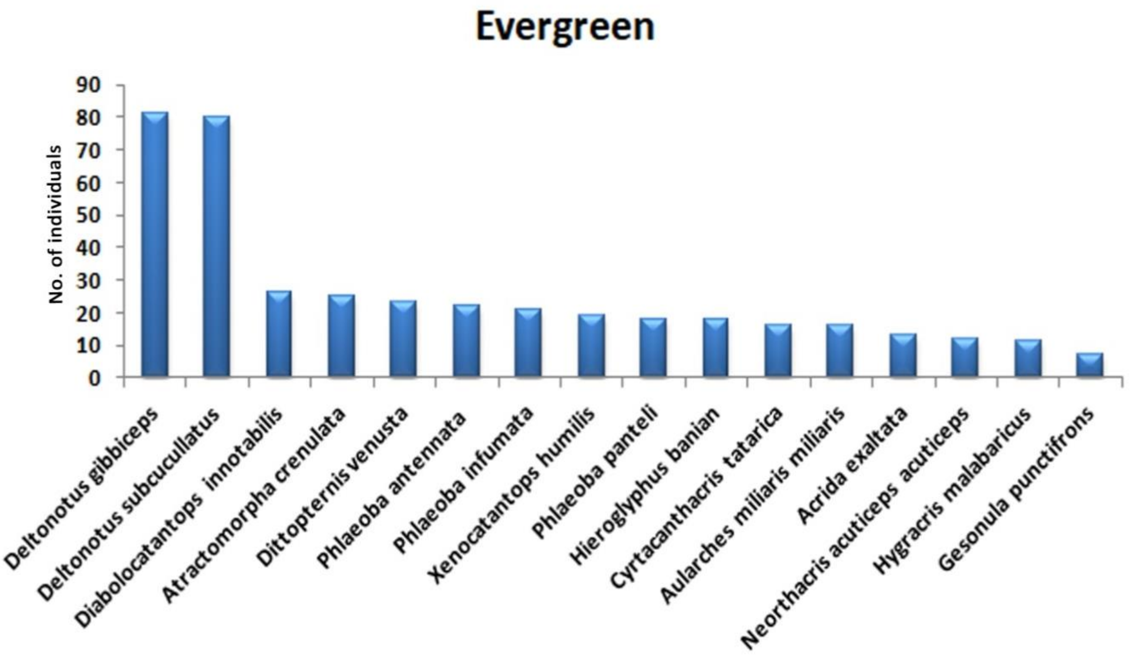


Fig. 4.12. Grasshopper abundance in Evergreen habitat of PKMTR

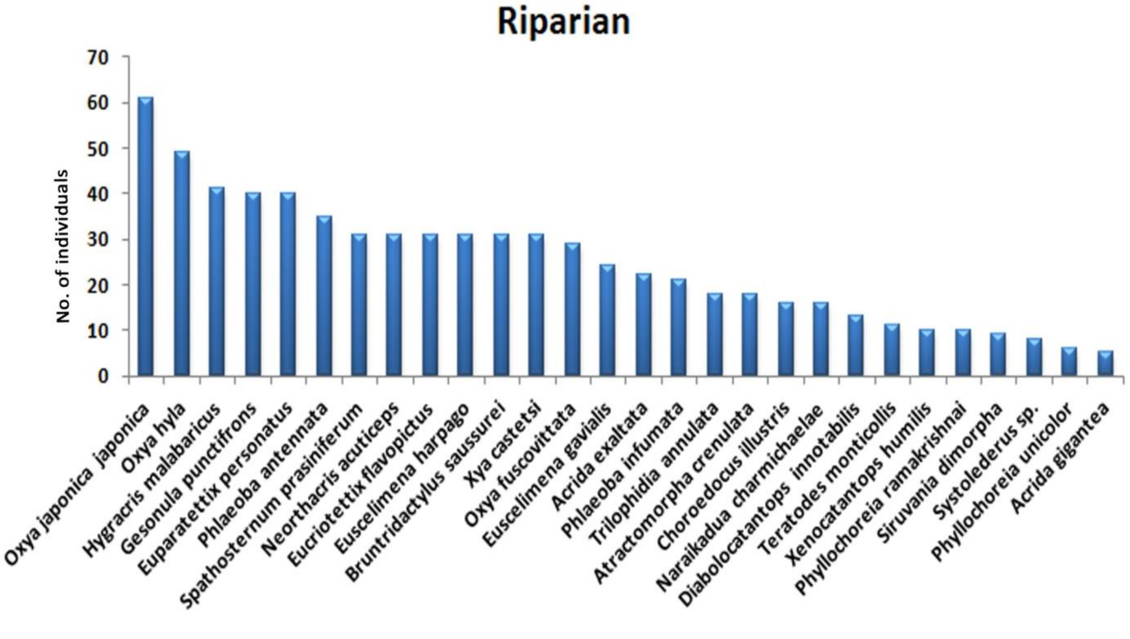


Fig. 4.13. Grasshopper abundance in riparian habitats of PKMTR

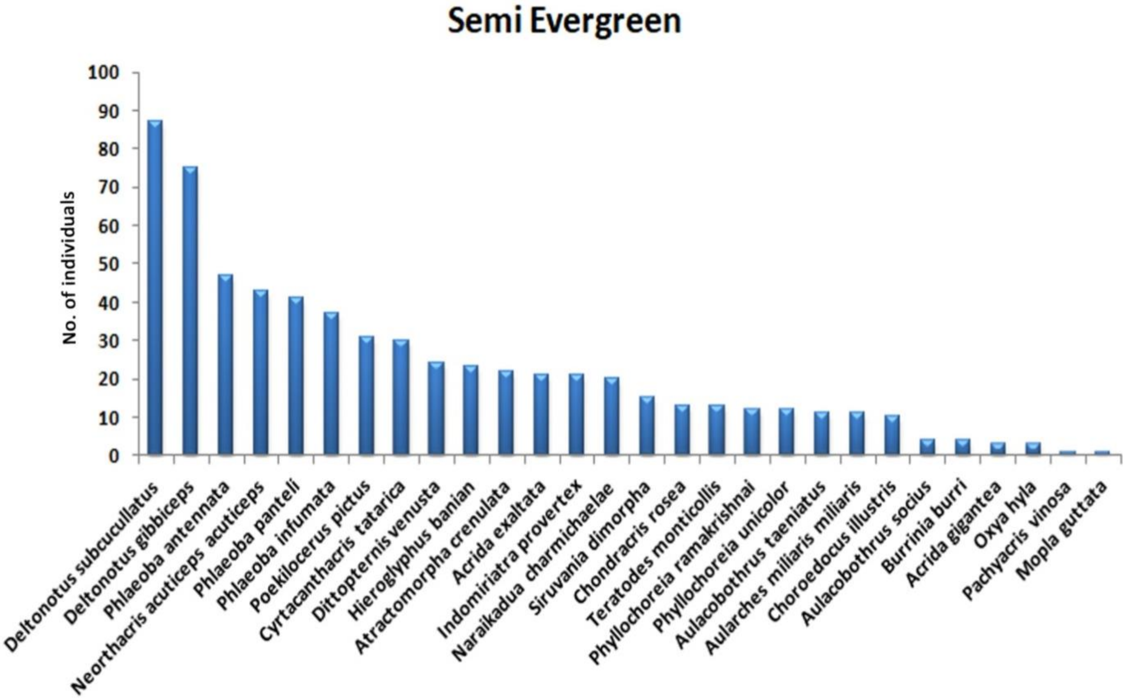


Fig. 4.14. Grasshopper abundance in Semi evergreen habitat of PKMTR

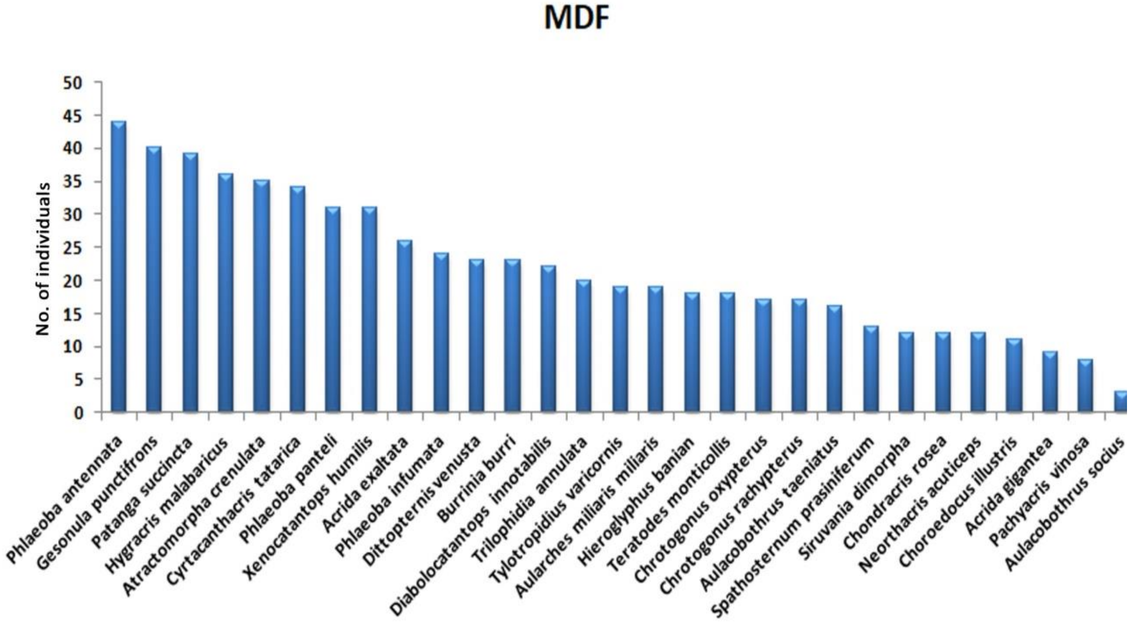


Fig. 4.15. Grasshopper abundance in MDF of PKMTR

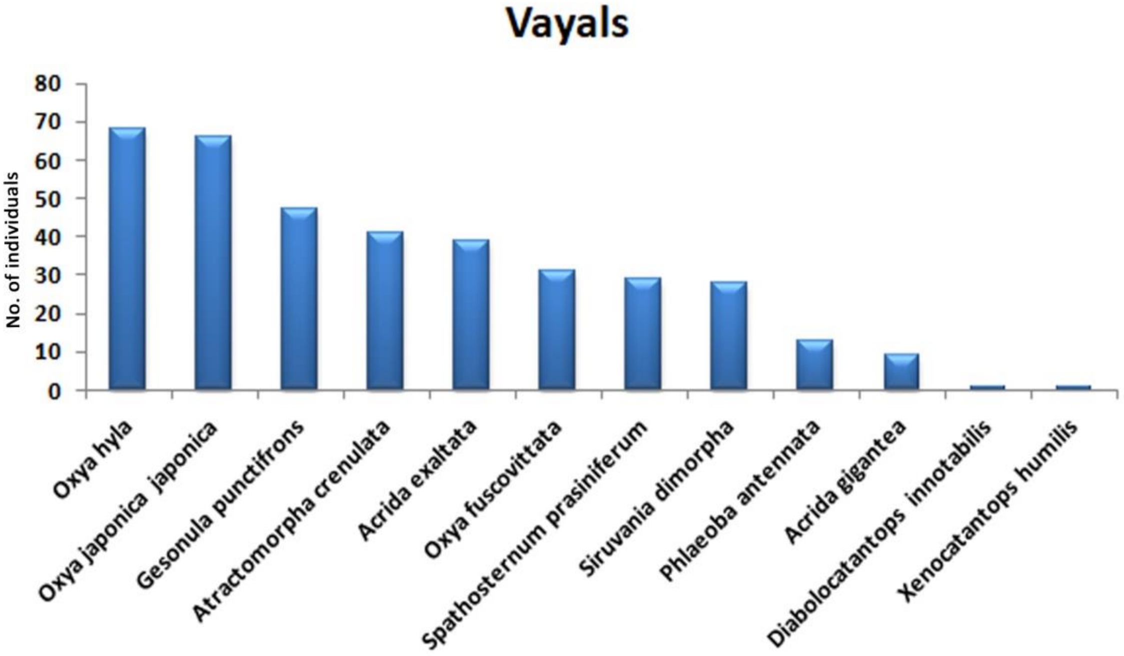


Fig. 4.16. Grasshopper abundance in vayals of PKMTR

Mean total of species and individuals in different habitats of ENP and PKMTR per transect count is given in Table 4.5. Mean total of species and individuals per transect count in ENP was highest in Grasslands, species in counts was equal for both Shola and Shrubs and the mean total of species and individuals per counts was least in shola habitats of ENP (Table 4.5). In PKMTR, mean total of species per counts was higher in grasslands and MDF habitats and least in vayals. Mean total of individuals per counts was higher in grasslands and least in vayals (Table 4.5).

The total number of grasshopper species per transect count was significantly different among the three habitats of ENP (Kruskal Wallis test χ^2= 23.97; $p \leq 0.01$; df = 2). Similarly, Mann-Whitney U test also found significant difference between shola and grassland, and between grassland and shrub of ENP, except between Shola and shrubs (Mann-Whitney U test p = 0.4578) (Table 4.6).

Transect Counts													
	Total counts	Species in counts	Total individuals	Species per count					Individuals per count				
Eravikulam National Park				Mean	SD	SE	Max	Min	Mean	SD	SE	Max	Min
Shola	30	9	174	4.7	1.93	± 0.35	8	1	5.8	2.97	± 0.54	12	1
Grasslands	30	12	424	7.7	2.43	± 2.43	12	3	14.13	6.4	± 1.18	28	5
Shrubs	30	9	246	5.1	1.68	± 0.3	8	2	8.2	4.7	± 0.85	18	2
Parambikulam Tiger Reserve													
MDF	30	29	632	15.76	3.5	± 0.64	22	9	21	5.72	± 1.04	30	11
Semi evergreen	30	28	635	13.1	2.39	± 0.43	18	9	21.16	5.2	± 0.95	32	13
Evergreen	30	16	408	8.2	1.74	± 0.31	12	5	13.7	2.71	± 0.49	20	9
Riparian	30	28	688	14.7	4.03	± 0.73	20	6	22.9	8.16	± 1.49	40	9
Vayals	30	12	373	7	1.5	± 0.27	10	4	12.43	3.74	± 0.68	22	7
Grasslands	30	24	875	15.9	2.21	± 0.4	20	12	29.1	7.13	± 1.3	43	17

Table 4.5. Total number of transect counts, species and individuals per count in both Eravikulam National Park and Parambikulam Tiger Reserve

	Sholas	**Shrubs**	**Grasslands**
Sholas		0.4578	$p \leq 0.01$
Shrubs	0.4578		$p \leq 0.01$
Grasslands	$p \leq 0.01$	$p \leq 0.01$	

Table 4.6. Significance of number of grasshopper species (Mann-Whitney test *p value*) between habitats of ENP

The total number of grasshopper individuals per transect count in ENP was significantly different among the three habitats (Kruskal Wallis test χ^2= 30.17; $p \leq 0.01$; df = 2). Mann-Whitney test with Bonferroni significance also found significant difference among the habitats of ENP, except for Shola and Grasslands (Mann-Whitney U test; p = 0.0787) (Table 4.7).

	Sholas	**Shrubs**	**Grasslands**
Sholas		$p \leq 0.01$	0.0787
Shrubs	$p \leq 0.01$		$p \leq 0.01$
Grasslands	0.0787	0.0001	

Table 4.7. Significance of number of grasshopper individuals (Mann-Whitney test *p value*) between habitats of ENP

There was significant difference between the total number of grasshopper species per transect count among the six habitats of PKMTR (Kruskal Wallis test χ^2= 114.5; $p \leq 0.01$; df = 5). Mann-Whitney test with Bonferroni significance also found significant difference among the six habitats of PKMTR, except between MDF and Riparian (p = 0.4314) MDF and grasslands (p= 0.9112) and Riparian and Grasslands (p = 0.3528) (Table 4.8).

	MDF	Semi Evergreen	Evergreen	Riparian	Vayals	Grasslands PKMTR
MDF		0.004915	$p \leq 0.01$	0.4314	$p \leq 0.01$	0.9112
Semi Evergreen	0.004915		$p \leq 0.01$	0.04803	$p \leq 0.01$	$p \leq 0.01$
Evergreen	$p \leq 0.01$	$p \leq 0.01$		$p \leq 0.01$	0.01206	$p \leq 0.01$
Riparian	0.4314	0.04803	$p \leq 0.01$		$p \leq 0.01$	0.3528
Vayals	$p \leq 0.01$	$p \leq 0.01$	0.01206	$p \leq 0.01$		$p \leq 0.01$
Grasslands PKMTR	0.9112	$p \leq 0.01$	$p \leq 0.01$	0.3528	$p \leq 0.01$	

Table 4.8. Significance of number of grasshopper species (Mann-Whitney test *p value*) between habitats of PKMTR

The total number of grasshopper individuals per transect count in PKMTR was significantly different among the six habitats (Kruskal Wallis test χ^2= 94.1; $p \leq 0.01$; df = 5). Mann-Whitney test with Bonferroni significance also found a significance difference between the total number of individuals per transect count between all the habitats of PKMTR, except between MDF and Semi evergreen (Mann-Whitney U test; p = 0.9233), MDF and Riparian (Mann-Whitney U test; p = 0.3356) and Riparian and Semi evergreen (Mann-Whitney U test; p = 0.3101) (Table 4.9).

	MDF	Semi Evergreen	Evergreen	Riparian	Vayals	Grasslands PKMTR
MDF		0.9233	$p \leq 0.01$	0.3356	$p \leq 0.01$	$p \leq 0.01$
Semi Evergreen	0.9233		$p \leq 0.01$	0.3101	$p \leq 0.01$	$p \leq 0.01$
Evergreen	$P \leq 0.01$	$p \leq 0.01$		$p \leq 0.01$	0.05894	$p \leq 0.01$
Riparian	0.3356	0.3101	$p \leq 0.01$		$p \leq 0.01$	0.005906
Vayals	$p \leq 0.01$	$p \leq 0.01$	0.05894	$p \leq 0.01$		$p \leq 0.01$
Grasslands PKMTR	$p \leq 0.01$	$p \leq 0.01$	$p \leq 0.01$	0.005906	$p \leq 0.01$	

Table 4.9. Significance of number of grasshopper individuals (Mann-Whitney test *p value*) between habitats of PKMTR

4.3.3 Species accumulation curves

Maximum trappable grasshopper species was recorded from 90 transect counts in the entire Eravikulam National Park. The species accumulation curve for the ENP approached an asymptote with 90 transects count resulting in 18 species. The curve of observed species (S Mean (runs)) matches with the estimated species richness curves (Chao 2 Mean and Jack 2 Mean) (Fig. 4. 17). This justifies the sampling efforts in ENP with very slow yield increase towards final transects. The estimation of second order "Chao" and "Jacknife" for ENP predicted 18 and 19.97 species respectively. Chao 2 Mean prediction was found to be more close to the observed species accumulation.

The species accumulation curve for the grasshoppers of Parambikulam Tiger Reserve reached an asymptote with 180 transect counts with 55 species. The curve of observed species (S Mean (runs)) matches with the estimated species richness curves (Chao 2 Mean and Jack 2 Mean) (Fig. 4.18) justifying the sampling efforts in PKMTR with very slow yield increase towards final transects. The estimation of second order "Chao" and "Jacknife" for PKMTR predicted 55 and 56.98 species respectively. Chao 2 Mean prediction was more close to the observed species accumulation.

Species accumulation curve for each habitat of both ENP (Shola, Shrubs and Grassland) and PKMTR (MDF, Evergreen, Semi Evergreen, Riparian, Vayals and Grasslands) are shown in Figures 4.19 – 4.27. All the curves for observed species (S Mean (runs)) are found to be matching with the estimated curves (Chao 2 Mean and Jack 2 Mean) as the survey progressed.

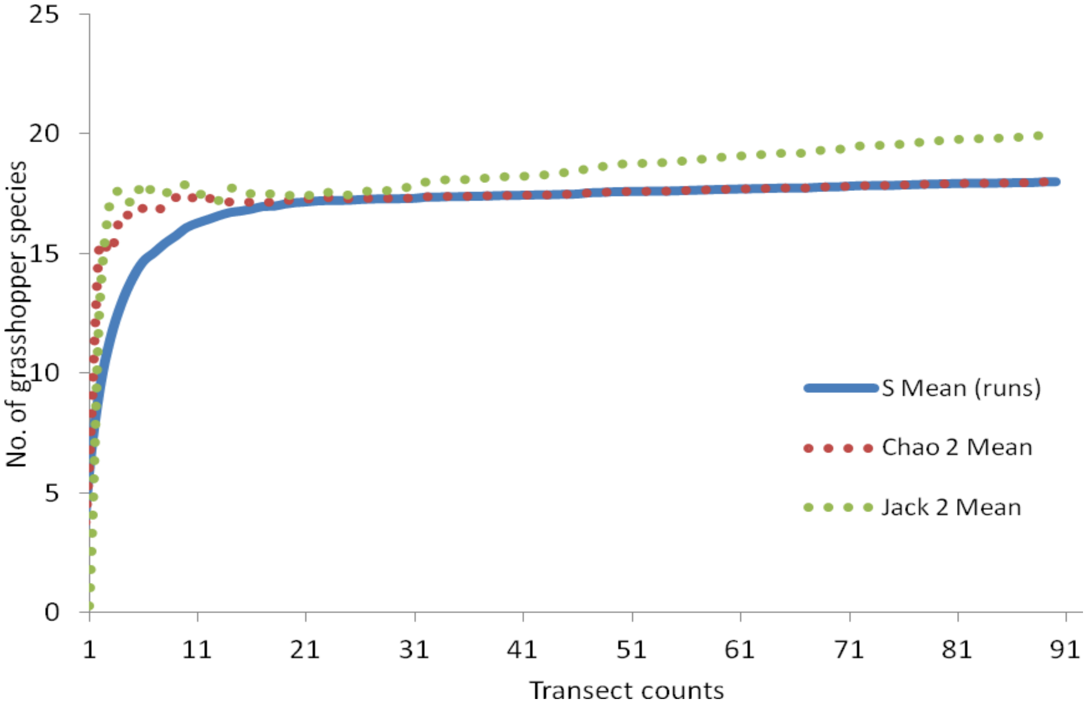


Fig. 4.17. Species accumulation curve of transect counts in the Eravikulam National Park

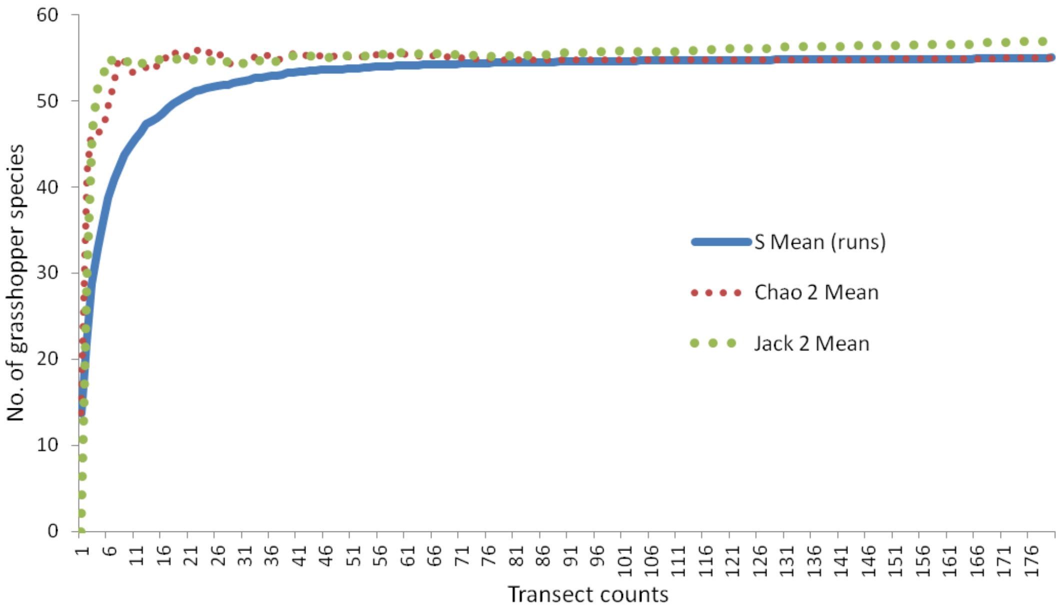


Fig. 4.18. Species accumulation curve of transect counts in the Parambikulam Tiger Reserve

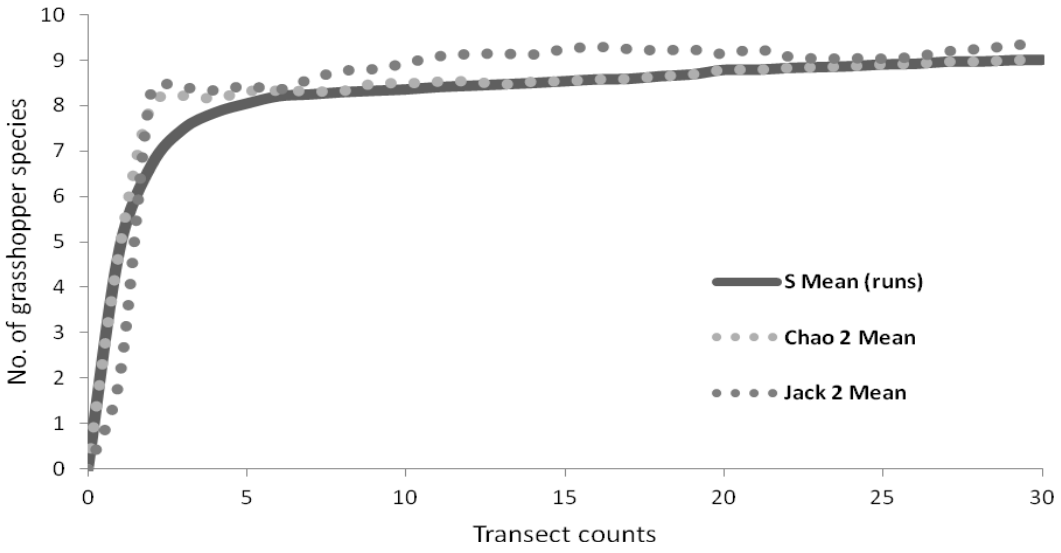


Fig. 4.19. Species accumulation curve of transect counts in the sholas of ENP

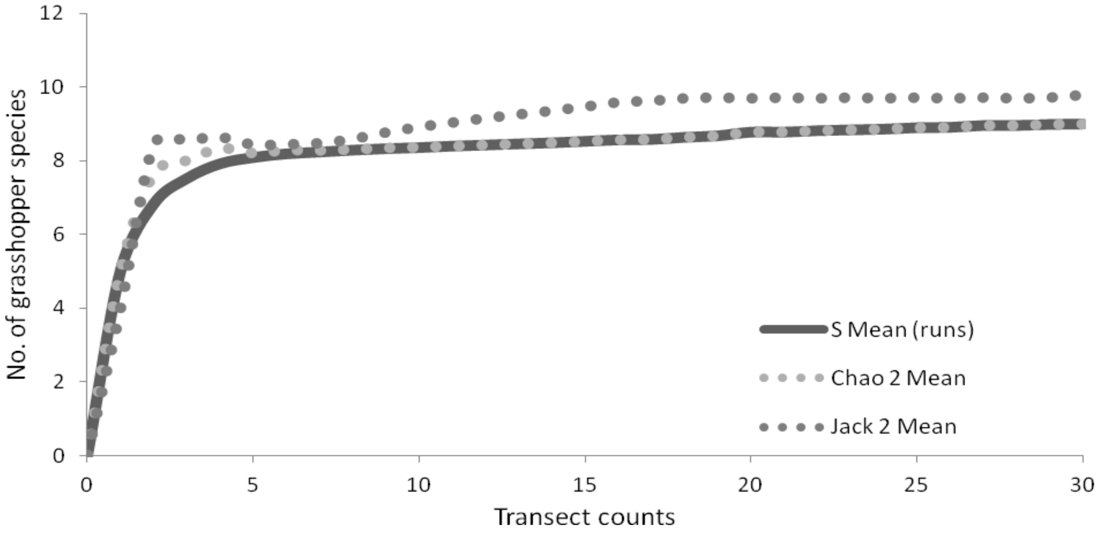


Fig. 4.20. Species accumulation curve of transect counts in the shrubs of ENP.

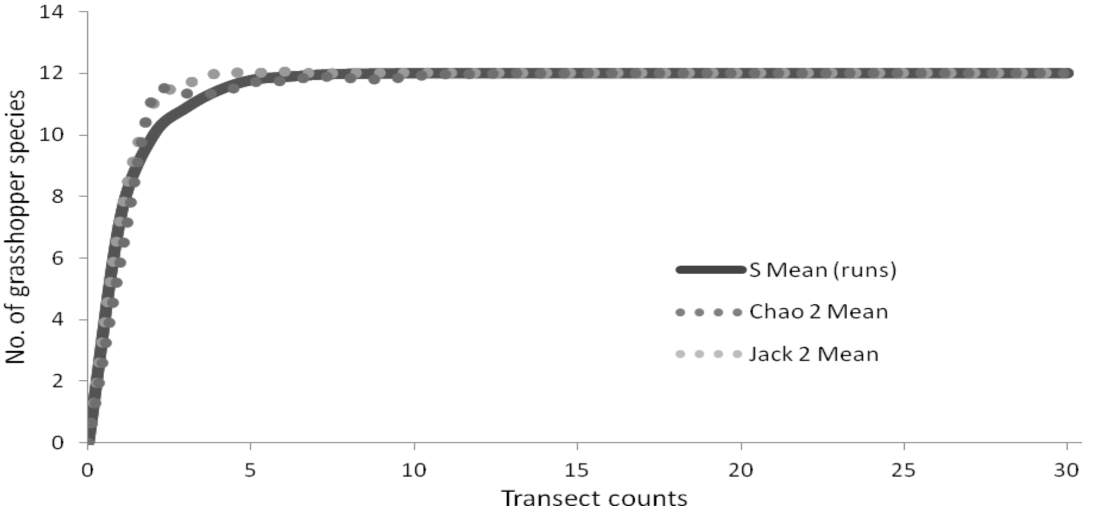


Fig. 4.21. Species accumulation curve of transect counts in the grasslands of ENP.

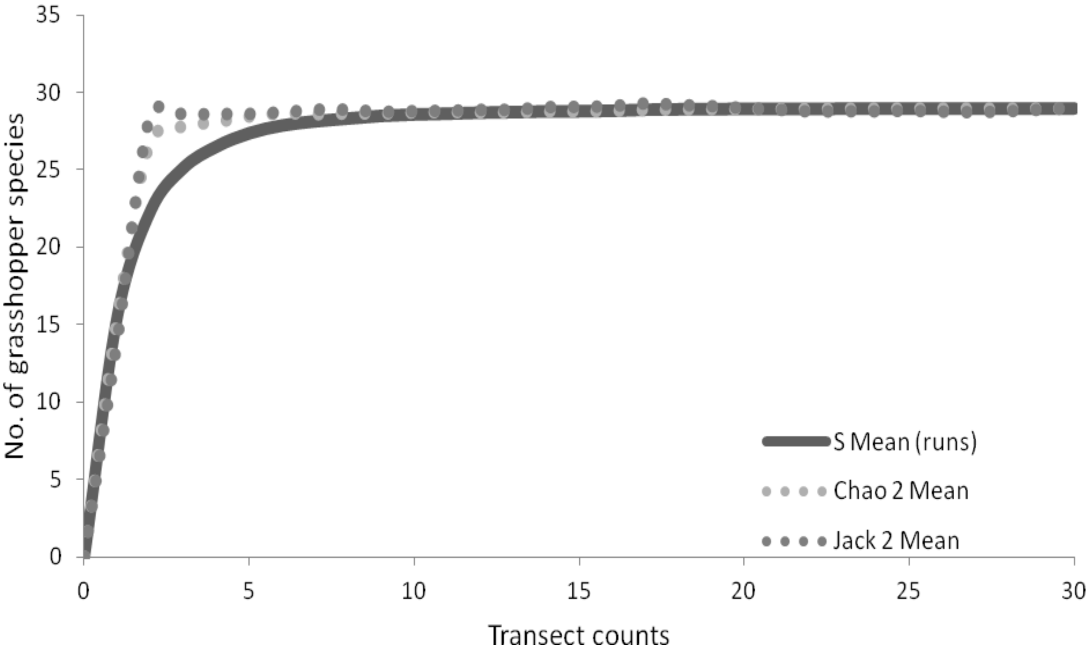


Fig. 4.22. Species accumulation curve of transect counts in the MDF habitats of PKMTR

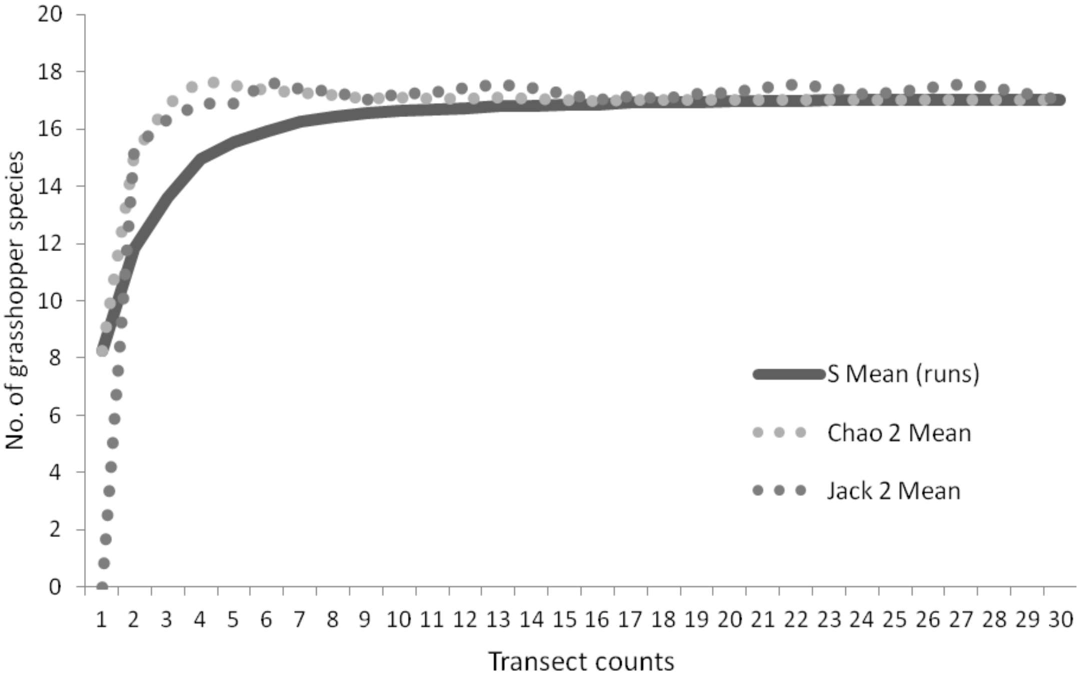


Fig. 4.23. Species accumulation curve of transect counts in the Evergreen habitats of PKMTR

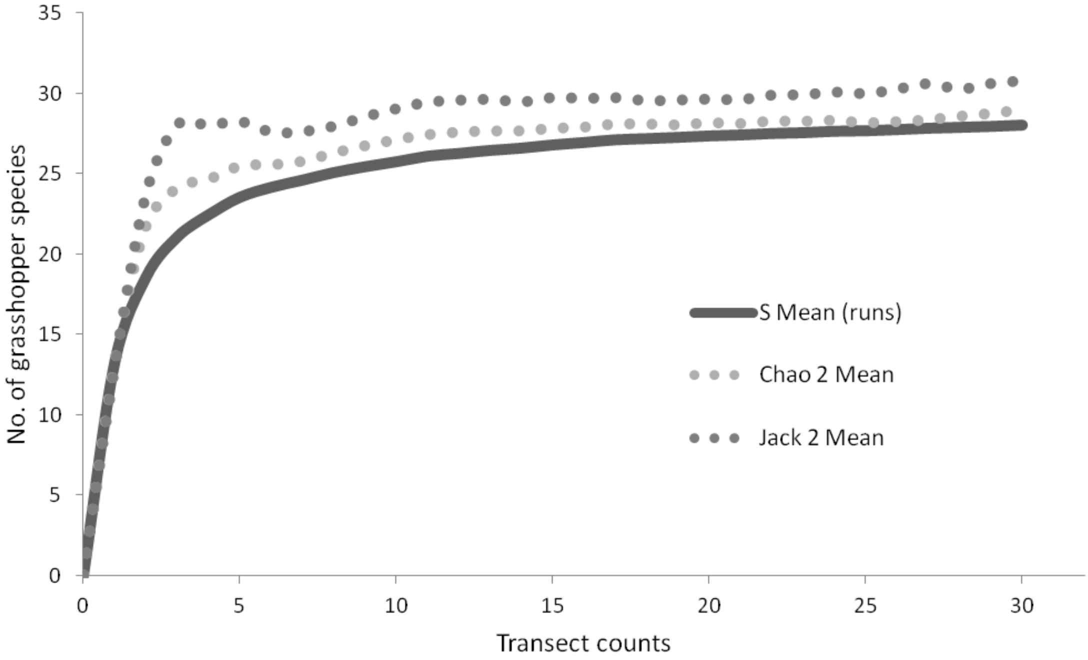


Fig. 4.24. Species accumulation curve of transect counts in the Semi Evergreen habitats of PKMTR

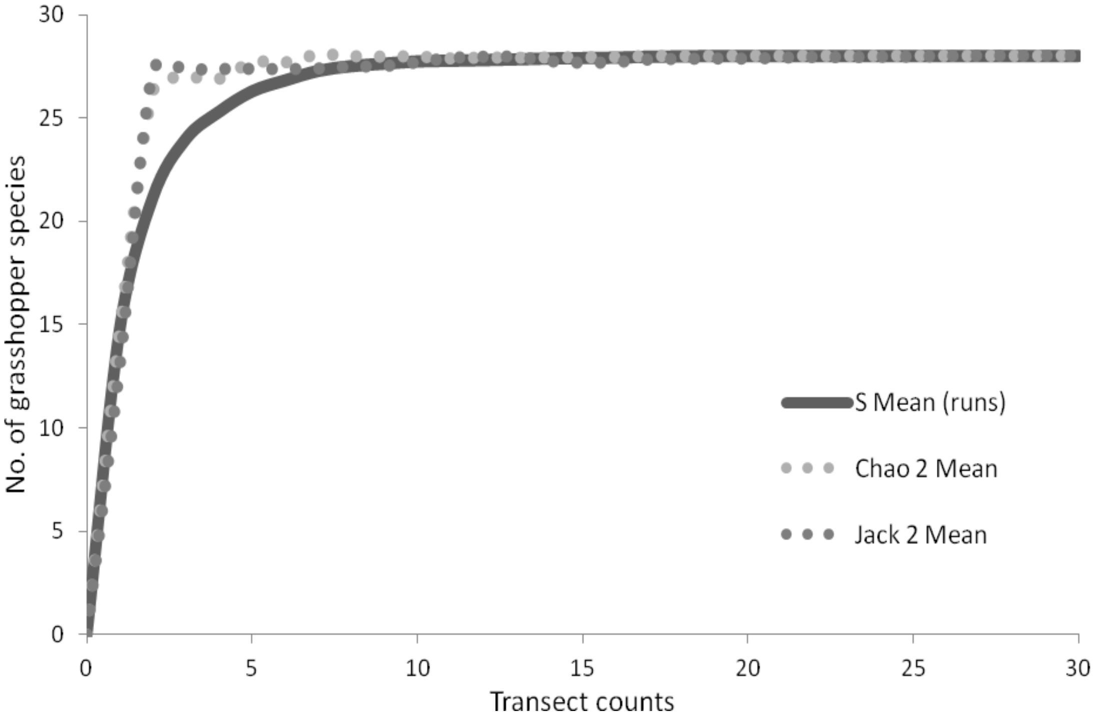


Fig. 4.25. Species accumulation curve of transect counts in the Riparian habitats of PKMTR

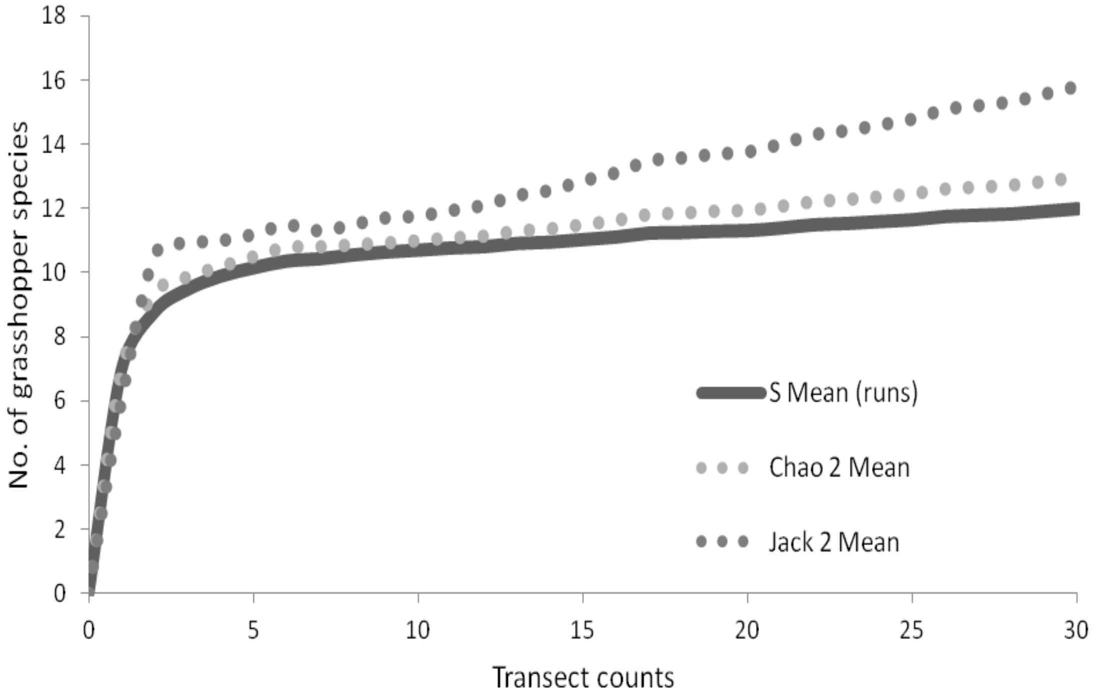


Fig. 4.26. Species accumulation curve of transect counts in the Vayals of PKMTR

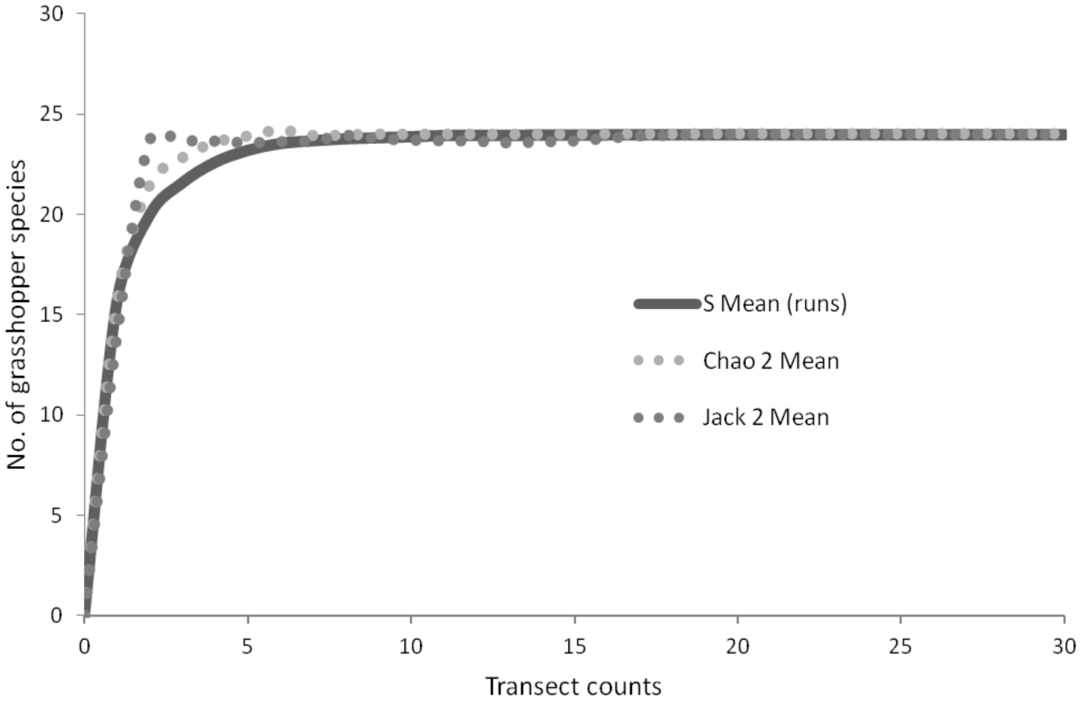


Fig. 4.27. Species accumulation curve of transect counts in the Grasslands of PKMTR

Habitats	No. of species	Individuals	Shannon (H)	Simpsons (1-D)	Equitability (J)	Fisher's alpha	Margalef
Eravikulam National Park	**18**	**844**	**2.622**	**0.9123**	**0.907**	**3.232**	**2.523**
Shola	9	174	2.04	0.8614	0.9284	2.013	1.551
Shrubs	9	246	2.04	0.8566	0.9286	1.834	1.453
Grasslands ENP	12	424	2.261	0.8721	0.91	2.297	1.818
Parambikulam Tiger Reserve	**55**	**3611**	**3.641**	**0.9687**	**0.9165**	**9.206**	**6.592**
MDF	29	632	3.25	0.9576	0.9651	6.274	4.342
Semi Evergreen	28	635	2.967	0.9348	0.8904	5.992	4.184
Evergreen	16	408	2.512	0.8936	0.9061	3.32	2.495
Riparian	28	688	3.174	0.9531	0.9525	5.866	4.132
Vayals	12	373	2.195	0.8762	0.8833	2.369	1.858
Grasslands PKMTR	24	875	2.961	0.9399	0.9317	4.561	3.395

Table 4.10. Grasshopper community characteristics of Eravikulam National Park and Parambikulam Tiger Reserve in various diversity indices

4.3.4 Species diversity

Various diversity indices (Shannon, Simpsons, Fisher's alpha and Margalef) were computed for each habitat of both the study areas. All the diversity indices showed higher diversity for PKMTR than ENP. Among the three habitats in ENP, grasslands yielded higher diversity values compared to shola and shrubs. In PKMTR, the MDF areas were higher in diversity values for all the computed indices (Table 4.10).

4.3.5 Evenness

The rank-abundance curve of Eravikulam National Park depicts that grasshoppers in grasslands were more evenly distributed than that of shola and shrubs. The shallow slope for the grasslands indicates even distribution of individuals among the species (Fig. 4.28). The rank abundance curves of Parambikulam Tiger Reserve shows that MDF,

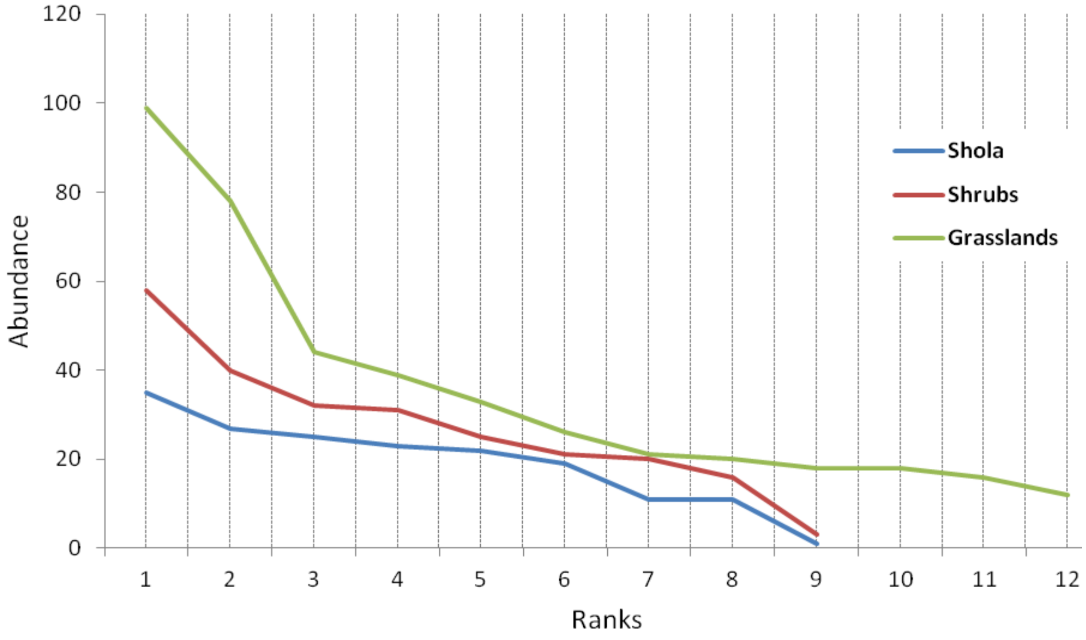


Fig. 4.28. Rank abundance curve of the three habitats of ENP

Riparian, Grasslands and Semi evergreen habitats are more even than the Vayals and Evergreen habitat in terms of grasshopper abundance. The Vayals of PKMTR were highly uneven than the other habitats (Fig. 4.29). A considerably shallow slope for the Grasslands, MDF, Riparian and Semi evergreen indicates even distribution of individuals among the species. A steep slope for the Evergreen and Vayals depicts that a few abundant species dominate the grasshopper community of that habitats (Fig. 4.29).

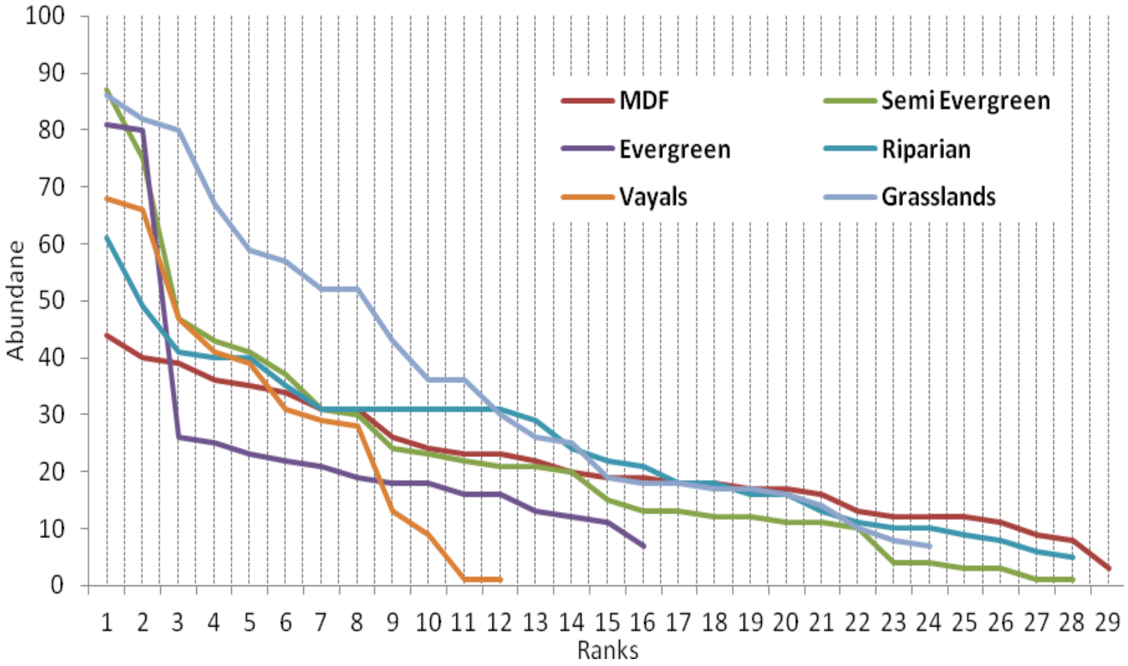


Fig. 4.29. Rank abundance curve of the six habitats of PKMTR.

4.3.6 Species composition

Cluster analysis among different habitats of ENP shows more similarities in species composition between shrubs and shola (Fig. 4.30). In PKMTR, semi evergreen and evergreen areas were similar in species composition. Likewise, riparian and vayals were more similar. It also indicated that the grasslands was very distinct in species composition (Fig. 4.31)

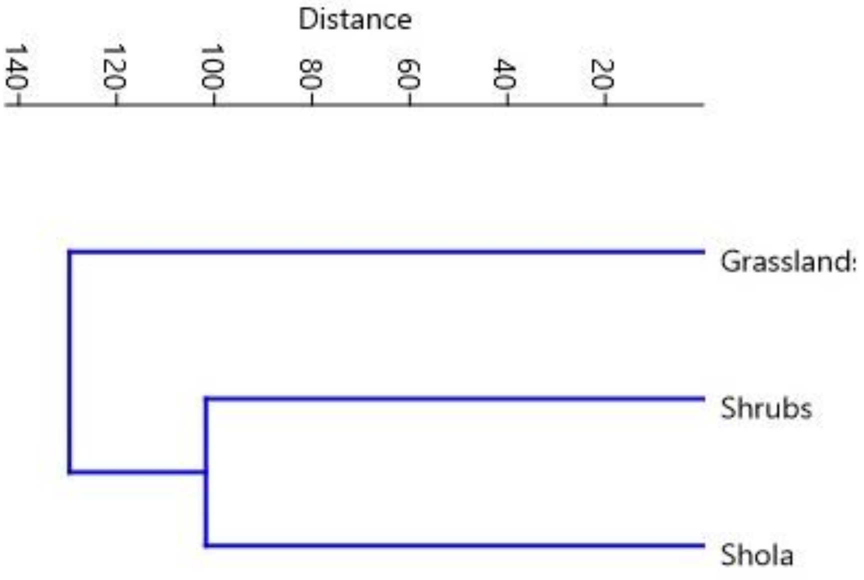


Fig. 4.30 Similarities in grasshopper species composition among habitats of ENP using Euclidean index (Cophenetic correlation: 0.559)

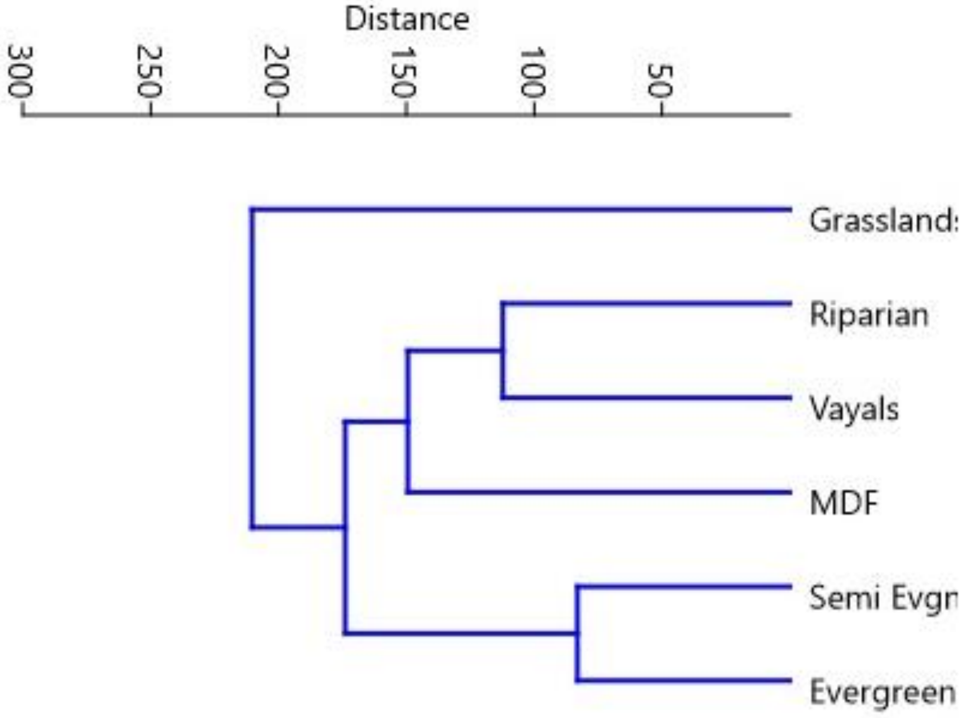


Fig. 4.31 Similarities in grasshopper species composition among habitats of PKMTR using Euclidean index (Cophenetic correlation: 0.917)

4.3.7 NEW SPECIES

Family	:	**Tetrigidae** Rambur, 1838
Subfamily	:	**Cladonotinae** Bolívar, 1887
Genus	:	***Tettilobus*** Hancock, 1909
Species	:	***Tettilobus trishula*** **sp. n.**

From Bolivar's 100 year old collections of south India, deposited in MNCN (Museo Nacional de Ciencias Naturales, Madrid, Spain), an old specimen was seen. The specimen was already recognized by Bolívar as a new species and labelled '*Potua suspecta*' (París 1994). But it was never published as a new species. The same species was observed in its natural habitat in the Shola forests of Eravikulam National Park and collected one male paratype. The species is dedicated to Lord Shiva, who has trident shaped trishula in similar fashion as pronotal apex of this new species (Siva's pygmy trishula *Tettilobus trishula* Skejo, Bhaskar et al. Stermšek sp. n.). Species photographs and its habitat together with drawings of important morphological characters are described.

Museums: KFRI (Kerala Forest Research Institute, Peechi, Thrissur, India), **MHNG** (Muséum d'histoire naturelle de la Ville de Genève, Geneva, Switzerland), **MNCN** (Museo Nacional de Ciencias Naturales, Madrid, Spain), **SMTD** (Museum für Tierkunde Dresden, Germany), **MNHN** (Muséum National d'Histoire Naturelle, Paris, France), **BNHM** (Natural History Museum, London, UK).

Taxonomy and nomenclature. Taxonomy follows Orthoptera Species File (OSF) (Cigliano et al. 2019) with addenda after Storozheno and Paik (2011) division of subfamily. Diagnoses followed from the original descriptive papers – Bolívar (1887), Kirby (1914 a), Günther (1938, 1979), Devriese (1999), Hancock (1904, 1907 a and b, 1909, 1915), Shishodia (1991), Storozhenko and Paik (2011), Storozhenko and Pushkar (2017), Skejo and Bertner (2017) and Tumbrinck (2014). Devriese's (1999) revision of the African Xerophyllini provides baseline for modern definition of Xerophyllini while Storozhenko and Paik's (2011) revision of the genus Bidentatettix with reorganization of Cladonotinae into Cladonotini and Xerophyllini serves as modern definition of Cladonotini. Nomenclature is in accordance with rules of the International Code of the Zoological Nomenclature (ICZN 1999).

Terminology and measurements. Morphological terminology follows Devriese (1991, 1996, 1999), Muhammad et al. (2018), Skejo and Bertner (2017), Storozhenko and Pushkar (2017) and Tumbrinck (2014). Measurements follow Tumbrinck (2014). Six major characters for genera and species recognition are 1) number and shape of antennal segments, 2) head characters in frontal view: compound eye position in relation to vertex (dorsal margin of the compound eye above the highest point of vertex or not), shape and height of lateral and transverse carinae, vertex length, angle between fastigium of the vertex (median carina) and frontal costa, scutellum and frontal carina length, antennal groove position in relation to a compound eye, fastigium shape and width, width of the vertex between the highest point of the transverse carinae in relation to compound eye vertical diameter, median, transverse and carinae shape and height, length and shape of frontal costa before bifurcation, position of the bifurcation of the frontal costa, shape of facial carinae, width of scutellum, position of the antennal groove, lateral ocellus position, ratio of the widest part of the head and its width in the level of the vertical widest part of the compound eyes, 3) head characters in dorsal view: vertex width, supra–ocular lobes presence, median carina of the vertex (length and shape), transverse carina morphology, lateral carina morphology, fossulae, anterior margin of the fastigium and 4) shape and size of pronotal projections and carinae: FM – (frontomedial projection), median carina, FL1 (frontolateral first projection), prozonal carina, FL2 (frontolateral second projection), extralateral carina, FL3 (frontolateral third projection), first and second sulci, PL1 (prolateral first projection), PL2 (prolateral second projection), lateral lobe, VL (ventrolateral projection) and its apex, PA (paranotal projections) [new character], ventral sinus, tegminal sinus, PML1 (promediolateral first projection). PML2 (promediolateral second projection), PM (promedial projection). Metazona: humero–apical carina, ML (metalateral projection), external lateral carina, infrascapular area, internal lateral carina, MML1 (metamediolateral first projection), MML2 (metamediolateral second projection), MM1 (metamedial first projection); 5) morphology of fore and mid legs: dorsal and ventral margins of fore and mid femora (if they have teeth, how large are teeth), ratio of fore and mid femur length and width; and 6) morphology of the hind legs:

ratio of hind femur length and width, shape of dorsal and ventral margins, texture of the outer area, shape of the proximal (first) tarsal segment of the hind tarsi, shape of its pulvilli. Measurements of holotype were taken in ImageJ after calibration with millimetre paper, and are shown in millimetres. Measurements taken were antennal groove width, body length (from the frontal costa to the apex of the ovipositor), compound eye horizontal diameter, fore femur length, fore femur width, mid femur length, mid femur width, hind femur length, hind femur length, hind femur width, ovipositor length, pronotum length, pronotal width (maximal between the lateral lobes), prozona width (between extralateral carinae), prozona length (including frontal projection), scapus width, scutellum width, vertex width.

Discovery of Shiva's pygmy trishula (*Tettilobus trishula* sp. n.). The holotype female (Fig. 4.32), found in MNCN, collected from the southern part of the Western Ghats, from Castet's expeditions in South India [Ind. Or.] in the end of the 19th century (1870-1890). Thus the holotype is about 130 years old. Part of the material with such labels originated from the Western Ghats of Tamil Nadu close to the border with Kerala (Singh 1964). One additional specimen was collected, male paratype, from Eravikulam National Park (ENP). The habitat represents wet-humid conditions with trees that are fully covered with bryophytes (Fig. 4.33). The specimen was collected during January 2018. The species inhabits humid rainforests in the Western Ghats (Eravikulam NP), where it can be observed on tree bark (corticolous species), feeding on moss.

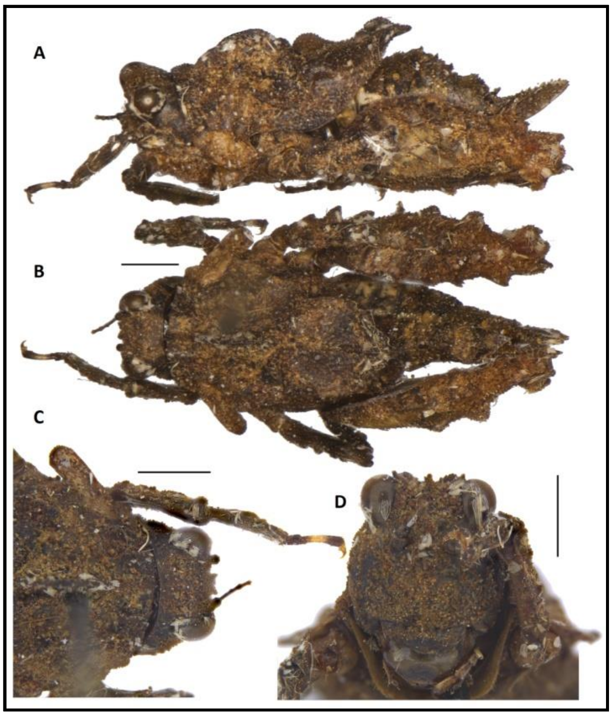


Fig. 4. 32. Holotype of *Tettilobus trishula* sp. n. from MNCN, Madrid. A. lateral view, B. dorsal view, C. head and prozona in dorsal view, detail, and D. frontal view. (Photo Mercedes París and Arabia Sánchez Terrón)

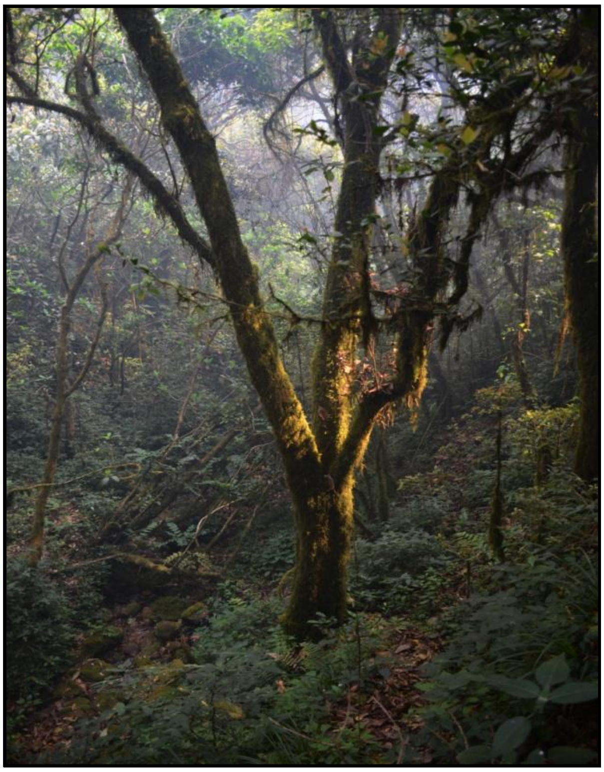


Fig. 4. 33. Habitat of *Tettilobus trishula* sp. n. The species inhabits humid rainforests in the Western Ghats (Eravikulam NP) where it can be observed on tree bark (corticolous species)

Taxonomic part

Key to Cladonotinae (Cladonotini, Xerophyllini) of India

1 In frontal view, vertex convex, arched, so highest in the place of median carina. Fastigial horns absent or indistinct. … tribe **Cladonotini** Bolívar, 1887**… 2**

\- In frontal view, vertex concave (depressed) or straight, so lowest in the place of median carina. Fastigial horns present and high. … tribe **Xerophyllini** Günther, 1979 ...**7**

2 Wings present. ... genus ***Yunnantettix*** Zheng, 1995, ***Y. elytratus*** (Günther, 1939) [NE INDIA: West Bengal]

- Wings absent. … **3**

3 Pronotum with one high elevation (projection). Pronotum and legs covered in warts and spines. … genus ***Cladonotus*** Saussure, 1862 … **4**

- Pronotum low or crested. Pronotum and legs smooth. ... genus ***Deltonotus*** Hancock, 1904 … **6**

4 High pronotal projection situated in the anterior margin of the pronotum, projected forwards above the head. … ***C. turrifer*** Walker, 1871 [SRI LANKA]

- High pronotal projection situated in the border of prozona and metazona. … **5**

5 Pronotal projection straight, directed upwards, compressed and widens towards the tip. … ***C. latiramus*** Hancock, 1904 [SRI LANKA]

\- Pronotal projection decurved, directed upward and then forward (above the head) … ***C. humbertianus*** (Saussure, 1862) [SRI LANKA]

6 Median carina of the pronotum highly crested, almost leaf-like. Anterior projection of pronotum covers vertex. Pronotal apex roundly acute. Fastigium projected before the eyes for 1/5th of a compound eye diameter. … ***D. subcucullatus*** (Walker, 1871) [S INDIA: Western Ghats and SRI LANKA]

\- Median carina of the pronotum slightly elevated, but still low, not leaf-like in appearance. Pronotum not projected anteriorly or weakly projected. Pronotal apex bilobate (Figs. 1K – 1L). Fastigium in lateral view strongly projected before the eyes. **...** ***D. gibbiceps*** (Bolívar, 1902) [S INDIA: Western Ghats and SRI LANKA]

7 Tegmina minute and visible, alae reduced, covered by pronotum. … genus ***Potua*** (?) … ***P. sabulosa*** Hancock, 1915 [S INDIA: Western Ghats]

- Wings not visible. Tegmina and alae completely absent or, if present, covered by pronotum and not visible. … genus *Tettilobus* Hancock, 1909

8 Lateral lobes with ventrolateral spine. … 9

- Lateral lobes with truncated apex. .. 10

9 In lateral view, angle between median carina of the vertex and frontal costa dentate, fastigial horns low. … ***T. prashadi*** Günther, 1938 [S INDIA: Western Ghats]

- In lateral view, angle between median carina of the vertex and frontal costa not visible, just high fastigial horns. … ***T. pelops*** (Walker, 1871) [SRI LANKA]

10 Pronotum covering abdominal apex … ***T.. portentosus*** (Kirby, 1914) **comb. nov.** [S INDIA: Western Ghats]

- Pronotum not covering abdominal apex … **11**

11 Pronotal apex trident-shaped, fastigial horns high. ***T. trishula*** Skejo, Bhaskar et Stermšek **sp. nov.** [S INDIA: Western Ghats]

- Pronotal apex bilobate, fastigial horns low. ***T. burri*** (Hancock, 1909) **comb. nov.** [SRI LANKA]

Genus *Tettilobus* Hancock, 1909

Broukus Blackith, 1992: LI [type species *Hancockia portentosa*] Otte 1997: 21 (as unnecessary replacement name for *Hancockia*).

Gignotettix Hancock, 1909 **syn. nov.** [type species *Gignotettix burri*, by original monotypy, here assigned to the genus *Tettilobus*] Hancock 1909: 397, 1915: 62, Sandrasagara 1950: 136, Liang 1990: 213, Blackith 1992: 81, Yin et al. 1996. 872, Otte 1997: 21.

Hancockella Uvarov, 1940 **syn. nov.** Uvarov 1940: 174 [new name for *Hancockia* Kirby, 1914 b, preoccupied by molluscan *Hancockia* Gosse, 1877, type species *Hancockia portentosa*, by original monotypy, here assigned to *Tettilobus*], Kirby 1914: 46 (as *Hancockia*), Günther, 1938: 345 (as *Hanockia*), Yin et al. 1996: 873, Otte 1997: 21, Shishodia et al. 2010: 142, Skejo & Bertner 2017: 665.

Mnema Kirby, 1914 a: 21 [type species *Cladonotus pelops* Walker, 1871, by original monotypy], Günther 1938: 344 (as synonym of *Tettilobus*).

Tettilobus Hancock, 1909: 396, Günther 1938: 344, Sandrasagara 1950: 136, Blackith 1992: 186, Yin et al. 1996: 925, Otte 1997: 28, Storozhenko & Paik 2011: 49-50.

Type species. *Tettilobus sponifrons* Hancock, 1909 (= *Tettilobus pelops*), by original designation and by original monotypy.

Distribution and composition. Five species inhabiting rain-forests of the Western Ghats in India (state of Kerala – *T. portentous* **comb. nov.***, T. prashadi* and *T. trishula* **sp .n.**) and rain-forests of the central province of Sri Lanka (*T. burri* comb. nov. and *T. pelops*).

Updated generic description

HEAD. Surface granulated, with numerous tubercles. ***In lateral view,*** head not exerted above the vertex, compound eye protruded above the vertex, median, lateral and transverse carinae horn-like elevated on their connection, frontal costa not strongly projected forwards, bifurcation positioned low, antennal groove below the lower margin of the compound eye. ***In frontal view,*** compound eye above vertex, excluding elevated carinae of the vertex, fastigium concave, 2x as wide as a compound eye, frontal costa before bifurcation long, almost as long as a compound eye, bifurcation of the frontal costa positioned low, facial carinae divergent after bifurcation, scutellum wide, antennal groove visibly below the lower margin of the compound eye, antennae filiform, lateral ocellus slightly below the bifurcation, in the level of the lower margins of the compound eye, median ocellus in the end of scutellum just above frontal carina, ratio of the widest part of the head and its width in the level of the vertical widest part of the compound eyes more than 1. ***In dorsal view,*** occipital area present, vertex 2x as wide as a compound eye, supraocular lobe absent, median carina of the vertex present in its apical third, compressed and elevated or low, transverse carina elevated or low, but certainly elevated towards the connection with lateral carina, lateral carina elevated behind fossula, fossula deep and evident, anterior margin of the fastigium indrawn, concave.

PRONOTUM. Wingless species of nano (*T. burri, T. pelops, T. prashadi, T. trishula*) or brachypronotal (*T. portentous*) states. Granulated with numerous fine, medium-sized, and large granules, not smooth. Projections are high in *T. pelops, T. burri* and *T. trishula*, while lower weaker in *T. prashadi* and *T. portentosus*. On the other hand *T. peopls* and *T. prashadi* have spiky ventrolateral projection, while other species do not. ***In lateral view***: *Prozona*: FM small, median carina continuous, but hardly visible because of numerous warts, prozonal and extralateral carinae tuberculated, FL1, FL2, FL3 evident, not strongly projected, PL1 and PL2 recognizable, lateral lobe strongly projected outwards, VL with rounded, toothed, or angular apex, PA small, ventral sinus present, tegminal sinus absent, PML1 and PML2 visible, PM elevated, strong, fused with MM1 (can be fused also with MML1s into hump, as in *T. burri*). *Metazona*: humero–apical carina short and tuberculated, ML present as small tubercle or absent, external lateral carina long and tuberculated, decurved, infrascapular area wide, internal lateral carina short, present in the apex, MM1 largest, fused to PM, MM2 absent or evident, MML1 and MML2 evident. ***In dorsal view*****:** anterior margin of the prozona truncated or slightly indrawn, FM small, median carina continuous,, FL1, FL2, and FL3 visible, small, prozonal carina tuberculated, short, with parallel margins, extralateral carina tuberculated, short, PL1, PL2, and PA (PA1, PA2) small, recognizable, lateral lobe directed outwards, with rounded or sharp apex (VL), PML1, and PML2 recognizable, PM short, ventral sinus triangular, *Metazona*: humero–apical carina short, forming widely rounded angle with external lateral carina, ML absent or weak, external lateral carina long, tuberculated, incurved, lateral area narrow, MM1 long, fused to PM, MM2 short or absent, median carina continuous, MML1, and MML2 recognizable, internal lateral carina short, compressed, and elevated, pronotal apex trident, bilobate or acute. ***In frontal view*** VL projected outwards, thin, FM weak, PM+MM1 elevated, visible above the vertex.

LEGS. ***Frontal leg***: Femur: dorsal and ventral margins – carinated, lobed or toothed external surface granulated, dorsal– and ventral–external carinae tuberculate. Tibia robust, rectangular in cross section, ventral, margins with spines. ***Mid leg: Frontal leg***: Femur: dorsal and ventral margins – carinated, lobate or toothed external surface granulated, dorsal– and ventral–external carinae tuberculate. Tibia robust, rectangular in cross section, ventral, margins with spines. ***Hind leg:*** Femur: dorsal and ventral margins with lappets and teeth, genicular and antegenicular teeth strong and evident, dorsal external surface with wart–like tubercles, ventral external area granulated, dorsal– and ventral–external carinae strong, tuberculate, ventro–external carina projected outwards, internal lateral area granulated, with net like elevations. Tibia with large and fine spines, not significantly widened towards apex. Proximal (first) tarsal segment longer than the third, pulvilli angular, not toothed in apex, enlarged towards the apex. **ABDOMEN.** Subgenital plate not conspicuously elongated, ovipositor with valvae with week teeth, abdominal tergites, if not covered by pronotum, bearing keels.

Notes. Members of this genus share several characters implying they belong to the same genus – they have fastigial horns elevated in similar fashion, vertex of comparable morphology, frontal costa is long and toothed, bifurcation and antennal grooves are positioned low, legs are toothed and pronotum bears recognizable small FM and large PM+MM1, elevated MML1 and MML2. Genus *Tettilobus* is easily distinguished from Indian Cladonotini by its straight or depressed vertex with high fastigial horns. It is distinguished from *Potua* (?) *sabulosa* by lack of wings. Research in future could probably prove that this species of *Potua* also belongs to *Tettilobus*.

***Tettilobus burri* (Hancock, 1909) comb. nov.**

Gignotettix burri Hancock, 1909: 397, 1915: 62, Sandrasagara 1950: 136, Liang 1990: 213, Blackith 1992: 81, Yin et al. 1996. 872, Otte 1997: 21,

Material examined. 1♂ HOLOTYPE SRI LANKA: Pundaluoya leg. Green 1906. (UMO).

Distribution. Central province of Sri Lanka: Pundaluoya and Ohiya.

Habitat. Likely rain-forest species, now known as a ground dwelling of Tree bark dwelling.

Notes. The species has been recorded twice, once from Pundaluoya (Hancock 1909) and by Sandrasagara (1950) from Ohiya. Species has been hitherto assigned to a montypic genus *Gignotettix*, but since we widened biogeographic and morphological definition of the genus *Tettilobus*, it is now assigned to latter. This small and humped species, endemic to Sri Lanka can easily be separated from its Sri Lankan congener, *T. pelops*, with following set of characters – pronotum with high hump (as opposed to compressed and elevated PM+MM1 in *T. pelops*), truncated ventrolateral projection (as opposed to spiky in *T. pelops*) and low, wart-like fastigial horns (as opposed to high, spine-like in *T. pelops*). From other species of the genus that lack spiky ventrolateral projection (*T. portentosus* and *T. trishula*), *T. burri* can be separated by bilobate pronotal apex (as opposed to tridentate in *T. trishula* and obliquely pointed in *T. portentosus*), and pronotum not covering abdominal apex (long and covering whole abdomen in *T. portentosus*). Visually, the species is most similar to *T. trishula*, new species discovered in the Western Ghats of Kerala, India.

***Tettilobus pelops* (Walker, 1871)**

Cladnotus pelops Walker, 1871: 843, Kirby 1910:9, 1914: 21.

Tettilobus pelops, Günther 1938: 344, Sandrasagara 1950: 136, Blackith 1988: 108, Blackith 1992: 186.

Tettilobus spinifrons Hancock, 1909: 296 [type locality SRI LANKA, type deposited in BMNH and examined in OSF photos], Uvarov 1929: 113 (as synonym of T. pelops)

Material examined. 1 ♀ (HOLOTYPE of *Cladonotus pelops*) (in Walker 1871 cited correctly as female, in OSF (Cigliano et al 2017 wrongly as male) Ceylon (Sri Lanka) leg. Hooker (BNHM); 1 ♀ (HOLOTYPE of *T. spinifrons*) Ceylon (Sri Lanka) 1872. leg. Thwaites (UMO).

Distribution. Western Province (Labugama) and Sabaragamuwa Provice (Bulutota)

Habitat. Likely rain-forest, but no published data.

Notes. The species is unique among congeners in having the highest fastigial horns, which are highly projected above the eyes as sharp spines. Also, ventrolateral projections are projected strongly outwards as sharp spines. Beside type specimens records (of *Cladonotus pelops* from the end of 19th century, and of *Tettilobus spinifrons* from the beginning of 20th century), Sandrasagara (1950) reported the species from the Western Province (Labugama) and Sabaragamuwa Provice (Bulutota) of Sri Lanka.

Tettilobus portentosus **(Kirby, 1914) comb. nov.**

Hancockia portentosa Kirby, 1914: 46, Günther 1938: 345*,*

Hancockella portentosa, Uvarov, 1940: 174, Yin et al. 1996: 873, Otte 1997: 21, Shishodia et al. 2010: 142, Skejo & Bertner 2017: 665, Li et al. 2018: 314.

Broukus portentosus, Blackith 1992,

Material examined. 1♂ + 1♀ SYNTYPES INDIA: Kerala: Travancore leg. Annandale 18.XI.1908 (BMNH).

Distribution. India: Kerala: Western Ghats: Travancore.

Habitat. Likely rain-forest, but no published data.

Notes. The species has truncated lateral lobes of paranota, so is easily distinguished from its spiky congeners. From *T. burri* and *T. trishula* it is easily separated by the following set of characters – pronotum covers whole abdomen (as opposed to short pronotum in *T. burri* and *T. trishula*), infrascapular area is long and runs towards the apex (as opposed to short and biconvex – or biconcave, depending on angle of definition – in *T: burri* and *T. trishula*), and very hairy body.

***Tettilobus prashadi* Günther, 1938**

Tettilobus prashadi Günther, 1938: 344, Blackith 1992: 186, Shishodia et al. 2010: 143.

Material examined. 1♂ and 1♀ SYNTYPES (out of 9 ♂♂ and 4 ♀♀ cited in the original descriptive paper) INDIA: S India: Cochin: Forest–tramway miles 10–14, 0–100 m a.s.l. IX.[19]14. leg. Gravely (SMTD).

Distribution. INDIA: Kerala: Western Ghats: Kochi.

Habitat. Likely rain-forest, but no data.

Notes. The species is known only from type series, which include altogether 13 specimens, so variability is covered at level of the type locality. *T. prashadi* is easily distinguished from other Indian congeners by presence of spiky ventrolateral projections. In other aspects, *T. prashadi* is similar to *T. trishula* sp. nov. From its spiky congener from Sri Lanka, *T. pelops*, this species can be distinguished by much less pronounced spikes.

***Tettilobus trishula* Skejo, Bhaskar et Stermšek sp. nov.** (habitat Fig. 4. 33, morphology Figs. 4. 32, 4. 34)

Type material. 1♀ HOLOTYPE INDIA: Western Ghats – labels: 1st (printed): Ind. Or. P. Castets, 2nd (handwritten by Bolívar): *Potua* Bol. *suspecta* Bol., 3rd (printed, published by París 1994): "especie" no publicada, 4th (printed, red): Holotipo, 5th (handwritten): *Tettilobus trishula* Skejo et Bhaskar, 6th 'MNCN_Ent 195791' (MNCN); 1♂ PARATYPE INDIA: Kerala: Eravikulam NP 2200 m a.s.l. N10 13'43.05" E077 05'09.39' leg. Dhaneesh Bhaskar I.2018. (KFRI).

Type material depository. HOLOTYPE is deposited in MNCN, Madrid, Spain, while PARATYPE is deposited in KFRI, Kerala, India.

Type locality. INDIA: Kerala: Western Ghats: Eravikulam NP, mountainous rainforest 2200 m, N10 13’43.05” E077 05’09.39.

Habitat. After the original collection label (Ind. Or. P. Castets), the only information we are sure was that the place of collection was situated towards South India. According to the distribution of species Castets documented during his expeditions (Desutter–Grandcolas & Jaiswara 2012, Online catalogue of MNHN Paris type specimens), it has to be from peninsular region of India (forested hills of Kerala and Tamil Nadu). Narrower type locality is of course Eravikulam NP, where the paratype male was collected. The species inhabits dense rainforest of the Western Ghats. It inhabits tree trunks where it probably feeds on mosses and detritus. It is thus, bark dwelling, corticolous species. It is not leaf-litter species like e.g. *Deltonotus subcucullatus* and *D. gibbiceps.*

Etymology: In Hindu mythology and epics like Mahabharata and Ramayana, *trishula* (originally from Sanskrit) is a three–pronged spear that Lord Shiva (with trident known as *trishulank*) used as his sacred weapon to fight off evil. Each tooth of the trishula is called a *guna* in Samkhya philosophy. Three *gunas* are in this new species made of highly compressed median carina and elevated curved external (large trishula) and internal (small trishula) lateral carinae of the pronotal apex.

Specific diagnosis. Nanopronotal small wingless species (body length from the apex of fastigium to the apex of the ovipositor 7.5 mm), antennal grooves situated below the lower margin of the compound eyes, scutellum as wide as a single antennal groove, frontal costa bifurcation situated on the level of a compound eye dorso-ventral diameter, frontal costa above bifurcation long, median carina of the vertex, lateral carinae of the vertex and transverse carinae projected as equally high horns, FM small, PM+MM1 compressed and highly elevated, MML1 and MML2 strong, VL projected downwards–outwards with rounded apex, strongly incurved external lateral carinae, internal lateral carinae forming with median carina acute upwards directed structure reminding of *trishula*, all femora armed with strong teeth, pronotum not covering the whole abdomen, visible part of the abdomen armed.

Holotype description

Description is divided into description of head, pronotum, legs and abdomen. Description of head and pronotum is organized into views (lateral, frontal and dorsal). So it is clear how to look at the specimen to follow the description. For head description in lateral view, follow Figs. 4.32C and 4.34D, in frontal view follow Fig. 4.32D, in dorsal view follow Figs. 4.32B and 4.32C. For pronotum description see Figs. 4.32B and 4.34C, while for lateral view Figs. 4.32A and 4.34A, for dorsal Figs. 4.32B and 4.34C. For description of legs see Figs. 4.32A and 4.32B.

HEAD. Whole surface with numerous fine and medium sized tubercles. ***In lateral view,*** occipital area wide as one–third of a compound eye horizontal diameter, a compound eye rounded with truncated lower margin proximal to pronotum, a compound eye exerted above the vertex, lateral and transverse carinae not visible in lateral view, but in slight dorso–lateral view visible as horn like elevations, vertex not projected in front of the compound eye, head not exerted above pronotum, fastigium of the vertex (median carina) and frontal costa forming a right angle, scutellum and frontal carina projected for one–half of the compound eye horizontal diameter, antennal groove below the lower margin of the compound eye, palpi compressed with segments widening towards apex. ***In frontal view,*** compound eye exerted above the vertex less than lateral carina of the vertex, transverse carina of the vertex and median carina of the vertex, concave fastigium of the vertex wider than a compound eye vertical diameter, width of the vertex between the highest point of the transverse carinae two times as the compound eye vertical diameter, median, transverse and carinae of the vertex elevated 0.12 mm above the vertex, frontal costa before bifurcation as long as dorso-ventral diameter of a compound eye, bifurcation of the frontal costa in the level with the lower margin of the compound eye, facial carinae between lateral ocelli and antennal groove divergent, then parallel, facial carinae approximately as wide as frontal costa, scutellum as wide as an antennal groove, antennal grooves 0.1 mm below the lower margin of the compound eye, antennae broken, scutellum and pedicel left of left antenna, first four elongated cylindrical antennomeres of the flagellum (altogether six antennomeres) preserved of right antenna, lateral ocellus in level with the lower margin of the compound eye and slightly below the frontal costa bifurcation, median ocellus in the end of scutellum, just above short frontal carina, ratio of the widest part of the head and its width in the level of the vertical widest part of the compound eyes 1.15, eyes ovoid. ***In dorsal view*** occipital area less granulated than the rest of the head, 0.17 mm wide, eyes semicircular, vertex two times wider than the vertical diameter of a compound eye, supra ocular lobes absent, median carina of the vertex laterally compressed and projected upwards and forwards as a horn, present only in the distal third of the vertex, transverse carina close to median carina low, higher towards eyes, forming a horn on the connection with lateral carina, lateral carina of the vertex high in the connection with the transverse carina, then almost absent and from the mid of the compound eye horizontal diameter towards median carina of the pronotum to the level of the compound eye margins proximal to pronotum again elevated in horn-like projections, fossulae very deep, anterior margin of the fastigium slightly concave (except of projected median carina). ***Coloration.*** Head dark brown, almost black, tubercles paler, microbial epizoic overgrowth present in vertex and frons, distal articles of palpi yellowish.

PRONOTUM. Nanopronotal (wingless species), pronotum reaching forth abdominal segment, fully covering only the first two abdominal segments. ***In lateral view***: *Prozona*: prozona finely serrate, rich with numerous small, medium sized, and large wart–like granules, FM (frontomedial projection) small and wart–like, median carina finely serrate, continuous, FL1 (frontolateral) small, prozonal carina visible, tuberculated and slightly elevated, FL2 small, extralateral carina weekly visible, FL3 small dentiform, sulci short and deep (first sulcus shorter than second), PL1 (prolateral) large, wart–like horn, PL2 small and indistinct, wart–like, lateral lobe directed downwards–outwards, VL (ventrolateral) with truncated apex, PA (paranotal) present as two wart–like tubercles, the one closer to ventral sinus, larger than the one in the direction of PL2, ventral sinus deep, tegminal sinus absent, PML1 (promediolateral) fused to prozonal carina, PML2 large, smaller than PML1, PM (promedial) elevated and fused with MM1. *Metazona*: humero–apical carina wide, tuberculated, and short, ML (metalateral) absent, external lateral carina wide, four–times as long as humero–apical, elevated and incurved in direction of median carina in shape of Gauss curve, infrascapular area wide, finely granulated, running to the level where internal lateral carina begins, having two sinuses in the places where the tegminal sinus would be and where the external lateral carina is incurved, internal lateral carina short and elevated, lateral area short and narrow, strongly directed upwards (45 degrees) and then forwards in the apex, MML1 elevated, MML2 long, strong, elevated and fused to external lateral horn–like tubercle, MM1 (metamedial) the largest projection, massive and high, its highest part in the level of the acute pronotal apex with blunt tip. ***In dorsal view***: prozona: anterior margin truncated, FM (frontomedial) short, median carina continuous, tuberculated and wide, FL1 (frontolateral) slightly projected, small and wart–like, prozonal carina compressed, slightly elevated, and tuberculated, as long as compound eye horizontal diameter, FL2 indistinct, FL3 small and dentiform, extralateral carina indistinct, first and second sulci short and deep, PL1 (prolateral) larger than PL2, both elevated, paranota triangular, PA wart–like elevations, (PA2 larger than PA1) lateral lobe projected downwards–outwards, not toothed, VL (ventrolateral) projection with rounded, blunt apex, not spine or saw like, PML1 (promediolateral) fused to prozonal carina, slightly elevated, PML2 distinct, PM (promedial) short, laterally compressed, elevated and fused to MM1, surface of prozona granulated, covered with microbial epizoic overgrowth (except of carinae and projections which have large tubercles and are not covered with overgrowth), ventral sinus triangular and deep, tegminal sinus absent. *Metazona*: humero–apical carina short, wide and tuberculated (toothed), forming widely rounded angle with external lateral carina, ML absent, external lateral carina wide, tuberculated, laterally compressed, elevated, and strongly incurved in sinusoidal curve, external lateral carina four times as long as humero-apical carina and three times as long as internal lateral carina, infrascapular area in the widest part as wide as pronotal dorsum between external lateral and median carinae, internal lateral carina short, strongly compressed and elevated, lateral area narrow, MM1 long, compressed and elevated, fused with

PM, median carina continuous to the apex, wide and smooth, with tuberculated parts, MML1 massive, wart–like, MML2 longer than MML1, as wide as MML1 highly elevated, pronotal dorsum flat from the level of MML2 to internal lateral carinae, pronotal apex acute (internal lateral carina alone forming bilobate apex, but median carina is acutely projected posteriorly) and elevated, reminding of the trident (*trishula*), which is made of laterally compressed median and internal lateral carinae pointed towards median carina. ***In frontal view*** VL strongly projected outwards, with the pointed apex, FM small, humeral angle not significantly wider than head, PM+MM1 crest–like elevation. ***Coloration*** – dark brown almost black.

LEGS. ***Frontal leg***: Femur: dorsal and ventral margins carinate, laterally compressed, dorsal margin with three teeth, proximal high and triangular, directed upwards and outwards, second long and triangular – running from proximal tooth to the distal one and highest in its distal part, distal (fore genicular) tooth blunt, wart–like, ventral margin trilobate, proximal lobe lowest, blunt, second lobe strongly compressed and projected outwards for about half the width of fore femur, third lobe (distal) compressed, semicircular, external surface granulated, dorsal– and ventral–external carinae tuberculated, not taking into account projection of dorsal and ventral margins –length/ width ratio 3. Tibia robust, rectangular in cross section, as long as femur, with laterally compressed, undulated and elevated dorsal and ventral, inner and outer margins, ventral margins with numerous fine spines, surface granulated. Proximal tarsal segment significantly shorter than distal, having rounded pulvilli, distal segment long and smooth, bearing claws. Coloration: femur dark brown, tibia differently colored from all sides – basal color black, ventral outer margin pale colors, with two pale stripes – one in the proximal third, and one in distal part, proximal tarsal segment black, distal black with wide white ring, claws yellowish with dark apex. ***Mid leg:*** Femur: dorsal and ventral margins carinate, laterally compressed, dorsal margin with a few teeth, triangular and low, ventral margin trilobate, proximal lobe lowest, semicircular, second and distal lobes strongly compressed and teeth-like projected outwards for about half the width of fore femur, external surface granulated, dorsal– and ventral–external carinae tuberculated, not taking into account projection of dorsal and ventral margins –length/ width ratio 3.2. Tibia robust, rectangular in cross section, slightly shorter than femur, with laterally compressed, undulated and elevated dorsal and ventral, inner and outer margins, ventral margins with numerous fine spines, surface granulated. Proximal tarsal segment significantly shorter than distal, having rounded pulvilli, distal segment long and smooth, bearing claws. Coloration: femur dark brown, tibia black, with two pale stripes, proximal tarsal segment black, distal black with barely visible white ring, claws yellowish with dark apex. ***Hind leg**:* Femur: dorsal and ventral margins carinate, laterally compressed, dorsal margin undulated and toothed, a small sharp lappet present in its apical third, genicular tooth blunt, antegenicular tooth sharp, ventral margin undulated, granulated and toothed, with three weak lappets of which the strongest is medial, dorsal external surface (4 or 5 large tubercles) and ventral external areas very granulated, dorsal– and ventral–external carinae tuberculated, ventro–external carina in the middle and distal third bearing two large, outwards directed teeth with rounded apices, internal lateral area smooth, without recognizable transverse ridges, but with net-like elevations in the proximal half, and tuberculated in the distal half, length/ width ratio 2.3. Tibia elongated, smooth, semicircular in cross section, with elevated dorsal margins, as long as femur, inner dorsal margin with six large spines and numerous fine spines between them, outer dorsal margin with a few recognizable spines in the apical fourth, the rest rich in fine spines. Proximal (first) tarsal segment longer than distal, having three angular pulvilli enlarging towards apex, mid tarsal segment short, distal segment smooth, bearing claws. Coloration: femur dark brown, with pale proximal half of external inner area, tibia dark brown, with pale colored inner dorsal margin (including spines, of which large have dark apices), one pale ring present in proximal part, proximal tarsal segment black and getting paler towards tip, mid (second) dark brown, distal pale, getting dark towards tip, claws yellowish with dark apex.

ABDOMEN. Sternites smooth and black, subgenital plate finely granulated, dark brown with black patch in the middle, conical, with slightly pointed apex, ovipositor elongated, hairy, dark brown, dorsal and ventral margins of valvae with small teeth, cerci conical, stout, with swollen base, with long hairs (longer than cercus alone), supra-anal plate (epiproct, 11th tergite) long, triangular, 10th tergite with deep square shaped pit, tergites black in ventro–lateral part, yellowish in dorsolateral part, armed and darker in dorsal part.

Variations. Species exhibit sexual dimorphism in size, but not in structures. Male is same as female but smaller. It has even shorter pronotum. Coloration probably varies, however little can be assessed from comparison of living specimen with centuries old museum specimen. Unfortunately, we were not able to take measurements of paratype male.

Holotype measurements. antennal groove width 0.28 mm, body length 7.71 mm, eye width 0.36 mm, fore femur length 1.39 mm, fore femur width 0.38 mm, mid femur length 1.83 mm, mid femur width 0.51 mm, hind femur length 3.85 mm, hind femur width 1.61, ovipositor length 1.13 mm, pronotum length 3.84, pronotum maximum width in the level of ventrolateral projections 3.59 mm, prozonal width between prozonal carinae 0.69 mm, prozonal length 0.59, scapus width 0.19 mm, scutellum width 0.23 mm, vertex width 0.71 mm.

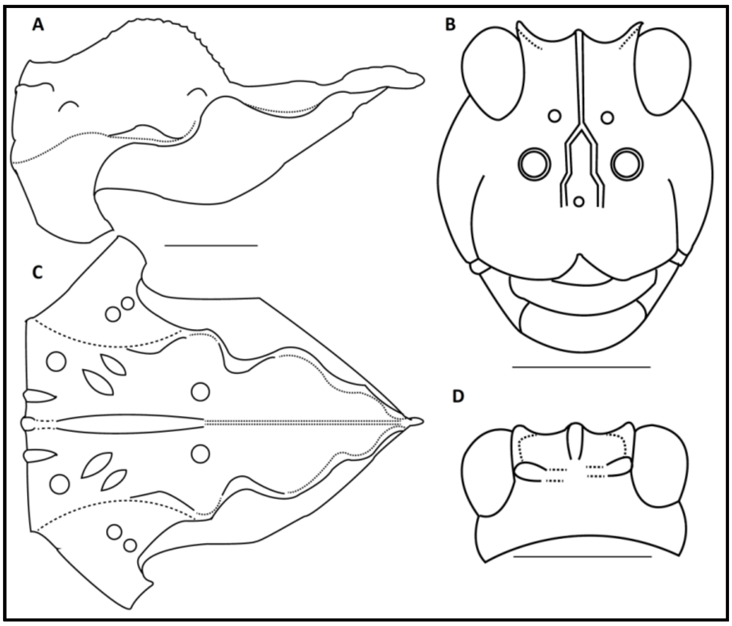


Fig. 4. 34. Taxonomic drawings of *Tettilobus trishula* – A. pronotum in lateral view, B. head in frontal view, C. pronotum in dorsal view and D. head in dorsal view. Drawings were made based on holotype female from MNCN, drawings by Sara Stermšek

4.3.8 REDISCOVERY

Family	:	**Acrididae** MacLeay, 1821
Subfamily	:	**Catantopinae** Brunner von Wattenwyl, 1893
Genus	:	***Mopla*** Henry, 1940
Species	:	***Mopla guttata*** *Henry, 1940*

Genus *Mopla* includes small brachypterous grasshoppers of subfamily Catantopine with bright yellow stripes and spots on a dark brown body (Fig 4.35). A very abbreviated frontal ridge that forms a short narrow rostrum (lamelliformly compressed) between the antennae, but becomes obsolete just below the antennal bases, and the absence of visible ocelli marks Mopla as a well noted genus among the subfamily Catantopinae. The laterally expanded terminal segment of the maxillary palp forms a pale-coloured broadly elliptical surface (probably for intra-specific communication).

Fig. 4. 35. Mopla guttata adult collected from Parambikulam Tiger Reserve. (Photo: Dhaneesh Bhaskar)

Henry (1940) described two species of the genus *Mopla* (*M. guttata* – (the type of the genus) and *M. rubra*) from the Western Ghats. The genus was named after the Muslim community of the Malabar region of south India (Kerala). Both the specimens were collected from the southern Western Ghats. The type specimen of *Mopla guttata* was collected from Top Slip, Anamalai Tiger Reserve, Tamil Nadu and that of *Mopla rubra* from Nilambur, Kerala. There has been no further record of these two species since its description. It was described with only a female specimen. No male has been described. The first male of this genus was collected during the study and described.

Depositories: NHMUK (Natural History Museum, London, United Kingdom), **KFRI** (Kerala Forest Research Institute, Kerala, India).

Description of the male of *M. guttata*

Allotype: adult male (opposite sex to the holotype) (Fig. 4.35): India: Kerala: Palakkad district: Parambikulam Tiger Reserve: Sungum Forest Range. Coordinates 10°41'93.40”N, 076.72'12.40”E. 28.09.2016 (leg. Dhaneesh, B). Specimen number OR0024 (KFRI).

Size: medium, L (length from fastigium to tip of sub genital plate) = 17.82 mm. Integument rugose, coarsely punctate, provided with numerous short white hairs. Antennae filiform, 22 segments, longer than head and pronotum together. Flagellum long and thick, black, flattened towards the tip with a light brown-yellow terminal segment (Fig. 4.35). Head with rounded occiput, fastigium of the vertex triangular, wider at its base than long, extending slightly beyond the anterior margins of the antennal scape segments, the tip bluntly rounded, dorsal surface finely punctate, devoid of lateral or medial carinae. Fastigial foveolae absent. Frontal ridge lamelliformly compressed, developed only between the antennal sockets, obsolete below; extends as a very thin semicircular rostrum between the antennal scapes; anterior surface smooth, not sulcate, over most of its length, but minutely sulcate and divergent just at its ventral extremity. Compound eyes large, globular and protuberant, interocular space narrow, less than width of antennal scape. Medial and lateral ocelli apparently obsolete. Pronotum transversely rounded, medial carina scarcely visible, lateral carinae absent; front margin broadly rounded, hind margin obtuse-angulate, with a rounded tip. Metazona much shorter than prozona. Itsmargins diverge strongly towards the rear. Disc of pronotum coarsely rugoso-punctate, deeply incised by the principal (most posterior) sulcus, and very weakly by one or two more anterior sulci. Prosternal tubercle short, vertical, slender and pointed. Brachypterous;

tegmina overlap dorsally and extend only into 7th abdominal tergite with rounded tips. Wings: tegmen 5.51mm long, olive brown in colour. Pro- and mesothoracic legs stout, femora widened and nearly cylindrical, fore and middle tibiae rounded, with numerous small hairs, punctured. Hind femur stout, strongly rounded, thick, exceeds both abdomen and the elytra in length, coarsely punctured; dorsal and ventral longitudinal carinae weakly serrate. External face of femur with prominent chevron patterning marked by rows of strong punctures. Hind knees with medial dorsal tooth, ventral lobes slightly downwardly curved, pointed, but not spinous. Hind tibia stout with 8 external and 10 internal spines, inner spines are slightly longer than the external spines; external apical spine present. Hind tibia (10.21mm) 2.40 times as long as hind tarsus (4.25mm). Third segment of hind tarsus longer than the first two segments together, foot formula 0.23, 0.17, 0.58; arolia well developed. For the foot formula, the value for each tarsal segment is obtained by expressing its length as a percentage of the sum of the three tarsal segmental lengths. E.g., the value for T2 is T2/ (T1 + T2 +T3). This formulation allows the feet of different species of different sizes to be compared with each other (Table 4.11).

Abdomen short, conical and compressed, tenth abdominal tergite divided, with a weak furcula (Fig. 4.36 A) Supra-anal plate roughly triangular, with a rounded tip. Male cerci fairly short, straight, tapering to an obliquely truncate tip (Fig. 4.36 B). Male subgenital plate rather short, apex smoothly rounded in lateral view (Fig. 4.36 C& D). Phallic complex: (Fig. 4.37). Elongate and slender, aedeagus equal in length to the more proximal parts of the phallus. Epiphallus: bridge shaped, broad, undivided medially, with short hooked ancorae and large tapering lobe-shaped lophi which are curved over at their tips. Lateral lobes weakly differentiated. Oval sclerites present, of irregular shape. Ectophallic apodemes long and slender, tapering, more or less parallel; zygoma rounded, rami slender, running rearwards at their tips, and giving rise to an extensive ectophallic sheath surrounding the dorsal aedeagal valves. Arch sclerite large, supporting long spatulate dorsal aedeagal valves that exceed the ventral valves in length. Endophallus slender, gonopore processes present and elongate, extending ventrally almost to the flexure. Flexure slender, ventral aedeagal valves tapering but not pointed. Endophallic apodemes small and narrow, not inflected laterally. Ejaculatory sac apparently lost in dissection, spermatophore sac lies ventrally, between and below the ventral aedeagal valves.

Dimensions of Specimen No OR0024-KFRI			**Foot formula**
Characters	**mm**		**Ratios**
Length from fastigium to tip of subgenital plate	L	17.82	
Length of hind femur	F	12.64	
Depth of femur (the maximum width of the hind femur)	FD	3.68	
Length of hind tibia	Tib	10.21	
Length of the most proximal tarsal segment	T1	1.01	0.23 (T1/T1-3)
Length of the second tarsal segment	T2	0.75	0.17 (T2/T1-3)
Length of the distal tarsal segment	T3	2.49	0.58 (T3/T1-3)
Total length of the three tarsal segments	T1-T3	4.25	1.00 (T1-T3/T1-3)
Length of elytron	E	5.51	
Length of antenna	Ant	31.89	
Length of pronotum in the dorsal midline	P	4.47	
Head and pronotum (combined length)	H+PN	7.43	

Table 4.11. Measurements of male *Mopla guttata* (specimen OR0024-KFRI)

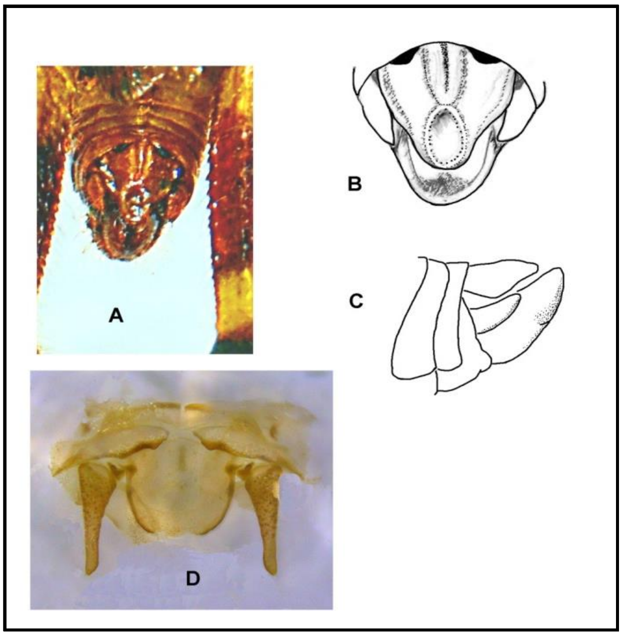


Fig. 4. 36. Male terminalia of *Mopla guttata*: A. Dorsal aspect of pinned specimen; B. Interpretive drawing of A; C. Lateral view; and D. Cleared preparation of abdominal tergites 10 and 11. Note that the terminal lobe of the supra anal plate is missing; compare with A and B. Furcula and the obliquely truncate cerci are clearly shown

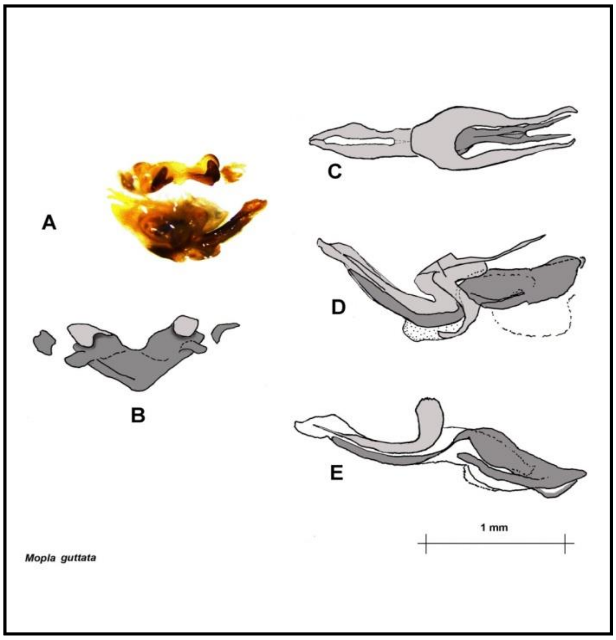


Fig. 4.37. *Mopla guttata*, phallic structures. A. Oblique posterior view of phallic complex before preparation and dissection; B. Epiphallus, anterior view; C. Dorsal and D. Lateral views of phallic complex with epiphallus, epiphallic, and ectophallic membranes removed; and E. Endophallus, arch sclerite, and ectophallic aedeagal valves, after removal of remaining ectophallic structures. In C–E the endophallus is in darker shading, the ectophallus in lighter shading. The broken line in D indicates the presumed position of the ejaculatory sac, missing from this preparation. Spermatophore sac stippled

4.4 DISCUSSION

Fifty eight species of grasshoppers were recorded from both the study areas, which include eighteen species endemic to India. Fifty-five grasshopper species were recorded from PKMTR and eighteen from ENP. Fifteen species were common to both areas. Thirty-nine species were exclusive to PKMTR and three to ENP. This is probably due to the habitat heterogeneity in PKMTR compared to that of ENP. The grasshoppers differ in their distribution across different habitats. This could be attributed to their difference in life-history traits (Ingrisch and Köhler 1998; Braschler et al. 2009). According to the habitat heterogeneity hypothesis, a greater diversity of insects in complex habitats is expected than that in simple habitats (Tscharntke et al. 2002; Tews et al. 2004). Increased numbers of niches with more structural arrangements extend the niche dimensions and habitat complexity (Kadmon and Allouche 2007). The complex habitats and increased number of niches in PKMTR favoured the increase in grasshopper diversity. The newly described pygmy grasshopper species (*Tettilobus trishula sp. nov*.) was collected from a shola tree bark (corticolous species), feeding on moss. Just like many other insect species, grasshoppers are highly specialized in their microhabitats such as vegetation structure (Weyer et al. 2012). Species such as *Tettilobus trishula* were found to be very specific in its microhabitat conditions.

An extremely rare Catantopinae species, *Mopla guttata* was rediscovered for the first time since its description in 1940 from MDF habitats of PKMTR. This was the first male specimen to be collected for this species (Bhaskar et al. 2020). Rediscovery of a species after 70 years since its description indicates the unique grasshopper distribution across the Western Ghats. This also indicates the need for further studies on this diverse group. The mobility of grasshoppers is known to be higher in males than in females (Mason et al. 1995; Maes et al. 2006; Walters et al. 2006; Lo´pez et al. 2007). The males actively search for females and female grasshoppers spend more time in search of food (Hochkirch et al. 2007). Both *Mopla guttata* and *Mopla rubra* were described after two female specimens (Henry 1940). Multiple failed attempts were made in search of a male specimen (Bhaskar et al. 2020). The difference in the mobility pattern among male and female grasshoppers could also be the reason for the rare sightings of male Mopla. The family Tetrigidae were also least explored in the Western Ghats region. *Euparatettix personatus* and *Deltonotus subcucullatus* collected from PKMTR were first records for India.

The family Acrididae is recognised to be the most diverse family within the Orthopteran suborder Caelifera (Cigliano et al. 2018). A family that hypothesized to have evolved in the early Cenozoic Era and diversified through the mid to late Cenozoic (Song et al. 2015) has a wide cosmopolitan distribution. With a total of 34 species from ENP and PKMTR, the family Acrididae were the most diverse grasshopper group recorded during the study. There are currently 26 recognized subfamilies within Acrididae (Cigliano et al. 2018). Of these, ten subfamilies (Acridinae, Catantopinae, Cyrtacanthacridinae, Eyprepocnemidinae, Gomphocerinae, Hemiacridinae, Oedipodinae, Oxyinae, Spathosterninae and Teratodinae) were recorded during the study. Acrididae dominates the habitats of ENP with ten species followed by Tetrigidae (four species), Pyrgomorphidae (two species), Chorotypidae (one species) and Mastacideidae (one species). With thirty three species, Acrididae dominates the grasshopper community of PKMTR followed by Tetrigidae (eight species), Pyrgomorphidae (seven species), Chorotypidae (three species), Mastacideidae (two species) and Tridactylidae (two species). The family tetrigidae represents small inconspicuous grasshoppers that are terricolous and inhabit humid places also some species shows semi-aquatic behaviour (Kočárek 2011). The tetrigidae observed from PKMTR and ENP were found to be very much associated with humid conditions. *Euscelimena harpago* exhibited semi-aquatic behaviour. The grasshoppers of family Pyrgomorphidae are commonly referred to as gaudy or bush grasshoppers. Theyare brightly coloured and are known to be aposematic and sequestering the plant secondary metabolites (Mariño-Pérez and Song 2017). Species such as *Poekilocerus pictus* and *Aularches miliaris* are brightly coloured.

4.4.1 *Tettilobus trishula* sp. n.

Pygmy grasshoppers (Orthoptera: Tetrigidae) are a widely diverse insect group in India (Shishodia et al. 2010). Species of peculiar body shapes were reported, especially from southern India – wingless, winged, slender, robust, spiky, smooth, and leaf-like (Kirby 1914 a). Indian fauna comprises of 96 species, within 36 genera. Six out of seven recognized Tetrigidae subfamilies – Batrachideinae, Cladonotinae, Metrodorinae, Scelimeninae, Tetriginae, Tripetalocerinae have distributional records from India. The only absent subfamily is Lophotettiginae endemic to South America (Shishodia et al. 2010; Cigliano et al. 2019). Subfamily Cladonotinae gathers brachypterous and apterous members with widely forked frontal costa forming wide scutellum. Hence, the group is being recognised as wide-nosed pygmy grasshoppers. Most of the genera and species are restricted to small geographical areas because of their low flight adaptations (Tumbrinck 2014).

Wide nosed pygmy grasshoppers are understudied group in India. India and Sri Lanka are inhabited by diverse Cladonotini and Xerophyllini. Only one Cladonotini species, *Yunnantettix elytratus* inhabits NE India (West Bengal) while other genera and species are restricted to rainforest of the Western Ghats and the central province of Sri Lanka. Genus *Deltonotus* (with *D. gibbiceps* and *D. subcucullatus*) inhabits both India and Sri Lanka. Two species can be found syntopically. Genus *Cladonotus* has unique pronotal morphology among Tetrigidae and is endemic to the rainforests of the central province of Sri Lanka.

Six Xerophyllini species are known to inhabit rainforests of the Western Ghats of India and Sri Lanka. Of these, one is currently assigned to the genus *Potua*, (*P.* (?) *sabulosa*) but with a question mark, while other five belong to the genus *Tettilobus*. Future research could probably show that *P.* (?) *sabulosa* belongs to *Tettilobus*, as well. *T. portentosus* comb. nov., *T. prashadi* and *T. trihula* sp. n. are endemic to the Western Ghats of Kerala, while *T. burri* comb. nov. and *T. pelops* are endemic to the rainforest of the central province of Sri Lanka.

After assignment of *T. trishula* based on similarity with *T. prashadi* and *T. pelops*, it became clear that description of the genus requires addenda. Now, genus *Tettilobus* has wider definition and includes all species of India and Sri Lanka that have fastigial horns, long and toothed frontal costa, straight or depressed vertex, toothed femora, and recognizable pronotal projections – small FM and larger PM+MM1. Thus, monotypic *Hancockella* syn. nov. and *Gignotettix* syn. nov. are synonymized with *Tettilobus*, their species being given new combinations. Discovery of *T. trishula* sp. n. in the shola forests of the Western Ghats points out the necessity of continuous and comprehensive research of micro-fauna in these mountains. The diversity of Western Ghats is not highlighted enough in media and biological textbooks in terms of its invertebrate diversity. The emphasis is given on charismatic vertebrates (e.g. tiger, elephant). Orthoptera diversity of Western Ghats should receive more attention as it can likely reveal biogeographic and taxonomic conclusions on the connection between South America, tropical Africa and Madagascar in the West, and Southeast Asia, Papua and North Australia in the East.

4.4.2 *Mopla guttata*

The two Catantopinae species of the genus *Mopla* by Henry (1940), *Mopla guttata* (genotype) and *Mopla rubra* are extremely rare endemic grasshoppers. Mopla specimens were collected from the southern Western Ghats. The type specimen of *Mopla guttata* was collected from Top Slip, Anamalai Tiger Reserve, Tamil Nadu and that of *Mopla rubra* was collected from Nilambur, Kerala. There has been no further record of these two species since its description and the description was based only on female specimens. The first male of this genus was collected and described in the present study. *Mopla rubra* is superficially identical to *M. guttata.* There are minor differences. *M. rubra* is slightly smaller than *M. Guttata* with relatively shorter antennae, shorter and less well-developed tegmina, that are much more widely separated at their bases and are not so distinctly divided into two planes at vein M; frontal ridge feebly constricted opposite antennal scrobes; below this point, irregularly sulcate to a point half-way to the clypeal suture; fastigium of vertex more evenly declivent, less tumescent than *in M. guttata;* puncturation of face, occiput, pronotum and pleurae less coarse than in the latter; pronotum with the angle of posterior margin rounded". The differences were confirmed by examining the type specimens of both *guttata* and *rubra* (both in the Natural History Museum, London (NHMUK)) and attempted to confirm these reported differences (Table 4.12).

Measurements in mm.	**(*guttata* female)**	***rubra* female**
Length of body. .	20.0	ca. 20.0
(probably 23.0 in life)		
Length of antenna. .	13.0	11.0
Width of head, across eyes. .	4.5	4.1
Length of pronotum. .	7.0	6.0
Greatest width of pronotum. .	6.25	5.3
Length of tegmen. .	9.0	6.4
Length of fore femur. .	4.2	3.7
Length of hind femur. .	12.3	10.3

Table 4.12. Measurements of both *M. rubra* and *M. guttata* specimens

Measurement results indicate that *guttata* is 10-20% larger than *rubra* except for length of the tegmen (T), where as that of *guttata* is apparently 40% longer than *rubra*. The slightly larger size of *guttata* is apparent when the two types are compared. After normalizing for the difference in size of the two species, by dividing each value by the length of the pronotum (P), the ratio of *guttata* to *rubra* values is close (≤10%) to unity throughout, indicating that the relative sizes of different body parts are identical in the two specimens. Henry was therefore incorrect in stating that the antennae of *rubra* are "relatively shorter" (the antennae are broken on both the types, and Henry's measurements could not be checked). The exception to the above is the length of the tegmen (T), which is 20% longer in *guttata* even after normalization. Presumably, this is the basis of Henry's statement that the tegmina of *rubra* are "shorter and less well-developed". By checking and recalculating the ratio T/P from photographs of the two specimens, new values of T = 1.24P for *guttata*, and T = 1.12P for *rubra* were obtained. This reduces the normalized *guttata/rubra* ratio to 1.24/1.12 = 1.11, in line with that of all the other body measurements. It is therefore concluded that Henry's tegmen measurement for *guttata* was somewhat too large and that all the morphometric ratios of the two type specimens are within 10% of each other.

The Separation of the wing bases seems to be merely a difference in the extent of overlap of the trailing edges of the tegmina, which could be influenced by the position of the tegmina or variation in their width. There is a slight difference in the posterior angles of the pronotum as noted by Henry. The posterior angle of the *rubra* type is indeed somewhat more smoothly rounded than that of *guttata.*

In summary, the differences in morphology claimed by Henry are only partially supported on re-examination. The confirmed differences are slight and alone are possibly insufficient for a specific separation, as Henry remarked.

Biogeography of the *Mopla* species: As mentioned above, the type localities of both *guttata* and *rubra* in the Western Ghats and are relatively close to each other. Significantly, however, they are separated by a prominent geographical feature, the 30—40 km Palghat Gap (Myers et al. 2000), which is the only significant break in the chain of the Ghats. The Palghat Gap is known to be a major biogeographic barrier for numerous plants (Bahulikar et al. 2004, Apte et al. 2006) and vertebrates (Vidya et al.

2005; Ram et al. 2015; Robin et al. 2010; Vijayakumar et al. 2016; Van Bocxlaer et al. 2012; Gunawardene et al. 2007) and could very well interrupt gene flow between populations of flightless grasshoppers such as *Mopla*. It is therefore quite plausible that the slight differences seen between *guttata* and *rubra* derive from genetic differences and represent at least incipient speciation. With a genus known from only three specimens, it is impossible to be sure of a specific determination as the range of intra-specific variation is unknown. However, all the available evidences (geographical, morphological, and colouration) suggest that we dealt with the previously unknown male of *Mopla guttata.*

Biology: Practically nothing is known of the way of life of this genus. The male specimen was caught on low bushes at a forest verge with predominantly herbaceous vegetation. Henry's holotypes were caught "in rain-forest" with no further details provided. The hind foot formula with a short second tarsal joint suggests a life on herbaceous plants rather than an arboreal one and the large arolia rule out a terrestrial way of life.

4.4.3 Community structure

Although the grassland and grasshopper community dynamics has been well documented, their interaction with other forest habitats is less investigated (Joshi et al. 1999). The grasshopper community structure across ENP and PKMTR varied significantly following the heterogeneity in habitat types of both the study areas. The greater plant heterogeneity favours more grasshopper species than less heterogeneous areas (Otte 1976). Short-horned grasshoppers (Caeliferans) are well known for their microhabitat specificity (Schirmel et al. 2010). Within the different habitats of ENP (Shola, Shrubs and Grasslands), very little variance was observed in terms of number of species. But the composition and abundance varied between habitats. Among the three habitats with a total of eighteen species, grasslands were found to be more species-rich with twelve species. Shola and shrubs were equally diverse with nine species. The reasons for grasshopper richness in grasslands compared to the shola and shrubs were probably due to the extent of exposed areas and the visible abundance of food. The grasshoppers are known to be occupying open-habitats such as grasslands. They are typical grassland insects and good indicators of the quality of open-land habitats (e.g. Hochkirch and Adorf 2007; Jonas and Joern 2007). The shrubs within the grasslands in ENP were found to be dominated with the Strobilanthus *kunthiana* (neelakurinji) with hard and hairy leaves and were found to be avoided by the grasshoppers. The species community structure within the shola was found to be different from that of the other two. This could also be due to the low sunlight availability and undergrowth. *Teratodes monticollis* and *Cyrtacanthacris tatarica* tatarica were seen occupying all the three habitats of ENP. Species such as Zygophlaeoba *sinuatocollis*, *Prionacantha picta* and the new species *Tettilobus trishula sp.nov* were found to be exclusive to habitats of ENP. Populations of flightless grasshopper species are found to be strongly isolated in higher elevations (Weyer 2012). All the three species exclusive to ENP are flightless and very specific to their microhabitats.

Among the six different habitats in PKMTR (MDF, Semi Evergreen, Evergreen, Riparian, Vayals and Grasslands), the MDF had higher species richness with twenty nine species followed by riparian and semi-evergreen with twenty eight species.

Grasslands had twenty four. Evergreen and vayals are habitats with low species richness, sixteen and twelve respectively. The distribution of MDF in Parambikulam with vayals and open grasslands presenting a mosaic of vegetation explain the species richness in MDF. In moist deciduous forest of India, grasshopper community was found to be very much viable, and considered as a diagnostic tool for assessing the environmental conditions (Joshi et al. 1999).

4.4.4 Grasshopper species abundance patterns

The species richness and abundance pattern in different habitats of both the study areas were not uniform. In Grasslands of ENP, the endemic flightless *Carliola carinata* was highly dominant followed by *Zygophlaeoba sinuatocollis*. They were most often observed to inhabit the grass clutches. Both the grassland dominant species of ENP (*C. carinata* and *Z. sinuatocollis*) exhibits reduced dispersal capacities and strongly confined to their specific habitats. Grasshoppers inhabiting the higher elevation habitats possess lower dispersal ability and are confined to their specific habitats (Reinhardt et al. 2005; Hochkirch et al. 2007a). Highly mobile *Cyrtacanthacris tatarica tatarica* was the least abundant grasshopper species in the grasslands of ENP. Since the shrubs of ENP are distributed as mosaics within the grasslands, the grassland dominant species *Carliola carinata* was also found to be dominant in the shrubs along with *Paramastacides ramachendrai.* They are not actively consuming the shrub vegetation but were observed to be basking on the shrub leaves. The *Paramastacides ramachendrai* was found to be more active during night hours, observed as resting and camouflaged with an invasive fern species (Pteridium) (Fig. 4.38). The species composition within the dense Shola habitats is observed to be different than the grasslands and shrubs of ENP. *Deltonotus gibbiceps,* a flightless pygmy grasshopper constituted most abundant species in the shola.

Fig. 4.38. ***Paramastacides ramachendrai*** **active during night hours, resting camouflaged on Pteridium (fern)**

The grasslands of PKMTR possess 24 species with more than 5 contributing to the abundance. The grasslands of PKMTR were also dominated by flightless endemic grasshopper species, *Neorthacris acuticeps acuticeps* and *Carliola carinata.* The cryptic flightless Tetrigidae species *Deltonotus subcucullatus* and *Deltonotus gibbiceps* were the most abundant grasshoppers in the evergreen habitats of PKMTR. They were observed to be well camouflaged with the litter beds of evergreen forests of PKMTR. Similarly, *Deltonotus gibbiceps* was recorded to be the most abundant in shola ground surface of ENP. Highly mobile and ferocious feeders, *Oxya japonica japonica* and *Oxya hyla* were highly dominant in the riparian habitats of PKMTR. The semi evergreen habitat of

PKMTR was also dominated by *Deltonotus subcucullatus* and *Deltonotus gibbiceps.* The *Phlaeoba antennata, Gesonula punctifrons* and *Patanga succincta* were highly abundant in the MDF areas of PKMTR. The vayals are considerably wet areas with monotonous grass species and weeds. Dominant species such as *Oxya hyla* and *Oxya japonica japonica* were found to be dependent on the grass species than the weeds.

4.4.5 Grasshopper diversity between habitats

The habitats of ENP and PKMTR were considerably very much distinct to each other. However, the vegetation in Parambikulam presents a mosaic nature at least in MDF dominated areas interspersed with vayals and grasslands. Both the areas are highly protected and human interventions are minimal. The shola, shrub and grasslands of high altitude areas of ENP are very unique in terms of its floral and faunal components. Although the grasslands of PKMTR possess similar grass species, the grasshopper species composition was observed to be different. It is mainly because of the low elevation grasslands of PKMTR with adjacent evergreen and semi evergreen habitats. All the diversity indices showed that the habitats of PKMTR are highly diverse in grasshopper than that of ENP. Grasslands of ENP yielded higher diversity values than that of shola and shrubs. The MDF areas of PKMTR had higher diversity values for all the computed indices. Heterogeneity in assemblage was observed in these areas.

The highly heterogeneous habitats and its grasshopper composition indicate the importance of habitats of both ENP and PKMTR. Each habitat of ENP and PKMTR are very much unique and need to be conserved with special reference to its invertebrate fauna, especially the grasshoppers.

DISTRIBUTION OF SHORT-HORNED GRASSHOPPERS (ORTHOPTERA - CAELIFERA) ALONG DIFFERENT ALTITUDINAL GRADIENTS

5.1 INTRODUCTION

The elevational gradients and associated environmental conditions are very significant in the field of ecology and evolutionary studies (Grinnel 1914). Biodiversity distribution and ecosystem functioning are influenced by various environmental conditions (Malhi et al. 2010). Darwin, Wallace and Humboldt (Lomolino 2001; McCain and Grytnes 2010) in the nineteenth century, have detailed the changes in biodiversity in the natural world with elevation. They mentioned that the habitat types and the species richness pattern varied across different elevation ranges (McCain and Grytnes 2010). As the elevations progress, the environmental conditions also change like the decline in temperature, atmospheric pressure and land area. Species distribution pattern across different elevation gradients is determined by various biotic and abiotic factors such as habitat heterogeneity, area, temperature, precipitation, soil quality, air pressure and solar radiation (Grytnes and Vetaas 2002; McCain 2009). Among these abiotic factors, the precipitation in the form of rain, snow or condensation of clouds is considered as one of the major influencing factors in species richness. The gradients of these factors determine the floral and faunal composition with increasing elevation.

The environmental condition across different elevational ranges plays a great role in shaping the community structure of plants and animals. Elevational gradients can be considered as natural experiment tool for studying the community and ecosystem responses to long-term climate changes and to predict the future of biodiversity in a changing world (Fukami and Wardle 2005; McCain and Colwell 2011). The comparative study of species ecology along altitudinal or latitudinal transects/gradients have been used to understand the response of both species and communities to climate change (Hodkinson 2005).

5.1.1 Patterns of species richness

The diversity distribution with elevation gradients was thought to be in a linear decreasing pattern (MacArthur 1972). However, the species richness pattern with elevation gradients has now been explained with four common patterns; decreasing, low plateau, a low plateau with a mid-elevational peak and mid-elevation peak (McCain 2009). These entire species richness pattern varies among different floral and faunal components. The decreasing pattern of species richness was explained as the pattern of species richness that decreases monotonically with increasing elevation. The low plateau richness pattern have higher species richness rate at the lower elevations and there after decreasing. Low plateau patterns with a mid-elevational peak have high richness at lower elevations with higher diversity in more than 300m from the base. Mid-elevation peaks show the peak in diversity at intermediate elevations and higher richness at the mid-elevations than at the base and top of the mountain (McCain and Grytnes 2010).

Increasing species richness pattern with elevation was rarely reported in salamanders and lichens (Martin 1958; Wake et al. 1992; Grytnes et al. 2006). The species richness pattern varied with taxonomic groups of terrestrial vertebrates. Mid-elevational peaks were observed among the non-flying small mammals (McCain 2005) and decreasing and mid-elevational peaks pattern among flying mammals including bats (McCain 2007). All the patterns of richness with elevation were visible in birds and reptiles (McCain 2010). These patterns of species richness were found to vary with different taxonomic groups among the invertebrates also. Insects with their short life span and extensive distribution are considered as a model taxon to investigate changing environmental conditions. Their response and distribution pattern across elevation gradients are very significant.

The response rate of small organisms such as insects to the short-term environmental fluctuations is higher than that of the populations of larger organisms (Belovsky and Slade 1995). Apart from the species richness, the development, survival, and distribution of insects are also being affected by elevational gradients and associated environmental factors such as temperature, precipitation and plant community composition (Price 1981; Mani 1968; McCoy 1990). Such adaptations of insects to elevational gradients include higher cold-tolerance, colour, body size and shorter wings (Mani 1968; Uvarov 1977; Gillis and Possai 1987; Somme 1989).

Primary consumers like grasshoppers are very much influenced by the vegetation structure and composition with elevational gradients. The grasshopper community composition varies across elevations within regions (Alexander 1951; Scoggan and Brusven 1973; Claridge and Singhrao 1978; Kemp et al. 1990a). Alexander and Hilliard (1969) reported monotonic decreasing pattern of species richness among grasshoppers. However, the relation of elevational gradients with the rest three pattern of species richness has not been tested properly in the case of grasshoppers (Sirin et al. 2010).

In the present study, the general pattern of grasshopper species richness with elevational ranges in Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR) was documented. The entire four described species richness pattern was tested. In addition, evidence for the mid-domain effect in both the study areas in terms of grasshopper species richness was investigated. Environmental parameters such as temperature, precipitation and Normalized Difference Vegetation Index (NDVI) were correlated with the grasshopper species richness. The range size and distribution pattern of grasshoppers along the elevation gradient was assessed by calculating the elevational range size of each grasshopper species.

5.2 METHODS

5.2.1 Elevational Gradients and Grasshopper sampling

The study area of ENP, from 1500 to 2700m, was divided into 12 elevation bands (Fig. 5.1) and PKMTR, from 400 to 1429m, was divided into 11 elevation bands (Fig. 5.2). These 23 elevation bands from 400m to 2700m were sampled for grasshopper species richness.

The grasshopper species richness was documented from January 2015 to May 2018 by visual count (direct observation) and hand searching methods on randomly plotted transects in every elevation bands. The sampling was done on the randomly laid 50m fixed sampling transects on each elevation band. Transects were marked using GPS at the central point. The number of transects varied depending on the area-composition in each gradient band (Table 5.1 and 5.2). Data on species richness in both the areas were collected as ten replicates from a total of 259 transects. In ENP, 109 transects were sampled across 12 elevation bands and 150 transects were sampled across 11 elevation bands in PKMTR. Data from 23 elevation bands were pooled to obtain total grasshopper species richness in each elevation gradients of both ENP and PKMTR.

Each transect was walked at a slow pace (2 km/h) and the number of grasshoppers flushed in a 0.5m strip in front of the observer counted (Isern-Vallverdu et al. 1993). Each transect walk took an average of 30 min to complete. Elevation and GPS coordinates were recorded for each transect walk. GPS coordinates were also recorded for each grasshopper specimen that were additionally collected from outside the transects.

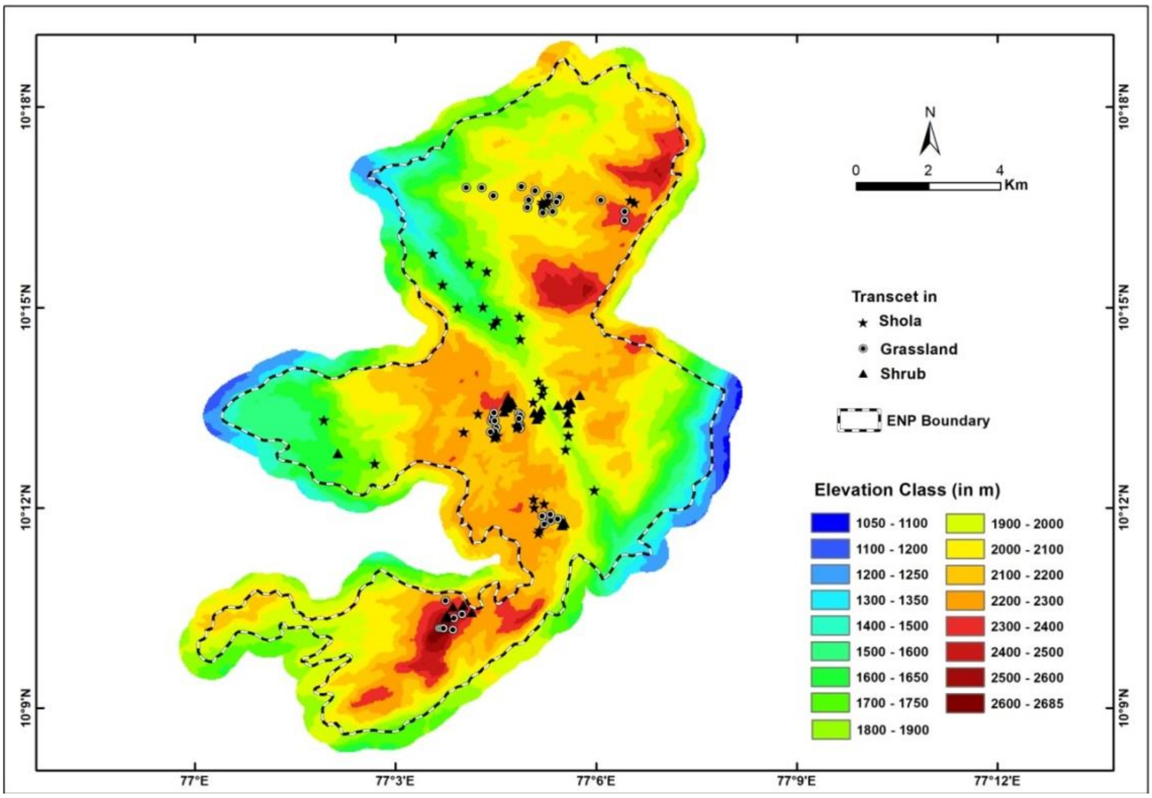


Fig. 5.1. Digital elevation model and transects laid in ENP between 1500 and 2700m

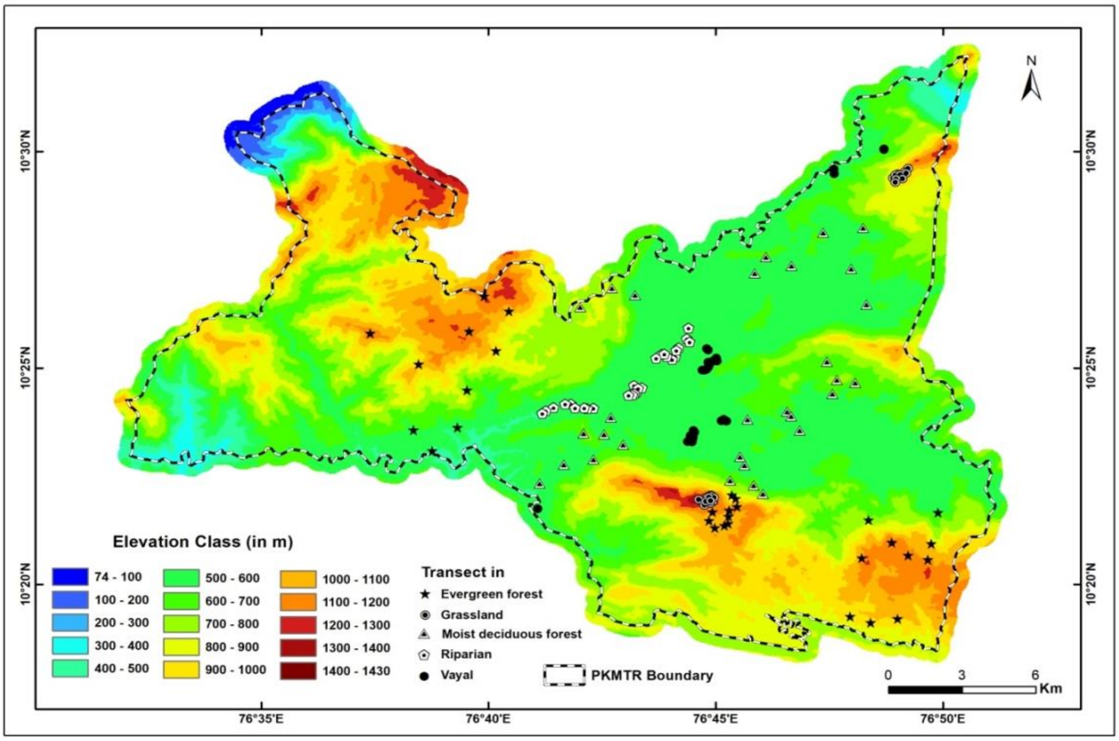


Fig. 5.2. Digital elevation model and transects laid in PKMTR between 400 to 1429m

Sr No	Elevation range	No of transects	Area (Km²)	Area%	Habitat type
1	1500 – 1600	1	2.69	2.29	**Shola**
2	1600 – 1700	6	6.28	5.34	**Shola, Shrub**
3	1700 – 1800	3	6.01	5.11	**Shola**
4	1800 – 1900	4	9.41	8.00	**Shola**
5	1900 – 2000	13	15.90	13.52	**Grassland, Shola, Shrub**
6	2000 – 2100	15	19.50	16.59	**Grassland, Shola, Shrub**
7	2100 – 2200	28	22.83	19.42	**Grassland, Shola, Shrub**
8	2200 – 2300	25	19.01	16.17	**Grassland, Shola, Shrub**
9	2300 – 2400	7	5.27	4.48	**Grassland, Shola, Shrub**
10	2400 – 2500	1	2.44	2.08	**Grassland, Shrub**
11	2500 – 2600	3	0.46	0.39	**Grassland, Shrub**
12	2600 – 2700	3	0.22	0.19	**Grassland**

Table 5.1. Elevation bands, area and number of sampling transects laid in ENP

Sr No	Elevation range	No of transcects	Area (Km²)	Area%	Habitat type
1	400 – 500	13	11.86	2.71	**EG, Rip**
2	500 – 600	66	137.74	31.52	**EG, MDF, Rip, Vayal**
3	600 – 700	12	72.04	16.49	**EG, MDF, Vayal**
4	700 – 800	4	59.46	13.61	**EG MDF**
5	800 – 900	3	49.25	11.27	**EG, MDF**
6	900 – 1000	8	40.52	9.27	**EG, Grassland**
7	1000 – 1100	20	33.15	7.59	**EG, Grassland**
8	1100 – 1200	8	20.26	4.64	**EG**
9	1200 – 1300	5	3.76	0.86	**EG, Grassland**
10	1300 – 1400	10	0.33	0.08	**Grassland**
11	1400 – 1429	1	0.04	0.01	**Grassland**

Table 5.2. Elevation bands, area and number of sampling transects laid in PKMTR
EG= Evergreen Forest, MDF =Moist Deciduous Forest

5.2.2 Data source for GIS and environmental variables

The area at each 100m elevation band was calculated based on digital elevation model prepared using SRTM 1 arc-second 30-m (Shuttle Radar Topography Mission) data set for study area downloaded from United States Geological Survey's Earth Explorer website (http://earthexplorer.usgs.gov). The GPS reading was recorded for each collected specimen using Garmin Etrax 30 GPS, datasheet of species occurrence was updated with the GPS coordinates. The GPS data were transferred to the GIS platform (Arc GIS 9.3) for further analysis. Environmental and climatic variables (temperature and precipitation) such as Annual Mean Temperature (AMT), Maximum Temperature of the Warmest Month (MTWM), Minimum Temperature of the Coldest Month (MTCM), Annual Precipitation (APn) were extracted from Worldclim online archive

Version 2.0 (http://www.worldclim.org) at one km resolution monthly averaged value of last 50 years (Fick and Hijmans 2017). The Normalized Difference Vegetation Index (NDVI) was used to quantify the vegetation greenness by measuring the difference between near-infrared (vegetation strongly reflects) and red light (vegetation absorbs). NDVI is useful in understanding vegetation density and plant health. Healthy vegetation (chlorophyll) reflects more near-infrared (NIR) and green light compared to other wavelengths. It absorbs more red and blue light. Satellite sensors like Landsat and Sentinel-2 have the necessary bands with NIR and red. NDVI was calculated as a ratio between the red (R) and near-infrared (NIR) values. NDVI always ranges from -1 to +1. The Landsat 8 satellite image of the study area was used for the NDVI analysis. The NDVI map of the ENP and PKMTR for January of the years 2015, 2016, 2017 and 2018 were prepared and the mean NDVI for four years calculated.

5.3 Data Analysis

5.3.1 Species Richness across Gradients

The observed grasshopper species richness at different elevation bands of PKMTR and ENP were plotted against the estimated species richness at different elevation bands. The total number of species appeared across all sampling efforts in various elevation ranges were tested against non-parametric estimators of species richness. Individual-based species accumulation curve (Colwell 2001) was estimated using EstimateS (Colwell 2009). Out of the predicted non-parametric estimators, second-order “Chao” (Chao 2) and second-order “Jacknife” (Jacknife 2) species richness values with 95% confidence interval were used to plot the species accumulation curve.

5.3.2 Correlation of Environmental Factors with Area, Elevation and Species Richness

Environmental variables such as Annual Mean Temperature (AMT), Maximum Temperature of the Warmest Month (MTWM), Minimum Temperature of the Coldest Month (MTCM) and Annual Precipitation (APn) were correlated with the elevation area and grasshopper species richness. Pearson correlation coefficient (r) was performed with the aid of the software PAleontological STatistics (PAST) Version 3.25. The non-linear regression models were carried out using PAST V 3.25.

5.3.3 Range size and Mid-Domain Effect

The difference between the higher elevation and lower elevation was estimated as range size of each species assuming that a species occupies a continuous range between its minimum and maximum ranges. The average of the minimum and maximum elevational range is estimated as the range midpoint. The range size and elevation was assessed by regressing range size of each species against the lower and upper limits of its elevation range.

The species richness pattern across elevation ranges was compared by using null model predictions Monte Carlo simulations program and mid-domain effect (MDE) null model was currently used (McCain 2004). The program simulates species richness curves based on empirical range sizes or range midpoints within a bounded domain based on the analytical–stochastic models (Colwell and Lees 2000; Colwell 1999 and Colwell and Hurtt 1994). The mid-domain null model explains the geometric pattern of random range sizes and placements between the endpoints of two boundaries that are shared by all species (McCain 2004). The model describes the bounded domain comprising of all species' ranges and the midpoint of the domain will have the large species' ranges (McCain 2004). The program enables to test the impact of spatial constraints on species richness curves and 95% prediction curves based on 50,000 simulations (without replacement) using empirical range sizes. The range size simulations were used as a better assessing fit to the null model for geometric constraints of species richness rather than the range mid-points, which is too constrained by the empirical data (McCain 2004). The mean of the predicted number of species was regressed against the observed empirical values to assess the role of geometric constraints in grasshopper species richness.

5.4 RESULTS

5.4.1 Grasshopper Species Richness

Fifty eight grasshopper species were recorded from 259 transects of 23 elevation bands laid across both ENP and PKMTR. Eighteen species were recorded from 109 transects of ENP and 55 from 150 transects of PKMTR. The non-parametric estimators of second-order Chao and Jacknife predicted similar species richness to the observed species richness across all the elevation bands in ENP (Table 5.3). Of the two estimator predictions, Chao 2 Mean prediction was found to be closer to the observed species richness at 95% confidence interval (Fig 5.3). The mean grasshopper species richness was 10.75 with a minimum of 2 species at elevation band between 2600 and 2700m and maximum of 16 species at elevation band of 1950 – 2150m. Higher grasshopper species richness was observed in 1900 – 2300m elevation band and lowest in 2600 – 2700 (2690m) (Fig 5.3).

Elevational midpoint (m)	Species richness (mean)	Chao 2	Jacknife 2
1550	6.5	6.6	6.9
1650	9.9	9.8	9.9
1750	5.7	5.8	6
1850	7.7	7.8	8
1950	15.9	15.9	16
2050	16.8	16.9	16.9
2150	16	11.9	12
2250	14.9	14.9	14.9
2350	13.9	13.9	14
2450	11	11.2	11.4
2550	8.9	8.9	9
2650	1.9	1.9	1.9

Table 5.3. Species richness estimates of Grasshoppers of different elevation bands in ENP

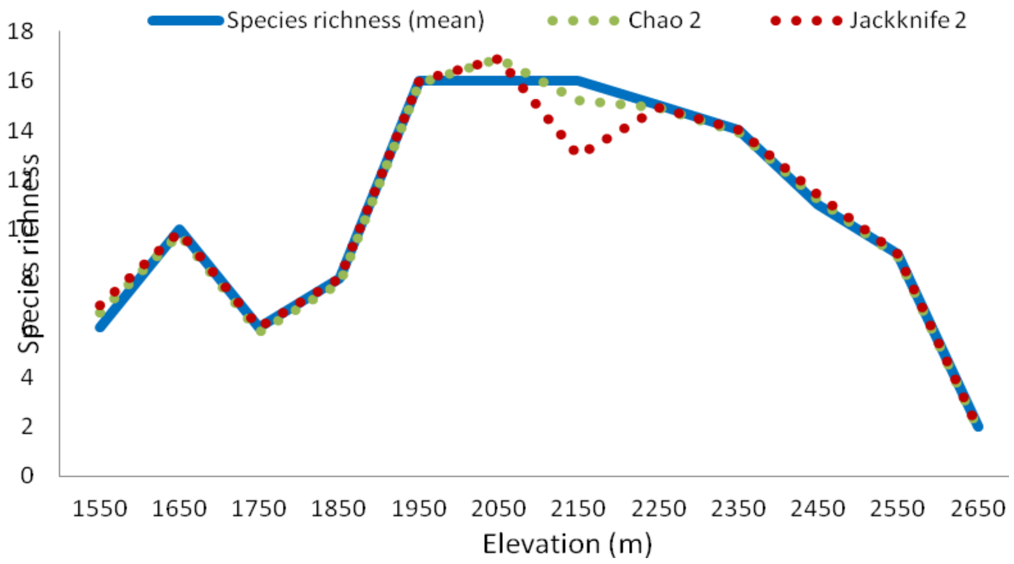


Fig. 5.3. Line curve comparing the observed species richness of ENP across elevation bands with estimated species richness

The non-parametric estimators of second-order Chao and Jacknife predicted similar species richness compared to the total number of species observed across all the elevation bands in PKMTR (Table 5.4). Chao 2 Mean prediction was closer to the observed species richness at 95% confidence interval (Fig 5.4). The mean grasshopper species richness was 32.1 with a minimum of 20 species at elevation band between 1400 and 1500m and maximum 44 species at elevation band between 500 and 600m. Lowest grasshopper species richness was observed in 1300 – 1500m gradient (Fig 5.4).

Elevational midpoint (m)	Species richness (mean)	Chao 2	Jacknife 2
450	33.9	33.9	33.7
550	43.9	43.9	43.9
650	34.9	34.9	34.7
750	34	31.8	31.9
850	34	30.8	31
950	36.9	36.9	36.5
1050	36.9	36.9	36.9
1150	26.7	26.8	26.9
1250	33.6	33.7	33.4
1350	22.9	22.9	22.78
1450	19.5	19.5	19.9

Table 5.4. Species richness estimates of Grasshoppers of different elevation bands in PKMTR

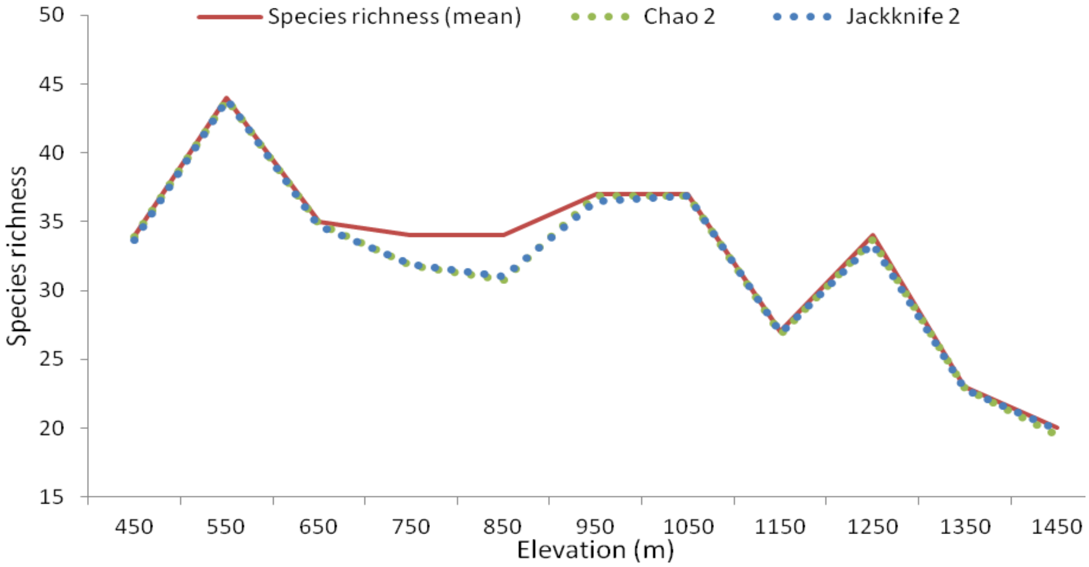


Fig. 5.4. Line curve comparing the observed species richness of PKMTR across elevation bands with estimated species richness

5.4.2 Grasshopper distribution

None of the 18 grasshopper species recorded across 12 different elevation bands in ENP was seen occupying all the elevation bands. Species such as *Cyrtacanthacris tatarica* and *Xenocatantops humilis* of family Acrididae were occupying all the elevation bands except the peak elevation of ENP (2600-2700m). *Dittopternis venusta*, *Oxya hyla* and *Teratodes monticollis* of Acrididae were present in all the elevation bands up to 2500m. *D. venusta*, *O. Hyla*, *T. Monticolli* and *C. tartarica* were observed in all the three habitats of ENP. *Bambusacris travancora,* an endemic flightless grasshopper species was found only in the grasslands between 2100 to 2400m elevations. *Eucriotettix flavopictus* and *Euscelimena harpago,* the pygmy grasshoppers of family Tetrigidae were recorded only from the wet rocks of streams in shola forests at an elevation range of 1800 - 2100m. *Deltonotus gibbiceps* of family Tetrigidae were exclusively found within the leaf litters of shola forests between 1500 and 2300m. The newly described *Tettilobus trishula sp.nov* was very unique in its habitat specificity as it was collected from the barks of a tree inside the shola forests at an elevation of 2150m.

In PKMTR, *Choroedocus illustris, Diabolocatantops innotabilis, Pachyacris vinosa, Gesonula punctifrons, Teratodes monticollis, Phyllochoreia unicolor, Neorthacris acuticeps acuticeps, Atractomorpha crenulata* and *Aularches miliaris* were distributed across all the elevation bands from 400m to 1429m. *Deltonotus subcucullatus* and *Deltonotus gibbiceps* were only within the evergreen patches of PKMTR at elevation range of 700 m -900m. Pygmy grasshoppers of family Tetrigidae of PKMTR such as *Euparatettix personatus, Eucriotettix flavopictus, Euscelimena gavialis, Euscelimena harpago* and *Systolederus sp* were found between 400 and 600m elevation ranges. They were in the riparian and evergreen areas with high moisture content.

Indomiriatra provertex of Tetrigidae family was an exception to this and was distributed across evergreen patches from 400m to 1300m. Grasshoppers such as *Carliola carinata, Leptacris filiformis, Paramastacides ramachendrai, Mastacides nilgirisicus* and *Neorthacris acuticeps nilgiriensis* were exclusive to the grasslands of PKMTR from 900m to 1429m. A male individual of extremely rare endemic *Mopla guttata* was located in MDF patches between 800m and 900m. *Trilophidia annulata* was distributed only at 400 - 600m in PKMTR. The low elevation areas including vayals were represented mainly by grasshopper species such as *Acrida exaltata, Acrida gigantea, Oxya hyla hyla, Oxya japonica japonica* and *Oxya fuscovittata*.

5.4.3 Elevation and Species Richness pattern

The grasshopper species richness in ENP touched its peak between 1900 and 2300m and between 1900m and 2500m. It resulted in a hump-shaped pattern in terms of species richness. The first peak of species richness was observed at midpoint 1950m with mean species richness of 16 species and showed the same pattern till 2150m midpoint. The estimator predicted the same pattern of species richness for the first peak between 1900 and 2500m (Fig 5.3). The grasshopper species richness in ENP was observed to be low at elevation midpoints of 1550m (6 species), 1750m (6 species) and 2690m (2 species). Among the lowest species rich elevation gradients in ENP, 1550m and 1750m was only of shola and 2690m was the peak hilltop with very low grassland occupied area. An increasing pattern was observed after the elevation midpoint 1850m and the trend continued till 2350m midpoint. A linear decrease in grasshopper species richness was visible from the midpoint 2450m and it reached the lowest number at the highest elevation of ENP (2650m).

The correlation between elevation bands and grasshopper richness was non-significant (r=0.02, p=0.940) (Fig. 5.5). The data were tested for a non-linear regression model, Gaussian normal distribution model. This was found to be the best fit to the data set (Fig. 5.6). Akaike IC = 65.66 Akaike Information Criterion (AIC) was used to select the model (lower values for the AIC imply a better fit).

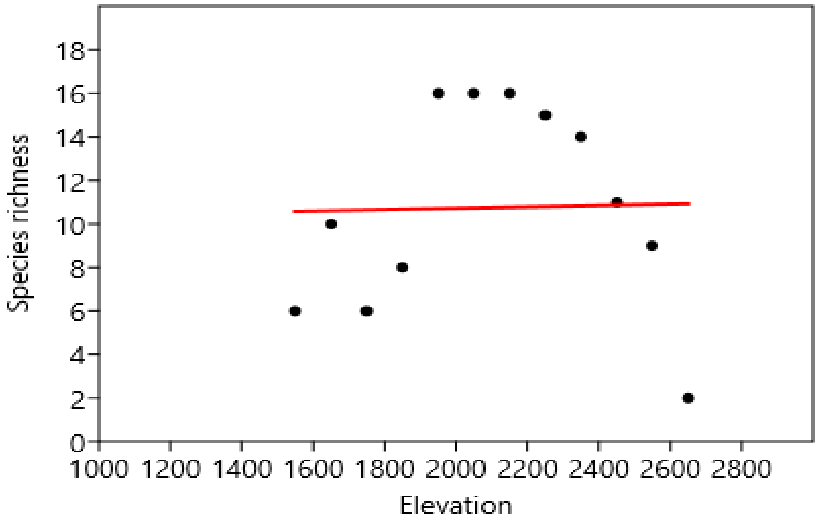


Fig. 5.5. Species richness pattern at elevation bands in ENP

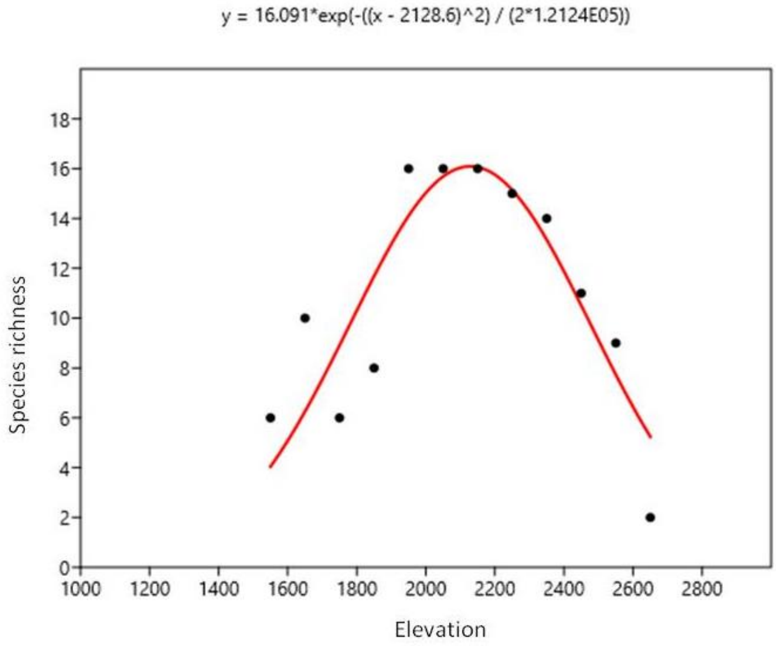


Fig. 5.6. Gaussian normal distribution model for species richness and elevation bands in ENP (Akaike IC = 65.66)

In PKMTR, a linear decreasing pattern was observed between elevation midpoints of 550m and 1450m. There was an increase in species richness between 450m and 550m. Three peaks were observed between 400m and 1450m elevation bands. The first and the highest peak that represents species richness were at a midpoint of 550m, the second was between 950m and 1050 midpoints and the third peak was at 1250m elevation band. It started a descent from 1250m and touched the minimum species richness at the highest elevation (1450m). The grasshopper species richness in PKMTR showed a significant negative correlation with elevation bands (r=-0.71, p=0.01) (Fig. 5.7). The data were tested for a non-linear regression model (Gaussian normal distribution model). The Gaussian normal distribution model and found to be the best fit for the data set (Fig. 5.8).

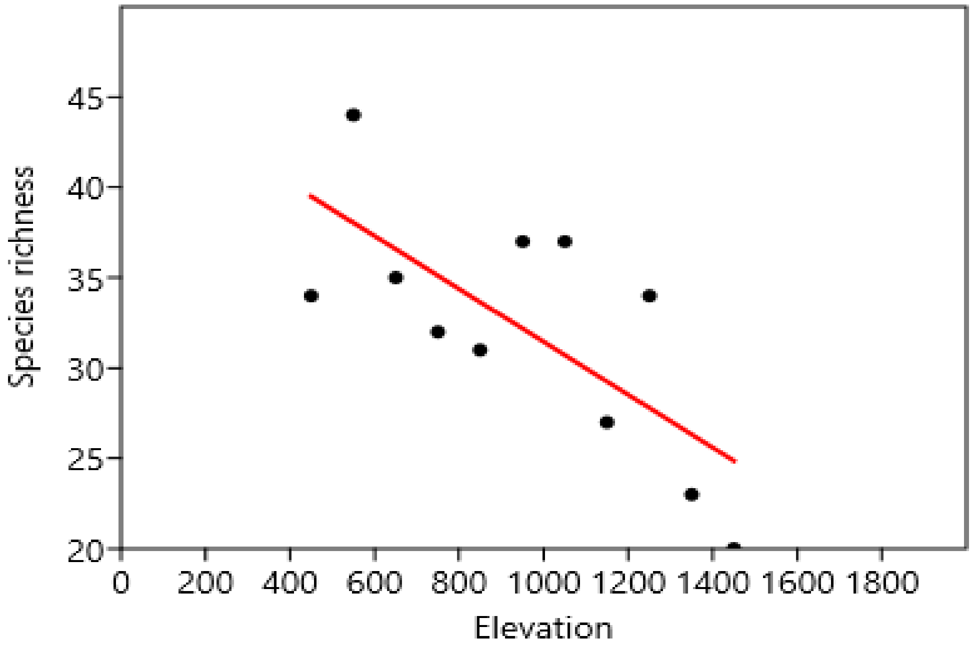


Fig. 5.7. Species richness pattern at elevation bands in PKMTR

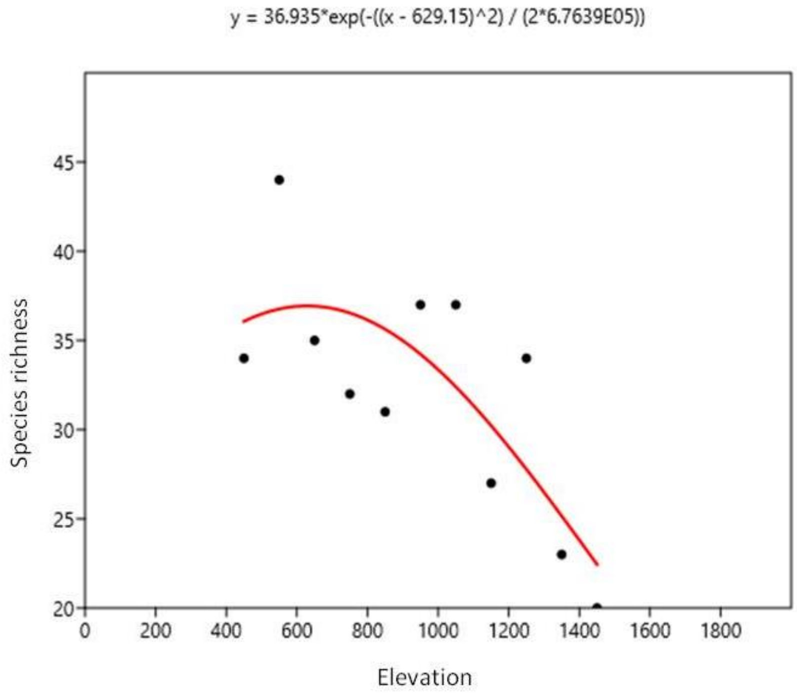


Fig. 5.8. Gaussian normal distribution model for species richness and elevation bands in PKMTR (Akaike IC = 200.32)

5.4.4 Influence of geographical area

The geographical area of each elevation band in ENP was increasing as the elevation progresses from 1500 to 2300m. After 2300m, the area decreased with a sudden steep. A negative correlation was found between elevation and area in ENP (r=-0.17, p= 0.05). The highest area was found between 2000 – 2300m at an average of 20km² at each 100m elevation band. The lowest area in terms of elevation gradient in ENP was between 2600 – 2700m (peak of Western Ghats - Anamudi 2690m). A significant positive correlation was observed between grasshopper species richness and area across different elevation bands in ENP (r=0.79, $p \leq 0.01$). The grasshopper species richness from 1500 – 1900m was found to be averaged at 7.5 species. As the elevation and area increased between 1900 – 2400m, the grasshopper richness also recorded an increase to 15.4 mean species. However, the grasshopper species richness rapidly decreased up to 2 species after 2400m (Fig. 5.9).

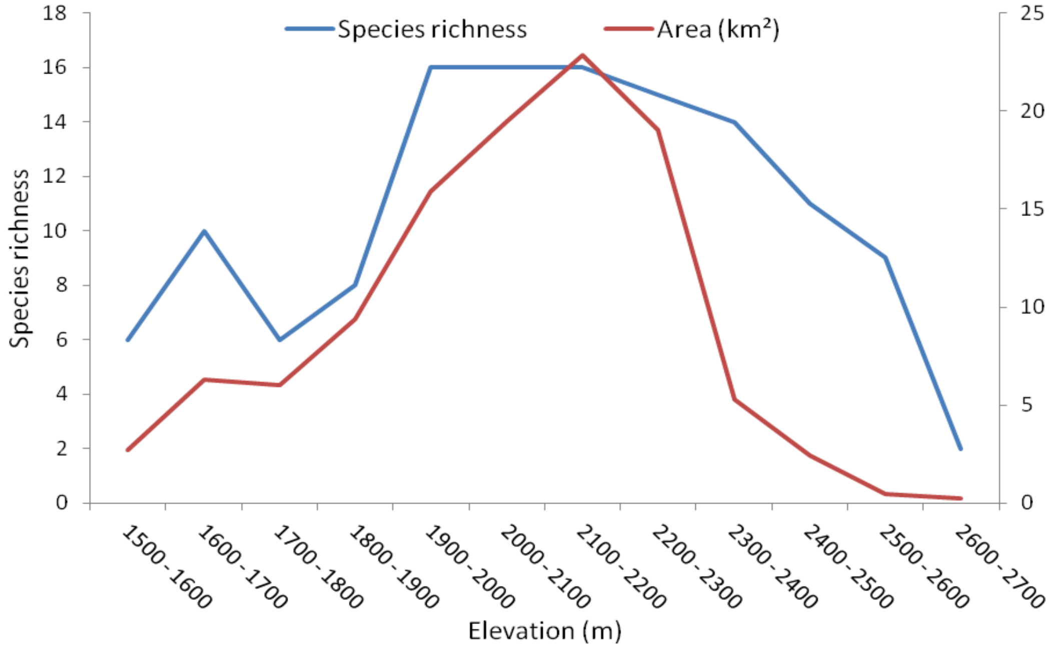


Fig. 5.9. Relationship between area across 100m elevation bands in ENP and grasshopper species richness

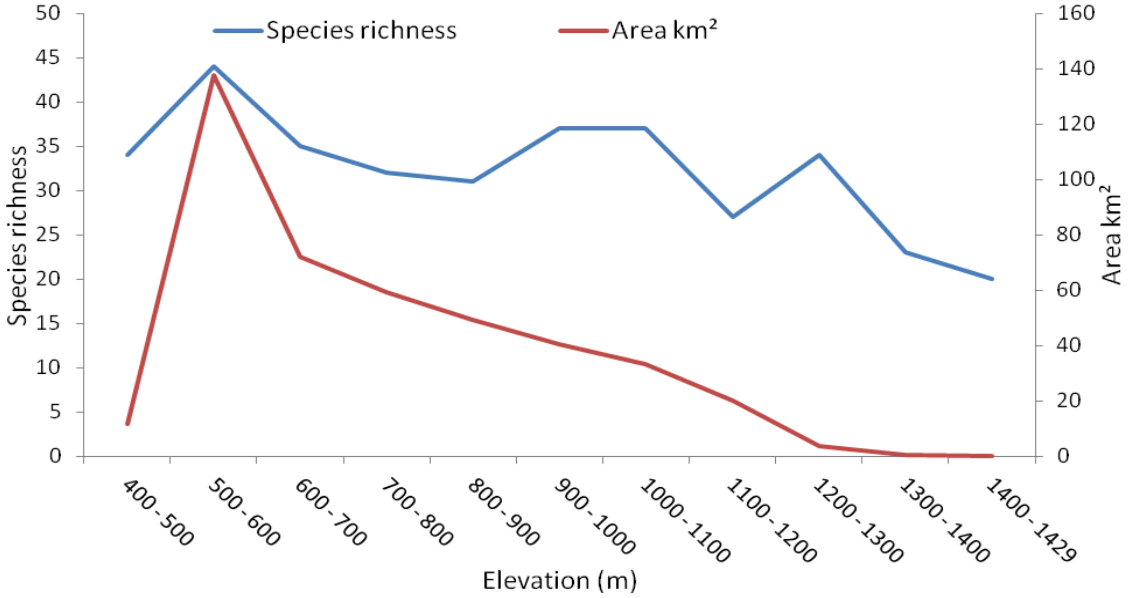


Fig. 5.10. Relationship between area across 100m elevation bands in PKMTR and grasshopper species richness.

In PKMTR, as the elevation progresses, the geographical area of each elevation band followed a sudden steep from 400m to 500m (Fig. 5.10) and marked 500 – 600m as the elevation band with the highest available area in PKMTR (Fig. 5.10). After 600m, a gradual linear decrease in the area was found as the elevation progresses. A strong significant negative correlation was found between area available under each 100m elevation band and elevation in PKMTR (r=-0.66, p= 0.02). The grasshopper species richness and the area resulted in a significant positive correlation (r=0.73, p=0.01). The grasshopper species richness was seen to be averaged up to 32.1 mean grasshoppers across each elevation band in PKMTR. The lowest grasshopper species richness 20 was observed between 1300 – 1429m (highest elevation in PKMTR) (Fig. 5.10).

5.4.5. Influence of environmental Variables and NDVI on Elevation and Grasshopper Species Richness

The environmental variables had strong relation with the elevation ranges in ENP. The annual mean temperature (AMT) showed a strong significant negative correlation with elevation (r=-0.98, $p \leq 0.01$) (Fig.5.11). The mean annual precipitation (APn) showed a strong significant positive correlation with elevation (r=0.90, $p \leq 0.01$) (Fig.5.12). A strong significant negative correlation was found between the maximum temperature of the warmest month (MTWM) (r=-0.98, $p \leq 0.01$) (Fig. 5.13) and elevation. The correlation between the minimum temperature of the coldest month (MTCM) (r=-0.98, $p \leq 0.01$) (Fig. 5.14) and elevation also had a negative correlation. The mean NDVI and elevation showed a strong negative correlation (r= -0.85, $p \leq 0.01$) (Fig. 5.15).

Correlation of grasshopper species richness of ENP with environmental variables was tested. The grasshopper species richness was not significantly correlated with annual mean temperature (AMT) (r=-0.54, p≥0.05) (Fig.5.11). The species richness also was non-significantly correlated with annual precipitation (APn) in ENP (r=-0.34, p≥0.05) (Fig.5.12). The species richness also showed a nonsignificant correlation with maximum temperature of the warmest month (r=-0.23, p≥0.05) (Fig.5.13) and the minimum temperature of the coldest month (MTCM) (r=-0.40, p≥0.05) (Fig.5.14). The grasshopper species richness showed no correlation with NDVI of January either (r=0.05, p≥0.05) (Fig.5.15).

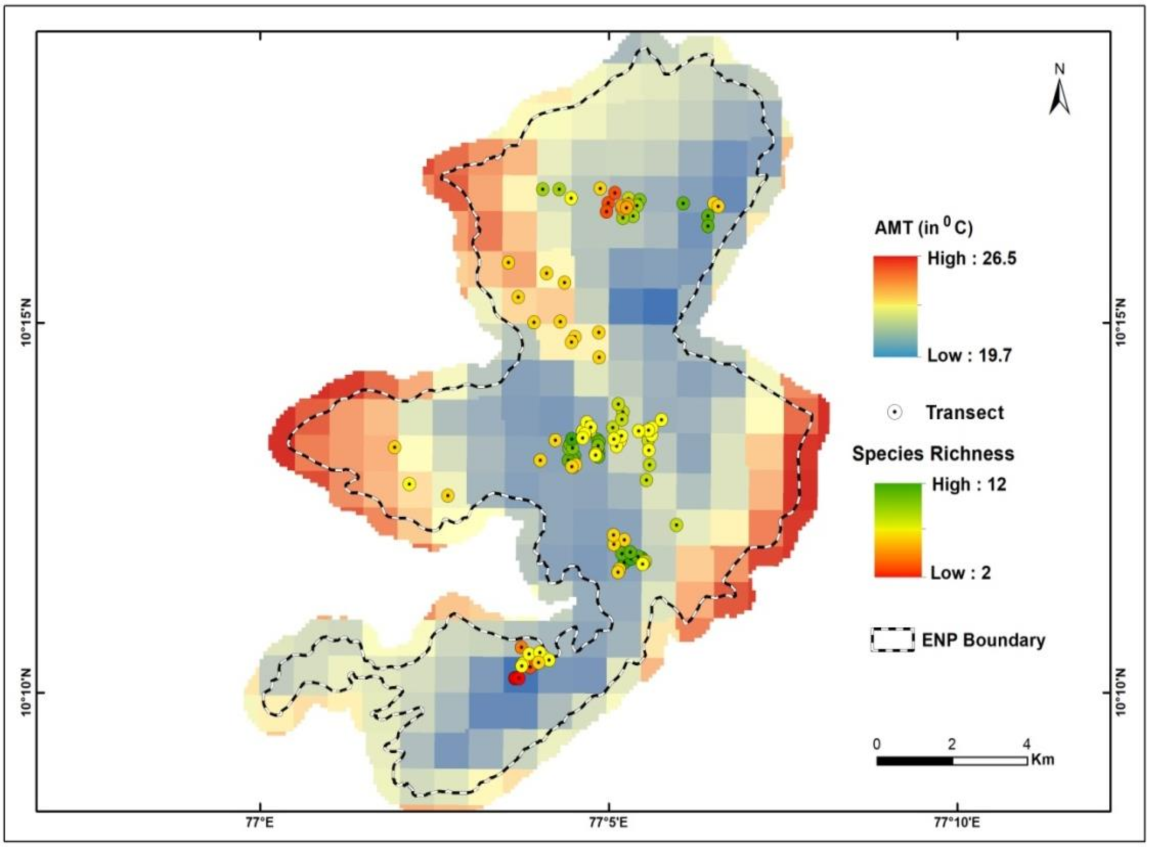


Fig. 5.11. The annual mean temperature (AMT) and grasshopper species richness in ENP

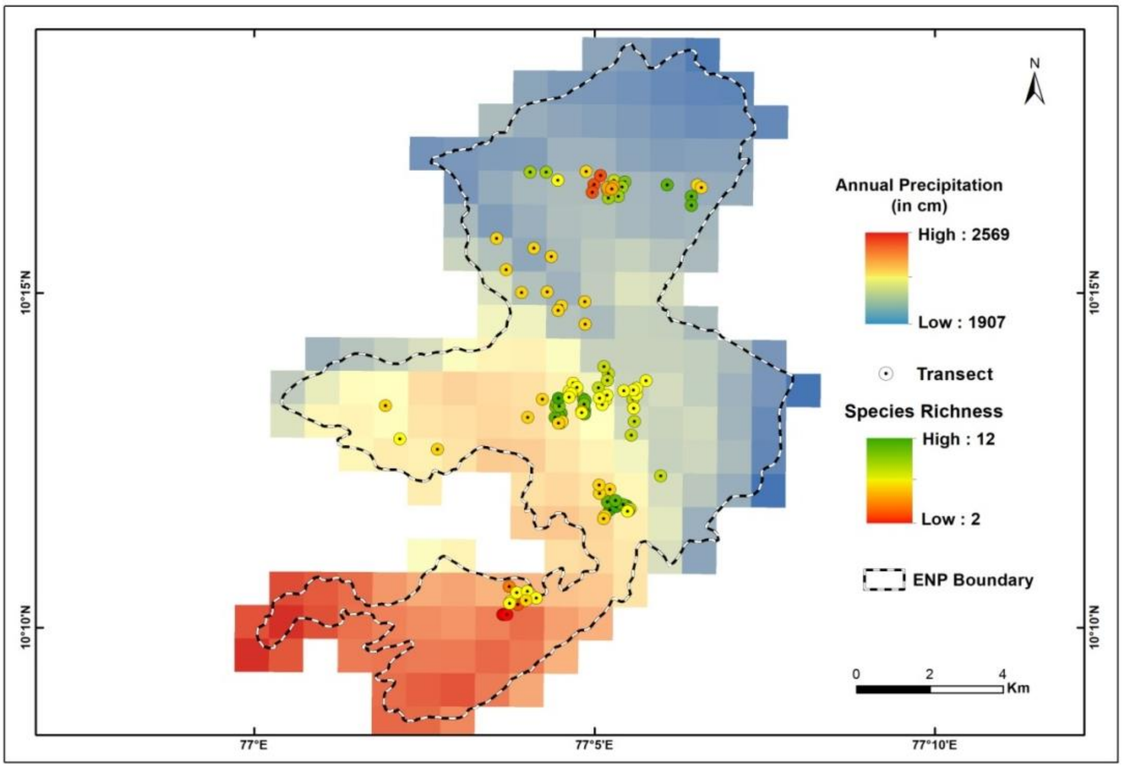


Fig. 5.12. The mean annual precipitation (APn) and grasshopper species richness in ENP

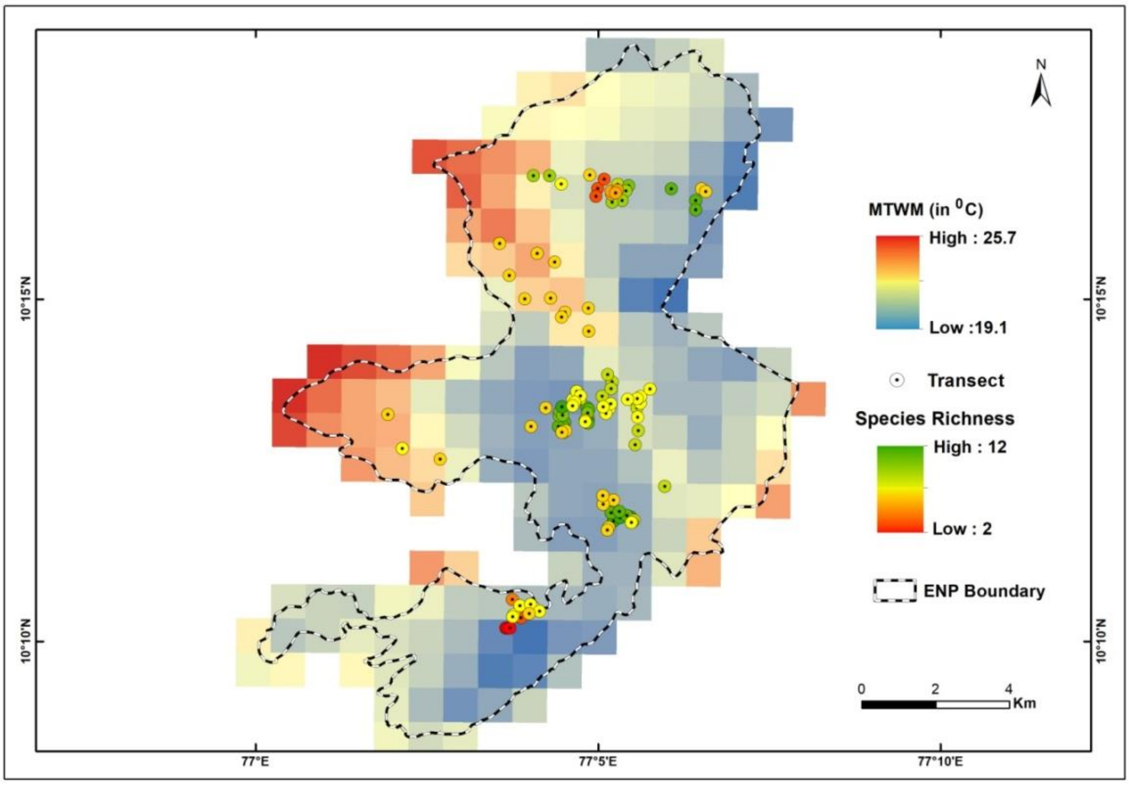


Fig. 5.13. Maximum Temperature of the Warmest Month (MTWM) and grasshopper species richness in ENP

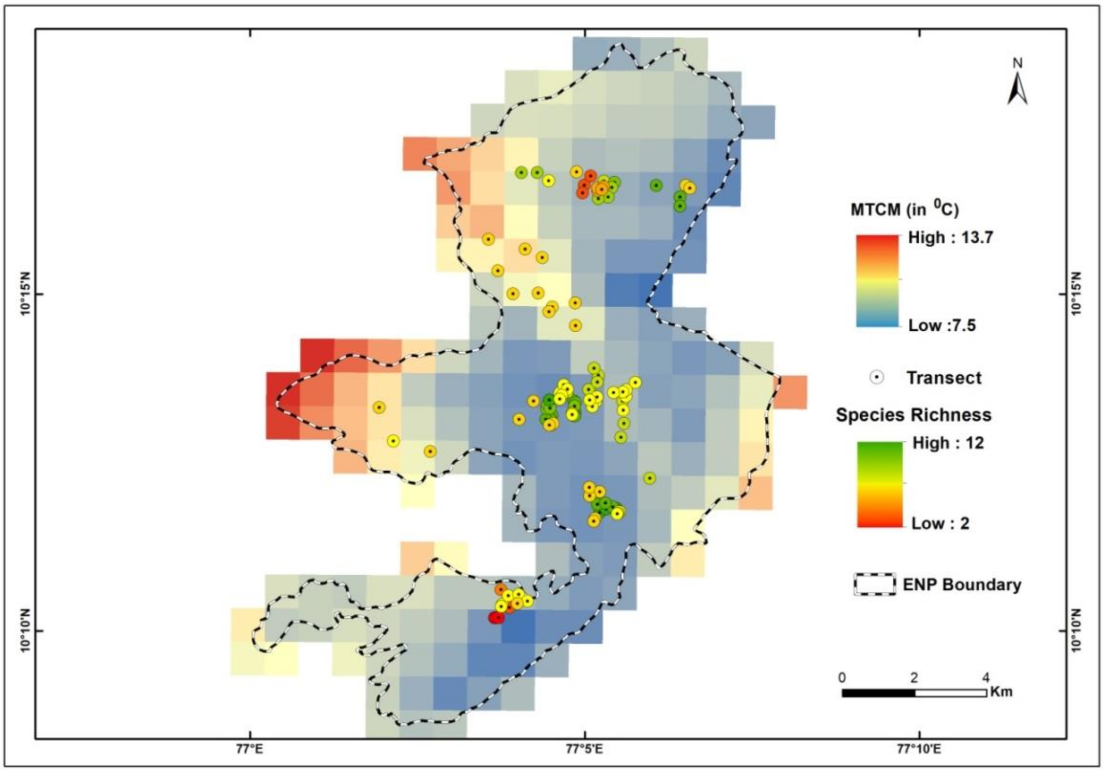


Fig. 5.14. Minimum Temperature of the Coldest Month (MTCM) and grasshopper species richness in ENP

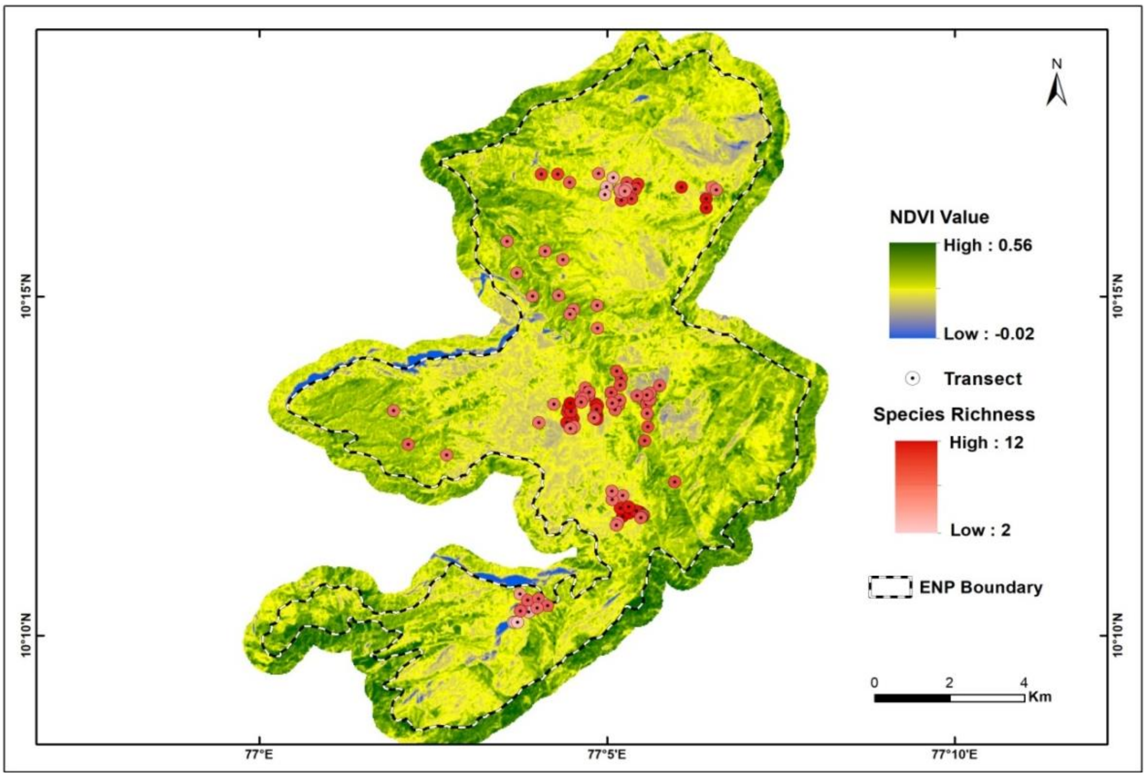


Fig. 5.15. The mean Normalized Difference Vegetation Index (NDVI) and grasshopper species richness in ENP

In PKMTR, the environmental variables were strongly correlated with the elevation ranges. The annual mean temperature (AMT) was negatively correlated with elevation (r=-0.93, $p \leq 0.01$) (Fig.5.16). The mean annual precipitation (APn) showed a strong significant positive correlation with elevation (r=0.73, $p \leq 0.01$) (Fig.5.17). A strong significant negative correlation was found between the maximum temperature of the warmest month (MTWM) (r=-0.97, $p \leq 0.01$) (Fig.5.18) and elevation and between minimum temperature of the coldest month (MTCM) (r=-0.98, $p \leq 0.01$) (Fig.5.19) and elevation. The mean NDVI and elevation showed no significant correlation (r= 0.30, p≥0.05) (Fig.5.20).

The grasshopper species richness, when tested for correlation with environment variables, was seen to be not significantly correlated with annual mean temperature (AMT) (r=0.58, p≥0.05) (Fig.5.16). Similarly, the annual precipitation (APn) in PKMTR was not significantly correlated with grasshopper species richness (r=-0.30, p≥0.05) (Fig.5.17). The correlations of grasshopper species richness with maximum temperature of the warmest (MTWM) month (r=0.51, p= 0.12) (Fig.5.18), minimum temperature of the coldest month (MTCM) (r=-0.14, p≥0.05) (Fig.5.19) and the mean NDVI of January (r=0.37, p≥0.05) (Fig.5.20) were also non-significant.

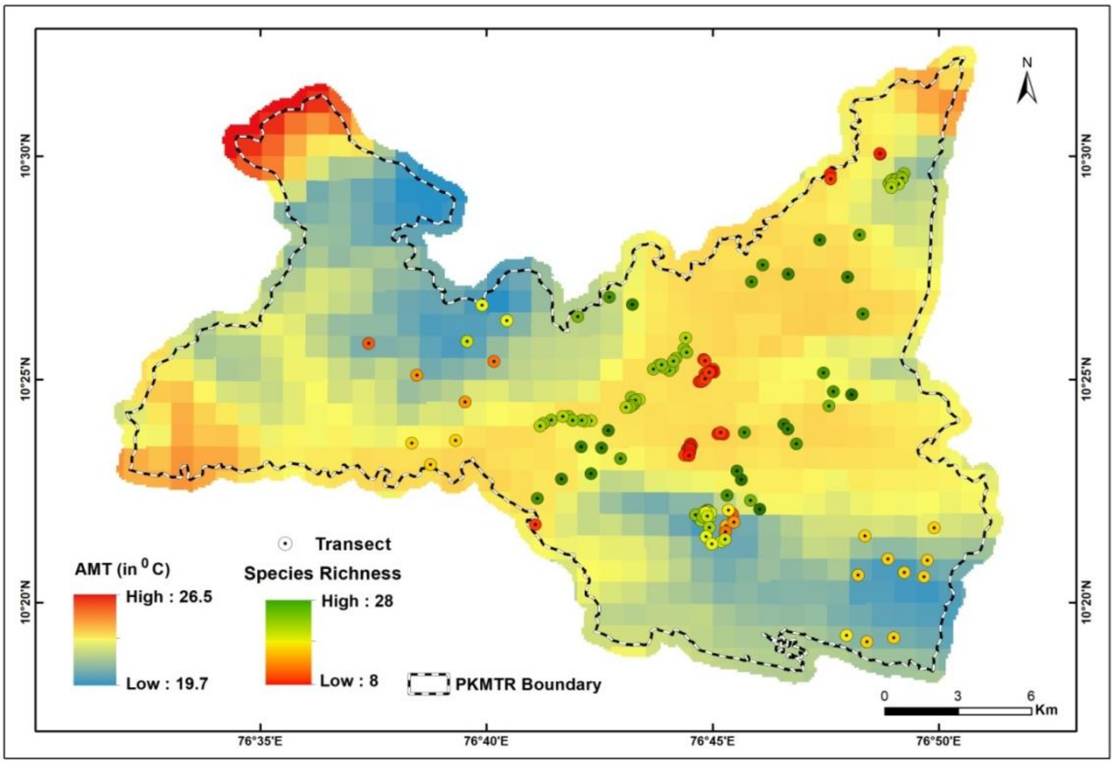


Fig. 5.16. The annual mean temperature (AMT) and grasshopper species richness in PKMTR

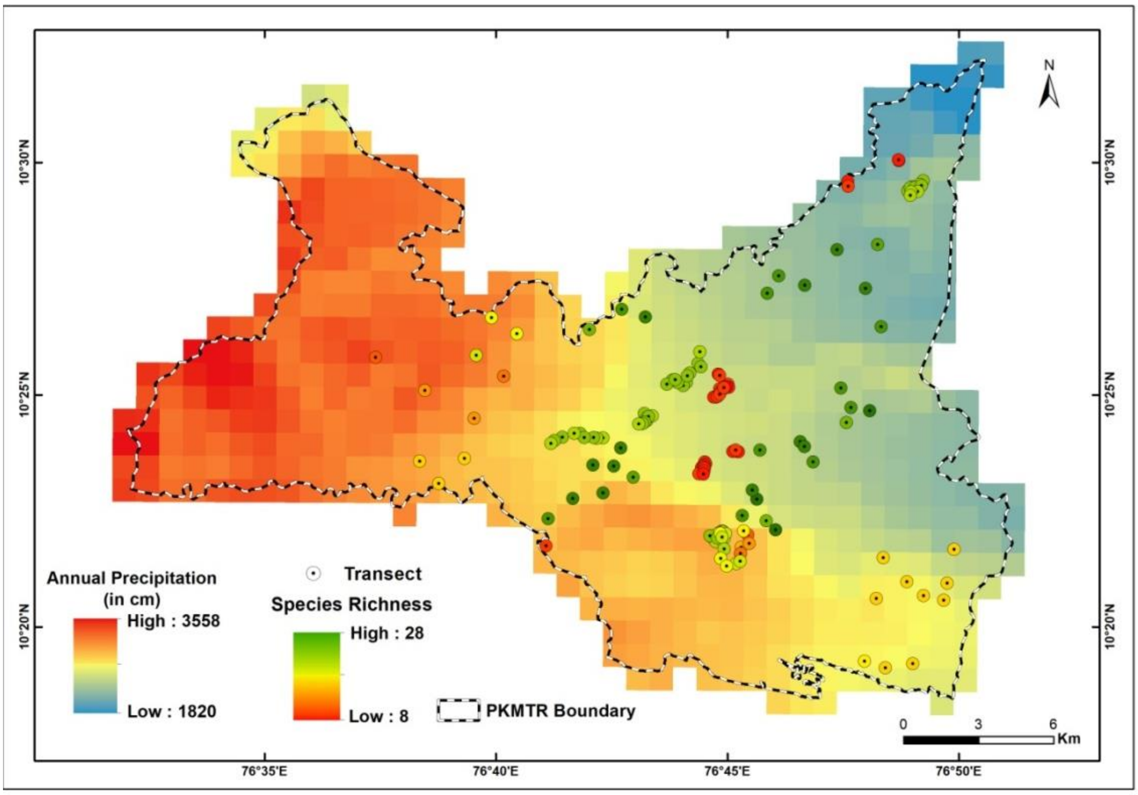


Fig. 5.17. The mean annual precipitation (APn) and grasshopper species richness in PKMTR

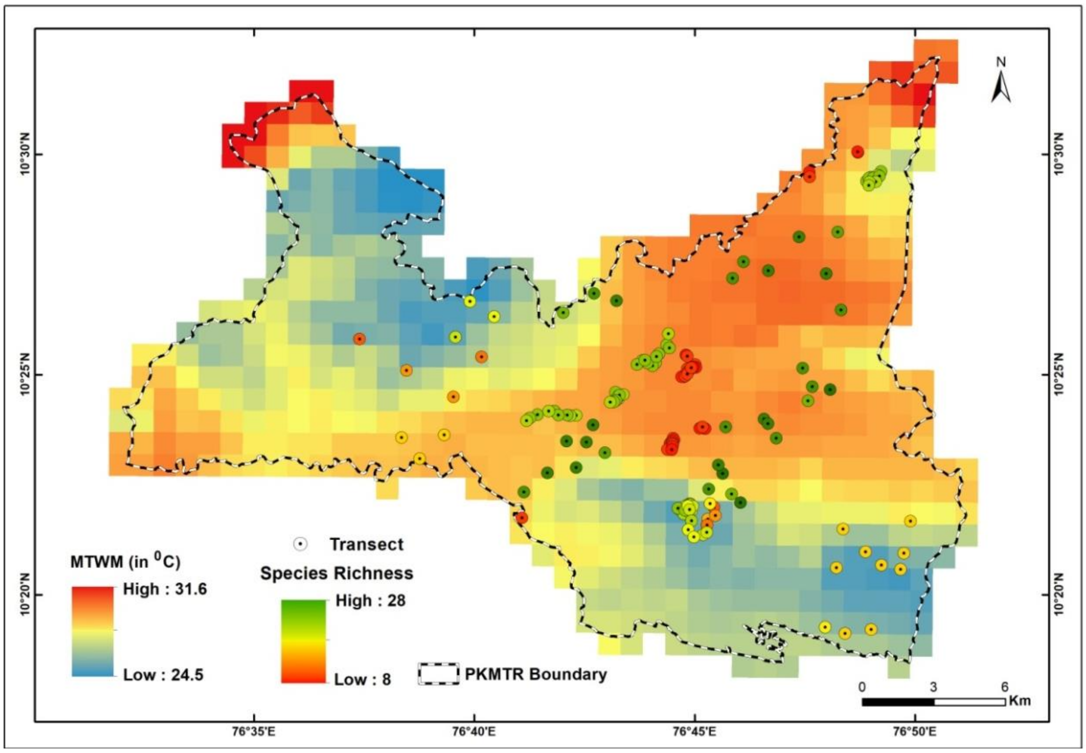


Fig. 5.18. Maximum Temperature of the Warmest Month (MTWM) and grasshopper species richness in PKMTR

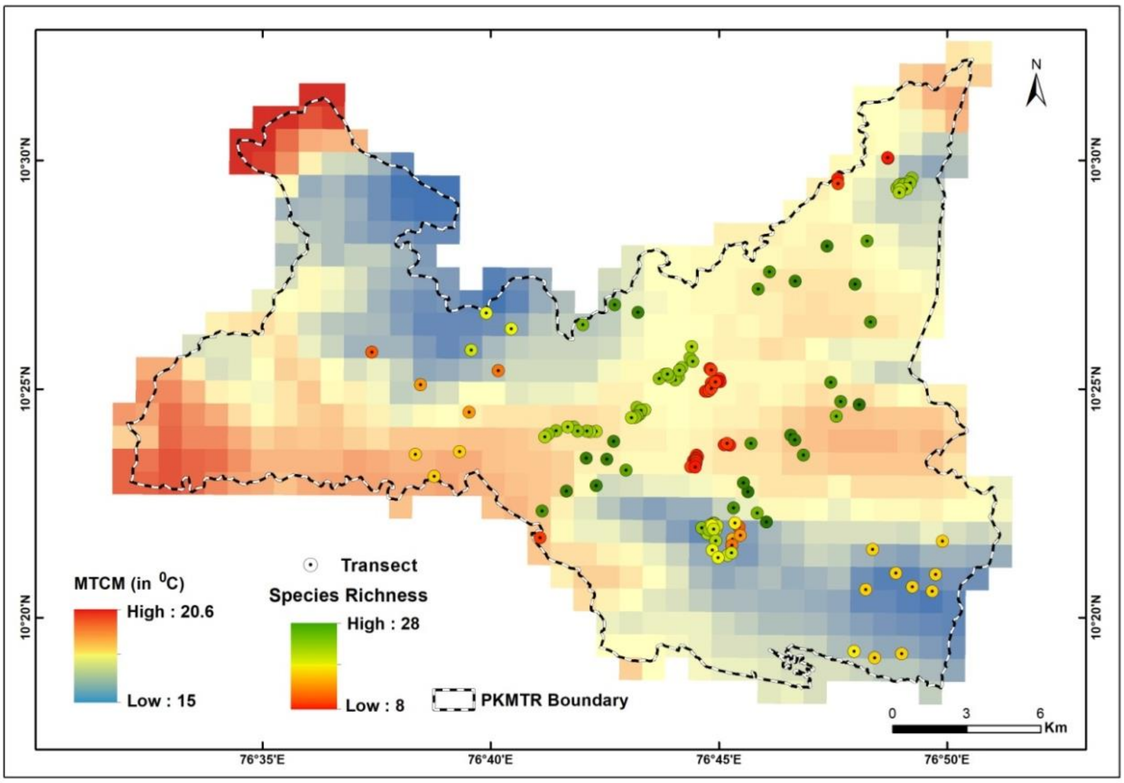


Fig. 5.19. Minimum Temperature of the Coldest Month (MTCM) and grasshopper species richness in PKMTR

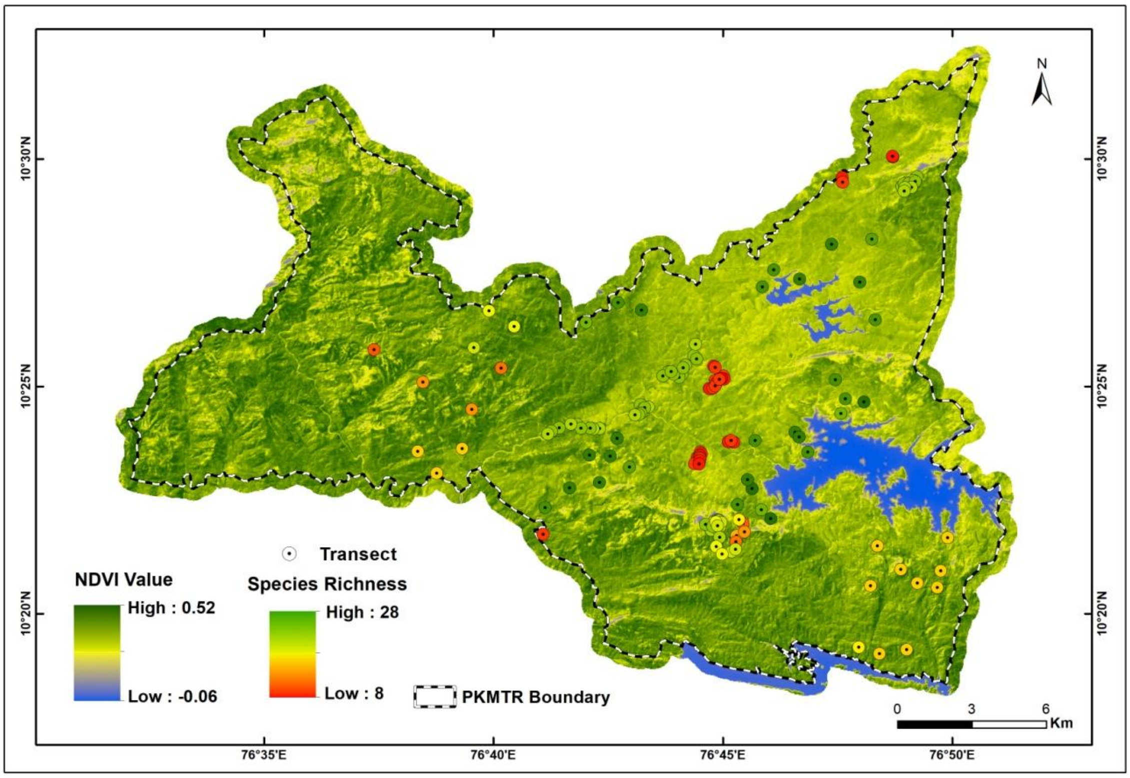


Fig. 5.20. The mean Normalized Difference Vegetation Index (NDVI) and grasshopper species richness in PKMTR

5.4.6. Mid-Domain Null Model

The grasshopper species richness in ENP exhibited a mid-domain effect (Fig.5.21). The species richness curves including the upper and lower limits peaked at the mid-elevations between 1700 – 2100m. The 95% prediction curves obtained from 50,000 simulations of Mid-Domain Null closely fit to the predictions of the null model with slight deviations at the peak elevations. A significant correlation was found between the empirical species richness and mean of predicted richness (r=0.93, p≤0.001). The grasshopper species richness in PKMTR does not fit to the upper and lower prediction curves (Fig.5.22). The empirical species richness curve is higher at low elevations than the predicted curves. No significant correlation was found between the empirical species richness and mean of predicted richness (r=0.43, p=0.17).

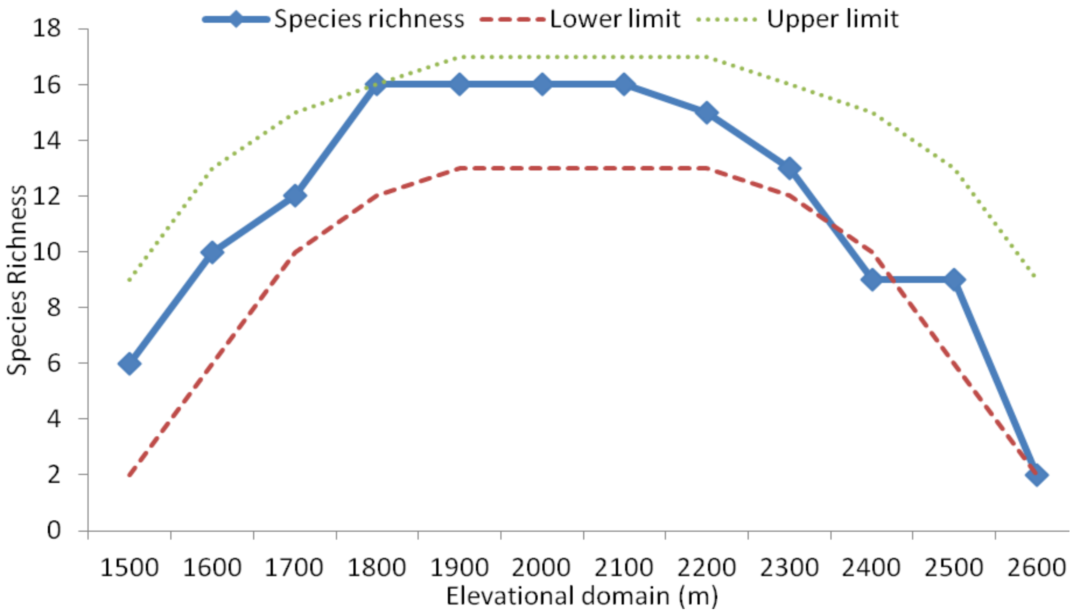


Fig. 5.21. Species richness curves (lines with data points), and the 95% prediction curves sampled without replacement from program Mid-Domain Null (50,000 simulations each) of ENP.

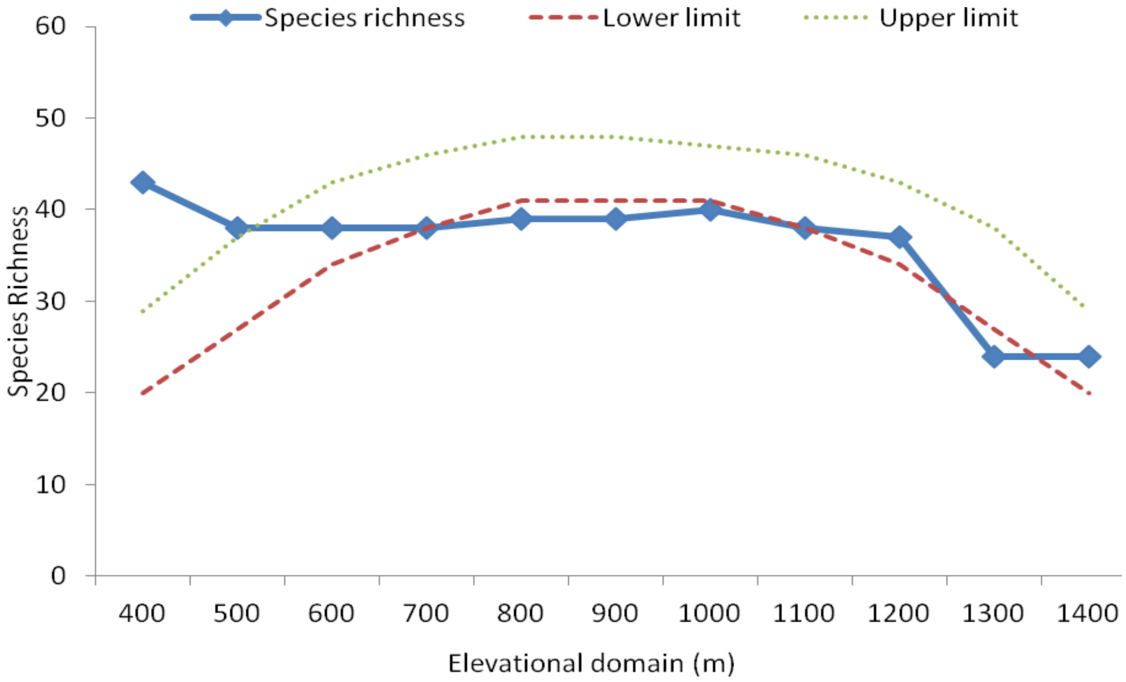


Fig. 5.22. Species richness curves (lines with data points), and the 95% prediction curves sampled without replacement from program Mid-Domain Null (50,000 simulations each) of PKMTR

5.4.7. Grasshopper Range Size

The elevation range size of grasshoppers in ENP was scattered with a slight increase at mid-elevations. There was also an increasing overlap of species ranges towards the mid-elevation ranges. The range size of grasshoppers towards the peak elevations of ENP was found to be low. A weak correlation was observed between elevation range mid-point and range size in ENP (r=-0.145, p=0.57). There was no evidence for Rapoport's rule for grasshopper species richness in ENP. The newly described grasshopper species (*Tettilobus trishula sp. nov.*) represented its range size with a single specimen. Hence the range for this species is zero (Fig. 5.23).

The elevation range size of grasshoppers in PKMTR was increasing as the elevation increases up to 1000m and afterwards, a slight decrease was observed towards the peak. There was a strong significant positive correlation between the range sizes and range mid-points in PKMTR (r=0.67, p≤0.001). The grasshopper species richness in lower elevations of PKMTR was found to be inflated but this trend was not visible towards higher elevations. The grasshopper species richness of PKMTR showed a monotonic decreasing trend with elevation justifying the Rappoport's rule related to elevation gradients. A grasshopper species (Mopla guttata) was rediscovered from PKMTR with a single specimen and hence the range size was zero in this case (Fig. 5.24).

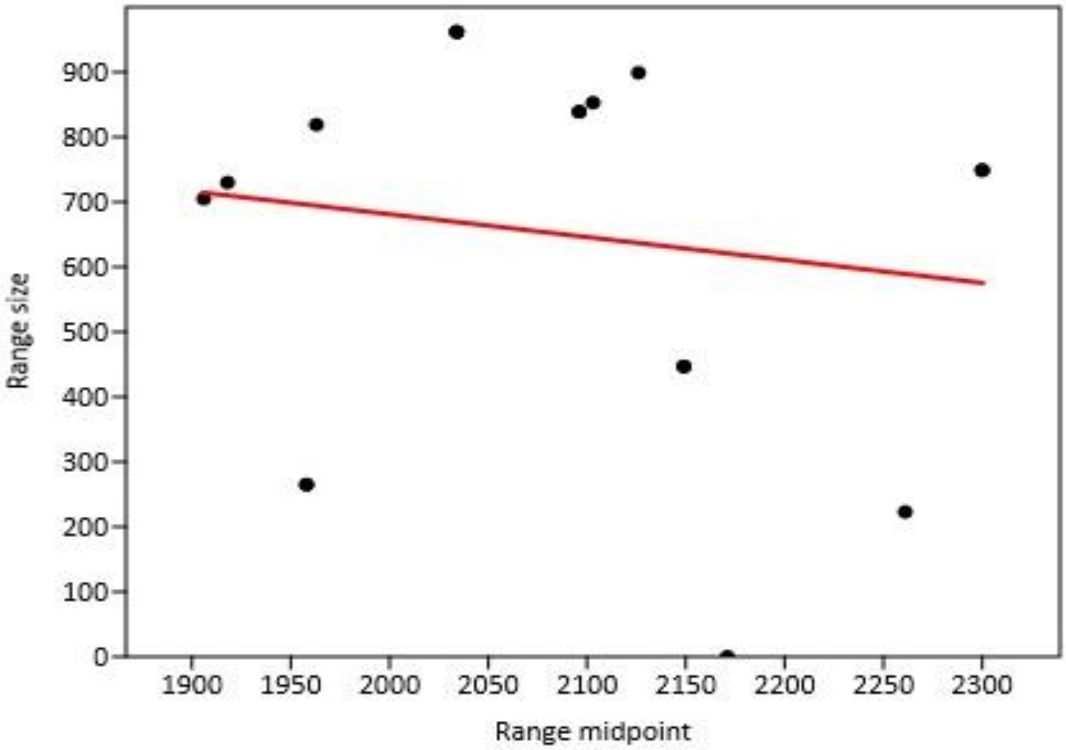


Fig. 5.23. Elevation range midpoints and range size of grasshoppers in ENP

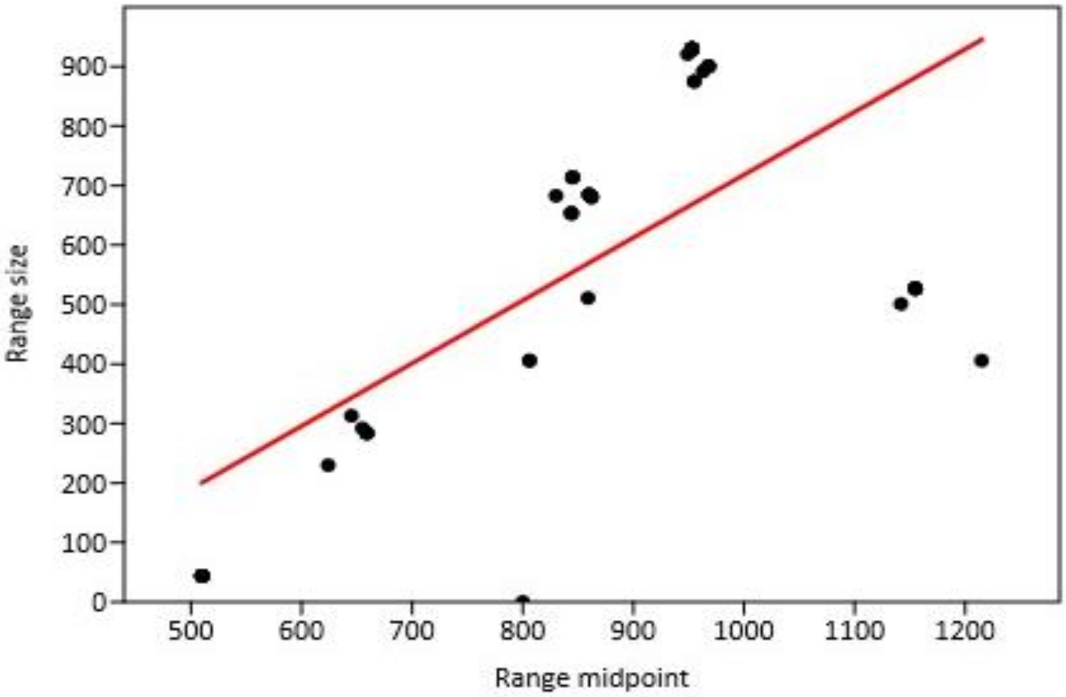


Fig. 5.24. Elevation range midpoints and range size of grasshoppers in PKMTR

5.5 DISCUSSION

A hump-shaped species richness pattern was observed in grasshopper distribution across elevation ranges of both ENP and PKMTR. Such pattern has been frequently documented in many organisms including birds (Acharya et al. 2011; McCain 2009; Price et al. 2014), small mammals (Heaney 2001; McCain 2004), herpetofauna (Fu et al. 2007; Meza-Joya and Torres 2016), invertebrates and plants (Kluge et al. 2006; Oommen and Shanker 2005; Sanders et al. 2003; Grau et al. 2007) and fishes (Bhatt et al. 2012). From the 23 elevation bands ranging from 400m to 2690m, 58 grasshopper species were recorded. The grasshopper species richness was considerably higher in PKMTR than that of ENP. A total of 55 species were recorded from 400 to 1450m elevation ranges of PKMTR and 18 species from 1500m to 2690m in ENP. The higher grasshopper species richness in PKMTR could be due to the habitat heterogeneity and the mosaic nature of the vegetation. The Tiger Reserve possesses six different habitat types (Evergreen, Semi-Evergreen, MDF, Riparian, Vayals and Grasslands) whereas ENP has only three habitat types (Shola, Shrubs and Grasslands). This justifies the habitat heterogeneity hypothesis (Tscharntke et al. 2002; Tews et al. 2004). According to the hypothesis, greater diversity of insects is expected in complex habitats than that of simple as the increased number of niches increases the habitat complexity (Dupont and Nielsen 2006) facilitating higher grasshopper species richness in PKMTR. The montane ranges of tropics are well known for their biological diversity and home for many endemic living organisms (McCoy 1990; Orme et al. 2005; Burgess et al. 2007). The mountains of tropics are interpreted as model systems in climate change research (Fielding et al. 1999; Brooker et al. 2007). The elevational ranges of PKMTR and ENP together represent lower and higher elevations of Western Ghats. The grasshopper species richness documented across elevational ranges from 400m to 2690m will provide basic information for future climate change researches.

The body size and developed wings of grasshopper species are known to be a key factor that determines their dispersal abilities (Levy and Nufio 2014). *Cyrtacanthacris tatarica* and *Xenocatantops humilis* of family Acrididae with developed wings and comparatively larger body size shows high dispersal abilities across all the elevation bands except the peak elevation of ENP (2600-2700m). The peak of ENP (2690m - Anamudi hills) is considered to be the highest peak of the Western Ghats and covered with grasses intermittent with plain rocky surfaces. Grasslands interspersed with exposed rocky surfaces are known to be influencing the grasshopper distribution in South Africa (Gebeyehu and Samways 2006). The reason for such a pattern has not been resolved (Crous et al. 2013). The grasshopper species richness was found to be higher between the mid-elevation ranges where the geographical area is also higher with an average of 20km^2. Larger the space (area), larger the number of species accommodated (Kattan and Franco 2004; Fu et al. 2006).

The unique habitats and elevation ranges of ENP are home to rare and endemic flightless grasshoppers. The less developed wing and smaller body restrict the dispersal ability of grasshoppers (Levy and Nufio 2014) which is true in the case of the endemic ranges. The Tetrigidae species such as *Eucriotettix flavopictus* and *Euscelimena harpago* were seen only in the wet rocks of streams in shola forests at an elevation range between 1800 - 2100m. Deltonotus gibbiceps of family Tetrigidae were exclusive to the leaf litters of shola forests at elevations from 1500 to 2300m. The newly described *Tettilobus trishula sp.nov* was found to be unique and specific in its habitats. It was collected from within the barks of a tree inside the shola forests at an elevation of 2150m. Hence, habitat conditions of ENP are very significant in terms of grasshopper species richness.

Temperature and land area are often highlighted as the most important factors influencing organisms along elevation gradients (Korner 2007). Similar to ENP, the grasshopper species richness and area were closely related in PKMTR. Lower elevations of PKMTR from 400m to 600m possess a larger geographical area. The area decreased as the elevation gradually progressed. Highly mobile grasshoppers species such as *Choroedocus illustris, Diabolocatantops innotabilis, Pachyacris vinosa, Gesonula punctifrons, Teratodes monticollis, Phyllochoreia unicolor, Neorthacris acuticeps acuticeps, Atractomorpha crenulata* and *Aularches miliaris* were present across all the elevation bands from 400m to 1429m. Grasshoppers of family Tetrigidae, *Deltonotus subcucullatus* and *Deltonotus gibbiceps* were observed only within the evergreen areas of PKMTR at an elevation range between 700 m and 900m. They were seen in the dry leaf litter bed of evergreen areas of PKMTR. This detritobryophagy feeding strategy has been very commonly observed among the ground-hoppers (Hochkirch et al. 2000). *Euparatettix personatus*, *Eucriotettix flavopictus*, *Euscelimena gavialis*, *Euscelimena harpago* and *Systolederus sp* of PKMTR were found between 400 to 600m elevation ranges. These tetrigidae species were found to occupy the riparian and evergreen areas of PKMTR where the surface moisture content was high. The pygmy grasshoppers of family tetrigidae are well known in their association with semi-aquatic habitats like marshes, margins of water bodies and floodplains (Amédégnato and Devriese 2008). The semi amphibious behaviour of tetrigidae is also well documented as they are good divers (Paranjape et al. 1987; Gröning et al. 2007; Amédégnato and Devriese 2008; Tan et al. 2017). An exception to this is *Indomiriatra provertex* of tetrigidae family, which was seen distributed across evergreen patches from 400m to 1300m elevation but not in riparian habitats. The mid-elevation grasslands between 900m to 1429m of PKMTR were rich with grasshoppers such as *Carliola carinata, Leptacris filiformis, Paramastacides ramachendrai, Mastacides nilgirisicus* and *Neorthacris acuticeps nilgiriensis.* An extremely rare endemic *Mopla guttata* was located from moist deciduous patches between 800m to 900m elevation after 76 years since its description (Henry 1940).

The mid-elevation species richness peaks have been explained by several hypotheses (Sanders 2002). Among such hypothesis, the “middle is good” states that the productivity at mid-elevations is higher because of the day-temperature, increased photosynthesis rate and cool evenings facilitating lower plants respiration (Janzen 1973; Janzen et al. 1976). The “middle is good” directly relates to the geographical and environmental conditions of ENP. The grasshoppers of ENP exhibited higher species richness across its mid-elevation ranges. The pattern of increasing species richness overlapping towards the mid elevational ranges bounded by the highest and lowest elevation in the region is explained as mid-domain effect by Colwell and Hurtt (1994). An apparent mid-domain effect was visible in the null model empirical species richness comparison (Colwell et al. 2004). The mid-range of ENP has larger areas than that of lower and higher elevations. In PKMTR, the lower elevations with large geographic areas and diverse habitats resulted in higher grasshopper species richness. In PKMTR, a gradual linear decrease in area, as well as grasshopper species richness, was found across the higher elevation ranges from 600m elevation in PKMTR. There was no evidence for the mid-domain effect in PKMTR. Such a difference between PKMTR and ENP could probably due to the difference in the elevational band where the lowest elevation in Parambikulam is 400m and that of ENP is 1500m.

Understanding the species richness patterns and the associated environmental factors is essential to derive the requirements to protect biodiversity effectively and efficiently (Schouten et al. 2008). The grasshopper species richness pattern in ENP was higher at the mid-elevation ranges (1900 – 2500m) compared to the lower and higher elevations. There were two peaks of species richness in ENP, the first and the smallest was between 1500 – 1700m and the second and largest peak was between 1800 – 2500m. This pattern of species richness was also the same as in the estimated species richness rates. The elevation range between 1500 and 1700m in the valleys of ENP was occupied by the high altitude shola forests. Only a very few grasshopper species were found in the unique shola forests of ENP. After 1800m elevation till 2500m, the ENP has a distribution of all the three habitats (Grasslands, Shola and Shrubs). Across this mid-elevation ranges, the grasshopper species richness was found to be high. But a clear transition zone with low grasshopper species richness was found between these two peaks in ENP.

The highest grasshopper species richness in PKMTR was observed between 500 and 600m elevation ranges. The grasshopper richness exhibited three peaks between 400 – 1450m in PKMTR. The first and the highest peak that represents species richness were between 400 – 700m, where all major habitat types (Evergreen, Semi-Evergreen, MDF, Riparian and Vayals) of PKMTR were available in a considerably larger geographical area. The second peak was observed between 800m and 1000m, where there is Evergreen, Semi-Evergreen and MDF as dominant vegetation types. The third observed species richness peak was between 1100 – 1300m where the Grasslands and Evergreen are dominant vegetations. The transition zones between species richness peak were also visible in PKMTR. This pattern of species richness was explained in the community overlap theory by Lomolino (2001). According to the theory, the species richness is expected to be peaked at some intermediate elevations with a transition zone between two adjacent species-rich communities.

Like the area influence species richness, the productivity that varies along elevational gradients also acts as a driving force behind the species richness pattern (Sanders 2002). The species richness pattern is related to productivity in two major ways: 1) A monotonic increase in species richness with increasing productivity (Hutchinson 1959; Preston 1962; Connell and Orians 1964; Sanders 2002) and 2) the species richness and productivity increases and peaks at mid-levels of productivity, and gradually decreases at higher productivities (Tilman 1982; Rosenzweig and Abramsky 1993). Both these patterns of species richness and productivity were visible in the grasshopper species richness in ENP and PKMTR. More information on the productivity of both the area is required to justify the relationship between productivity and grasshopper species richness.

An increasing overlapping in grasshopper species richness at the mid elevation ranges was observed in ENP. There was no evidence of positive correlation between species richness and elevation gradients in ENP and hence no evidence to support the Rapoport's rule for grasshopper species richness in the Park. In the case of PKMTR, the elevational range size of grasshoppers increase with increasing elevation up to 1000m and a slight decrease was observed afterwards towards the peak. The monotonic decreasing trend in grasshopper richness with increasing elevation in PKMTR agrees with Rapoport's rule (Stevens, 1992). The monotonic decrease in grasshopper richness in PKMTR with increasing elevation recalls the rescue effect of Rapoport's elevational rule (Stevens 1992; Sanders 2002).

The microhabitat conditions, area, productivity and environmental heterogeneity are known to affect the distribution of organisms (Sanders 2002). Vegetation structure and composition are known to greatly influence the distribution of Orthoptera species (Guido and Gianelle 2001). Both the study areas (ENP and PKMTR) exhibit habitat heterogeneity and different environmental conditions at their elevation ranges. In ENP and PKMTR, the environmental variables (AMT, APn, MTWM and MTWM) were found to be in strong relation with the elevation ranges. The mean NDVI of ENP and elevation showed a strong negative correlation. But in PKMTR, the mean NDVI and elevation showed no significant correlation. The structural differences and habitat conditions are known to modify the temperature, light intensity and soil moisture. All these are considered to be determining factors in diversity and distribution patterns of arthropods (Guido and Gianelle 2001; Nufio et al. 2010). Grasshoppers are important primary and secondary consumers in many ecosystems especially in grasslands. As a primary prey species, they are an abundant source of food for many predators (e.g. insectivorous birds, spiders) (Zografou et al. 2017). Their sensitive nature to microclimatic conditions (Zografou et al. 2009) qualifies them as bioindicators for several regions (Báldi and Kisbenedek 1997). Thermal conditions such as increased ambient temperatures are known to have a direct effect on the metabolic and developmental rates and activity patterns (Zografou et al. 2017) of grasshoppers. The thermal conditions are also known to determine their ability to avoid predation (Pitt 1999).

The species activities among invertebrates are being controlled by seasonal thermal conditions, which influence the community level dynamics also (Ghil 2002; Zografou et al. 2017). Changes in other habitat-specific variables such as the cover of flower-heads, presence of shrubs or altitudinal changes were shown to influence the Orthoptera community significantly (Zografou et al. 2009). Although these environmental factors are known to play a vital role in determining the distribution of invertebrates, the grasshopper species distribution across different elevation ranges resulted in no significant correlation.

Both the study areas (ENP and PKMTR) resulted in two different patterns of grasshopper species richness with elevational ranges. Other than the environmental factors such as temperature and precipitation, the geographical area available across elevational ranges was found to be influencing the grasshopper distribution along with habitat heterogeneity. The higher species richness and unique distribution patterns of grasshoppers in ENP and PKMTR stress the need for more conservation and management strategies with particular reference to lower fauna.

IMPACT OF PRESCRIBED FIRE PRACTICES ON SHORT-HORNED GRASSHOPPERS (ORTHOPTERA - CAELIFERA)

6.1 INTRODUCTION

Large mammals are most often given top priority in conservation programmes and are used as flagship species in conservation planning (Bowen-Jones and Entwistle 2002). This is particularly true for mammals with threatened red list status (Williams et al. 2002). Management and maintenance of open habitats are considered important because of the association of large herbivore with these habitats (Swengel 2001). Typical strategies to keep such habitats open include grazing, mowing or burning (e.g. Collins et al. 1998). Fire is widely used as a tool in the management of open habitats even with its potential detrimental effects on biota (Whelan 1995). The impact of fire on biodiversity has been studied in a variety of habitats, including prairies, savannahs, coniferous forests and peat bogs (Warren et al. 1987; Swengel 1996 and 2001; Hochkirch and Adorf 2007). The studies have indicated that the effects of fire vary among ecosystems, species and burning parameters (e.g. season, fire intensity and burned area). The studies have also proved the critical importance of studying the impacts of each specific burning strategy in management areas to avoid any adverse effects on biodiversity. The scale of burnt area is one of the major aspects to be considered. According to the habitat heterogeneity hypothesis (Tscharntke et al. 2002; Tews et al. 2004), Small-scale burning is expected to have comparatively low detrimental effect on biodiversity than large-scale burning. Potential negative effects of burning on species rich insect communities could thus be minimised by selecting the extent of burned areas. The Western Ghats in India belong to the global hotspots of biodiversity (Myers et al. 2000) because of the high diversity of natural ecosystems including wetlands, tropical wet evergreen, moist and dry deciduous forests and the unique Shola forests (Southern montane wet temperate forest) and grassland ecosystems (Champion and Seth 1968). Each habitat within this biodiversity hotspot contains unique endemic floral and faunal elements (Myers et al. 2000). The Nilgiri tahr (*Nilgiritragus hylocrius*), a mountain goat, is endemic to the Western Ghats and confined to the tropical shola-grassland ecosystem. With 1800-2000 mature individuals, a continuing decline in population size and small subpopulations, the species is listed as Endangered on the IUCN Red List of threatened species (Alempath and Rice 2008). The species is currently seen in several habitat fragments of Protected Areas of Tamil Nadu and Kerala in southern India (Easa and Alembath 2019). Eravikulam National Park (ENP) with the adjacent contiguous area of Anamalai Tiger Reserve harbours the largest Tahr population. This population is considered viable because of its population size and the extent of its preferred habitat.

Traditionally, the grasslands of ENP are managed by prescribed “cold burning” (cold season burning) with the help of Muduvans, the local tribal community. Burning is practised in 50 ha plots to provide palatable food for the endemic herbivore. According to Davidar (1978), this has been practiced since the British colonial time. The Nilgiri tahr recovery plan (Easa et al. 2010) stresses the importance of systematic monitoring of impact of fire on tahr habitats. The impact of burning of the tahr habitats on other biota has never been documented especially since the management objective is to improve the status of the endangered tahr. However, the Western Ghats (including ENP) are known to maintain an exceptionally high number of endemic invertebrates. Recently, burning has also been experimentally introduced in Parambikulam Tiger Reserve (PKMTR) in Western Ghats. It has been practiced at a much smaller scale (10 x 10 m) in the area. It is crucial to understand the effects of these burning strategies on these species so as to avoid unnoticed extinctions of endemic invertebrates.

Swengel (2001) and Fredericksen and Fredericksen (2002) have opined that the impact of fire on invertebrates can vary substantially. Grasshoppers are a major group of herbivorous insects dominating open ecosystems (Belovsky and Slade 2017) and often the most important primary consumers (Odum et al. 1962). They are sensitive to grassland management (e.g. Weiss et al. 2013; Bröder et al. 2018). The group is also known to be suitable for bioindication of grassland quality and restoration success (Henle et al. 1999; Alignan et al. 2018). Many grasshopper species are sensitive to environmental change and prone to high extinction risk because of their flightless nature and endemicity to narrow geographic ranges (Hochkirch et al. 2016). Therefore, their response to fire management is of high interest. As grasshoppers represent a major faunal component of grasslands, effects of fire on the group can be easily investigated in grassland habitats (Anderson et al. 2001; Chambers and Samways, 1998; Swengel 2001; Fredericksen and Fredericksen 2002; Huntzinger 2003; Gardiner et al. 2005; Joern 2005, Ferrando et al. 2016).

The impact of prescribed burning on grasshoppers was studied in Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR), Kerala, in the Southern Western Ghats (India). The stress was on understanding the recovery of grasshopper species and communities after burning and the differences of the specific management practices (large-scale versus small-scale burning) in both the Protected Areas. It is hypothesized that large-scale burning is more detrimental and hampers recovery of grasshopper abundances compared to small-scale burning.

6.2 METHODS

6.2.1 Study area

The study was conducted in the grasslands of Parambikulam Tiger Reserve (PKMTR) and the high altitude tropical shola grassland ecosystems of Eravikulam National Park (ENP) (India, Fig. 6.1). Details of these two areas are given in Chapter III. ENP is 97 km^2 in extent and consists of high altitudinal grasslands interspersed with sholas (Southern montane wet temperate forest). A high rolling plateau with a base elevation of ca. 2,000 m asl comprises the main body of the Park. In the early 1800s, the area was under the management of British colonials, who preserved the habitat as a game reserve. The change in the status of the area, however, did not alter the management practices substantially and thus the fire management of “cold burning” (January-February) is still being practised with the objective of providing lush green grass to the Nilgiri tahr. Prescribed burning results in a mosaic of burned and unburned grassland areas.

The entire grasslands in ENP are divided into 1st, 2nd and 3rd plots of 50 ha. Each year, the managers set fire to the same numbered grids so that a three-year cycle of prescribed burning is applied to the particular 50 ha plot every third year.

PKMTR was declared as Tiger Reserve in February 2010. The Tiger Reserve has an area of 644 km^2 and an altitudinal range from 460 m to 1439 m. The vegetation types include evergreen, semi-evergreen and moist deciduous forests, plantations of teak and eucalypts and riparian forests. In PKMTR, fire was never introduced before as a management practice. The extent of grassland is less in PKMTR than in ENP in terms of the area covered by the dominant lemongrass (*Cymbopogon sp*). The presence of Nilgiri tahr in this grassland led to the decision to test prescribed burning in these grasslands. However, contrary to ENP, only small areas (10 x 10 m plots) were burned with adjacent unburned habitats.

The climate of the study areas is dominated by the monsoon circulation of the wind blows from oceans to the south of the Asian land mass. The monsoon months last from June to August, pre-monsoon from January to May and post-monsoon from September to December.

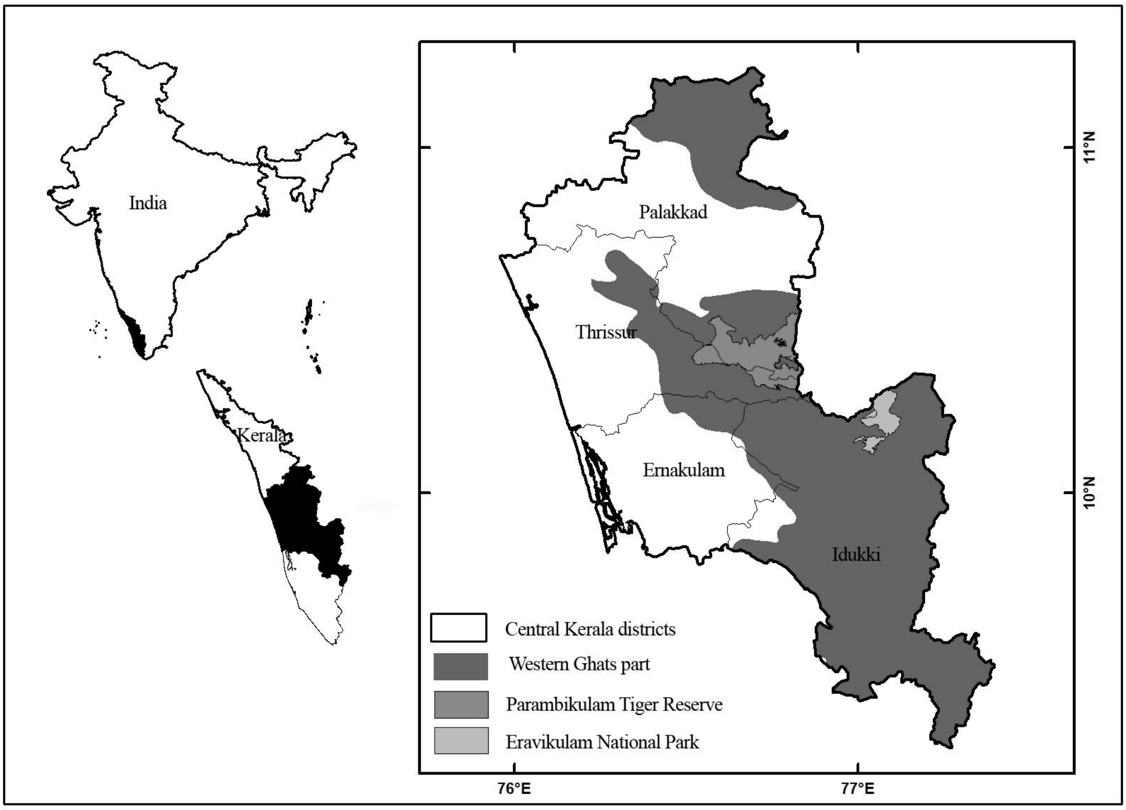


Fig. 6.1. Map showing the situation of Eravikulam National Park and Parambikulam Tiger Reserve, Kerala, India.

6.2.2 Sampling

Grasshopper (Caelifera) diversity of ENP and PKMTR was studied from 2015 to 2018 to obtain a general species inventory. Information on the diversity of adult grasshoppers in both the study areas were recorded after collection using standard sweep net, hand picking and direct observation.

For studying the impact of large-scale burning on grasshoppers (ENP), 18 plots were randomly laid (6 pre-burned, 6 control (unburned) and 6 experimental (burned) plots) in the study area. The plots were of 10 x 10 m size. Pre-burned plots of ENP were sampled one year before the fire and served as a second (temporal) control (same site, but before burning). Burned plots were laid immediately after the fire on the burned grasslands and control plots were on the opposite hills with similar vegetation which have not been burned since three years (same date, but different site). Each plot (unburned and control) was sampled every month for two years, while pre-burned plots were sampled only in the year before the fire.

Similar to ENP, 18 plots were laid (6 pre-burned, 6 control (unburned) and 6 experimental (burned) plots) across the study sites of small scale burning in PKMTR. Pre-burned plots of PKMTR were sampled for two months before the sites were burned as there was no initial knowledge whether burning would be conducted in the following year).

Orthoptera were sampled on each plot every month from February 2015 to May 2018 in both the study areas. Sampling within the plots was done by using sweep nets along two transects of 14 m from the corner of a plot to the opposite corner, resulting in an X-shaped transect on each plot. This was to ensure a pattern of sweeping and for maximum representation of grasshopper abundance within the plots. After each sweep along the transect, the grasshoppers were photographed, quantified, identified and released outside the plots, except for some voucher specimens (we were not permitted to collect all specimens captured in the sweep net in Protected Areas). Collected voucher specimens were preserved and deposited in Kerala Forest Research Institute (KFRI) Entomology Museum. Unidentified and taxonomically difficult species were later identified using a variety of taxonomic literature (Westwood 1839; Bolívar 1900 and 1902; Kirby 1914 b; Uvarov 1929; Chopard 1969; Henry 1937 and 1940) and by consulting experts. The specimens were also compared with the type specimens in the British Natural History Museum London (BNHM), Natural History Museum Madrid (MNCN), Natural History Museum Paris (MNHN) and Natural History Museum Geneva (NHM). The taxonomy follows the latest version of the Orthoptera Species File (Cigliano et al. 2018). The average temperature of fire within the grass tussock and within and under the surface of soil during burning was recorded using thermocouples (TCAV-L).

6.2.3 Statistical analysis

A two-way repeated measures analyses of variances (ANOVA) in R 3.5.0 (R Core Team 2018) was used to test for differences in total Orthoptera abundance and the abundances of the most common species between pre-burned, unburned (control) and burned (experiment) plots of ENP and PKMTR. Box-Cox-Transformation as implemented in the MASS package for R was used to obtain the optimal exponent (λ) to fit the data to the model assumptions. In one explanatory variable the status of the plots (i.e. burned, pre-burned, control) with the year (1-3) and season (pre-monsoon and post-monsoon) were combined. For the latter, each count to the respective season (pre monsoon from Jan to May and post monsoon from Sep to Dec) was assigned as abundances differed substantially among seasons but only little within season (see results). The monsoon months (Jun - Aug) were discarded from the analysis as these were strongly influenced by annual rainfall patterns and abundances were quite variable. The reason for combining treatment, year and season was that the pre-burned plots were studied only during one season and year, while the burned and control plots were studied during two seasons of three years each. Furthermore, it was expected that during the third year abundances would have recovered and approach the pre-burned situation.

Principal component analysis (PCA) was performed using the ClustVis online tool (Metsalu and Vilo 2015) to analyse the changes on community level. The abundance of grasshopper species on each plot of each studied site (Karimala-PKMTR and Eravikulam-ENP) were sorted as six column annotations (number of column, treatment - control/preburned/burned, month, year, season, and month number in chronological order) and two row annotations (number of row and name of the species) (provided in supplementary material). Unit variance scaling was applied to rows; SVD with imputation was used to calculate principal components. The data used were absolute abundances (number of individuals recorded) per month at each locality; control, preburned, and burned (transects and plots are fused, giving the single value in the Table). The PCA data (matrix, principal components, variance explained by principal components as well as component loadings) for Karimala-PKMTR (Appendix A) and Eravikulam-ENP (Appendix B).

6.3 RESULTS

6.3.1 Effects of burning on grasshopper abundance

Total mean grasshopper abundance in PKMTR was generally higher than in ENP (Fig. 6.2, ANOVA, $\lambda = 0.75$, $F_{1,260} = 1494$, $p < 0.001$). It was higher in the post-monsoon period than in the pre-monsoon period (ANOVA, $\lambda = 0.75$, $F_{1,260} = 135.6$, $p < 0.001$). The average temperature of fire within the grass tussock during burning was 310°C during large-scale burning (ENP) and approximately 120°C during small-scale burning (PKMTR). In ENP (large-scale burning), A significant decrease in total grasshopper abundance in the burned plots was observed compared to the pre-burned plots during the pre-monsoon period for both years (Fig. 6.3, ANOVA, $\lambda = 0.78$, $F_{6,88} = 27.9$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p < 0.001$). In contrast, there was no significant difference between the grasshopper abundance in the pre-burned plots and the control in both years (pairwise t-test with Bonferroni correction: $p = 0.99$). During the year of the fire as well as one year after, total grasshopper abundance was significantly higher in the control plots than in the burned plots (pairwise t-test with Bonferroni correction: $p < 0.001$). During the post-monsoon season, higher grasshopper abundances were observed in the pre-burned plots and the control plots compared to the burned plots (pairwise t-test with Bonferroni correction: $p < 0.001$).

In PKMTR (small-scale burning), significant differences in abundance between plot burning status was observed (Fig. 6.4, ANOVA, $\lambda = 1.42$, $F_{11,155} = 7.2$, $p < 0.001$). During the first pre-monsoon season, grasshopper abundance was significantly lower in the burned plots compared to the pre-burned situation and the control plots (pairwise t-test with Bonferroni correction: $p < 0.001$). However, in the second and third year, there was no significant difference in grasshopper abundance in burned and control plots (pairwise t-test with Bonferroni correction: $p = 0.99$). During the post-monsoon season, we found no significant difference between burned and control plots for any year (pairwise t-test with Bonferroni correction: $p_1 = 0.99$, $p_2 = 0.57$, $p_3 = 0.08$). This means that only during the pre-monsoon season, soon after burning, there was a significant decrease in grasshopper abundance in PKMTR.

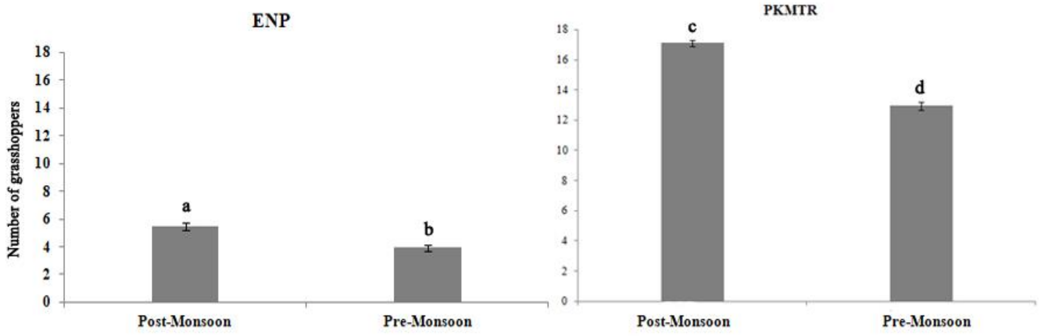


Fig. 6.2. Mean total grasshopper abundance per plot in Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR), Kerala, India, during Pre-Monsoon and - Post Monsoon Seasons (Error bars are standard errors)

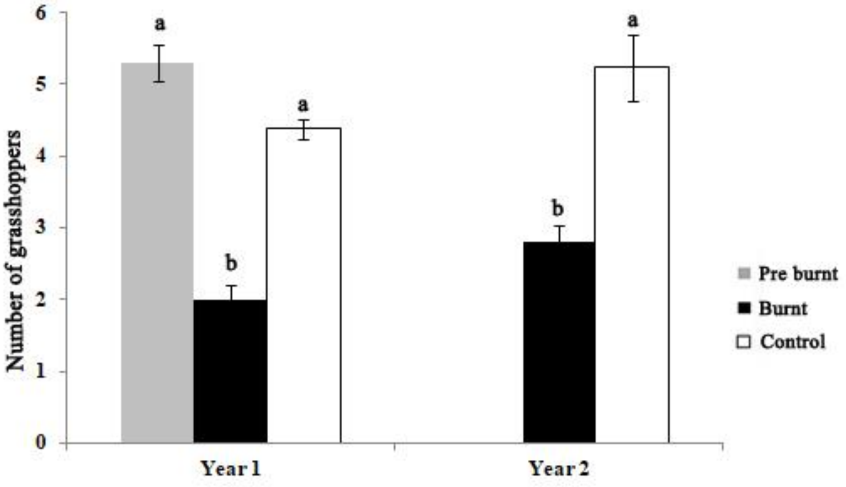


Fig. 6.3. Mean total grasshopper abundance on pre-burned plots, burned and control plots during the pre-monsoon period for both years after burning in Eravikulam National Park, Kerala, India (error bars are standard errors)

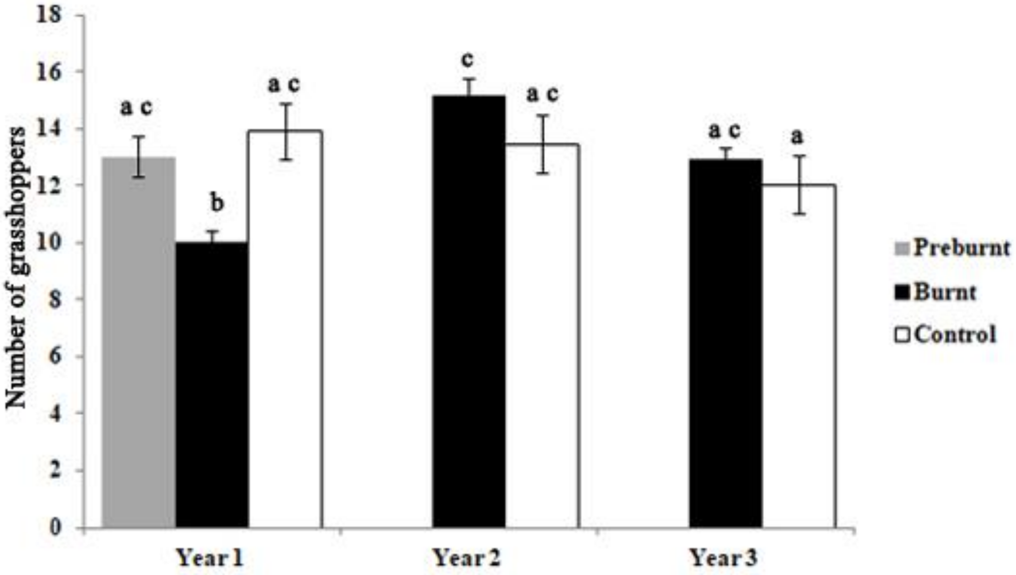


Fig. 6.4. Mean total grasshopper abundance on pre-burned plots, burned and control plots during the pre-monsoon period for both years after burning in Parambikulam Tiger Reserve, Kerala, India (error bars are standard errors).

6.3.2 Effects of burning at species level

When grasshopper species were examined individually, only the most common species showed a very similar response to burning, following the pattern explained above. For example, the abundance of *Zygophlaeoba sp.* decreased significantly in burned plots in ENP after burning compared to the pre-burned situation and the control plots just during the post-monsoon season and the second pre-monsoon season (but not during the first pre-monsoon season; ANOVA, $\lambda = 0.12$, $F_{7,88} = 5.3$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p < 0.02$). Butno significant differences between control plots and the pre-burned situation were found (pairwise t-test with Bonferroni correction: $p = 0.99$). For *Paramastacides ramachendrai* only, a significantly lower abundance on burned plots during the first pre-monsoon season was detected compared to the pre-burned situation (ANOVA, $\lambda = 0.18$, $F_{7,88} = 2.5$, $p = 0.02$; pairwise t-test with Bonferroni correction: $p = 0.047$). The abundance later recovered rapidly and was not significantly different from the control plots or the pre-burned situation (pairwise t-test with Bonferroni correction: $p = 0.99$). For *Palniacris maculatus*, a significant decrease in population size was observed during the first and second pre-monsoon season in burned plots compared to the pre-burned and control plots (ANOVA, $\lambda = 0.11$, $F_{7,88} = 17.8$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p < 0.001$), but not for the post-monsoon season (pairwise t-test with Bonferroni correction: $p = 0.99$). *Carliola carinata* showed a significant decrease in the burned plots compared to the pre-burned plots during all seasons (ANOVA, $\lambda = 0.17$, $F_{7,88} = 5.45$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p_1 = 0.03$, $p_2 = 0.047$, $p_3 = 0.03$). However, during the post-monsoon season, a significant difference to the control plots was seen (pairwise t-test with Bonferroni correction: $p = 0.006$). For *Atractomorpha crenulata,* a significant decrease in abundance on the burned plots was found during the first pre-monsoon season compared to the pre-burned and control plots (ANOVA, $\lambda = 0.06$, $F_{7,88} = 8.4$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p_{1+2} < 0.001$) and for the first post-monsoon season compared to the control (pairwise t-test with Bonferroni correction: $p = 0.04$). There was no significant difference during the second pre-monsoon season for this species.

In PKMTR, *Neorthacris acuticeps nilgiriensis* had a significant lower abundance in the burned plots only during the first pre-monsoon season compared to the control (ANOVA, $\lambda = 0.65$, $F_{12,155} = 7.7$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p < 0.001$). The same was true for *Neorthacris acuticeps acuticeps*, which decreased significantly in burned plots during the first pre-monsoon season after burning compared to the pre-burned situation, but also in comparison with the control plots (ANOVA, $\lambda = 0.4$, $F_{12,155} = 5.2$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p_{1+2} < 0.001$). However, no significant differences to the control plots were found later for these species (pairwise t-test with Bonferroni correction: $p = 0.99$). All the other species showed no significant differences in abundance in burned sites compared to the pre-burned or control plots. Butsome species showed differences in abundance between seasons or years. For example, the most abundant species (*C. carinata*) had a significantly higher abundance in the post-monsoon season of the second year compared to the pre-monsoon season of the first year (ANOVA, $\lambda = 0.5$, $f_{12,155} = 2.32$, $p = 0.009$; pairwise t-test with Bonferroni correction: $p < 0.001$). But there was no differences within a season or year.

6.3.3 Fire induced melanism

The prescribed burning practices in ENP and PKMTR exposed the grasslands in to large and small mosaics of burned and unburned patches. The flightless grasshoppers such as *Carliola carinata* that are normally brown in colour (Fig. 6.5 a) was exposed in the burned grounds and became easily detectable to their predators. During the first week after fire in ENP, there was no trace of *C. carinata* in the burned grounds. But in PKMTR *C. carinata* was observed but less in number in the burned areas. After one week, it was observed that the existing individuals within the fire affected area of PKMTR changed their colour in to an ashy black (Fig. 6.5 b) enabling them to stay camouflaged with the burned habitat. Number of melanised morphs was observed to be increasing during the first weeks of fire. The morphological comparison of both the black and brown morphoforms showed no marked differences except for the body colour. Both the melanised and normal morphs of grasshoppers (Fig. 6.6 a,b) were compared with holotype specimens of *Carliola carinata* deposited in Natural History Museum Geneva (Fig. 6.6 c,d,e). Morphologically, the field specimens were confirmed as *Carliola carinata.*

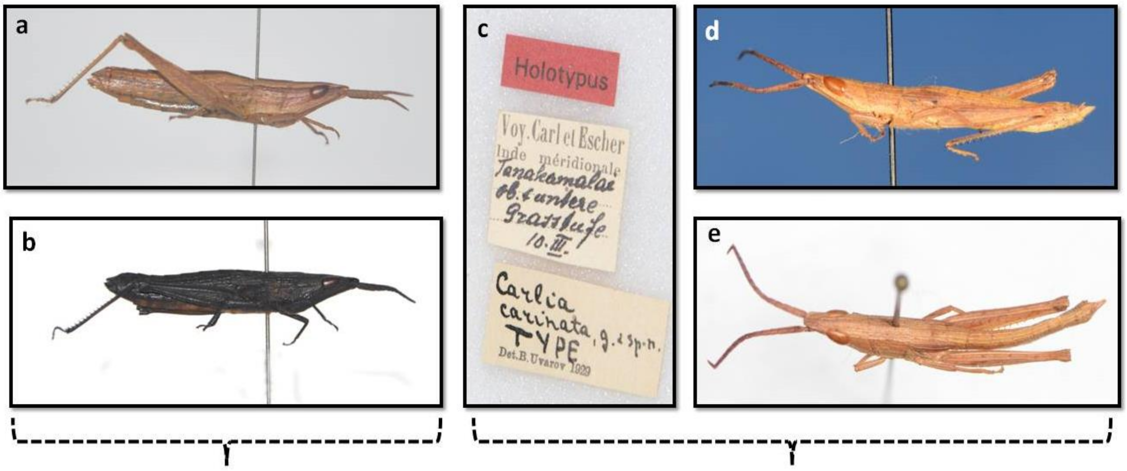
To confirm species status of both these morphoforms, mitochondrial *CO1* barcoding was performed. Genomic DNA was extracted from both the brown and black morphoforms of *C. carinata* using SDS method (Milligan 1998). The DNA samples were separated on 1.5 per cent agarose gel, stained in ethidium bromide and visualized under UV transilluminator (Fig. 6.7). Polymerase Chain Reaction (PCR) of the *CO1* barcode region was done using the reported forward (LCO1490) 5' TGTAAAACGACGGCCAGTGGTCAACAAATCATAAAGATATTGG 3' and reverse primers (HCO2198) 5'CAGGAAACAGCTATGACTAAACTTCAGGGTGACCAAAAATCA 3' (Nazir et al. 2014). PCR products were resolved on 2 percent agarose gels stained with ethidium bromide. PCR reaction was scaled up to 50 µL for the purpose of elution and then purified using Nucleospin Elution kit (Machery-Nagel, U.S.A.). DNA sequencing was performed from the eluted PCR products in forward direction employing Sanger's dideoxy chemistry. The raw sequence chromatograms obtained after sequencing were edited using *BioEdit* Software v.7.0. The edited sequences were used for multiple sequence alignment in *CLUSTAL X* (Thompson et al*.,* 1997). Sequence similarities of both brown and melanised morphoforms of *C. carinata* were tested. The *CO1* barcode sequences after alignment were deposited in NCBI GenBank (http://www.ncbi.nlm.nih.gov/genbank/). The sequence of *CO1* barcode gave a read length of 480 bp in the forward Sanger's sequencing reaction. Multiple sequence alignment of the *CO1* sequences showed absolutely no nucleotide variations in the black (melanised) and brown (normal) morphoforms of grasshopper, *C. carinata*. The *CO1* barcode sequences with 100 percent similarity confirmed the species status of brown and black morphoforms as *C. carinata* (Fig. 6.8).

a. Before fire

b. One week after fire

c. One month after fire

Fig. 6.5. Different colour morphoforms of *Carliola carinata* before and after prescribed burning practices.



Normal and melanised morphoforms of *Carliola carinata*

Type specimen of *Carliola carinata* from MHNG Geneva (Switzerland)

Fig. 6.6. Field specimens compared with holotype specimen of *Carliola carinata.*

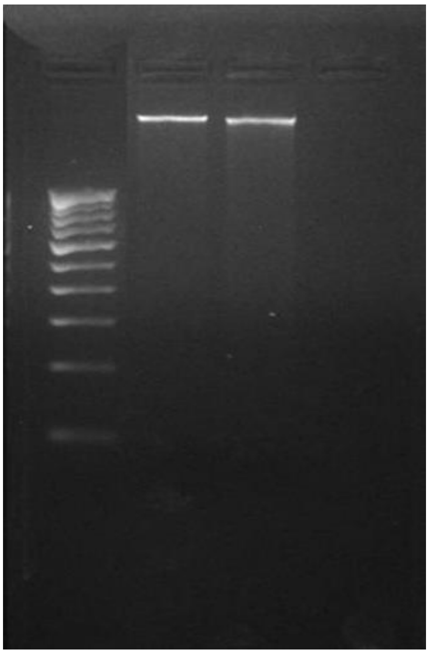
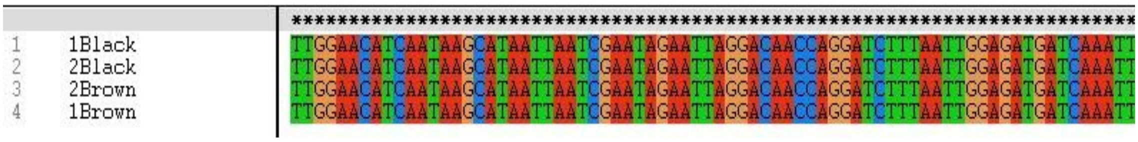


Fig. 6.7. Total genomic DNA of *C. carinata*



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                     **************************************************************************
1    1Black          TTGGAACATCAATAAGCATAATTAATCGAATAGAATTAGGACAACCAGGATCTTTAATTGGAGATGATCAAATT
2    2Black          TTGGAACATCAATAAGCATAATTAATCGAATAGAATTAGGACAACCAGGATCTTTAATTGGAGATGATCAAATT
3    2Brown          TTGGAACATCAATAAGCATAATTAATCGAATAGAATTAGGACAACCAGGATCTTTAATTGGAGATGATCAAATT
4    1Brown          TTGGAACATCAATAAGCATAATTAATCGAATAGAATTAGGACAACCAGGATCTTTAATTGGAGATGATCAAATT
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Fig. 6.8. Multiple Sequence Alignment (MSA) of *CO1* sequences of black and brown morphoforms of *C. carinata*

6.3.4 Multivariate analysis

The PCA plot for ENP (Fig. 6.9 a-c) showed on the first axis (explaining 70.5% of the total variance) a gradient of grasshopper communities on burned plots (with negative loadings) and pre-burned/control plots (with positive loadings). In PKMTR (Fig. 6.9 d-f), the first component explained 55% of the total variance. Contrary to ENP, the overlap of burned, pre-burned and control plots was higher. The PCA results show that in PKMTR, the Orthoptera community (grasshopper abundance) recovers positively within six months (overlapping of burned group towards the right side of the chart with control plots) after fire. In ENP, grasshopper assemblages after fire were not recovering even after two years.

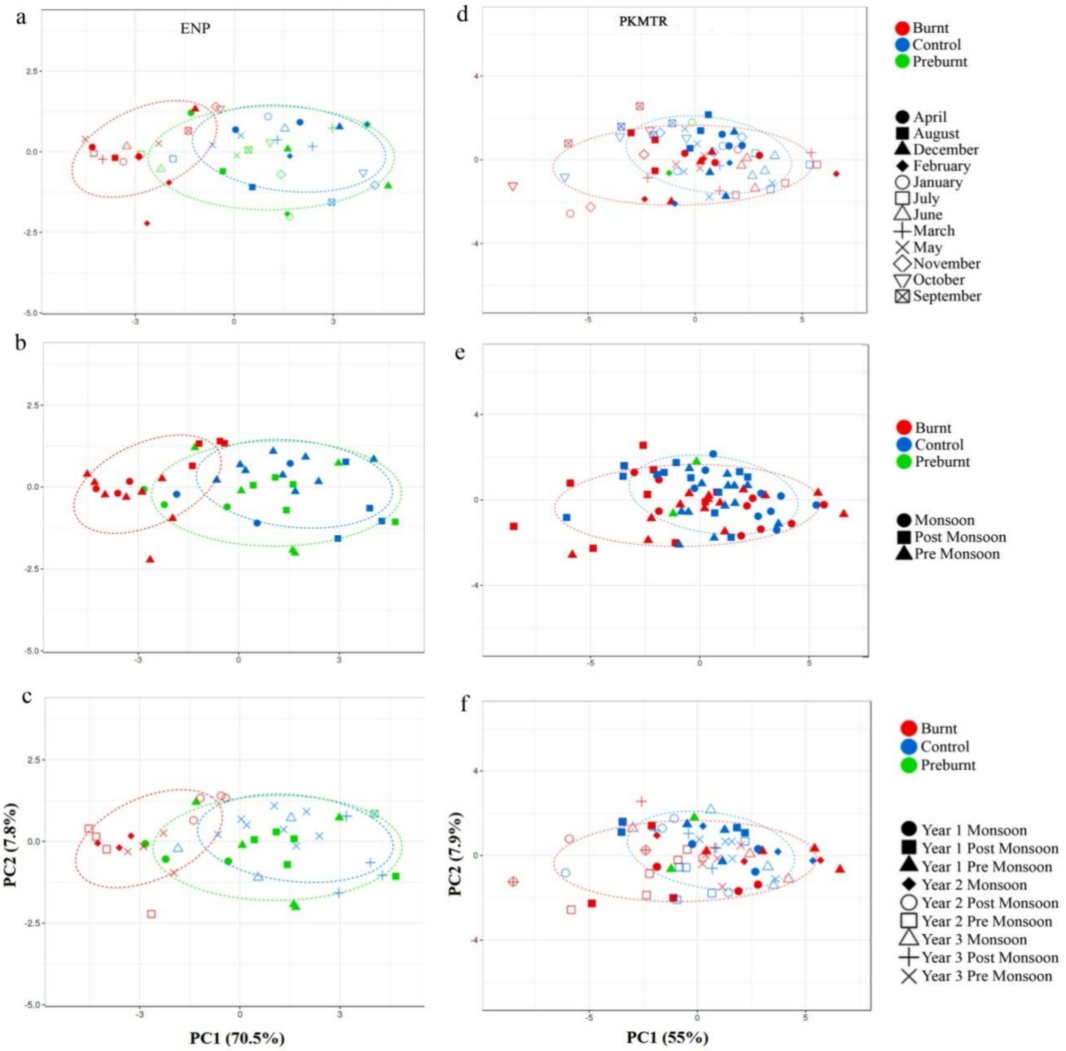

Fig. 6.9: PCA plots for Eravikulam National Park (ENP Fig. 6.9 a-c) and Parambikulam Tiger Reserve (PKMTR Fig. 6.9 d-f) Kerala, India (prediction ellipses are such that with probability 0.75, a new observation from the same group will fall inside the ellipse).

6.4 DISCUSSION

The results confirm the hypothesis that small-scale burning has comparatively less detrimental effects on grasshopper abundances compared to large-scale burning. These results are in line with the habitat heterogeneity hypothesis (Tscharntke et al. 2002; Tews et al. 2004) as both grasshopper species richness and abundances were higher in the more heterogeneous habitats of PKMTR compared to the more homogeneous habitats of ENP. In PKMTR, a rapid recovery of grasshopper communities, total abundance as well as abundance of individual species after burning were observed. The abundance of the most common species dropped significantly only during the first pre-monsoon season after burning. From the first post-monsoon season onwards, there were no significant differences in total grasshopper abundance between burned and control plots. In contrast, grasshopper abundance remained low for much longer in ENP, where large areas were burned. Generally, grasshopper species richness and abundances were higher in PKMTR than in ENP suggesting long-term effects of fire history in ENP. Only 18 grasshopper species were seen in ENP compared to 55 in PKMTR. However, it cannot be excluded that this result might also be affected by the different locations of both study sites. The main difference between the fire management in ENP and PKMTR is the extent of burned area, which covered 100 m^2 for each plot in PKMTR and 500,000 m^2 in ENP. But fire behaviour (i.e. temperature, speed etc.) may also have differed. In ENP, the grasslands were burned as circle of fire starting from the perimeter of the circled hill towards the centre, leaving grasshoppers little chances to escape from a burned area. In PKMTR, fire was restricted within 10 x 10 m plots.

The effect of fire on ecosystems and organisms varies depending on the ecological history of the taxa, fire intensity, behaviour, extent and frequency of the fire in addition to the moisture content and topography (Warren et al. 1987; McCullough et al. 1998; Keeley et al. 2005). Fire can affect organisms directly by combustion and indirectly by altering the structure and composition of vegetation (Rice 1932; Bock and Bock 1991). Both grasslands differ by only 600 m in elevation and the composition and structure of the soil is almost similar. *Cymbopogon* (lemon grass) is the dominant grass in both the Protected Areas. However, in ENP an invasive fern (*Pteridium aquilinum*) was seen spreading in moist areas along the burned grounds to the hills. In PKMTR, the fern was less common. But in the burned experimental plots, it was found spreading. The effects of this invasive plant on grasshoppers are not known. But as many grasshoppers have strong requirements regarding vegetation structure and microclimate (Joern 1982; Gardiner and Dover 2005), and some are specialized in diet (Joern 1979), it might negatively affect the community in the long run. Likewise, the endemic shrub *Strobilanthes kunthiana* (Neelakurinji) was dominant in frequently burned grasslands of ENP. We found no grasshoppers on this shrub (which has very hairy and hard leaves), suggesting negative effects of these vegetation changes on grasshoppers.

Although the vegetation and the dominant grass species are similar in both grasslands, grasshopper diversity was substantially lower in ENP compared to PKMTR. The continuous fire history could be one reason for the lower grasshopper diversity. But fire behaviour and intensity might also differ. In ENP, fires are comparatively slow lasting almost 4 to 5 h for 50 ha, whereas in PKMTR plots, fires lasted only for 15 minutes. The average temperature of fire within the grass tussock during burning was 310°C in ENP and approximately 120°C in PKMTR, which probably affect survival of grasshopper adults and nymphs directly. The eggs of grasshoppers might also be differentially affected by fires. Most grasshoppers of the study regions oviposit in the ground, where eggs may be sheltered from high temperatures. Prescribed fires that rapidly move across the vegetation cause only minor changes in soil temperatures (Niemeyer et al. 2004). Indeed, comparatively minor temperature differences were found in the soil (30 cm depth) in ENP, but no change at all in PKMTR. Therefore, eggs might be exposed to higher temperatures in ENP compared to PKMTR, which might be another reason for the lower grasshopper diversity in ENP. A significant decrease in abundance was also noted for flightless grasshopper species (*Zygophlaeoba sp.*, *Pa. ramachendrai*, *P. maculatus*, *C. carinata*, *N. a. nilgiriensis*, *N. a. acuticeps*, and *C. carinata*), which are less mobile and, therefore cannot recolonize large burned areas rapidly.

Among the flightless grasshopper species, the *C. carinata* exhibited "homochromy". Homochromy is a phenomenon among grasshoppers that enables the insect to change their body colour in response to the surrounding habitats (Uvarov 1966; Hochkirch et al. 2008; Gardiner 2014). Colour polymorphism among grasshoppers in response to their substrates may not be entirely reliant on genetic determination (natural selection) but rather on phenotypic plasticity (Hochkirch et al. 2008). Apart from the genetically determined characteristics, habitat induced changes can also play a vital role in colour polymorphism. Melanism is well documented among insects as the occurrence of darker pigmentation in individuals within or among closely related species. It is explained as a phenomenon evolved for mate attraction, crypsis (cryptic colouration) resistance to disease and desiccation or due to extreme environmental conditions (Harris et al. 2013). Cryptic colouration allows prey animals to blend into the background reducing their vulnerability to visually searching predators (Cott 1957).

Normal brown morph of *C. carinata* was observed from the adjacent habitats where fire was absent. Melanism within the burned ground is considered as a special case of homochromy (Uvarov 1966). This has been explained by Poulton (1926) with observations on African Orthopterans in burned ground. Gardiner (2014) observed dark colour morphs (individuals with no green colour) of *Myrmeleotettix maculatus* in higher numbers on one of the recently burned grounds in Waveney Forest in East Norfolk, U. K. Gradual decrease of melanised forms of *C. carinata* was also observed as the habitat recovers from the fire. As Forsman et al. (2011) suggested, increase in number of the melanised individuals in burned ground represents rapid evolution of grasshoppers in relation to the environmental and genetic factors. Similar reports by Hochkirch et al. (2008) mentioned the homochromic response of ground hoppers (Tetrigidae) displaying phenotypic plasticity, which enabled the insects to adjust to the environmental conditions. It is found that the melanised individuals of *C. carinata* were effectively camouflaged from predation in both the studied sites.

Grasshoppers are considered as good indicators of grassland health (Belovsky 2000; Anderson et al. 2001). Because of the importance of microclimate and vegetation structure for grasshoppers (Uvarov 1977; Joern 1982; Ingrisch 1983; Chappell and Whitman 1990; Matenaar et al. 2014), the impact of fire on grasshoppers is typically negative for species inhabiting dense vegetation and positive for those preferring bare ground (Hochkirch and Adorf 2007). As both grasslands of our study sites have dense grass cover with lemon grass, negative impacts on grasshopper abundance appear to dominate. Even after two years, the grasshopper communities and populations did not achieve the status of pre-burned and control plots in ENP, while in PKMTR recovery took place within six months after fire. Generally, graminivorous species often benefit from burning, while forb-feeders typically decline (Evans 1984 and 1988a and b; Bock and Bock 1991). In PKMTR, the fresh sprouting vegetation in burned plots compared to unburned and control plots might benefit grasshoppers, confirming the findings by Ferrando et al. (2016). However, this was probably affected by the existence of viable grasshopper populations adjacent to the burned plots and the small size of the burned plots that allows species to recolonize these areas rapidly. Evans (1984) considered post-fire dispersal as critical as many Orthoptera are known to disperse no more than a few meters during their life (Ingrisch and Köhler 1998; Weyer et al. 2012). In PKMTR, we observed active recolonization of two common species, *C. carinata* and *N. acuticeps*. In ENP, large scale burning resulted in very large distances between burned and unburned plots, hampering recolonization. This illustrates that small scale burning and providing unburned areas between the burned grounds is less detrimental to grasshoppers than large scale burning practices.

Another factor influencing the recolonization process is the fire cycle. In Konza Prairie Biological Station (Kansas, USA), different types of fire management have been tested. When fire was applied in the watersheds of 16-55 ha every four years, no negative effects on species richness, diversity and composition of grasshoppers were found. But the relative abundance of grass feeders initially increased and declined again in succeeding years without fire (Evans 1988b). After more than 25 years of fire management at this site, it was found that prescribed burning during spring has less detrimental effects on grasshopper abundance than burning in other seasons (Jonas and Joern 2007). Welti et al. (2019) observed that plant and grasshopper community compositions at Konza Prairie Biological Station were affected by changes in fire frequency. A shorter fire cycle is known to benefit grass-feeding species while areas burned less frequently are dominated by forb-feeding grasshoppers (Gibson 1988). The current management in the Protected Areas is mainly carried out for Nilgiri tahr. But it is important to adopt the burning management to benefit the whole community rather than a single species (Easa et al. 2010). Our results from the experimental burning in PKMTR suggest that small-scale burning is sufficiently effective in providing palatable food for the ungulate, but the direct effects on the tahr still need to be studied. We also found indirect evidence of carnivorous mammals (pug marks of tiger and leopard) along with other large herbivores. Presence of unburned and burned vegetation at a small scale increases heterogeneity and may help ambush predators like tiger to sit-and-wait for their prey. However, in ENP, the large size of the burned plots makes the vegetation more homogenous and predators more visible to the prey from long distance.

According to Parr and Brockett (1999), spatial and temporal heterogeneity is more important to maintain biological diversity than stable conditions. Disturbance such as fire is an important mechanism for producing spatial heterogeneity in grasslands (Collins 1989, 1992; Chaneton and Facelli 1991). In the Mediterranean climate shrublands of South Africa (*fynbos*), fire is the most important type of disturbance and appears to control patterns of species richness (Schwilk et al. 1997). While introducing such management tools to sensitive habitats, specific scientific studies are required. Spatial and temporal mosaic management has been suggested before when applying fire management to homogenous landscapes (Chambers and Samways, 1998; Law and Dickman 1998; Parr and Brockett 1999; Shriver and Vickery 2001; Swengel 2001; Pons et al. 2003). The management plan of ENP aims to create spatio-temporal mosaic patches of burned and unburned areas of grasslands. However, the repeated fire events and in larger extent have not resulted in mosaic patchiness. On the contrary, the entire grasslands are converted into homogenous burned grassland, even though this entails a mosaic of fresh and old grass patches. This is the result of the management plan aiming at a single ungulate species, which needs to be revised by considering other biota.

Focusing on single flagship species to manage the habitat may not always benefit biological diversity (Williams et al. 2000). Since small-scale burning in PKMTR was found less detrimental to grasshoppers than large-scale burning and probably also suitable for supporting plant germination for Nilgiri tahr, we suggest to replace the large-scale burning practice in ENP based upon these new findings. However, since ENP has generally larger grasslands than PKMTR, it might be more feasible to use slightly larger plots of 25 x 25 m or 50 x 50 m with unburned adjacent areas between plots. We also suggest testing changes in the fire cycle from the current three years to five or more years, in order to achieve healthy invertebrate generations after fire. The study shows that grassland management can be optimized to benefit a larger part of the biota within a Protected Area by studying the response of invertebrate species, which is often neglected in conservation management.

CONCLUSIONS

The diversity and distribution of lower organisms play a significant role in determining the conservation importance of the area. As one of the significant biodiversity indicators, insects are very susceptible to changing environmental conditions. Among the invertebrates, grasshoppers of the order Orthoptera occupy a wide range of habitats which identified themselves as a model organism for studying anatomy, physiology, neurobiology, bioacoustics, chemical ecology, life-history traits, speciation research, and evolutionary ecology.

The Protected Areas of Western Ghats are considered to be one of the prominent biodiversity hotspots in the Indian Subcontinent. Of these, Parambikulam Tiger Reserve (PKMTR) and Eravikulam National Park (ENP) in Kerala part of the southern Western Ghats are considered very significant because of the species richness and uniqueness of the habitat. PKMTR is blessed with diverse ecosystems distributed in part as a mosaic of vegetation. ENP is at high altitude dominated with grasslands and shoal vegetations. Although the diversity of these two Protected Areas are comparatively well documented, the lower organisms are least explored. The grasshoppers of Western Ghats were never properly documented. The diversity and richness of grasshoppers across different habitats and geographical ranges of PKMTR and ENP were documented as part of this study. The role of grasshoppers as a grassland health indicator in ENP and PKMTR has also been studied.

7.1 Grasshopper Diversity

Fifty eight grasshopper species were recorded from PKMTR and ENP together of which eighteen are endemic to India. Fifty-five grasshopper species were documented from PKMTR and eighteen from ENP. Fifteen species were common to both the Protected Areas. Thirty-nine species were found to be exclusive to PKMTR and three to ENP. The habitat heterogeneity hypothesis and insect distribution pattern were visible in both the study areas. A greater diversity of insects was recorded in the complex habitats of PKMTR than that of monotonous habitats of ENP. Increased number of niches and habitat complexity in PKMTR favoured the increase in grasshopper diversity. The unique niche preference of grasshoppers was explained with a new pygmy grasshopper species description from the genus *Tettilobus* (Orthoptera: Tetrigidae). The species named as *Tettilobus trishula sp. nov.* was found to be exclusive to the shola forests of ENP. The rediscovery of an extremely rare Catantopinae species *Mopla guttata* since its description in 1940 from MDF habitats of PKMTR highlights the grasshopper richness in PKMTR. *Euparatettix personatus* and *Deltonotus subcucullatus,* two Tetrigids from PKMTR was an addition to Indian Orthoptera.

Among the Caeliferans, the Acrididae was the most diverse grasshopper family in both the study areas. The grasslands in ENP and moist deciduous forets were the species rich habitats. In ENP, grasshoppers such as *Teratodes monticollis* and *Cyrtacanthacris tatarica tatarica* were occupying all the three habitats such as shoal, grasslands and shrubland. *Atractomorpha crenulata* was common to all six habitats of PKMTR. The high altitude grasslands of ENP were dominated by *Carliola carinata,* an endemic flightless grasshopper along with *Zygophlaeoba sinuatocollis*. A reduced dispersal pattern was visible among the flightless grasshoppers in the grasslands of ENP. Species such as *Paramastacides ramachendrai* and its association with an invasive fern species (Pteridium) was unique. Further observations may result in more interesting plant animal interactions. Habitat preference of *Deltonotus gibbiceps* in both the study area indicates its specific association with evergreen litter surface. The grasslands of PKMTR was more species-rich than the grasslands of ENP. Flightless endemic grasshopper *Neorthacris acuticeps acuticeps* and *Carliola carinata* were abundant in grasslands of PKMTR. The grasslands of PKMTR were more diverse because of its nearness to the adjacent semi-evergreen habitats and lower elevation.

7.2 Grasshopper distribution

The grasshopper distribution across different elevation ranges of ENP and PKMTR was documented. A total of 23 elevation bands between 400m to 2690m were considered for grasshopper species richness. The elevation ranges of PKMTR from 400m to 1450m accounts 55 species of grasshopper whereas the higher elevations of ENP between 1500m to 2690m had only 18 species. A hump-shaped species richness pattern was observed across elevation ranges of both the study areas. Such a pattern has been reported to be common in both vertebrates and invertebrates. The habitat heterogeneity of PKMTR favoured the higher species richness. Species with high dispersal abilities such as *Cyrtacanthacris tatarica* and *Xenocatantops humilis* of family Acrididae were seen in all the elevation bands except the peak elevations of ENP (2600-2700m). Many species did not fill the peak of ENP (2690m - Anamudi hills) because of less abundance and thin surface of the grass.

The grasshopper species richness in ENP peaked at mid-elevational ranges. The grasshopper species richness was very much associated with the extent of geographical area, which is reflected in the species richness at the mid-elevational ranges. Grasshoppers such as *Dittopternis venusta*, *Oxya hyla* and *Teratodes monticollis* of

Acrididae were present in all the elevation bands in ENP. The monotonic grasslands across the mid-elevational ranges (2100m to 2400m) were home for many endemic grasshoppers such as *Bambusacris travancora.* The cliff between the mountain ranges leads to lower elevation valleys with streams. The streams and the wet surfaces in the areas between 1800 and 2100m provide favourable conditions for rare grasshoppers such as *Eucriotettix flavopictus* and *Euscelimena harpago* of family tetrigidae.

The species distribution pattern in PKMTR was found to be in close relation to the geographical area. In contrast to ENP, lower elevations of PKMTR from 400m to 600m possess a larger geographic area and it decreases towards peak elevations. Grasshoppers such as *Choroedocus illustris, Diabolocatantops innotabilis, Pachyacris vinosa, Gesonula punctifrons, Teratodes monticollis, Phyllochoreia unicolor, Neorthacris acuticeps acuticeps, Atractomorpha crenulata* and *Aularches miliaris* were present in all the elevation bands of PKMTR from 400m to 1429m. There was no evidence for the mid-domain effect in PKMTR. As explained in the community overlap theory by Lomolino (2001), transition zone of low grasshopper species richness was observed between species richness peaks in both ENP and PKMTR.

Species richness in ENP and PKMTR were observed to be peaked at some intermediate elevations with a transition zone between two adjacent species-rich communities. There was no evidence for Rapoport's rule for grasshopper species richness in ENP. But the decreasing trend in grasshopper richness with increasing elevation in PKMTR agrees with Rapoport's rule. The relationship of microhabitat conditions and environmental heterogeneity with grasshopper species distribution were tested. In ENP and PKMTR, the environmental variables such as Annual Mean

Temperature (AMT), Maximum Temperature of the Warmest Month (MTWM), Minimum Temperature of the Coldest Month (MTCM), Annual Precipitation (APn) were having strong relation with the elevation ranges. The mean Normalized Difference Vegetation Index (NDVI) of ENP and elevation showed a strong negative correlation. But, in PKMTR, the mean NDVI and elevation showed no significant correlation. Other than the environmental factors such as temperature and precipitation, the area available across elevational ranges were influencing the grasshopper distribution. In addition, the habitat heterogeneity in PKMTR explains higher grasshopper species richness in the area.

7.3 Impact of prescribed burning on grasshoppers

Habitat management strategies across the globe are often focusing on flagship species such as large threatened mammals. This is also true for most Protected Aareas of India, where large mammals such as tiger or Asian Elephant represent focal species of conservation management. However, a shift towards other species of groups can be observed in recent times. Prescribed burning is a controversially debated method to manage open habitat types. The method of cold burning is practised as a tool to manage the habitat of the endangered Nilgiri tahr, *Nilgiritragus hylocrius* (an endemic mountain goat) at a large scale (50 ha grids) in ENP. However, the impact of prescribed burning on other biota of this unique environment in a global biodiversity hotspot has not been studied. The impact of large-scale prescribed burning on grasshopper abundances in ENP with small-scale burning in PKMTR was compared to assess the impact of the different fire management practices of these reserves.

A negative response of grasshoppers to burning of larger contiguous areas in terms of their recovery after fire events was observed. However, burning small patches in a mosaic pattern facilitated the rapid recovery of grasshopper communities. In PKMTR, a rapid recovery of grasshopper communities, total abundance as well as the abundance of individual species after burning were seen. In contrast, grasshopper abundance remained low for much longer in ENP, where a large area was burned. The study concludes that small-scale burning has comparatively less detrimental effects on grasshopper abundance compared to large-scale burning. The results also suggest that burning management can be optimised to benefit both the flagship vertebrate species as well as species-rich invertebrate communities. The fire history of ENP grasslands is one of the reasons for the lower grasshopper species richness compared to PKMTR.

The response of individual grasshopper species to prescribed fire mainly includes the decrease in abundance of flightless grasshopper species (*Zygophlaeoba sp.*, *Pa. ramachendrai*, *P. maculatus*, *C. carinata*, *N. a. nilgiriensis*, *N. a. acuticeps*, and *C. carinata*). Their flightless nature was one of the reasons of their failure in re-colonisation after fire. Among the flightless grasshopper species, *C. carinata* exhibited “homochromy” in response to their substrate colour. A gradual decrease of melanised forms of *C. carinata* was also observed as the habitat recovers from the fire. The experimental burning in PKMTR suggests that small-scale burning is sufficiently effective in providing palatable food for the ungulates. An interaction of herbivorous and carnivorous mammals (as evident from pug marks of tiger and leopard) in the small-scale burned areas was also noted. In larger open grassland habitats of ENP, the mosaic of unburned and burned patches will increase the heterogeneity and may help ambush predators like tiger to sit-and-wait for their prey. Spatial and temporal heterogeneity in habitats is significant to maintain biological diversity than stable conditions. This will also fulfil the suggestions in the management plan of ENP that aims to create spatio-temporal mosaic patches of burned and unburned areas of grasslands. The management strategy has to be revised in favour of the diversity and ecology of the habitat. Grassland management strategies should be optimised to benefit a larger part of the biota within a Protected Area by studying the response of neglected invertebrate species.

7.4 Recommendations

- Grasshoppers occupy a wide range of habitats they are excellent indicators of diversity and ecosystem functioning. Such an important taxon is very less explored in our Protected Areas. Grasshopper should be studied as an indicator species.
- Considering the sensitivity of Grasshoppers to environmental conditions, their distribution across different elevation gradients should also be documented.
- Focusing on single flagship species to manage the habitat may not always benefit biological diversity. Conservation management strategies should focus on lower organisms also.
- Since the burning in large extent of area is detrimental to invertebrates, it is suggested to replace the large-scale burning practice in ENP based upon these new findings.
- ENP has generally larger extent of grasslands than PKMTR, it might be more feasible to use slightly larger plots of 25 × 25 m with unburnt adjacent areas between plots.
- It is also suggested to test the changes in the fire cycle from the current 3–5 or more years to achieve healthy invertebrate generations after the fire.

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APPENDIX A. PRINCIPAL COMPONENT ANALYSIS DATA - PKMTR

		1	2	3	4	5	6	7	8	9
		Pre Burnt	**Pre Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**
	Month	**January**	**February**	**February**	**March**	**April**	**May**	**June**	**July**	**August**
	Year	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**
	Season	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Monsoon**	**Monsoon**	**Monsoon**
		Month 1	**Month 2**	**Hour 1**	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**
1	*Atractomorpha crenulata*	8	9	1	1	3	14	5	6	15
2	*Aularches miliaris*	2	2	0	0	0	0	0	0	1
3	*Carliola carinata*	24	24	4	10	15	21	6	5	22
4	*Cercina obtusa*	7	10	0	6	6	11	5	3	6
5	*Cyrtacanthacris tatarica*	5	3	0	0	0	3	1	2	6
6	*Neorthacris acuticeps nilgiriensis*	16	18	2	6	10	12	7	7	8
7	*Neorthacris acuticeps*	25	19	0	6	11	11	6	9	13
8	*Phlaeoba panteli*	9	4	0	0	7	6	6	7	11
9	*Oxya hyla*	9	9	0	0	2	5	5	6	17
10	*Oxya fuscovittata*	3	2	0	0	2	4	4	5	12
11	*Spathosternum prasiniferum*	3	6	0	0	0	0	0	2	4
12	*Xenocatantops humilis*	2	3	0	0	0	4	4	6	7
13	*Diabolocatantops innotabilis*	6	7	0	1	3	3	3	3	5
14	*Tylotropidius varicornis*	2	5	0	0	3	6	3	6	4
15	*Gesonula punctifrons*	2	5	0	0	2	2	4	3	4
16	*Phyllochoreia unicolor*	0	1	0	0	0	1	1	1	1
17	*Phyllochoreia ramakrishnai*	0	1	0	0	1	1	0	0	0

Appendix A. Contd....

		10	11	12	13	14	15	16	17	18
		Burnt	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**
	Month	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**
	Year	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**
	Season	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**
		Month 7	**Month 8**	**Month 9**	**Month 10**	**Month 11**	**Month 12**	**Month 13**	**Month 14**	**Month 15**
1	*Atractomorpha crenulata*	21	14	15	8	14	16	16	15	15
2	*Aularches miliaris*	2	2	3	0	2	1	5	2	2
3	*Carliola carinata*	27	20	21	19	25	22	19	22	20
4	*Cercina obtusa*	13	8	9	6	12	8	9	6	9
5	*Cyrtacanthacris tatarica*	8	7	12	7	6	6	9	4	6
6	*Neorthacris acuticeps nilgiriensis*	16	17	15	12	23	19	17	19	10
7	*Neorthacris acuticeps*	18	20	18	12	21	12	13	11	14
8	*Phlaeoba panteli*	11	12	10	6	10	7	10	10	12
9	*Oxya hyla*	17	16	12	8	14	9	9	8	9
10	*Oxya fuscovittata*	8	7	17	16	15	5	6	4	5
11	*Spathosternum prasiniferum*	4	4	5	2	10	6	5	4	3
12	*Xenocatantops humilis*	8	8	8	6	7	5	5	6	3
13	*Diabolocatantops innotabilis*	6	6	12	8	13	8	4	5	3
14	*Tylotropidius varicornis*	4	4	6	3	7	5	3	1	2
15	*Gesonula punctifrons*	3	2	6	3	4	5	5	2	4
16	*Phyllochoreia unicolor*	0	0	2	2	3	2	1	1	1
17	*Phyllochoreia ramakrishnai*	1	0	1	1	2	2	2	1	2

Appendix A. Contd....

		19	20	21	22	23	24	25	26	27
		Burnt	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**
	Month	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**
	Year	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 3**	**Year 3**
	Season	**Monsoon**	**Monsoon**	**Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**
		Month 16	**Month 17**	**Month 18**	**Month 19**	**Month 20**	**Month 21**	**Month 22**	**Month 23**	**Month 24**
1	*Atractomorpha crenulata*	8	3	15	19	19	10	11	16	14
2	*Aularches miliaris*	2	0	1	4	8	2	8	8	0
3	*Carliola carinata*	11	6	26	26	30	22	14	9	20
4	*Cercina obtusa*	6	0	6	15	14	11	8	5	10
5	*Cyrtacanthacris tatarica*	4	0	6	12	14	10	7	5	7
6	*Neorthacris acuticeps nilgiriensis*	5	3	8	25	33	17	10	4	16
7	*Neorthacris acuticeps*	8	4	21	24	22	18	8	11	12
8	*Phlaeoba panteli*	6	3	11	15	16	10	8	4	6
9	*Oxya hyla*	4	2	18	14	15	8	6	5	5
10	*Oxya fuscovittata*	3	1	6	10	14	7	5	3	2
11	*Spathosternum prasiniferum*	0	0	4	5	6	4	2	1	2
12	*Xenocatantops humilis*	3	0	4	6	13	8	2	5	3
13	*Diabolocatantops innotabilis*	4	0	7	9	10	6	6	1	3
14	*Tylotropidius varicornis*	4	1	5	6	7	4	5	1	2
15	*Gesonula punctifrons*	2	0	4	5	8	3	3	2	1
16	*Phyllochoreia unicolor*	0	0	0	0	2	0	0	0	2
17	*Phyllochoreia ramakrishnai*	1	0	0	3	2	2	0	0	1

Appendix A. Contd....

		28	29	30	31	32	33	34	35	36
		Burnt	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**
	Month	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**
	Year	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**
	Season	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Monsoon**	**Monsoon**	**Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**
		Month 25	**Month 26**	**Month 27**	**Month 28**	**Month 29**	**Month 30**	**Month 31**	**Month 32**	**Month 33**
1	*Atractomorpha crenulata*	4	8	10	5	3	22	20	19	10
2	*Aularches miliaris*	4	1	2	3	0	1	3	8	2
3	*Carliola carinata*	10	17	13	9	12	26	23	30	22
4	*Cercina obtusa*	5	3	9	4	0	8	11	14	11
5	*Cyrtacanthacris tatarica*	5	6	4	4	0	6	9	14	10
6	*Neorthacris acuticeps nilgiriensis*	6	16	8	8	3	18	25	33	17
7	*Neorthacris acuticeps*	8	10	7	9	4	18	21	22	18
8	*Phlaeoba panteli*	5	10	18	7	5	11	14	16	10
9	*Oxya hyla*	6	7	8	4	4	17	10	15	8
10	*Oxya fuscovittata*	4	3	5	4	1	8	10	14	7
11	*Spathosternum prasiniferum*	5	4	5	0	4	7	2	6	4
12	*Xenocatantops humilis*	5	2	2	5	4	6	5	13	8
13	*Diabolocatantops innotabilis*	5	5	3	4	0	9	6	10	6
14	*Tylotropidius varicornis*	3	2	2	2	1	1	1	7	4
15	*Gesonula punctifrons*	2	0	2	0	0	3	1	8	3
16	*Phyllochoreia unicolor*	0	1	1	0	1	0	0	2	0
17	*Phyllochoreia ramakrishnai*	2	1	1	1	0	1	1	2	2

Appendix A. Contd....

		37	38	39	40	41	42	43	44	45
		Burnt	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**
	Month	**December**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**
	Year	**Year 3**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**
	Season	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Monsoon**	**Monsoon**	**Monsoon**	**Post Monsoon**	**Post Monsoon**
		Month 34	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**
1	*Atractomorpha crenulata*	20	5	12	16	5	4	10	21	19
2	*Aularches miliaris*	3	0	0	1	1	1	2	2	1
3	*Carliola carinata*	12	15	22	25	9	11	20	27	21
4	*Cercina obtusa*	6	8	7	9	4	7	9	13	19
5	*Cyrtacanthacris tatarica*	6	3	4	6	5	6	6	8	5
6	*Neorthacris acuticeps nilgiriensis*	6	15	17	22	8	6	17	16	18
7	*Neorthacris acuticeps*	6	19	17	18	7	8	15	18	18
8	*Phlaeoba panteli*	9	1	4	4	6	6	8	11	13
9	*Oxya hyla*	7	7	3	7	6	4	4	17	16
10	*Oxya fuscovittata*	6	3	1	4	3	3	5	8	5
11	*Spathosternum prasiniferum*	4	5	1	3	1	1	1	4	2
12	*Xenocatantops humilis*	2	1	3	2	1	2	6	8	7
13	*Diabolocatantops innotabilis*	6	3	2	4	3	3	6	6	13
14	*Tylotropidius varicornis*	3	3	3	6	4	3	4	4	1
15	*Gesonula punctifrons*	1	4	2	2	1	0	0	3	3
16	*Phyllochoreia unicolor*	0	0	0	0	1	0	1	0	2
17	*Phyllochoreia ramakrishnai*	0	1	1	0	0	0	1	1	1

Appendix A. Contd....

		46	47	48	49	50	51	52	53	54
		Control	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**
	Month	**November**	**December**	**January**	**February**	**May**	**April**	**May**	**June**	**July**
	Year	**Year 1**	**Year 1**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**
	Season	**Post Monsoon**	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Monsoon**	**Monsoon**
		Month 9	**Month 10**	**Month 11**	**Month 12**	**Month 13**	**Month 14**	**Month 15**	**Month 16**	**Month 17**
1	*Atractomorpha crenulata*	5	10	10	8	5	7	10	6	4
2	*Aularches miliaris*	0	0	1	1	0	1	0	0	0
3	*Carliola carinata*	16	14	18	21	17	18	16	5	4
4	*Cercina obtusa*	6	6	6	7	8	6	6	4	4
5	*Cyrtacanthacris tatarica*	2	2	5	5	6	3	6	4	2
6	*Neorthacris acuticeps nilgiriensis*	15	13	14	12	10	14	22	8	2
7	*Neorthacris acuticeps*	12	16	16	13	13	11	16	8	4
8	*Phlaeoba panteli*	5	7	8	7	3	4	7	6	2
9	*Oxya hyla*	5	6	10	9	7	3	6	4	1
10	*Oxya fuscovittata*	2	3	7	6	5	3	5	3	1
11	*Spathosternum prasiniferum*	0	3	6	5	2	2	3	0	1
12	*Xenocatantops humilis*	4	4	4	4	2	3	5	0	0
13	*Diabolocatantops innotabilis*	9	4	9	6	6	4	4	2	0
14	*Tylotropidius varicornis*	0	1	2	2	1	2	6	2	1
15	*Gesonula punctifrons*	1	0	2	5	5	1	3	1	0
16	*Phyllochoreia unicolor*	0	0	1	2	2	0	1	0	0
17	*Phyllochoreia ramakrishnai*	0	0	1	2	1	0	1	0	0

Appendix A. Contd....

		55	56	57	58	59	60	61	62	63
		Control	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**
	Month	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**May**	**April**
	Year	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 3**	**Year 3**	**Year 3**	**Year 3**
	Season	**Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**
		Month 18	**Month 19**	**Month 20**	**Month 21**	**Month 22**	**Month 23**	**Month 24**	**Month 25**	**Month 26**
1	*Atractomorpha crenulata*	5	13	18	16	6	15	7	2	9
2	*Aularches miliaris*	3	4	9	8	6	2	0	0	3
3	*Carliola carinata*	19	20	26	21	9	11	18	10	18
4	*Cercina obtusa*	10	11	12	10	5	5	5	4	4
5	*Cyrtacanthacris tatarica*	4	5	12	9	6	5	2	4	4
6	*Neorthacris acuticeps nilgiriensis*	22	25	30	21	8	10	8	6	15
7	*Neorthacris acuticeps*	12	17	20	22	4	14	10	9	12
8	*Phlaeoba panteli*	10	9	14	10	5	4	7	3	6
9	*Oxya hyla*	7	8	11	6	4	9	8	2	5
10	*Oxya fuscovittata*	5	4	8	3	4	3	6	5	3
11	*Spathosternum prasiniferum*	3	2	7	0	5	3	3	0	1
12	*Xenocatantops humilis*	5	4	10	3	2	4	4	0	1
13	*Diabolocatantops innotabilis*	6	8	8	4	5	5	3	2	4
14	*Tylotropidius varicornis*	2	4	6	6	4	1	1	1	2
15	*Gesonula punctifrons*	0	2	6	3	5	2	4	3	0
16	*Phyllochoreia unicolor*	0	0	2	1	0	0	0	1	0
17	*Phyllochoreia ramakrishnai*	0	0	1	0	0	0	0	0	2

Appendix A. Contd....

		64	65	66	67	68	69	70	71
		Control	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**
	Month	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
	Year	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**
	Season	**Pre Monsoon**	**Monsoon**	**Monsoon**	**Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**
		Month 27	**Month 28**	**Month 29**	**Month 30**	**Month 31**	**Month 32**	**Month 33**	**Month 34**
1	*Atractomorpha crenulata*	16	5	7	12	14	12	11	4
2	*Aularches miliaris*	2	4	1	0	5	4	2	7
3	*Carliola carinata*	15	8	9	17	26	22	17	12
4	*Cercina obtusa*	8	7	4	12	14	4	12	8
5	*Cyrtacanthacris tatarica*	5	4	5	4	4	6	5	6
6	*Neorthacris acuticeps nilgiriensis*	16	6	1	18	25	17	10	11
7	*Neorthacris acuticeps*	12	5	3	15	19	18	12	12
8	*Phlaeoba panteli*	8	4	3	9	10	9	8	6
9	*Oxya hyla*	5	5	2	9	8	10	4	8
10	*Oxya fuscovittata*	5	2	1	9	3	8	4	6
11	*Spathosternum prasiniferum*	5	1	3	0	2	2	2	4
12	*Xenocatantops humilis*	6	1	3	3	4	4	2	2
13	*Diabolocatantops innotabilis*	6	2	2	2	6	4	3	2
14	*Tylotropidius varicornis*	1	1	1	2	5	2	3	4
15	*Gesonula punctifrons*	2	1	2	0	0	3	2	4
16	*Phyllochoreia unicolor*	0	1	1	0	2	0	1	0
17	*Phyllochoreia ramakrishnai*	0	0	0	0	1	0	0	0

APPENDIX B. PRINCIPAL COMPONENT ANALYSIS DATA - ENP

		1	2	3	4	5	6	7	8	9	10
		Preburnt	**Preburnt**	**Preburnt**	**Preburnt**	**Preburnt**	**Preburnt**	**Preburnt**	**Preburnt**	**Preburnt**	**Preburnt**
	Month	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**
	Year	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**	**Year 1**
	Season	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Monsoon**	**Monsoon**	**Monsoon**	**Post Monsoon**
		Month 1	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**	**Month 10**
1	*Atractomorpha crenulata*	4	4	3	6	3	2	2	1	5	2
2	*Carliola carinata*	8	7	8	6	3	6	1	1	5	3
3	*Cyrtacanthacris tatarica tatarica*	4	2	2	7	4	1	2	0	2	5
4	*Dittopternis venusta*	3	1	1	5	3	5	1	1	3	3
5	*Oxya hyla hyla*	7	6	5	5	1	1	1	1	3	4
6	*Palniacris maculatus*	4	7	8	5	3	3	1	1	2	3
7	*Paramastacides ramachendrai*	4	7	5	5	0	5	3	2	3	4
8	*Prionacantha picta*	4	5	5	6	1	4	1	1	2	4
9	*Xenocatantops humilis*	5	3	3	6	3	4	1	2	2	3
10	*Zygophlaeoba sp.*	5	8	10	7	4	5	6	4	7	8

APPENDIX B. Contd..

		11	12	13	14	15	16	17	18	19	20
		Preburnt	**Preburnt**	**Preburnt**	**Preburnt**	**Preburnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**
	Month	**October**	**November**	**December**	**January**	**February**	**February**	**March**	**April**	**May**	**June**
	Year	**Year 1**	**Year 1**	**Year 1**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**
	Season	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Monsoon**
		Month 11	**Month 12**	**Month 13**	**Month 14**	**Month 15**	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**
1	*Atractomorpha crenulata*	5	5	10	6	6	0	0	0	0	2
2	*Carliola carinata*	6	3	10	5	5	3	2	1	0	0
3	*Cyrtacanthacris tatarica tatarica*	4	4	7	5	5	0	0	0	0	1
4	*Dittopternis venusta*	5	3	5	6	6	0	0	0	0	2
5	*Oxya hyla hyla*	3	4	7	8	8	0	0	0	0	0
6	*Palniacris maculatus*	4	4	6	8	8	0	0	0	0	0
7	*Paramastacides ramachendrai*	4	6	6	6	6	5	0	0	0	2
8	*Prionacantha picta*	3	7	7	6	6	0	0	0	0	1
9	*Xenocatantops humilis*	4	3	4	8	8	0	0	0	0	0
10	*Zygophlaeoba sp.*	6	8	11	9	9	9	3	1	0	2

APPENDIX B. Contd..

		21	22	23	24	25	26	27	28	29	30
		Burnt	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**	**Burnt**
	Month	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**
	Year	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 2**	**Year 3**	**Year 3**	**Year 3**	**Year 3**
	Season	**Monsoon**	**Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**
		Month 6	**Month 7**	**Month 8**	**Month 9**	**Month 10**	**Month 11**	**Month 12**	**Month 13**	**Month 14**	**Month 15**
1	*Atractomorpha crenulata*	0	1	1	1	4	2	0	1	1	1
2	*Carliola carinata*	0	2	1	4	2	0	2	3	0	0
3	*Cyrtacanthacris tatarica tatarica*	0	1	3	5	3	2	1	1	1	1
4	*Dittopternis venusta*	0	0	1	4	5	5	0	2	1	1
5	*Oxya hyla hyla*	0	1	2	5	4	2	0	0	0	0
6	*Palniacris maculatus*	0	0	3	2	3	4	1	1	1	1
7	*Paramastacides ramachendrai*	2	2	3	2	3	3	3	7	4	4
8	*Prionacantha picta*	0	0	3	2	2	4	0	0	0	0
9	*Xenocatantops humilis*	0	0	4	3	3	2	1	2	2	2
10	*Zygophlaeoba sp.*	0	0	3	3	1	1	1	3	3	3

APPENDIX B. Contd..

		31	32	33	34	35	36	37	38	39	40
		Burnt	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**
	Month	**May**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**
	Year	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**
	Season	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Monsoon**	**Monsoon**	**Monsoon**	**Post Monsoon**	**Post Monsoon**
		Month 16	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
1	*Atractomorpha crenulata*	2	6	4	2	3	6	3	8	12	7
2	*Carliola carinata*	2	5	5	4	4	6	4	6	6	7
3	*Cyrtacanthacris tatarica tatarica*	1	5	5	3	1	4	2	3	3	7
4	*Dittopternis venusta*	1	6	6	3	4	5	1	3	4	4
5	*Oxya hyla hyla*	4	8	5	3	4	4	2	4	6	6
6	*Palniacris maculatus*	0	8	6	5	5	6	2	3	7	9
7	*Paramastacides ramachendrai*	4	6	6	3	3	3	2	6	7	7
8	*Prionacantha picta*	0	6	5	5	5	5	2	3	6	7
9	*Xenocatantops humilis*	3	8	4	4	4	4	1	1	2	4
10	*Zygophlaeoba sp.*	0	9	8	3	4	4	2	3	7	8

APPENDIX B. Contd..

		41	42	43	44	45	46	47
		Control	**Control**	**Control**	**Control**	**Control**	**Control**	**Control**
	Month	**November**	**December**	**January**	**February**	**March**	**April**	**May**
	Year	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**	**Year 3**
	Season	**Post Monsoon**	**Post Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**	**Pre Monsoon**
		Month 10	**Month 11**	**Month 12**	**Month 13**	**Month 14**	**Month 15**	**Month 16**
1	*Atractomorpha crenulata*	8	7	4	6	6	5	3
2	*Carliola carinata*	6	7	4	4	4	4	3
3	*Cyrtacanthacris tatarica tatarica*	5	5	4	5	5	4	2
4	*Dittopternis venusta*	5	4	5	5	5	7	4
5	*Oxya hyla hyla*	7	8	4	1	1	5	2
6	*Palniacris maculatus*	8	5	4	7	7	6	4
7	*Paramastacides ramachendrai*	9	3	5	6	6	5	4
8	*Prionacantha picta*	9	5	5	3	3	3	3
9	*Xenocatantops humilis*	4	8	5	4	4	5	2
10	*Zygophlaeoba sp.*	8	9	2	8	4	7	3

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ORIGINAL PAPER

Large scale burning for a threatened ungulate in a biodiversity hotspot is detrimental for grasshoppers (Orthoptera: Caelifera)

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Abstract

Habitat management strategies across the globe are often focusing on flagship species, such as large threatened mammals. This is also true for most protected areas of India, where large mammals such as the Tiger or Asian Elephant represent focal species of conservation management, although a shift towards other species groups can be observed in recent times. Prescribed burning is a controversially debated method to manage open habitat types. This method is practised as a tool to manage the habitat of the endangered Nilgiri tahr, *Nilgiritragus hylocrius* (an endemic goat) at a large scale (50 ha grids) in Eravikulam National Park of the Western Ghats (Kerala, India). However, the impact of prescribed burning on other biota of this unique environment in a global biodiversity hotspot has not been studied. We compared the impact of large-scale prescribed burning on grasshopper abundances in Eravikulam National Park with small-scale burning in Parambikulam Tiger Reserve from 2015 to 2018, to assess the impact of the different fire management practices of these reserves on this species-rich insect group. We observed a negative response of grasshoppers to burning of larger contiguous areas in terms of their recovery after fire events, whereas burning small patches in a mosaic pattern facilitated rapid recovery of grasshopper communities. Our results suggest that burning management can be optimized to benefit both, the flagship vertebrate species as well as species-rich invertebrate communities.

Keywords Western Ghats · Habitat heterogeneity · Fire extent · Grasshopper abundance · Grassland management · Insect conservation · Prescribed burning

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Introduction

Large mammals represent major priorities in conservation management and they are often used as flagship species in conservation planning (Bowen-Jones and Entwistle 2002). This is particularly true for mammals with a threatened red list status (Williams et al. 2002). Many large mammalian herbivores are associated with open habitats and habitat management is thus key to the maintenance of these habitat types (Swengel 2001). Typical strategies to keep such habitats open are grazing, mowing or burning (e.g. Collins et al. 1998). Despite its potential detrimental effects on biota, fire is meanwhile a widely used tool in the management of open habitats (Whelan 1995). The effect of fire on biodiversity has been studied in a variety of habitats, including prairies, savannahs, coniferous forests and peat bogs (Warren et al. 1987; Swengel 1996, 2001; Hochkirch and Adorf 2007). These studies have shown that the effects of fire vary among ecosystems, species and burning parameters (e.g. season, fire intensity and burnt area). It is thus of critical importance to study the effects of each specific burning strategy in management areas to avoid any detrimental effects on biodiversity. One major aspect of burning is the scale of the burnt area. According to the habitat heterogeneity hypothesis (Tscharntke et al. 2002; Tews et al. 2004) it is expected that small-scale burning has a less detrimental effect on biodiversity than large-scale burning. Adjusting the area burnt during prescribed burning may thus be an adequate strategy to minimize potential negative effects on species-rich insect communities.

The Western Ghats in India belong to the global hotspots of biodiversity (Myers et al. 2000). This region has a high diversity of natural ecosystems including wetlands, tropical wet evergreen, moist and dry deciduous forests and the unique Shola forests (Southern montane wet temperate forest) and grassland ecosystems (Champion and Seth 1968). Each habitat within this biodiversity hotspot contains unique endemic floral and faunal elements (Myers et al. 2000). The Nilgiri tahr (*Nilgiritragus hylocrius*), a mountain goat, is endemic to the Western Ghats and confined to the tropical shola-grassland ecosystem. With 1800–2000 mature individuals, a continuing decline in population size and small subpopulations, the species is listed as Endangered on the IUCN Red List of threatened species (Alempath and Rice 2008). The species occurs in several habitat fragments of protected areas of southern India (Easa et al. 2010). Eravikulam National Park (ENP) with the adjacent contiguous area of Anamalai Tiger Reserve harbours the largest Tahr population, which is considered to be viable because of its population size and the extent of its preferred habitat.

Traditionally, the grasslands of ENP are managed by prescribed "cold" burning (cold season burning) with the help of the local tribal community. Burning is practised on 50 ha plots to provide palatable food for the endemic herbivore and has been practised since the British colonial time (Davidar 1978). However, the impact of burning of the Nilgiri tahr habitats on other biota has never been documented. The Nilgiri tahr recovery plan (Easa et al. 2010) stresses the need for systematic monitoring of impact of fire on tahr habitats of ENP. Since the target of the management is to improve the status of this mammal species, the impact on other groups, especially invertebrates, has been neglected. However, the Western Ghats (including ENP) are known to maintain an exceptional high number of endemic invertebrates. Recently, burning has also been experimentally introduced in Parambikulam Tiger Reserve (PKMTR) in Western Ghats, but here it has been practised at a much smaller scale (10 × 10 m). To avoid unnoticed extinctions of endemic invertebrates, it is crucial to understand the effects of burning strategies on these species.

The impact of fire on invertebrates can vary substantially (Swengel 2001; Fredericksen and Fredericksen 2002). Grasshoppers are a major group of herbivorous insects dominating open ecosystems (Belovsky and Slade 2017) and often the most important primary consumers (Odum et al. 1962). They are sensitive to grassland management (e.g. Weiss et al. 2013; Bröder et al. 2018) and also known to be a suitable group for bioindication of grassland quality and restoration success (Henle et al. 1999; Alignan et al. 2018). As many grasshopper species are flightless and endemic to narrow geographic ranges, they are sensitive to environmental change and exhibit a high extinction risk (Hochkirch et al. 2016). Therefore, their response to fire management is of high interest. As grasshoppers represent a major faunal component of grasslands, effects of fire on them can be easily studied in grassland habitats (Anderson et al. 2001; Chambers 1998; Swengel 2001; Fredericksen and Fredericksen 2002; Huntzinger 2003; Gardiner et al. 2005; Joern 2005; Ferrando et al. 2016).

We studied the impact of prescribed burning on grasshoppers in Eravikulam National Park and Parambikulam Tiger Reserve, Kerala, in the Southern Western Ghats (India). We were particularly interested in understanding the recovery of grasshopper species and communities after burning and the differences of the specific management practices (large-scale versus small-scale burning) in both nature reserves. We hypothesized that large-scale burning is more detrimental and hampers recovery of grasshopper abundances compared to small-scale burning.

Methods

Study area

Our study areas were the grasslands of Parambikulam Tiger Reserve (PKMTR) and the high altitude tropical shola grassland ecosystems of Eravikulam National Park (ENP) India (Fig. 1). Eravikulam National Park (10°05′–10°20′N, 77°0′–77°10′E) is located in the Kannan Devan hills of Idukki district, Kerala. It has an area of 97 km^2 and consists of high altitudinal grasslands interspersed with sholas (Southern montane wet temperate forest). A high rolling plateau with a base elevation of ca. 2000 m asl comprises the main body of the Park. In the early 1800s, the area was under the management of British colonials, who preserved the habitat as a game reserve. The change in the status of the area, however, did not alter the management practices substantially and thus the fire management of “cold burning” (January–February) is still being practised with the objective of providing lush green grass to the Nilgiri tahr. Prescribed burning results in a mosaic of burnt and unburnt grassland areas. The entire grasslands in ENP are divided into 1st, 2nd and 3rd plots of 50 ha. Each year, the managers set fire to the same numbered grids so that a three-year cycle of prescribed burning is applied to the particular 50 ha plot every third year.

Parambikulam Tiger Reserve is situated between Anamalai and Nelliyampathi hill ranges in Palakkad district in Kerala (10°20′–10°32′N, 76°35′–76°5′E) and was established as Tiger Reserve in February 2010. The Tiger Reserve has an area of 644 km^2 and an altitudinal range from 460 to 1439 m. The vegetation types include evergreen, semi-evergreen and moist deciduous forests, plantations of teak and eucalypts and riparian forests. In PKMTR, fire was never introduced before as a management practice. The extent of grassland is less in PKMTR than in ENP in terms of the area covered by the dominant lemongrass (*Cymbopogon* sp.). The presence of Nilgiri tahr in this grassland led to the decision

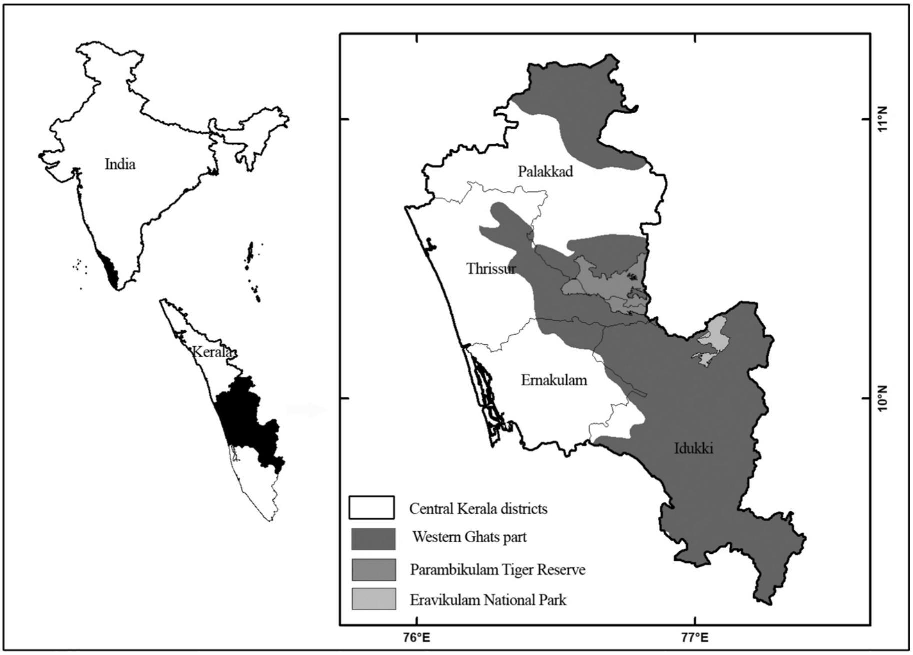

Fig. 1 Map showing the situation of Eravikulam National Park and Parambikulam Tiger Reserve, Kerala, India

to test prescribed burning in these grasslands. However, contrary to ENP, only small areas (10 × 10 m plots) were burnt with adjacent unburnt habitats.

The climate of the study areas is dominated by the monsoon circulation of the wind blows from oceans to the south of the Asian land mass. The monsoon months last from June to August, pre-monsoon from January to May and post-monsoon from September to December.

Sampling

Grasshopper (Caelifera) diversity of ENP and PKMTR was studied from 2015 to 2018 to obtain a general species inventory. We collected and recorded the diversity of adult grasshoppers in both study areas using standard sweep net, hand picking and direct observation and noted the presence of each species.

For studying the impact of large-scale burning on grasshoppers (ENP), we randomly laid 18 plots (6 pre-burnt, 6 control (unburnt) and 6 experimental (burnt) plots) in the study area, each with a size of 10 × 10 m. Pre-burnt plots of ENP were sampled 1 year before the fire and served as a second (temporal) control (same site, but before burning). Burnt plots were laid immediately after the fire on the burnt grasslands and control plots were on the opposite hills with similar vegetation which have not been burnt since 3 years (same date, but different site). Each plot (unburnt and control) was sampled every month for 2 years, while pre-burnt plots were sampled only in the year before the fire. Similar to ENP, we also laid 18 plots (6 pre-burnt, 6 control (unburnt) and 6 experimental (burnt) plots) across the study sites of small scale burning (PKMTR). Pre-burnt plots of PKMTR were sampled for 2 months before the sites were burnt (as there was no initial knowledge where burning would be conducted in the following year).

Orthoptera were sampled on each plot every month from February 2015 to May 2018 in both study areas. Sampling within the plots was done by using sweep nets along two transects of 14 m from the corner of a plot to the opposite corner, resulting in an X-shaped transect on each plot. This was to ensure a pattern of sweeping and for maximum representation of grasshopper abundance within the plots. After each sweep along the transect, the grasshoppers were photographed, quantified, identified and released outside the plots, except for some voucher specimens (we were not permitted to collect all specimens captured in the sweep net in Protected Areas). Collected voucher specimens were preserved and deposited in Kerala Forest Research Institute (KFRI) Entomology Museum. Unidentified and taxonomically difficult species were later identified using a variety of taxonomic literature (Westwood 1839; Bolívar 1900, 1902, 1914, 1930; Kirby 1914; Uvarov 1929; Chopard 1969; Henry 1937, 1940) and by consulting experts. The specimens were also compared with the type specimens in the British Natural History Museum London (BNHM), Natural History Museum Madrid (MNCN), Natural History Museum Paris (MNHN) and Natural History Museum Geneva (NHM). The taxonomy follows the latest version of the Orthoptera Species File (Cigliano et al. 2018). The average temperature of fire within the grass tussock and within and under the surface of soil during burning was recorded using thermocouples (TCAV-L).

Statistical analysis

To test for differences in total Orthoptera abundance and the abundances of the most common species between pre-burnt, unburnt (control) and burnt (experiment) plots of ENP and PKMTR, we used a two-way repeated measures analysis of variances (ANOVA) in R 3.5.0 (R Core Team 2018). We used Box-Cox-Transformation as implemented in the MASS package for R to obtain the optimal exponent (λ) to fit the data to the model assumptions. In one explanatory variable we combined the status of the plots (i.e. burnt, pre-burnt, control) with the year (1–3) and season (pre-monsoon and post-monsoon). For the latter we assigned each count to the respective season (pre monsoon from Jan to May and post monsoon from Sep to Dec) as abundances differed substantially among seasons but only little within season (see "Results"). The monsoon months (June–August) were discarded from the analysis as these were strongly influenced by annual rainfall patterns and abundances were quite variable. The reason for combining treatment, year and season was that the pre-burnt plots were only studied during one season and year, while the burnt and control plots were studied during two seasons of 3 years each. Furthermore, we expected that during the third year abundances would have recovered and approach the pre-burnt situation.

To analyse the changes on community level, a principal component analysis (PCA) was performed using the ClustVis online tool (Metsalu and Vilo 2015). The abundance of grasshopper species on each plot of each studied site (Karimala-PKMTR and Eravikulam-ENP) were sorted as six column annotations (number of column, treatment–control/preburnt/burnt, month, year, season, and month number in chronological order) and two row annotations (number of row and name of the species) (provided in supplementary material). Unit variance scaling was applied to rows; SVD with imputation was used to calculate principal components. The data used were absolute abundances (number of individuals recorded) per month at each locality; control, preburnt, and burnt (transects and plots are fused, giving the single value in the table). The PCA data (matrix, principal components, variance explained by principal components as well as component loadings) for Karimala (PKMTR) is available at https://biit.cs.ut.ee/clustvis/?s=Karimala_fire_grasshoppers and Eravikulam (ENP) at https://biit.cs.ut.ee/clustvis/?s=Eravikulam_fire_grasshoppers.

Results

Species richness

During the general inventory of the study sites, a total of 57 species were found, 18 of which are endemic to India. Fifty-four grasshopper species were recorded in PKMTR and 18 in ENP (Table 1), with 15 species common to both areas. Thirty-nine species were exclusively found in PKMTR, but only three in ENP. We discovered one hitherto undescribed pygmy grasshopper species (Tetrigidae) in each reserve (*Deltonotus* sp. in PKMTR and *Tettilobus* sp. in ENP). In PKMTR, we also rediscovered the Catantopinae species *Mopla guttata* for the first time since its description in 1940, representing also the first male collected for this species. In PKMTR we found *Euparatettix personatus* (Tetrigidae) as the first record from India.

Effects of burning on grasshopper abundance

Total mean grasshopper abundance in PKMTR was generally higher than in ENP (Fig. 2, ANOVA, $\lambda = 0.75$, $F_{1,260} = 1494$, $p < 0.001$) as well as higher in the post-monsoon period than in the pre-monsoon period (ANOVA, $\lambda = 0.75$, $F_{1,260} = 135.6$, $p < 0.001$). The average temperature of fire within the grass tussock during burning was 310 °C during large-scale burning (ENP) and approximately 120 °C during small-scale burning (PKMTR). In ENP (large-scale burning) we found a significant decrease in total grasshopper abundance in the burnt plots compared to the pre-burnt plots during the pre-monsoon period for both years (Fig. 3, ANOVA, $\lambda = 0.78$, $F_{6,88} = 27.9$, $p < 0.001$; pairwise *t* test with Bonferroni correction: $p < 0.001$). In contrast, there was no significant difference between the grasshopper abundance in the pre-burnt plots compared to the control in both years (pairwise t-test with Bonferroni correction: $p = 0.99$). During the year of the fire as well as 1 year after, total grasshopper abundance was significantly higher in the control plots than in the burnt plots (pairwise t-test with Bonferroni correction: $p < 0.001$). During the post-monsoon season, we also found higher grasshopper abundances on the pre-burnt plots and the control plots compared to the burnt plots (pairwise t-test with Bonferroni correction: $p < 0.001$).

In PKMTR (small-scale burning) we found significant differences in abundance between plot burning status (Fig. 4, ANOVA, $\lambda = 1.42$, $F_{11,155} = 7.2$, $p < 0.001$). During the first pre-monsoon season, grasshopper abundance was significantly lower in the burnt plots compared to the pre-burnt situation and the control plots (pairwise t-test with Bonferroni correction: $p < 0.001$). However, in the second and third year, there was no significant difference in grasshopper abundance in burnt and control plots (pairwise t-test with Bonferroni correction: $p = 0.99$). During the post-monsoon season, we found no significant difference between burnt and control plots for any year (pairwise t-test with Bonferroni correction: $p_1 = 0.99$, $p_2 = 0.57$, $p_3 = 0.08$). This means that only during the pre-monsoon season, soon after burning, there was a significant decrease in grasshopper abundance in PKMTR.

Table 1 Inventory of grasshopper species (Caelifera) found in Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR) and their distributional status (+ present, – absent,*endemic to India)

Sr no.	Taxon	PKMTR	ENP	Distribution
Infraorder ACRIDIDEA				
Family ACRIDIDAE				
Subfamily ACRIDINAE				
1.	*Acrida exaltata*	+	–	–
2.	*Acrida gigantean*	+	–	–
3.	*Carliola carinata*	+	+	*
4.	*Phlaeoba antennata*	+	–	–
5.	*Phlaeoba infumata*	+	–	–
6.	*Phlaeoba panteli*	+	–	–
7.	*Zygophlaeoba* sp.	–	+	–
Subfamily CATANTOPINAE				
8.	*Bambusacris travancora*	+	+	*
9.	*Choroedocus illustris*	+	–	*
10.	*Diabolocatantops innotabilis*	+	–	–
11.	*Naraikadua charmichaelae*	+	–	*
12.	*Pachyacris vinosa*	+	–	–
13.	*Palniacris maculatus*	+	+	*
14.	*Siruvania dimorpha*	+	+	*
15.	*Xenocatantops humilis*	+	+	–
16.	*Mopla guttata*	+	–	*
Subfamily CYRTACANTHACRIDINAE				
17.	*Chondracris rosea*	+	–	–
18.	*Cyrtacanthacris tatarica tatarica*	+	+	–
19.	*Patanga succincta*	+	–	–
Subfamily EYPREPOCNEMIDINAE				
20.	*Tylotropidius varicornis*	+	–	–
Subfamily GOMPHOCERINAE				
21.	*Aulacobothrus taeniatus*	+	–	–
22.	*Aulacobothrus socius*	+	–	–
Subfamily HEMIACRIDINAE				
23.	*Hieroglyphus banian*	+	–	–
24.	*Leptacris filiformis*	+	–	*
Subfamily OEDIPODINAE				
25.	*Dittopternis venusta*	+	+	–
26.	*Trilophidia annulata*	+	–	–
Subfamily OXYINAE				
27.	*Gesonula punctifrons*	+	–	–
28.	*Hygracris malabaricus*	+	–	*
29.	*Oxya hyla*	+	+	–
30.	*Oxya japonica japonica*	+	–	–
31.	*Oxya fuscovittata*	+	–	–
Subfamily SPATHOSTERNINAE				
32.	*Spathosternum prasiniferum*	+	–	–

Table 1 (continued)

Sr no.	Taxon	PKMTR	ENP	Distribution
Subfamily TERATODINAE				
33.	*Teratodes monticollis*	+	+	–
Family CHOROTYPIDAE				
Subfamily CHOROTYPINAE				
34.	*Phyllochoreia ramakrishnai*	+	–	*
35.	*Phyllochoreia unicolor*	+	–	*
36.	*Burrinia burri*	+	–	*
Subfamily PRIONACANTHINAE				
37.	*Prionacantha picta*	–	+	–
Family MASTACIDEIDAE				
Subfamily MASTACIDEINAE				
38.	*Paramastacides ramachendrai*	+	+	*
39.	*Mastacides nilgirisicus*	+	–	*
Family PYRGOMORPHIDAE				
Subfamily ORTHACRIDINAE				
40.	*Neorthacris acuticeps acuticeps*	+	–	*
41.	*Neorthacris acuticeps nilgiriensis*	+	–	*
Subfamily PYRGOMORPHINAE				
42.	*Atractomorpha crenulata*	+	+	–
43.	*Aularches miliaris miliaris*	+	–	–
44.	*Chrotogonus oxypterus*	+	–	–
45.	*Chrotogonus trachypterus*	+	–	–
46.	*Poekilocerus pictus*	+	+	–
Family TETRIGIDAE				
Subfamily CLADONOTINAE				
47.	*Deltonotus* sp.	+	–	–
48.	*Deltonotus gibbiceps*	+	+	*
49.	*Tettilobus* sp.	–	+	New species
Subfamily TETRIGINAE				
50.	*Euparatettix personatus*	+	–	New to India
Subfamily SCELIMENINAE				
51.	*Eucriotettix flavopictus*	+	+	–
52.	*Euscelimena gavialis*	+	–	–
53.	*Euscelimena harpago*	+	+	–
Subfamily METRODORINAE				
54.	*Systolederus* sp.	+	–	–
55.	*Indomiriatra provertex*	+	–	–
Infraorder TRIDACTYLIDEA				
Subfamily DENTRIDACTYLINAE				
56.	*Bruntridactylus saussurei*	+	–	–
Subfamily TRIDACTYLINAE				
57.	*Xya castetsi*	+	–	–

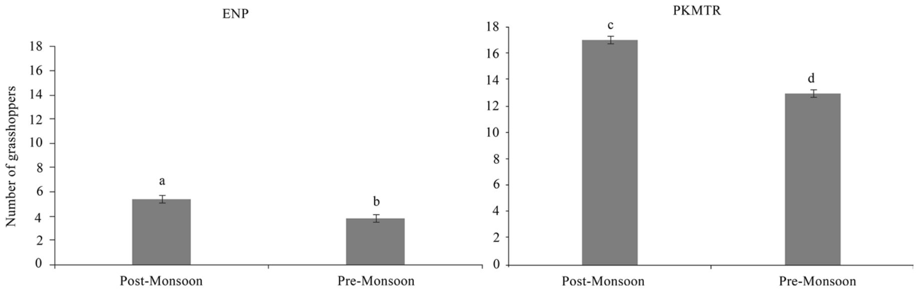

Fig. 2 Mean total grasshopper abundance per plot in Eravikulam National Park (ENP) and Parambikulam Tiger Reserve (PKMTR), Kerala, India, during pre-monsoon and post-monsoon seasons (Error bars are standard errors)

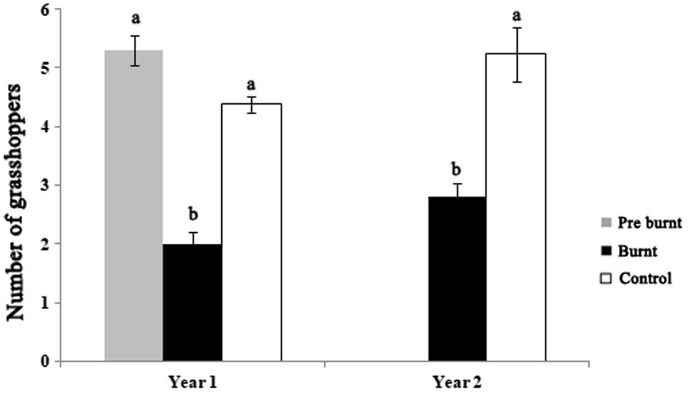

Fig. 3 Mean total grasshopper abundance on pre-burnt plots, burnt and control plots during the pre-monsoon period for both years after burning in Eravikulam National Park, Kerala, India (error bars are standard errors)

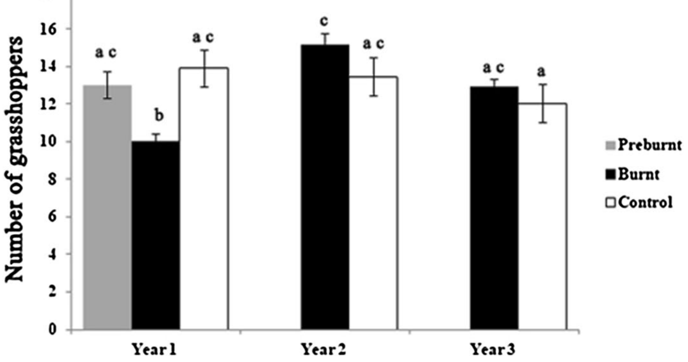

Fig. 4 Mean total grasshopper abundance on pre-burnt plots, burnt and control plots during the pre-monsoon period for both years after burning in Parambikulam Tiger Reserve, Kerala, India (error bars are standard errors)

Effects of burning on species level

When examining grasshopper species individually, only the most common species showed a very similar response to burning, following the pattern explained above. For example, the abundance of *Zygophlaeoba* sp. decreased significantly in burnt plots in ENP after burning compared to the pre-burnt situation and the control plots just during the post-monsoon season and the second pre-monsoon season (but not during the first pre-monsoon season; ANOVA, $\lambda = 0.12$, $F_{7,88} = 5.3$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p < 0.02$), but no significant differences between control plots and the pre-burnt situation were found (pairwise t-test with Bonferroni correction: $p = 0.99$). For *Paramastacides ramachendrai* only, we detected a significantly lower abundance on burnt plots during the first pre-monsoon season compared to the pre-burnt situation (ANOVA, $\lambda = 0.18$, $F_{7,88} = 2.5$, $p = 0.02$; pairwise t-test with Bonferroni correction: $p = 0.047$), while the abundance later recovered rapidly and was not significantly different from control plots or the pre-burnt situation (pairwise t-test with Bonferroni correction: $p = 0.99$). For *Palniacris maculatus*, a significant decrease in population size was observed during the first and second pre-monsoon season in burnt plots compared to the pre-burnt and control plots (ANOVA, $\lambda = 0.11$, $F_{7,88} = 17.8$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p < 0.001$), but not for the post-monsoon season (pairwise t-test with Bonferroni correction: $p = 0.99$). *Carliola carinata* showed a significant decrease in the burnt plots compared to the pre-burnt plots during all seasons (ANOVA, $\lambda = 0.17$, $F_{7,88} = 5.45$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p_1 = 0.03$, $p_2 = 0.047$, $p_3 = 0.03$). However, during the post-monsoon season, we also found a significant difference to the control plots (pairwise t-test with Bonferroni correction: $p = 0.006$). For *Atractomorpha crenulata,* a significant decrease in abundance on the burnt plots was found during the first pre-monsoon season compared to the pre-burnt and control plots (ANOVA, $\lambda = 0.06$, $F_{7,88} = 8.4$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p_{1+2} < 0.001$) and for the first post-monsoon season compared to the control (pairwise t-test with Bonferroni correction: $p = 0.04$). There was no significant difference during the second pre-monsoon season for this species.

In PKMTR, *Neorthacris acuticeps nilgiriensis* had a significant lower abundance in the burnt plots only during the first pre-monsoon season compared to the control (ANOVA, $\lambda = 0.65$, $F_{12,155} = 7.7$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p < 0.001$). The same was true for *Neorthacris acuticeps acuticeps*, which decreased significantly in burnt plots during the first pre-monsoon season after burning compared to the pre-burnt situation, but also in comparison with the control plots (ANOVA, $\lambda = 0.4$, $F_{12,155} = 5.2$, $p < 0.001$; pairwise t-test with Bonferroni correction: $p_{1+2} < 0.001$). However, no significant differences to the control plots were found later for these species (pairwise t-test with Bonferroni correction: $p = 0.99$). All other species showed no significant differences in abundance in burnt sites compared to the pre-burnt or control plots, but some species showed differences in abundance between seasons or years. For example, the most abundant species (*C. carinata*) had a significantly higher abundance in the post-monsoon season of the second year compared to the pre-monsoon season of the first year (ANOVA, $\lambda = 0.5$, $f_{12,155} = 2.32$, $p = 0.009$; pairwise t-test with Bonferroni correction: $p < 0.001$), but no differences within a season or year.

Multivariate analysis

The PCA plot for ENP (Fig. 5a–c) shows on the first axis (explaining 70.5% of the total variance) a gradient of grasshopper communities on burnt plots (with negative loadings) and pre-burnt/control plots (with positive loadings). In PKMTR (Fig. 5d–f), the first component explained 55% of the total variance. Contrary to ENP, the overlap of burnt, pre-burnt and control plots was higher. The PCA results show that in PKMTR, the Orthoptera community (grasshopper abundance) recovers positively within six months (overlapping of burnt group towards the right side of the chart with control plots) after fire. In ENP, grasshopper assemblages after fire were not recovering even after 2 years.

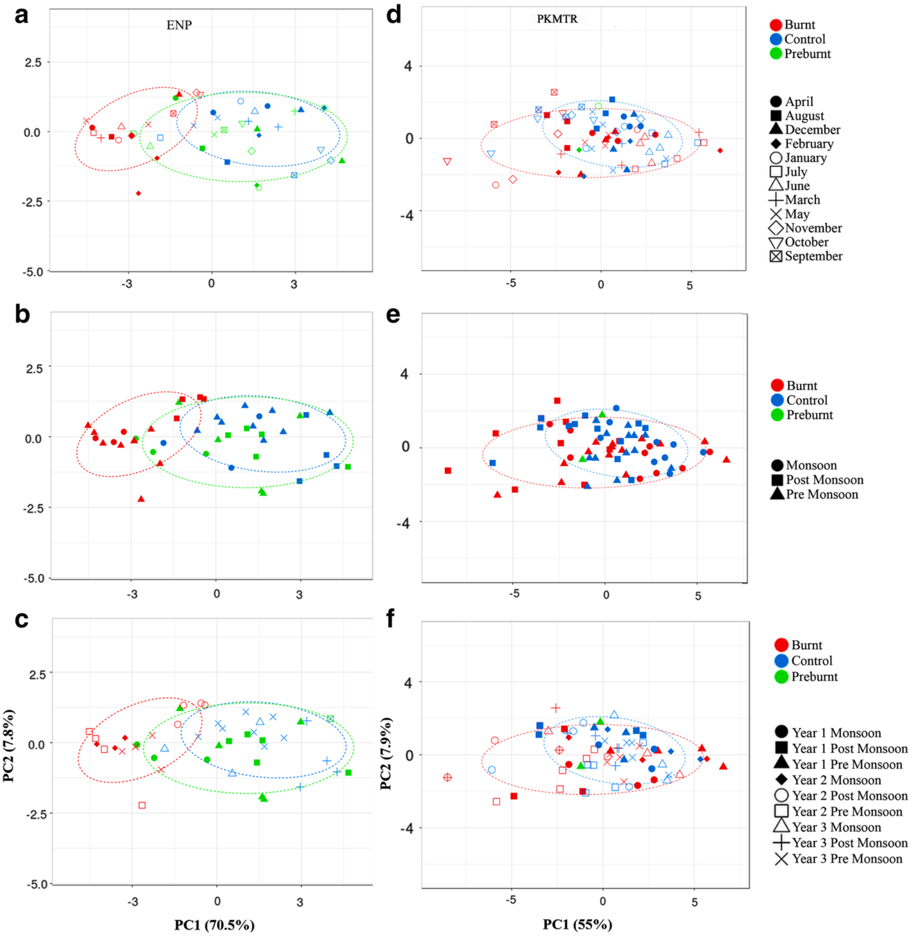

Fig. 5 PCA plots for Eravikulam National Park (ENP **a**–**c**) and Parambikulam Tiger Reserve (PKMTR **d**–**f**) Kerala, India (prediction ellipses are such that with probability 0.75, a new observation from the same group will fall inside the ellipse)

Discussion

Our results confirm the hypothesis that small-scale burning has comparatively less detrimental effects on grasshopper abundances compared to large-scale burning. These results are also in line with the habitat heterogeneity hypothesis (Tscharntke et al. 2002; Tews et al. 2004) as both grasshopper species richness and abundances were higher in the more heterogeneous habitats of PKMTR compared to the more homogeneous habitats of ENP. In PKMTR we observed a rapid recovery of grasshopper communities, total abundance as well as abundance of individual species after burning. Only during the first pre-monsoon season after burning the abundance of the most common species dropped significantly. From the first post-monsoon season onwards, there were no significant differences in total grasshopper abundance between burnt and control plots. In contrast, grasshopper abundance remained low for much longer in ENP, where large areas were burnt. Generally, grasshopper species richness and abundances were higher in PKMTR than in ENP suggesting long-term effects of fire history in ENP. We found only 18 grasshopper species in ENP compared to 54 in PKMTR. However, it cannot be excluded that this result might also be affected by the different locations of both study sites. The main difference between the fire management in ENP and PKMTR is the burnt area, which covered 100 m^2 for each plot in PKMTR and 500,000 m^2 in ENP, but fire behaviour (i.e. temperature, speed etc.) may also have differed. In ENP, the grasslands were burnt as circle of fire starting from the perimeter of the circled hill towards the centre, leaving grasshoppers little chances to escape from a burnt area. In PKMTR, fire was restricted within 10 × 10 m plots.

The effect of fire on ecosystems and organisms varies depending on the ecological history of the taxa, fire intensity, behaviour, extent and frequency of the fire in addition to the moisture content and topography of the soil (Warren et al. 1987; McCullough et al. 1998; Keeley et al. 2005). Fire can affect organisms directly by combustion and indirectly by altering the structure and composition of vegetation (Rice 1932; Bock and Bock 1991). Both grasslands differ by only 600 m in elevation and the composition and structure of the soil is similar. *Cymbopogon* (lemon grass) is the dominant grass in both the reserves. However, in ENP we observed an invasive fern (*Pteridium aquilinum*) spreading in moist areas along the burnt grounds to the hills. In PKMTR, the fern was less common, but in the burnt experimental plots we also found it spreading. The effects of this invasive plant on grasshoppers is not known, but as many grasshoppers have strong requirements regarding vegetation structure and microclimate (Joern 1982; Gardiner and Dover 2005), and some are specialized in diet (Joern 1979) it might negatively affect the community in the long term. Likewise, the endemic shrub *Strobilanthes kunthiana* (Neelakurinji) was dominant in frequently burnt grasslands of ENP. We found no grasshoppers on this shrub (which has very hairy and hard leaves), suggesting negative effects of these vegetation changes on grasshoppers.

Although the vegetation and the dominant grass species are similar in both grasslands, grasshopper diversity was substantially lower in ENP compared to PKMTR. The continuous fire history could be one reason for the lower grasshopper diversity, but fire behaviour and intensity might also differ. In ENP, fires are comparatively slow lasting almost 4–5 h for 50 ha, whereas in PKMTR plots fires lasted only for 15 min. The average temperature of fire within the grass tussock during burning was 310 °C in ENP and approximately 120 °C in PKMTR, which probably affect survival of grasshopper adults and nymphs directly. The eggs of grasshoppers might also be differentially affected by fires. Most grasshoppers of the study regions oviposit in the ground, where eggs may be sheltered from high temperatures. Prescribed fires that rapidly move across the vegetation cause only minor changes in soil temperatures (Niemeyer et al. 2004). Indeed, we found comparatively minor temperature differences in the soil (30 cm depth) in ENP, but no change at all in PKMTR. Therefore, eggs might be exposed to higher temperatures in ENP compared to PKMTR, which might be another reason for the lower grasshopper diversity in ENP. A significant decrease in abundance was also noted for flightless grasshopper species (*Zygophlaeoba* sp., *Pa. ramachendrai*, *P. maculatus*, *N. a. nilgiriensis*, *N. a. acuticeps*, and *C. carinata*), which are less mobile and, therefore, cannot recolonize large burnt areas rapidly.

Grasshoppers are considered good indicators of grassland health (Belovsky 2000; Anderson et al. 2001). Because of the importance of microclimate and vegetation structure for grasshoppers (Uvarov 1977; Joern 1982; Ingrisch 1983; Chappell and Whitman 1990; Matenaar et al. 2014), the impact of fire on grasshoppers is typically negative for species inhabiting dense vegetation and positive for those preferring bare ground (Hochkirch and Adorf 2007). As both grasslands of our study sites have dense vegetation with lemon grass, negative impacts on grasshopper abundance appear to dominate. Even after 2 years, the grasshopper communities and populations did not achieve the status of pre-burnt and control plots in ENP, while in PKMTR recovery took place within 6 months after fire. Generally, graminivorous species often benefit from burning, while forb-feeders typically decline (Evans 1984, 1988; Bock and Bock 1991). In PKMTR, we observed that the fresh sprouting vegetation on burnt plots compared to unburnt and control plots might benefit grasshoppers, confirming the findings by Ferrando et al. (2016). However, this was probably affected by the existence of viable grasshopper populations adjacent to the burnt plots and the small size of the burnt plots that allows species to recolonize these areas rapidly. Evans (1984) considered post-fire dispersal as critical as many Orthoptera are known to disperse no more than a few meters during their life (Ingrisch and Köhler 1998; Weyer et al. 2012). In PKMTR, we observed active recolonization of two common species: *C. carinata* and *N. acuticeps*. In ENP, large scale burning resulted in very large distances between burnt and unburnt plots, hampering recolonization. This illustrates that small scale burning and providing unburnt areas between the burnt grounds is less detrimental to grasshoppers than large scale burning practices.

Another factor influencing the recolonization process is the fire cycle. In Konza Prairie Biological Station (Kansas, USA), different types of fire management have been tested. When fire was applied in the watersheds of 16–55 ha every 4 years, no negative effects on species richness, diversity and composition of grasshoppers were found, but the relative abundance of grass feeders initially increased and declined again in succeeding years without fire (Evans 1988). After more than 25 years of fire management at this site, it was found that prescribed burning during spring has less detrimental effects on grasshopper abundance than burning in other seasons (Jonas and Joern 2007). Welti et al. (2019) observed that plant and grasshopper community compositions at Konza Prairie Biological Station were affected by changes in fire frequency. A shorter fire cycle is known to benefit grass-feeding species, while areas burnt less frequently are dominated by forb-feeding grasshoppers (Gibson 1988). The current management in the protected areas is mainly carried out for Nilgiri tahr, but it is important to adapt the burning management to benefit the whole community rather than a single species (Easa et al. 2010). Our results from the experimental burning in PKMTR suggest that small-scale burning is sufficiently effective in providing palatable food for the ungulate, but the direct effects on the tahr still need to be studied. We also found indirect evidence of carnivorous mammals (pug marks of tiger and leopard) along with other large herbivores. Presence of unburnt and burnt vegetation at a small scale increases heterogeneity and may help ambush predators like tiger to sit-and-wait for their prey, whereas in ENP the large size of the burnt plots makes the vegetation more homogenous and predators more visible to the prey from long distance.

According to Parr and Brockett (1999), spatial and temporal heterogeneity is more important to maintain biological diversity than stable conditions. Disturbance such as fire is an important mechanism for producing spatial heterogeneity in grasslands (Collins 1989, 1992; Chaneton and Facelli 1991). In the Mediterranean climate shrublands of South Africa (*fynbos*), fire is the most important type of disturbance and appears to control patterns of species richness (Schwilk et al. 1997). While introducing such management tools to sensitive habitats, specific scientific studies are required. Spatial and temporal mosaic management has been suggested before when applying fire management to homogenous landscapes (Chambers 1998; Law and Dickman 1998; Parr and Brockett 1999; Shriver and Vickery 2001; Swengel 2001; Pons et al. 2003). The management plan of ENP aims to create a spatio-temporal mosaic patches of burnt and unburnt areas of grasslands. However, the repeated fire events and their large scale has not resulted in mosaic patchiness, but converted the entire grasslands into homogenous burnt grassland, even though this entails a mosaic of fresh and old grass patches. This is a result of the management plan aiming at a single ungulate species, which needs to be revised by considering other biota.

Focusing on single flagship species to manage the habitat may not always benefit biological diversity (Williams et al. 2000). Since we found small-scale burning in PKMTR being less detrimental to grasshoppers than large-scale burning and probably also suitable for supporting plant germination for Nilgiri tahr, we suggest to replace the large-scale burning practice in ENP based upon these new findings. However, since ENP has generally larger grasslands than PKMTR, it might be more feasible to use slightly larger plots of 25 × 25 m or 50 × 50 m with unburnt adjacent areas between plots. We also suggest to test changes in the fire cycle from the current 3–5 or more years, in order to achieve healthy invertebrate generations after fire. Our study shows that grassland management can be optimized to benefit a larger part of the biota within a protected area by studying the response of invertebrate species, which is often neglected in conservation management (Hochkirch 2016).

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Mopla guttata (Acrididae: Catantopinae) rediscovered in the Western Ghats, Kerala, India

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Abstract

The endemic Catantopinae genus *Mopla* was described by Henry in 1940 from the Malabar region of South India. Henry described two species under this genus, *M. guttata* and *M. rubra.* The female type specimens of *Mopla* are deposited in the Natural History Museum, London, UK. There have been no further records of these two species since their description. Seventy-six years later, the first male specimen of the genus *Mopla* was discovered in the Western Ghats, Kerala, India, in 2016. This paper describes the specimen, thought to be of *Mopla guttata*, and reconsiders its systematic placement.

Keywords

endemism, first male of genus, grasshopper, systematics, tropical forest

Introduction

Most of the 1033 known Indian grasshopper species were described by foreign researchers (Chandra et al. 2010). In modern India, grasshoppers are considered agricultural pests, hence research publications are confined to agricultural universities and regional pest research centers (Priya and Narendran 2003, Chandra et al. 2010, Nayeem and Usmani 2012). The Western Ghats region, a biodiversity hotspot, is the type locality for some endemic grasshoppers (Cigliano et al. 2018). Most of the 790 species mentioned in the Faunal Diversity in India by Tandon and Hazra (1998) are from biodiversity hotspots such as Western Ghats.

Henry (1940) collected many Catantopinae from southern India as part of a joint expedition of the British Museum and the Colombo Museum from 1936 to 1938. He recorded the exact collection locations for future researchers and explorers; as he mentioned, this was to facilitate further work on the Orthoptera fauna of India. In Henry's (1940) publication he described some very interesting Catantopinae species including *Tinnevellia andrewi*, *Bambusacris travancora*, *Siruvania dimorpha*, *Naraikadua charmichaelae*, *Palniacris maculatus*, *Coniocara rubropicta*, *Mopla guttata*, and *Mopla rubra*. Most of these need further investigation. However, these diversity-rich highlands were never revisited for grasshoppers after the departure of the foreign researchers. Bhaskar et al. (2018) reported 130 species of Orthoptera from the Kerala part of Western Ghats. From 2015 onwards we started searching for grasshoppers in protected areas of the State of Kerala, part of the Western Ghats. In September 2016, we came across a completely unfamiliar grasshopper in the Parambikulam Tiger Reserve (PKMTR), Kerala. Unfortunately, we have since failed to find any further specimens. Later the specimen was found to be very close to the type-specimens of *Mopla* that DB had photographed previously at the Natural History Museum, London, UK (NHMUK). Our male specimen was at first misidentified as *Mopla rubra* and illustrations were provided on the sample page of the proposed field guide to Indian Orthoptera (Bhaskar et al. 2018).

Mopla are small brachypterous catantopine grasshoppers with distinctive coloration of bright yellow stripes and spots on a dark brown background (Fig. 1). Morphologically, the genus is notable for: A) its very abbreviated frontal ridge that forms a short narrow rostrum that is lamelliformly compressed between the antennae, but becomes obsolete immediately below the antennal bases; B) the absence of visible ocelli, both medial and lateral; and C) the terminal segment of the maxillary palp is laterally expanded, forming a pale-colored broadly elliptical surface (Fig. 2). These modified palps are probably used in intraspecific communication; a similar structure is found in several other tropical forest acridid taxa, such as *Ateliacris* or *Silvitettix*.

Henry (1940) erected the genus *Mopla* with two species: *guttata*, the type of the genus, and *rubra*. The two species were described from two female grasshoppers from the forests of the Western Ghats Mountains of southern India, in what are now the states of Tamil Nadu and Kerala. Henry (1940) named this genus for the Muslim community inhabiting the Malabar region of South India; the Muslims of this region are locally called "Mapla" in the Malayalam language of Kerala. The type specimen of *Mopla guttata* was collected from Top Slip, Anamalai Tiger Reserve, Tamil Nadu, and that of *Mopla rubra* was collected from Nilambur, Kerala. To our

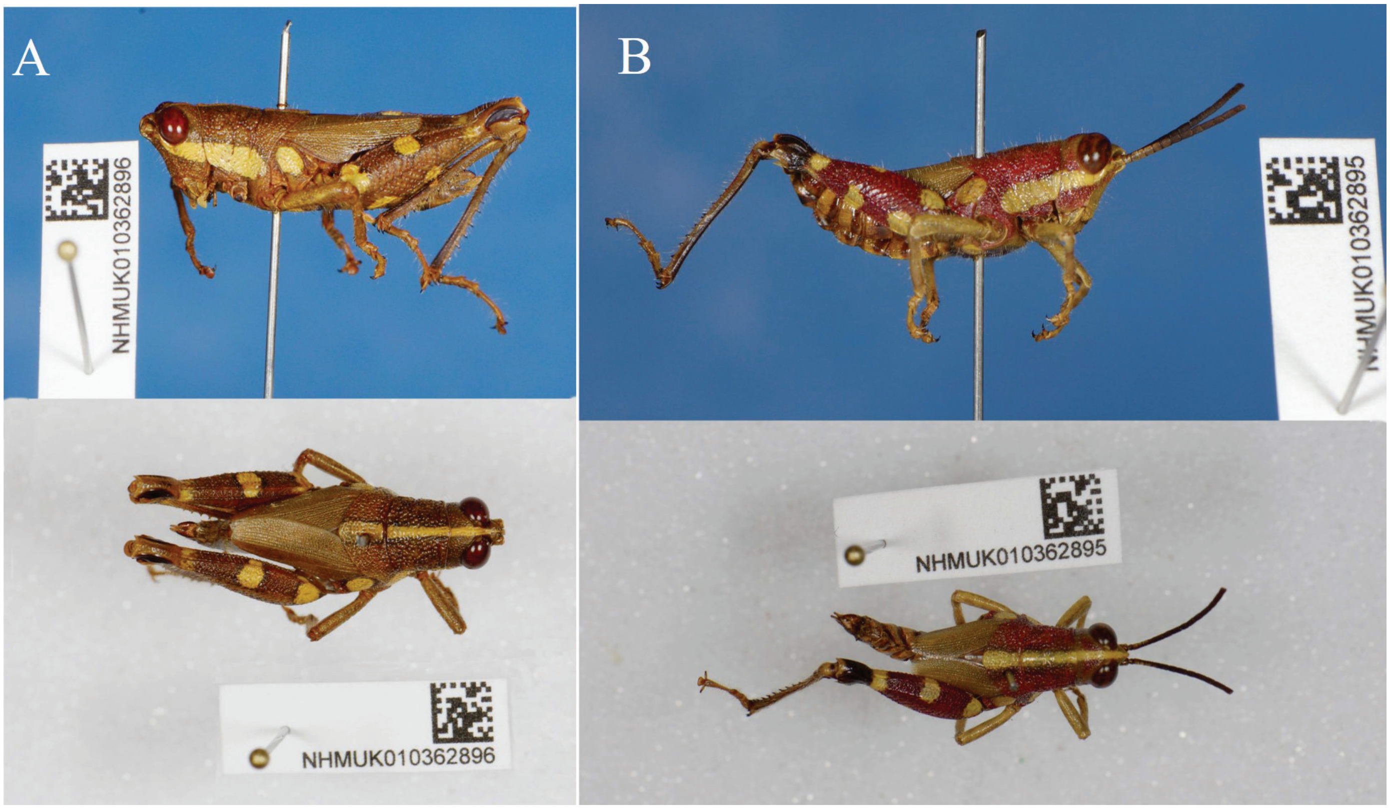

Fig. 1. A. *Mopla guttata*, holotype female (NHMUK); **B.** *Mopla rubra*, holotype female (NHMUK). Photo credit: D. Bhaskar.

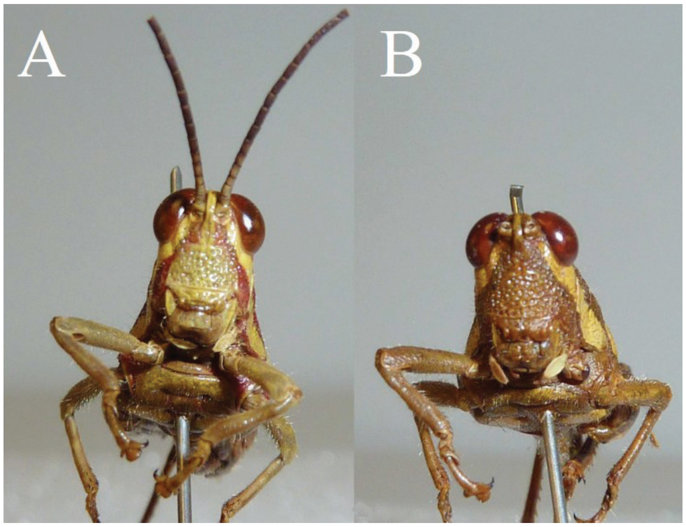

Fig. 2. Facial coloration of the female holotypes of **A.** *Mopla rubra* and **B.** *M. guttata*, showing the expanded terminal segments of the labial palps, and the difference in structure of the frontal ridges. The frontal ridge of *guttata* is almost devoid of medial sulcus, only a trace at the extreme ventral margin is apparent. In *rubra* there is a faint sulcus over the entire length. Photo credit: L.D.C. Fishpool.

knowledge, there has been no further record of this taxon since the original publication, and no male has been described.

We now report the capture of the first male of this genus. Its identification and description necessarily require reconsideration of Henry (1940)'s publication and of the type material.

Methods

Study area.—Parambikulam Tiger Reserve (PKMTR) of Kerala is one of the richest wildernesses in the Western Ghats of India. PKMTR (10°20'–10°32'N, 76°35'–76°5'E) is situated between Anamalai and Nelliyampathi hill ranges in the Palakkad District, Kerala, India. PKMTR has an area of 643.662 km^2 and extends over an altitude ranging from 460 m to 1439 m asl. The vegetation types include evergreen, semi-evergreen, teak, moist deciduous, and riparian forests.

Grasshopper diversity of PKMTR was documented from 2015 to 2018. We collected and recorded the diversity of grasshoppers by using sweep netting and hand-picking of specimens. Standard Orthoptera taxonomy was followed using the Orthoptera Species File (Cigliano et al. 2018). The pinned specimens were deposited at the Kerala Forest Research Institute (KFRI) entomology museum.

The male *Mopla* specimen was relaxed in water to dissect the phallic complex. The phallic complex was extracted after treating the last abdominal segments with 10% KOH that loosened the attached muscles and membranes. This procedure unfortunately destroyed the tergites and sternites of these segments, which are therefore missing from the final specimen. The components of the phallic complex were separated and sorted in vials with 70% alcohol. The phallic complex was then verified by CHFR. The complex was stained using acid fuchsin and differentiated in water. Dimensions were measured using a graticule eyepiece in the stereo microscope and a digital stage reading to 0.01 mm to move the pinned specimen under an appropriate magnification (between 6 and 50 times, depending on the size of the structure being measured). Drawings were made under the stereo microscope and edited using Photoshop CS5 (Adobe Systems Inc.). Specimens were imaged using digital camera DFC 295 attached to a Leica S8AP0 stereomicroscope and processed using software LAS V3.8. Image editing was accomplished using Adobe Photoshop CS4.

Abbreviations of depositories:

NHMUK	Natural History Museum, London, United Kingdom.
KFRI	Kerala Forest Research Institute, Kerala, India.

Results

Comparison of M. guttata *and* M. rubra.—Henry's (1940) two specimens are almost identical superficially and obviously congeneric (Fig. 1A, B). When describing the second specimen as *M. rubra*, Henry (1940) wrote: "Very near to *M. guttata*, of which it will probably eventually be regarded as a subspecies; it differs from the latter, however, in so many minor points that I feel the only satisfactory course is to treat it as a full species". These "minor points" of difference were listed as follows: "Slightly smaller than *M. guttata*, with relatively shorter antennae; shorter and less well-developed tegmina, which are much more widely separated at their bases and are not so distinctly divided into two planes at vein M; frontal ridge feebly constricted opposite antennal scrobes; below this point, irregularly sulcate to a point half-way to the clypeal suture; fastigium of vertex more evenly declivent, less tumescent than in *M. guttata*; puncturation of face, occiput, pronotum and pleurae less coarse than in the latter; pronotum with the angle of posterior margin rounded". Henry also noted differences in coloration, which are discussed later below.

We have examined and photographed the type specimens of both *guttata* and *rubra* (both in NHMUK), and have attempted to confirm these reported differences.

Size: Henry (1940) provided measurements of both specimens (Table 1), and there seems to be no reason to doubt his accuracy:

It is noteworthy, however, that Henry (1940) stressed that both body length measurements were uncertain, although he ultimately suggested the same value (20 mm) for both. All the other measurements show that *guttata* is 10–20% larger than *rubra*, except for length of the tegmen (T), where that of *guttata* is apparently 40% longer than *rubra*. The slightly larger size of *guttata* is apparent when the two types are compared (Fig. 3).

After normalizing for the difference in size of the two species by dividing each value by the length of the pronotum (P), the ratio of *guttata* to *rubra* values is close to unity (≤10% difference) throughout, indicating that the relative sizes of different body parts are identical in the two specimens. Henry (1940) was therefore incorrect in stating that the antennae of *rubra* are "relatively shorter". The antennae are broken on both the types, and Henry's (1940) measurements cannot be checked. The exception to the above is the length of the tegmen (T), which is 20% longer in *guttata* even after normalization. Presumably this is the basis of Henry's (1940) statement that the tegmina of *rubra* are "shorter and less well-developed". We have checked this by recalculating the ratio T/P from photographs of the two specimens, yielding new values of T = 1.24P for *guttata*, and T = 1.12P for *rubra*. This reduces the normalized *guttata*/*rubra* ratio to 1.24/1.12 = 1.11, in line with that of all the other body measurements. We conclude, therefore, that Henry's (1940) tegmen measurement for *guttata* was somewhat too large, and that all the morphometric ratios of the two type specimens are within 10% of each other.

Table 1. Measurements of female *Mopla guttata* and *M. rubra* (Henry 1940).

Measurements (mm)	*guttata* female	*rubra* female
Length of body	20.0	ca. 20.0
Length of antenna	13.0	11.0
Width of head, across eyes	4.5	4.1
Length of pronotum	7.0	6.0
Greatest width of pronotum	6.25	5.3
Length of tegmen	9.0	6.4
Length of fore femur	4.2	3.7
Length of hind femur	12.3	10.3

Fig. 3. Female holotypes of *Mopla guttata* (bottom) and of *M. rubra* (top), showing the slightly smaller size and distinctly redder ground coloration of *M. rubra*. Photo credit: L.D.C. Fishpool.

Separation of the wing bases: Henry's (1940) claim that *M. rubra*'s wing bases are "much more widely separated" than those of *M. guttata* is unconvincing. In photographs of the types (Fig. 1), there seems to be merely a difference in the extent of overlap of the trailing edges of the tegmina, which could be influenced by the position of the tegmina or variation in their width.

Posterior angles of the pronotum: We traced the outlines of the pronotum in lateral photographs of the types and superimposed them. We found a slight difference as noted by Henry (1940), in that the posterior angle of the *rubra* type is indeed somewhat more smoothly rounded than that of *guttata*.

The remaining morphological criteria (slope and convexity of the fastigium, puncturation of the integument) cannot be examined critically in the available photographs.

In summary, the differences in morphology claimed by Henry (1940) are only partially supported on reexamination. The confirmed differences are slight, and alone are possibly insufficient for a specific separation, as Henry (1940) remarked.

Biogeography of the Mopla *species.*—As mentioned above, the *guttata* and *rubra* type localities are both located in the Western Ghats and are relatively close to each other. Significantly, however, they are separated by a prominent geographical feature, the 30–40 km Palghat Gap (Myers et al. 2000), which is the only significant break in the chain of the Ghats. The Palghat Gap is known to be a major biogeographic barrier for numerous plant (Bahulikar et al. 2004, Apte et al. 2006) and vertebrate (Vidya et al. 2005, Gunawardene et al. 2007, Robin et al. 2010, Van Bocxlaer et al. 2012, Ram et al. 2015, Vijayakumar et al. 2016) species, and could very well interrupt gene flow between populations of flightless grasshoppers such as *Mopla*. It is therefore quite plausible that the slight differences seen between *guttata* and *rubra* derive from genetic differences and represent at least incipient speciation.

Is the newly captured male rubra *or* guttata*?*—Our male *Mopla* specimen was collected in the Anamalai Hills, only 3 km from the *guttata* type locality. If the Palghat Gap is suspected of being a boundary between the two populations of *Mopla*, this alone suggests that the male belongs to *guttata*. At least two morphological findings strengthen this hypothesis:

1. The detailed structure of the frontal ridge is very similar in our male and in the *guttata* female type (compare Figs 2 vs. 4). In both, the narrow rostral part of the ridge terminates just above the point where the medial ocellus would be expected, and at that point the ridge suddenly becomes sulcate for a very short distance immediately before its disappearance. This results in a small "fishtail" structure at the lower end of the frontal ridge, seen in both specimens. The faint suggestion of a longitudinal sulcus, seen in the holotype of *rubra*, is absent from both the female and the putative male of *guttata*.
2. The ratio T/P can be calculated from dorsal photos of the male as previously described for the female types. This produces a value of T/P = 1.28, much closer to the female *guttata* value (1.24) than to the female *rubra* value (1.12). It is not unusual in grasshoppers for males to have relatively longer tegmina than females.

Henry (1940) further noted a difference in coloration between his two specimens. While both have a similar pattern of yellow markings on a brown background, in the female *rubra* he reported that much of the brown area was suffused with crimson (hence his specific name). This is not visible in the 80-year old type today, and has probably been lost by fading over time, but the *rubra* holotype is still distinctly more reddish brown than the olive-brown *guttata* holotype (Fig. 3). Significantly, however, the freshly caught male (Fig. 4) also shows no crimson coloration. This too supports the hypothesis that the male is *guttata* and not *rubra*, although sexual dimorphism in coloration is, of course, possible.

Henry (1940) also noted, but did not stress, a difference in facial coloration. Comparison of recent photographs of the holotypes (Fig. 2) shows that the frons of *rubra* is predominantly yellow, while that of *guttata* is dark brown. Our male has the latter coloration, as expected of *guttata*, at least in the absence of sexual dimorphism.

With a genus known from only three specimens, it is impossible to be sure of a specific determination as the range of intraspecific variation is unknown. However, all the available evidence (geographical, morphological, and coloration) suggest that we are dealing with the previously unknown male of *Mopla guttata*.

Material examined and depository.—Allotype: Adult male (opposite sex to the holotype) (Fig. 4): INDIA: Kerala: Palakkad district: Parambikulam Tiger Reserve: Sungum range, coordinates 10°41'93.40"N, 076°72'12.40"E. 28.09.2016 (leg. D. Bhaskar). Specimen number OR0024 (KFRI).

Size: Table 2. Medium, L (length from fastigium to tip of sub genital plate) = 17.82 mm.

Description of the male of M. guttata.—Integument rugose, coarsely punctate, with numerous short white hairs. Antennae filiform, 22 segments, longer than head and pronotum together. Flagellum long and thick, black, flattened towards the tip with a light brown-yellow terminal segment (Fig. 4). Head with rounded occiput, fastigium of the vertex triangular, wider at its base than long, extending slightly beyond the anterior margins of the antennal

Fig. 4. *Mopla guttata*, male. **A.** Whole animal alive; the odd position of the right tibia is due to specimen being injured in capture. **B.** Oblique frontal view to show frontal ridge, for comparison with Fig. 2. Photo credit: D. Bhaskar and L.D.C. Fishpool.

Table 2. Measurements of male *Mopla guttata* (specimen OR0024-KFRI).

Character	Code	Length (mm)
Length from fastigium to tip of subgenital plate	L	17.82
Length of elytron	E	5.51
Length of antenna	Ant	31.89
Length of pronotum in the dorsal midline	P	4.47
Head and pronotum (combined length)	H+PN	7.43
Length of hind femur	F	12.64
Depth of femur (the maximum width of the hind femur)	FD	3.68
Length of hind tibia	Tib	10.21
Length of the most proximal tarsal segment	T1	1.01
Length of the second tarsal segment	T2	0.75
Length of the distal tarsal segment	T3	2.49
Total length of the three tarsal segments	T1-T3	4.25
Foot formula ratio 0.23 (T1/T1-3)		
0.17 (T2/T1-3)		
0.58 (T3/T1-3)		

scape segments, the tip bluntly rounded, dorsal surface finely punctate, devoid of lateral or medial carinae. Fastigial foveolae absent. Frontal ridge lamelliformly compressed, developed only between the antennal sockets, obsolete below; extends as a very thin semicircular rostrum between the antennal scapes; anterior surface smooth, not sulcate, over most of its length, but minutely sulcate and divergent just at its ventral extremity (Fig. 4). Compound eyes large, globular and protuberant, interocular space narrow, less than width of antennal scape. Medial and lateral ocelli apparently obsolete.

Pronotum transversely rounded, medial carina scarcely visible, lateral carinae absent; front margin broadly rounded, hind margin obtuse-angulate, with a rounded tip. Metazona much shorter than prozona, its margins diverging strongly towards the rear. Disc of pronotum coarsely rugoso-punctate, deeply incised by the principal (most posterior) sulcus, and very weakly by one or two more anterior sulci. Prosternal tubercle short, vertical, slender and

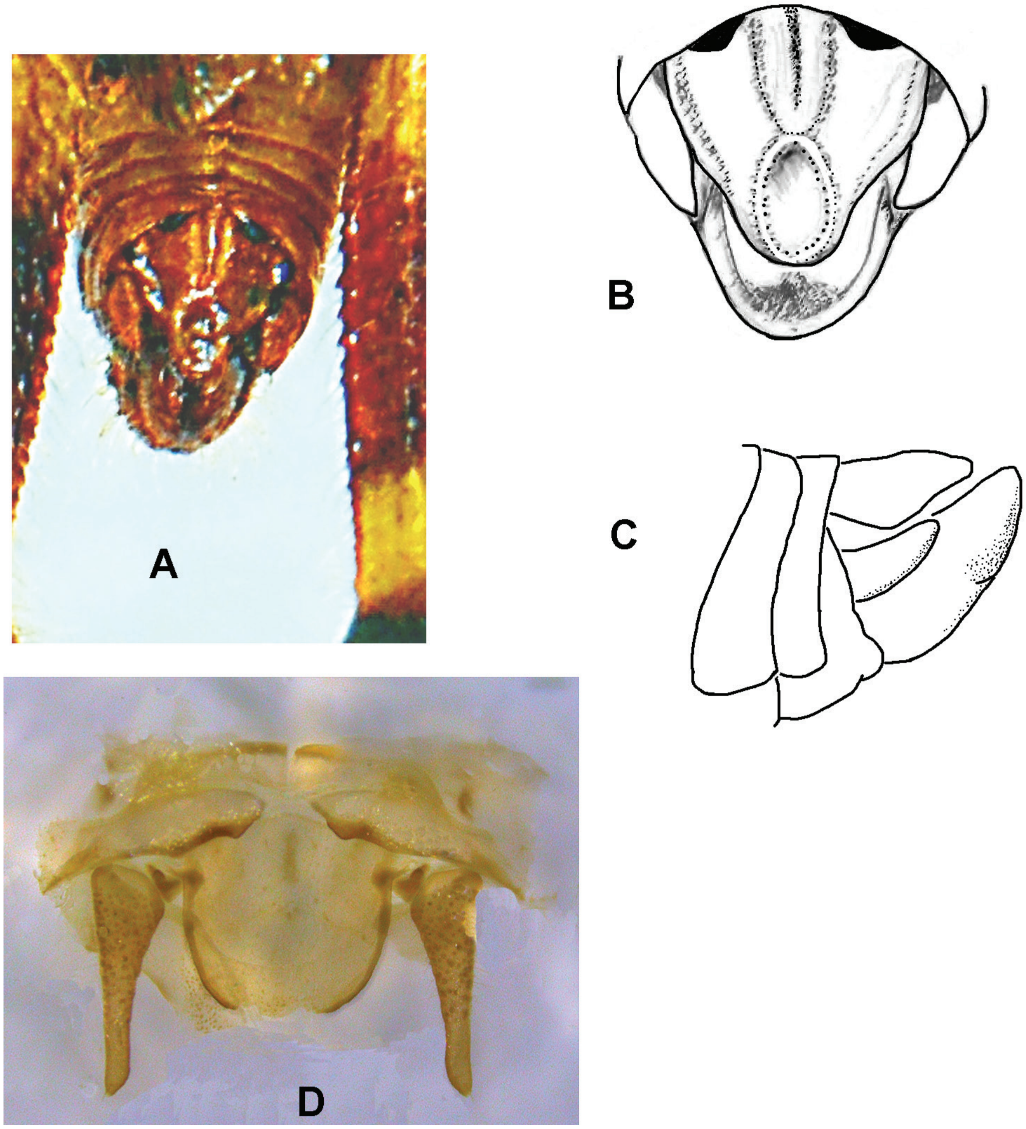

Fig. 5. Male terminalia of *Mopla guttata*. **A.** Dorsal aspect of pinned specimen; **B.** Interpretive drawing of **A**; **C.** Lateral view; and **D.** Cleared preparation of abdominal tergites 10 and 11. Note that the terminal lobe of the supraanal plate is missing; compare with **A** and **B.** Furcula and the obliquely truncate cerci are clearly shown.

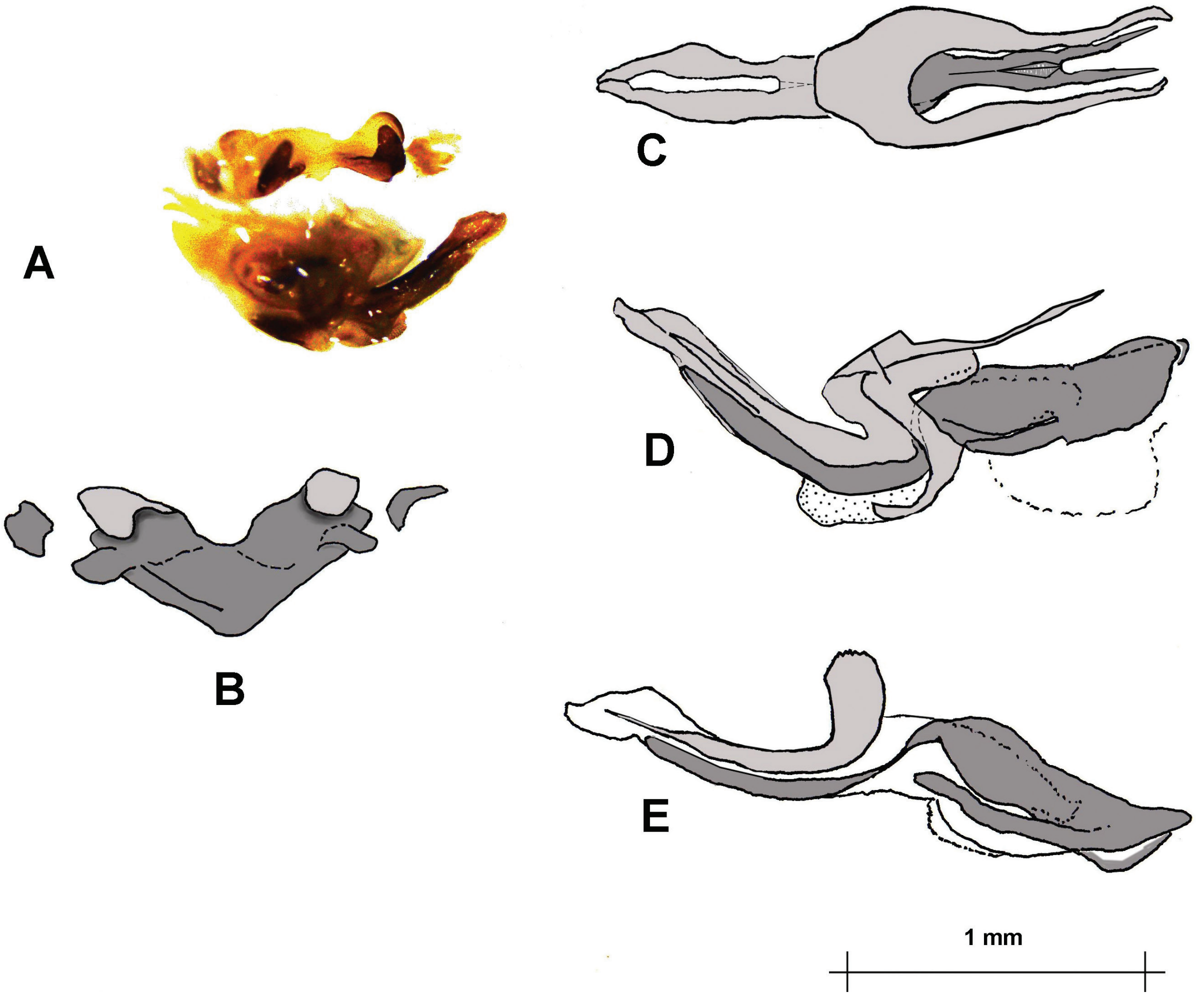

Fig. 6. *Mopla guttata*, phallic structures. **A**. Oblique posterior view of phallic complex before preparation and dissection; **B.** Epiphallus, anterior view; **C.** Dorsal and **D.** Lateral views of phallic complex with epiphallus, epiphallic, and ectophallic membranes removed; and **E.** Endophallus, arch sclerite, and ectophallic aedeagal valves, after removal of remaining ectophallic structures. In **C–E** the endophallus is in a darker shading, the ectophallus in lighter shading. The broken line in **D** indicates the presumed position of the ejaculatory sac, missing from this preparation. Spermatophore sac stippled.

pointed. Brachypterous; tegmina overlap dorsally and extend only to 7th abdominal tergite, with rounded tips. Wings: tegmen 5.51 mm long, olive brown in color. Legs: Pro- and mesothoracic legs stout, femora widened and nearly cylindrical, fore and middle tibiae rounded, with numerous small hairs, punctured. Hind femur stout, strongly rounded, thick, exceeds both abdomen and the elytra in length, coarsely punctured; dorsal and ventral longitudinal carinae weakly serrate. External face of femur with prominent chevron patterning marked by rows of strong punctures. Hind knees with medial dorsal tooth, ventral lobes slightly downwardly curved, pointed, but not spinous. Hind tibia stout with 8 external and 10 internal spines, inner spines are slightly longer than the external spines; external apical spine present. Hind tibia (10.21 mm) 2.40 times as long as hind tarsus (4.25 mm). Third segment of hind tarsus longer than the first two segments together, foot formula 0.23, 0.17, 0.58; arolia well developed. For the foot formula, the value for each tarsal segment is obtained by expressing its length as a percentage of the sum of the three tarsal segmental lengths; e.g., the value for T2 is T2/(T1 + T2 + T3). This formulation allows the feet of different species of different sizes to be compared with each other.

Abdomen: Short, conical and compressed, tenth abdominal tergite divided, with a weak furcula (Fig. 5). Supra-anal plate roughly triangular, with a rounded tip. Male cerci fairly short, straight, tapering to an obliquely truncate tip (Fig. 5). Male subgenital plate rather short, apex smoothly rounded in lateral view.

Phallic complex: (Fig. 6). Elongate and slender**,** aedeagus equal in length to the more proximal parts of the phallus. Epiphallus**:** bridge shaped, broad, undivided medially, with short hooked ancorae and large tapering lobe-shaped lophi that are curved over at their tips. Lateral lobes weakly differentiated. Oval sclerites present, of irregular shape. Ectophallic apodemes long and slender, tapering, more or less parallel; zygoma rounded, rami slender, running rearwards at their tips, and giving rise to an extensive ectophallic sheath surrounding the dorsal aedeagal valves. Arch sclerite large, supporting long spatulate dorsal aedeagal valves that exceed the ventral valves in length. Endophallus slender, gonopore processes present and elongate, extending ventrally almost to the flexure. Flexure slender, ventral aedeagal valves tapering but not pointed. Endophallic apodemes small and narrow, not inflected laterally. Ejaculatory sac apparently lost in dissection, spermatophore sac lies ventrally, between and below the ventral aedeagal valves.

Biology.—Practically nothing is known of the way of life of this genus. The male specimen was caught on low bushes at a forest verge with predominantly herbaceous vegetation. Henry's (1940) holotypes were caught "in rain-forest", with no further details provided. The hind foot formula, with a short second tarsal joint, suggests a life on herbaceous plants rather than an arboreal one, and the large arolia rules out a terrestrial way of life.

Discussion

Henry (1940) tentatively placed *Mopla* in the Catantopinae; his reservations were based on the lack of a precise diagnosis of this subfamily. Dirsh (1961) later described the Catantopinae as a subfamily with no exclusive diagnosis; historically the subfamily has been used as a depository for forms that do not fit the criteria for other Old-World subfamilies (Akite and Rowell 2013). The present description shows that *Mopla* has a typically catantopine phallic complex with a long sheathed aedeagus, the sheath being derived from the ectophallus, very reminiscent of that seen in e.g., the African Serpusiae (Rowell et al. 2018).

Henry (1940) mentioned a discussion he had with Uvarov regarding an alleged similarity of *Mopla* to Neotropical grasshoppers and its differences from other Old-World grasshoppers. Some characters of *Mopla*, especially the structure of the head and the unique bold spotting and banding all over the body including on the femora, apparently caused Henry to perceive a faint affinity of this genus to the Neotropical group Tropinoti. It is not clear what characters could have led Uvarov or Henry to this speculation; *Tropinotus* Serville 1831 is now considered a junior synonym of *Xyleus*, a large macropterous Romaleinae savanna grasshopper, completely different from *Mopla* in both habitus and ecology. *Mopla* seems to be well placed in the Catantopinae as currently understood and has morphology typical of tropical forest light-gap species worldwide, with brightly contrasting coloration, prominent eyes, and diminished flight ability (Rowell 1978).

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