Diversity Assessment and Molecular Characterization of Geometridae moths (Lepidoptera: Heterocera) in Nanda Devi Biosphere Reserve, Uttarakhand

Thesis submitted

For the award of the Degree of

DOCTOR OF PHILOSOPHY

In

WILDLIFE SCIENCE

by

PRITHA DEY

to

Saurashtra University, Rajkot (Gujarat)

Under the Supervision of

Supervisor	Co-supervisors
DR. V.P. UNIYAL	**DR. KAILASH CHANDRA** **DR. AXEL HAUSMANN**

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

August 2018

Acknowledgements

The little things that run the world -I read this work by Dr. E.O. Wilson as a Masters' student, and though honestly, I did not understand most of it then, it left me curious. Being always interested in insect ecology as a Zoology student, I started my journey of studying moths as an amateur who has just completed her Masters' degree back in 2012. I joined the Wildlife Institute of India as a Junior Research Fellow, in a DST-Govt. of India funded project which aimed to document the moth fauna diversity in different Protected Areas in Uttarakhand. I was more thrilled at an opportunity of travelling around the Himalayan state in an 'all expenses paid' trip! In all these years, my experiences have been shaped in the most unforgettable way.

Dr. Abesh Sanyal introduced me to the world of moths, who as a senior moth researcher gave me my first task to compile a list of all the species documented in Uttarakhand. That gave me the first inkling as to how vastly diverse this group of insects is and intrigued me further! Then I met, Dr. Anshuman Raha at the Zoological Survey of India, Kolkata, where my co-supervisor Dr. Kailash Chandra hosted me to teach me the taxonomic nitty-gritty of these wonderful insects. Anshuman da, Dr. Chandra's student, took up the task, and taught me the basics: how to identify moths, how to preserve them and how to go about the field work. Chhana da (Dr. Sutirtha Dutta) helped me design my study, built up my analytical skills and taught me how to perceive an ecological study. Indro da (Indranil Mondal) introduced me to GIS, mapping and has always helped me look at my study from a 'satellite' point of view. Dr. Amit Kumar introduced me to the landscape of western

Himalaya and taught me everything about the flora of the area. Dr. Manish Bhardwaj also gave his valuable inputs to my study through discussions; Dr. Tapajit Bhattacharya, who would always answer my stupid analytical questions in the most patient way. Not to forget, Dr. Sabuj Bhattacharya, Dr. Monika Kaushik and Dr. Shazia Quasin who would always stand by me, criticise me, encourage me, support me whenever needed or not needed!

When I bagged the DAAD (Deutsche Akademischer Austauchsdienst) Scholarship, Dr. Vishnupriya Kolipakam nurtured my ideas for the proposal and helped me in every step. My experience in Germany, with the scholarship cannot be put in few words. Axel, (Dr. Axel Hausmann), a very funny and generous man, accepted me as his student for the scholarship and refined my taxonomic skills. I would end up in his office with the most naïve questions and leave with a smile on my face. He made me a 'Herbulation', by giving me an opportunity to present at the Forum Hebulot IX, in Chile in 2017. I was exposed to the stalwarts and the great minds working towards Geometrid taxonomy worldwide. I was also fortunate to meet and discuss my work with Dr. Gunnar Brehm, another Geometrid expert, who understood the limitations of my work, appreciated and supported me to make my study better. Also, to mention, Dr. Hossein Rajaei, who supports and understands my work that I did and want to do further.

I perceived, embarked upon, failed repeatedly and finally wrote my PhD thesis from Room no.32 (later in Room no.17) of the Old Hostel in the WII campus. The people who made the hostel a fabulous place to live in, through pranks, gossips, fights, late night parties and friendships are Manjari di, Shikha di, Chhana da, Nitya, Deepak, Ankita, Ayan da, Abesh da, Indro da, Kaushik da Shazia di, Neeraj, Shivam, Akanksha, Pallavi, Nikit, Rajat, Aishwarya, Naman, Rohi, Suresh, Zehidul, Shaheer and more recently Abir, Sutirtha, Sumashini, and Subashini.

The field experience at Nanda Devi Biosphere Reserve, changed me as a person, taught me the value of simplicity, humility and warmth. The local Bhotiya people though very curious about my work in the forest at night, would host me, feed me and make me a part of their lives. Lajjo Rani, Laxmi Bhabi, Bisht aunty are some of the ladies of the village Lata and Joshimath who taught me their ways and embraced me as one of their own. Dipu, Prakash bhaiyya, Anoop bhaiyya were my guides and assistants in the forest, they taught me how to climb a mountain and not to be afraid of any challenges during the fieldwork. I would also like to thank Shuvendu Das and Ritwika Ghosh, two young wildlife enthusiasts, who volunteered to help me with my fieldwork.

I cannot thank enough Dr. V.P. Uniyal, my supervisor, for believing in me and supporting me in every step. I would bring up weird ideas, and he would never say no. Dr. Samrat Mondal helped me with sequencing some specimens for molecular taxonomy part of my work, when I ran out of funds to complete it. Without them, it would have been way too difficult to conclude this journey.

I convey my heartfelt gratitude to Dr. V.B. Mathur, Director, WII, Dr. P.K. Mathur, Dr. G.S. Rawat, ex- and current Dean, WII, Dr. K. Sankar, Dr. Bitapi Sinha, ex- and current Research Coordinator, for facilitating my Ph.D and research work. Furthermore, to Sh. Qamar Qureshi, Dr. S.P. Goyel, Dr. B.S. Adhikari, Dr. K. Vasudevan for their advice and inputs. I also convey my sincere thanks to the

Uttarakhand Forest Department, especially Dr. S.K. Chandola, Sh. S.S. Rasaily, Sh. Rajiv Dhiman (DFO NDBR) for providing necessary permission and all the facilities for fieldwork in Nanda Devi Biosphere Reserve (NDBR). Special regards to all the management staff for making my stay wonderful there.

My parents, and my brother (dada) -the pillars of my life, supported my aspirations and gave me the freedom to pursue a career in Wildlife research, where at the same time my contemporaries were earning big bucks in other fields. I was away from home for so long, when dada took care of my parents. My partner in love and crime, Rohit Chakravarty, a bat biologist himself, held me strong throughout and filled up my life for everything that I had missed so far, and beyond!

Thesis summary

My doctoral thesis is based on molecular characterization of the moths and understanding their ecology and diversity patterns. The study aims to combine traditional morphological and modern molecular tools to answer the questions on diversity, the patterns and the factors governing the patterns. Molecular data provides the basic data on diversity by understanding the taxonomy, which paved the way to understand the underlying patterns and other research questions that I aimed to answer. To make sense of the ecology of the moth fauna of the area, the fundamental work is to understand their taxonomic classification. Molecular tools complement the traditional morphological approach to settle the taxonomic stand of the species concerned. The moth taxonomy lacks significant addition in this particular landscape since the "*Fauna of British India*" series published in 1892 to 1896 by Hampson. The information existing is poor and fragmentary. There is a lack of comprehensive study on moth fauna in the Indian Himalayan region. The Himalayan region with its unique physical attributes is home to a distinctive faunal diversity. The baseline data itself is missing to pile on further extensive research on the moths. I have thus chosen to explore the Western Himalaya, in terms of moth species diversity and richness. Keeping all these in mind, the idea is to understand how the moths of the region have evolved. The molecular data will actually help generate the baseline data of diversity and form the foundation for future applications on the ecology and patterns across other taxa.

I evaluated this ‘wedding’ of barcoding and inventories (Janzen et al. 2005) and its effectiveness for the initial screening for a faunal inventory in a hyper-diverse group, as well as its ability to flag exotic and cryptic species.

Study Area

The study was conducted in Nanda Devi National Park area which is a part of the Nanda Devi Biosphere Reserve (NDBR), Uttarakhand, India. It covers an area of 6,407.03 km² (core area: 712.12 sq.km, buffer zone: 5148.57 sq.km and transition zone: 546.34 sq.km), with an altitudinal range of 1800m-7816m asl. It lies in the northern part of Western Himalayas in the biogeographic zone 2B. It is one of the major protected areas of the Western Himalayan Region.

Key Research Questions

1) How do species composition and pattern of diversity change in the Geometridae family of moths along the altitudinal and vegetation gradient?

2) How do molecular tools complement traditional morphology to ascertain species diversity and unveil cryptic diversity?

Objectives

1. To prepare an inventory of the geometrid moths of the study area.
2. To assess the ecological factors those, affect the diversity and species composition of Geometrid moths in the study area.
3. To establish a DNA barcode library for the Geometrid moths of NDBR

Methodology

The study area (Nanda Devi Biosphere Reserve) was stratified on the basis of elevation & vegetation and sampled at every 200m along the elevation between 2000-3800m. Two mountain gradients 1) Joshimath and 2) Lata were chosen for a comparative study. DNA extraction and sequencing were performed at the CCDB, University of Guelph. Sequences of further specimens from the Zoologische Staatssammlung München from western Himalaya (Himachal Pradesh and Kashmir) and eastern Himalaya (Sikkim) were included into the analysis.

Main results

A total of 185 geometrid morphospecies were recorded, belonging to 77 genera, out of which 113 species were subjected to DNA barcoding. Distinct Barcode Gaps exist between most of the species studied, thus confirming their discrimination. Our results revealed one new species (*Prometopidia* sp. nov.), one new distribution record for India (*Alcis paghmana*) and considerable distribution extensions of 15 other species within India. Four species from Sikkim show deep genetic divergences (K2P distance) from conspecifics, indicating potential crypsis.

Differential response of species richness exists in both gradients, where Lata gradient clearly shows a unimodal peak in the mid-elevation Western Mixed Coniferous forest type and the western Himalayan birch oak forest (3300-4000m) shows high species nestedness. In both cases, vegetation composition and structure define the species composition of the area and more species are accommodated in a complex vegetation habitat. Both the gradients sampled within the landscape, showed that anthropogenic disturbance caused as a result of habitat fragmentation (human habitation), resource extraction in form of fuelwood and timber (lopping and felling) as well grazing (pellet signs) impacts the geometrid moth assemblage structure and their patterns across the elevation.

Conclusion

The investigated landscape faces degradation and loss of biodiversity but also is a refuge to unique diversity. This study will aid further research, providing effective geographical distribution data, ecological understanding and foundation for their conservation in the face of habitat degradation and climate change.

List of appendices

	Details
Appendix 3.1	List of species collected and identified in the study with collection details.
Appendix 4.1	Details of the light trapping locations across the study area.
Appendix 5.1	Neighbour-joining tree (Kimura 2 parameter) of all the 294 CO1 sequences generated from the specimens collected during the study and Collection Herbulot samples from Zoologische Staatssammlung München, Germany and Wildlife Institute of India.

List of appendices

	Details
Appendix 3.1	List of species collected and identified in the study with collection details.
Appendix 4.1	Details of the light trapping locations across the study area.
Appendix 5.1	Neighbour-joining tree (Kimura 2 parameter) of all the 294 CO1 sequences generated from the specimens collected during the study and Collection Herbulot samples from Zoologische Staatssammlung München, Germany and Wildlife Institute of India.

Contents

Chapter 1

Introduction

1.1 Need for insect conservation:

Insects are widely known for their huge diversity than other taxonomically equivalent groups (Ferns & Jervis, 2015). May (1988) express it thus: ‘To a rough approximation . . . it can be said that essentially all organisms are insects’. Insects are capable of feeding on a variety of food sources and colonising a vast array of habitats and are thus likely to be rich in diversity. The relatively species-poor group of insects are scattered widely among the species–rich groups, which is a striking feature in insect ordinal phylogeny similar to the evolution of the lower insect taxa (Kristensen, 1999; Grimaldi & Engel, 2005). There are more than 30 known insect groups, seven of them have around 10,000 species and four over 100,000 (Ferns & Jervis, 2015). Lepidoptera is one such group which has gone through the most recent diversification, as their larvae exploit a wide range of food resources but the adults mostly depend on the on nectars for their powerful and sometimes long-distance flights.

The world has plunged into an environmental crisis due to the ever-increasing habitat loss resulting in high species extinction (Pimm et al.1995, Vitousek et al. 1997). An insect species is far more likely to go extinct than ever before (Régnier et al. 2015), for which it goes unnoticed (Fonseca, 2009). The resources available to combat this crisis are no match to the cause of this rate of decline (James et al. 1999). Habitat loss and forest fragmentation top the list of causes of biodiversity crisis (Wilson, 2002 and Ceballos et al. 2015). But what is this biodiversity comprised of? We have incomplete knowledge, which impedes our ability to account for the species extinctions and is best exemplified by the hyperdiverse invertebrate communities in tropical rainforests (Basset et al. 2012 and Lamarre et al. 2016).

Insect studies/surveys have become a challenge because of the vast sampling effort and taxonomic expertise required. There is a lack of both as there are field constraints and a shortage of available resources. Attaining an asymptote in entomological studies is extremely difficult (Fontaine et al. 2012; Ashton et al. 2014; Lees et al. 2014). Consequently, the lack of basic knowledge on insect diversity is reducing our ability to save and conserve the group of animals which dominate the global biodiversity.

Traditional approaches to document the unknown biodiversity need to be supplemented with measures to tackle the rate of changes taking place in the demographic, economic and socio-political scenarios (Sharma et al. 2008). DNA barcoding is an important method to supplement traditional morphological and anatomical taxonomy (Lamarre et al. 2016). Many new species have been described using a combination of DNA barcoding and traditional taxonomy, thereby, this updated knowledge is important for managerial purposes and to formulate local conservation policies to prevent "Centinelean extinctions" (extinction before the discovery of the species) (Wilson, 2002)

1.2 Need for integrative taxonomy

Biological diversity is in an era of unprecedented loss, which has created a need for effective methods of species discovery (Kekkonen et al. 2015). Species delineation has become crucial to science than ever before. Traditionally, this has been approached based on morphological traits alone. With environmental changes over evolutionary timescales, different species have combated the situation giving rise to genetic variation. The morphological characteristics are often misleading owing to such variation. Taxonomy, which is a dedicated field of discovery, identification and describing new species has been the topic of many discussions (Lee, 2002; Blaxter & Floyd, 2003; Lipscomb et al. 2003; Moritiz & Cicero, 2004; Prendini, 2005; Meier et al. 2006; De Carvalho et al. 2008). The “taxonomy crisis” (Wilson, 1985) is mainly due to the lack in communication between different species delimitation techniques, tedious nature of the work, lack of specialists in different groups and geographic areas and also the lack of funds (Wilson, 2000; Godfray, 2002; Mallet & Willmott, 2003, Scotland et al. 2003).

The most fundamental question that we need to address through taxonomy is not how to identify species but rather how to delineate them and classify them (Dayrat, 2005), which nowadays are handled by employing phylogenetic methods (Wiens, 1998; Wiens et al. 2003; Kress et al. 2009; Wheeler, 2004; Munch et al. 2008; Pramaul et al. 2010; Feng et al. 2011; Wong et al. 2011; Liu et al. 2011; Biju et al. 2014 to name a few). These are more informative as they aim to reconstruct natural relationships among living beings. Integrative (molecular) approach towards taxonomy is suggested to solve this problem, to revitalize the traditional taxonomy by complementing it (Tautz et al. 2003, Hebert et al. 2003a). “Integrative taxonomy is defined as the science that aims to delimit the units of life’s diversity from multiple and complementary perspectives (phylogeography, morphology, population genetics, ecology, development, behaviour etc.)” (Dayrat, 2005). Rigorous species delineation is needed as many broad questions regarding the ecology, biogeography and evolutionary relationships (Brown et al. 1996; Blackburn & Gaston, 1998; Brooks & McLennan, 1999, Baraclough & Nee, 2001; Sites et al. 2004) depend partly or wholly on the baseline data of species inventories.

There are about 10 million species yet to be discovered (Wilson, 2004), so the debate over integrative taxonomy is the call of the hour. Traditional taxonomy is limited by the fact that it only discriminates "morphospecies" (Cain, 1954) and describes the "morphodiversity". Morphospecies is a concept which needs to be evaluated by different approaches. Several new methods of species delineation have been developed in the last two decades or so (Avise & Ball, 1990, Avise, 2000, Sites & Marshall, 2003). The application of several methods helps taxonomy to go beyond the naming of species and, also to understand the processes bringing it about (Shlick-steiner et al. 2010). The contributions of these methods are significant in terms of uncovering cryptic species in tropical terrestrial taxa (Bickford et al. 2007; Burns et al. 2008; Condon et al. 2008; Malhotra & Thorpe, 2004; Raxworthy et al. 2007; Yoder et al. 2005) and in situations of high intra- and interspecific variations. Integrative taxonomy does not replace, but it avoids the slow taxonomic routine of traditional taxonomy compressing it into one procedure (Adams, 2001; Agnarson & Kuntner, 2007; Hey et al. 2003; Wheeler, 2004; 2007) improving the rigor for creating biodiversity inventories (Schlick-steiner et al. 2010)

DNA Barcoding is based on 650 base pair (bp) segment of the mitochondrial Cytochrome oxidase (CO1). It was initiated by Hebert et al. (2003a), and it promptly started a revolution in the existing species delineation methods. The tool works on the concept of "barcoding gap" which states that the intraspecific divergence in CO1 has to be less than the interspecific divergence among two potential species. In the drive for global biodiversity assessment and conservation, identifying the unknown, in a time and cost-effective way defines the goal of DNA Barcoding.

Reference libraries of DNA Barcodes for the group of Lepidoptera are comprehensive till date (records on the Barcode of Life Database or BOLD; www. Lepbarcoding.org) (Ratnasingham & Hebert, 2007; 2013). These reference libraries can facilitate rapid identification where morphological identification is insufficient. The taxonomic impediment delaying the process of describing new species to science can be overcome with such an approach (Mora et al. 2011). Taxa identified and proposed by integrating molecular and traditional taxonomy will better support the foundation for further studies, and define species which would best reflect the existing biodiversity (Dayrat, 2005; Pires & Marinoni, 2010). But these databases are incomplete, particularly for certain under-surveyed tropical/sub-tropical regions and, require taxonomic intervention, incorporating distributional data by co-ordinating with the experts (Lamarre et al. 2016)

1.3 Moth as an indicator taxon

There is a progressive clearing (or fragmentation) of ecosystems of undisturbed areas for human use, which has a profound effect on the biological diversity. The vegetation patterns change and become more complex. Consequently, species richness declines, patterns of abundance change, endemism patterns are altered; overall modifying the structure of the ecosystem (Kitching et al. 2000; Schelhas & Greenberg 1996; Laurance & Bierregaard, 1997).

Many studies have shown invertebrates as indicators of the environmental quality and monitoring human impacts on biodiversity (Andersen et al. 2002; Pearce & Venier 2006; Nakamura et al. 2007; Brown 1997; Fleishman & Murphy 2009). Arthropods, in general, are negatively affected by grazing, shelter loss, predation and other disturbances (van Klink et al. 2015). Niemelä et al. (1993), which explains how fast-reproducing species (with short generation times) have a faster response to disturbance, and thus, are better indicator species. Invertebrates adapt rapidly to changes in the environment and habitat compared to plants and lichens, as they are mobile (Enkhtur et al. 2016). Bioindicator plants and lichens are difficult to monitor and complicates their presence or absence in a particular area (Best & Bork, 2003). Moths, in particular, have been known to be responsible for many ecological processes as pollinators, selective herbivores and prey for passerine birds (Lomov et al. 2006; Corlett, 2016; Hahn & Brühl, 2016).

How moths can adapt to the habitat alterations is largely governed by their dispersal abilities, species traits and resource demands (Hawes et al. 2009; Merckx et al. 2009, 2010, 2012; Slade et al. 2013). Moths of the Geometridae family are highly vulnerable to land use change as they are forest-dependent and tightly linked to the environmental conditions (Ricketts et al. 2001; Hilt et al. 2006; Kitching et al. 2000; Beck et al. 2002, 2007; New, 2004). High diversity of Geometridae are found in high understory diversity forest (Intachat et al. 1999). Geometridae moths are thus considered a potential indicator group to monitor forest recovery or habitat disturbance. Other moth families (like Arctiinae subfamily of the family Erebidae) have the capacity for colonizing human affected areas replacing the forest species with generalists or herb feeding taxa (Summerville et al. 2004; Winfree et al. 2011; Summerville & Crist, 2004; Hilt & Fiedler, 2005; Nöske et al. 2008).

Moths are useful indicator species as they are abundant, well distributed in different habitat, closely interact with the vegetation structure (Axmacher et al. 2011) and sensitive to environmental alterations (Maleque et al. 2009). If the species number and the species range can be monitored, new insights in environmental changes and broader climate change impacts can be ascertained (Bachand et al. 2014; Folcher et al. 2012; Summerville et al. 2004; Kitching et al. 2000; Kroupa et al. 1990). Sometimes moths can be used as surrogate taxa for other animal groups (Lund & Rahbek, 2002). Moths can integrate information of a larger geographical area (Enkhtur et al. 2016). Enkthur et al. 2016 also demonstrated that moths are useful indicators for overgrazed and less grazed and might be better indicators than arthropod groups of other trophic levels and life histories (ants, beetles) as these groups are less exposed to the direct impacts of grazing and related pressures.

Thus, macro-moths can be used as accurate indicators of ecosystem quality and at least in the present situation of habitat degradation and climate change; it may be a quicker way to do it quantitatively; along with careful and qualitative vegetation assessment (Kitching et al. 2000)

1.4 Importance of the study in the context of the current status

In the context of literature review for Indian studies on moth, it can be said that there is still plenty of lacking for even faunistic inventory for a particular state or landscape or in a Protected Area. This study aims to document the diversity within the Protected Area of Nanda Devi Biosphere Reserve. Other Protected Areas where the moth fauna has been studied in the state of Uttarakhand are the Gangotri National Park and Govind Pashu Vihar Wildlife Sanctuary (Sanyal, 2015; Sanyal et al. 2011, 2013). Outside Uttarakhand, moth inventories (partial or full) of some Protected Areas have been made (Mathew & Rahmathulla, 1995; Chandra & Rajan, 1995; Chandra, 1996; Chandra et al. 1996; Chandra & Nema, 2003; 2006; Sivasankaran et al. 2011; Chandra

& Sambath, 2013; Bharamal, 2015; Biswas et al. 2016; Singh & Ranjan, 2016; Shah et al. 2017 among others). This present study will enrich knowledge about the moth biodiversity in Uttarakhand which has a unique landscape pattern of western Himalaya, the meeting point of Oriental and Palaearctic faunal elements.

An inventory of biodiversity is of primary importance as part of biodiversity conservation for sustainable development, particularly in threatened and fragmented landscapes like western Himalaya that harbours a unique assemblage of flora, fauna of considerable conservation importance. Inventory of insects in Western Himalayan landscape is still fragmentary and incomplete which makes monitoring and conservation of insect biodiversity impractical for the protected area managers. Instead of studying the entire insect community the attention should be given to identify and select an easy-to-monitor assemblage that serves as a surrogate for entire insect community and act as an indicator of changes in habitat quality. Order Lepidoptera comprising butterfly and moth can easily serve this purpose as they are critical to the functioning of many ecosystems being strongly associated with vegetation structure and composition. The butterfly taxonomy and distribution relatively well studied in western Himalayan perspective. But the moth study lacks significant addition in this particular landscape since the "Fauna of British India" series published in 1892 to 1896, although sampling moths are relatively easy as they are readily attracted to light traps, and they are extremely diverse to offer powerful discrimination in detecting ecosystem level impacts. In this context, the current study proposes to document moth diversity and distribution in the Protected Area Network of Uttarakhand. An attempt will also be made to correlate moth diversity as a surrogate for overall insect diversity so that by sampling this subset of fauna, protected area managers can have an overall picture of insect diversity in a particular landscape and work towards their conservation.

In this study, I have provided an initial database of moth fauna and from field sampling. The sampling protocol can be established for forest moth survey and monitoring in temperate and alpine zone of Himalaya which is so far poorly studied for this particular group. This study will add to the diversity and distribution of Geometridae moth assemblages among different elevations and vegetation types of Protected Areas of Uttarakhand. The influence of climatic, topographic and anthropogenic effect on Geometridae has been understood. It is possible to identify groups of indicator species with correspondence to intact or disturbed patches in given landscape. This will have a conservation implication by depicting the habitat condition of the landscape which is a very important repository for unique Himalayan flora and fauna. In short, this study will promote moth as model terrestrial insect group for concurrent conservation management target.

Importance of the family Geometridae

The Lepidoptera family Geometridae (Lepidoptera: Geometroidea), also known as looper moths, is, together with the Erebidae, the most species-rich family of moths worldwide. This group is a well-established model group for biodiversity studies in temperate and tropical regions (Brehm, 2002; Brehm & Fiedler, 2003; 2004; Brehm et al. 2003 a & b; 2005; 2007; 2013; Axmacher et al. 2004; 2009 a & b; Barlow, 1982, Barlow & Woiwod, 1989). Geometridae family includes many pest species and is also very important from an economic point of view and for forest management. There exists cryptic colouration in the adult specimens, mostly nocturnal, resting position is with wings lying flat on the substrate (i.e. planiform). It is a cosmopolitan family with the exception of Antarctica and their diversity peaks in tropical South America, Africa and South-east Asia (Brehm, 2002; Brehm & Fiedler, 2003, 2004; Brehm et al. 2003 a & b; 2005; 2007; 2013; Axmacher et al. 2004; 2009 a & b; Barlow, 1982, Barlow & Woiwod, 1989). Large parts of this diverse family may be at the risk of extinction due to destruction and fragmentation of their habitats.

Although the taxonomy of this family is well established for the temperate regions, the tropical areas need large-scale revisions. Around 23,000 species have been described comprehensively to date worldwide (Scoble & Hausmann, 2007). There is no comprehensive morphology-based phylogeny available for geometrid moths, but the relationships between subfamilies and many tribes were recently assessed from the analysis of several nuclear genes (Young, 2006; Yamamoto & Sota, 2007; Regier et al. 2009; Sihvonen et al. 2011) largely confirming the traditional classification derived from morphological traits.

Geometrid species are formally described only by very few taxonomists. A cursory inspection shows high synonymy at the species level in this family which suggests much more revisionary work is pending. Many species are still based on syntypic series and do not yet have primary types designated. The revisionary work if done at the generic level would be the most valuable contribution to Geometridae taxonomy (Scoble et al. 1995).

The most prominent work on the ecology of Geometridae moth are done by: Beck & Chey (2007) who worked on the beta diversity of Geometrid moth from northern Borneo and effect of habitat, time and space on moth assemblages. Brehm & Fiedler (2004) who saw the pattern of body size change and Brehm et al. 2003 a & b, 2005 looked into beta diversity and overall diversity patterns of Geometrid moths along an elevational gradient in the Andean rainforest. Axmacher et al. 2004; 2009 a & b; looked into the determinants of diversity and the diversity patterns along elevation in the Afrotropical rainforest.

1.5 The Himalaya as a biodiversity hotspot

Mountains have always been considered as centres of spectacular biological diversity, so the Himalayas also stand as one of the major mountain systems supporting high biodiversity. But human activities are threatening such an important resource. The Himalayan mountain system has been recognized globally for its ecosystem services for maintaining slope stability, regulating hydrological integrity, sustaining high levels of biodiversity and gaining attention for biodiversity conservation in global agendas (Sharma et al. 2008).

The Himalayan region offers unique biodiversity and high endemism partly due to topographical isolation (Körner, 2004; Salick et al. 2004). As a combined effect of habitat diversity and climatic zone compression, species richness is higher in the Himalayan region (Xu et al. 2009). There are numerous critical ecoregions of global importance (Olson et al. 2001; Olson & Dinerstein, 2002). Species will start to shift their range if they can detect the shifting climatic zones (Menzel et al. 2006). The niches to be occupied by shifting species might decrease in size along elevational gradients (Körner, 2007) and the climatic and geographic barriers in the Himalayan region might prevent migration across latitudes also (Xu et al. 2009)

The Himalayan Region expands over 300km across northern Pakistan, North-western and north-eastern states India, Nepal, and Bhutan. The 'Himalayan Biodiversity Hotspot', is one of the 34 global biodiversity hotspots, has a rich spectrum of floral and faunal species. The mountains exhibit drastic changes in elevation resulting in a diversity of habitat and ecosystems. There are about 3160 endemic species of plants, 269 species of Fishes, 105 species of amphibians, 176 reptiles and 977 birds. Birdlife International has identified 4 Endemic Bird Areas in the Himalayan Region. Himalayan forests have major functions as they harbour unique biodiversity, anchor soil and water, act as carbon sinks and regulate climate. The forests are also important for forest produce for local livelihoods and economies. There is a predicted shift of ecosystems in the 21st Century, but it remains unclear as to what these shifts will mean. The ongoing resource extraction and forest habitat fragmentation will definitely affect biodiversity loss, but nothing has been linked yet to climate change predictions (Pandit et al. 2007)

The steadily increasing human encroachment is leading to cleared forests for cultivation and logging for fuelwoods. The forests are fragmented and natural habitat is degrading as a result of the ever-growing human settlements. Along with this problem, there is intensive grazing by livestock in the lowlands and the alpine grasslands. The mountains are also cut through for the construction of roads, dams across rivers which are endangering the ecosystem for the survival of the animals (source:**http://tech-organic.blogspot.de/2011/09/himalayan-biodiversity-hotspot.html**)

1.6 Some prominent studies on Geometridae moths from the western Himalaya

The comprehensive work on moths of different regions of western Himalaya within the Indian territory was mostly carried out by Hampson (1892, 1894, 1895 & 1896) in his “Fauna of British India” series and Cotes & Swinhoe (1887) in “A catalogue of moths of India”. There are some notable studies focussing the on Geometridae moths from this region; Pajni & Walia (1984 a & b) described three new species of subfamily Geometrinae namely *Chlorissa albifasciata, Euchloris pallidmarginata, Chloeres multimaculata, Mixocera albilineata* in from Himachal Pradesh and North-West India. Walia & Pajni (1987) wrote the taxonomic keys to 12 genera of subfamily Scopulinae and reported 40 species from North-West India including eight new species. Rose (1986) reported a new species of *Chlorissa* from North India, Walia (1988, 2005) published a list of 33 and 184 Geometridae moths from Northwest India, Chandigarh and Himachal Pradesh respectively, Walia & Anju (2005) reported a new species *Chlororithra sairighatensis* (Subfamily: Geometrinae) from Himachal Pradesh, Smetacek (2004) reported *Corymica deducata caustolomaria* as a new subspecies, Kirti et al. (2007; 2008 a & b; 2009; 2011; 2014) published more than 20 species and described genitalic structures of some Geometrid species, Stüning & Walia (2009) recorded four species of *Astygisa* and described a new species *Astygisa hollowayi*. From Uttarakhand state, some prominent works include Arora (1997; 2000) who published some moth species from the Nanda Devi Biosphere Reserve, Garhwal Himalaya, Smetacek, 1994; 2008; Sanyal, 2015; Sanyal et al. 2011; 2013; 2017; Dey et al. 2015; 2017 and Sondhi & Sondhi 2016. Sanyal et al. 2011; 2013 and Dey et al. 2015; 2017 have looked into the diversity and distribution of moth assemblages but none of the studies so far have ventured into the molecular phylogenetics area of research. Fig.1.1 shows the locations of the studies done so far from the state of Uttarakhand. There is a lot of area to be studied in this mountainous state to understand the diversity and the underlying patterns in a more comprehensive way.

1.7 Aims and Objectives of the study

1. To prepare an inventory of the geometrid moths of the study area.
2. To assess the ecological factors those, affect the diversity and species composition of Geometrid moths in the study area.
3. To establish a DNA barcode library for the Geometrid moths of Nanda Devi Biosphere Reserve.

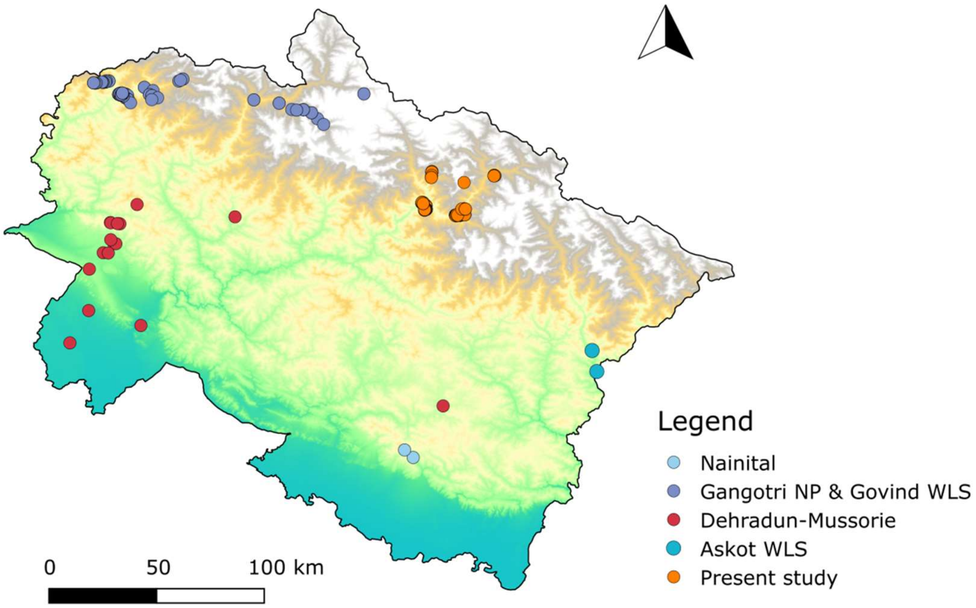


Figure 1.1: Map showing the locations of studies on moths done so far from the state of Uttarakhand, India

Chapter 2

Study Area

2.1 Study Area: Nanda Devi Biosphere Reserve

Nanda Devi Biosphere Reserve (NDBR), (30º 08’-31º 02’N, 79º 12’- 80º 19’E), which includes both the Nanda Devi National Park (NDNP) and Valley of Flowers National Park (VoFNP) (Negi, 2002), is located in the northern parts of the western Himalaya in the biogeographically classified zone, 2B (Rodgers et al. 2000). It covers an area of 6,407.03 km^2 (core area: 712.12 km^2, buffer zone: 5148.57km^2 and transition zone: 546.34 km^2), with an altitudinal range of 1800m-7816m asl. It spreads across Chamoli, Bageshwar and Pithoragarh districts of the state of Uttarakhand. It was established under UNESCO’s Man and Biosphere Program (MAB) on 18 January 1988. It is a high-altitude Biosphere Reserve in the Indian Himalayan Region. The region comprises a unique habitat of temperate forests, alpine meadows and glaciers. The core zone comprises of the Rishi Ganga Catchment Area. All the reserve forests within the boundary of the Protected Area lie in the Chamoli district (Rao et al. 2000). Both Nanda Devi and Valley of Flowers National Parks are exceptionally beautiful high-altitude Western Himalayan landscapes with outstanding biodiversity. Nested high in west Himalaya, Valley of Flowers National Park is a meadow of endemic alpine vegetation and outstanding natural beauty. The area is well-protected due to its remoteness and limited access. The highest point is the Nanda Devi Peak at 7817m surrounded by the deep Rishi Ganga gorge and the spectacular topographies of glaciers, moraines and alpine meadows.

A brief chronology of the establishment of the region as a UNESCO World Heritage site is as follows:

1980: The Valley of Flowers was declared a National Park by Government Order 4278/XIV-3-66-80; under the provisions of the Wildlife Protection Act of 1972, for the conservation of its flora;

1982: The Park was renamed Nanda Devi National Park;

1988: The Nanda Devi Biosphere Reserve was established (2236.74 km^2) with the National Park as core zone (624.62 km^2) and a 5148.57 km^2 buffer area surrounding both sites; restrictions were imposed on the rights of nearby villagers;

2000: The Biosphere Reserve was extended by the government to 586,069 ha and the Valley of Flowers National Park was added as the second core zone (624.62 km^2 + 87.50 km^2, totalling core areas of 712.12 km^2;

2004: The two core zones and buffer zone were designated as UNESCO MAB Reserve.

(Source: UNEP-WCMC document on Nanda Devi & Valley of Flowers National Parks Uttaranchal, India)

The Biosphere Reserve is considered one of the most biologically diverse Protected Area. Sudden changes in elevation have formed different topographical and climatic zones giving a mosaic of different vegetation types and a region of unique species distribution. The gentle rolling meadows of the Valley of Flowers National Park is in contrast to the steep, rugged landscape of the Nanda Devi National Park.

The area is subjected to community-based ecotourism in different parts but otherwise there is no grazing related anthropogenic pressure since 1983. There is ongoing extraction of forest resources by the local communities. The natural processes are maintained here and thus the region can be targeted for long-term ecological monitoring. There is a buffer zone of 5148.57 km^2 in the protected areas which has a wide range of elevation and habitats. The Kedarnath Wildlife Sanctuary and the Reserved Forest divisions located in the west, south and east of the Biosphere Reserve add to the buffer region. The region is also an Endemic Bird Area (EBA).

2.2 Forest Types

Forests are dominated by Pine species (*Pinus roxburghii, Pinus walichiana*), West Himalayan Fir (*Abies pindrow)* and *Rhododendron campanulatum* upto about 3500m. Forming a broad belt between these and the alpine meadows is Himalayan birch (*Betula utilis)* forest, with an understorey of rhododendron. The vegetation changes from forest to dry alpine communities, with a dominance of scrub juniper (*Juniperus pseudosabina*). As one goes up the elevation, junipers give way to grasses, mosses and lichens, and to annual herbs and dwarf willow (*Salix* spp.) on riverine soil. Woody vegetation extends along the sides of the main glaciers before changing gradually to squat alpines and lichens (Lavkumar, 1979; Hajra, 1983).

Forest types sampled:

Intensive sampling was done in two main gradients: i) Joshimath-Sunil-Auli ii) Lata-Belta-LataKharak and in and around four other villages namely Tolma, Malari, Bhyundar and Ghangria. The latter two villages were the only places sampled within the buffer zone of the Valley of Flowers National Park (Fig. 2.1; 2.2; 2.3).

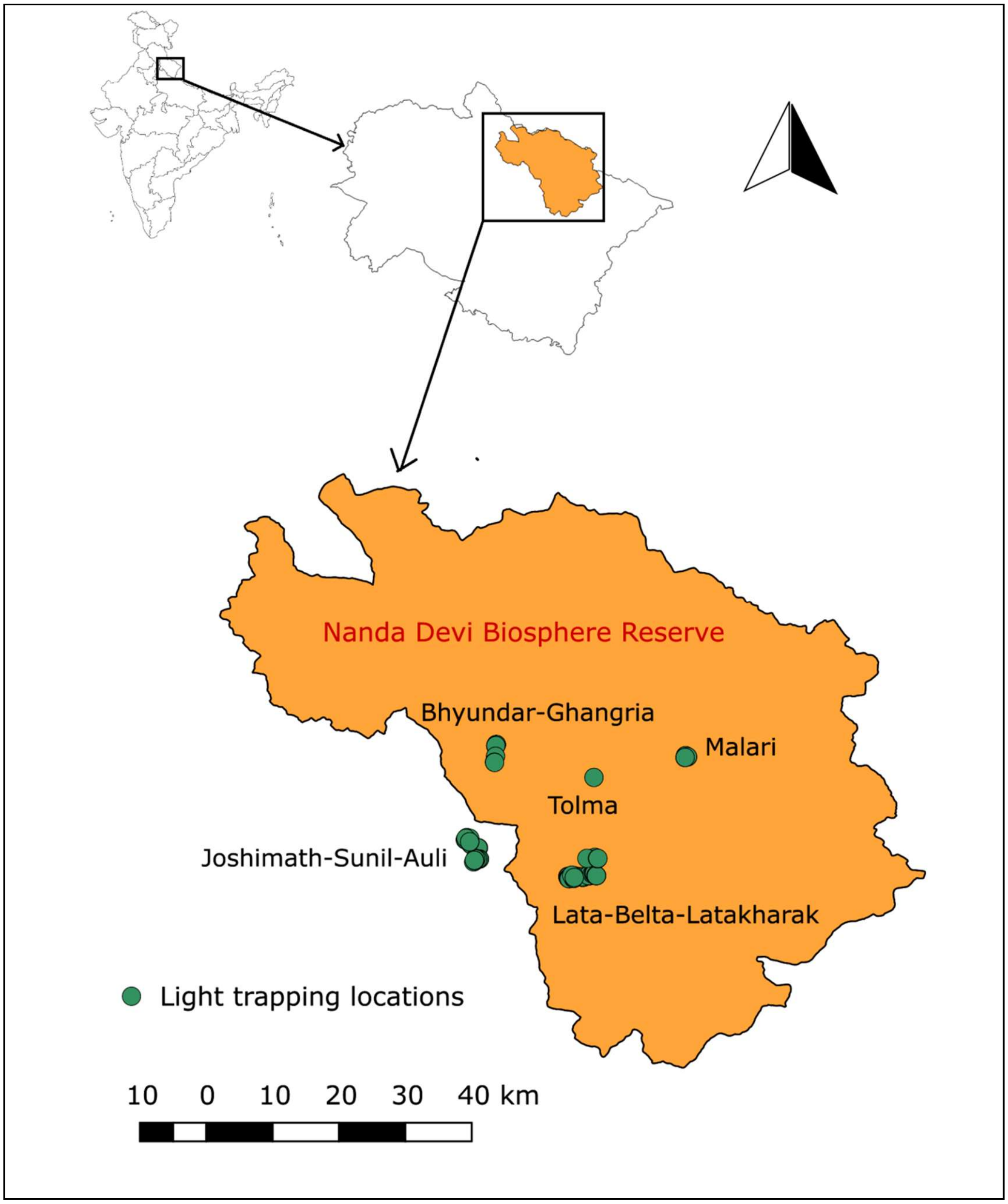


Figure 2.1: Map showing location of the study area Nanda Devi Biosphere Reserve within the state of Uttarakhand and the sampling locations in and around the Protected Area.

The forest types sampled, were classified based on the dominant vegetation according to Champion & Seth (1968) as follows:

Group 12: Himalayan moist temperate forests

1) C1: Lower Western Himalayan temperate forests having the following subtypes:
    a) Moru Oak forest (C1b) (2600-2800m)
    b) Moist deodar forest (C1c) (2200-2400m)
    c) Western mixed coniferous forest (C1d) (2300-2500m; *Pinus-Cupressus-Abies*); (2500-2700m; *Pinus-Cedrus*); (2700-3100m; *Pinus-Abies*)
    d) Low-level Blue Pine forest(C1f) (2000-2200)
2) C2: Upper Western Himalayan temperate forests having the following subtypes:
    a) Kharsu Oak forest (C2a) (3000-3400m)
    b) West Himalayan Upper Oak-Fir forest (C2b) (2800-3000m)

Group 14: Sub-alpine forests:

1) C1: West Himalayan sub-alpine birch/fir forest
    a) West Himalayan birch/fir forest (3500-3900m)

2.3 Floral and Faunal diversity

2.3.1 Floral diversity

A total of 490 species belonging to 281 genera and 89 families of Angiosperms (480 species, 274 genera and 85 families) and Gymnosperms (10species, 7 genera and 4 families) have been recorded from NDNP. Of these, 357 species are herbs, 103 shrubs and 30 trees. Eleven families, Rosaceae (36 spp.), Asteraceae (32 spp.), Ranunculaceae (31 spp.), Poaceae (24 spp.), Apiaceae (22spp.), Orchidaceae (20 spp.), Fabaceae (18 spp.), Polygonaceae (17 spp.), Saxifragaceae (15 spp.), Lamiaceae (14 spp.) and Cyperaceae (13 spp.) were most speciose. *Saxifraga* (12 spp.), *Polygonum* and *Primula* (9 spp., each), *Carex* and *Potentilla* (8 spp., each), *Berberis*, *Corydalis*, *Lonicera*, *Rhodiola* and *Salix* (6 spp., each), and *Geranium*, *Ribes, Thalictrum*, *Cotoneaste*r (5 spp., each) are the dominant genera (Samant & Joshi, 2003). 8 threatened species recorded include *Nardostachys grandiflora*, *Picroehi zakurrooa* (VU), *Cypripedium elegans, C. himalaicum*, *Dioscorea deltoidea* (VU) and *Allium stracheyi* (VU). Local people use a total of 97 species, 17 for medicinal purposes, 55 as food plants, 15 as fodder, 16 for fuel, 5 for tools, 8 for house building, 2 as fibres, 6 for miscellaneous uses, and 11 for religious purposes.

The Valley of Flowers has an astounding 600 species with many rarities. The habitats include valley bottom, river bed, small forests, meadows, eroded, scrubby and stable slopes, moraine, plateau, bogs, stone desert and caves. The lower surrounding hills in the buffer zone are thickly forested. *Aconitum falconeri, A. balfouri*, Himalayan Maple (*Acer caesium)*, the Blue Himalayan poppy (*Mecanopsis aculeata)* and *Saussurea atkinsoni* (Green & Peard, 2005) are some of the threatened species found exclusively here. The dominant family is the Asteraceae with 62 species. 45 medicinal plants are used by local villagers and several species, such as *Saussurea obvallata* (Brahmakamal) are collected for religious offerings to Nanda Devi and other deities. It is dominated by the uncommon Himalayan Maple (*Acer caesium)* (VU), West Himalayan fir (*Abies pindrow)*, Himalayan White Birch (*Betula utilis)*, and *Rhododendron campanulatum* with Himalayan Yew (*Taxus wallichiana), Sorbus lanata*. Common herbs are *Arisaema jacquemontii, Boschniakia himalaica, Corydalis* *cashmeriana, Polemonium caerulium, Polygonum polystachyum* (Himalayan Knotweed- a rampant tall weed).

Common and singleseed junipers like *Juniperus communis* and *J. squamata*, *Rhododendron anthopogon*, *Salix* spp., *Lonicera myrtillus*, *Cotoneaster microphyllus*, and *Rubus ellipticus* are the major shrub species in this zone.

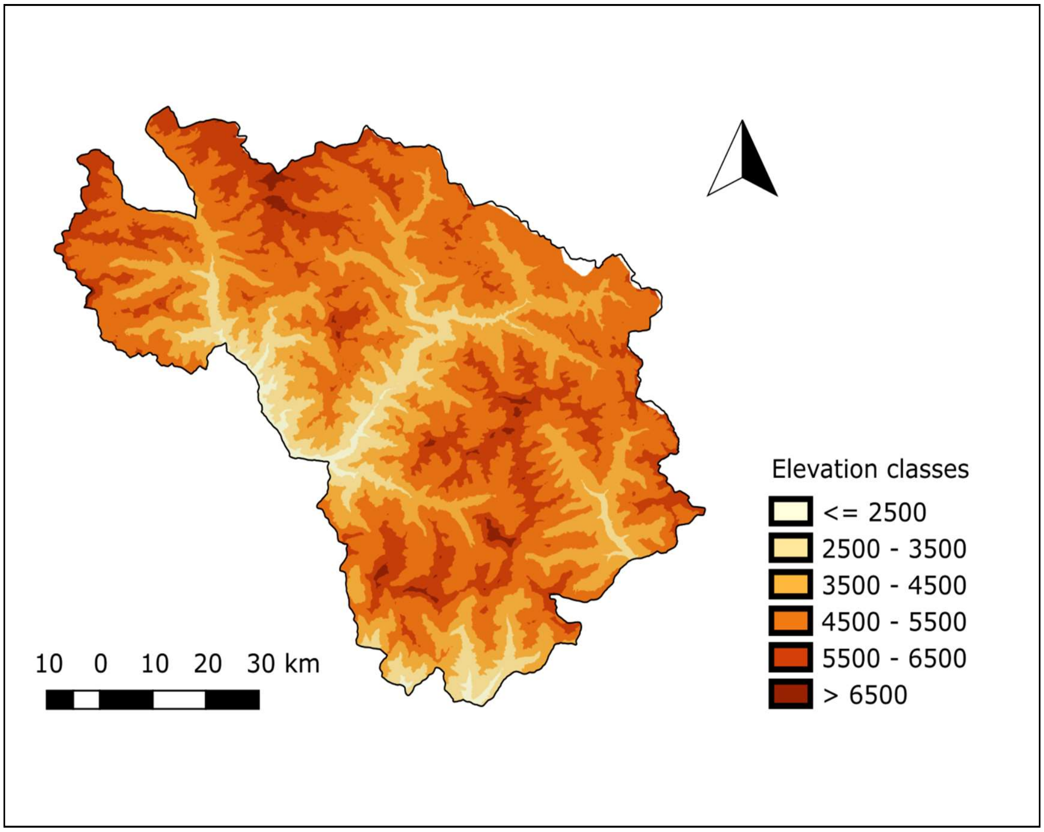


Figure 2.2: A digital elevation map of Nanda Devi Biosphere Reserve showing the different elevation zones (meters above sea level) within the Protected Area

2.3.2 Faunal diversity

Around 518 faunal species including mammal, birds, fishes, reptiles, amphibians, molluscs, annelids and invertebrates have been recorded so far in NDBR.

It comprises of 29 mammals, 228 birds, 3 reptiles, 8 amphibians, 6 annelids, 14 molluscs and 229 species of arthropods (Kumar et al. 2001). Snow Leopard (*Panthera uncia*), Common Indian Leopard (*Panthera pardus fusca*), Himalayan Musk Deer (*Moschus chryogaster*), Himalayan Tahr (*Hemitragus jemlahicus*), Himalayan Goral (*Naemorhedus goral*), Himalayan Serow (*Capricornis thar*), Bharal (*Pseudois nayaur*), Asiatic Black Bear (*Ursus thibetanus*) and Himalayan Brown Bear (*Ursus arctos isabellinus*) have been found in this region (Dang, 1961; Khachar, 1978; Kandari, 1982; Lamba, 1987; Uniyal, 2004; Sathyakumar, 1993; 2004; Bhattacharya et al. 2007; 2009 and Kandpal, 2010).

Common birds found are Grey-crested Tit (*Lophophanes dichrous*), Yellow-bellied Fantail (*Chelidorhynx hypoxanthus*), Himalayan Bluetail (*Tarsiger rufilatus*), Blue-fronted Redstart (*Phoenicurus frontalis*), Olive-backed Pipit (*Anthus hodgsoni*), Rosy Pipit (*A. roseatus*), Common Rosefinch (*Carpodacus erythrinus*), Lammergeier (*Gypaetus barbatus*), Himalayan Vulture (*Gyps himalayensis*), Yellow-billed and Red-billed Choughs (*Pyrrhocorax graculus* and *P. pyrrhocorax*), Scaly-bellied and Greater Yellow-naped Woodpeckers (*Picus squamatus* and *P. flavinucha*), Great and Blue-throated Barbets (*Megalaima virens* and *M. asiatica*), Snow Pigeon (*Columba leuconota*) and Spotted Dove (*Spilopelia chinensis*), Himalayan golden Eagle (*Aquila chrysaetos daphancea*), Black Eagle (*Ictinaetus malaiensis*), Himalayan Snowcock (*Tetragullus himalayensis*), Himalayan Monal (*Lophophorus impejanus*), Koklass (*Pucrasia macrolopha*) and Satyr Tragopan (*Tragopan satyra*) to name a few (Shankaran, 1993; Tak & Kumar, 1987; Reed, 1979 and Sathyakumar, 2004).The only primate was the Northern plains Gray langur (*Semnopithecus entellus*) (Tak & Lamba, 1985; Lamba, 1987) , but now it is known as the Central Himalayan Langur

(*Semnopithecus schistaceus*), although Rhesus Macaque (*Macaca mulatta*) has been also common now. Most often seen high altitude reptiles are Kashmir/Himalayan Rock Agama (*Laudakia tuberculata; cf. himalayanus*), Himalayan Ground Skink (*Asymblepharus himalayanus*) and Himalayan Pit Viper (*Gloydius himalayanus*). Not much is known about the invertebrate fauna of the region. Kumar et al. (2001) reported invertebrates from NDBR: 15 species of Mollusca, 6 species Annelida, 17 species of Arachnida, 1 species of Thysanura, 2 species of Collembola, 6 species of Odonata, 14 species of Orthoptera, 7 species of Dermaptera, 13 Hemiptera, 4 species of Neuroptera, 80 species of Lepidoptera, 2 species of Trichoptera, 24 species of Diptera, 24 Hymenoptera and 3 species of Chilopoda.

Baindur (1993) and Uniyal (2004) recorded the butterflies found in these areas: Common Yellow Swallowtail (*Papilio machaon*), Common Blue Apollo (*Parnassius hardwickii*), Dark Clouded Yellow (*Colias fieldii*), Queen of Spain Fritillary (*Issoria lathonia*), and Indian Tortoiseshell (*Aglais caschmirensis*). Quasin (2011) did an extensive study on spiders of the region, recording 244 species belonging to 108 genus and 33 families.

2.4 Protection and management requirements

Scientific forest management came into action only in 1990. However, large-scale timber extraction was stopped due to the famous "Chipko Movement" in 1974 by the women of the local village Reni. The reserve area is home to many plant and animal species of economic value. But, due to exploitation and anthropogenic influences, the natural populations are in a declining state.

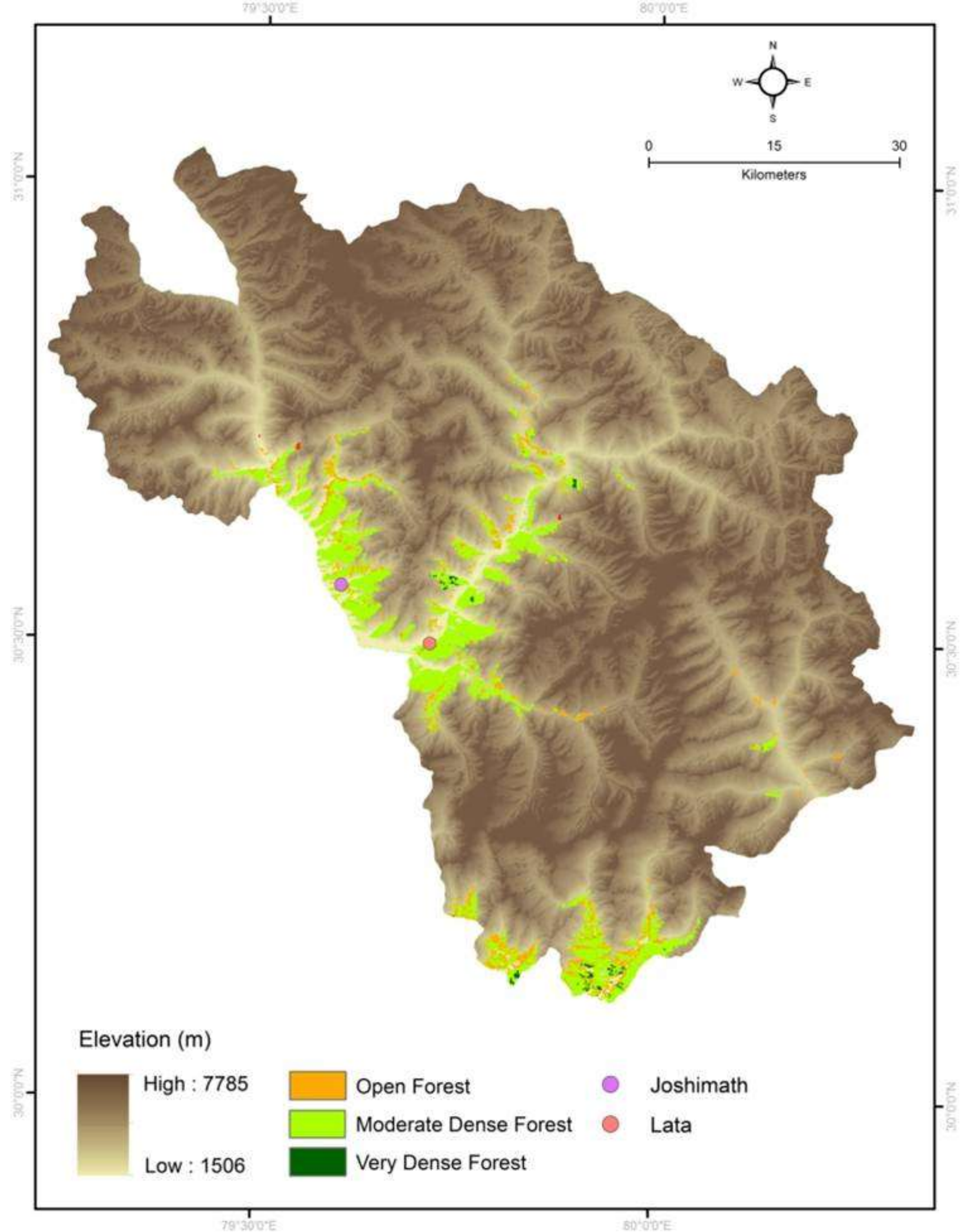


Fig. 2.3: The study area of Nanda Devi Biosphere Reserve showing the elevational extent and forest cover in the Protected Area and the two gradients sampled: Joshimath and Lata

The region is naturally well-protected due to limited accessibility. The Forest Department organises regular monitoring of the limited routes. The Protected Area is subjected to anthropogenic pressure with community-based eco-tourism regularly taking place, facilitated by the Park Management. The status of flora, fauna and the habitats are monitored through expeditions involving experts and scientists every 10 year since 1993. These expeditions have reported a sustained improvement in the status of flora and fauna and the habitats. Both the National parks and the Reserved Forests in the buffer zone are well protected and managed as per wildlife management and working plans. Regular monitoring of wildlife, tourism and pilgrimage management needs to be continued to maintain protection in this area. Community participation in resource management for biodiversity conservation is strong. Increasing tourism, trekking activities and development projects (hydro power projects) inside the buffer zone are the existing and potential threats that need to be addressed (Rao et al. 2000; Silori, 2004; Bosak, 2008).

Unorganized mountaineering activities threaten the biological integrity of the National Park. Pollution is one of the biggest problems caused by tourists. The camping sites on the trails become polluted with garbage from frequent hikers. Rivers and streams also become contaminated with leftover garbage, causing harm to the animals living in them and drinking from them. Deforestation and forest fires are also the environmental problems that the Nanda Devi Biosphere needs to control. Forest fires are the result of irresponsible fire building in the campsites of the park. Human activities in this Biosphere Reserve appear to have harmed, more than benefitted, the National Park (Bosak, 2008). A case where human activities had helped the Biosphere Reserve was the Chipko Movement when village women protested to save forests of the area (Nanda Devi Campaign). They stopped deforestation from occurring in their local forests one year. The residents of Nanda Devi want to do anything they can to help save their environment and keeps it flourishing for as long as possible.

With the plethora of different habitats and their dynamic nature, it is a hitherto unexplored regarding the insect fauna. A record of diversity and distribution of moths from this region would serve as a crucial baseline for future ecological research and will transcend into other groups of insects as well.

Chapter 3

Faunistic inventory of the Geometridae moths of Nanda Devi Biosphere Reserve

---

3.1 Introduction

The most fundamental questions that we ask in conservation science are: how many species exist, where they exist and, what are the drivers of the observed patterns of their distribution. For insects, the revealed patterns so far indicate the most accepted approaches to estimate species richness (Ødegaard, 2000). Insect conservation importance has now been recognised, but most insects' studies are impeded by what we call as the Linnean Shortfall (only a small fraction of the extant taxa is known) and the Wallacean short fall (sparse distribution data for most geographical regions) (Cardoso et al. 2011). Even the groups that have good taxonomic resolution are still incompletely known from regions which are poorly studied, like the tropics (Fattorini et al. 2012a); whereas the fundamental characters of dispersal, speciation and evolutionary divergence are common to most insects (Finlay et al. 2006).

Insects, in general, have a negative public perception and are thus often ignored in conservation plans by the conservation fraternity at large (Kim, 1993; McNaughton, 1989; Hafernik, 1992). The insects are the most economically important and hyperdiverse group of organisms on the Earth, but there is no consensus on the best way to document their diversity at multiple spatial scales (Finlay et al. 2006), and the task of documentation is full of uncertainty (Stork, 1997). Understanding the method to document the fauna is of utmost importance in evaluating the inventory completeness of insects (Fattorini, 2013), but it is so far an unexplored issue. The global insect species richness still is an elusive number, and there are evidences of ongoing extinction (Thomas et al. 2004) which makes the need of 'fast- tracking' the process of knowing the global insect diversity glaringly evident.

Inventory of biodiversity forms the base for developing practical, cost-effective monitoring programmes. Thus, faunal surveys help at obtaining maximal information return on the distribution of species and their habitats, although the ground plans of what and how to do are determined by the goals of each programme (Kim, 1993). There is a dearth of effective and reliable approaches to accurately assess the species richness at a regional scale, as nowadays, the biodiversity policies and conservation efforts are inclining towards a landscape scale or a country scale (Heywood, 1995; Fattorini et al. 2012 a & b).

Many studies have focussed on the importance of the little-known taxa in conservation science (Dunn, 2005; Pearson & Cassola, 1992 and Pimm & Gittleman, 1992). But, there is also a need for adequate information on these neglected groups; where in many groups, there are museum collections and specialized literature which can provide important and valuable data (Meier & Dikow, 2004; Guralnick & Van Cleve, 2005). Quick and general collecting techniques should be first adopted to form a general profile of the diversity present in an area and which will also provide a more comprehensive accounts for specific taxa. But from the conservation point of view, taxonomic surveys must be integrated with environmental surveys and continue for systematic and evolutionary research (Kim, 1993). Understanding the relationship between collecting effort and the number of species provides a basic approach to collecting surveys and acts as a predictive tool for biodiversity and conservation studies (Soberón et al. 1993).

Moths have long been regarded as the "poor cousins" of butterflies in Lepidoptera conservation, and have lagged well behind butterflies in popularity and the attention given to their conservation status and needs. Only rarely do they gain greater prominence, despite the enormous taxonomic and biological variety they display. Forest moth species have important functional roles as selective herbivores, pollinators, detritivores, and prey for migratory passerines. Furthermore, they have shown promise as forest indicator taxa (Summerville et al. 2003, Kitching et al. 2000). As for their ecology and habitat requirements, it is a difficult task to elucidate the myriad life histories and species interactions that exist, especially in the hyper diverse tropics (Leather et al. 2008). This is despite the widely appreciated importance of moths to the diversity and function of terrestrial ecosystems, at least among entomologists. The quantification of moth species diversity, and understanding the processes that drive their variation in diversity across space and time, form the basis of some of the most fundamental questions in moth ecology and evolutionary biology. Traditionally, these have been based on morphology-based species identification (Jin et al. 2013).

On the species level, there is a stark contrast in the situation between the geographic regions (Õunap, 2010). Species diversity and composition are well known in the western Palearctic, but the most biodiverse regions; like the tropics are still quite poorly studied (Holloway, 1993, 1996, 1997; Hausmann, 2003; Pitkin, 2005). In the present study, I have made an inventory of the Geometridae moths from a hitherto unexplored area of Nanda Devi Biosphere Reserve through systematic study.

Geometridae is known to be forest-dependent species and hence sampling was done in the different forest types in the study area to attempt to document the maximum diversity.

3.2 Methodology

3.2.1 Collecting Moths

Moth samples were collected through the light-trapping method during the study. Light –trapping is the most efficient and successful method of collecting moth samples worldwide and enables a wide array of taxonomic group to be sampled quantitatively in large numbers. Many factors are involved for the success of collection of moths through light-trapping, like the effect of light wave length (particularly in the ultraviolet), intensity, trap-type, climatic factors (such as wind, humidity, temperature, rainfall), moon light, trap sites, sex differences (males are generally taken in greater frequency than females) and time from emergence. The ideal time for light-trapping is from dawn to dusk, but different species are active in flying at different times during this period, so different light-trap timings should be employed. Sampling was done for the first 3-4 hours from dusk to capture the time of maximum activity of the Geometrid species. Late night sampling was not possible due to logistic constraints. Catches were restricted to phases between 5 days after full moon until 5 days before full moon, because the moon phase has an important impact on the efficiency of light traps (Yela & Holyoak 1997). Temperature, Humidity and windspeed variation was recorded at every hour of the collection time.

3.2.2 Preservation

While collecting, the moths from the field were temporarily kept in insect envelopes with labels. Specimens were pinned with micro pins and preserved in insect boxes. Male genitalia were also dissected out for specimens having confusions in the morphological identification and kept in 10% KOH solution for 12 hours, rinsed in distilled water for several times and then preserved in 70% alcohol for further identification.

3.2.3 Identification of Geometridae moths

It is a large family of moths, mostly found to be slenderly built. They are weak-flying, semi-diurnal or crepuscular in habit. Their food habit varies from mono-to polyphagy. They occupy tropico-temperate hills and mountains. They are low-flying insects inhabiting constricted spaces of thorny bushes. Geometrids are recognised by the forewing with the second median (M2) nearer the first (M1) than the third (M3) at the origin (though not very prominent in Fig.3.1), hindwing with a precostal spur at the extreme base and the abdomen houses antero-ventral tympanal organs (Fig.3.2) (Mondal & Ghosh, 1997). Proboscis and Frenulum present or rarely absent. Legs and tarsi slender, elongated and slightly hairy or naked. Forewing: vein 1a is forming a fork with 1b; 1c is absent; vein from above or middle of discocellulars, vein 7 rises from 8,9. Hindwing: Frenulum present, except for a few genera; vein 1a very short or absent in some; vein 1 b running into the anal angle; 1c absent; vein 8 has a well-developed precostal spur (Hampson, 1895). At rest, the fascia of wings is continuous. They can be readily differentiated from Pyralidae by their glossy wings, longer legs and sitting posture. The egg is generally flat. Two or three pairs of ventral prolegs of the larva are reduced or absent. The larva of most species prefers leaves of trees or shrubs as a food source. Many larvae produce green secretion from the mouth parts as a defence mechanism. They pupate under or on the surface of the ground or in leaves of the food plant. Certain Larentiinae from Hawaii are carnivorous, catching files and other active prey (Ghosh, 2003).

Some species exhibit sexual dimorphism. Male has a bipectinate antenna, hind tibia dilated, the frenulum is single bristle, thicker, sometimes with fovea, fascia more prominent, where as female posseses simple or smaller pectination, hind tibia not dilated, frenulum composed of a bundle of thinner bristles, fovea absent in female, in size comparatively bigger, fascia less prominent. In Holarctic regions, in cold countries, during winter some of the females are wingless, also known as the winter moth.

The traditional morphologically established Geometridae classification comprises of nine subfamilies: i) Ennominae ii) Larentiinae iii) Sterrhinae iv) Geometrinae v) Desmobathrinae vi) Oenochrominae vii) Archiearinae viii) Orthostixinae and ix) Alsophilinae (Holloway, 1997; Hausmann, 2001). In our study, we have found species from only the first four of these subfamilies, the details of which have been described in the following section. Recent molecular studies (Abraham et al. 2001; Young, 2006; Yamamoto & Sota, 2007; Wahlberg et al. 2010) have shown that these subfamilies, Ennominae, Larentiinae, Sterrhinae and Geometrinae, are monophyletic groups.

The entire family is defined by the tympanal organ structure, particularly the presence of the tympanic handle or ansa (Minet, 1983; Cook & Scoble, 1992). Geometridae and Uranoidea have chaetosemata, which distinguishes them from Drepanoidea, Bombycoidea and Noctuoidea. The characteristic feature of the larva is the abdominal prolegs reduced to those on A6 and A10 (Holloway, 1993).

3.2.4 Variations in the tympanal organ in different subfamilies

Lepidopteran tympanal organs consist of a tympanic membrane or tympanum and, a mechanoreceptor (chordonotal organ) is attached to it. The tympanum is supported by an air-filled chamber. Sound waves cause the tympanum to vibrate and, these vibrations are picked up by the sensor transmitting it to the auditory nerve. The tympanal organs of Geometridae have been less extensively studied than those of Pyralidae and Noctuidae. It is predominantly present in all species except, in somewhere it is reduced secondarily or lost (Cook & Scoble, 1992). Minet (1983) suggested that the tympanal organs are essentially the same throughout the family, but there is sexual dimorphism in the basic structure.

The hammer-headed ansa and the absence of tympanic lacinia (Fig.3.3) relate the two subfamilies; Larentiinae and Sterrhinae (Cook & Scoble, 1992). The bursa copulatrix in both is generally scobinate, spined or rugose, very rarely with a prominent signum. In Ennominae and Geometrinae there is a prominent signum. The absence of a tympanic lacinia may perhaps be considered as a loss in Sterrhinae and Larentiinae since the structure occurs in the other subfamilies and may be a basic characteristic of Geometridae.

Subfamily Ennominae

The tympanal organs are well separated and vary in size in shape. The asymmetric extension of the ansa (*Tephrina pulinda*) and umbrella-shaped ansa (*Oxymacaria persimilis*) are some of the modifications typical to this subfamily. Also, the occurrence of a lobe on the cavus wall, where the tympani lacinia partly covers the opening of the cavus is restricted to Ennominae (Cook & Scoble, 1992).

Subfamily Larentiinae

The tympana are small but, the tympanal organs lie close together. The ansa broadens out at the apex and gives the hammer-head shape. No lobe on the cavus.

Subfamily Sterrhinae

The tympanum is comparatively larger than the diameter of the abdomen, but they are well-separated. The ansa is broad /narrow at the base and has a hammer-head tip in most species.

Subfamily Geometrinae

Well-separated tympanal organs and with the most homogenous structure within Geometridae. A rare occurrence of sexual dimorphism is also noted, like: the female *Anisozyga pieriodes* has a lobe on the cavus wall, unlike the male. The characteristically shaped ansa of Geometrinae is probably a synapomorphic character of this subfamily.

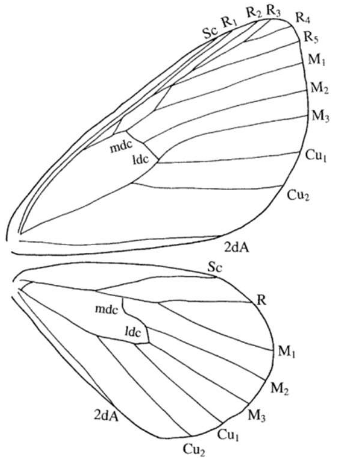


Figure 3.1: Typical wing venation of Geometridae family: wing venation of *Diathera uctuata* (Larentiinae) (source: Choi, 1999)

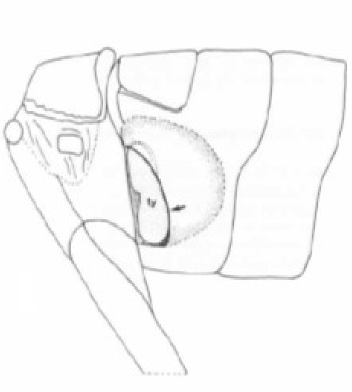


Figure 3.2: A typical Tympanal organ of Geometridae: lateral view of metathorax and base of abdomen of *Larentia trisrata.* Outline of cavus tympani indicated by broken line. Sclerotized edge of cavus arrowed. Tympanal surface is that facing opening of cavus to exterior. (Source: Cook & Scoble,1992)

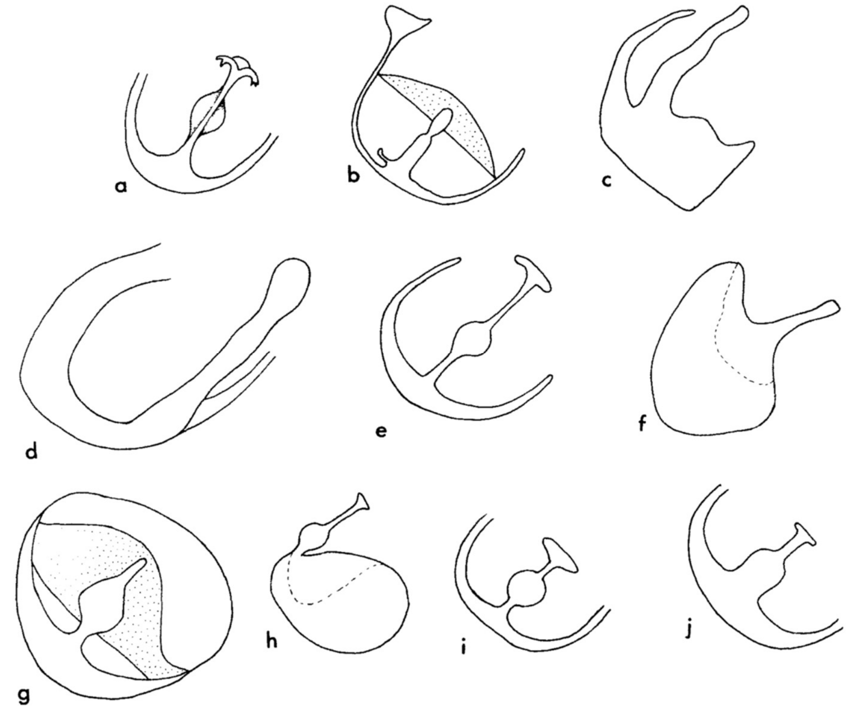


Figure 3.3: Tympanal organ showing ansa of Geometridae: a, b, Ennominae: (a) *Oxymacaria persimilis;* (b) *Tephrina pulinda deerraria,* lacinia stippled: c-f.

Oenochrominae: (c) *Antasia flavicapirufa:* (d) *Celerena lerne; (e) Bumelea horinata;* (f) *Zeuctophlebia squalida;*(g) *Geometra papilionaria* (Geornetrinae), lacinia stippled: (h) *Pleuroprucha rudirnenfaria* (Sterrhinae): i.j, Larentiinae: (i) *Chloroclystis hawkensi:* (j) *Eirsrroma elisfa.*

(Source: Cook & Scoble, 1992)

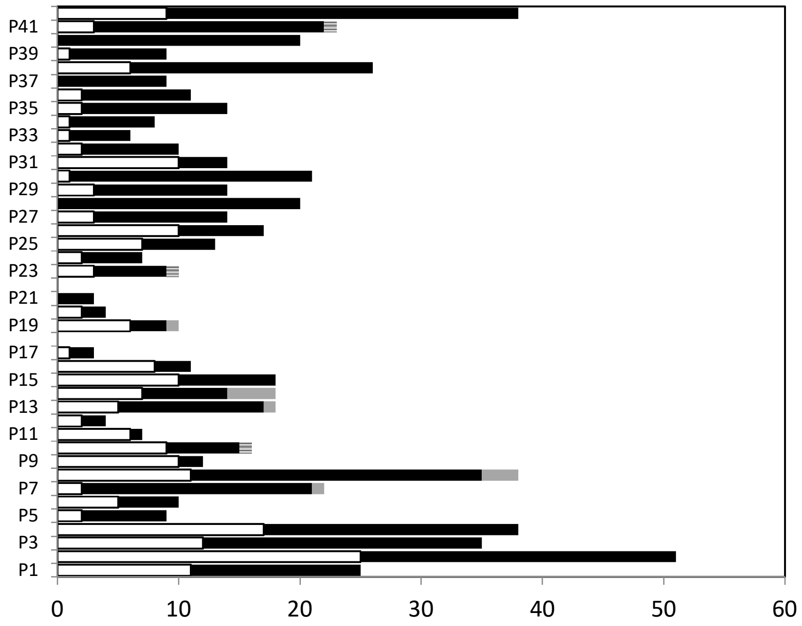
3.2.5 Analyses

The identified species from each of the subfamilies were counted and compared among the individual sampling plots and locations (Joshimath and Lata). The identified genera were assigned to one of the three biogeographical realms (Indo-Malayan, Palearctic, Paleotropical) or cosmopolitan from the available literature and online sources (Lepindex, nic.funet.fi, BOLD database). The assignment was done based on which biogeographical realm had the maximum number of species of the genera distributed.

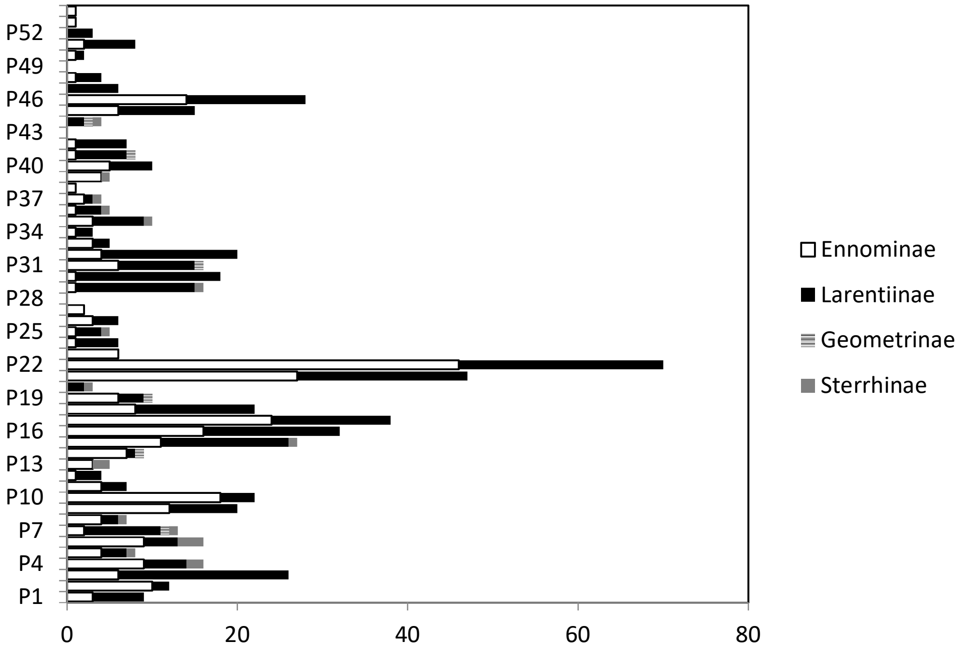
3.3 Results

The study recorded 185 species belonging to the four subfamilies: (a) Ennominae (73 species), (b) Larentiinae (101 species), (c) Sterrhinae (8 species) (d) Geometrinae (7 species), and 77 genera (Appendix 3.1).In my study, the most abundant subfamilies were Ennominae and Larentiinae across all the plots in both Joshimath and Lata (Fig. 3.4 and 3.5). Figure 3.6 also shows the estimated species richness of the two subfamilies in both the gradients.

. Most of the genera found in the study belonged to the Paleotropical biogeographical realm (Fig. 3.7a), and across the elevation gradient, the lower elevations showed a high number of individuals for all the biogeographical classes with a decline in high elevation areas (Fig.3.7b). I had 43 species as new records from the state of Uttarakhand: Ennominae (14 species); Larentiinae (27 species); (Sterrhinae (1 species); Geometrinae (1 species) and 24 species as new records for India Ennominae (7 species); Larentiinae (15 species); Sterrhinae (1 species); Geometrinae (1 species). All these new records will be subjected to further taxonomic investigation to confirm identifications further.



a)



b)

Figure 3.4: Subfamily proportions/trap sites in along the elevation in a) Joshimath and b) Lata

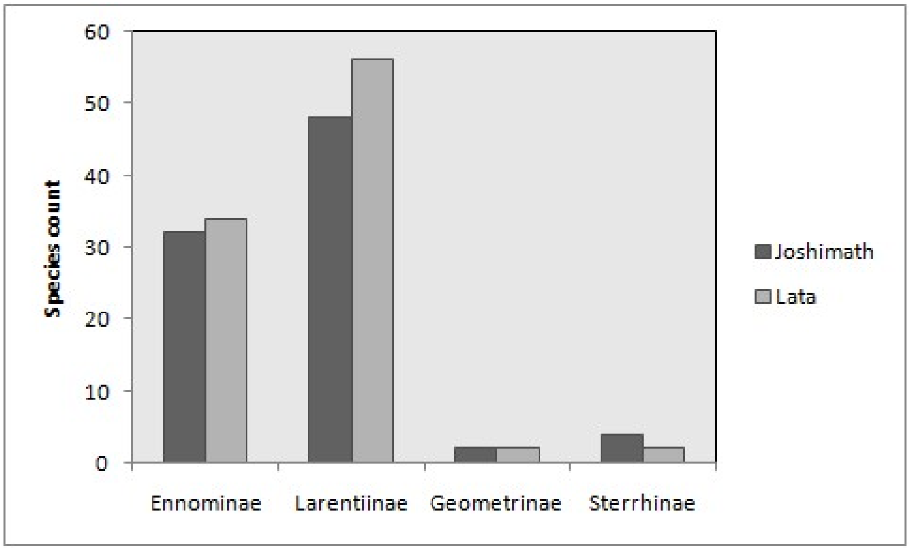


Figure 3.5: Subfamily species count in the entire samples collected at Joshimath and Lata. Ennominae and Larentiinae were found to be the most abundant sub-families at both the locations.

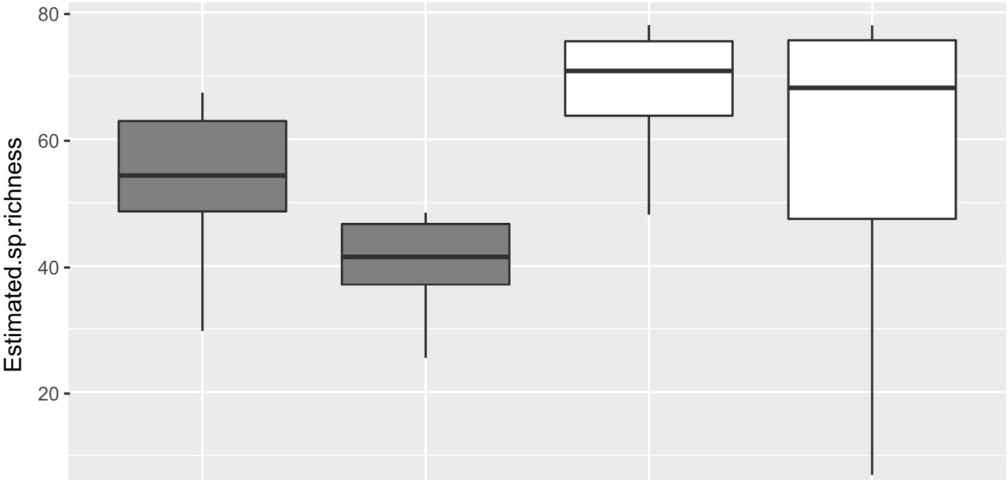


Figure 3.6: Estimated species richness (measured as Chao 1 index) in the two most abundant subfamilies Ennominae and Larentiinae in Joshimath and Lata.

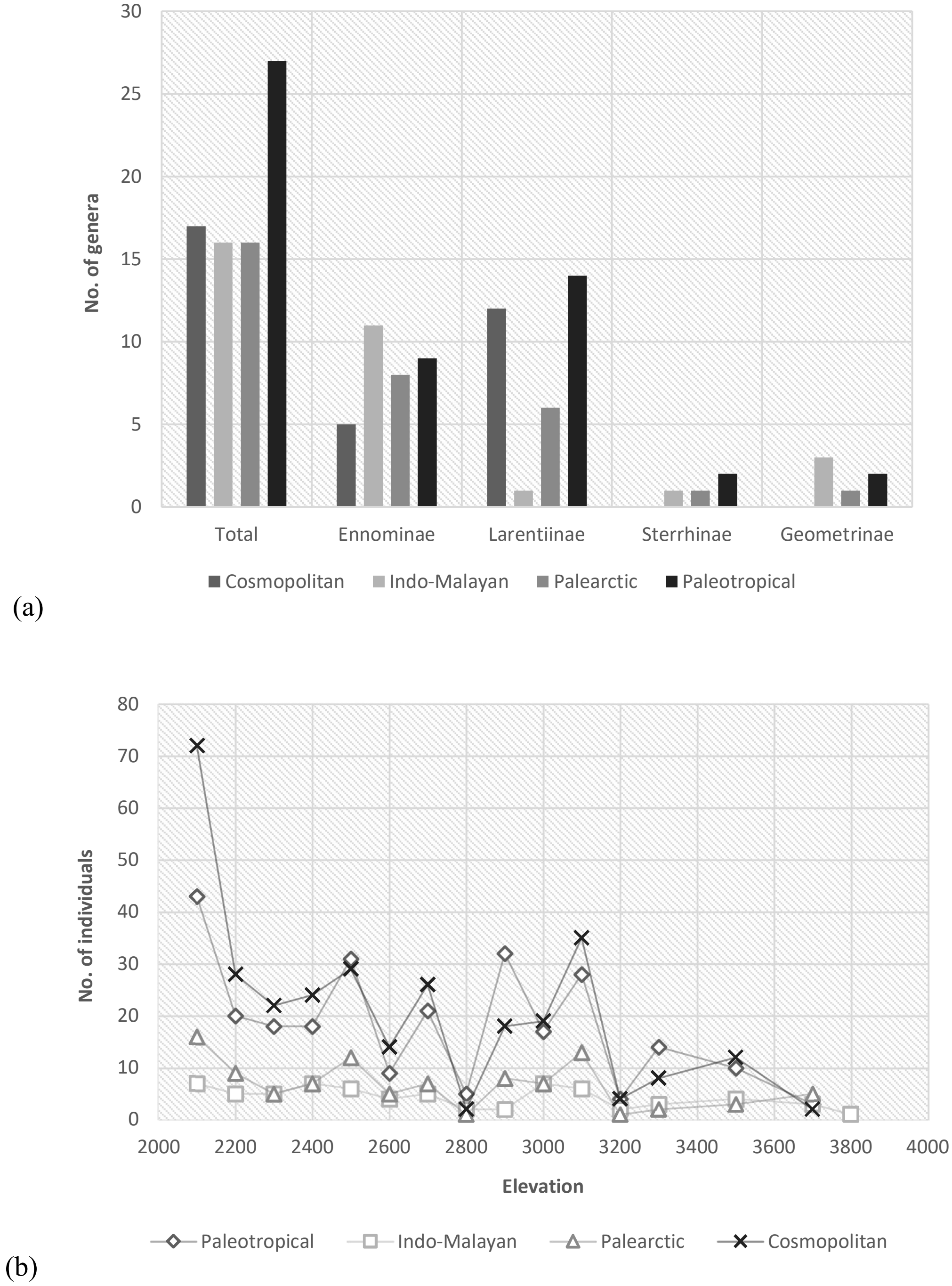


Figure 3.7: (a) The number of genera belonging to the different biogeographical realms in total and in the different subfamilies. Most of the species belong to the

Paleotropical realm across the classes, (b) The number of individuals belonging to the different biogeographical realm across the elevation gradient.

3.4 Subfamily wise characteristics and species recorded

Subfamily Ennominae:

It is the largest subfamily. The diagnostic feature of this subfamily is the absence or loss (or reduced to a fold) of vein M2 on the hindwing. This subfamily is having a wide ecological range except for very high altitudes. Ennominae are most diverse in the lower montane zone (Holloway, 1993, Robinson & Tuck, 1990). Ennomines are found to be specific to lowland forest types and several species are found in the forest understorey and poorly represented in open habitats. Thus, it is an established environmental indicator group (Holloway, 1985; Holloway & Barlow, 1992).

Genus *Abraxas*:

1. ***Abraxas picaria* (Moore,1868)**

Abraxas picaria: Moore, 1868, Proc. zool. Soc. Lond. 1867:652

Abraxas semilugens: Warren, 1893 Proc. zool. Soc. Lond. 1893: 393

Abraxas picaria: Hampson, 1895, Fauna of British India (Moths) 3:301

Abraxas picaria: Prout, 1915 in Seitz Macrolep IV: 310

Abraxas picaria: Prout, 1927 Journal of Bombay nat. Hist. Soc XXXI: 949

Abraxas picaria: Inoue, 1995, in Haruta (ed), Moths of Nepal: 4, Tinea14 (Suppl.2):119, pl.119, fig. 3-6

Distribution: West China; India: Bengal (Darjeeling), Uttarakhand (Kumaon), Sikkim, Himachal Pradesh

2. ***Abraxas superpicaria*** **(Inoue,1970*)***

Abraxas superpicaria Inoue, 1970, Spec. Bull. Lepid. Soc. Jap. 4: 204, pl.1, fig 13; pl.3, fig. 36; pl.5, fig. 51; pl.6, fig. 57

Abraxas superpicaria: Inoue, 1995, in Haruta (ed), Moths of Nepal: 4, Tinea14 (Suppl.2):119, pl.119, fig. 7-9.

Distribution: Nepal; India: Darjeeling, Sikkim, Bhutan, Himalayas

3. ***Abraxas (Calospilos) cf. leopardina*** **(Kollar,1844)**

Zerene leopardina Kollar, 1844, in Hügel, Kaschmir und das Reich Siek 4:490

Abraxas (Calospilos) aphorista: Inoue, 1970, Spec. Bull. Lepid. Soc. Jap. 4:208, pl.1, fig 6; pl.6, fig. 12, necProut

Abraxas leopardina: Inoue, 1995, in Haruta (ed), Moths of Nepal: 4, Tinea14 (Suppl.2):124, pl.121, fig. 9, 10

Distribution: Nepal, Vietnam, Bhutan, Pakistan; India: Kashmir, New to Uttarakhand**.**

Genus ***Alcis***:

1. ***Alcis granitaria*** **(Moore,1888)**

Boarmia granitaria Moore, 1888, in Hewitson& Moore, Descr.new Indian lepid. Insects Colln late Mr Atkinson: 246

Alcis sublimis Butler, 1889, Ill. Het. Vii, p.103, pl.135, fig. 19.

Boarmia granitaria: Hampson, 1895, Fauna of British India (Moths) 3:274

Boarmia granitaria Prout,1915, in Seitz Macrolep. IV: 372; pl.21: b

Distribution: N.W. Himalayas, Kashmir, Chamba, Sikkim

2. ***Alcis leucophaea* (Fletcher,1961)**

Alcis leucophaea Fletcher, 1961, Veröff. Zool. StSamml. Münch.6:175, pl.17, figs 14,16,17,19; pl.23, figs 38-40.

Alcis leucophaea: Sato, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1):44, pl.73, fig. 10, 11

Distribution: Nepal; New to India

3. ***Alcis nigralbata* (Warren,1893)**

Alcis nigralbata Warren, 1893, Proc.zool. Soc. Lond.1893:421

Boarmia nigralbata: Hampson, 1895, Fauna of British India (Moths) 3:266

Alcis nigralbata: Sato, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1):44, pl.74, fig. 4

Distribution: Sikkim, New to Uttarakhand

4. ***Alcis nudipennis* (Warren,1888)**

Alcis nudipennis Warren, 1888. Proc. Zool. Soc. Lond.:320

Distribution: Thundiani, New to Uttarakhand

5. ***Alcis oxyrrina* (Wehrli,1945)**

Boarmia (Alcis) oxyrrina Wehrli, 1945, in Seitz, Gross-Schmett.Erde 4 (Suppl.):502

Alcis oxyrrina: Inoue, 1982, Bull. Fac. Domest.Sci. Otsuma Wom. Univ.18:181

Alcis oxyrrina: Sato, 1998, in Haruta (ed), Moths of Nepal: 5, Tinea15 (Suppl.1):20, pl.130, fig. 13,14

Distribution: Nepal, Yunnan

6. ***Alcis paghmana* (Wiltshire,1967)**

Alcis paghmana, Wiltshire, 1967, Beitr.naturk. Forsch. Südw Dt 1; 26: 162

Distribution: Afghanistan, New to India

7. ***Alcis paraclarata* (Sato, 1993)**

Alcis paraclarata Sato, 1993, in Haruta (ed), Moths of Nepal: 2, Tinea13 (Suppl.3):10, pl.35, fig. 5

Alcis paraclarata Sato, 1995, Trans. Lepid. Soc. Japan 46(4):212

Distribution: Nepal, Japan; New to India

8. ***Alcis perspicuata* (Moore,1868)**

Boarmia perspicuata, Moore, 1867, Proc. Zool. Soc. Lond. 1867: 630

Boarmia perspicuata, Prout, 1914 in Seitz Macrolep IV:371

Cleora perspicuata Prout, 1927, Journal of Bombay nat. hist. Soc XXXI: 940

Alcis perspicuata Wehrli, 1939, in Seitz Macrolep IV, Suppl.:499

Alcis perspicuata: Sato, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1):43, pl.34, fig. 12, 13

Distribution: West China; India: Dharmsala, New to Uttarakhand

9. ***Alcis semiclarata* (Walker,1862)**

Selidosema semiclarata, Walker, 1862 Cat. Lep. Het. B.M. xxiv: 1029

Scotosia quadrifera, Walker, 1867, Cat. Lep. Het. B.M xxxv: 1687

Cleora semiclarata, Moore, 1867 Proc. Zool. Soc. Lond.: 629

Boarmia semiclarata: Hampson, 1895, Fauna of British India (Moths) 3:267

Boarmia semiclarata Prout, 1915 in Seitz: Macrolep. IV: 373

Cleora semiclarata Prout, 1927, Journal of Bombay nat. hist. Soc XXXI: 940

Alcis semiclarata Wehrli, 1943, in Seitz: Macrolep. World IV. Suppl.: 513.

Distribution: Darjeeling, N.W. Himalayas, Sikkim, New to Uttarakhand

10. ***Alcis* sp.**

Genus *Anonychia*:

1. ***Anonychia grisea* (Butler, 1883)**

Nadagara grisea Butler, 1883, Proc. Zool. Soc. Lond.1883:172

Anonychia exilis: Yazaki, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1):22, pl.70, fig. 6, syn. n

Anonychia grisea: Yazaki, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea 14 (Suppl.1):22, pl.70, fig.6, as exilis

Distribution: Nepal; India: West Bengal (Darjeeling), Sikkim, Uttarakhand (As *Anonychia exilis*)

2. ***Anonychia lativitta* (Moore, 1888)**

Onychia lativitta Moore, 1888, in Hewitson& Moore, Descr. New Indian lepid. Insects Colln late Mr Atkinson: 279

Anonychia lativitta: Hampson, 1895, Fauna of British India (Moths) 3:179

Anonychia lativitta: Yazaki, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1):22, pl.70, fig. 5

Distribution: Nepal; India: Darjeeling, Sikkim, N.W. Himalayas and Uttarakhand

3. ***Anonychia violacea* (Moore,1888)**

Anonychia violacea Moore, 1888, in Hewitson & Moore, Descr.new Indian lepid. Insects Colln late Mr Atkinson: 279.

Anonychia violacea: Hampson, 1895, Fauna of British India (Moths) 3:178

Distribution: Darjeeling, Sikkim, Uttarakhand

Genus *Apoheterolocha*:

1. ***Apoheterolocha patalata* (Felder & Rogenhofer, 1875)**

Heterolocha patalata Felder & Rogenhofer, 1875, Reiseöst.Fregatte Novara (Zool.) 2: pl.132, figs.9, 9A

Marcala varians Swinhoe, 1891 Trans. Ent. Soc.:487

Heterolocha patalata: Hampson, 1895, Fauna of British India (Moths) 3:180

Heterolocha patalata Butler, 1926 Journal of Bombay nat. hist. Soc xxxi: 791.

Heterolocha patalata: Yazaki, 1992, in Haruta (ed), Moths of Nepal: 1, Tinea13 (Suppl.2):40, pl.12, fig.19

Distribution: Nepal; India: Rampur: NE of Shimla, Punjab (3300ft), Khasis

2. ***Apoheterolocha quadraria* (Leech,1897)**

Heterolocha quadraria Leech, 1897, AMNH (6) xix: 231; pl.6: 8

Heterolocha quadraria Prout, 1915, in Seitz Macrolep. IV: 341; pl.18: a

Distribution: West China, Pakistan; New to India

Genus *Arichanna:*

1. ***Arichanna (Paricterodes) albivertex* (Wehrli, 1933)**

Paricterodes albivertex Wehrli, 1933, Ent.Z., Frankf.a.M. 47:48, fig.5.

Arichanna albivertex: Sato, 1994, in Haruta (ed.), Moths of Nepal: 3, Tinea14 (Suppl.1):42, pl.73, fig. 7

Distribution: Nepal; India: Sikkim, New to Uttarakhand

2. ***Arichanna (Epicterodes) flavinigra* (Hampson,1907)**

Arichanna flavinigra Hampson, 1907, J. Bombay nat. Hist. Soc. 18:43

Arichanna flavinigra: Sato, 1994, in Haruta (ed.), Moths of Nepal: 3, Tinea14 (Suppl.1):41, pl.34, fig. 1

Distribution: Tibet: Yatong, Nepal; India: Kashmir, Chamba, Punjab, Dalhousie, Dharmsala, Kumaon, Ralam valley, Jumnotri, Duggre, Sikkim

3. ***Arichanna (Icterodes) ramosa*** **(Walker,1866)**

Scotosia ramosa Walker, 1866, List Specimens lepid. Insects Colln Br. Mus. 35:1688.

Arichanna ramosa ramosa Sato, 1994, in Haruta (ed.), Moths of Nepal: 3, Tinea14 (Suppl.1):43, pl.34, fig. 7

Distribution: Nepal; India: Darjeeling, Sikkim, New to Uttarakhand

4. ***Arichanna (Icterodes) sparsa*** **(Butler,1890)**

Icterodes sparsa Butler, 1890, Entomologist 23:316

Arichanna sparsa Prout, 1915 in Seitz Macrolep IV: 304, pl., 14 b

Arichanna sparsa: Hampson, 1895, Fauna of British India (Moths) 3:294

Arichanna sparsa: Sato, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1):42, pl.34, fig. 2

Distribution: Dharmsala, New to Uttarakhand

5. ***Arichanna tramesata*** **(Moore,1868)**

Arichanna tramesata Moore, 1868, Proc. zool. Soc. Lond. 1867:658, pl.33, fig.2

Arichanna tramesata: Hampson, 1895, Fauna of British India (Moths) 3:290

Arichanna tramesata Wehrli,1939, in Seitz Suppl.IV:255

Arichanna tramesata: Sato, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1):43, pl.34, fig. 11

Distribution: Nepal, Bengal, Sikkim, Khasis

6. ***Arichanna (Paricterodes) tenebraria* (Moore, 1868)**

Abraxas tenebraria Moore, 1868, Proc. zool. Soc. Lond. 1867:652

Arichanna tenebraria: Hampson, 1895, Fauna of British India (Moths) 3:293

Arichanna tenebraria: Sato, 1994, in Haruta (ed.), Moths of Nepal: 3, Tinea14 (Suppl.1):42, pl.73, fig. 5

Distribution: Nepal; India: Bengal, Uttarakhand, Sikkim, Meghalaya (Khasis)

Genus *Artemidora:*

1. ***Artemidora disistaria* (Walker,1862)**

Aspilates disistaria Walker, 1862, List Specimens lepid. Insects Colln Br. Mus.24: 1075

Artemidora disistaria: Stüning, 1998, in Haruta (ed.), Moths of Nepal: 5, Tinea15 (Suppl.1):101, pl.170, fig. 11,12,15,16.

Distribution: Nepal; India: W. Himalaya, Punjab

Genus *Charissa*:

1. ***Charissa* sp.**

Genus *Ctenognophos*:

1. ***Ctenognophos eolaria* (Guenée,1858)**

Gnophos eolaria Guenée, 1858 Spec. Gen IX: 294

Gnophos eolaria Prout, 1915 in Seitz Macrolep. IV: 384; pl.22: b

Ctenognophos eolaria: Sato 1998, in Haruta (ed), Moths of Nepal: 5, Tinea15 (Suppl.1): 25, pl.131, fig.4

Distribution: W. China, Nepal; India: West Bengal, Sikkim, North India, throughout Himalayas

2. ***Ctenognophos fuscobrunnea*** **(Warren,1896)**

Catacasia eoalria ab. fuscobrunnea Warren, 1896, Nov. Zool. III: 318

Gnophos (Ctenognophos) eolaria ab. fuscobrunnea Prout, 1915 in Seitz Macrolep. IV: 384

Ctenognophos eolaria ab. fuscobrunnea Wehrli, 1953 in Seitz Gross-Schmetterlinge der Erde 4(Suppl.): 569

Ctenognophos fuscobrunnea Sato, 2003 Trans. Lepid. Soc. Japan 54 (4):241-247

Distribution: Assam, Cherrapunji, Sikkim, Nepal, New to Uttarakhand

Genus *Ectropis*:

1. ***Ectropis*** **sp. 1**
2. ***Ectropis*** **sp.2**

Genus *Gnophos*:

1. ***Gnophos albidior*** **(Hampson,1895)**

Medasina albidior Hampson, 1895, Fauna of British India (Moths) 3:290

Gnophos albidior Inoue, 1995, in Haruta (ed), Moths of Nepal: 4, Tinea14 (Suppl.2):32, pl.102, fig. 17

Distribution: Nepal; India: Nagaland, Uttarakhand

Genus *Heterolocha*:

1. ***Heterolocha desistaria*** **(Walker,1862)**

Heterolocha desistaria Walker, 1862 List Specimens lepid. Insects Colln Br. Mus xxiv: 1073.

Heterolocha desistaria: Hampson, 1895, Fauna of British India (Moths) 3:180

Distribution: North India

2. ***Heterolocha falconaria* (Walker,1866)**

Aspilates falconaria Walker, 1866, List Specimens lepid. Insects Colln Br. Mus. xxxv: 1665

Heterolocha falconaria: Hampson, 1895, Fauna of British India (Moths) 3:179

Heterolocha falconaria Prout, 1915, in Seitz Macrolep. IV: 340; pl.17: i

Heterolocha falconaria Butler, 1926 Journal of Bombay nat. hist. Soc xxxi: 790.

Heterolocha falconaria Prout, 1932 Journal F.M.S Mus. xvii: 86

Distribution: Nepal, Bhutan, W. China; India: N. India, West Bengal, Sikkim, Assam, Punjab, N.W. Himalayas.

3. ***Heterolocha phaenicotaeniata* (Kollar,1844)**

Aspilates phaenicotaeniata Kollar, 1844, in Hügel, Kaschmir und das Reich Siek 4:487

Heterolocha phaenicotaeniata Felder, 1875 Reis. Nov. pl.133, figs. 6A

Pyrinia phoeniocotaeniata Butler, 1886 Proc. Zool. Soc. London: 388

Pyrinia phoeniocotaeniata Warren, 1888 Proc. Zool. Soc. London: 319.

Heterolocha phaenicotaeniata: Hampson, 1895, Fauna of British India (Moths) 3:179

Heterolocha incolorata Warren, 1896 Novit. Zool.:449

Heterolocha phaenicotaeniata Prout, 1915, in Seitz Macrolep. IV: 340; pl.17: i

Heterolocha phaenicotaeniata: Yazaki,1992, in Haruta (ed), Moths of Nepal: 1, Tinea13 (Suppl.2):39, pl.12, fig.18

Distribution: Nepal; India: Kashmir, Murree, N.W. Himalayas, Kulu, Thundiani, Uttarakhand

Genus *Hirasa*:

1. ***Hirasa muscosaria* (Walker, 1866)**

Gnophos muscosaria Walker, 1866, List Specimens lepid. Insects Colln Br. Mus. 35: 1596

Gnophos muscosaria Prout, 1915, in Seitz Macrolep. IV: 362; pl. 20b

Hirasa muscosaria Sato, 1993, in Haruta (ed), Moths of Nepal: 2, Tinea13 (Suppl.3):20, pl.37, fig. 17

Distribution: Nepal, Omei-Shan, Ta-chien-Lu; India: Darjeeling, Uttarakhand, Sikkim

Genus *Hypomecis*:

1. ***Hypomecis* sp**.

Genus *Lomographa*:

1. ***Lomographa distans* (Warren,1894)**

Bapta distans Warren, 1894, Novit.zool.1:404

Bapta distans Prout, 1915, in Seitz Macrolep. IV: 315; pl.15e

Bapta distans Butler, 1926 Journal of Bombay nat. hist. Soc xxxi: 785

Lomographa distans: Yazaki, 1992, in Haruta (ed), Moths of Nepal: 1, Tinea13 (Suppl.2):24, pl.7, fig.13

Distribution: Nepal, W. China, Japan; India: N.W. India, Sikkim, Dharmsala

Genus *Loxaspilates:*

1. ***Loxaspilates hastigera* (Butler, 1889)**

Aspilates hastigera Butler, 1889, Illust.typical Specimens Lepid.Heterocera Colln Br. Mus. 7: 112, pl.138, fig.4,5

Loxaspilates hastigera Prout, 1920, in Seitz Macrolep. IV: 410; pl.25k

Loxaspilates hastigera Hampson, 1895, Fauna of British India (Moths) 3:182

Distribution: Afghanistan; India: Himachal Pradesh (Dharmsala), Sikkim, Uttarakhand

2. ***Loxaspilates obliquaria* (Moore, 1868)**

Aspilates obliquaria Moore, 1868, Proc.zool. Soc.Lond.1867: 649

Loxaspilates obliquaria Hampson, 1895, Fauna of British India (Moths) 3:181

Loxaspilates obliquaria Butler, 1926 Journal of Bombay nat. Hist. Soc xxxi: 791.

Loxaspilates obliquaria Prout, 1915, in Seitz Macrolep. IV: 410; pl.25b

Loxaspilates obliquaria: Yazaki 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1): 25, pl.71, fig.8

Distribution: Afghanistan, West China, Nepal; India: N.W. Himalayas, Uttarakhand, Sikkim

Genus *Medasina*:

1. ***Medasina albidaria* (Walker, 1866)**

Boarmia albidaria Walker, 1866, List Specimens lepid. Insects Colln Br. Mus. 35: 1582

Boarmia albidaria Moore,1867 Proc. Zool. Soc. Lond.: 630

Medasina albidaria Prout, 1915, in Seitz Macrolep. IV: 361

Medasina albidaria Prout, 1927 Journal of Bombay nat. Hist. Soc xxxi: 946

Distribution: China, Formosa; India: Himachal Pradesh (Simla, Dharmsala), West Bengal (Darjeeling), Sikkim, Meghalaya (Shillong, Khasis), Uttarakhand

2. ***Medasina cervina* (Warren, 1893)**

Deinotricha cervina Warren,1893, Proc.zool. Soc. Lond.1867:419

Medasina pallidimargo Swinhoe, 1905 Ann. Mus. Nat. Hist., 16: 627.

Deinotrichia cervina Sato, 1994 Moths of Nepal: 3, Tinea14 (Suppl.1):52, pl.76, fig. 1,2.

Distribution: Nepal; India: Kashmir, Sikkim, Uttarakhand

3. ***Medasina interruptaria* (Moore,1868)**

Hemerophila interruptaria Moore, 1868, Proc.zool. Soc. Lond.1867:626

Medasina interruptaria: Hampson, 1895, Fauna of British India (Moths) 3:287

Medasina interruptaria: Ghosh, 2003 Fauna of Sikkim, 4: 217-342.

Deinotricha interruptaria: Sato 1995, in Haruta (ed), Moths of Nepal: 4, Tinea14 (Suppl.2): 33, pl.76, fig.3

Distribution: Sikkim, West Bengal, Uttarakhand

Genus *Menophra*:

1. ***Menophra (Ephemerophila) subplagiata* (Walker,1860)**

Hemerophila subplagiata Walker, 1860, List Specimens lepid. Insects Colln Br. Mus. 21:319

Hemerophila retractaria Moore, 1867, Proc. Zool. Soc. Lond: 627

Hemerophila senilia Butler,1900 Illust.typical Specimens Lepid.Heterocera Colln Br. Mus. 2: 48; pl.35, fig. 12

Hemerophila jugorum Felder,1875, Reis. Nov. pl. 126; fig.2

Menophra toriidaria Moore, 1888, in Hewitson & Moore, Descr. New Indian lepid. Insects Colln late Mr Atkinson: 237; pl.8; fig.27

Boarmia subplagiata Hampson, 1895, Fauna of British India (Moths) 3:275

Hemerophila lignata Warren, 1896 Nov. Zool.: 680

Hemerophila subplagiata Prout, 1915, in Seitz Macrolep. IV: 362; pl. 20b

Menophra subplagiata Sato, 1993, in Haruta (ed), Moths of Nepal: 2, Tinea13 (Suppl.3):20, pl.37, fig. 10, 11

Distribution: Japan; India: N.W. Himalayas, Uttarakhand, Sikkim.

Genus *Micrabraxas*:

1. ***Micrabraxas incolorata* (Warren, 1893)**

Micrabraxas incolorata Warren, 1893, Proc.zool. Soc.Lond.1893: 427

Boarmia incolorata Hampson, 1895, Fauna of British India (Moths) 3:282

Micrabraxas incolorata: Yazaki 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1): 25, pl.71, fig.4

Distribution: Nepal; India: Sikkim, New to Uttarakhand

2. ***Micrabraxas seriopuncta* (Hampson, 1902)**

Loxaspilates seriopuncta Hampson, 1902, Journal of Bombay nat. Hist. Soc xiv: 498, pl. C, fig.28

Micrabraxas incolorata: Yazaki 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1): 25, pl.71, fig.6

Distribution: Nepal, Tibet; India: Uttarakhand

Genus *Myrioblephara:*

1. ***Myrioblephara duplexa* (Moore,1888)**

Cleora duplexa Moore, 1888, in Hewitson& Moore, Descr. New indianlepid. Insects Colln late Mr. Atkinson:239

Boarmia duplex: Hampson, 1895, Fauna of British India (Moths) 3:258

Boarmia (Myrioblephara)duplexa Prout,1915 in Seitz: Macrolep. IV: 379

Ectropis duplexa Prout, 1927 J. Bombat nat. Hist. Soc. xxxi:952

Myrioblephara duplexa Inoue, 1987, Bull.Fac.domest.Sci. OtsumaWom. Univ.23:266

Myrioblephara duplexa Sato, 1993, in Haruta (ed), Moths of Nepal: 3, Tinea13 (Suppl.3):17, pl.36, fig. 14-16

Distribution: Nepal; India: Sikkim, Darjeeling, New to Uttarakhand

Genus *Odontopera:*

1. ***Odontopera heydena* (Swinhoe,1894)**

Brozullis heydena Swinhoe, 1894 Trans. Ent. Soc. London*:* 203.

Odontopera heydena, Swinhoe, 1900 Cat. East Lep. Oxf. Mus., 2: 255.

Odontopera heydena Sato, 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1):32, pl.72, fig. 7

Distribution*:* Nepal, Japan; India: Meghalaya, Uttarakhand

2. ***Odontopera kametaria* (Felder,1873)**

Crocallis kametaria Felder, 1873, Reis. Nov., 23: 28.

Crocallis kametaria: Hampson, 1895, Fauna of British India (Moths) 3:233

Odontopera kametaria: Yazaki, 1998, in Haruta (ed), Moths of Nepal: 5, Tinea15 (Suppl.1):14, pl.103, fig. 15

Distribution: Nepal; India: Uttar Pradesh, Himalaya, Uttarakhand

3. ***Odontopera veneris* (Inoue, 1987)**

Odontopera veneris Inoue, 1987, Bull. Fac. Domest. Sci. OtsumaWom. Univ. 23:251, fig. 71A

Odontopera veneris: Yazaki 1995, in Haruta (ed), Moths of Nepal: 4, Tinea14 (Suppl.2):12, pl.100, fig. 18

Distribution: Nepal; India: Himachal Pradesh (Spiti valley), New to Uttarakhand

Genus *Opisthograptis*:

1. ***Opisthograptis mimulina* (Butler,1886)**

Rumia mimulina Butler, 1886 Proc. Zool. Soc. Lond.: 388

Rumia crataegata Hampson, 1895, Fauna of British India (Moths) 3: 183

Opisthograptis mimulina Prout, 1915, in Seitz Macrolep. IV: 339; pl.17l

Opisthograptis mimulina: Yazaki 1995, in Haruta (ed), Moths of Nepal: 4, Tinea14 (Suppl.2): 25, pl.71, fig.8

Distribution: North India, Dharmsala

2. ***Opisthograptis sulphurea* (Butler, 1880)**

Rumia sulphurea Butler, 1880, Ann. Mag.nat. Hist. (5) 6: 123

Rumia sulphurea Butler, 1886, Illust.typical Specimens Lepid.Heterocera Colln Br. Mus. 6 :54, pl.114, fig.6

Rumia sulphurea Hampson, 1895, Fauna of British India (Moths) 3: 184

Opisthograptis sulphurea Prout, 1915, in Seitz Macrolep. IV: 339; pl.17l

Opisthograptis sulphurea: Yazaki 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1): 28, pl.72, fig.5

Distribution: Szechuan (China), Nepal; India: Sikkim, West Bengal, Uttarakhand

3. ***Opisthograptis tridentifera* (Moore, 1888)**

Rumia tridentifera Moore, 1888, Lep. Auk.: 230.

Rumia tridentifera Hampson,1895 Fauna of British India (Moths) 3: 184.

Opisthograptis tridentifera, Prout, 1915, in Seitz Macrolep. IV: 339; pl.17l

Distribution: Bhutan; India: Sikkim, Uttarakhand

4. ***Opisthograptis* sp.**

Genus *Ourapteryx:*

1. ***Ourapteryx* sp.**

Genus *Peetula*:

1. ***Peetula stramineata* (Warren,1888)**

Angerona stramineata Warren, 1888 Proc. Zool. Soc. Lond.: 319

Peetula stramineata: Hampson, 1895, Fauna of British India (Moths) 3:188

Distribution: Thundiani, Punjab, New to Uttarakhand

Genus *Percnia:*

1. ***Percnia maculata* (Moore, 1868)**

Rhyparia maculata Moore, 1868, Proc.zool.Soc. Lond.1867:651

Zenoplia subfumida Warren, 1896 Novit. Zool: 416

Percnia maculata: Hampson, 1895, Fauna of British India (Moths) 3:307

Percnia maculata: Yazaki, 1992, in Haruta (ed), Moths of Nepal: 1, Tinea13 (Suppl.2):24, pl.8, fig.24

Distribution: North India, Sikkim, Khasis

Genus *Phthonandria:*

1. ***Phthonandria atrlineata* (Butler,1881)**

Hemerophila atrilineata Butler, 1881 Trans. Ent. Soc.:405

Phthonandria atrilineata Warren, 1894 Nov. Zool.:438

Boarmia atrilineata: Hampson, 1895, Fauna of British India (Moths) 3:279

Hemerophila (Phthonandria) atrilineata Prout, 1915 in Seitz Macrolep. IV:363; pl.20:c

Hemerophila atrilineata Steineck, 1928 Deutsch ent. Zt: 211

Phthonandria atrilineata: Liao et. al. 2010, Int. J. Biol. Sci. 6(2): 172-186

Distribution: Japan, Korea, W. China; India: Dharmsala, Uttarakhand

Genus *Prometopidia:*

1. ***Prometopidia conisaria* (Hampson,1902)**

Prometoipdia conisaria Hampson, 1902, J, Bombay nat. Hist. Soc. 14:509

Prometopidia conisaria: Yazaki, 1995, in Haruta (ed), Moths of Nepal: 4, Tinea14 (Suppl.2):18, pl.100, fig. 11

Distribution: Nepal; India: Kashmir, Sikkim, New to Uttarakhand

2. ***Prometopidia* sp.nov.**

Genus *Pseudomiza*:

1. ***Pseudomiza cruentaria* (Moore, 1868)**

Cimicodes cruentaria Moore, 1868, Proc.zool. Soc. Lond.1867:616

Heteromiza cruentaria Hampson, 1895, Fauna of British India (Moths) 3:237

Pseudomiza cruentaria Prout, 1915, in Seitz Macrolep. IV: 328; pl.16c

Pseudomiza cruentaria Butler, 1926 Journal of Bombay nat. Hist. Soc xxxi: 797

Pseudomiza cruentaria: Yazaki, 1992, in Haruta (ed), Moths of Nepal: 1, Tinea13 (Suppl.2):38, pl.12, fig.2

Distribution: Nepal, Bengal, Uttarakhand

Genus *Psilalcis*:

1. ***Psilalcis inceptaria* (Walker, 1866)**

Tephrosia inceptaria, Walker, 1866, List. Lep. Ins., XXXV: 1590

Narapa breta Swinhoe, 1889, Proc. Zool. Soc. Lond.:426

Cleora indistincta Hampson, Ill. Het.vii:106; pl.150, fig.3.

Boarmia inceptaria Hampson, 1895, Fauna of British India (Moths) 3:188

Ectropis inceptaria Prout, 1927 Journal of Bombay nat. Hist. Soc XXXI:936

Psilalcis inceptaria Singh, 1953, Ind. For. Rec., 8(7):105, figs. 8,30 (larva)

Distribution: Malay Peninsula and Sunda Islands, Sri Lanka, Burma, Flores; India: Uttarakhand, Nilgiri Hills, Poona, Darjeeling, Sikkim, widely distributed in India,

Genus *Psyra:*

1. ***Psyra crypta* (Yazaki,1994)**

Psyra crypta: Yazaki 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1): 26, pl.71, fig.10,13,16

Distribution: Nepal, New to India

2. ***Psyra cuneata* (Walker,1860)**

Psyra cuneata Walker, 1860, List Specimens lepid. Insects Colln. Br. Mus. 21:483

Psyra similaria Moore, 1867 Proc. Zool. Soc. Lond: 659

Psyra cuneata: Hampson, 1895, Fauna of British India (Moths) 3:223

Psyra cuneata Prout, 1915, in Seitz Macrolep. IV: 410; pl.25l

Psyra cuneata: Yazaki, 1992, in Haruta (ed), Moths of Nepal: 1, Tinea13 (Suppl.2):34, pl.11, fig.6

Distribution: Japan, Formosa, Nepal; India: West Bengal, N.W. Himalayas, Nagaland, Sikkim, Khasis, N. India

3. ***Psyra indica* (Butler,1889)**

Tetracis indica Butler, 1889, Illust.typical Specimens Lepid.Heterocera Colln Br. Mus. 7:99, pl.135, fig.16

Psyra indica Hampson, 1895, Fauna of British India (Moths) 3:222

Psyra indica Prout, 1915, in Seitz Macrolep. IV: 410; pl.24 g.

Psyra indica: Yazaki 1998, in Haruta (ed), Moths of Nepal: 5, Tinea15 (Suppl.1):14, pl.130, fig. 2.

Distribution: Nepal, Dharmsala, Uttarakhand

4. ***Psyra moderata* (Inoue, 1982)**

Psyra moderata Inoue, 1982, Bull.Fac.domest.Sci. OtsumaWom. Univ.18:190, fig.51B

Psyra moderata: Yazaki, 1992, in Haruta (ed), Moths of Nepal: 1, Tinea13 (Suppl.2):34, pl.11, fig.5

Distribution: Nepal; New to India

5. ***Psyra similaria* (Moore,1868)**

Psyra similaria Moore, 1868, Proc.zool. Soc. Lond.1867:659

Psyra similaria: Yazaki 1994, in Haruta (ed), Moths of Nepal: 3, Tinea14 (Suppl.1): 26, pl.71, fig.7

Distribution: Nepal; India: Darjeeling, Uttarakhand

Genus *Seleniopsis:*

1. ***Seleniopsis sp.***

Genus *Sirinopteryx:*

1. ***Sirinopteryx duplicilinea* (Hampson,1895)**

Stenorumia duplicilinea Hampson, 1895, Fauna of British India (Moths) 3:183

Sirinopteryx duplicilinea: Yazaki 1998, in Haruta (ed), Moths of Nepal: 5, Tinea15 (Suppl.1):17, pl.130, fig. 10.

Distribution: Dalhousie

2. ***Sirinopteryx harutai* (Yazaki, 1998)**

Sirinopteryx duplicilinea: Yazaki 1998, in Haruta (ed), Moths of Nepal: 5, Tinea15 (Suppl.1):17, pl.130, fig. 10.

Distribution: Nepal; New to India

3. ***Sirinopteryx* sp.**
4. ***Stenorumia (Sirinopteryx) ablunata* (Guenée, 1858)**

Rumia ablunata Gueneé, 1858 Spec. Gen IX: 110

Stenorumia ablunata: Hampson, 1895, Fauna of British India (Moths) 3:183

Stenorumia ablunata Prout, 1915, in Seitz Macrolep. IV: 340; pl.17i

Sirinopteryx ablunata: Yazaki 1998, in Haruta (ed), Moths of Nepal: 5, Tinea15 (Suppl.1):16, pl.130, fig. 9.

Distribution: N.W. Himalayas, Dharmsala

Genus *Tanaoctenia:*

1. ***Tanaoctenia haliaria* (Walker, 1861)**

Geometra haliaria Walker, 1861, List Specimens lepid. Insects Colln Br. Mus. 22:518

Geometra decoraria Walker, 1866, List Specimens lepid. Insects Colln Br. Mus. 35:1601

Geometra haliaria Butler, 1886 Ill. Het. VI: 70; Pl. (XVII, 7)

Metrocampa haliaria: Hampson, 1895, Fauna of British India (Moths) 3:157

Tanaoctenia haliaria Prout, 1926 Journal of Bombay nat. Hist. Soc: 186.

Tanaoctenia haliaria: Yazaki, 1992, in Haruta (ed), Moths of Nepal: 1, Tinea13 (Suppl.2):35, pl.11, fig.13

Distribution: Nepal; India: Sikkim, Khasis, Uttarakhand

Subfamily Larentiinae:

The subfamily Larentiinae was diagnosed by Holloway (1997: 99) according to the wing pattern, “each fascia in forewing tending to be multiple…and meeting the dorsum at right angle. …the species rest with the forewing mostly or wholly covering the hind wing" (Common 1990). The larentiinae forewing venation is characteristic in veins Rs and M1 stalked or, if separate, M1 proceeds in line with the anterior margin of the discal cell (Õunap et al. 2005, 2008). On the hindwing, Sc+R1 is strongly anastomosed with Rs, or nearly connected with it by a bar beyond middle of cell in male. Holloway 1986b higlighted the typically montane character of tropical Larentiinae.

Genus *Apithecia*:

1. ***Apithecia viridata* (Moore,1868)**

Cidaria viridata Moore, 1868, Proc. Zool. Soc.Lond. 1867:661

Distribution: Temperate Europe, Central Asia, Asia Minor; India: West Bengal, Sikkim, Meghalaya (Khasis), New to Uttarakhand

Genus Atopophysa:

1. ***Atopophysa sinotibetaria* (Wehrli,1931)**

Atopophysa sinotibetaria Wehrli, 1931 N. Beit. Suppl. Inseckten k.V:36

Atopophya sinotibetaria Prout, 1938 in Seitz, Macrolepid. World 4, Suppl. (173), pl.14d; 12:273

Distribution: Kumkalashan, Ta-tsiem-Lou, New to India

Genus *Chartographa*:

1. ***Chartographa trigoniplaga* (Hampson,1895)**

Callabraxas trigoniplaga Hampson, 1895, Trans. ent. Soc. Lond. 1895:312

Callabraxas trigoniplaga: Hampson, 1896, Fauna of British India (Moths) 4:558

Lygris trigoniplaga: Prout, 1937, in Seitz, Macrolepid World 4 (Suppl.): 108, pl.10:h

Chartographa trigoniplaga: Prout, 1941, ibidem 12:317

Distribution: Nepal, New to Uttarakhand

Genus *Cidaria*:

1. ***Cidaria basharica* (Bang-Haas,1927)**

Cidaria basharica: Bang-Haas, 1927 Horae. Macrolep.1: 93, pl. XI:20

Cidaria basharica Prout, 1914 in Seitz, Macrolepid. World 4. Suppl (110), pl.11: b

Cidaria basharica: Yazaki, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): 11, pl. 162, fig. 16

Distribution: Nepal; India: Himalaya, Himachal Pradesh, New to Uttarakhand.

Genus *Coenolarentia*:

1. ***Coenolarentia argentiplumbea* (Hampson,1903)**

Asthenoides argentiplumbea Hampson 1903, Journal of Bombay Nat. Hist. Soc XIV:648, pl. cf

Coenolarentia argentiplumbea Aubert, 1959, Z.wien.ent.Ges. 44:199

Coenolarentia argentiplumbea Prout, 1914, in Seitz Macrolepid. 4.Suppl. (139):274

Distribution: Yatong, Tibet, Nepal; New to India

Genus *Colostygia*:

1. ***Colostygia albigirata* (Kollar,1844)**

Cidaria albigirata Kollar, [1844], in Hügel, Kaschmir und das Reich der Siek 4: 489

Cidaria albigirata Guenée 1857: Spec. Gen. X: 472

Cidaria signata Moore 1867, Proc. Zool. Soc. Lond.:661

Cidaria thomasata Warren 1888, Proc. Zool. Soc. Lond.:329

Cidaria jamexa Butler 1889, A.M. N.H (5) i: 452; id.Ill. Het. Iii: 55, fig.9

Larentia albigirata: Hampson, 1895, Fauna of British India (Moths) 3: 367

Cidaria albigirata Prout, 1914, in Seitz, Macrolepid. World 4:229, suppl (129); 12:267 (1939)

Lampropteryx cidaria Inoue, 1976, Tinea, 10:16

Distribution: Japan, SE Siberia, West China; India: Kashmir, Uttarakhand (Masuri), N.W. Himalayas, Sikkim

Genus *Costicoma*:

1. ***Costicoma exangulata* (Warren, 1909)**

Perizoma exangulata Warren, 1909 Novit. Zool. xvi: 127

Thera exangulata Prout,1914, in Seitz Macrolepid. World 4: 217, Pl.8 row l, Suppl. (113)

Costicoma exangulata Choi,2000 American Museum Novitates, no.3295:19

Distribution: Kashmir: Srinagar, New to Uttarakhand

Genus *Docirava*:

1. ***Docirava fulgurata* (Guenée, 1857)**

Anaitis fulgurata Guenée, 1857, in Boisduval&Guenée, Hist. nat. Insectes (Lépid.) 10: 498

Anaitis macrocelata Walker, 1862, List Specimens lepid. Insects Colln Br. Mus. 25:1447

Orsonoba (?) medmaria Walker, [1863] 1862, ibidem 26:1521.

Eubolia reciproca Walker, 1866, ibidem 35:1698

Docirava medmaria: Butler, 1886, Illust. Typical Specimens Lepid Heterocera Colln Br. Mus. 6:87.

Anaitis fulgurata: Hampson, 1895, Fauna of British India (Moths) 3: 341

Docirava fulgurata: Prout, 1941, in Seitz, Macrolepid. World 12:332, pl.34: e

Docirava fulgurata: Yazaki, 1992, in Haruta (ed.), Moths of Nepal: 1, Tinea 13 (Suppl.2):17, pl.6, fig.6

Distribution: Nepal; India: West Bengal, N.W. Himalayas, Sikkim

2. ***Docirava pudicata*** **(Guenée, 1857)**

*Anaitis pudicata***,** Guenée, 1857, in Boisduval&Guenée, Hist. nat. Insectes (Lépid.) 10: 497

Anaitis pudicata: Hampson, 1895, Fauna of British India (Moths) 3: 341

Aspilates uvaria, Wlk. Cat.xxvi, p.1681; Cotes & Swinhoe. No. 3908

Anaitis vastata, Wlk. Cat.xxxv, p.1700

Docirava pudicata: Yazaki, 1994, in Haruta (ed.), Moths of Nepal: 3, Tinea 14 (Suppl.1):13, pl.68, fig.2

Distribution: Nepal, Afghanistan; India: West Bengal, N.W. Himalayas, Sikkim

Genus *Dysstroma*:

1. ***Dysstroma dentifera*** **(Warren, 1896)**

Polyfascia dentifera Warren, 1896, Novit. Zool. 3: 387

Dysstroma dentifera: Heydemann, 1929, Mitt. Münchenent. Ges.19; 273, pl. 6:74; pl.8:74:pl. 9: 81a ; pl.13:65

Cidaria (Dysstroma) dentifera: Prout, 1938, in Seitz, Macrolep. IV (Suppl.):122, pl.11: g.

Dysstroma dentifera: Yazaki, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): 10, pl. 162, fig. 10

Distribution: Nepal; India: Sikkim, New to Uttarakhand

2. ***Dysstroma fulvipennis*** **(Hampson,1902)**

Larentia fulvipennis Hampson, 1902, J. Bombay nat. Hist. Soc. 14:517

Cidaria (Dysstroma) dentifera: Prout, 1938, in Seitz, Macrolep. IV (Suppl.):122, pl.11: h

Distribution: Kashmir, New to Uttarakhand.

3. ***Dysstroma shirakawai*** **(Yazaki, 2000)**

Dysstroma shirakawai Inoue, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1):32, figs.1253, pl.162:12

Distribution: Nepal; New to India

Genus *Ecliptopera*:

1. ***Ecliptopera postpallida*** **(Prout,1938)**

Cidaria (Ecliptopera) postpallida Prout,1938, in Seitz, Macrolep.IV(Suppl.):154, pl.15: e

Ecliptopera postpallida: Prout, 1940, ibidem 12:305

Distribution: Ta-tsiem-La; India: Uttarakhand

2. ***Ecliptopera substituta*** **(Walker,1866)**

Cidariasubstituta Walker, 1866, List Specimens lepid. Insects Colln Br. Mus. 35:1691.

Ecliptopera substituta: Prout, 1940, in Seitz, Macrolepid. World 12:305, pl.30: d

Ecliptopera substituta: Yazaki, 1992, in Haruta (ed.), Moths of Nepal: 2, Tinea 13 (Suppl.2):18, pl.6, fig.13

Distribution: Nepal; India: North India

3. ***Ecliptopera*** **sp.1**

4. ***Ecliptopera*** **sp.2**

Genus *Electrophaes:*

1. ***Electrophaes aspretifera*** **(Prout,1938)**

Electrophaes aspretifera Prout,1938, in Seitz Macrolep IV, Suppl.156, pl.15, row h

Electrophaes aspretifera Prout 1940, in Seitz, Gross-Schmett. Erde 12:297, pl.29, row f.

Distribution: Kashmir, New to Uttarakhand

2. ***Electrophaes chrysophaes*** **(Prout,1923)**

Electrophaes chrysophaes Prout,1923 novit. Zool. Xxx, p.198

Electrophaes chrysophaes Prout,1940, in Seitz, Gross-Schmett. Erde 12:297, pl.29, row f.

Distribution: Meghalaya (Khasis), New to Uttarakhand

3. ***Electrophaes marginata*** **(Yazaki,1994)**

Electrophaes marginata: Yazaki, 1994, in Haruta (ed.), Moths of Nepal: 3, Tinea 14 (Suppl.1):30, pl.69, fig.4

Distribution: Nepal, New to India

4. ***Electrophaes niveonotata*** **(Warren, 1901)**

Cidaria niveonotata Warren, 1901, Novit.zool.8:26

Electrophaes niveonotata: Prout,1923, ibidem 30:198.

Electrophaes niveonotata Prout,1940, in Seitz, Gross-Schmett. Erde 12:297, pl.29, row f.

Electrophaes aliena: Yazaki, 1992, in Haruta (ed.), Moths of Nepal: 1, Tinea 13 (Suppl.2):19, pl.6, fig.28

Distribution: Nepal; India: Sikkim, New to Uttarakhand

5. ***Electrophaes recta*** **(Yazaki,1994)**

Electrophaes recta: Yazaki, 1994, in Haruta (ed.), Moths of Nepal: 3, Tinea 14 (Suppl.1):15, pl.69, fig.1

Distribution: Nepal; India: Uttarakhand

6. ***Electrophaes tsermosaria*** **(Oberthür, 1893)**

Cidaria tsermosaria, Oberthür, 1893 Et. D'Ent xvii :39, pl. 3. Fig.43

Electrophaes niveonotata Prout, 1940, in Seitz, Gross-Schmett. Erde 12:296, pl.29, row e.

Distribution: TaTsanhun; New to India

7. ***Electrophaes zaphenges*** **(Prout, 1940)**

Electrophaes zaphenges Prout,1940, in Seitz, Gross-Schmett. Erde 12:297, pl.29, row f.

Electrophaes fulgidaria Yazaki,1992, Tinea 13(Suppl.2): 19, pl.6, fig.27 (nec Leech)

Electrophaes zaphenges: Yazaki, 1994, in Haruta (ed.), Moths of Nepal:3, Tinea 14 (Suppl.1):30, pl.6, fig.27, as *fulgidaria* 69:2)

Distribution: Nepal; India: Meghalaya (Khasis), New to Uttarakhand

Genus *Entephria*:

1. ***Entephria poliotaria*** **(Hampson, 1902)**

Larentia poliotaria Hampson, 1902, J. Bombay nat. Hist. Soc. 14:517

Cidaria (Entephria) poliotaria: Prout, 1914, in Seitz, Macrolepid. World 4: 237, pl.13: n

Entephriapoliotaria: Prout, 1939, ibidem 12:274.

Distribution: N.W. Himalayas, Kashmir

2. ***Entephria punctatissima*** **(Warren,1893)**

Glaucopteryx punctatissima Warren,1893, Proc. Zool. Soc. Lond. 1893:368

Larentia punctatissima: Hampson, 1895, Fauna of British India (Moths) 3: 369

Entephria punctatissima: Prout, 1939, in Seitz, Macrolepid. World 12: 274, pl. 27: e

Entephria punctatissima Aubert, 1959, Z.wien.ent.Ges., 44:197

Distribution: Sikkim, New to Uttarakhand

3. ***Entephria* sp.**

Genus *Euphyia*:

1. ***Euphyia cinnamifusa* (Prout,1939)**

Cidaria (Euphyia) cinnamifusa: Prout, 1939, in Seitz, Macrolepid 12:328, pl. 27: l.

Distribution: Kashmir (Gulmarg), New to Uttarakhand

2. ***Euphyia subangulata (Kollar,1844)***

Euphyia subangulata Kollar, [1844], in Hügel, Kaschmir und das Reich der Siek 4: 490

Melanippe cymaria Butler, 1889, Illust. typical Specimens Lepid. Heterocera Colln Br. Mus. 7:24 (necGueneé, 1857)

Cidaria subangulata: Hampson, 1895, Fauna of British India (Moths) 3:356.

Cidaria (Euphyia) subangulata: Prout, 1914, in Seitz, Macrolepid. World 4:246, pl.10: b

Distribution: Afghanistan; India: N.W. Himalayas, Assam.

3. ***Euphyia* sp.**

Genus *Eupithecia*:

1. ***Eupithecia acuta* (Vojnits,1983)**

Eupithecia acuta Vojnits, 1983 Data to the Eupithecia fauna of Nepal.II (Lepidoptera: Geometridae) Op.cit.29:276

Eupithecia acuta: Inoue,2000, in Haruta (ed.), Moths of Nepal:6, Tinea 16 (Suppl.1): 27, pl. 165, fig. 1

Distribution: Nepal; India: NE India, West Bengal (Darjeeling), New to Uttarakhand

2. ***Eupithecia darjeelica* (Inoue,2000)**

Eupithecia darjeelica Inoue, 2000, in Haruta (ed.), Mtohs of Nepal: 6, Tinea 16 (Suppl.1):32, figs.1293, pl.165:16

Distribution: Nepal, Thailand; India: NE India, Darjeeling (West Bengal), New to Uttarakhand

3. ***Eupithecia fletcheri* (Prout,1926)**

Eupithecia fletcheri Prout, 1926: 252; Seitz Macro Lep. IV. Suppl. 184, pl.16k

Eupithecia fletcheri: Inoue, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): 33, pl. 165, fig. 18

Distribution: Nepal; India: Kumaon: Muktesar

4. ***Eupithecia liliptana* (Inoue,2000)**

Eupithecia liliptana Inoue, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1):35, figs.1303, 1343, pl.165:26

Distribution: Nepal; New to India

5. ***Eupithecia nigrilinea* (Warren,1896)**

Tephroleptia nigrilinea Warren, 1896, Nov. Zool. III, p.317

Eupithecia nigrilinea, Prout, 1926 in Seitz Macro Lep. IV, Suppl. 209, pl.176

Eupithecia nigrilinea: Inoue, 2000, in Haruta (ed.), Mtohs of Nepal:6, Tinea 16 (Suppl.1): 38, pl. 166, fig. 1

Distribution: Nepal; India: Kasauli

6. ***Eupithecia quadripunctata* (Warren,1888)**

*Eupithecia quadripunctata*Warren, 1888 Proc. Zool. Soc.:331

Eupithecia rajata (part): Hampson, 1895, Fauna Br. India (Moths) 3:399, necGuenee

Eupithecia infestata, Swinhoe 1889, Proc. Zool. Soc.: 430

Eupithecia quadripunctata: Inoue, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): 40, pl. 166, fig. 8

Distribution: Ceylon, Nepal; India: NE India, West Bengal (Darjeeling), Thundiani, Khasis (Meghalaya), Nagaland, Mhow, Nilgiris, Himachal Pradesh, New to Uttarakhand

7. ***Eupithecia subrubescens* (Warren,1888)**

Cidaria subruberescens Warren, 1888, Proc. Zool.Soc. 1888: 329;

Cidaria subrubescens: Hampson, 1895, Fauna Br. India (Moths) 3: 356

Melanippe despicienda Butler, 1889, Ill. Het. Vii, p.117, pl.137, fig. 17

Horisme subrubescens: Prout, 1938, in Seitz, Macrolepid. World 4 Suppl: 212, pl.17: e; id.,1941:353

Eupithecia subrubescens: Inoue, 1987: Bull. Fac. Domest. Sci. Otsuma. Wom. Univ 23: 241, figs 63: C. 65: C

Eupithecia subrubescens: Inoue, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): 41, pl. 166, fig. 13

Distribution: Nepal, N.W. Himalayas

8. ***Eupithecia* sp.1**
9. ***Eupithecia* sp.2**

Genus *Heterothera:*

1. ***Heterothera consimilis* (Warren, 1888)**

Thera consimilis Warren, 1888, Proc. Zool. Soc. Lond. 1888: 326

Larentia consimilis Hampson, 1895, Fauna of British India (Moth) 3: 380

Viidaleppia consimilis: Yazaki, 1992, in Haruta (ed.), Moths of Nepal: 1, Tinea 13 (Suppl.2):19, pl.6, fig.25

Distribution: Nepal, Afghanistan; India: N.W. Himalayas, Kashmir (Collection Herbulot, ZSM)

2. ***Heterothera dentifasciata*** **(Hampson, 1895)**

Larentia dentifasciata Hampson, 1895, Fauna of British India (Moth) 3: 379

Thera dentifasciata Prout, 1941, in Seitz, Gross-Schmett. Erde 12:324

Viidaleppia dentifasciata: Yazaki, 1994, in Haruta (ed.), Moths of Nepal: 3, Tinea 14 (Suppl.1):15, pl.68, fig.17

Distribution: Nepal; India: Himachal Pradesh (Dalhousie), Muree

3. ***Heterothera comis*** **(Butler,1879)**

Larentia comis Butler, 1879, Ann.mag. N.H. (S) IV, p.443

Larentia comis Hampson, 1895, Fauna of British India (Moth) 3: 379

Cidaria comis, Prout, 1914 in Seitz Macrolep IV, Suppl. 114, p.219 pl.13 row e

Distribution: Japan, Sikkim

Genus *Horisme:*

1. ***Horisme nigrovittata*** **(Warren,1888)**

Phibalapteryx nigrovittata Warren,1888, Proc. Zool. Soc: 327

Horisme nigrovittata Prout, 1914 in Seitz, Macrolepid. World 4:214, pl.17d

Distribution: Thundiani

2. ***Horisme plurilineata*** **(Moore,1888)**

Phibalapteryx plurilineata Moore, 1888, in Hewitson& Moore, Descr. New Indian lepid. Insects Colln late Mr Atkinson: 273.

Phibalapteryx plurilineata: Hampson, 1895, Fauna of British India (Moths) 3: 346

Phibalapteryx nigripunctata Warren, 1888 Proc. Zool. Soc: 328

Phibalapteryx nigrovittata Warren1888, Proc. Zool. Soc: 327

Horisme plurilineata Prout 1914, in Seitz Macrolepid World 4:302, pl.7b suppl. (215)

Horisme plurilineata: Yazaki,1995, in Haruta (ed.), Mtohs of Nepal: 4, Tinea 14 (Suppl.2): 10, pl. 100, fig. 9

Distribution: Nepal, Kashmir, N.W. Himalayas, Meghalaya (Khasis, Cherrrapunji).

3. ***Horisme* sp.1**
4. ***Horisme* sp.2**
5. ***Horisme* sp.3**

Genus *Hydrelia*:

1. ***Hydrelia bicolorata* (Moore,1868)**

Hyria bicolorata Moore, 1868, Proc. Zool. Soc. Lond., 1867 :642,

Hydrelia bicolorata: Hampson, 1895, Fauna of British India (Moths) 3:413.

Hydria undulosata Moore, Lep. Atk. P.251

Hydrelia bicolorata Prout, 1914, Seitz Macrolep IV, p.269, Suppl (178), pl.169

Hydrelia bicolorata: Yazaki, 1992, in Haruta (ed.), Moths of Nepal:1, Tinea 13 (Suppl.2):19, pl.6, fig.30

Distribution: Nepal; India: Himachal Pradesh (Dharmsala), Nagaland, Meghalaya (Khasis), Sikkim, Bengal, Uttarakhand

2. ***Hydrelia controversa* (Inoue,1982)**

Hydrelia controversa Inoue,1982, Bull. Fac.domestic Sci., Otsuma Woman's Univ., 18:158, figs 26E, 27D,28D

Distribution: Nepal, Kambachen; New to India

3. ***Hydrelia rubrilinea*** **(Inoue, 1987)**

Hydreliarubrilinea Inoue, 1987, Bull. Fac. Domest. Sci. Otsuma Wom. Univ. 23:229, fig. 56F, 58C, 60B

Hydrelia rubrilinea: Yazaki, 1995, in Haruta (ed.), Moths of Nepal: 4, Tinea 14 (Suppl.2): 10, pl.99; fig. 24

Distribution: Nepal, Walungchung; New to India

4. ***Hydrelia rubricosta (Inoue, 1982)***

Hydrelia rubricosta Inoue, 1982, Bull. Fac. Domest. Sci. Otsuma Wom. Univ.18:161, fig. 26Q, 27H, 28H

Hydrelia rubrilinea: Yazaki, 1995, in Haruta (ed.), Moths of Nepal: 4, Tinea 14 (Suppl.2): 10, pl.100; fig. 1

Distribution: Nepal, Nango-La; New to India

5. ***Hydrelia sericea*** **(Butler,1880)**

Noreia sericea Butler, 1880, Ann. Mag. Nat. Hist. (5) 6:225

Hydrelia sericea: Prout, 1938, in Seitz, Macrolepid. IV (Suppl.):179.

Hydrelia sericea: Yazaki, 1992, in Haruta (ed.), Moths of Nepal:1, Tinea 13 (Suppl.2):19, pl.6, fig.31.

Distribution: NE Himalaya, New to Uttarakhand

Genus *Hysterura*:

1. ***Hysterura protagma*** **(Prout, 1940)**

Hysterura protagma Prout, 1940, in Seitz, Macrolepid World 12: 311

Hysterura protagma Prout, 1940 Bull. Bri. Mus. Ent. 6(12):369

Distribution: Burma: East Pegu; India: Assam, Meghalaya (Cherrapunji, Khasia Hills), New to Uttarakhand

Genus Lobogonodes:

1. ***Lobogonodes* sp.**

Genus *Melanthia*:

1. ***Melanthia catenaria* (Moore,1868)**

Melanippe catenaria Moore, 1868, Proc.zool.Soc. Lond.1867: 655, pl.33, fig.9

Cidaria catenaria Hampson, 1895, Fauna of British India (Moths) 3: 354.

Melanthia catenaria Inoue, 1971, Bull. Fac. Domestic Sci. Otsuma Wom. Univ. 7:164

Distribution: West Bengal, Sikkim, Meghalaya (Khasis), New to Uttarakhand

Genus *Neotephria*:

1. ***Neotephria ramalaria* (Felder,1875)**

Cidaria ramalaria Felder, 1875 Reis. Nov. pl. (XXXII.31)

Cidaria ramalaria: Hampson, 1895, Fauna of British India (Moths) 3:353.

Cidaria ramalaria Prout,1914, Macrolepid. World 4: 238, pl.13 a, 12: 275 (*Neotephria)*

Neotephria ramalaria: Yazaki,1995, in Haruta (ed.), Moths of Nepal: 4, Tinea 14 (Suppl.2): 7, figs.8 pl.99: 13

Distribution: Nepal; N.W. Himalayas, Dharmsala, Kulu, Kangra district to Gulmarg

2. ***Neotephria* sp.**

Genus Orthonama:

1. ***Orthonama obstipata* (Fabricius, 1794)**

Phalaena obstipata Fabricius, 1794, Ent.Syst.3 (2): 199

Geometra fluviata Hübner, [1799] 1796, Samml. Eur. Schmett. 5: pl.54:280

Geometra gemmata Hübner, [1799] 1796, ibidem 5: pl.54:283.

Phalaena angustata Haworth, 1809: Lepid. Brit.2:340 (United Kingdom; USA; Georgia). Syntype (s)

Phalaena albicinctata Haworth 1809: Lepid. Brit.2:344 (England: Peckham). Syntype(s).

Larentia gemmaria Boisduval, 1840: Genera Index meth.eur. Lepid:205. Unjustified emendation of gemmata (*cf.* p.12)

Larentia quaerendaria Costa, 1850: Fauna Regno Napoli Lepidotteri: (418), pl. (Geom.) 13, fig.2 (southern Italy: Napoli region). Syntype(s).

Camptogramma obstipata: Guenée, 1857, in Boisduval&Guenée, Hist. nat. Insectes (Lépid.) 10: 430 (as syn. of *gemmata*)

Camptogramma baccata Guenée, 1858, in Boisduval&Guenée, Hist. nat. Insectes (Spec gén Lépid.) 10: 430 (Sri Lanka). Holotype Male (BMNH)

Camptogramma lapillata Guenée, 1858, in Boisduval&Guenée, Hist. nat. Insectes (Spec gén Lépid.) 10: 430 (Ethiopia, 'Abyssinae'). Holotype Male (BMNH).

Melanippe contrariata Walker, 1862: List specimens lepid. Insects Colln Br.Mus.25:1298.

Philabalapteryx intrusata Walker, 1862: List specimens lepid. Insects Colln Br.Mus.25:1339. Syntype(s)

Camptogramma exagitata Walker, 1862: List specimens lepid. Insects Colln Br.Mus.25:1331. Holotype Male (BMNH)

Cidaria peraculata Walker,1862: List specimens lepid. Insects Colln Br.Mus.25:1331. Holotype Male (BMNH)

Camptogramma signataria Walker, 1863: List specimens lepid. Insects Colln Br.Mus.26:1718. Syntype(s) female (BMNH)

Coremia obruptata Walker, 1863: List specimens lepid. Insects Colln Br.Mus.26:1713.

Coremia pigrata Walker, 1866: List specimens lepid. Insects Colln Br. Mus.35:1681.

Nycterosa brunneipennis Hulst, 1896, Trans. Am. Ent. Soc. 23:263.

Ochyria inconspicua Warren 1896: Novit. Zool. 3:122

Ochyria discata Warren, 1905, Novit. Zool. 12: 391

Cidaria (Orthonama) obstipata: Prout, 1914, in Seitz, Macrolepid. World 4: 228, pl. 9: e

Orthonama obstipata: Janse, 1917, Check List Tranvs. Mus: 100.

Nycterosa obstipata: Prout, 1933, in Seitz, Macrolepid. World 16:86.

Orthonama obstipata: Yazaki, 1995, in Haruta (ed.), Moths of Nepal:1, Tinea 13 (Suppl.2):17, pl.6, fig.5

Distribution: Polycontinental, migrant. Srilanka, Brazil, Europe, United Kingdom, North America, South Africa, Burma, Nepal; India: Throughout India, Khasi Hills

Genus *Parentephria*:

1. ***Parentephria stellata* (Warren,1893)**

Glaucopteryx stellata Warren,1893, Proc. Zool Soc. Lond: 367

Larentia adjrouraria Oberthür, 1894, Ètudesd´Ent. 18:36, pl.4:59

Larentias tellata: Hampson,1895, Fauna of British India (Moths) 3: 369.

Cidaria (Entephria) stellata: Prout, 1914 in Seitz, Macrolepid. World 4: 237, pl.10: i

Entephria stellata: Prout,1939, ibidem 12:274; Inoue,1982, Bull. Fac. Domestic Sci., Otsuma Woman’s Univ. 18:152, fig.24: A

Eulype stellata: Aubert,1959, Z. wien. Ent. Ges. 44:202, pl.22:124

Parentephria stellata: Yazaki,1995, in Haruta (ed.), Moths of Nepal: 4, Tinea 14 (Suppl.2): 7, figs.560,561,567, pl.99:9

Distribution: Nepal, India: Sikkim

2. ***Parentephria debilis* (Yazaki,1995)**

Parentephria stellata: Yazaki, 1995, in Haruta (ed.), Moths of Nepal: 4, Tinea 14 (Suppl.2): 7, fig: 7; pl.99:10

Distribution: Nepal; New to India

Genus *Pasaphila*:

1. ***Pasaphila (Rhinoplora) palpata* (Walker, 1862)**

Cidaria palpata Walker, 1862, List Specimens lepid. Insects Colln Br. Mus. 25:1404.

Chloroclystis palpata: Hampson, 1895 Fauna of British India (Moths) 3: 391

Rhinoplora palpata: Yazaki,1995, in Haruta (ed.), Moths of Nepal: 4, Tinea 14 (Suppl.2): 17, figs: 10; pl. 100, fig. 4

Distribution: Ceylon, Nepal, Japan; India: Himachal Pradesh (Dharmsala), Sikkim, Nilgiris, New to Uttarakhand

Genus *Perizoma*:

1. ***Perizoma affinis* (Moore, 1888)**

Larentia affinis Moore, 1888 Lep.Atk. p.277; Cotes & Swinhoe., no.3837.

Larentia affinis: Hampson, 1895, Fauna of British India (Moths) 3: 375.

Cidaria (Perizoma) seriata: Prout,1914, in Seitz, Macrolepid. World 4:259, pl. 13: m

Distribution: West Bengal (Darjeeling), New to Uttarakhand

2. Perizoma albofasciata (Moore, 1888)

Cidaria albofasciata Moore,1888, in Hewitson& Moore, Descr. New Indian lepid. Insects Colln late Mr Atkinson: 277

Larentia albofasciata: Hampson, 1895, Fauna of British India (Moths) 3: 374.

Larentia albofasciata Moore, Lep.Atk. p.277; Cotes & Swinhoe., no.3839.

Perizomaalbofasciata: Prout,1938:277; Inoue,1987 (as albofasciatum); Yazaki,1994:17, pl.69:10

Cidaria (Perizoma)albofasciata: Prout,1914, in Seitz, Macrolep. IV: 259, pl.7:h

Perizoma rantaizanensis Wileman, 1915, Entomologist 48: 59.syn nov.

Perizoma albofasciata f. mixtifascia Prout,1938:277. Synnov.

Perizoma albofasciata: Prout, 1939, ibidem 12: 277.

Perizoma albofasciata mixtifascia: Parsons et al., 1999:719

Perizoma albofasciata: Yazaki, 1994, in Haruta (ed.), Moths of Nepal:3, Tinea 14 (Suppl.1):17, pl.69, fig.10

Distribution: Nepal, Taiwan, Myanmar; India: Himachal Pradesh (Dharmsala), West Bengal (Darjeeling) and other N. Indian localities

3. Perizoma conjuncta (Warren,1893)

Perizoma conjuncta Warren, 1893 Proc. Zool. Soc. Lond. P.381

Larentia conjuncta Hampson, 1895, Fauna of British India (Moths) 3: 374.

Perizoma conjuncta Prout,1939, in Seitz, Gross-Schmett.Erde 12:279

Perizoma conjuncta: Inoue,2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): 45, pl. 166, fig. 20

Distribution: Nepal, Upper Burma, E. Pegu; India: Meghalaya (Khasis), New to Uttarakhand

4. ***Perizoma constricta* (Warren,1901)**

Perizoma constricta Warren, 1901, Novit. Zool.8:28

Perizoma constricta Prout, 1939, Seitz Macrolep IV. Suppl. 165. P. 279, Pl.16 a

Perizoma constricta: Inoue, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): 50, pl. 167, fig. 15,16.

Distribution: Nepal; India: Himachal Pradesh (Dalhousie), New to Uttarakhand

5. ***Perizoma micropunctum* (Inoue,2000)**

Perizoma micropunctum Inoue, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): p.52, figs.1372, pl.167:29

Distribution: Nepal; India: NE India (Darjeeling), New to Uttarakhand

6. ***Perizoma seriata* (Moore, 1888)**

Cidaria seriata Moore, 1888, in Hewitson& Moore, Descr. New Indian lepid. Insects Colln late Mr Atkinson: 278.

Larentia seriata: Hampson,1895, Fauna of British India (Moths) 3: 373.

Larentia seriata Moore, Lep.Atk. p.278; Cotes & Swinhoe., no.3869.

Cidaria (Perizoma) seriata: Prout,1914, in Seitz, Macrolepid. World 4:259, pl. 7: h

Perizoma seriata: Prout,1939, ibidem 12:279.

Perizoma seriata: Yazaki,1993, in Haruta (ed.), Moths of Nepal:2, Tinea 13 (Suppl.3):111, pl.60, fig.6

Distribution: Nepal, Tibet; India: N.W. Himalayas, Himachal Pradesh (Dharmsala), Sikkim, West Bengal (Darjeeling).

7. ***Perizoma variabilis* (Warren,1893)**

Perizoma variablis Warren, 1893, Proc. Zool. Soc. Lond. Xxv p.377, pl. xxx 17

Cidaria variabilis Prout, 1914, Seitz Macrolep IV, p. 259, pl.13m

Perizoma variabilis: Inoue, 2000, in Haruta (ed.), Moths of Nepal: 6, Tinea 16 (Suppl.1): 48, pl. 167, fig. 2.

Distribution: Nepal; India: Sikkim, N.W. Himalayas

8. ***Perizoma vinculata* (Staudinger,1895)**

Cidaria vinculata Staudinger, 1895, Dt. Ent. Z. Iris 8:340

Larentia vinculata: Staudinger, 1901, in Staudinger & Rebel, Cat. Lepid.Palaearct. Faunengeb.1: 294.

Cidaria (Perizoma) vinculata: Prout, 1914, in Seitz, Macrolep IV: p. 258, pl.8:1

Distribution: Tibet, Nepal; New to India

9. ***Perizoma* sp.1**

10. ***Perizoma* sp.2**

Genus *Photoscotosia*:

1. ***Photoscotosia amplicata* (Walker,1862)**

Cidaria amplicata Walker, 1862, List Specimens lepid. Insects Colln Br. Mus. 25: 1404

Cidaria trisignata Moore,1868, Proc.zool. Soc. Lond. 1867:663.

Trichopleura amplicata: Alphéraky, 1892, Rom, sur Lepid. 6:76.

Photoscotosia amplicata: Hampson, 1895, Fauna of British India (Moths) 3: 382.

Photoscotosia amplicata, Oberthur, Seitz Macrolep IV, p. 203, pl. 6l

Distribution: China, Tibet; India: Sikkim, N.W Himalayas

2. ***Photoscotosia cf. dejuta* (Prout,1937)**

Photoscotosia dejuta Prout, 1937, Seitz Macrolep IV. Suppl.:103, Pl.10; fig. d

Distribution: W. China, Wuin-kin; India: Uttarakhand

3. ***Photoscotosia occidens***

Identified from Collection Herbulot in Zoologische Staatssammlung Münich, Germany

Distribution: Himachal Pradesh, Spiti Valley (Forum Herbulot Collection, ZSM), New to Uttarakhand.

4. ***Photoscotosia metachryseis* (Hampson,1896)**

Photoscotosia metachryseis Hampson, 1896, Fauna of British India (Moths) 4: 557

Distribution: Sikkim, Kanchenjunga (from ZSM collection)

5. ***Photoscotosia miniosata* (Walker,1862)**

Scotosia miniosata Walker, 1862, List Specimens lepid. Insects Colln Br. Mus. 25: 1354

Photoscotosia stigmatica, Warren, Nov.Zool. p.680.

Photoscotosia miniosata: Warren 1888, Proc. Zool. Soc. Lond.1888:328.

Photoscotosia miniosata, Walker, Seitz Macrolep IV, p. 202, pl. 6k

Distribution: W. China, Phillipines, Formosa, Bangladesh (Sylhet); India: West Bengal, Uttarakhand, Sikkim, N. India, Himachal Pradesh

Genus *Rheumaptera*:

1. ***Rheumaptera alternata* (Staudinger,1895)**

Eucosmia alternata Staudinger, 1895, Dt. Ent. Z. Iris 8:332

Calocalpe alternata: Prout 1914, in Seits, Macrolepid. World 4:200, pl. 5:i

Distribution: Tibet; New to India

2. ***Rheumaptera melanoplagia* (Hampson, 1902)**

Scotosia melanoplagia Hampson, 1902, J. Bombay Nat. Hist. Society 14: 512

Triphosa melanoplagia: Prout, 1941, in Seitz, Macrolepid. World 12: 328, pl. 33: h

Calocalpe melanoplagia: Fletcher, 1961, Veröff. Zool. Staatssamml. München 6:171.

Rheumaptera melanoplagia: Yazaki, 1995, in Haruta (ed.), Moths of Nepal: 4, Tinea 14 (Suppl.2): 4, pl.97, fig.20.

Distribution: Tibet, Yatong (Bingham), Nepal, India: Sikkim (Dudgeon)

3. ***Rheumaptera tremodes*** **(Prout,1940)**

Calocalpe tremodes Prout, 1941, in Seitz, Macrolepid World 12:328, pl. 34, line a.

Calocalpe tremodes Prout, 1958, Bull. Brit. Mus. Ent.,6(12):375

Rheumaptera tremodes: Yazaki, 1992, in Haruta (ed.), Moths of Nepal:1, Tinea 13 (Suppl.2):18, pl.6, fig.12

Distribution: Nepal; India: Sikkim

4. ***Rheumaptera*** **sp.**

Genus *Scotopteryx*:

1. ***Scotopteryx nasifera*** **(Warren,1888)**

Eubolia nasifera Warren, 1888 Proc. Zool. Soc.Lond.:331

*Eubolia nasifera***:** Hampson, 1895, Fauna of British India (Moths) 3: 343

Ortholita nasifera Prout, 1914, in Seitz, Macrolepid World 4: 161, pl.11:a; 12:262

Distribution: Thundiani, Punjab, N.W. Himalayas

Genus *Trichoplites*:

1. ***Trichoplites lateritata*** **(Moore, 1888)**

Anticlea lateritata Moore,1888, in Hewitson & Moore, Descr.new Indian lepid. Insects Colln late Mr Atkinson: 273.

Trichoplites lateritata: Yazaki, 1993, Moths of Nepal:2, Tinea 13 (Suppl.3):111, pl.60, fig.2

Distribution: Nepal; India: Darjeeling, New to Uttarakhand

Genus *Trichopterigia*:

1. ***Trichopterigia rufinotata* (Butler,1889)**

Lobophora rufinotata Butler, 1889, Illust. Typical Specimens Lepid. Heterocera Colln Br. Mus. 7:116, pl. 137: 13

Trichopterigia rufinotata: Hampson, 1895, Fauna of British India (Moths) 3: 404

Distribution: Himachal Pradesh (Kulu), Sikkim

2. ***Trichopterigia* sp.1**
3. ***Trichopterigia* sp.2**

Genus *Triphosa*:

1. ***Triphosa dubiosata* (Walker,1862)**

Scotocia dubiosata Walker, 1862, List Specimens lepid. Insects Colln Br. Mus. 25:1352.

Scotosia dubiosata Hampson, 1895, Fauna of British India (Moths) 3: 344, fig.173

Triphosa dubiosata Prout,1914, in Seitz Macrolepid. World 4: 198, pl.11: g

Calocalpe dubiosata Fletcher,1961 Veröff. Zool. staatssammlung München 6: 170

Scotosia sideritaria, Oberthur, Et. Ent.x, p.34, pl.1, fig.13

Rheumaptera dubiosata: Yazaki,1995, in Haruta (ed.), Moths of Nepal: 4, Tinea 14 (Suppl.2): 15, pl.6; fig. 2

Distribution: Afghanistan, Japan, Bhutan; India: N.W. Himalayas, Sikkim, Nilgiris, Uttarakhand (Kumaon)

2. ***Triphosa (Rheumaptera) hydatoplex* (Prout,1938)**

Triphosa hydatoplex Prout,1938, in Seitz, Macrolepid. World 4 (Suppl.): 244, pl.18:1.

Rheumapterahydatoplex: Xue,1995, Sinozoologia 12:230.

Distribution: Ta-tsien-lu; New to India

3. ***Triphosa (Rheumaptera) nigralbata*** **(Warren, 1888)**

Scotosia nigralbata Warren, 1888, Proc. zool. London 1888: 327 (Thundiani)

Larentia nigralbata: Hampson, 1895, Fauna of British India (Moths) 3: 370

Triphosa nigralbata: Prout, 1937, in Seitz, Macrolepid. World 4 (suppl.): 100

Rheumaptera nigralbata: Xue, 1995, Sinozoologia 12: 229

Distribution: Thundiani, Punjab, Sikkim

4. ***Triphosa venimaculata*** **(Moore,1868)**

Scotosia venimaculata Moore, 1868, Proc. Zool. Soc. Lond. 1867: 657

Scotosia rubrodotata: Hampson,1895 Fauna of British India (Moths) 3: 345

Triphosa venimaculata: Prout, 1941, in Seitz, Macrolepid. World 12: 325, pl. 33: d

Distribution: Bengal, Punjab, Sikkim

5. ***Triphosa*** **sp.**

Genus *Venusia:*

1. ***Venusia crassisigna*** **(Inoue, 1987)**

Venusia classisigna Inoue, 1987, Bull.Fac. domest. Sci.OtsumaWom. Univ. 23: 225, figs. 56B, 57C, 59D.

Venusia classisigna: Yazaki, 1994, in Haruta (ed.), Moths of Nepal:3, Tinea 14 (Suppl.1):16, pl.6, fig.29

Distribution: Nepal: Kambachan; India: Uttarakhand

Genus *Xanthorhoe*:

1. ***Xanthorhoe mecoterma* (Prout,1938)**

Xanthorhoe mecoterma Prout, 1938 in Seitz, Macrolepid. World 4. Suppl (129) pl.12d; 12: 260

Distribution: Kashmir, New to Uttarakhand

2. ***Xanthorhoe obfuscata* (Warren, 1893)**

Xanthorhoe obfuscata Warren, 1893, Proc. Zool. Soc. Lond. 1893: 376

Cidaria bareconia Swinhoe, 1894, Trans. Ent.Soc.1894, p.189

Cidaria obfuscata: Hampson, 1895, Fauna of British India (Moths) 3: 365

Cidaria (Asaphodes) muscicapata obfuscata: Prout, 1914, in Seitz, Macrolepid. World 4: 234.

Cidaria (Loxofidonia) muscicapata obfuscata: Prout, 1938, ibidem 4 (suppl.): 137

Loxofidonia obfuscate: Prout, 1914, ibidem 12: 333, pl. 34: f.

Distribution: Sikkim, Meghalaya (Khasis), Nagas, New to Uttarakhand

3. ***Xanthorhoe saturata* (Guenée, 1857)**

Larentia saturata Guenée, 1857, in Boisduval&Guenée, Hist.nat.Insectes (Spec. gén. Lepid) 10:269.

Larentia exliturata Walker, 1862, List Specimens lepid. Insects Colln Br. Mus. 24:1105.

Coremia livida Butler,1878, Ann. Mag. Nat. Hist. (5) 1: 449

Larentia inamoena Butler, 1879, ibidem (5) 4: 444.

Cidaria saturata: Hampson, 1895, Fauna of British India (Moths) 3:362

Cidaria (Xanthorhoe) saturata: Prout, 1914, in Seitz, Macrolepid. World 4: 227, pl.7: f.

Xanthorhoe saturata: Prout, 1939, ibidem 12: 260.

Xanthorhoe saturata: Yazaki, 1992, in Haruta (ed.), Moths of Nepal: 1, Tinea 13 (Suppl.1):17, pl.6, fig.9

Distribution: Japan, China, South Africa, Nepal; India: N.W. Himalayas, Meghalaya (Khasis), Nilgiris

4. ***Xanthorhoe stupida*** (Alphéraky,1897)

Cidariastupida Alphéraky, 1897, Rom. Mem. Lepid.9:73.

Larentiaunidentaria var. *stupida*: Staudinger, 1901, in Staudiger& Rebel, Cat. Lepid.Palaearct. Faunengeb 1:298

Cidaria (Xanthorhoe) ferrugata stupida: Prout, 1914, in Seitz, Macrolepid. World 4:227.

Cidaria (Xanthorhoe) stupida: Prout, 1937, ibidem 4 (suppl.):127, pl.12: c.

Xanthorhoe stupida: Viidalepp, 1977, Ent. Obozr.56:567

Distribution: Europe, North America, Tibet, W. Central China, New to India

5. ***Xanthorhoe* sp.1**
6. ***Xanthorhoe* sp.2**
7. ***Xanthorhoe* sp.3**

Genus *Xenortholita*:

1. ***Xenortholita falcata* (Yazaki,1993)**

Xenortholita falcata: Yazaki, 1993, in Haruta (ed.), Moths of Nepal:2, Tinea 13 (Suppl.3):110, pl.59, fig.33

Distribution: Nepal; New to India

2. ***Xenortholita propinguata* (Kollar,1844)**

Cidaria propinguata Kollar, [1844], in Hügel, Kaschmir und das Reich der Siek 4: 490

Ortholita propinguata Prout 1939, in Seitz Macrolepid. World 4 Suppl. (75) (1937); 12 :263

Xenortholita propinguata: Yazaki, 1993, in Haruta (ed.), Moths of Nepal: 2, Tinea 13 (Suppl.3):109, pl.6, fig.21

Distribution: Nepal; India: Kashmir, Masuri, Kumaon

Subfamily Sterrhinae:

Established by Fletcher, 1979, Sterrhinae and Larentiinae were found to be sister taxa (Sihvonen, 2011). The members of this subfamily are often called 'waves' because of the numerous wavy fasciae present in the wings. This family is identified as the hindwing Sc+R1 is slightly anastomosed with Rs near base and never connected with it by bar in either sex. This is a diverse group of moths which shows huge variation in morphology and ecology. The species are usually smaller in size than the other subfamilies and prominent sexual dimorphism in wing size, shape and pattern. There are about 2800 described species globally but it has a tropical distribution (Covell, 1983; Heppner, 1991; Scoble et al. 1995) and poorly represented in high altitudes (Hausmann, 2001; Brehm 2002). The phylogeny of this subfamily is in a constant flux and has been studied in some recent works (Kaila & Albrecht, 2008; Õunap et al. 2005, 2008, Õunap 2010; Sihvonen, 2003, 2005)

Genus *Idaea:*

1. ***Idaea sp.*1**
2. ***Idaea sp.*2**

Genus *Rhodostrophia*:

1. ***Rhodostrophia aquila* (Yazaki,1998)**

Rhodostrophia aquila: Yazaki 1998, in Haruta (ed), Moths of Nepal: 5, Tinea15 (Suppl.1):6, pl.129, fig. 10.

Distribution: Nepal; New to India

2. ***Rhodostrophia herbicolens* (Butler,1883)**

Delocharis herbicolens Butler 1883, Proc.Zool. Soc. Lond.:173

Rhodostrophia herbicolens Hampson,1895, Fauna of British India (Moths) 3: 457

Rhodostrophia herbicolens Prout 1913: in Seitz, Macrolep IV; suppl.:25; pl.4a (1935)

Distribution: N.W. Himalayas, Himachal Pradesh (Solan).

3. ***Rhodostrophia olivacea* (Warren, 1895)**

Rhodostrophia olivacea Warren 1895 Novit.zool.,2: 99

Rhodostrphia olivacea Prout, 1938: in Seitz, Macrolep. World 12: 144; pl.15c

Rhodostrophia olivacea: Yazaki, 1994, in Haruta (ed), Moths of Nepal:3, Tinea 14 (Suppl.1): 10, pl.67, fig.18

Distribution: Burma, Nepal; India: West Bengal (Darjeeling), Sikkim, New to Uttarakhand

Genus *Scopula*:

1. ***Scopula pulchellata* (Fabricius,1794)**

Phalaena pulchellata Fabricius, 1794, Ent. Syst., 3(2): 171

Acidalia nictata Guenée, 1857, Hist.nat. Insectes, Spec. Gen. Lep., 9: 506

Acidalia ligataria Walker, 1861, List Specimens lepid. Insects Colln Br. Mus., 22:748

Acidalia metaspilaria Walker, 1861, Ibid., 23: 793.

Acidalia spatiosaria Walker, 1866, Ibid., 35: 1631

Idaea grandicularia Swinhoe, 1886, Proc. Linn. Soc. Lond., 1885: 858

Craspedia spilodorsata Warren, 1895 Novit.zool., 2:93, syn.n

Scopula spilodorsata cosmeta Prout, 1938, gross-Schmett. Erde, 12:200, syn.n

Scopula perlineata obdiscata Prout, 1938, S.p. spilotis Prout, 1938, Ibid. 12:201 syns.n.

Scopula nictata semperi Prout, 1938, S.n. takowensis Prout, 1938, Ibid. 12: 201

Distribution: Burma, Sri Lanka, Sino-Malayan, South Yemen and Ethiopio-Malagassic; India: West Bengal (Calcutta); East and North-West Himalaya and throughout the rest of the Peninsula; Lakshadweep Is.

2. ***Scopula* sp.**

Genus *Synegiodes*:

1. ***Synegiodes hyriaria* (Walker,1866)**

*Anisodes hyriaria*Walker, 1866, List Specimens lepid. Insects Colln Br. Mus. 35:1617

Synegiodes histrionaria Swinhoe, 1892 Tans. Ent. Soc: 12

Erythrolophus hyriarius Hampson,1895, Fauna of British India (Moths) 3: 453

Synegiodes hyriaria Prout,1938: in Seitz, Macrolep. World 12: 152, pl: 16d

Synegiodes hyriaria: Yazaki, 1994, in Haruta (ed), Moths of Nepal:3, Tinea 14 (Suppl.1):10, pl.5, fig.16

Distribution: Burma, West China, Nepal (Collection Herbulot); India: Sikkim, Khasis, North India, Darjeeling, Meghalaya, Sikkim

Genus *Timandra*:

1. ***Timandra correspondens* (Hampson,1895)**

Timandra correspondens Hampson, 1895, Fauna of British India (Moths) 3:459

Timandra correspondens: Prout, 1938; in Seitz, Macrolep. World, 12: 153, pl.16: f

Distribution: N.W. India, Dharmsala

Subfamily Geometrinae:

The Geometrinae subfamily comprise of the Emerald moths, named after the typical green colouration of this group. On the hindwing, the M2 vein is closer to M1 than M3. This group is particularly diverse in the tropical region and most members are nocturnal (Pitkin, 1996). The caterpillars are hard to locate as they often resemble the parts of the plant they feed on and has similar reduction of abdominal prolegs like the other subfamilies. According to the global taxonomic database by Scoble, Gaston and Crook (1995), there are about 2500 species of this subfamily present globally.

Genus *Chlororithra*:

1. ***Chlororithra fea* (Butler,1889)**

Chlororithra fea Butler, 1889, Illust.typical Specimens Lepid.Heteroc. Colln Br. Mus. 8:106, pl. 136, fig. 9.

Geometra fea Hampson, 1895, Fauna of British India (Moths) 3: 497.

Distribution: Nepal; India: Himachal Pradesh (Kangra district, Dharmsala).

Genus *Euchloris*:

1. ***Euchloris (Thetidia) radiata* (Walker, 1862)**

Thetidea (?) radiata, 1862, Walk. Cat. Lep. Het. xxvi.: 1567.

Euchloris radiata Hampson, 1895, Fauna of British India (Moths) 3: 498.

Distribution: West China; India: Himachal Pradesh (Kulu, Dharmsala), New to Uttarakhand

Genus *Hemithea*:

1. ***Hemithea distinctaria* (Prout, 1912), Chlorissa *distinctaria* (Walker, 1866)**

Thalassodes distinctaria Walker, 1862 Cat. Lep. Het. xxxv.: 1607.

Hemithea distinctaria Hampson,1895, Fauna of British India (Moths) 3: 491

Hemithea distinctaria: Prout, 1913, in Seitz, Macrolepid. World, 4:23, 2d

Chlorissa distinctaria Inoue, 1982, Bull. Fac. Domest. Sci. Otsuma. Wom. Univ 18: 134, figs 6A, 7B

Distribution: China; India: Himachal Pradesh (Sikkim), Uttarakhand (Nainital)

2. ***Hemithea* sp.**

Genus *Hemistola*:

1. ***Hemistola alboneura* (Fletcher,1961)**

Hemistola alboneura Fletcher, 1961, Veröff. Zool. Stsamml. Münch., 6:164, pl.16, fig.2, pl.18, figs 22,23, pl.26, fig 49

Distribution: Nepal, Tibet; New to India.

Genus *Mixochlora*:

1. ***Mixochlora vittata* (Moore, 1868)**

Geometra vittata Moore, 1868, Proc.zool. Soc.Lond. 1867:636

Tanaorhinus vittata: Prout, 1912, in Seitz, Macrolepid. World, 4:16, 2a

Mixochlora vittata: Holloway, 1976, Moths of Borneo with special reference to Mount Kinabalu: 61

Distribution: Borneo, Sarawak (Gunung Mulu National Park), Hunan (China), Nepal, Thailand; India: Bengal, N.W. India, Himachal Pradesh (Dalhousie), Meghalya (Khasis), Sikkim, West Bengal (Darjeeling), khasia hills Assam.

Genus *Thalassodes*:

1. ***Thalassodes (Pelagodes) veraria*** **(Guenée, 1857)**

Thalassodes veraria Guenée, 1857, in Boisduval&Guenée, Hist.nat.Insectes (Spec. gén. Lepid) 9: 360.

Thalassodes veraria Hampson,1895, Fauna of British India (Moths) 3: 508

Distribution: Ceylon, Java; India: Himalayas, Meghalaya (Khasis), Nagaland, Nilgiris.

Plate 3.1: Subfamily: Ennominae

1. *Abraxas picaria* (Moore,1868)

2. *Abraxas superpicaria* (Inoue,1970)

3. *Abraxas cf. leopardina* (Kollar,1844)

4. *Alcis granitaria* (Moore,1888)

5. *Alcis leucophaea* (Fletcher,1961)

6. *Alcis oxyrrina* (Wehrli,1945)

7. *Alcis paghmana* (Wiltshire,1967)

8. *Alcis paraclarata* (Sato,1993)

9. *Alcis perspicuata* (Moore,1868)

10. *Alcis semiclarata* (Walker, 1862)

11. *Anonychia grisea* (Butler,1883)

12. *Anonychia lativitta* (Moore,1888)

Plate 3.2: Subfamily: Ennominae


1. *Anonychia violacea* (Moore,1888)


2. *Apoheterolocha patalata* (Felder & Rogenhofer, 1875)


3. *Apoheterolocha quadraria* (Leech,1897)


4. *Arichanna albivertex* (Wehrli, 1933)


5. *Arichanna flavinigra* (Hampson,1907)


6. *Arichanna ramosa* (Walker,1866)


7. *Arichanna sparsa* (Butler,1890)


8. *Arichanna tramesata* (Moore,1868)


9. *Arichanna tenebraria* (Moore,1868)


10. *Artemidora disistaria* (Walker, 1862)


11. *Charissa* sp.


12. *Ctenognophos eolaria* (Guenée,1858)

Plate 3.3: Subfamily: Ennominae

1. *Ctenognophos fuscobrunnea* (Warren,1896)

2. *Ectropis* sp.1

3. *Ectropis* sp.2

4. *Gnophos albidior* (Hampson,1895)

5. *Heterolocha desistaria* (Walker,1862)

6. *Heterolocha falconaria* (Walker,1866)

7. *Heterolocha phaenicotaeniata* (Kollar,1844)

8. *Hirasa muscosaria* (Walker,1866)

9. *Lomographa distans* (Warren,1894)

10. *Loxaspilates hastigera* (Butler,1889)

11. *Loxaspilates obliquaria* (Moore,1867)

Plate 3.4: Subfamily: Ennominae

1. *Medasina albidaria* (Walker,1866)

2. *Medasina cervina* (Warren,1893)

3. *Medasina interruptaria* (Moore,1868)

4. *Menophra subplagiata* (Walker, 1860)

5. *Micrabraxas incolorata* (Warren,1893)

6. *Micrabraxas seriopuncta* (Hampson,1902)

7. *Myrioblephara duplexa* (Moore,1888)

8. *Odontopera heydena* (Swinhoe,1894)

9. *Odontopera kametaria* (Felder,1873)

10. *Odontopera veneris* (Inoue,1987)

11. *Opisthograptis mimulina* (Butler,1886)

12. *Opisthograptis sulphurea* (Butler,1880)

Plate 3.5: Subfamily: Ennominae

1. *Opisthograptis tridentifera* (Moore,1888)

2. *Ourapteryx* sp.

3. *Peetula stramineata* (Warren,1888)

4. *Percnia maculata* (Moore,1868)

5. Phthonandria atrilineata (Butler,1881)

6. *Prometopidia conisaria* (Hampson,1902)

7. *Pseudomiza cruentaria* (Moore,1868)

8. *Psyra crypta* (male) (Yazaki,1994)

9. *Psyra crypta* (female) (Yazaki,1994)

10. *Psyra cuneata* (Walker,1860)

11. *Psyra indica* (Butler,1889)

12. *Psyra similaria* (Moore,1868)

Plate 3.6: Subfamily: Ennominae

1. *Seleniopsis* sp.

2. *Sirinopteryx duplicilinea* (Hampson,1895)

3.*Sirinopteryx harutai* (Yazaki,1998)

4. *Sirinopteryx* sp.

5.*Stenorumia ablunata* (Guenée,1858)

6. *Tanaoctenia haliaria* (Walker,1861)

Subfamily: Larentiinae

8. *Apithecia viridata* (Moore,1868)

9. *Atopophysa sinotibetaria* (Wehrli,1931)

10. *Chartographa trigoniplaga* (Hampson,1895)

Plate 3.7: Subfamily: Larentiinae

1. *Cidaria basharica*
(Bang-Haas,1927)

2. *Coenolarentia argentiplumbea*
(Hampson,1903)

3. *Colostygia albigirata*
(Kollar,1844)

4. *Costicoma exangulata*
(Warren,1909)

5. *Docirava fulgurata*
(Guenée,1857)

6. *Docirava pudicata*
(Guenée,1857)

7. *Dysstroma dentifera*
(Warren,1896)

8. *Dysstroma fulvipennis*
(Hampson,1902)

9. *Dysstroma shirakawai*
(Yazaki,2000)

10. *Ecliptopera postpallida*
(Prout,1938)

11. *Ecliptopera substituta*
(Walker,1866)

12. *Electrophaes aspretifera*
(Prout,1938)

Plate 3.8: Subfamily: Larentiinae

1. *Electrophaes marginata* (Yazaki,1994)

2. *Electrophaes recta* (Yazaki,1994)

3. *Electrophaes tsermosaria* (Oberthūr,1893)

4. *Entephria poliotaria* (Hampson,1902)

5. *Entephria punctatissima* (Warren,1893)

6. *Euphyia cinnamifusa* (Prout,1939)

7. *Euphyia subangulata* (Kollar,1844)

8. *Eupithecia fletcheri* (Prout,1926)

9. *Eupithecia subrubescens* (Warren,1888)

10. *Eupithecia* sp.1

11. *Eupithecia* sp.2

12. *Heterothera dentifasciata* (Hampson,1895)

Plate 3.9: Subfamily: Larentiinae

1. *Horisme nigrovittata* (Warren,1888)

2. *Hydrelia bicolorata* (Moore,1868)

3. *Hydrelia controversa* (Inoue,1982)

4. *Hydrelia rubricosta* (Inoue,1982)

5. *Hydrelia sericea* (Butler,1880)

6. *Hysterura protagma* (Prout,1940)

7. *Lobogonodes* sp.

8. *Melanthia catenaria* (Moore,1868)

9. *Neotephria ramalaria* (Felder,1875)

10. *Parentephria stellata* (Warren,1893)

11. *Pasaphila palpata* (Walker,1862)

12. *Perizoma albofasciata* (Moore,1888)

Plate 3.10: Subfamily: Larentiinae

1. *Perizoma conjuncta*
(Warren,1893)

2. *Perizoma seriata*
(Moore,1888)

3. *Perizoma variabilis*
(Warren,1893)

4. *Perizoma vinculata*
(Staudinger,1895)

5. *Perizoma* sp.1

6. *Photoscotosia amplicata*
(Walker,1862)

7. *Photoscotosia* cf. *dejuta*
(Prout,1937)

8. *Photoscotosia occidens*

9. *Photoscotosia metachryseis*
(Hampson,1896)

10. *Photoscotosia miniosata*
(Walker,1862)

11. *Rheumaptera melanoplagia*
(Hampson,1902)

12. *Scotopteryx nasifera*
(Warren,1888)

Plate 3.11: Subfamily: Larentiinae

1. *Trichoplites lateritata* (Moore,1888)

2. *Trichopterigia* sp.1

3. *Triphosa dubiosata* (Walker,1862)

4. *Triphosa hydatoplex* (Prout,1938)

5. *Triphosa nigralbata* (Warren,1888)

6. *Triphosa venimaculata* (Moore,1868)

7. Venusia crassisigna (Inoue,1987)

8. *Xanthorhoe mecoterma* (Prout,1938)

9. *Xanthorhoe obfuscata* (Warren,1893)

10. *Xanthorhoe* sp.1

11. *Xenortholita falcata* (Yazaki,1993)

12. *Xenortholita propinguata* (Kollar,1844)

Plate 3.12: Subfamily: Sterrhinae

1. *Rhodostrophia herbicolens* (Butler,1883)

2. *Scopula pulchellata* (Fabricius,1794)

3. *Synegiodes hyriaria* (Walker,1866)

4. *Timandra correspondens* (Hampson,1895)

Subfamily: Geometrinae

4. *Euchloris (Thetidia) radiata* (Walker,1862)

5. *Hemithea distinctaria* (Prout,1912)

6. *Hemithea* sp.

7. *Hemistola alboneura* (Fletcher,1961)

8. *Thalassodes (Pelagodes) veraria* (Guenée,1857)

Chapter 4

Patterns along the altitudinal and vegetation gradients

4.1 Introduction

Mountains comprise 25% of land surface on Earth (Barthlott et al. 1996) and offer one of the most fascinating natural experiments to study evolutionary processes in relatively small spatial scales. This attribute of mountains has caught the interest of researchers and scientists all over the world for more than a century (Humboldt & Bonpland ,1807; Bonnier & Flauhalt, 1878; Körner, 2003 and 2004).

Some of the general theories of the origin of life were centred on the elevational gradients in biological communities. Along mountain slopes, a compressed well-ordered succession in climate and vegetation exists which mimics the latitudinal gradient at a local scale. Elevation gradients have served as an investigative tool, through generations of scientists, from von Humboldt's (1849) detailed observations along Mount Chimborazo in the Ecuadorian Andes in the early 1800s, to those of Darwin (1839, 1859) in the Chilean Andes, Wallace in Indonesia (1876, 1878), C. Hart Merriam (1890) in the North American Rockies during the mid- and later decades of the 19th century, to Robert H. Whittaker's (1960); Whittaker & Niering (1965) surveys in the Santa Catalina, Great Smokey and Siskiyou Mountains (southeastern and western North America) and James H. Brown's (1971) research in the Great Basin of North America. In recent years, however, latitudinal gradients have gained prominence in research on diversity patterns (Lomolino, 2001). Predictable changes in species composition and diversity have become a stronghold for the contemporary questions in ecology and evolution and critical understanding of patterns in biodiversity, global change and conservation (Sphen & Körner, 2009; McCain & Grytness, 2010).

Stevens (1992) claimed that ecologically restrictive climatic conditions appear to increase with elevation as they do with latitude. The decreasing species richness from the equator to the poles has been accepted as a general pattern (Rahbek, 1995) across; exceptions are the taxa with few species (Rohde, 1992). Many authors had accepted the decline of species richness with increasing altitude as a general biogeographic pattern (MacArthur, 1972; Terborgh & Weske, 1975; Terborgh, 1977, 1985; Begon et al. 1990; Brown, 1988; Stevens, 1992; Rohde, 1992) observed across taxa in terrestrial as well as aquatic systems. But Rahbek (1995) reviewed that in recent studies, for a wide variety of taxa, the mid-elevation peak in species richness is a more general pattern. Some recent studies have documented this pattern of species richness along elevation for many taxa (Heaney, 2001; Kessler et al. 2001; Sanders, 2002; Brehm et al. 2003 b; 2007; Grytnes, 2003; Herzog et al. 2005 and many more). There is a general acceptance of the altitudinal gradients as a model for hypotheses of large-scale patterns of diversity, though there is a little consensus (Nogués-Bravo et al. 2008).

4.1.1 Patterns along elevational gradients

Elevation has been studied as a critical biogeographic gradient in different parts of the world (Paudel, 2018) and the species richness patterns along the elevation are often linear or hump-shaped in different groups of organisms (Colwell et al. 2000; Jetz et al. 2001; Sanders et al. 2003; Brehm et al. 2007; Beck & Chey, 2008; Baniya et al. 2010; Acharya et al.2011; Paudel & Šipoš, 2014; Rahbek, 1995, 2005; McCain & Grytnes, 2010; Kessler et al., 2001, Peters et al. 2016).

Guo et al. (2013) reviewed 443 elevational gradients across latitudes in both northern and southern hemisphere, and 63% gradients showed unimodal patterns in richness as well as reported that vertebrates have a significantly higher diversity at high altitudes than invertebrates. Elevational gradients have been increasingly represented as a model template for other environmental gradients. Going up the elevation we can find different organisms adapted to the local conditions, but the environmental changes resonate the combined effect of regional or local alterations and altitude (Körner, 2007). The factors that primarily determine species richness patterns within gradients and cause substantial variability observed among mountain systems and taxa almost always remain uncertain as several gradients of environmental factors combine in elevational gradients and influence the spatial variation in species richness and diversity (Beck et al. 2017). The environmental factors are often confounding, thus, difficult to interpret as an ecological consequence. Different hypotheses regarding the patterns in elevational gradients are nonetheless tested using statistical correlations (Nogués-Bravo et al. 2008).

The analyses of these empirical data support the view that species richness declines with elevation, but not the view that this decline is necessarily monotonic (Rahbek, 1995). Some possible reasons for variation in the exact shape of the relationship between species richness and elevation for different taxa and zoo-geographic areas are commented, but our understanding of the relation between elevation and species richness still appears to be incomplete (Rahbek, 2005). When several co-variates are present in the general elevation related patterns, the practicality of the study becomes questionable. The driving variables should be accounted for in much detail to have a fruitful theory testing (Austin, 1999). Influences of sampling design and an effect of the area have been ignored in such a generalisation of monotonic decline. Whittaker (1952) is among the first studies describing how insect diversity changes along elevational gradients and brought out a linear decrease and mid-elevation peak as the patterns. Afterwards many recent studies have looked into insect (apart from moths) species richness along elevations globally (Warren et al. 1988; McCoy, 1990; Kearns, 1992; Reynolds & Crossley, 1997; Fleishmann et al. 1998; Blanche & Ludwig, 2001; Sanders, 2002, 2003; Escobar et al. 2005; Hodkinson, 2005; Ashton et al. 2009; Garibaldi et al. 2011; Larsen et al. 2011; Longino & Colwell, 2011; Robledo, 2016 among others). There also have been many studies assessing the diversity patterns of moths belonging to different families globally and, clearly, the mid-elevation peak is the most prominent pattern so far (Table 4.1). Geometridae family of moths have been studied the most, which is also the focal group for my study. Beck et al. (2017) have reviewed the elevation gradient studies on Geometridae moths and found the unimodal pattern to be the most common pattern observed.

Tropical communities are the most diverse and least understood (Brehm et al. 2007). Although the tropical mountains are much taller due to warmer temperatures at lower latitudes. They provide a much longer elevational gradient and tend to display unimodal patterns of richness (McCain & Grytnes, 2010; Guo et al. 2013), few studies have analyzed the possible underlying mechanisms responsible for the changes in diversity across small spatial scales in tropical ecosystems (e.g. Schulze, 2000; Basset, 2001; Hill et al., 2001). The tropical treeline temperature might be the same as the base of the temperate mountains, which accounts for the different patterns in similar elevational ranges globally (Guo et al. 2013). The temperate species groups generally increase in diversity with elevation, but in the tropics, the diversity declines with elevation (Tattersfield et al. 2001). The lack of taxonomic knowledge contributes little to our understanding of insect communities in tropical forests. Hence, tropical insects are under-represented in conservation biology at large (Novotny et al. 2007). However, in the current scenario of climate change and habitat degradation, tropical species will be particularly vulnerable as they have lower ranges of thermal tolerance (Laurance et al. 2011; Cadena et al. 2012)

Tropical mountain systems are classified into tropical, sub-tropical, temperate and alpine zones which mirror the latitudinal gradients and show variable patterns in species richness with the highest precipitation in mid-elevation zones (Chapman, 1917; McCain & Grytnes, 2010). It was around the late 1970s that ecologists started exploring the biodiverse tropics with Terborgh & Weske (1975); Terborgh (1977, 1985) examining the bird communities in the Andes. They found a decreasing pattern with increasing altitude as well as the similarity between latitudinal and elevational gradients. There is a lot of difference in the scale of the changing climatic parameters in the latitudinal gradient with an increased seasonality towards the poles, but in tropical elevational gradients, the temperature across zones is fairly constant. This difference would have differential impacts on the ecosystem processes on the two gradients (Rahbek, 1995). The scale has been an important factor which gives rise to conflicting diversity patterns, but in the present day, it might be affected by anthropogenic influences. Mountain ecosystems and human influences are interdependent, leading to alterations in habitat characteristics especially in the lower altitudes. This is the main reason of our inability to have a universal consensus of altitudinal diversity pattern and underlying mechanisms (Nogués-Bravo et al. 2008).

Moth families studied	Author	Location	Patterns observed
Geometridae	Axmacher et al. 2004	Afrotropical rainforest	linearly declining
Sphingidae	Beck and Chey, 2008	Northern Borneo, Malaysia	mid-elevation peak
Geometridae	Axmacher and Fiedler, 2008	Mt. Kilimanjaro, Tanzania	linearly declining
Geometridae	Brehm et al. 2002, 2003a, b	Andean montane rainforest	no relation with altitude
Geometridae	Brehm, 2007	Braulio Carrillo National Park, Costa Rica,	hump-shaped pattern
Geometridae, Erebidae, Noctuidae	Choi, 2016	South Korea	mid-elevation peak
All families	Sanyal et al. 2015	western Himalaya (Gangotri National Park)	unimodal
All families	Ashton et al. 2016a	China	No clear pattern
All families	Ashton et al. 2016b	Australia	Mid-elevation

Table 4.1: The observed patterns in elevational gradient studies done so far in different families of moths.

The present study aims to document the diversity of the Geometridae family of moths along an elevational and vegetation gradient in Nanda Devi Biosphere Reserve. The aim is to understand how the species composition and pattern of diversity in the

Geometridae moths change along the gradients and whether elevation plays an important role in shaping the diversity within the different communities. This is the first study on the elevational distribution and understanding the underlying causes of the assemblage structure of Geometridae moths across the elevation in India. Documenting diversity and associated patterns on species from unexplored areas under challenging conditions is the need of the hour for the conservation of biodiversity, a much-needed insight into the extant diversity and past evolutionary scenarios. The results from this study will also further help to formulate protocols for long-term monitoring programme and future conservation actions.

4.2 Methodology

4.2.1 Field collection

The study area was stratified by elevation and vegetation types to explore the moth diversity along the gradient. I sampled at every 200m along the elevation between 2000-3800m. Intensive sampling was done in two main gradients i) Joshimath-Sunil-Auli (collectively referred to as Joshimath) ii) Lata-Belta-Lata Kharak (collectively referred to as Lata) and in and around four other villages namely Tolma, Malari, Bhyundar and Ghangria. The latter two villages were the only places sampled within the buffer zone of the Valley of Flowers National Park. Each site was selected randomly at every 200m elevation band to include the different vegetation types. The numbers of trap sites were selected at each stratum so that comprehensive representation of the moth diversity can be accounted. On each night, I sampled at two sites. The trap sites were situated in the centre of plots with homogeneous vegetation cover, so that moth collection at weak light sources should largely reflect the local communities. The minimum distance between neighbouring sites was 50 m, with lamps not being visible from neighbouring sites, to prevent cross-habitation sampling does not occur. At each site, I sampled for three nights at different times from dusk to dawn to capture at least 90% of species of that area. Data from all three nights were then pooled for analysis. I also sampled for three nights (two trap sites/night) within the villages (Lata, Joshimath, Sunil and Ghangria). In Joshimath there were 6 different forest types based on the vegetation structure and from lower to higher elevation as follows: Low level blue Pine (LLBP); Moist Deodar (MD); Western Mixed Coniferous (WMC); Moru Oak (MO); Western Himalayan Upper Oak-Fir (UOF) and Kharsu Oak (KO) and in Lata site there were three forest type from lower to higher elevation as follows: LLBP, WMC and Western Himalayan Birch-fir (WHBF), the classification of Champion & Seth, (1968) was followed.

Moths were trapped by their attraction to weak light sources. Sampling was not conducted five days before and after the full moon, as moths are less attracted to artificial light sources during this period (Yela & Holyoak,1997) Optimal sample sizes were determined after the initial data analysis (from species-area accumulation curve and rarefaction). Total effective sampling effort is shown in Table 4.2 and details of all the trapping locations are provided as Appendix 4.1.

i) Habitat and disturbance Variables:

The following variables were considered as sites covariates: Temperature, humidity, wind speed, distance from human habitation, grazing signs present, signs of grazing, logging & lopping, canopy cover, grass cover, litter cover and slope.

ii) Vegetation Sampling:

Vegetation sampling was done by a nested sampling method. Two plots were placed randomly within a 50m radius of each light-trap site. 20m diameter circular plots were laid for the tree species with the number and types of trees were noted along with their mean Girth at Breast Height (GBH) and mean height. Within this a 10m diameter shrub plot was laid to record the shrub species along with their mean height, density and four 1x1m square plots will be laid randomly within the 20m diameter to note down the herb species and percentage grass cover (Rawat et al. 2004)

4.2.2 Data analyses

The analyses were done aiming at identifying the factors which can best explain the comparative patterns of faunal change and distribution along elevation and forest types in Joshimath and Lata. Rarefied species richness (Cole rarefaction) and estimated species richness indices (Chao 1 mean, and Jack 1 mean) were calculated for all the plots in the two gradients Joshimath and Lata. Simple linear regression of absolute species richness with elevation and variance in mean abundance of species in the elevation bands (200m) were calculated in both the gradients to understand how elevation affects species richness and abundance. The estimated species richness (Chao 1 mean) was calculated for each of the different forest types sampled in both the gradients.

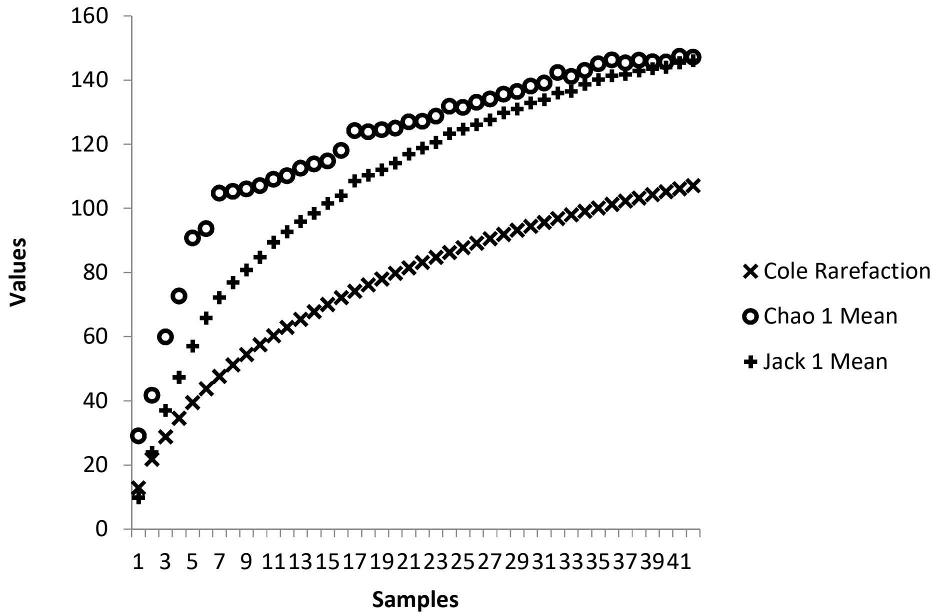
The alpha diversity and species turnover were calculated by pooling samples along each elevation band (200m) to reduce the influence of outliers. Fisher's alpha (Fisher et al. 1943) is more robust, and a good discriminant of different samples from different sites, independent of sample size and is not influenced by the rare and abundant species. The variation in species composition among forest types was analysed with the (βsim) (Lennon et al. 2001; Simpson 1943).

Location	trap sites	Effective trapping hours	Elevation range covered (m)	seasons sampled
Joshimath-Auli	42	131.5	2104-3152	Pre-monsoon+ post-monsoon
Lata-Lata Kharak	54	167	2137-3800	Pre-monsoon+ post-monsoon
Joshimath + sunil Village	6	19.5	2000-2272	Pre-monsoon+ post-monsoon
Lata village	6	18	2183-2399	Pre-monsoon+ post-monsoon
Ghangria village	8	24	3091-3213	Pre-monsoon+ post-monsoon
Tolma village	8	24	2567-2667	Pre-monsoon+ post-monsoon
Malari village	8	24	3015-3088	Pre-monsoon+ post-monsoon

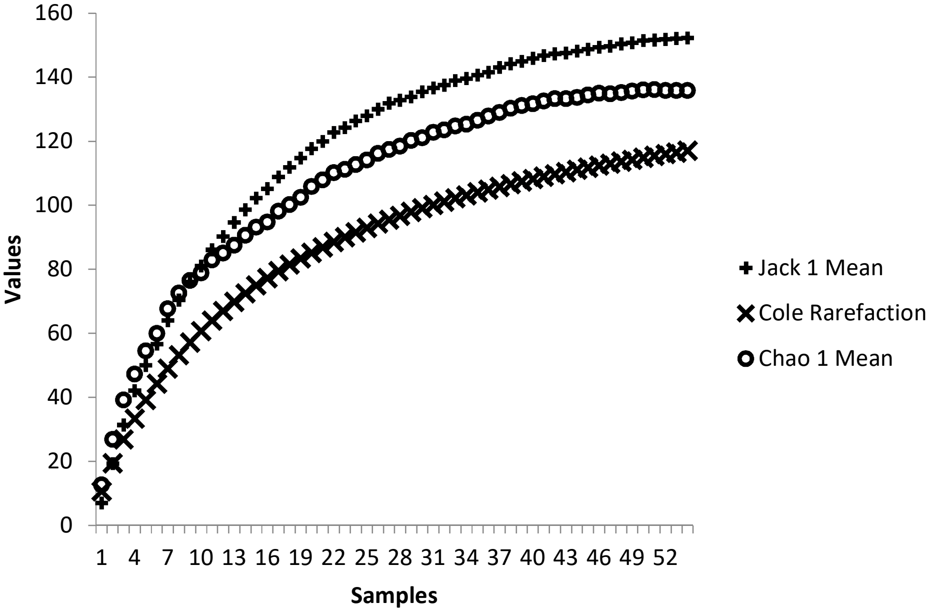
Table 4.2: Total effective sampling effort in all the trapping sites included in the study

This index quantifies the spatial turnover component of beta diversity, i.e. the dissimilarity caused by the substitution of some species by others, removing the effect of richness differences on beta diversity (Baselga 2010; Baselga et al. 2012). Incidence-based species turnover (Simpson's dissimilarity), species nestedness (Sorensen dissimilarity) and abundance-based species turnover (Bray-Curtis Index) were also calculated for total species, for Ennominae, for Larentiinae at each elevation band and on total species for the different forest types found in both Joshimath and Lata. A pair-wise dissimilarity matrix based on βsim was computed using command beta. pair in R package betapart (Baselga and Orme 2012). The plotting was done to interpret the similarities of the plots in the different forest types based on their species composition. The different variables were categorised into detection variables (Temperature, windspeed, relative humidity), site-covariates (the variables collected which defined each trap location like the Grass cover, litter cover, shrub diversity &

density, herb diversity & density, mean tree height, mean GBH, bare soil, canopy cover) and disturbance variables (pellet density, lopping density, felling density, distance to settlement and distance to cultivation). Principal Component Analysis was performed to reduce the different variables (detection variables, site covariates and disturbance variables) into principal components that best explains the assemblage structure at Joshimath and Lata. Linear regression of the principal components with estimated species richness (Chao 1) as the response variable and then was plotted in each case with the corresponding r-square values to find out the correlation with the Principal Components. To assess species habitat association, we performed the Indicator Species Analysis, which Dufrêne and Legendre (1997) introduced as the indicator value (IndVal) method (indicspecies package in R), which treats each species separately using a pre-determined partition of sites as the input.



a)



b)

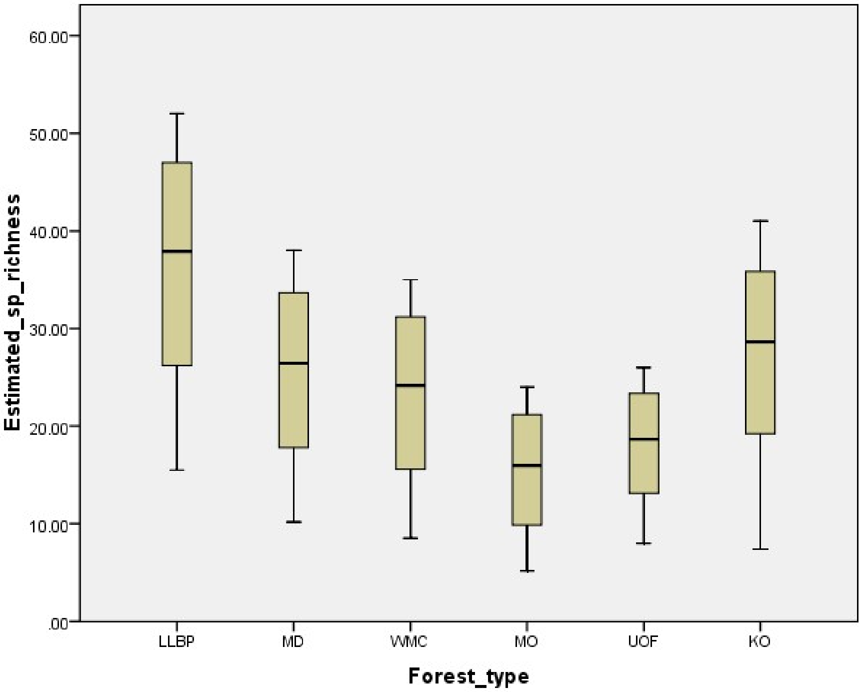
Figure 4.1: Rarefied species richness (Cole rarefaction) and total richness estimated indices (ACE mean, Jack 1 mean and Chao 1 mean) of Geometridae moths from a) Joshimath b) Lata.

4.3 Results

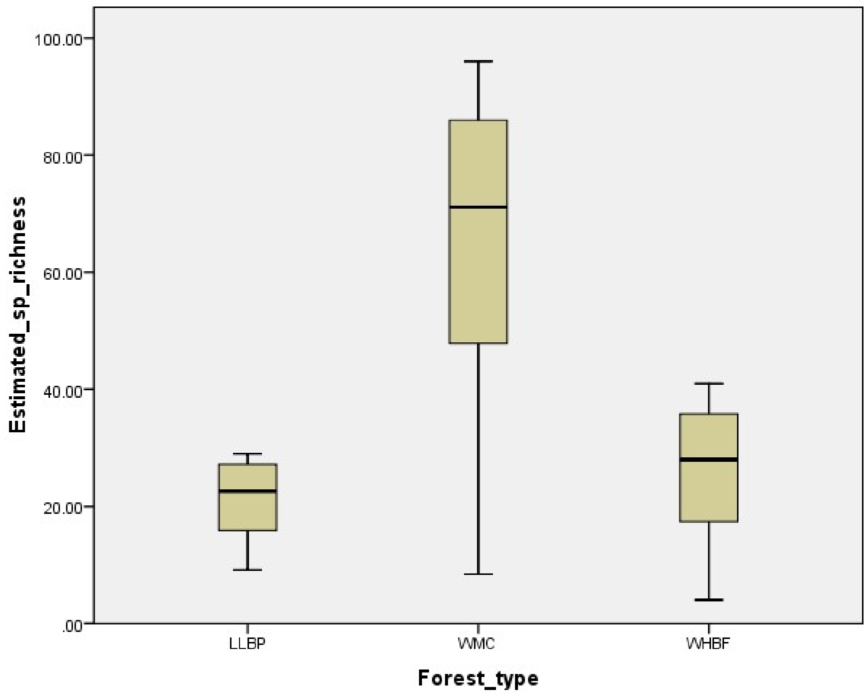
The sampling across all the plots across different habitats failed to reach the asymptote, indicating that the samples do not cover the entire species diversity expected to be found in the area (Fig.4.1).

	a	b	r-square	df	F	P
Joshimath	22.728342	-0.00524	0.1236	1 and 40	5.64	0.05
Lata	20.262502	-0.00449	0.2007	1 and 52	13.05	0.001
Pooled	21.483868	-0.00485	0.1833	1 and 94	21.1	0.001

Table 4.3: Simple linear regression of species richness with elevation for Joshimath and Lata and combined for both the studied gradients (a=intercept, b=regression co-efficient)



a)



b)

Figure 4.2: The estimated species richness (Chao 1 mean) across the different habitat types in a) Joshimath b) Lata. [Low level blue Pine (LLBP); Moist Deodar (MD); Western Mixed Coniferous (WMC); Moru Oak (MO); Western Himalayan Upper Oak-Fir (UOF) and Kharsu Oak (KO) and Western Himalayan Birch-fir (WHBF)].

The first and often the only parameter considered for diversity patterns is the species richness based on taxonomic identifications. Even if the taxonomy of the group is well known, it is not the case for tropical fauna (Barlow and Woiwod, 1989). Absolute species richness with elevation shows a significant decline in both Joshimath and Lata (Table 4.3). It is observed that in Joshimath there is a decline in estimated species richness (Chao 1) in the mid-elevation Moru Oak forest type, after which it shows an increasing trend in the higher elevation forest types (Fig. 4.2). But, at Lata, the species richness clearly shows a unimodal peak in the mid-elevation Western

Mixed Coniferous forest type (Fig. 4.2). Fig. 4.3 also shows a similar pattern in the variance of the mean relative abundance of all species combined at each elevation band (200m) in Joshimath and Lata.

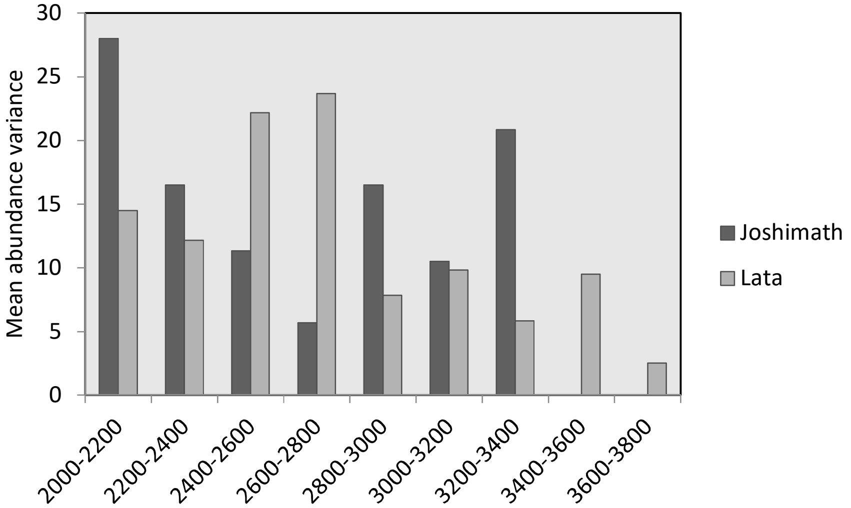


Figure 4.3: Mean relative abundance variance of all species combined at all the plots pooled for each elevation band of 200m at Joshimath and Lata

	Joshimath	Lata
Species Abundance: Ennominae	-.448**	-.545**
Species Abundance: Larentinae	0.143	-.272*

Table 4.4: Spearman rank correlation (rho) (**p=0.01, *p=0.05) of the relative abundance of Ennominae and Larentiinae subfamilies with elevation.

The most abundant subfamily of Geometridae across all trap sites was Ennominae and Larentiinae as we saw in the previous chapter. Here, we looked at how the abundance of Ennominae and Larentiinae responded to elevation (Table 4.4).

Ennominae abundance shows significant negative correlation with elevation at both the gradients, but interestingly abundance of Larentiinae shows differential response to the elevation at both the gradients. The alpha–diversity and species turnover patterns (Fig. 4.4) show similar mid-elevation decline at Joshimath and Lata respectively. Evidently, not only elevation and vegetation, but other environmental/disturbance factors act locally to define the community structure.

From Table 4.5, we can see that; incidence-based and abundance-based species turnover were higher in Moru-oak forest type in Joshimath and Western Mixed Coniferous forest type in Lata. Species nestedness was found to be high in moist deodar forest type and Western Himalayan Birch-Fir forest type in Lata. The plots in the different forest types are more similar in species composition and cluster together in Lata than at Joshimath (Fig. 4.5). Principal components reduced the number of variables (detection variables, disturbance variables and site-covariates) that would explain the diversity patterns (Fig. 4.6) and the estimated species richness was found to vary significantly with detection (negatively, $p=0.001$) and disturbance (positively, $p=0.01$) variables in Joshimath and only with disturbance (positively, $p=0.001$) in Lata (Table 4.6 and Fig.4.7 a &b).

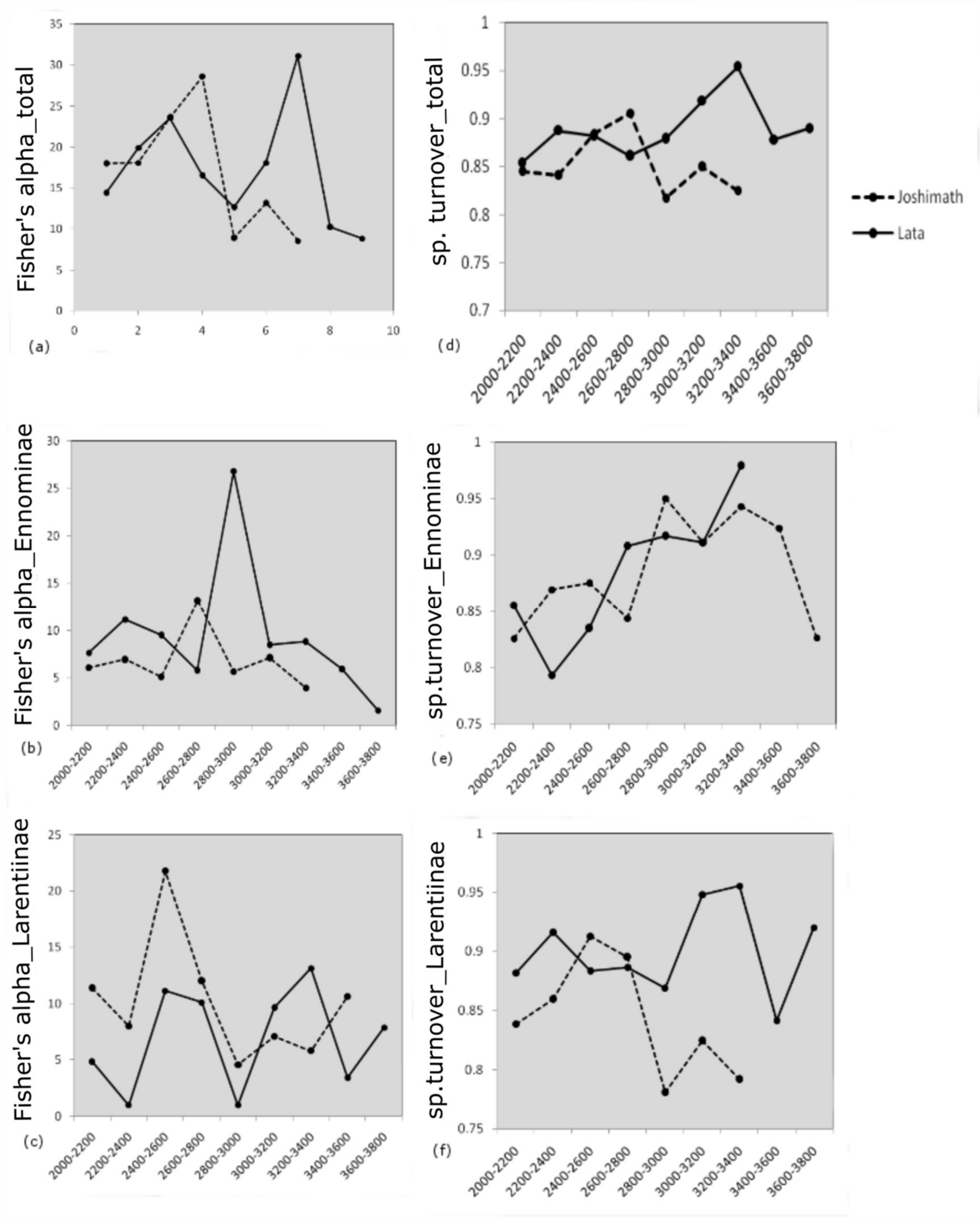


Figure 4.4: For alpha-diversity, Fisher's alpha (a parameter of the log-series species–abundance distribution model; Fisher et al., 1943) for each elevation band (200m) at both the locations; a) total species, b) Ennominae subfamily, c) Larentiinae subfamily. For beta-diversity, abundance-based species turnover (measured as Bray-Curtis Index)

at the sampling plots pooled in an elevation band (200m) at both the locations.; d) total species, e) Ennominae subfamily and f) Larentiinae subfamily.

	Joshimath			**Lata**		
Forest Types	Incidence-based Species turnover	Species nestedness	abundance-based species turnover	Incidence-based Species turnover	species nestedness	abundance-based species turnover
Low level Blue Pine	0.6821705	0.1143555	0.845953	0.75925926	0.03520714	0.7986577
Western Mixed Coniferous	0.76470588	0.07034566	0.8848485	**0.92065107**	0.03175894	**0.96301**
Moist Deodar	0.6849315	**0.1477958**	0.8417582			
Moru Oak	**0.8372093**	0.04988747	**0.9058824**			
Western Himalayan Upper Oak-fir	0.71794872	0.05982906	0.8177677			
Kharsu Oak	0.8267148	0.05692156	0.8862876			
Western Himalayan Birch-fir				0.89473684	**0.04471444**	0.9550814

Table 4.5: Incidence-based species turnover = Simpson's dissimilarity; Species nestedness= measured as nestedness resultant fraction (Sorensen dissimilarity); Abundance-based species turnover=Bray-Curtis Index in different forest types in Joshimath and Lata (values in red indicate the highest values).

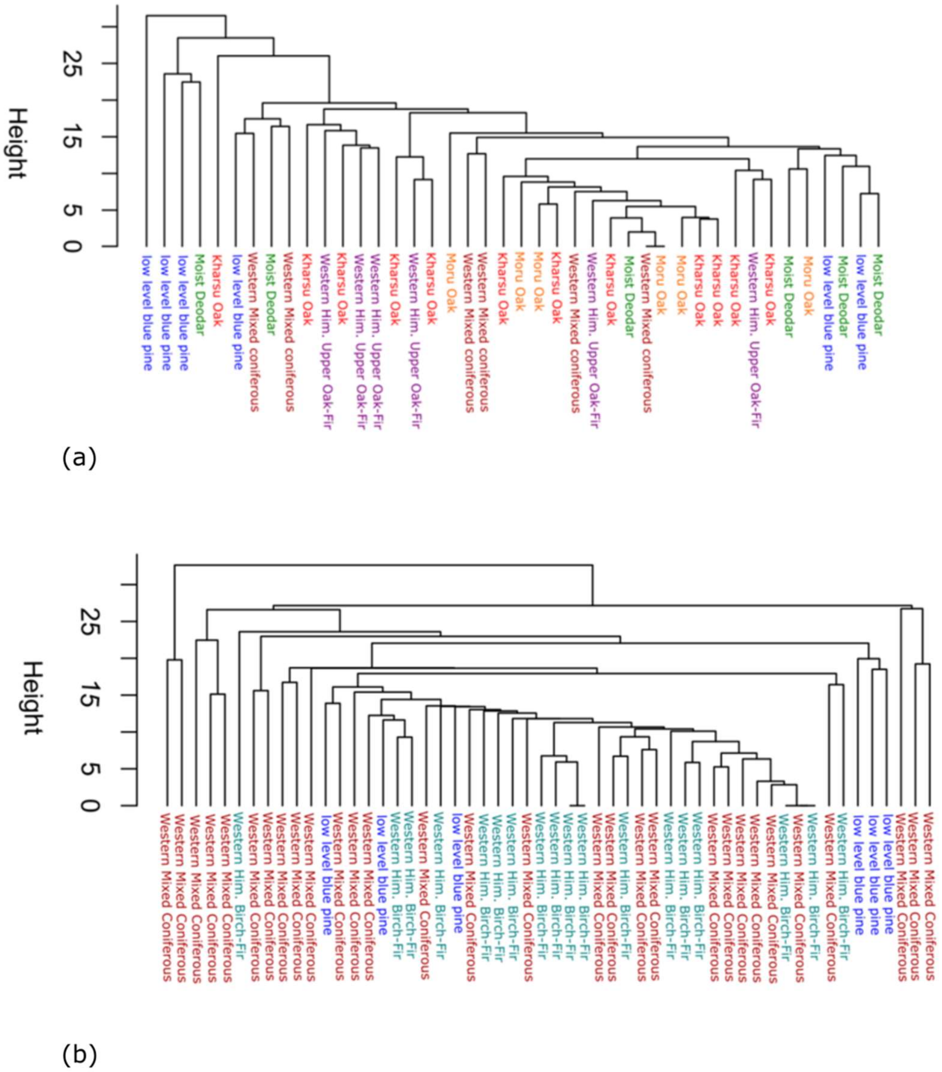


Figure 4.5: A pair-wise dissimilarity matrix by means of an agglomerative hierarchical clustering analysis a) Joshimath, b) Lata based on the Simpson's index of dissimilarity (βsim) dissimilarity matrix, using command hclust (R Development Core Team 2013) with average linkage, in order to identify and visually inspect plots with similar fauna and variation in species composition (Height=dissimilarity).

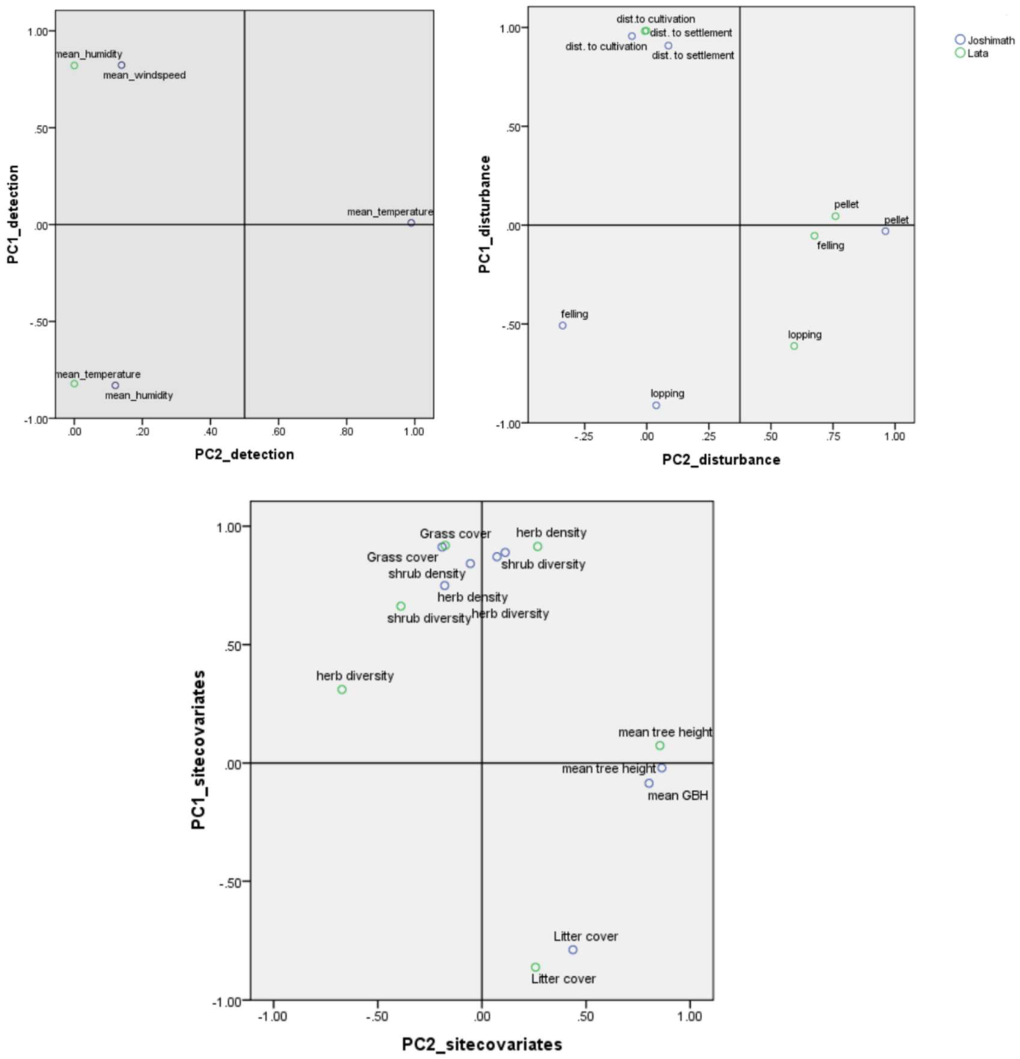


Figure 4.6: The biplots representing the component scores of different the variables in relation to the with the Principal Components (PC1 and PC2) in Joshimath and in Lata.

Joshimath

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	120.038	2.780	43.186	<2e-16 ***
PC1_detection	-11.580	2.944	-3.933	0.000344 ***
PC1_disturbance	19.522	5.884	3.318	0.002007 **
PC1_site covariates	2.601	6.014	0.433	0.667793

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 18.01 on 38 degrees of freedom
Multiple R-squared: 0.6142, Adjusted R-squared: 0.5837
F-statistic: 20.16 on 3 and 38 DF, p-value: 0.00000005526

Lata

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	107.138	2.554	41.949	<2e-16 ***
PC1_detection	5.538	3.404	1.627	0.110
PC1_disturbance	22.896	3.341	6.853	0.0000000102 ***
PC1_site covariates	1.676	3.693	0.454	0.652

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 18.77 on 50 degrees of freedom
Multiple R-squared: 0.6546, Adjusted R-squared: 0.6339
F-statistic: 31.59 on 3 and 50DF, p-value: 1.339e-11

Table 4.6: Model Summary for the Linear regression Model of the Estimated Species Richness (Chao 1 Mean) with the Principal Components of the variables (detection, disturbance and site covariates).

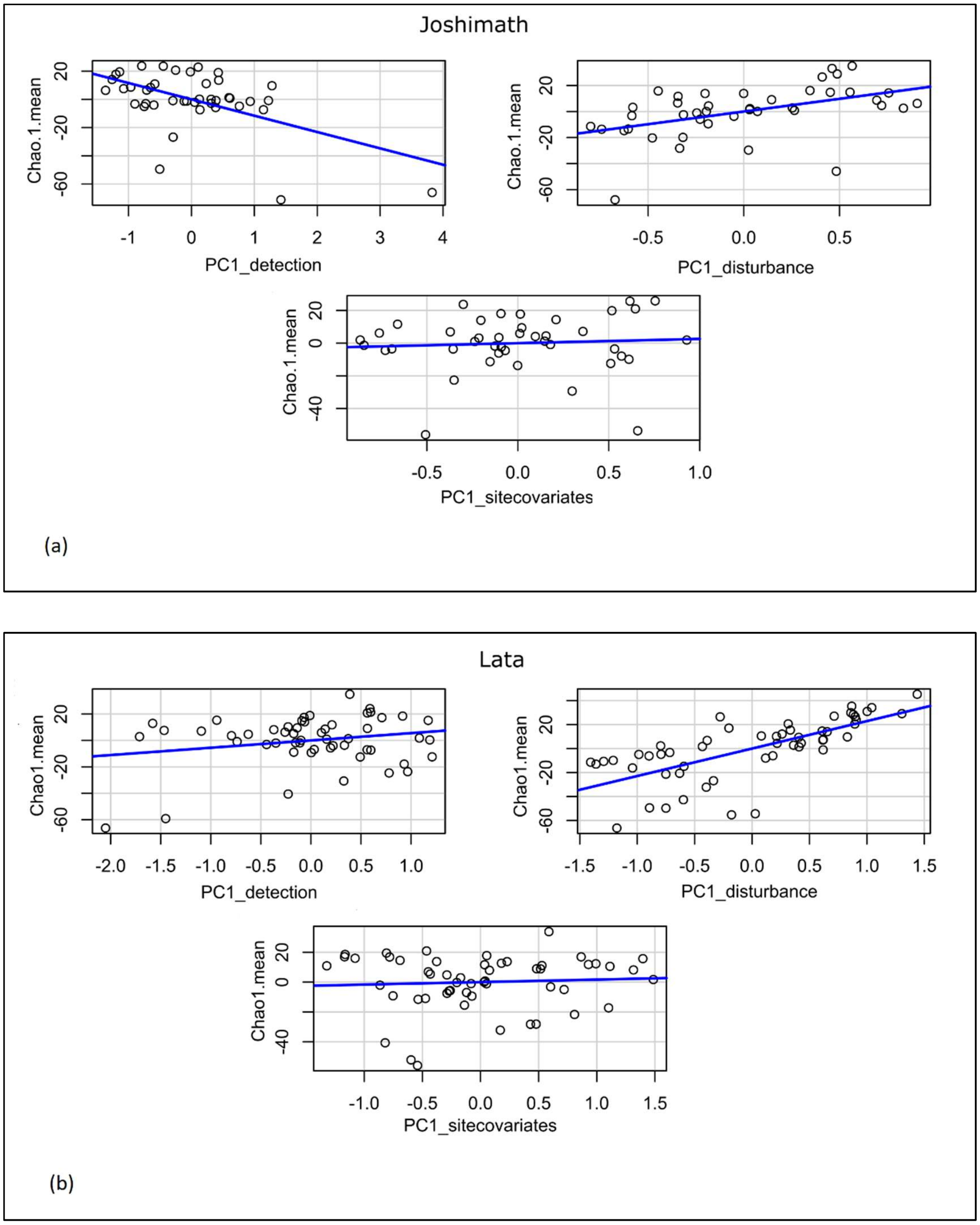


Figure 4.7: Linear regression plots of Estimated species richness (Chao 1 Mean) with the Principal components in a) Joshimath and b) Lata.

Geometrids are known to be forest-dependent species and since anthropogenic disturbance was found to affect the species richness at both Joshimath and Lata, so apart from Lata and Joshimath, we sampled at three more villages in the landscape at different altitudes; Tolma (circa 2500m), Malari (circa 3000m) and Ghangria (circa 3100m). The number of Geometrids at the trap sites pooled together for each village was lower than at the forest patch nearest to the village, except for at Lata (Fig.4.8).

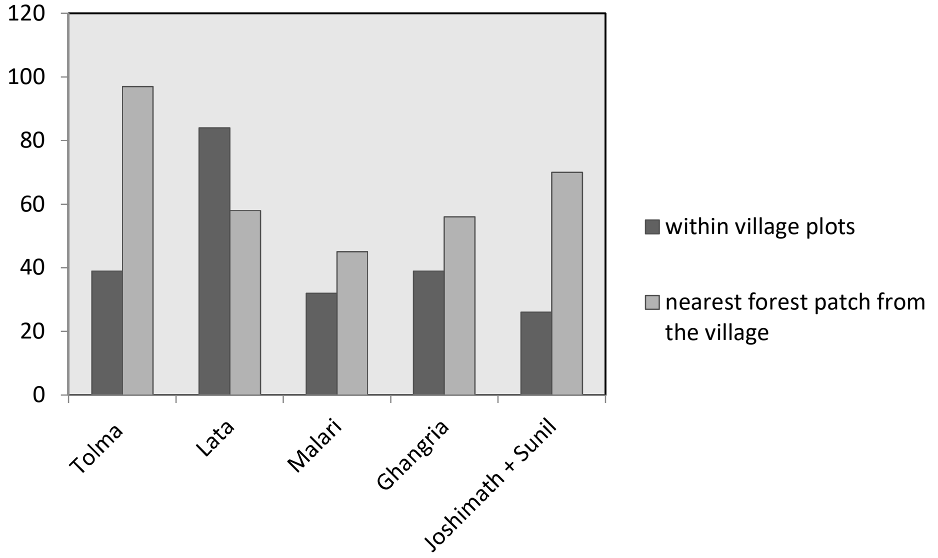


Figure 4.8: The number of Geometridae moths at all the trap sites within the village and in forests at a distance of >1km from the village. Except for at Lata, all the trap sites within the villages had lower number of Geometrids than the forest plots.

The Indicator Value Index determines how strongly the target species is related to the groups of sites forming the existing partition. De Cáceres (2010) had improved the approach, which considered structures that come from combinations of groups of the initial partition of the sites. For each species, the combination of site groups to be retained and tested for statistical significance is the one with the maximum association strength. Species that have a strong association with the forest type and the elevation (as an interaction) as shown in Fig. 4.9 shows their distribution in the studied area and the basis for categorising the widespread and restricted range of these species. Most of the species found to have significant indicator values have been found in many of the sampled trap sites, except for *Parentephria stellata* and *Prometopidia* sp.nov. which have been only found in the habitats they are highly associated with.

4.4 Discussion

The results of my study are the first of its kind on the elevational distribution and understanding the underlying causes of the assemblage structure of Geometridae moths in India. The species diversity (Fisher's alpha) showed a mid-elevation decline in both the location and estimated species richness was highest in the Western Mixed Coniferous Forest of the Lata gradient. Both the gradients sampled within the landscape, showed that anthropogenic disturbance caused as a result of habitat fragmentation (human habitation), resource extraction in the form of fuelwood and timber (lopping and felling) as well grazing (pellet signs) impacts the geometrid moth assemblage structure and their patterns across the elevation. This pattern is similar to those observed small non-volant mammals, salamanders, ants and ferns in having highest richness in the mid elevations (Beck et al. 2017). But, a larger elevation gradient, which in this study was only from 2000-4000m asl, would have provided more robust patterns.

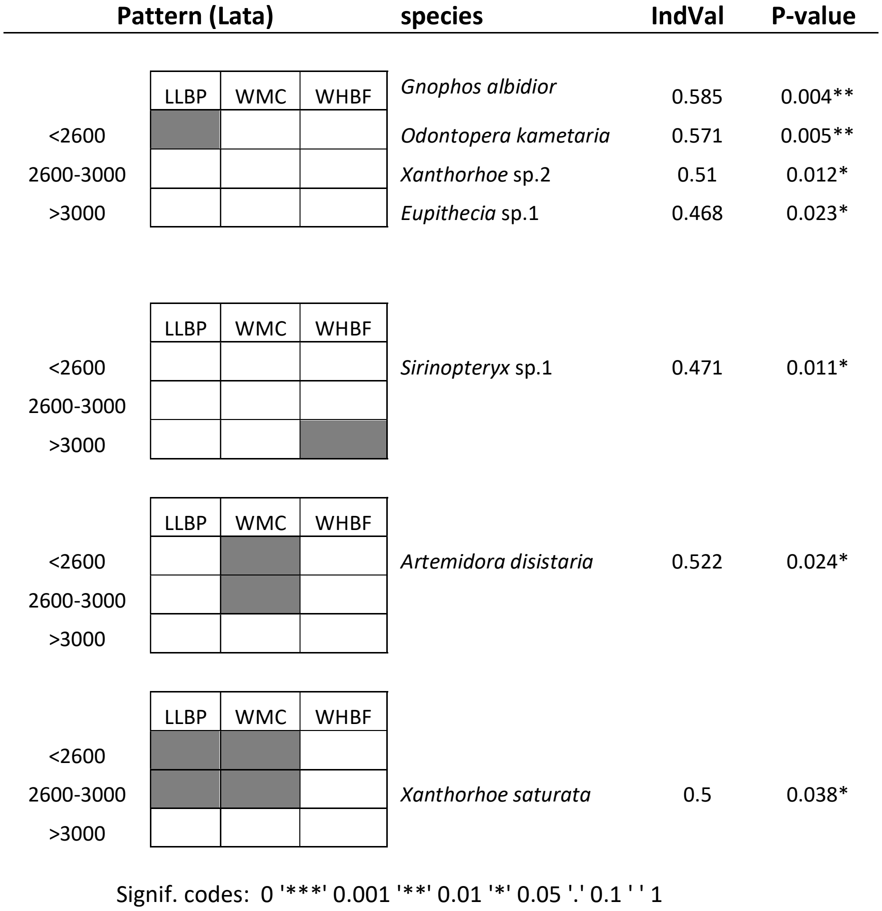
The observed pattern reflects the most common pattern of species composition of Geometridae moths along an elevational gradient, which has been found to have dominance of Larentiinae subfamily at higher elevations in many such studies (Brehm et al. 2003 a, b; Axmacher et al. 2004). But in Lata, the subfamily Larentiinae shows a significant inverse relationship with elevation (rs= -.272, significant at p=0.05) which can be due to extreme weather fluctuations and further inability to carry out sampling due to logistic constraints. But the other sites in the Western Himalayan

Birch-Fir forest type (3300-4000m) were efficiently sampled and can explain the high-nestedness of the habitat.

Species nestedness was found to be high in the Moru Oak forest type in Joshimath, which occupies the mid-elevation zone of the gradient and the habitat restricted to the higher altitudes (3300-4000m) (WHBF) in Lata. According to Wright & Reeves (1992), nestedness component of the Beta diversity would be high for the sites with lower species number which is a subset of the larger assemblage and when quantified for a presence-absence matrix measures (the frequency of occurrence or “distribution” of species) at a community scale.

Moreover, if the small isolated reserves with high species nestedness will not only lose species but will possibly lose species which are uncommon in the landscape (Wright and Reeves, 1992). Patterson (1984) suggested that extinction-dominant systems tend to have high species nestedness. MacArthur (1972) explains how mountains are special cases of the equilibrium/island paradigm, being isolated systems. Mountains should have high extinction rates and low immigration rates and, therefore the equilibrial species number is lower than lowland communities (Mac Arthur & Wilson, 1967). Species which have low-extinction rate would be more wide-spread and vice-versa. Species density/richness should change with the local environmental and climatic conditions and show peaks at elevation where an optimal combination of variables occurs for the target species (Lomolino, 2001). Inadequate sampling/more number of rare species might overestimate the species turnover and rely on only taxonomically known species underestimates the extent of the beta-diversity (Novotny et al. 2007).

Pattern (Joshimath)						species	IndVal	P-value
	LLBP	MD	WMC	WHUOF	KO	*Perizoma micropunctum*	0.673	0.008**
<2600								
2600-3000								
>3000				▨				
	LLBP	MD	WMC	WHUOF	KO			
<2600						*Euphyia subangulata*	0.577	0.005**
2600-3000						*Sirinopteryx harutai*	0.5	0.048*
>3000					▨			
	LLBP	MD	WMC	WHUOF	KO	*Alcis semiclarata*	0.711	0.001***
<2600	▨	▨				*Xanthorhoe* sp.2	0.663	0.006**
2600-3000						*Triphosa dubiosata*	0.662	0.002**
>3000						*Artemidora disistaria*	0.659	0.005**
	LLBP	MD	WMC	WHUOF	KO			
<2600						*Entephria* sp.	0.766	0.001***
2600-3000								
>3000				▨	▨			
	LLBP	MD	WMC	WHUOF	KO			
<2600	▨	▨	▨			*Prometopidia conisaria*	0.816	0.001***
2600-3000						*Eupithecia subruberescens*	0.624	0.005**
>3000						*Xanthorhoe saturata*	0.577	0.019*
	LLBP	MD	WMC	WHUOF	KO			
<2600	▨		▨	▨		*Loxaspilates obliquaria*	0.576	0.016*
2600-3000								
>3000								
	LLBP	MD	WMC	WHUOF	KO			
<2600						***Parentephria stellata***	0.756	0.001***
2600-3000				▨	▨	*Photoscotosia amplicata*	0.66	0.004**
>3000				▨	▨			
	LLBP	MD	WMC	WHUOF	KO			
<2600	▨	▨	▨	▨				
2600-3000						***Prometopidia* sp.nov**	0.588	0.027*
>3000								



Pattern (Lata)	species	IndVal	P-value

	LLBP	WMC	WHBF
<2600	▨		
2600-3000			
>3000			

species	IndVal	P-value
Gnophos albidior	0.585	0.004**
Odontopera kametaria	0.571	0.005**
Xanthorhoe sp.2	0.51	0.012*
Eupithecia sp.1	0.468	0.023*

	LLBP	WMC	WHBF
<2600			
2600-3000			
>3000			▨

species	IndVal	P-value
Sirinopteryx sp.1	0.471	0.011*

	LLBP	WMC	WHBF
<2600		▨	
2600-3000		▨	
>3000			

species	IndVal	P-value
Artemidora disistaria	0.522	0.024*

	LLBP	WMC	WHBF
<2600	▨	▨	
2600-3000	▨	▨	
>3000			

species	IndVal	P-value
Xanthorhoe saturata	0.5	0.038*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Figure 4.9: The Indicator Species Analysis showing the species highly associated the combination of the elevation classes and the Forest Types at both Joshimath (five forest types) and Lata (three forest types).[Low level blue Pine (LLBP); Moist Deodar (MD); Western Mixed Coniferous (WMC); Moru Oak (MO); Western Himalayan Upper Oak-Fir (WHUOF) and Kharsu Oak (KO) and Western Himalayan Birch-fir (WHBF)].

Beta-diversity of tropical herbivores has been examined along latitudinal, altitudinal disturbance and climatic gradients (Novotny & Weiblen, 2005; Ødegaard, 2006; Beck & Chey, 2007) which showed high species turnover among very different vegetation types. The influence of host specificity, plant species composition is unknown from the present study area and also for the large-scale distribution of insects in tropics. Herbivorous insects are broadly distributed which suggest that they track their host plant even in a dynamic system. Knowledge of historical distribution, along with present and past ecological processes maintaining tropical biodiversity are required to predict the extinction of species, habitat alteration as well as plan to protect natural systems (Novotny et al. 2007). If high elevation sites are isolated and large enough to allow population persistence and divergence over evolutionary time, they might become hotspots of speciation and endemism (Terborgh, 1977; McCoy, 1990; Rahbek, 1995; Heaney, 2001).

In Joshimath, sites with low relative humidity, high wind speed was found to have lower species richness; while sites away from human settlements and cultivation, which had lower lopping and felling densities showed higher species richness. In Lata, similarly, sites with lower lopping densities and further from human settlements and cultivation have higher species richness. Site-covariates had no significant relation with the species richness in both Joshimath and Lata. Influences of environmental factors other than elevation have to be understood by strategic site-selection and broadly documenting the potentially confounding co-variables (Körner, 2007). The drivers of richness patterns can be climatic, spatial, biotic processes and evolutionary history (Pianka, 1966; Gaston, 2000; Mc Cain 2007a, Grytness & McCain, 2013), but, the mid-domain effect (Tattersfield et al. 2001; Colwell & Hurtt, 1994) and anthropogenic disturbances (Heaney,2001; Currie & Kerr, 2008) also form a major factor. Abiotic factors change with time, and so does the diversity and functional role of the species (Brehm et al. 2003b). The effect of human disturbance in the low elevations along the elevation gradient reduces the available area for the species (Nogués-Bravo et al. 2008). Regional species richness is largely influenced by area and sampling (Rahbek, 2005; McCain, 2007b; Guo et al. 2013). General patterns in nature are not affected by the presumed independent effect of a force but a combination of convergent processes (Ricklefs & Schluter, 1993; Lawton, 1996; Brown & Lomolino, 1998). However, habitat structures have to include provision of favourable microclimate, larval host plants and adult feeding sources. Since tropical Geometridae moths are mainly known to be forest-dwelling (as we can see from the abundance comparison in Fig. 4.8); they respond very sensitively to habitat alteration (Kitching et al., 2000; Beck et al., 2002) and are effective indicator species.

I found many species indicative of the combination of forest types and elevation which can be used to classify unexplored ecosystems as disturbed or intact habitat. More indicator species will be observed by chance if the classification of the habitats is defined by the species composition (De Cáceres & Legendre 2009). But considering a combination of sites instead characterizes species habitat preferences from qualitative environmental data (De Cáceres et al. 2010), considering the fact that niche breadths vary among species. But it does not address the process attributed to such habitat association. A broader topographical and geographical extent of this work would be necessary to say that the studied species are indeed highly associated or indicative of the habitats.

The qualitative description of the elevational patterns is related to the studied taxonomic group, and the groups exhibiting higher richness (with narrower distribution range) show a higher probability of a hump-shaped pattern (Guo et al. 2013). So smaller groups exhibit varied elevational patterns, as found across latitudinal gradient (Hildebrand, 2004). Comparative studies across larger spatial scales, between taxonomic groups, between different mountains will be the most convincing but they must account for local confounding variables for comprehending the theory of elevational gradient of species richness and understanding the large-scale variation in species richness (Körner, 2007, McCain & Grytness, 2010; Guo et al.2013). The extrapolation and interpolation of macroecological patterns may provide a practical step towards understanding the dimensions of diversity in similar regions or other geographical scales (Blackburn & Gaston, 2002), despite the existence of region-specific processes (Finlay et al. 2006).

There is always under-representation of species in elevational gradient, as is common in studies in the tropics, where species occur at low densities (Rahbek, 1995) and also caused by the difficulty to sample and identify invertebrates compared to vertebrates and or plants. This, in general, leads to a marked scarcity in the distribution data to assess biodiversity patterns (Freijero & Baselga, 2016). Sampling robustness is of utmost importance, with more sampling effort there will be more confidence with the estimates (Gotelli & Colwell, 2001). Though invertebrates form the largest fraction of regional and global biodiversity; most macroecological theories have been tested through vertebrate and plant data (Erwin, 1982; Gaston, 1991; Ødegaard, 2000; Stork, 1997). To understand the biodiversity patterns fully, the only way is to gather more distribution data and assess large-scale biodiversity patterns.

4.4.1 Conclusion

The study advances our understanding of the diversity and distributions of moths of an unexplored area, the western Himalaya. It will provide the much-needed baseline to confirm more robust and comprehensive patterns of species distribution of such a hyperdiverse and interesting group of insects. Our results suggest that the landscape faces degradation and loss of biodiversity but also is a refuge for unique diversity. The typical steep contrasts in environmental factors within a small geographical area result in unique diversity and species pattern. But the observed patterns cannot be generalised at present. The factors governing the distribution of high altitude insects differ among different mountains systems, depending partly on the present ecological conditions and historical distribution. The wide variations of the geological conditions provide diversified edaphic factors (Mani, 1968). This study will aid further research, providing effective geographical distribution data, ecological understanding and foundation for their conservation in the face of habitat degradation and climate change.

Chapter 5

DNA barcoding of the Geometridae moths of Nanda Devi biosphere Reserve

---

5.1 Introduction

The Barcode of Life initiative (Hebert et al. 2003 a & b), which started more than a decade ago, has been established as a standardized method for identifying species and for reducing the morphological taxonomic burden, by using a single gene, cytochrome c oxidase subunit 1 (CO1). DNA-based taxonomy – as initially proposed by Tautz et al. (2003) – has, since then, proven to be an immensely useful tool to solve taxonomic problems of lesser- known groups (*cf.* Miller et al. 2016). DNA barcoding adds genetic information to the already established Linnean taxonomy, but sometimes the barcode analysis reveals a mismatch with existing Linnean binomials (Pons et al. 2006). This mismatch or incongruency is an effect of either cryptic species (Hebert et al. 2004 a & b); or a lack of expert taxonomic species delineation (Agapow et al. 2004, Wiens & Penkrot, 2002). DNA Barcoding, thus far, has been successfully applied across taxa and across countries, including plants (Group et al. 2009), fishes (Ward et al. 2005, Hubert et al. 2008), mammals (Clare et al. 2007), birds (Kerr et al. 2007), insects (Hebert et al. 2004a; Hastings et al. 2008; Hendrich et al. 2015; Moriniere et al. 2014; Schmidt et al. 2015; Hawlitschek et al. 2017), crustaceans (Hou et al. 2009) among others. The order Lepidoptera has received particular attention (Janzen et al. 2005; 2009; Hajibabaei et al. 2006; Burns, 2008; Silva-Brandao et al. 2009; Hausmann et al. 2011 a & b, 2013; 2016, Mutanen et al. 2016 and many more) with currently 1.09

million barcode records on BOLD, the Barcode of Life Data System (Ratnasingham & Hebert 2007). The success of DNA barcoding has encouraged efforts to build DNA Barcode Libraries across various groups and regions globally (Ekrem et al. 2007, Kerr et al. 2007, Zhou et al. 2009;2011; deWaard et al. 2010; 2011, Dincã et al. 2011, Kuzmina et al. 2012, Webb et al. 2012, Raupach et al. 2014) also using natural history collections in museums (Strutzenberger, 2012, Hebert et al. 2013, Hausmann et al. 2016). DNA Barcodes in recent years have shown promising new prospects in answering fundamental ecological questions that govern community assemblage, macroevolutionary processes and conservation of species (Joly et al. 2014, Veldman et al. 2014). The ecological information coupled with the understanding of evolutionary histories from DNA barcodes across taxa can assist in answering complex questions relevant to species assembly and distribution in the era of bioinformatics (Joly et al. 2014). Moreover, it is a valuable tool to understand feeding habits (González-Varo et al. 2014) and target protection of habitats (Kress et al. 2015).

Despite their fundamental roles in nature as selective herbivores, pollinators, detritivores, and prey for birds, e.g. migratory passerines; forest indicator taxa (Summerville et al. 2004, Kitching et al. 2000, Beck et al. 2002, 2017, New 2004) and potential in the definition of conservation priority areas, moths have been strongly neglected in conservation studies. Geometridae, together with the Erebidae, are the most species-rich family of moths worldwide. Geometridae is a cosmopolitan family except Antarctica and shows diversity peaks in tropical South America, Africa and South-east Asia. This group is a well-established model group for biodiversity studies in temperate and tropical regions (Brehm et al. 2003 a & b, 2013; Axmacher et al. 2004, 2009, Barlow, 1982, Barlow & Woiwod 1989 and many more). Geometrids are known to associate with the prevailing environmental conditions while other families like Erebidae include larger portions of species which can colonize human-affected habitats replacing forest species (Summervillle, 2005; Winfree et al. 2011). Large parts of the diverse Geometridae family may be at the risk of extinction due to destruction and fragmentation of their habitats in the tropics. The taxonomy of geometrid moths is replete with ambiguities. A global review suggests that there is some degree of synonymy at the species level in this family (Scoble et al. 1995) which suggests that taxonomic revisions are impending). There is no comprehensive morphology-based phylogeny available for geometrid moths, but the relationships between subfamilies and many tribes were recently assessed from the analysis of several nuclear genes (Young, 2006, Yamamoto & Sota, 2007, Regier et al. 2009, Õunap 2011, Sihvonen et al. 2011) largely confirming the traditional classification derived from morphological traits.

Coming to the Indian scenario, it is bleak except Gaikwad et al. (2012) who barcoded the butterflies from the Western Ghats region of India. DNA barcoding of groups other than Lepidoptera from India has also been attempted in recent years (Kumar et al. 2007; 2012, Lakra et al. 2011, Dubey et al. 2011, Laskar et al. 2013, Gaikwad et al. 2017, Kaur & Sharma, 2017). The integration of molecular tools and morphology for taxonomic research, especially for Lepidoptera is still in a nascent state. Moths can be regarded as the “poor cousins” (New, 2014) of butterflies in Lepidoptera conservation in India. How do we conserve species with limited knowledge of which species are endangered or even how many species there are? There is no inventory for moths from the present study area, Nanda Devi Biosphere Reserve in the western Himalaya (Fig. 5.1 along with other sampling sites in Himachal

Pradesh and Uttarakhand) despite being one of the most biodiverse regions. The Himalayas provide an array of habitats and forest types comprising an excellent scenario to understand the diversity and the related evolutionary processes in this mosaic landscape. Moreover, we find Himalayan-Chinese and Indo-Malayan faunal dominance in the eastern Himalaya as compared to the western Himalaya (Mani, 1968). The factors governing the distribution of high altitude insects differ among different mountains systems, depending partly on the present ecological conditions and historical distribution. The wide variations of the geological conditions provide diversified edaphic factors (Mani, 1968). The western Himalaya, where the Oriental and Palearctic elements merge (Meinertzhagen, 1928), has unique biodiversity and interesting patterns can be expected. Faunistic inventories are the basis of biodiversity conservation, particularly in threatened and fragmented landscapes like the western Himalaya. An inventory of the moth fauna based on both morphological and molecular characteristics from this area would definitely add valuable information to the existing data and help us look into moth diversity in a comprehensive manner. The intention behind this study is to combine the exploration of unstudied biodiversity of the study area and using DNA barcoding as an established tool for improving classifications and, understand diversity patterns for highly diverse groups like the geometrid moths in India.

5.2 Materials and Methods

Abbreviations

BOLD: Barcode of Life Data Systems

CCDB: Canadian Centre for DNA Barcoding

ZSM: SNSB - Zoologische Staatssammlung München, Germany (Bavarian State Collection of Zoology, Munich)

5.2.1 Collecting

Moth specimens were collected in the Nanda Devi Biosphere Reserve, using light-trapping (vertical sheet method). Specimens were collected across the elevational and vegetation gradient of the study area. A part of the collected specimens was pinned, labelled, mounted and identified at the ZSM to provide a reference collection for the DNA Barcode Library initiative for the western Himalaya. Not all specimens could be used due to legal restrictions in transferring biological material outside the country of collection. Locations of all the specimens used for DNA analysis are shown in Fig. 5.1. Fig. 5.2 (a & b) shows the elevational distribution of all the specimens and the two most abundant subfamilies (Ennominae and Larentiinae)

5.2.2 DNA sequencing

One dry leg was removed from each specimen collected by the first author and some specimens from the Herbulot collection stored in the ZSM, with sterile forceps and transferred to a 96-well microplate preloaded with one drop of 95% ethanol in each well. DNA extraction and sequencing were performed at the CCDB, University of Guelph, following standardized high-throughput protocols for DNA barcode amplification and sequencing (Ivanova et al. 2006, deWaard et al. 2008). DNA sequencing of some samples (80 sequences) was performed at the facility of the Wildlife Conservation Genetics and Forensic Cell at the Wildlife Institute of India.

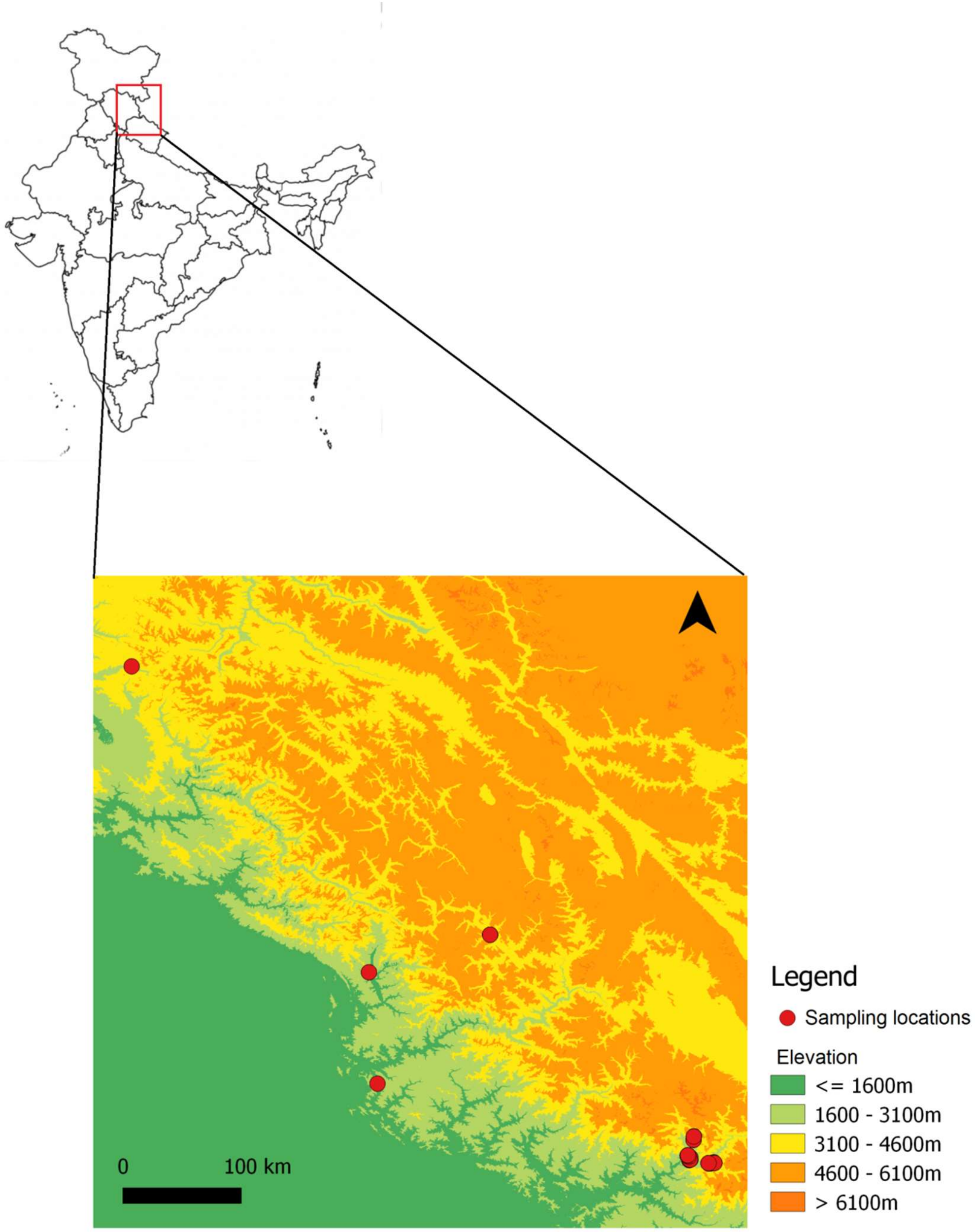


Figure 5.1: The elevational gradient map shows the different sampling points (red dots) from parts of states of Uttarakhand, Himachal Pradesh and Kashmir in the western Himalaya.

Detailed information on the voucher specimens, genetic sequences, images, taxonomic classification, collection data and other relevant information for the specimens (sequenced by CCDB) is available in the public data set DS-INDIAGEO in the Barcode of Life Datasystems (BOLD; www.boldsystems.org) (Ratnasingham & Hebert, 2007; 2013).

5.2.3 DNA sequence analyses:

A Neighbour-joining tree using the Kimura 2 Parameter model (Kimura,1980) was made from the sequences obtained from CCDB and Wildlife Institute of India (Appendix 5.1). It constructs the phylogeny of the group using the evolutionary distance data (Saitou et al. 1987). Additional sequences from the specimens collected in Himachal Pradesh, Kashmir and Sikkim regions of India, stored in the Herbulot collection at the ZSM and available in BOLD were included into some analysis steps. Sequence divergences for the barcode region were calculated for only the 224 specimens collected by the first author, using the analytical tools on BOLD Barcode Gap Analysis with BOLD alignment, pairwise deletion) using the Kimura 2 Parameter model (Kimura, 1980). Distances between species are presented as minimum pairwise distances, intraspecific variation as the mean and maximum pairwise distance within that species. BOLD assigns a Barcode Index Number (BIN) (Ratnasingham & Hebert, 2013) automatically to sequences >500bp which belong to the related sequence cluster BINs very often coincide with the traditional species concepts but can reveal genetic splits within an “established” species or can reveal BIN-sharing (“merge”) of two taxa which in previous studies were thought to be two different species. In cases of discrepancy between the sequence based and morphological taxonomy, the specimens were re-examined morphologically to ascertain their identification.

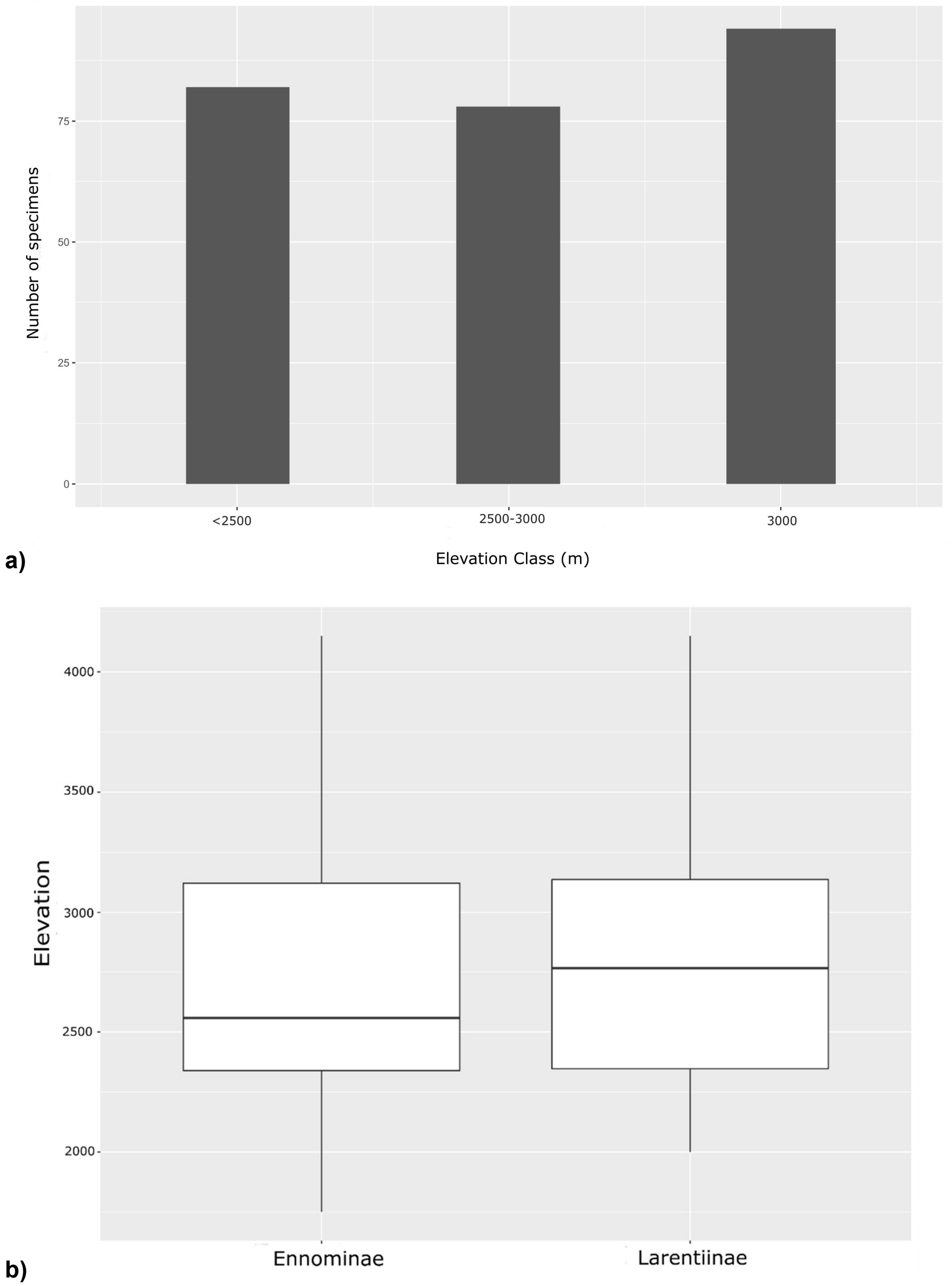


Figure 5.2: a) The graph shows that specimens of Geometridae moths from different altitudes in western Himalayan states of Uttarakhand, Himachal Pradesh and Kashmir were collected with almost equal number of specimens across the elevational classes. b) The box-plot shows the elevational distribution of the two most speciose subfamilies

(Ennominae and Larentiinae) of Geometridae in the present study. The highest altitude of collected specimens in both the subfamilies was 4150m (asl).

5.3 Results

In the present study, we were able to generate 224 CO1 sequences from 250 specimens (90%). 46 sequences out of 68 specimens (67%) were added from the collection Herbulot in the ZSM.

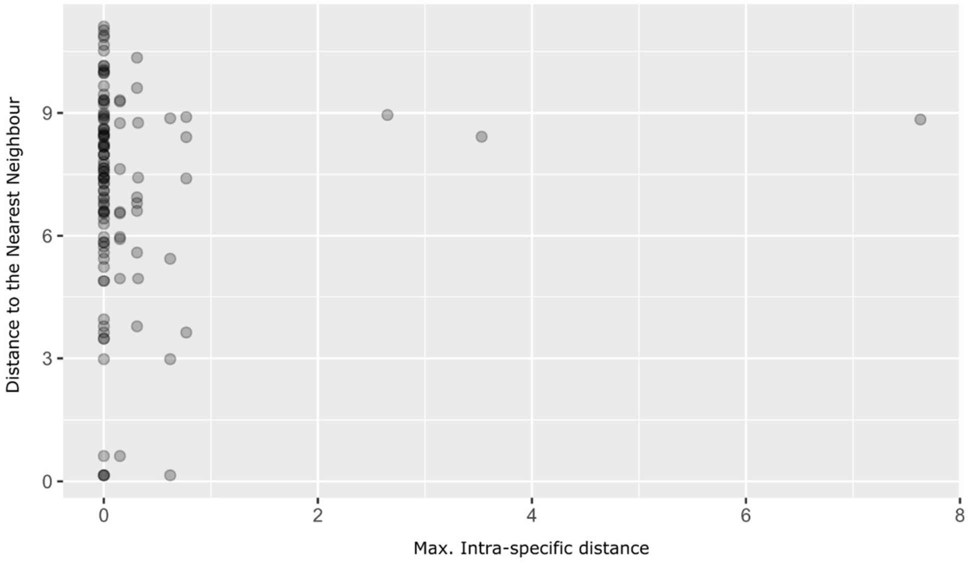
Present study specimens from Uttarakhand, western Himalaya: Out of the 224 DNA barcoded specimens, 35 specimens have only been identified to genus level while the rest (184 = 82.14%) were assigned morphologically to a Linnean species name, while 5 specimens remain unidentified. Out of the 250 specimens subjected to DNA barcoding, 148 specimens belong to Larentiinae, while 90 belong to the subfamily Ennominae, 8 and 4 specimens to Sterrhinae and Geometrinae respectively. A total of 113 morphological species belonging to 51 genera were assigned to 116 BINs, out of which 63 BINs were singletons. All pre-identified species with multiple records/specimens were placed in a single BIN and successfully discriminated with a distinct Barcode Gap without any overlap in the study area except for: *Alcis nudipennis* - *Alcis leucophaea* (BOLD: AAJ3727), *Opisthograptis mimulina – Opisthograptis* PD01 (BOLD: AAK5702) sharing their BINs. Some species were assigned to more than one BIN -*Loxaspilates obliquaria* (BOLD: ADF4071; BOLD: ABA2651); *Trichopterigia* PD01(sp.1) (BOLD: ADF3716; BOLD: ADF2951) and *Euphyia subangulata* (BOLD: AAL5265; BOLD: ADF3104). Fig. 5.3 (a & b) shows the distance to nearest neighbour in relation to the max. Intra specific distance and the frequency distribution of nearest neighbour distances obtained from Barcode Gap Analysis on BOLD. 12 BINs (10.3%) include a different morphological species from outside the study area (requiring further study). There was overlap of BINs (as currently present on BOLD Data Systems) including specimens from mainly the countries of the Indian subcontinent: Pakistan (24 BINs shared), Bhutan (10 BINs), Nepal (6 BINs), while from a biogeographical point of view 50 BINs are shared with Indo-Malayan realm, and only 4 BINs are shared with Palearctic countries. Comparison of conspecific CO1 sequences from Himachal Pradesh, Kashmir and eastern Himalaya (Sikkim, Kanchenjunga) as generated from ZSM (specimens from Herbulot collection) revealed high intraspecific divergence in four species between western (Uttarakhand) and eastern (Sikkim) Himalaya: *Arichanna flavinigra, Heterolocha falconaria, Abraxas superpicaria and Ecliptopera substituta* with intraspecific minimum pairwise genetic distance (Kimura-2-Parameter) generated from CO1 sequences in MEGA 7 varying from 3 to 6% as shown in (Fig.5.4). These four species will be subjected to further detailed taxonomic examination and molecular evidence based on more samples. The highest divergence was in *Heterolocha falconaria* (5.9%) followed by *Ecliptopera substituta* (5%), *Abraxas superpicaria* (4.1%) and *Arichanna flavinigra* (3.1%). These species show a very characteristic morphology so any chance of misidentification can be ruled out.

Three male and one female specimens of a taxon, initially identified as *Prometopidia conisaria* Hampson ,1902 (new distribution for the state of Uttarakhand) showed 6.6% genetic divergence, and with further investigation of genitalia and type specimen comparison, it was found that the female specimen is a new species of the genus *Prometopidia*. The morphological analysis of these specimens is beyond the scope of this paper and is discussed in detail in another paper (Dey et al. in prep.)

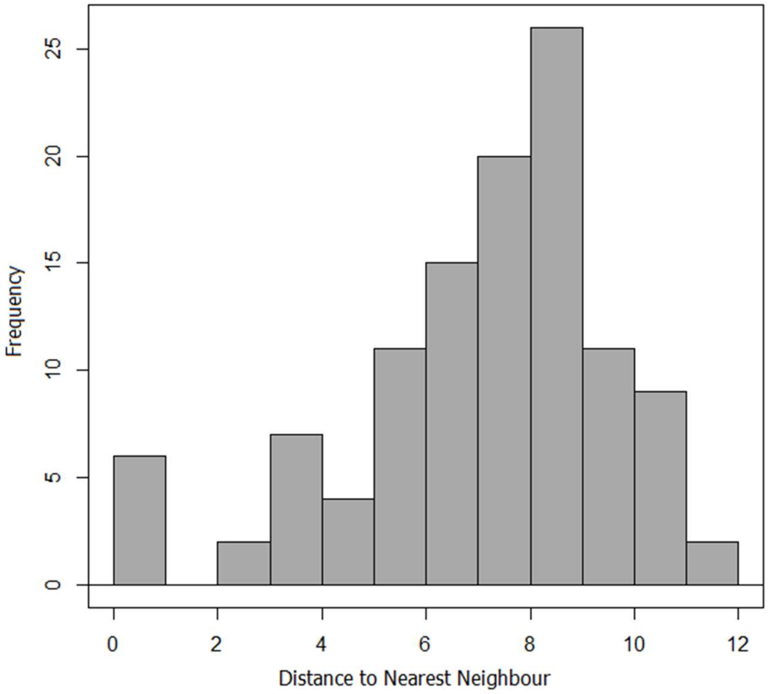
Alcis paghmana Wiltshire 1967 was identified through sequence matching in BOLD and thereafter morphological confirmation, representing a new distribution record for India. Correlating intra-/inter-species sequence divergence results and re-examining morphology revealed the following species with new distribution records for Uttarakhand: *Alcis nudipennis, Alcis perspicuata, Arichanna sparsa, Peetula stramineata, Entephria poliotaria, Perizoma variabilis, Costicoma exangulata, Triphosa venimaculata, Perizoma variabilis, Perizoma conjuncta, Perizoma seriata, Electrophaes zaphenges, Entephria punctatissima,* and *Thera comis.*

5.4 Discussion

This study is a first initiative for assembling a DNA barcode reference library for geometrid moths from western Himalaya, India. Investigation of DNA barcode variation and BIN-based species delimitation was successful for 113 species of Geometridae comparable to Gaikwad et al. (2012) and reconfirmed the reliability of DNA barcoding as an effective tool for species discrimination in Lepidoptera. Except for two species pairs with <2% divergence from the nearest neighbour, intraspecific divergence was found to be lower than the distance to the nearest neighbour, thus allowing successful separation. Similarly, high success rates for lepidopteran species re-identifications were found for Germany (Hausmann et al. 2011b), Pakistan (Ashfaq et al. 2013; 2017), and Costa Rica (Hajibabaei et al. 2006). Recent studies have explored continent-wide samples also with high (~93%) re-identification success, e.g. for European geometrids (Hausmann et al. 2013) and North American Noctuoidea (Zahiri et al. 2014, 2017).



a)



b)

Figure 5.3: Barcode Gap Analysis performed with BOLD analytical tool shows the a) max. Intra-Specific distances in relation to the distances to the Nearest-Neighbour and

b) frequency distribution of the Nearest-Neighbour distances in all the specimens collected from Uttarakhand by the first author.

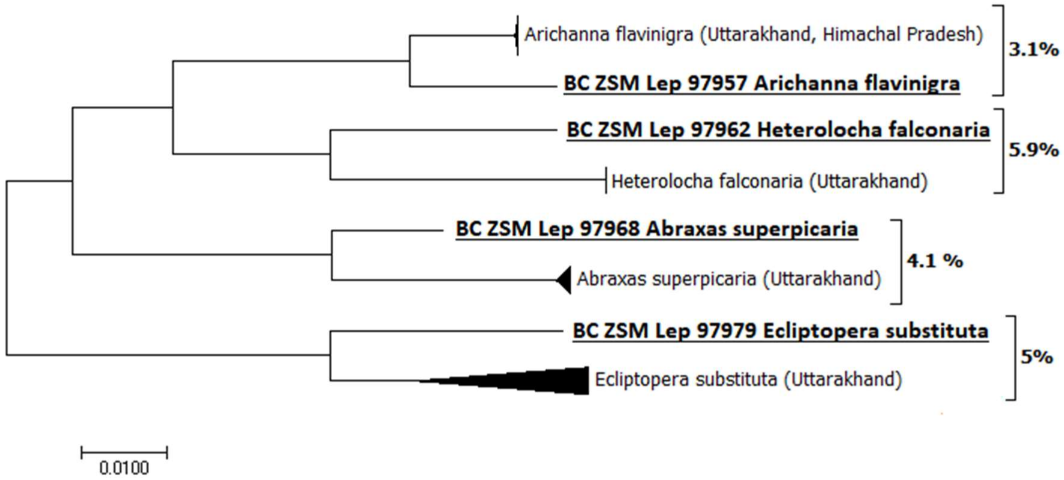


Figure 5.4: Neighbour-joining tree (unrooted) showing the genetic divergence between specimens from western and eastern Himalaya found in four species. The names of the branches marked in bold and underlined are the specimens from eastern Himalaya (Sikkim) from Collection Herbulot stored in ZSM. Locations of the rest from western Himalaya are given in parentheses.

Since our study area holds much higher species richness than other studies cited here, our results strongly support the importance of molecular taxonomy in the geometrid moth taxonomy in the country where the majority of the fauna awaits genetic analysis.

The success of DNA barcoding depends on the match between the BIN assignments and the taxonomic pre-identification. Neighbour-joining clustering analysis showed a high incidence of monophyly in our study results, but the study area is restricted only to western Himalaya, and the sample size was comparatively small.

Thus, the relationship between successful species differentiation and geographical range of the samples could not be exploited. We had four species showing intraspecific divergences of 3-6% collected from two different parts of India, Uttarakhand and Sikkim (at a distance of about 1000km). Ashfaq et al. 2013; 2017 showed maximum faunal overlap between Pakistan and India. Likewise, our study reveals the highest number of BINs (24) shared with Pakistan. The case of BIN-sharing of distinct species like that of *Alcis leucophaea* and *Alcis nudipennis* might indicate ancestral polymorphisms with subsequent incomplete lineage sorting (Zahiri et al. 2017) or just a lack of sound taxonomic diagnosis. Discrepancies between DNA Barcodes and standard taxonomy (once misidentifications are out ruled) can be treated as a scope to go in depth both in taxonomy and in the underlying evolutionary processes. Low or no interspecific divergence may suggest potential synonymy (Yang et al. 2016) and species with remarkably high intraspecific divergence demand further in-depth taxonomic analysis as they might include cases of cryptic diversity. However, in our case, low sample sizes and lack of sister species sampling might have affected the intra- and inter-specific distances in some cases giving poorly informative values (Meyer & Paulay, 2005). A sample size of 20 samples per species is suggested for a robust DNA barcode analysis (Bergsten et al. 2012, Zhang et al. 2010, Luo et al. 2015). We have shown that some (4 out of 113) eastern and western Himalayan species show considerable intraspecific divergence which can be explained by the ecological distinctiveness of these two regions. Intraspecific variations in DNA barcodes of species are a key to their unexploited ecological modifications (Joly et al. 2014). The western Himalaya was formed more recently than the eastern Himalaya, and hence there are ecological anomalies in the biogeographical distribution of different species, especially Lepidoptera (Mani, 1968) perhaps due to subsequent climatic fluctuations. The environmental factors like, the mean elevation, humidity, forest cover, and precipitation are also higher in the eastern than in the western Himalaya (Price et al. 2011). Intraspecific genetic distances might increase with geographic distance but not significantly enough to challenge the efficacy of DNA barcoding (Huemer et al. 2014) and species with discontinuous distribution not necessarily show effects on genetic divergence correlated with geography (Mutanen et al. 2012). Habitat-induced low dispersal due to discontinuity of physical, geological, ecological and microclimatic conditions might have led to their geographical isolation. Similarly, adaptation to ecological niches is known to cause genetic divergence (Papadopoulou, 2008). Study on birds (Price et al. 2003) have shown that species composition varies in different parts of the Himalaya mountains due to local extinctions of populations and that species numbers in the Himalaya decline with the latitudinal gradient. While studies on Himalayan butterflies have shown a significant rarefaction of humid-tropical-forest species westwards of the Sikkim state contrary to the significant increase of the temperate-forest species towards the west (reviewed in Mani, 1968). The abundance and number of individuals per species were found to decrease by about five times from the east to the west between western Nepal and Pakistan, where the mountains take a northwards track (Mani, 1968, Price et al. 2003, Ghosh-Harihar 2013). Detailed examination of host plant relationships and extending the sampling region to cover more of the distribution range of the investigated species is required to further tease apart the effect of elevation and habitat types from species ecology on cryptic diversity.

A detailed study of past geological and climatic events coupled with phylogeny can probably explain many of these cases of BIN discordance. The prevailing ecological conditions in the Himalaya mountain system favour a high rate of speciation with higher numbers of endemics than any other mountain chain (e.g. the Alps, where there are more relict species). Apparently, this can be attributed to the more intensive Pleistocene glaciations in Europe than in Asia (Mani, 1968). Past evolutionary patterns were directed towards ecological specializations while at present the high-altitude fauna is evolving towards increasing species 'enrichment' (Mani, 1968). As for the ecology and habitat requirements of largely unexplored biota, like the Himalayan fauna, it is a difficult task to elucidate even a small fraction of the existing life histories and species interactions.

5.4.1 Need and benefits of a DNA Barcode Library for India

In tropical regions the taxonomy of hyper-diverse groups of arthropods is a neglected field and, often, morphospecies are surrogates for species (Basset et al. 2012, Ashton et al. 2015), with major constraints due to little availability of taxonomic expertise and resources (Zenker et al. 2016). Thus, an ambitious insect inventory project can quickly overwhelm taxonomists with too many species and specimens. Adding to this, the concentration of expertise to only a few well-known species leads to 'taxonomic impediment' (de Carvalho et al. 2005). As a result, there is the unavailability of fine-scale data for conservation for many groups. Along with species diversity, functional diversity and phylogenetic diversity are new dimensions to biodiversity studies, but they are not yet particularly well studied in tropical regions among species-rich insect groups (Brehm et al. 2013). India has a lot of unexplored biodiverse areas since the British left the country. 1838-1923, Warren, 1889 to name a few) exist for moths from different parts of the country.

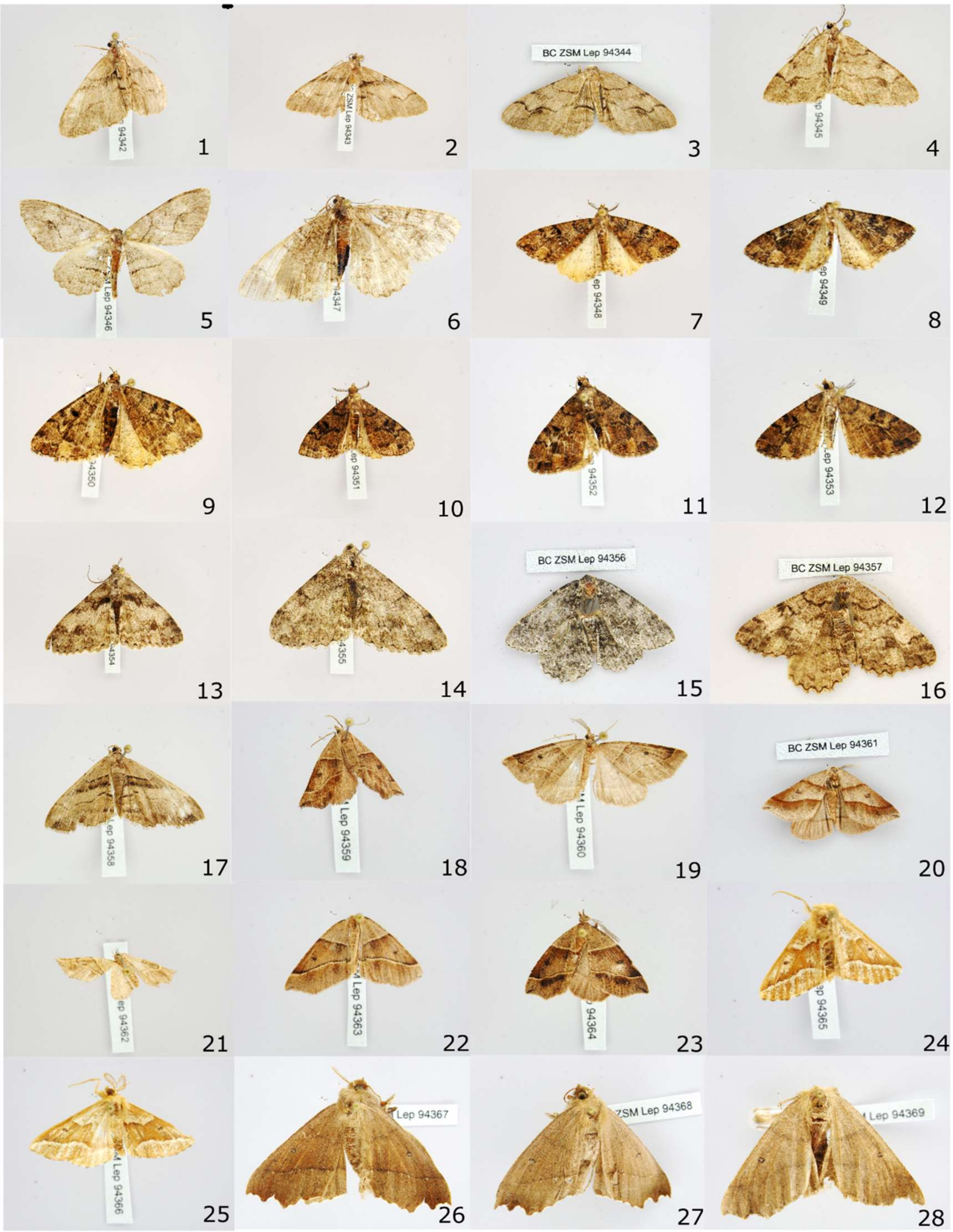
Based on the results of the present study, it is clear that the taxonomy of geometrid moth species from the study area is currently obscured in some degree of uncertainty. We need to further investigate correlations between the genetic divergence and morphological characteristics and to try to uncover overlooked species (Janzen et al. 2009) which have not been included in previous taxonomic work. Species at lower elevations show a wider range of distribution than those at the higher elevations, which also may be reflected and thus measurable by genetic variation. For addressing questions like "how many species are there ", geographically large-scale reference libraries are required. A logical, great step forward will be to use DNA barcodes to understand large-scale ecological patterns in intraspecific variation, and to explore the causes and the outcomes of such variations (Joly et al. 2014). As Janzen et al. 2009 predicted, DNA barcoding will bridge the gap between what is already known and what can be found out.

DNA barcoding has furthermore been shown as a valuable tool for unveiling host-plant associations (Smith, 2006, Miller et al. 2007, Matheson et al. 2008, Jurado-Riviera et al. 2009), when collected larvae were fogged or cannot be reared to adult because of food-plant supply constraints or failed rearing (Hausmann & Scalercio, 2016). Lastly, very often the conservation efforts are directed towards the Himalayas as a unit, but because of the inherent diverse nature of this mountain system, area-specific conservation should be targeted (Price et al. 2003). A characterisation of such poorly studied groups of insects (e.g. moths) at a molecular level, will allow a large step forward in resolving moth taxonomy using a valuable, integrative approach.

Details of the DNA Barcoded Geometridae specimens (Plate 5.1)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Alcis paghmana*	Ennominae	BC ZSM Lep 94342	Lata	30.49547222	79.7216388	2528
2	*Alcis paghmana*	Ennominae	BC ZSM Lep 94343	Lata	30.49583333	79.70511111	2126
3	*Alcis paghmana*	Ennominae	BC ZSM Lep 94344	Lata	30.49583333	79.70511111	2126
4	*Alcis* sp.	Ennominae	BC ZSM Lep 94345	Joshimath	30.52227778	79.56408333	2987
5	*Alcis paghmana*	Ennominae	BC ZSM Lep 94346	Lata	30.49483333	79.72841667	2766
6	*Alcis perspicuata*	Ennominae	BC ZSM Lep 94347	Lata	30.49961111	79.74083333	3122
7	*Alcis semiclarata*	Ennominae	BC ZSM Lep 94348	Joshimath	30.555	79.54797222	2069
8	*Alcis semiclarata*	Ennominae	BC ZSM Lep 94349	Joshimath	30.55466667	79.54766667	2104
9	*Alcis semiclarata*	Ennominae	BC ZSM Lep 94350	Lata	30.49463889	79.71333333	2339
10	*Alcis semiclarata*	Ennominae	BC ZSM Lep 94351	Joshimath	30.55297222	79.54502778	2227
11	*Alcis semiclarata*	Ennominae	BC ZSM Lep 94352	Bhyundar	30.67375	79.59083	2547
12	*Alcis semiclarata*	Ennominae	BC ZSM Lep 94353	Bhyundar	30.67411	79.59064	2564
13	*Alcis leucophaea*	Ennominae	BC ZSM Lep 94354	Bhyundar	30.67375	79.59083	2547
14	*Alcis leucophaea*	Ennominae	BC ZSM Lep 94355	Lata	30.49463889	79.71333333	2339
15	*Alcis nigralbata*	Ennominae	BC ZSM Lep 94356	Ghangria	30.7015	79.59353	3112
16	*Alcis perspicuata*	Ennominae	BC ZSM Lep 94357	Lata	30.49461111	79.71338889	2320
17	*Psilalcis inceptaria*	Ennominae	BC ZSM Lep 94358	Lata	30.49519444	79.70538889	2143
18	*Artemidora disistaria*	Ennominae	BC ZSM Lep 94359	Lata	30.49547222	79.72163889	2528
19	*Artemidora disistaria*	Ennominae	BC ZSM Lep 94360	Lata	30.49927778	79.74072222	3105
20	*Artemidora disistaria*	Ennominae	BC ZSM Lep 94361	Lata	30.49480556	79.73019444	2911
21	*Artemidora disistaria*	Ennominae	BC ZSM Lep 94362	Lata	30.49513889	79.72113889	2526
22	*Artemidora disistaria*	Ennominae	BC ZSM Lep 94363	Lata	30.49513889	79.72113889	2526
23	*Artemidora disistaria*	Ennominae	BC ZSM Lep 94364	Lata	30.49513889	79.72113889	2526
24	*Odontopera kametaria*	Ennominae	BC ZSM Lep 94365	Lata	30.49517	79.72164	2544
25	*Odontopera kametaria*	Ennominae	BC ZSM Lep 94366	Lata	30.49452778	79.72827778	2793
26	*Odontopera veneris*	Ennominae	BC ZSM Lep 94367	Lata	30.49927778	79.74072222	3105
27	*Odontopera veneris*	Ennominae	BC ZSM Lep 94368	Lata	30.49916667	79.74094444	3109
28	*Odontopera veneris*	Ennominae	BC ZSM Lep 94369	Lata	30.50027778	79.74608333	3533

Plate 5.1: DNA Barcoded Geometridae specimens



Details of the DNA Barcoded Geometridae specimens (Plate 5.2)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Abraxas superpicaria*	Ennominae	BC ZSM Lep 94370	Lata	30.50030556	79.74641667	3555
2	*Abraxas superpicaria*	Ennominae	BC ZSM Lep 94371	Lata	30.50030556	79.74641667	3555
3	*Sirinopteryx harutai*	Ennominae	BC ZSM Lep 94372	Joshimath	30.52369444	79.56163889	3006
4	*Sirinopteryx harutai*	Ennominae	BC ZSM Lep 94373	Joshimath	30.52305556	79.56113889	3030
5	*Sirinopteryx duplicilinea*	Ennominae	BC ZSM Lep 94374	Lata	30.49961111	79.74083333	3122
6	*Sirinopteryx* sp.	Ennominae	BC ZSM Lep 94375	Lata	30.50027778	79.74675	3578
7	*Myrioblephara duplexa*	Ennominae	BC ZSM Lep 94376	Joshimath	30.52294444	79.56727778	2887
8	*Myrioblephara duplexa*	Ennominae	BC ZSM Lep 94377	Joshimath	30.52411111	79.56066667	3064
9	*Heterolocha phoenicotaeniata*	Ennominae	BC ZSM Lep 94378	Lata	30.49583333	79.70511111	2126
10	*Heterolocha falconaria*	Ennominae	BC ZSM Lep 94379	Lata	30.49483333	79.72841667	2766
11	*Heterolocha falconaria*	Ennominae	BC ZSM Lep 94380	Lata	30.49461111	79.71338889	2320
12	*Heterolocha falconaria*	Ennominae	BC ZSM Lep 94381	Joshimath	30.52208333	79.56422222	2985
13	*Arichanna sparsa*	Ennominae	BC ZSM Lep 94382	Lata	30.49517	79.72164	2544
14	*Arichanna flavinigra*	Ennominae	BC ZSM Lep 94383	Lata	30.50019444	79.74411111	3373
15	*Arichanna sparsa*	Ennominae	BC ZSM Lep 94384	Lata	30.49463889	79.71333333	2339
16	*Arichanna tenebraria*	Ennominae	BC ZSM Lep 94385	Joshimath	30.52	79.55911111	3152
17	*Loxaspilates obliquaria*	Ennominae	BC ZSM Lep 94386	Joshimath	30.5565	79.54736111	2049
18	*Loxaspilates obliquaria*	Ennominae	BC ZSM Lep 94387	Lata	30.49555556	79.72205556	2533
19	*Loxaspilates obliquaria*	Ennominae	BC ZSM Lep 94388	Joshimath	30.54588889	79.55369444	2424
20	*Loxaspilates obliquaria*	Ennominae	BC ZSM Lep 94389	Lata	30.49719444	79.74927778	3775
21	*Loxaspilates obliquaria*	Ennominae	BC ZSM Lep 94390	Lata	30.49463889	79.71333333	2339
22	*Photoscotosia occidens*	Larentiinae	BC ZSM Lep 94391	Ghangria	30.69958	79.59247	3213
23	*Ourapteryx* sp.	Ennominae	BC ZSM Lep 94392	Lata	30.49463889	79.71333333	2339
24	*Ectropis* sp.	Ennominae	BC ZSM Lep 94393	Joshimath	30.5565	79.54736111	2049
25	*Gnophos albidior*	Ennominae	BC ZSM Lep 94394	Lata	30.49519444	79.70538889	2143
26	*Gnophos albidior*	Ennominae	BC ZSM Lep 94395	Lata	30.49263889	79.70638889	2347
27	*Gnophos albidior*	Ennominae	BC ZSM Lep 94396	Lata	30.49263889	79.70638889	2347
28	*Gnophos albidior*	Ennominae	BC ZSM Lep 94397	Lata	30.49516667	79.70533333	2137

Plate 5.2: DNA Barcoded Geometridae specimens

1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

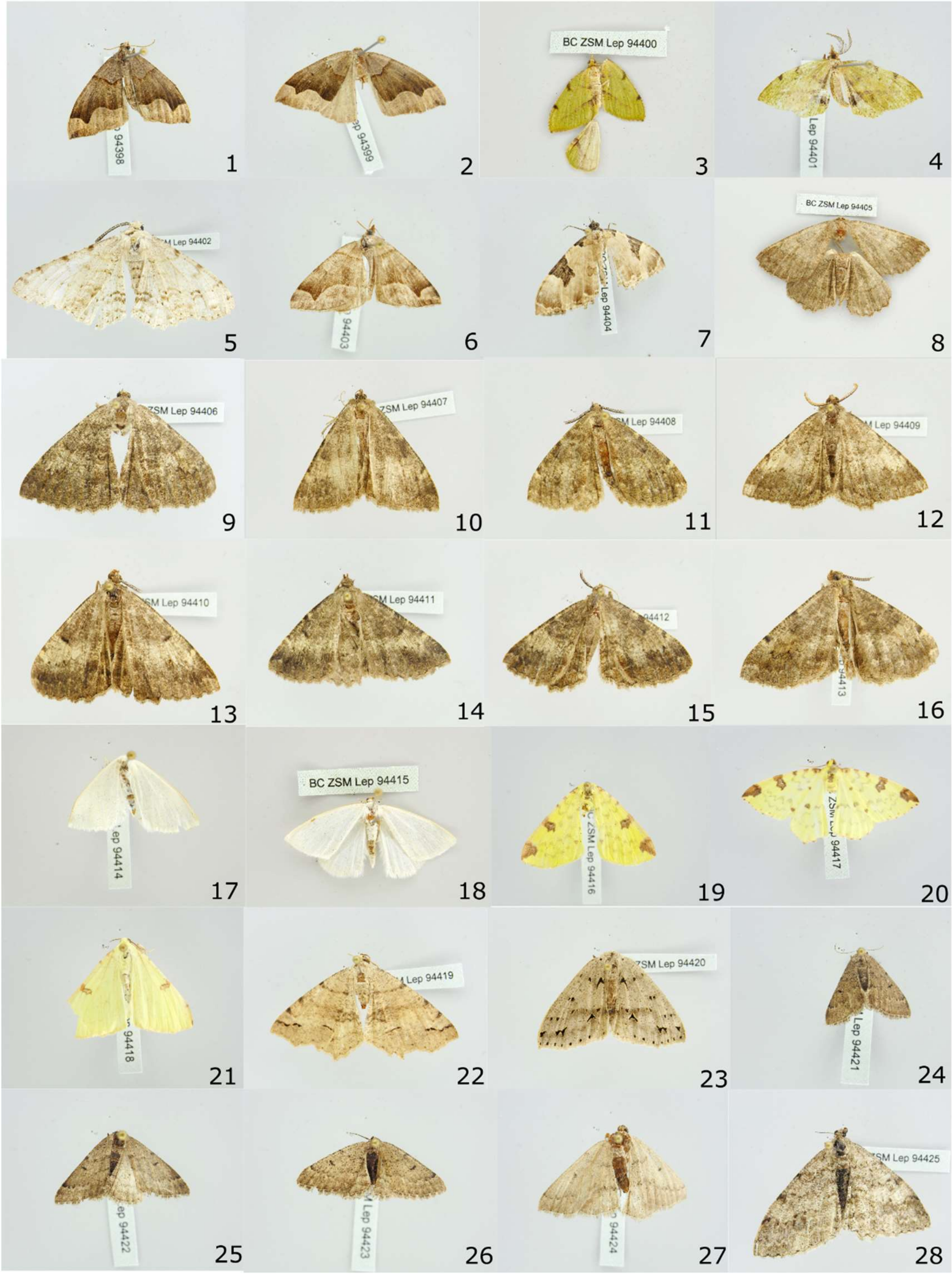
27

28

Details of the DNA Barcoded Geometridae specimens (Plate 5.3)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Anonychia lativitta*	Ennominae	BC ZSM Lep 94398	Lata	30.49452778	79.72827778	2793
2	*Anonychia lativitta*	Ennominae	BC ZSM Lep 94399	Lata	30.49483333	79.72841667	2766
3	*Apoheterolocha patalata*	Ennominae	BC ZSM Lep 94400	Joshimath	30.5565	79.54736111	2049
4	*Apoheterolocha patalata*	Ennominae	BC ZSM Lep 94401	Joshimath	30.54555556	79.55402778	2433
5	*Medasina albidaria*	Ennominae	BC ZSM Lep 94402	Joshimath	30.49693	79.75019	3137
6	*Anonychia grisea*	Ennominae	BC ZSM Lep 94403	Lata	30.49555556	79.72205556	2533
7	*Rheumaptera melanoplagia*		BC ZSM Lep 94404	Joshimath	30.52083333	79.55930556	3141
8	*Ctenognophos fuscobrunnea*	Ennominae	BC ZSM Lep 94405	Lata	30.50019444	79.74411111	3373
9	*Ctenognophos fuscobrunnea*	Ennominae	BC ZSM Lep 94406	Lata	30.49463889	79.71333333	2339
10	*Ctenognophos fuscobrunnea*	Ennominae	BC ZSM Lep 94407	Lata	30.49483333	79.72841667	2766
11	*Ctenognophos fuscobrunnea*	Ennominae	BC ZSM Lep 94408	Lata	30.49452778	79.72827778	2793
12	*Ctenognophos eolaria*	Ennominae	BC ZSM Lep 94409	Lata	30.50001111	79.74455556	3367
13	*Ctenognophos fuscobrunnea*	Ennominae	BC ZSM Lep 94410	Lata	30.50019444	79.74411111	3373
14	*Ctenognophos fuscobrunnea*	Ennominae	BC ZSM Lep 94411	Lata	30.4952	79.72206	2553
15	*Ctenognophos fuscobrunnea*	Ennominae	BC ZSM Lep 94412	Lata	30.49517	79.72164	2544
16	*Ctenognophos fuscobrunnea*	Ennominae	BC ZSM Lep 94413	Lata	30.49483333	79.72841667	2766
17	*Lomographa distans*	Ennominae	BC ZSM Lep 94414	Lata	30.49555556	79.72205556	2533
18	*Lomographa distans*	Ennominae	BC ZSM Lep 94415	Lata	30.49555556	79.72205556	2533
19	*Opisthograptis mimulina*	Ennominae	BC ZSM Lep 94416	Lata	30.49463889	79.71333333	2339
20	*Opisthograptis mimulina*	Ennominae	BC ZSM Lep 94417	Lata	30.50001111	79.74455556	3367
21	*Opisthograptis* sp.	Ennominae	BC ZSM Lep 94418	Lata	30.49547222	79.72163889	2528
22	*Psyra indica*	Ennominae	BC ZSM Lep 94419	Lata	30.49555556	79.72205556	2533
23	*Psyra moderata*	Ennominae	BC ZSM Lep 94420	Joshimath	30.55325	79.54502778	2210
24	*Prometopidia conisaria*	Ennominae	BC ZSM Lep 94421	Joshimath	30.546	79.55411111	2414
25	*Prometopidia conisaria*	Ennominae	BC ZSM Lep 94422	Joshimath	30.54588889	79.55369444	2424
26	*Prometopidia conisaria*	Ennominae	BC ZSM Lep 94423	Joshimath	30.55325	79.54502778	2210
27	*Prometopidia* sp. nov.	Ennominae	BC ZSM Lep 94424	Joshimath	30.55325	79.54502778	2210
28	Not identified		BC ZSM Lep 94425	Lata	30.49461111	79.71338889	2320

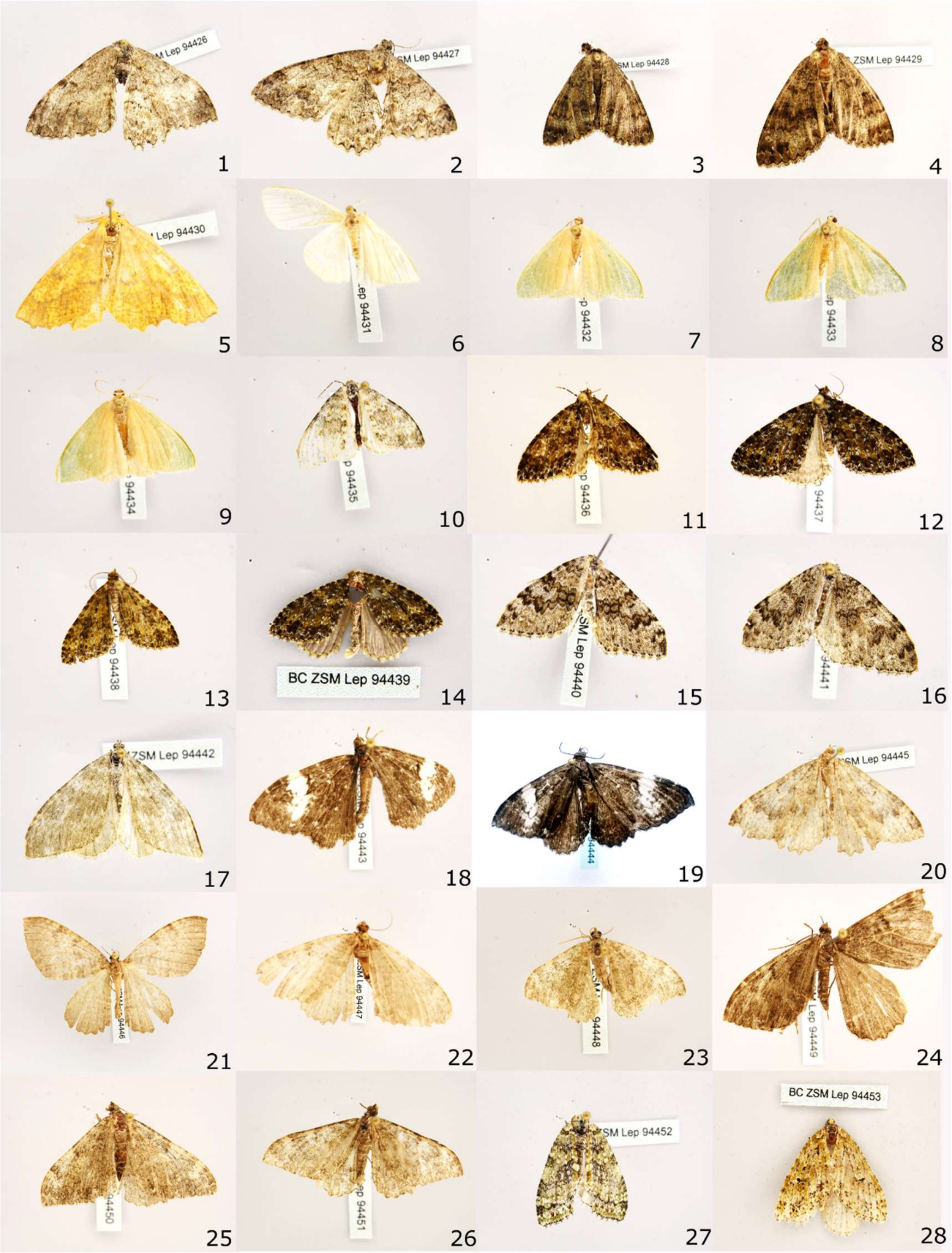
Plate 5.3: DNA Barcoded Geometridae specimens



Details of the DNA Barcoded Geometridae specimens (Plate 5.4)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Alcis leucophaea*	Ennominae	BC ZSM Lep 94426	Lata	30.49463889	79.71333333	2339
2	*Alcis nudipennis*	Ennominae	BC ZSM Lep 94427	Lata	30.49463889	79.71333333	2339
3	*Hirasa muscosaria*	Ennominae	BC ZSM Lep 94428	Joshimath	30.49693	79.75019	3137
4	*Hirasa muscosaria*	Ennominae	BC ZSM Lep 94429	Joshimath	30.52311111	79.56133333	3018
5	*Peetula stramineata*	Ennominae	BC ZSM Lep 94430	Lata	30.50030556	79.74641667	3555
6	*Hemithea distinctaria*	Sterrhinae	BC ZSM Lep 94431	Joshimath	30.54022222	79.56511111	2619
7	*Hemithea distinctaria*	Sterrhinae	BC ZSM Lep 94432	Lata	30.49305556	79.70602778	2311
8	*Hemithea distinctaria*	Sterrhinae	BC ZSM Lep 94433	Lata	30.49986111	79.74361111	3310
9	*Hemithea distinctaria*	Sterrhinae	BC ZSM Lep 94434	Lata	30.49547222	79.72163889	2528
10	*Entephria poliotaria*	Larentiinae	BC ZSM Lep 94435	Lata	30.497	79.74919444	3768
11	*Parentephria stellata*	Larentiinae	BC ZSM Lep 94436	Ghangria	30.70158	79.5935	3116
12	*Parentephria stellata*	Larentiinae	BC ZSM Lep 94437	Joshimath	30.49693	79.75019	3137
13	*Parentephria stellata*	Larentiinae	BC ZSM Lep 94438	Joshimath	30.52263889	79.56413889	2977
14	*Prentephria stellata*	Larentiinae	BC ZSM Lep 94439	Joshimath	30.52255556	79.56427778	2959
15	*Neotephria* sp.	Larentiinae	BC ZSM Lep 94440	Joshimath	30.52	79.55911111	3152
16	*Neotephria* sp.	Larentiinae	BC ZSM Lep 94441	Joshimath	30.52263889	79.56413889	2977
17	*Entephria* sp.	Larentiinae	BC ZSM Lep 94442	Ghangria	30.70158	79.5935	3116
18	*Triphosa hydatoplex*	Larentiinae	BC ZSM Lep 94443	Lata	30.49483333	79.72841667	2766
19	*Triphosa hydatoplex*	Larentiinae	BC ZSM Lep 94444	Lata	30.49483333	79.72841667	2766
20	*Triphosa* sp.	Larentiinae	BC ZSM Lep 94445	Joshimath	30.555	79.54797222	2069
21	*Triphosa venimaculata*	Larentiinae	BC ZSM Lep 94446	Joshimath	30.546	79.55411111	2414
22	*Triphosa venimaculata*	Larentiinae	BC ZSM Lep 94447	Lata	30.49305556	79.70602778	2311
23	*Triphosa dubiosata*	Larentiinae	BC ZSM Lep 94448	Joshimath	30.55566667	79.54755556	2053
24	*Rheumaptera tremodes*	Larentiinae	BC ZSM Lep 94449	Lata	30.49452778	79.72827778	2793
25	*Triphosa dubiosata*	Larentiinae	BC ZSM Lep 94450	Lata	30.49555556	79.72205556	2533
26	*Triphosa dubiosata*	Larentiinae	BC ZSM Lep 94451	Joshimath	30.55308333	79.54516667	2237
27	*Trichopterigia rufinotata*	Larentiinae	BC ZSM Lep 94452	Ghangria	30.69958	79.59247	3213
28	*Trichopterigia* sp.2	Larentiinae	BC ZSM Lep 94453	Joshimath	30.51844444	79.55805556	3220

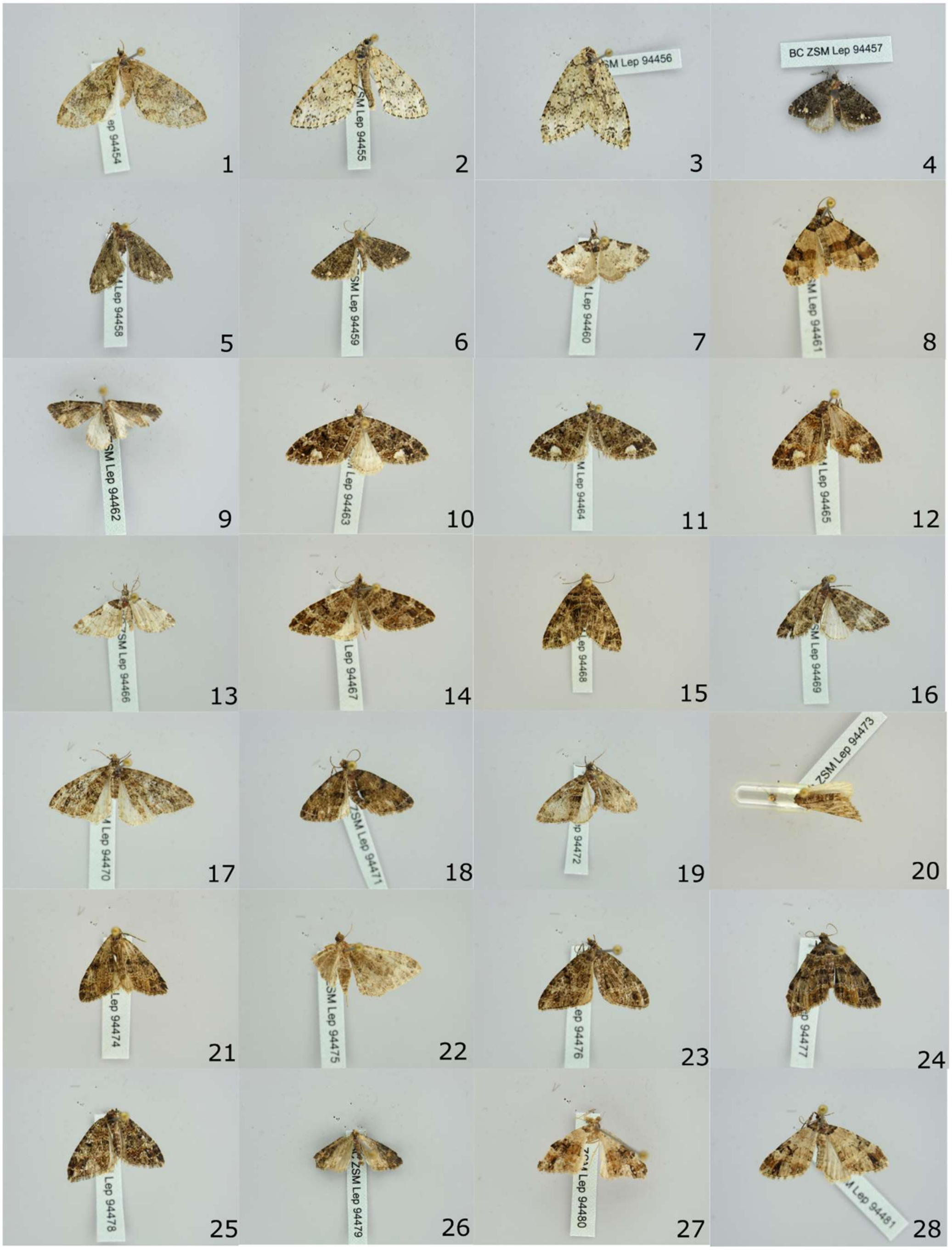
Plate 5.4: DNA Barcoded Geometridae specimens



Details of the DNA Barcoded Geometridae specimens (Plate 5.5)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	Not identified	Larentiinae	BC ZSM Lep 94454	Joshimath	30.546	79.55411111	2414
2	*Trichopterigia* sp.1	Larentiinae	BC ZSM Lep 94455	Lata	30.49986111	79.74361111	3310
3	*Trichopterigia* sp.1	Larentiinae	BC ZSM Lep 94456	Lata	30.49716667	79.73713889	3106
4	*Perizoma micropunctum*	Larentiinae	BC ZSM Lep 94457	Joshimath	30.52263889	79.56413889	2977
5	*Perizoma micropunctum*	Larentiinae	BC ZSM Lep 94458	Joshimath	30.52227778	79.56408333	2987
6	*Perizoma micropunctum*	Larentiinae	BC ZSM Lep 94459	Joshimath	30.54022222	79.56511111	2619
7	*Perizoma albofasciata*	Larentiinae	BC ZSM Lep 94460	Lata	30.49502778	79.70536111	2182
8	*Perizoma vinculata*	Larentiinae	BC ZSM Lep 94461	Lata	30.49958333	79.74083333	3111
9	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94462	Lata	30.49517	79.72164	2544
10	*Perizoma seriata*	Larentiinae	BC ZSM Lep 94463	Joshimath	30.51911111	79.55858333	3227
11	*Perizoma seriata*	Larentiinae	BC ZSM Lep 94464	Joshimath	30.52291667	79.56680556	2893
12	*Perizoma seriata*	Larentiinae	BC ZSM Lep 94465	Joshimath	30.51844444	79.55805556	3220
13	*Perizoma conjuncta*	Larentiinae	BC ZSM Lep 94466	Lata	30.49502778	79.70536111	2182
14	*Perizoma seriata*	Larentiinae	BC ZSM Lep 94467	Joshimath	30.52344444	79.56086111	3067
15	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94468	Lata	30.50002778	79.74616667	3535
16	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94469	Joshimath	30.54022222	79.56511111	2619
17	*Perizoma seriata*	Larentiinae	BC ZSM Lep 94470	Joshimath	30.52291667	79.56680556	2893
18	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94471	Lata	30.49305556	79.70602778	2311
19	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94472	Joshimath	30.52227778	79.56408333	2987
20	*Apithecia viridata*	Larentiinae	BC ZSM Lep 94473	Lata	30.5005	79.74583333	3522
21	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94474	Lata	30.49452778	79.72827778	2793
22	*Xanthorhoe saturara*	Larentiinae	BC ZSM Lep 94475	Lata	30.49452778	79.72827778	2793
23	*Perizoma seriata*	Larentiinae	BC ZSM Lep 94476	Joshimath	30.52344444	79.56086111	3067
24	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94477	Lata	30.49719444	79.74927778	3775
25	*Perizoma seriata*	Larentiinae	BC ZSM Lep 94478	Joshimath	30.51911111	79.55858333	3227
26	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94479	Joshimath	30.55308333	79.54516667	2237
27	*Perizoma vinculata*	Larentiinae	BC ZSM Lep 94480	Bhyundar	30.67375	79.59083	2547
28	*Perizoma vinculata*	Larentiinae	BC ZSM Lep 94481	Ghangria	30.70164	79.59333	3129

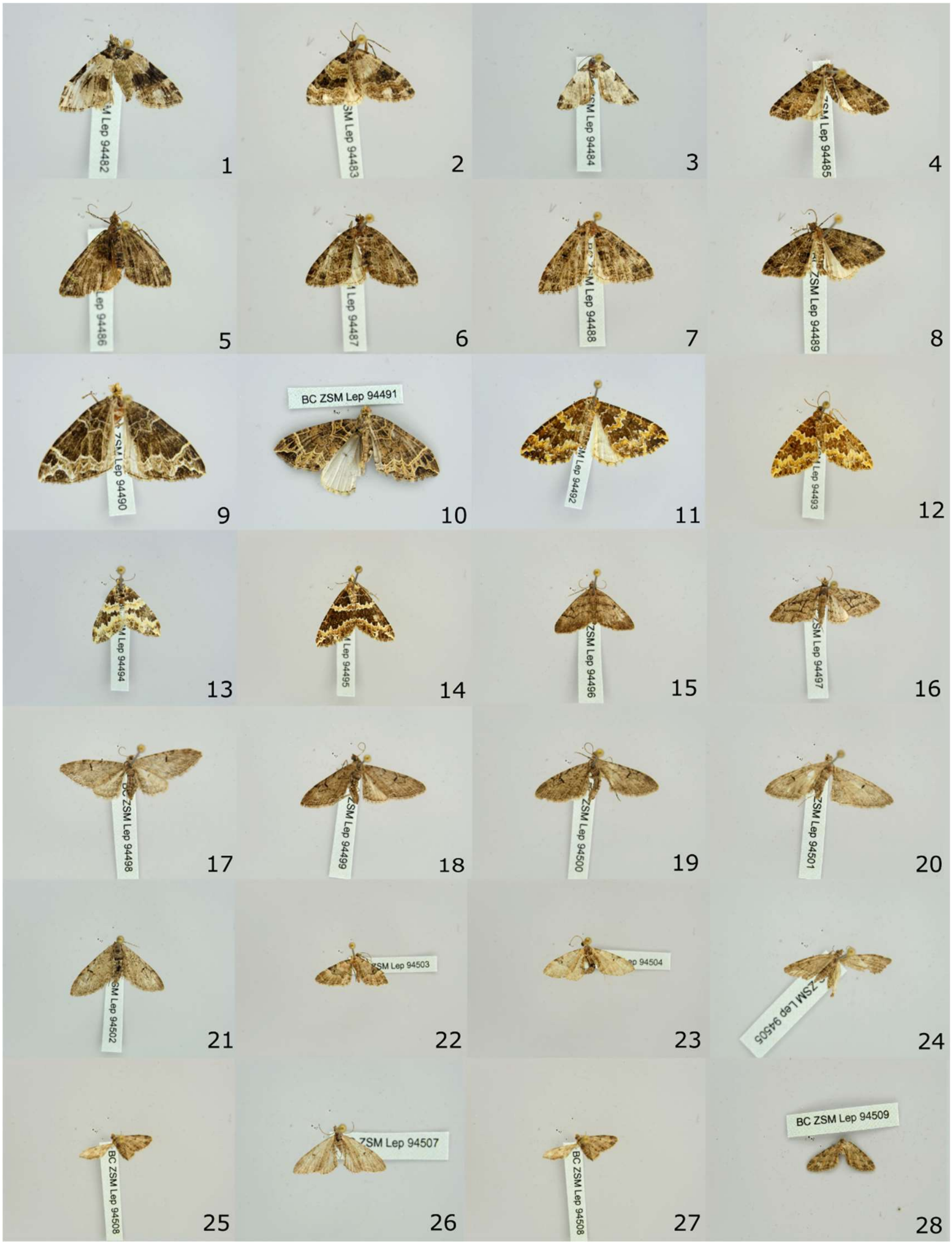
Plate 5.5: DNA Barcoded Geometridae specimens



Details of the DNA Barcoded Geometridae specimens (Plate 5.6)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Perizoma vinculata*	Larentiinae	BC ZSM Lep 94482	Ghangria	30.69994	79.59272	3118
2	*Perizoma* sp.2	Larentiinae	BC ZSM Lep 94483	Joshimath	30.52305556	79.56113889	3030
3	*Perizoma conjuncta*	Larentiinae	BC ZSM Lep 94484	Lata	30.49519444	79.70538889	2143
4	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94485	Lata	30.49263889	79.70638889	2347
5	*Apithecia viridata*	Larentiinae	BC ZSM Lep 94486	Lata	30.49517	79.72164	2544
6	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94487	Lata	30.49455556	79.72752778	2700
7	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94488	Lata	30.4946	79.73004	2900
8	*Perizoma constricta*	Larentiinae	BC ZSM Lep 94489	Lata	30.49483333	79.72841667	2766
9	*Ecliptopera substituta*	Larentiinae	BC ZSM Lep 94490	Joshimath	30.52083333	79.55930556	3141
10	*Ecliptopera postpallida*	Larentiinae	BC ZSM Lep 94491	Lata	30.49983333	79.74366667	3327
11	*Electrophaes marginata*	Larentiinae	BC ZSM Lep 94492	Joshimath	30.54558333	79.55436111	2422
12	*Electrophaes zaphenges*	Larentiinae	BC ZSM Lep 94493	Joshimath	30.49693	79.75019	3137
13	Not identified		BC ZSM Lep 94494	Lata	30.49961111	79.74083333	3122
14	*Electrophaes niveonotata*	Larentiinae	BC ZSM Lep 94495	Joshimath	30.55297222	79.54502778	2227
15	*Eupithecia subrubescens*	Larentiinae	BC ZSM Lep 94496	Joshimath	30.55566667	79.54755556	2217
16	*Eupithecia nigrilinea*	Larentiinae	BC ZSM Lep 94497	Joshimath	30.5565	79.54736111	2049
17	*Eupithecia quadripunctata*	Larentiinae	BC ZSM Lep 94498	Lata	30.49555556	79.72205556	2533
18	*Eupithecia acuta*	Larentiinae	BC ZSM Lep 94499	Joshimath	30.55466667	79.54772222	2106
19	*Eupithecia quadripunctata*	Larentiinae	BC ZSM Lep 94500	Joshimath	30.55566667	79.54755556	2217
20	*Eupithecia quadripunctata*	Larentiinae	BC ZSM Lep 94501	Lata	30.49555556	79.72205556	2533
21	*Eupithecia quadripunctata*	Larentiinae	BC ZSM Lep 94502	Lata	30.49555556	79.72205556	2533
22	*Eupithecia fletcheri*	Larentiinae	BC ZSM Lep 94503	Lata	30.49483333	79.72841667	2766
23	*Eupithecia fletcheri*	Larentiinae	BC ZSM Lep 94504	Lata	30.49483333	79.72841667	2766
24	*Eupithecia* sp.1	Larentiinae	BC ZSM Lep 94505	Lata	30.49497222	79.70536111	2152
25	*Eupithecia* sp.1	Larentiinae	BC ZSM Lep 94506	Lata	30.49497222	79.70536111	2152
26	*Eupithecia* sp.1	Larentiinae	BC ZSM Lep 94507	Joshimath	30.55566667	79.54755556	2053
27	*Eupithecia* sp.2	Larentiinae	BC ZSM Lep 94508	Joshimath	30.55566667	79.54755556	2053
28	*Eupithecia* sp.2	Larentiinae	BC ZSM Lep 94509	Joshimath	30.55566667	79.54755556	2053

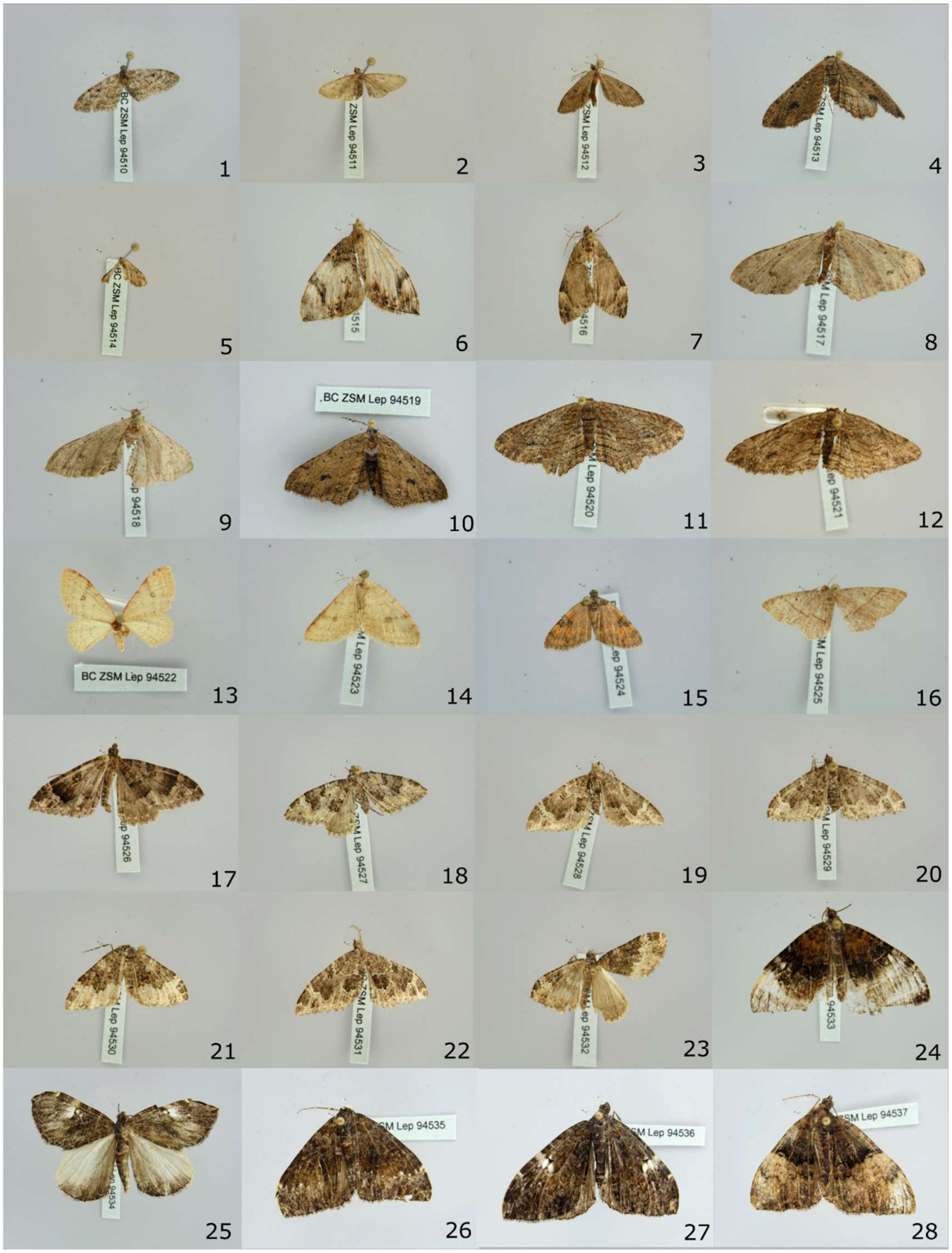
Plate 5.6: DNA Barcoded Geometridae specimens



Details of the DNA Barcoded Geometridae specimens (Plate 5.7)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Eupithecia* sp.1	Larentiinae	BC ZSM Lep 94510	Lata	30.49494444	79.7055	2164
2	*Eupithecia liliptana*	Larentiinae	BC ZSM Lep 94511	Lata	30.4952	79.72206	2553
3	*Eupithecia darjeelica*	Larentiinae	BC ZSM Lep 94512	Lata	30.49483333	79.72841667	2766
4	*Horisme nigrovittata*	Larentiinae	BC ZSM Lep 94513	Joshimath	30.546	79.55411111	2414
5	*Not identified*		BC ZSM Lep 94514	Lata	30.49958333	79.74083333	3111
6	*Dysstroma dentifera*	Larentiinae	BC ZSM Lep 94515	Joshimath	30.52083333	79.55930556	3141
7	*Dysstroma dentifera*	Larentiinae	BC ZSM Lep 94516	Joshimath	30.52	79.55911111	3152
8	*Horisme plurilineata*	Larentiinae	BC ZSM Lep 94517	Lata	30.50019444	79.74411111	3373
9	*Horisme plurilineata*	Larentiinae	BC ZSM Lep 94518	Lata	30.50027778	79.74608333	3533
10	*Horisme nigrovittata*	Larentiinae	BC ZSM Lep 94519	Joshimath	30.52311111	79.56133333	3018
11	*Horisme* sp.1	Larentiinae	BC ZSM Lep 94520	Joshimath	30.555	79.54797222	2069
12	*Horisme* sp.2	Larentiinae	BC ZSM Lep 94521	Lata	30.49513889	79.72113889	2526
13	*Hydrelia rubricosta*	Larentiinae	BC ZSM Lep 94522	Lata	30.49225	79.70733333	2374
14	*Hydrelia rubricosta*	Larentiinae	BC ZSM Lep 94523	Lata	30.49661111	79.73833333	2905
15	*Hydrelia bicolorata*	Larentiinae	BC ZSM Lep 94524	Lata	30.49461111	79.71338889	2320
16	*Not identified*	Larentiinae	BC ZSM Lep 94525	Bhyundar	30.67375	79.59083	2547
17	*Colostygia albigirata*	Larentiinae	BC ZSM Lep 94526	Joshimath	30.5565	79.54736111	2049
18	*Xanthorhoe* sp.2	Larentiinae	BC ZSM Lep 94527	Joshimath	30.55325	79.54502778	2210
19	*Colostygia albigirata*	Larentiinae	BC ZSM Lep 94528	Lata	30.4952	79.72206	2553
20	*Colostygia albigirata*	Larentiinae	BC ZSM Lep 94529	Lata	30.49927778	79.74072222	3105
21	*Xanthorhoe* sp.1	Larentiinae	BC ZSM Lep 94530	Joshimath	30.52208333	79.56422222	2985
22	*Colostygia albigirata*	Larentiinae	BC ZSM Lep 94531	Lata	30.49555556	79.72205556	2533
23	*Xanthorhoe* sp.1	Larentiinae	BC ZSM Lep 94532	Joshimath	30.54022222	79.56511111	2619
24	*Photoscotosia amplicata*	Larentiinae	BC ZSM Lep 94533	Lata	30.50027778	79.74608333	3533
25	*Photoscotosia amplicata*	Larentiinae	BC ZSM Lep 94534	Lata	30.50030556	79.74641667	3555
26	*Photoscotosia amplicata*	Larentiinae	BC ZSM Lep 94535	Lata	30.50027778	79.74608333	3533
27	*Photoscotosia amplicata*	Larentiinae	BC ZSM Lep 94536	Lata	30.50019444	79.74411111	3373
28	*Photoscotosia miniosata*	Larentiinae	BC ZSM Lep 94537	Joshimath	30.54558333	79.55436111	2422

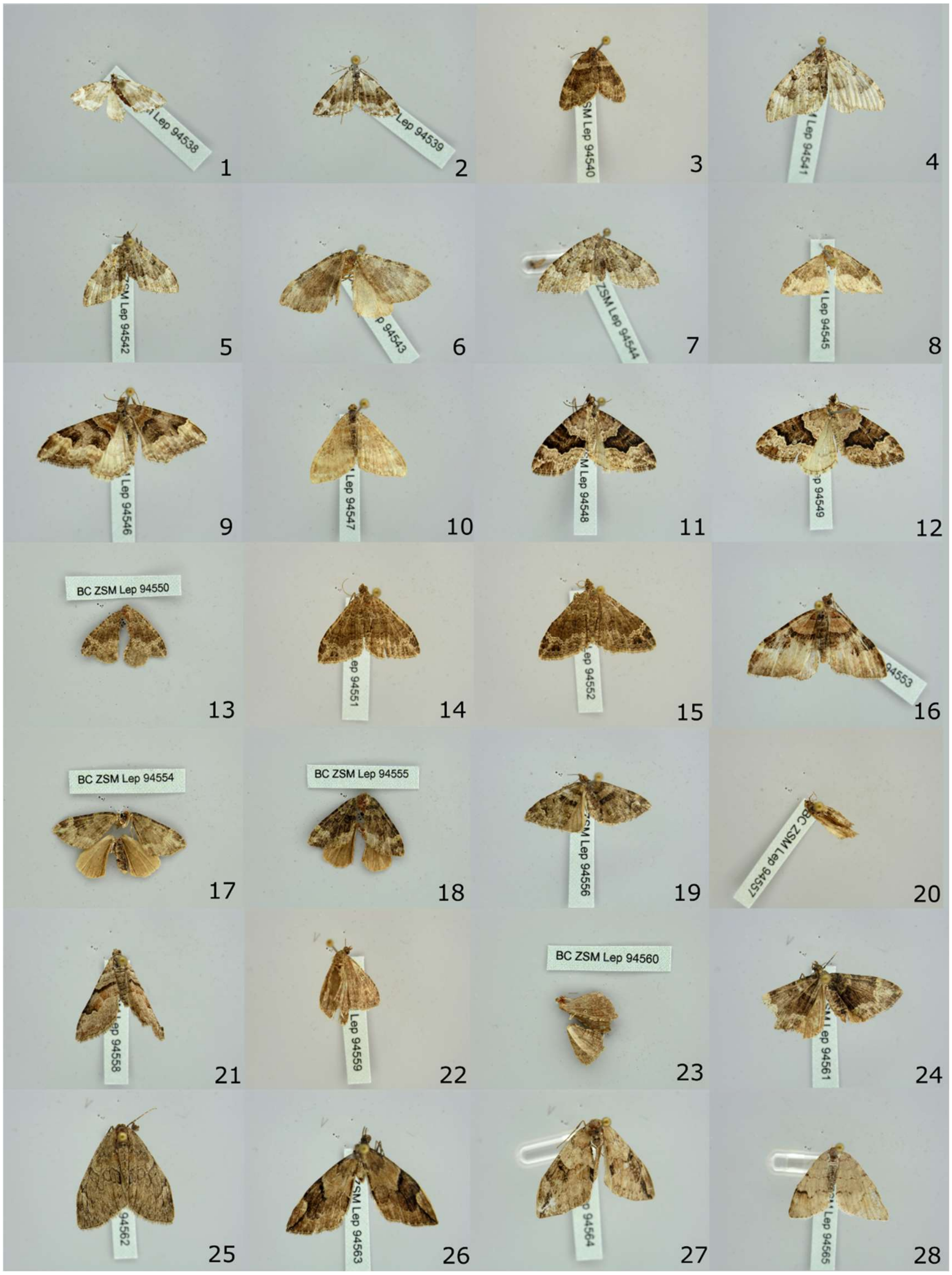
Plate 5.7: DNA Barcoded Geometridae specimens



Details of the DNA Barcoded Geometridae specimens (Plate 5.8)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Euphyia* sp.	Larentiinae	BC ZSM Lep 94538	Lata	30.49497222	79.70536111	2152
2	*Euphyia* sp.	Larentiinae	BC ZSM Lep 94539	Lata	30.49497222	79.70536111	2152
3	*Perizoma* sp.1	Larentiinae	BC ZSM Lep 94540	Lata	30.49452778	79.72827778	2793
4	*Xanthorhoe* sp.2	Larentiinae	BC ZSM Lep 94541	Joshimath	30.5565	79.54736111	2049
5	*Xanthorhoe* sp.2	Larentiinae	BC ZSM Lep 94542	Lata	30.49497222	79.70536111	2152
6	*Apithecia viridata*	Larentiinae	BC ZSM Lep 94543	Bhyundar	30.67411	79.59064	2564
7	*Xanthorhoe* sp.2	Larentiinae	BC ZSM Lep 94544	Joshimath	30.55566667	79.54755556	2053
8	*Xanthorhoe* sp.2	Larentiinae	BC ZSM Lep 94545	Lata	30.49461111	79.71338889	2320
9	*Euphyia subangulata*	Larentiinae	BC ZSM Lep 94546	Lata	30.49927778	79.74072222	3105
10	*Euphyia subangulata*	Larentiinae	BC ZSM Lep 94547	Lata	30.49463889	79.71333333	2339
11	*Costicoma exangulata*	Larentiinae	BC ZSM Lep 94548	Lata	30.49502778	79.72763889	2913
12	*Costicoma exangulata*	Larentiinae	BC ZSM Lep 94549	Lata	30.49513889	79.72113889	2526
13	*Xanthorhoe saturata*	Larentiinae	BC ZSM Lep 94550	Joshimath	30.54555556	79.55402778	2433
14	*Xanthorhoe* sp.2	Larentiinae	BC ZSM Lep 94551	Joshimath	30.55461111	79.54736111	2130
15	*Xanthorhoe saturata*	Larentiinae	BC ZSM Lep 94552	Joshimath	30.55461111	79.54736111	2130
16	*Xanthorhoe stupida*	Larentiinae	BC ZSM Lep 94553	Lata	30.49916667	79.74094444	3109
17	*Apithecia viridata*	Larentiinae	BC ZSM Lep 94554	Lata	30.49463889	79.71333333	2339
18	*Apithecia viridata*	Larentiinae	BC ZSM Lep 94555	Lata	30.49461111	79.71338889	2320
19	*Perizoma* sp.1	Larentiinae	BC ZSM Lep 94556	Bhyundar	30.67411	79.59064	2564
20	*Perizoma* sp.1	Larentiinae	BC ZSM Lep 94557	Lata	30.4952	79.72206	2553
21	*Xanthorhoe mecoterma*	Larentiinae	BC ZSM Lep 94558	Lata	30.49480556	79.73019444	2911
22	*Orthonama obstipata*	Larentiinae	BC ZSM Lep 94559	Joshimath	30.55566667	79.54755556	2053
23	*Orthonama obstipata*	Larentiinae	BC ZSM Lep 94560	Joshimath	30.5405	79.56563889	2604
24	*Apithecia viridata*	Larentiinae	BC ZSM Lep 94561	Bhyundar	30.67375	79.59083	2547
25	*Thera consimilis*	Larentiinae	BC ZSM Lep 94562	Joshimath	30.54588889	79.55369444	2424
26	*Thera dentifasciata*	Larentiinae	BC ZSM Lep 94563	Joshimath	30.55566667	79.54755556	2053
27	*Thera comis*	Larentiinae	BC ZSM Lep 94564	Joshimath	30.5565	79.54736111	2049
28	*Venusia crassisigna*	Larentiinae	BC ZSM Lep 94565	Lata	30.49463889	79.71333333	2339

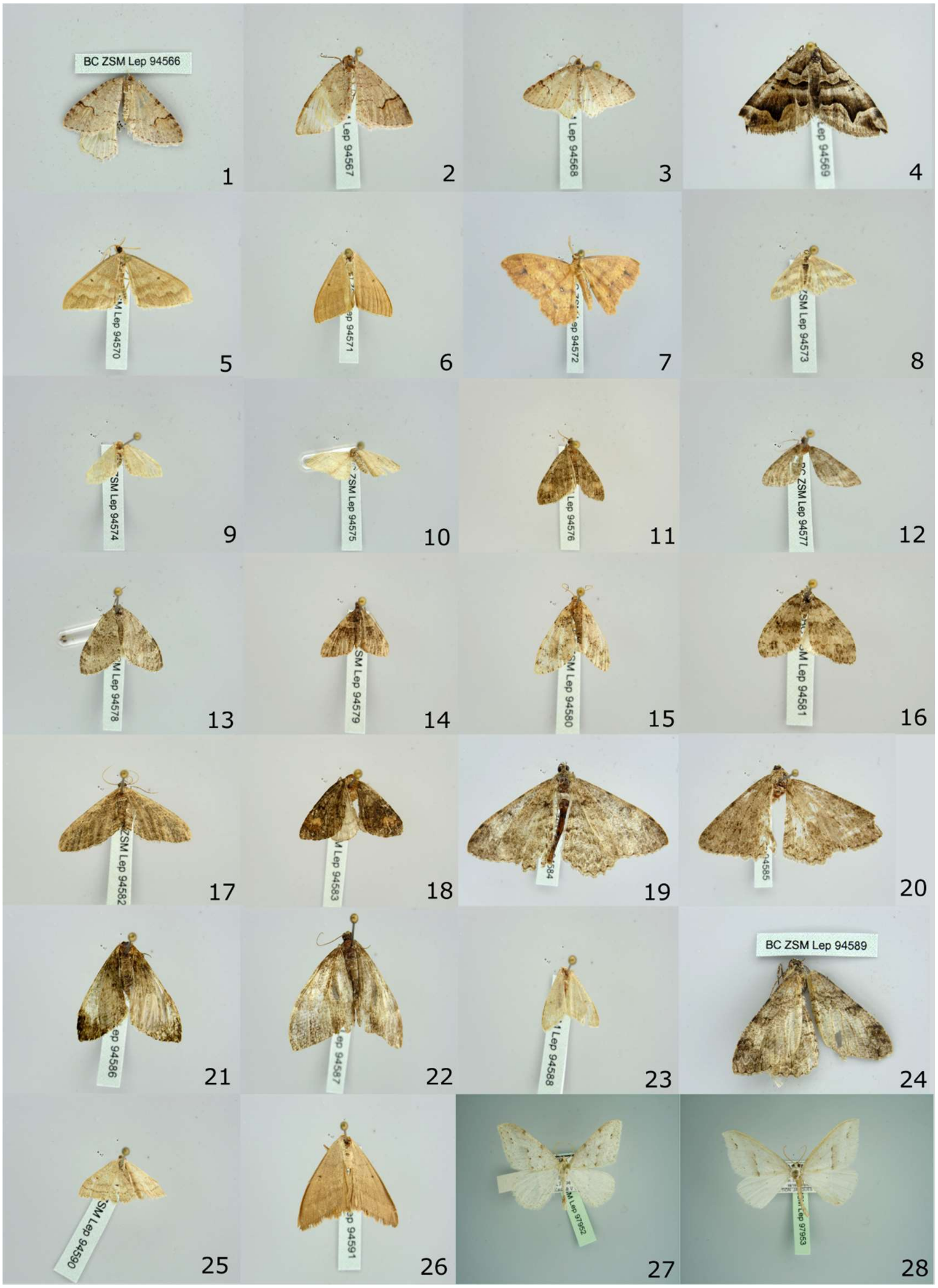
Plate 5.8: DNA Barcoded Geometridae specimens



Details of the DNA Barcoded Geometridae specimens (Plate 5.9)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Venusia crassisigna*	Larentiinae	BC ZSM Lep 94566	Joshimath	30.52083333	79.55930556	3141
2	*Venusia crassisigna*	Larentiinae	BC ZSM Lep 94567	Joshimath	30.52208333	79.56422222	2985
3	*Venusia crassisigna*	Larentiinae	BC ZSM Lep 94568	Lata	30.49517	79.72164	2544
4	*Scotopteryx nasifera*	Larentiinae	BC ZSM Lep 94569	Lata	30.49916667	79.74094444	3109
5	*Rhodostrophia herbicolens*	Larentiinae	BC ZSM Lep 94570	Lata	30.49716667	79.73713889	3106
6	*Rhodostrophia herbicolens*	Larentiinae	BC ZSM Lep 94571	Lata	30.49494444	79.7055	2164
7	*Synegiodes hyriaria*	Sterrhinae	BC ZSM Lep 94572	Lata	30.49516667	79.70533333	2137
8	*Idaea* sp.1	Larentiinae	BC ZSM Lep 94573	Bhyundar	30.67411	79.59064	2564
9	*Scopula* sp.	Larentiinae	BC ZSM Lep 94574	Lata	30.49483333	79.72841667	2766
10	*Scopula* sp.	Larentiinae	BC ZSM Lep 94575	Joshimath	30.54555556	79.55402778	2433
11	*Perizoma variabilis*	Larentiinae	BC ZSM Lep 94576	Lata	30.50030556	79.74641667	3555
12	*Perizoma variabilis*	Larentiinae	BC ZSM Lep 94577	Lata	30.50027778	79.74608333	3533
13	unknown 2		BC ZSM Lep 94578	Lata	30.49983333	79.74366667	3327
14	*Perizoma* sp.1	Larentiinae	BC ZSM Lep 94579	Lata	30.49497222	79.70536111	2152
15	unknown 4		BC ZSM Lep 94580	Joshimath	30.54555556	79.55402778	2433
16	unknown 5		BC ZSM Lep 94581	Lata	30.50030556	79.74641667	3555
17	*Horisme* sp.3	Larentiinae	BC ZSM Lep 94582	Joshimath	30.55302778	79.54525	2238
18	*Perizoma variabilis*	Larentiinae	BC ZSM Lep 94583	Lata	30.50030556	79.74641667	3555
19	*Alcis nudipennis*	Ennominae	BC ZSM Lep 94584	Ghangria	30.70158	79.5935	3116
20	unknown 9		BC ZSM Lep 94585	Lata	30.49916667	79.74094444	3109
21	*Photoscotosia amplicata*	Larentiinae	BC ZSM Lep 94586	Joshimath	30.49693	79.75019	3137
22	*Parentephria stellata*	Larentiinae	BC ZSM Lep 94587	Joshimath	30.49693	79.75019	3137
23	*Idaea* sp.2	Sterrhinae	BC ZSM Lep 94588	Joshimath	30.55566667	79.54755556	2217
24	*Alcis leucophaea*	Ennominae	BC ZSM Lep 94589	Ghangria	30.69958	79.59247	3213
25	unknown 13		BC ZSM Lep 94590	Lata	30.49502778	79.70536111	2182
26	*Rhodostrophia aquila*	Sterrhinae	BC ZSM Lep 94591	Lata	30.49519444	79.70538889	2143
Collection Herbulot specimen (ZSM)							
27	*Loxaspilates obliquaria*	Ennominae	BC ZSM Lep 97952	Him.Pra. Spiti valley	32.24614	78.03492	4150
28	*Loxaspilates obliquaria*	Ennominae	BC ZSM Lep 97953	Kashmir, Lithenwan	34.30316	75.29311	2850

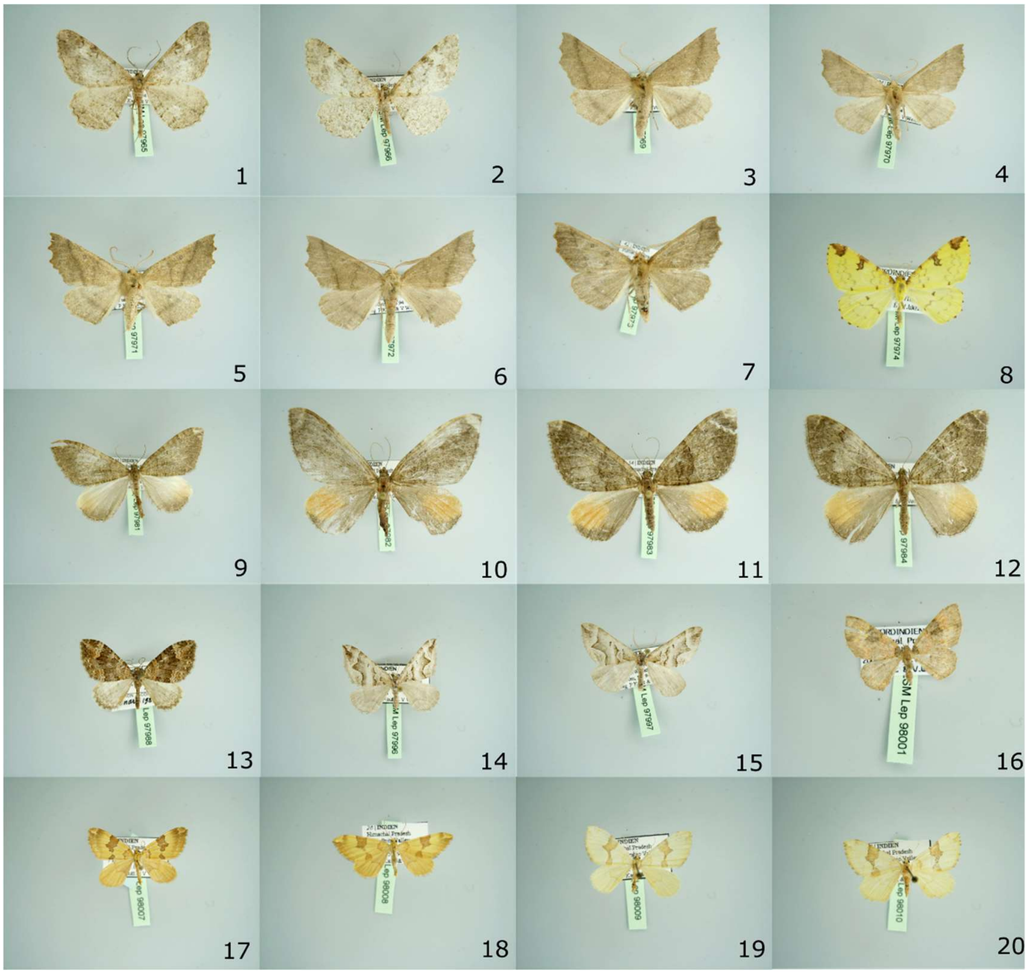
Plate 5.9: DNA Barcoded Geometridae specimens



Details of the DNA Barcoded Geometridae specimens (Plate 5.10)

S. no.	Species	Subfamily	Barcode no.	Exact Site	Latitude (N)	Longitude (E)	Elevation
1	*Alcis subrepandata*	Ennominae	BC ZSM Lep 97965	Him.Pra. Spiti valley	32.24614	78.03492	4150
2	*Alcis subrepandata*	Ennominae	BC ZSM Lep 97966	Him.Pra. Spiti valley	32.24614	78.03492	3800
3	*Odontopera veneris*	Ennominae	BC ZSM Lep 97969	Him.Pra. Spiti valley	32.24614	78.03492	3600
4	*Odontopera veneris*	Ennominae	BC ZSM Lep 97970	Him.Pra. Spiti valley	32.24614	78.03492	3550
5	*Odontopera veneris*	Ennominae	BC ZSM Lep 97971	Him.Pra. Spiti valley	32.24614	78.03492	4100
6	*Odontopera veneris*	Ennominae	BC ZSM Lep 97972	Him.Pra. Spiti valley	32.24614	78.03492	3900
7	*Odontopera veneris*	Ennominae	BC ZSM Lep 97973	Him.Pra. Spiti valley	32.24614	78.03492	4150
8	*Opisthograptis mimulina*	Ennominae	BC ZSM Lep 97974	Him.Pra. Kullu Valley, Manali	31.95835	77.10823	2000
9	*Photoscotosia occidens*	Larentiinae	BC ZSM Lep 97981	Him.Pra. Spiti valley	32.24614	78.03492	4150
10	*Photoscotosia occidens*	Larentiinae	BC ZSM Lep 97982	Him.Pra. Spiti valley	32.24614	78.03492	3850
11	*Photoscotosia occidens*	Larentiinae	BC ZSM Lep 97983	Him.Pra. Spiti valley	32.24614	78.03492	3800
12	*Photoscotosia occidens*	Larentiinae	BC ZSM Lep 97984	Him.Pra. Spiti valley	32.24614	78.03492	3600
13	*Euphyia cinnamifusa*	Larentiinae	BC ZSM Lep 97988	Kashmir, Sonmarg	34.30316	75.29311	2500
14	*Scotopteryx nasifera*	Larentiinae	BC ZSM Lep 97996	Him.Pra. Spiti valley	32.24614	78.03492	3690
15	*Scotopteryx nasifera*	Larentiinae	BC ZSM Lep 97997	Him.Pra. Spiti valley	32.24614	78.03492	3550
16	*Hydrelia bicolorata*	Larentiinae	BC ZSM Lep 98001	Him.Pra. Kullu Valley, Manali	31.95835	77.10823	2000
17	*Cidaria basharica*	Larentiinae	BC ZSM Lep 98007	Him.Pra. Spiti valley	32.24614	78.03492	4150
18	*Cidaria basharica*	Larentiinae	BC ZSM Lep 98008	Him.Pra. Spiti valley	32.24614	78.03492	3550
19	*Cidaria basharica*	Larentiinae	BC ZSM Lep 98009	Him.Pra. Spiti valley, Parashio Valley	32.24614	78.03492	3800
20	*Cidaria basharica*	Larentiinae	BC ZSM Lep 98010	Him.Pra. Spiti valley, Parashio Valley	32.24614	78.03492	3850
	Only sequences added from the BOLD (Barcode of Life Database) system						
21	*Euphyia subangulata*	Larentiinae	BC ZSM Lep 60840	HP, kullu valley	31.95835	77.10823	2000
22	*Stenorumia ablunata*	Ennominae	BC ZSM Lep 72950	HP, Kullu valley	31.95835	77.10823	1750
23	*Peribatodes paghmana*	Ennominae	BC ZSM Lep 59069	HP, Kullu valley	31.95835	77.10823	1750
24	*Psyra indica*	Ennominae	BC ZSM Lep 74590	HP, Kullu valley	31.95835	77.10823	2000
25	*Scotopteryx nasifera*	Larentiinae	BC ZSM Lep 60800	Him.Pra. Spiti valley	32.24614	78.03492	3900
26	*Xanthorhoe saturata*	Larentiinae	BC ZSM Lep 60774	Him.Pra. Shimla	31.10481	77.1734	2200
27	*Xanthorhoe saturata*	Larentiinae	BC ZSM Lep 71412	Him.Pra. Shimla	31.10481	77.1734	2200

Plate 5.10: DNA Barcoded Geometridae specimens



Abraham, D., Ryrholm, N., Wittzell, H., Holloway, J.D., Scoble, M.J. and Löfstedt, C. 2001. Molecular phylogeny of the subfamilies in Geometridae (Geometroidea: Lepidoptera). *Molecular Phylogenetics and Evolution, 20(1),* pp.65-77.

Acharya, K.P., Vetaas, O.R. and Birks, H.J.B. 2011. Orchid species richness along Himalayan elevational gradients. *Journal of Biogeography, 38(9),* pp.1821-1833.

Adams, B.J. 2001. The species delimitation uncertainty principle. *Journal of Nematology, 33(4)*, p.153.

Agapow, P.M., Bininda-Emonds*, O.R., Crandall, K.A., Gittleman, J.L., Mace, G.M., Marshall, J.C. and Purvis, A. 2004. The impact of species concept on biodiversity studies. *The quarterly review of biology*, *79(2)*, pp.161-179.

Agnarsson, I. and Kuntner, M. 2007. Taxonomy in a changing world: seeking solutions for a science in crisis. *Systematic Biology*, *56(3)*, pp.531-539.

Andersen, A.N., Hoffmann, B.D., Müller, W.J. and Griffiths, A.D. 2002. Using ants as bioindicators in land management: simplifying assessment of ant community responses. *Journal of Applied Ecology*, *39(1)*, pp.8-17.

Arora, G. S. 1997. Insecta: Lepidoptera. Fauna of Conservation Area 9: Fauna of Nanda Devi Biosphere Reserve, Zoological Survey of India, pp.7-88.

Arora, G. S. 2000. Studies on some Indian Pyralid species of Economic Importance, Part-1 (Lepidoptera – Pyralidae.). *Zoological Survey of India, 181*, pp.1-169.

Ashfaq, M., Akhtar, S., Khan, A.M., Adamowicz, S.J. and Hebert, P.D.N. 2013. DNA barcode analysis of butterfly species from Pakistan points towards regional endemism. *Molecular ecology resources*, *13(5)*, pp.832-843.

Ashfaq, M., Akhtar, S., Rafi, M.A., Mansoor, S. and Hebert, P.D.N. 2017. Mapping global biodiversity connections with DNA barcodes: Lepidoptera of Pakistan. *PloS one*, *12(3)*, p.e0174749.

Ashton, L.A., Barlow, H.S., Nakamura, A. and Kitching, R.L. 2015. Diversity in tropical ecosystems: the species richness and turnover of moths in Malaysian rainforests. *Insect Conservation and Diversity*, *8(2)*, pp.132-142.

Ashton, L.A., Nakamura, A., Burwell, C.J., Tang, Y., Cao, M., Whitaker, T., Sun, Z., Huang, H. and Kitching, R.L. 2016a. Elevational sensitivity in an Asian 'hotspot': moth diversity across elevational gradients in tropical, sub-tropical and sub-alpine China. *Scientific reports*, *6*, p.26513.

Ashton, L.A., Odell, E.H., Burwell, C.J., Maunsell, S.C., Nakamura, A., McDonald, W.J.F. and Kitching, R.L. 2016b. Altitudinal patterns of moth diversity in tropical and subtropical Australian rainforests. *Austral ecology, 41(2)*, pp.197-208.

Ashton, S., Gutierrez, D. and Wilson, R.J. 2009. Effects of temperature and elevation on habitat use by a rare mountain butterfly: implications for species responses to climate change. *Ecological Entomology, 34(4)*, pp.437-446.

Austin, M.P. 1999. The potential contribution of vegetation ecology to biodiversity research. *Ecography*, *22(5)*, pp.465-484.

Avise, J.C. 2000. Phylogeography: the history and formation of species. Cambridge: Harvard University Press. 447pp.

Avise, J.C. and Ball, M. 1990. Principles of genealogical concordance in species concepts and biological taxonomy. *Oxford Surveys in Evolutionary Biology 7*, pp.45-67.

Axmacher, J.C. and Fiedler, K. 2009a. Habitat type modifies geometry of elevational diversity gradients in geometrid moths (Lepidoptera Geometridae) on Mt. Kilimanjaro, Tanzania. *Tropical Zoology*, *21(2)*, pp.243-251.

Axmacher, J.C., Brehm, G., Hemp, A., Tünte, H., Lyaruu, H.V.M., Müller-Hohenstein, K. and Fiedler, K. 2009b. Determinants of diversity in afrotropical herbivorous insects (Lepidoptera: Geometridae): plant diversity, vegetation or abiotic factors? *Journal of Biogeography, 36,* pp.337-349.

Axmacher, J.C., Holtmann, G., Scheuermann, L., Brehm, G., Müller- Hohenstein, K. and Fiedler, K. 2004. Diversity of geometrid moths (Lepidoptera: Geometridae) along an Afrotropical elevational rainforest transect. *Diversity and Distributions, 10*, pp.293-302.

Axmacher, J.C., Liu, Y., Wang, C., Li, L., Yu, Z. 2011. Spatial -diversity patterns ofdiverse insect taxa in Northern China: lessons for biodiversity conservation. *Biol. Conserv., 144,9*, pp. 2362–2368.

Bachand, M., Pellerin, S., Côté, S.D., Moretti, M., De Cáceres, M., Brousseau, P.M., Cloutier, C., Hébert, C., Cardinal, É., Martin, J.-L. and Poulin, M. 2014. Species indicators of ecosystem recovery after reducing large herbivore density: comparing taxa and testing species combinations. *Ecological Indicators, 38*, pp.12–19.

Baindur, A. 1993. The butterflies of Nanda Devi. In Scientific and Ecological Expedition Nanda Devi, 2nd May to 22nd July 1993. Army Corps of Engineers; W.I.I; Salim Ali Centre for Ornithology and Natural History, WWF-India, G.B. Pant Institute of Himalayan Environment and Development, Botanical Survey of India, Delhi.

Baniya, C.B., Solhøy, T., Gauslaa, Y. and Palmer, M.W. 2010. The elevation gradient of lichen species richness in Nepal. *The Lichenologist*, *42(1)*, pp.83-96.

Barlow, H. S. 1982. An Introduction to the Moths of South East Asia. *The Malayan Nature Society, Kualalumpur*, pp. 1-292.

Barlow, H.S. and Woiwod, I.P. 1989. Moth diversity of a tropical forest in Peninsular Malaysia. *Journal of Tropical Ecology, 5(1)*, pp.37-50.

Barraclough, T.G. and Nee, S. 2001. Phylogenetics and speciation. *Trends in Ecology & Evolution, 16(7)*, pp.391-399.

Barthlott, W., Lauer, W. and Placke, A. 1996. Global Distribution of Species Diversity in Vascular Plants: Towards A World Map of Phytodiversity (Globale Verteilung der Artenvielfalt Höherer Pflanzen: Vorarbeiten zu einer Weltkarte der Phytodiversität). *Erdkunde*, pp.317-327.

Baselga, A. and Orme, C.D.L. 2012. betapart: An R package for the study of beta diversity. *Methods in Ecology and Evolution*, *3(5)*, pp.808-812.

Baselga, A. 2010. Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography*, *19(1)*, pp.134-143.

Basset, Y. 2001. Invertebrates in the canopy of tropical rain forests How much do we really know? *Plant Ecology*, *153(1-2)*, pp.87-107.

Basset, Y., Cizek, L., Cuénoud, P., Didham, R.K., Guilhaumon, F., Missa, O., Novotny, V., Ødegaard, F., Roslin, T., Schmidl, J. and Tishechkin, A.K. 2012. Arthropod diversity in a tropical forest. *Science*, *338(6113)*, pp.1481-1484.

Beck J. and Chey V.K. 2008. Explaining the elevational diversity pattern of geometrid moths from Borneo: a test of five hypotheses. *Journal of Biogeography, 35*, pp.1452–1464.

Beck, J. and Chey, V.K. 2007. Beta-diversity of geometrid moths from northern Borneo: effects of habitat, time and space. *J. Anim. Ecol. 76*, pp. 230–237.

Beck, J., McCain, C.M., Axmacher, J.C., Ashton, L.A., Bärtschi, F., Brehm, G., Choi, S.W., Cizek, O., Colwell, R.K., Fiedler, K. and Francois, C.L. 2017. Elevational species richness gradients in a hyperdiverse insect taxon: a global meta-study on geometrid moths. *Global Ecology and Biogeography*, *26(4)*, pp.412-424.

Beck, J., Schulze, C.H., Linsenmair, K.E. and Fiedler, K. 2002. From forest to farmland: diversity and community structure of geometrid moths along two habitat gradients on Borneo. *Journal of Tropical Ecology 17*, pp.33–51.

Begon, M., Harper, J.L. and Townsend, C.R. 1990. Ecology: individuals, populations, and communities. Blackwell Scientific Publications, Boston. 752pp.

Bergsten, J., Bilton, D.T., Fujisawa, T., Elliott, M., Monaghan, M.T., Balke, M., Hendrich, L., Geijer, J., Herrmann, J., Foster, G.N. and Ribera, I. 2012. The effect of geographical scale of sampling on DNA barcoding. *Systematic biology, 61(5)*, pp.851-869.

Best, J.N. and Bork, E.W. 2003. Using transplanted plains rough fescue (Festucahallii (Vasey) Piper) as an indicator of grazing in Elk Island National Park. *Canada.Nat. Areas J. 23*, pp.202–209.

Bharamal, D.L. 2015. An Inventory of the Moth Fuana of (Lepidoptera) of Amboli Reserve Forest, Maharashtra, *India. Int. J. of Curr. Micro. and Appl. Sci, 4912*, pp.803-806.

Bhattacharya, T., Sathyakumar, S. and Rawat, G.S. 2007. Studies on animal habitat interactions in the buffer zone of Nanda Devi Biosphere Reserve. Wildlife Institute of India, Dehradun. 103pp.

Bhattacharya, T., Sathyakumar, S. and Rawat, G.S. 2009. Distribution and abundance of Galliformes in response to anthropogenic pressures in the buffer zone of Nanda Devi Biosphere Reserve. *International Journal of Galliformes Conservation*, *1*, pp.78-84.

Bickford, D., Lohman, D.J., Sodhi, N.S., Ng, P.K., Meier, R., Winker, K., Ingram, K.K. and Das, I. 2007. Cryptic species as a window on diversity and conservation. *Trends in ecology & evolution*, *22(3)*, pp.148-155.

Biju, S.D., Garg, S., Mahony, S., Wijayathilaka, N., Senevirathne, G. and Meegaskumbura, M. 2014. DNA barcoding, phylogeny and systematics of Golden-backed frogs (Hylarana, Ranidae) of the Western Ghats-Sri Lanka biodiversity hotspot, with the description of seven new species. *Contributions to Zoology*, *83(4)*, pp.269-335.

Biswas, O., Modak, B.K., Mazumder, A. and Mitra, B. 2016. Moth (Lepidoptera: Heterocera) diversity of Sunderban Biosphere Reserve, India and their pest status to economically important plants. *Journal of Entomology and Zoology Studies, 4(2)*, pp.13-19.

Blackburn, T.M. and Gaston, K.J. 1998. Some methodological issues in macroecology. *The American Naturalist*, *151(1)*, pp.68-83.

Blackburn, T.M. and Gaston, K.J., 2002. Scale in macroecology. *Global Ecology and Biogeography*, *11*(3), pp.185-189.

Blanche, K.R. and Ludwig, J.A. 2001. Species richness of gall-inducing insects and host plants along an altitudinal gradient in Big Bend National Park, Texas. *The American Midland Naturalist*, *145(2)*, pp.219-232.

Blaxter, M. and Floyd, R. 2003. Molecular taxonomics for biodiversity surveys: already a reality. *Trends in Ecology & Evolution*, *18(6)*, pp.268-269.

Bonnier, G. and Flahault, Ch. 1878. Sur les modifications des ve´ge´taux. *Ann. Sci. Nat. 7,* pp.93–125

Bosak, K. 2008. Nature, conflict and biodiversity conservation in the Nanda Devi Biosphere Reserve. *Conservation and Society*, *6(3)*, pp.211-224.

Brehm, G. and Fiedler, K. 2003. Faunal composition of geometrid moths changes with altitude in an Andean montane rain forest. *Journal of Biogeography, 30(3)*, pp.431-440.

Brehm, G. and Fiedler, K. 2004. Bergmann's rule does not apply to geometrid moths along an elevational gradient in an Andean montane rain forest. *Global Ecology and Biogeography*, *13(1)*, pp.7-14.

Brehm, G. 2002. Diversity of geometrid moths in a montane rainforest in Ecuador. (Doctoral dissertation, University of Bayreuth, Germany).

Brehm, G., Colwell, R.K. and Kluge, J. 2007. The role of environment and mid-domain effect on moth species richness along a tropical elevational gradient. *Global Ecology and Biogeography*, *16(2)*, pp.205-219.

Brehm, G., Süssenbach, D. and Fiedler, K. 2003a. Unique elevational diversity patterns of geometrid moths in an Andean montane rainforest. *Ecography*, *26(4)*, pp.456-466.

Brehm, G., Homeier, J. and Fiedler, K. 2003b. Beta diversity of geometrid moths (Lepidoptera: Geometridae) in an Andean montane rainforest. *Diversity and Distributions*, *9(5)*, pp.351-366.

Brehm, G., Pitkin, L.M., Hilt, N. and Fiedler, K. 2005. Montane Andean rain forests are a global diversity hotspot of geometrid moths. *Journal of Biogeography, 32(9)*, pp.1621-1627.

Brehm, G., Strutzenberger, P. and Fiedler, K. 2013. Phylogenetic diversity of moths decreases with elevation in the tropical Andes. *Ecography, 36*, pp.1247-1253

Brooks, D.R. and McLennan, D.A. 1999. Species: turning a conundrum into a research program. *Journal of nematology*, *31(2)*, p.117-133.

Brown, J. H. 1988. Species diversity. - In: Myers, A. A. and Giller, P. S. (eds), Analytical biogeography - an integrated approach to the study of animal and plant distribution. Chap-man and Hall, New York, pp. 57-89. - and Gibson, A. C. 1983. Biogeography. - C.V. Mosby, St. Louis.

Brown, J.H. and Lomolino, M.V. 1998. Biogeography, 2nd edn Sinauer Associates: Sunderland. *MA, USA*. 691pp.

Brown, J.H. 1971. Mammals on mountaintops: nonequilibrium insular biogeography. *The American Naturalist*, *105*(945), pp.467-478.

Brown, J.H., Stevens, G.C. and Kaufman, D.M. 1996. The geographic range: size, shape, boundaries, and internal structure. *Annual review of ecology and systematics*, *27(1)*, pp.597-623.

Brown, K.S. 1997. Diversity, disturbance, and sustainable use of Neotropical forests: insects as indicators for conservation monitoring. *Journal of Insect conservation*, *1(1)*, pp.25-42.

Burns, J.M., Janzen, D.H., Hajibabaei, M., Hallwachs, W. and Hebert, P.D.N. 2008. DNA barcodes and cryptic species of skipper butterflies in the genus Perichares in Area de Conservacion Guanacaste, Costa Rica. *Proceedings of the National Academy of Sciences*, *105(17)*, pp.6350-6355.

Cadena, C.D., Kozak, K.H., Gómez, J.P., Parra, J.L., McCain, C.M., Bowie, R.C., Carnaval, A.C., Moritz, C., Rahbek, C., Roberts, T.E. and Sanders, N.J. 2011. Latitude, elevational climatic zonation and speciation in New World vertebrates. *Proceedings of the Royal Society of London B: Biological Sciences*, p.rspb20110720.

Cain, A.J. 1954. Animal species and their evolution. New York: Harper & Row. 210pp.

Cardoso, P., Erwin, T.L., Borges, P.A. and New, T.R. 2011. The seven impediments in invertebrate conservation and how to overcome them. *Biological Conservation*, *144*(11), pp.2647-2655.

Ceballos, G., Ehrlich, P.R., Barnosky, A.D., Garcia, A., Pringle, R.M. and Palmer, T.M. 2015. Accelerated modern human–inducedspecies losses: entering the sixth mass extinction. *Science Advances, 1,* e1400253.

Champion, H.G. and Seth, S.K. 1968. A revised survey of forest types of India. Government of India, New Delhi. Reprinted, 2005. 404pp.

Chandra, K. and Nema, D.K. 2003. Moths of Pench Tiger Reserve, Seoni, Madhya Pradesh. *Journal of Tropical Forestry, 19(1-2)*, pp.68-78.

Chandra, K. and Nema, D.K. 2006. Moths of Kanger Valley National Park (Bastar), Chhattisgarh. *Records Zoological Survey of India, 106(2)*, pp.13-23.

Chandra, K. and Rajan, P.T. 1995. Moths of Mount Harriet National Park, Andaman. *Journal of Andaman Science Association*, *11(1)*, pp.71-75.

Chandra, K. and Sambath, S. 2013. Moth diversity of Tawang District, Arunachal Pradesh, India. *Journal of Threatened Taxa, 5(1)*, pp.3565-3570.

Chandra, K. 1996. Moths of Great Nicobar Biosphere Reserve, India. *Malayan Nature Journal*, *50*, pp.107-108.

Chapman, F. M. 1917. The distribution of bird-life in Colombia: a contribution to a biological survey of South America. - *Bull. Amer. Mus. Nat. Hist. 36*, pp.1-729.

Choi, S.W. 1999. Taxonomic review of a new genus, *Diathera* gen. n., from Southeast Asia (Lepidoptera, Geometridae: Larentiinae). *Journal of natural history*, *33(7)*, pp.1039-1048.

Clare, E.L., Lim, B.K., Engstrom, M.D., Eger, J.L. and Hebert, P.D.N. 2007. DNA barcoding of Neotropical bats: species identification and discovery within Guyana. *Molecular Ecology Resources*, *7*(2), pp.184-190.

Colwell, R.K. and Hurtt, G.C. 1994. Nonbiological gradients in species richness and a spurious Rapoport effect. *The American Naturalist*, *144(4)*, pp.570-595.

Colwell, R.K. and Lees, D.C. 2000. The mid-domain effect: geometric constraints on the geography of species richness. *Trends in ecology & evolution*, *15(2)*, pp.70-76.

Condon, M.A., Scheffer, S.J., Lewis, M.L. and Swensen, S.M. 2008. Hidden neotropical diversity: greater than the sum of its parts. *Science, 320(5878)*, pp.928-931.

Cook, M.A. and Scoble, M.J. 1992. Tympanal organs of geometrid moths: a review of their morphology, function, and systematic importance. *Systematic Entomology, 17(3)*, pp.219-232.

Corlett, R.T. 2016. Ecological roles of animals in tropical forests. *Tropical Forestry Handbook*, pp.503-510.

Cotes, E. C. and Swinhoe, C. 1886. A catalogue of Moths of India. 801pp.

Covell, C.V. 1983. The state of our knowledge of the Neotropical Sterrhinae (Geometridae). In *Second Symposium on Neotropical Lepidoptera, Arequipa, Peru,1*, pp. 17-23.

Currie, D.J. and Kerr, J.T. 2008. Tests of the mid-domain hypothesis: a review of the evidence. *Ecological Monographs*, *78(1)*, pp.3-18.

Dang, H. 1961. A natural sanctuary in the Himalaya: Nanda Devi and the Rishiganga Basin. *Journal of Bombay Natural History Society*, *58*, pp.707-714.

Darwin, C. 1839. Journal of the Researches into the Geology and Natural History of Various Countries Visited by H.M.S. Beagle, under the Command of Captain Fitzroy, R.N. from 1832 to 1836. Henry Colburn, London.

Darwin, C. 1859. On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life. John Murray, London.

Dayrat, B. 2005. Towards integrative taxonomy. *Biological journal of the Linnean society*, *85(3)*, pp.407-415.

De Cáceres, M. and Legendre, P. 2009. Associations between species and groups of sites: indices and statistical inference. *Ecology*, *90(12)*, pp.3566-3574.

De Cáceres, M., Legendre, P. and Moretti, M. 2010. Improving indicator species analysis by combining groups of sites. *Oikos*, *119(10)*, pp.1674-1684.

De Carvalho, M.R., Bockmann, F.A., Amorim, D.S. and Brandao, C.R.F. 2008. Systematics must embrace comparative biology and evolution, not speed and automation. *Evolutionary Biology*, *35(2)*, pp.150-157.

De Carvalho, M.R., Bockmann, F.A., Amorim, D.S., de Vivo, M., de Toledo-Piza, M., Menezes, N.A., de Figueiredo, J.L. and McEachran, J.D. 2005. Revisiting the taxonomic impediment. *Science*, *307(5708)*, pp.353-.

deWaard, J.R. Hebert, P.D.N. and Humble, L.M. 2011. A comprehensive DNA barcode library for the looper moths (Lepidoptera: Geometridae) of British Columbia, Canada. *PLoS One 6(3),* p. e18290.

deWaard, J.R., Ivanova, N.V., Hajibabaei, M. and Hebert, P.D.N. 2008. Assembling DNA barcodes: analytical protocols. In Martin C, editor. *Methods in molecular biology: environmental genetics. Totowa: Humana Press,* pp. 275–293.

deWaard, J.R., Mitchell, A., Keena, M.A., Gopurenko, D., Boykin, L.M., Armstrong, K.F., Pogue, M.G., Lima, J., Floyd, R., Hanner, R.H. & Humble, L.M. 2010. Towards a global barcode library for Lymantria (Lepidoptera: Lymantriinae) tussock moths of biosecurity concern. *PLoS One 5(12),* p. e14280.

Dey, P., Uniyal, V.P. and Chandra, K. 2017. A Prefatory Estimation of Diversity and Distribution of Moths in Nanda Devi Biosphere Reserve, Western Himalaya, India. *National Academy Science Letters*, *40(3)*, pp.199-203.

Dey, P., Uniyal, V.P. and Sanyal, A.K. 2015. Moth assemblages (lepidoptera: heterocera) as a potential conservation tool for biodiversity monitoring–study in western himalayan protected areas. *Indian Forester*, *141(9)*, pp.985-992.

Dincã, V., Zakharov, E.V., Hebert, P.D.N. and Vila, R. 2011. Complete DNA barcode reference library for a country's butterfly fauna reveals high performance for temperate Europe. *Proceedings of the Royal Society of London B: Biological Sciences*, *278(1704)*, pp.347-355.

Dubey, B., Meganathan, P.R. and Haque, I. 2011. DNA mini-barcoding: an approach for forensic identification of some endangered Indian snake species. *Forensic Science International: Genetics*, *5(3)*, pp.181-184.

Dufrêne, M. and Legendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological monographs, 67(3)*, pp.345-366.

Dunn, R.R. 2005. Modern insect extinctions, the neglected majority. *Conservation biology, 19(4)*, pp.1030-1036.

Ekrem, T., Willassen, E. and Stur, E. 2007. A comprehensive DNA sequence library is essential for identification with DNA barcodes. *Molecular phylogenetics and evolution, 43(2)*, pp.530-542.

Enkthur, K., Pfeiffer, M., Lkhagva, A and Boldgiv, B. 2016. Response of moths (Lepidoptera: Heterocera) to livestock grazing in Mongolian rangelands. *Ecological Indicators, 72*, pp.667-674.

Erwin, T.L. 1982. Tropical forests: their richness in Coleoptera and other arthropod species. The Coleopterists’ Bulletin, 36 (1), pp.74-75.

Escobar, F., Lobo, J.M. and Halffter, G. 2005. Altitudinal variation of dung beetle (Scarabaeidae: Scarabaeinae) assemblages in the Colombian Andes. *Global Ecology and Biogeography, 14(4)*, pp.327-337.

Fattorini, S. 2013. Regional insect inventories require long time, extensive spatial sampling and good will. *Plos One, 8(4)*, p.e62118

Fattorini, S., Dennis, R.L. and Cook, L.M. 2012b. Use of cross-taxon congruence for hotspot identification at a regional scale. *PLoS One, 7(6)*, p.e40018.

Fattorini, S., Maurizi, E. and Giulio, A.D. 2012a. Tackling the taxonomic impediment: a global assessment for ant-nest beetle diversity (Coleoptera: Carabidae: Paussini). *Biological journal of the Linnean Society, 105(2)*, pp.330-339.

Feng, Y., Li, Q., Kong, L. and Zheng, X. 2011. DNA barcoding and phylogenetic analysis of Pectinidae (Mollusca: Bivalvia) based on mitochondrial COI and 16S rRNA genes. *Molecular Biology Reports, 38(1)*, pp.291-299.

Ferns, P.N. and Jervis, M.A. 2016. Ordinal species richness in insects—a preliminary study of the influence of morphology, life history, and ecology. *Entomologia Experimentalis et Applicata, 159(2)*, pp.270-284.

Finlay, B.J., Thomas, J.A., McGavin, G.C., Fenchel, T. and Clarke, R.T. 2006. Self-similar patterns of nature: insect diversity at local to global scales. *Proceedings of the Royal Society of London B: Biological Sciences, 273(1596)*, pp.1935-1941.

Fisher, R.A., Corbet, A.S. and Williams, C.B. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. *The Journal of Animal Ecology*, pp.42-58.

Fleishman, E. and Murphy, D.D. 2009. A realistic assessment of the indicator potential of butterflies and other charismatic taxonomic groups. *Conservation Biology, 23(5)*, pp.1109-1116.

Fleishman, E., Austin, G.T. and Weiss, A.D. 1998. An empirical test of Rapoport's rule: elevational gradients in montane butterfly communities. *Ecology, 79(7)*, pp.2482-2493.

Folcher, L., Weissenberger, A. and Delos, M. 2012. Quantitative relationships between Ostrinia nubilalis activity and deoxynivalenol contamination in French maize. *International journal of pest management, 58(4)*, pp.302-309.

Fonseca, C.R. 2009. The silent mass extinction of insect herbivores in biodiversity hotspots. *Conservation Biology, 23(6)*, pp.1507-1515.

Fontaine, B., Perrard, A. and Bouchet, P. 2012. 21 years of shelf life between discovery and description of new species. *Current Biology, 22(22)*, pp.R943-R944.

Freijeiro, A. and Baselga, A. 2016. Spatial and environmental correlates of species richness and turnover patterns in European cryptocephaline and chrysomeline beetles. *ZooKeys, (597)*, pp.81-99.

Gaikwad, S., Warudkar, A. and Shouche, Y. 2017. Efficacy of DNA barcoding for the species identification of spiders from Western Ghats of India. *Mitochondrial DNA Part A, 28(5)*, pp.638-644.

Gaikwad, S.S., Ghate, H.V., Ghaskadbi, S.S., Patole, M.S. and Shouche, Y.S. 2012. DNA barcoding of nymphalid butterflies (Nymphalidae: Lepidoptera) from Western Ghats of India. *Molecular biology reports, 39(3)*, pp.2375-2383.

Garibaldi, L.A., Kitzberger, T. and Chaneton, E.J. 2011. Environmental and genetic control of insect abundance and herbivory along a forest elevational gradient. *Oecologia, 167(1)*, pp.117-129.

Gaston, K.J. 1991. The magnitude of global insect species richness. *Conservation biology, 5(3)*, pp.283-296.

Gaston, K.J. 2000. Global patterns in biodiversity. *Nature, 405(6783)*, pp.220-227.

Ghosh, S.K. 2003. Fauna of Sikkim. *Zooogical Survey of India*, *9*, pp.217-342.

Ghosh-Harihar, M. 2013. Distribution and abundance of foliage-arthropods across elevational gradients in the east and west Himalayas. *Ecological research, 28(1)*, pp.125-130.

Godfray, H.C.J. 2002. Challenges for taxonomy. *Nature, 417(6884)*, pp.17-19.

González-Varo, J.P., Arroyo, J.M. and Jordano, P. 2014. Who dispersed the seeds? The use of DNA barcoding in frugivory and seed dispersal studies. *Methods in Ecology and Evolution, 5(8)*, pp.806-814.

Gotelli, N.J. and Colwell, R.K. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology letters, 4(4)*, pp.379-391.

Green, M. and Peard, G. 2005. World Heritage Nomination IUCN Summary: Valley of Flowers National Park (India). IUCN, Gland, Switzerland

Grimaldi, D. and Engel, M.S. 2005. *Evolution of the Insects*. Cambridge University Press.755pp.

Group, C.P.W., Hollingsworth, P.M., Forrest, L.L., Spouge, J.L., Hajibabaei, M., Ratnasingham, S., van der Bank, M., Chase, M.W., Cowan, R.S., Erickson, D.L. and Fazekas, A.J. 2009. A DNA barcode for land plants. *Proceedings of the National Academy of Sciences, 106(31)*, pp.12794-12797.

Grytnes, J.A. and McCain, C.M. 2013. Elevational trends in biodiversity. *Encyclopedia of biodiversity, 3*, pp.149-154.

Grytnes, J.A. 2003. Ecological interpretations of the mid-domain effect. *Ecology Letters, 6(10)*, pp.883-888.

Guo, Q., Kelt, D.A., Sun, Z., Liu, H., Hu, L., Ren, H. and Wen, J. 2013. Global variation in elevational diversity patterns. *Scientific reports*, *3*, p.3007.

Guralnick, R. and Van Cleve, J. 2005. Strengths and weaknesses of museum and national survey data sets for predicting regional species richness: comparative and combined approaches. *Diversity and Distributions, 11(4)*, pp.349-359.

Hafernik, J.E. 1992. Threats to invertebrate biodiversity: implications for conservation strategies. *Conservation Biology,* pp. 171-195.

Hahn, M. and Brühl, C.A. 2016. The secret pollinators: an overview of moth pollination with a focus on Europe and North America. *Arthropod-Plant Interactions, 10(1)*, pp.21-28.

Hajibabaei, M., Janzen, D.H., Burns, J.M., Hallwachs, W. and Hebert, P.D.N. 2006. DNA barcodes distinguish species of tropical Lepidoptera. *Proceedings of the National Academy of Sciences of the United States of America, 103(4)*, pp.968-971.

Hajra, P.K. and Jain, S.K. 1983. A contribution to the Botany of Nanda Devi National Park in Uttar Pradesh, India. *Howrah: Principal Investigator for Project on Study, Survey and Conservation of Endangered Species of Flora, Botanical Survey of India 38p.-illus. En Geog*, *6*.

Hampson, G.F. 1892. Fauna of British India Moths 1. Taylor & Francis, London. 527pp.

Hampson, G.F. 1894. Fauna of British India Moths 2, Taylor & Francis, London. 528pp.

Hampson, G.F. 1895. Fauna of British India Moths 3, Taylor & Francis, London. 517pp.

Hampson, G.F. 1896. Fauna of British India Moths 4. Taylor & Francis, London. 595pp.

Hastings, J.M., Schultheis, P.J., Whitson, M., Holliday, C.W., Coelho, J.R. and Mendell, A.M. 2008. DNA barcoding of new world cicada killers (Hymenoptera: Crabronidae). *Zootaxa, 1713,* pp.27-38.

Hausmann, A. 2001. The Geometrid Moths of Europe. Volume 1. Introduction. Archiearinae, Orthostixinae, Desmobathrinae, Alsophilinae, Geometrinae. Apollo Books. Stenstrup.

Hausmann, A. and Scalercio, S. 2016. Host-plant relationships of 29 MediterraneanLepidoptera species in forested ecosystemsunveiled by DNA Barcoding (Insecta: Lepidoptera). *SHILAP Revista de Lepidopterología, 44(175)*, pp.463-471.

Hausmann, A. 2003. Die afrotropischen Arten der Gattung Hypochrosis Guenee, [1858] mit Beschreibung einer neuen Gattung (Cherbulois, gen. nov.) und 17 neuer Arten (Lepidoptera, Geometridae, Ennominae). *Spixiana, 26(2)*, pp.97-128.

Hausmann, A., Godfray, H.C.J., Huemer, P., Mutanen, M., Rougerie, R., van Nieukerken, E.J., Ratnasingham, S. and Hebert, P.D.N. 2013. Genetic patterns in European geometrid moths revealed by the Barcode Index Number (BIN) system. *PloS one, 8(12)*, p.e84518.

Hausmann, A., Haszprunar, G. and Hebert, P.D.N. 2011a. DNA barcoding the geometrid fauna of Bavaria (Lepidoptera): successes, surprises, and questions. *PLoS One, 6(2)*, p.e17134.

Hausmann, A., Haszprunar, G., Segerer, A.H., Speidel, W., Behounek, G. and Hebert, P.D.N. 2011b. Now DNA-barcoded: the butterflies and larger moths of Germany. *Spixiana, 34(1)*, pp.47-58.

Hausmann, A., Miller, S.E., Holloway, J.D., Dewaard, J.R., Pollock, D., Prosser, S.W. and Hebert, P.D.N. 2016. Calibrating the taxonomy of a megadiverse insect family: 3000 DNA barcodes from geometrid type specimens (Lepidoptera, Geometridae). *Genome, 59(9)*, pp.671-684.

Hawes, J., da Silva Motta, C., Overal, W.L., Barlow, J., Gardner, T.A. and Peres, C.A. 2009. Diversity and composition of Amazonian moths in primary, secondary and plantation forests. *Journal of Tropical Ecology, 25(3)*, pp.281-300.

Hawlitschek, O., Morinière, J., Lehmann, G.U.C., Lehmann, A.W., Kropf, M., Dunz, A., Glaw, F., Detcharoen, M., Schmidt, S., Hausmann, A. and Szucsich, N.U. 2017. DNA barcoding of crickets, katydids and grasshoppers (Orthoptera) from Central Europe with focus on Austria, Germany and Switzerland. *Molecular ecology resources, 17(5)*, pp.1037-1053.

Heaney, L.R. 2001. Small mammal diversity along elevational gradients in the Philippines: an assessment of patterns and hypotheses. *Global Ecology and Biogeography, 10(1)*, pp.15-39.

Hebert, P.D.N., Cywinska, A. and Ball, S.L. 2003a. Biological identifications through DNA barcodes. *Proceedings of the Royal Society of London B: Biological Sciences, 270(1512)*, pp.313-321.

Hebert, P.D.N., Penton, E.H., Burns, J.M., Janzen, D.H. and Hallwachs, W. 2004a. Ten species in one: DNA barcoding reveals cryptic species in the neotropical skipper butterfly *Astraptes fulgerator*. *Proceedings of the National Academy of Sciences of the United States of America, 101(41)*, pp.14812-14817.

Hebert, P.D.N., Ratnasingham, S. and de Waard, J.R. 2003b. Barcoding animal life: cytochrome c oxidase subunit 1 divergences among closely related species. *Proceedings of the Royal Society of London B: Biological Sciences*, *270* (Suppl 1), pp. S96-S99

Hebert, P.D.N., Stoeckle, M.Y., Zemlak, T.S. and Francis, C.M. 2004b. Identification of birds through DNA barcodes. *PLoS biology, 2(10)*, p.e312.

Hebert, P.D.N., Zakharov, E.V., Prosser, S.W., Sones, J.E., McKeown, J.T., Mantle, B. and La Salle, J. 2013. A DNA 'Barcode Blitz': Rapid digitization and sequencing of a natural history collection. *PLoS One, 8(7)*, p.e68535.

Hendrich, L., Morinière, J., Haszprunar, G., Hebert, P.D.N., Hausmann, A., Köhler, F. and Balke, M. 2015. A comprehensive DNA barcode database for Central European beetles with a focus on Germany: adding more than 3500 identified species to BOLD. *Molecular Ecology Resources, 15(4)*, pp.795-818.

Heppner, J.B. 1991. Faunal regions and the diversity of Lepidoptera. Association for *Tropical lepidoptera*. 85pp.

Herzog, S.K., Kessler, M. and Bach, K. 2005. The elevational gradient in Andean bird species richness at the local scale: a foothill peak and a high-elevation plateau. *Ecography, 28(2)*, pp.209-222.

Hey, J., Waples, R.S., Arnold, M.L., Butlin, R.K. and Harrison, R.G. 2003. Understanding and confronting species uncertainty in biology and conservation. *Trends in Ecology & Evolution, 18(11)*, pp.597-603.

Heywood, V.H. and Watson, R.T. 1995. *Global biodiversity assessment* (Vol. 1140). Cambridge: Cambridge University Press.

Hill, J., Hamer, K., Tangah, J. and Dawood, M. 2001. Ecology of tropical butterflies in rainforest gaps. *Oecologia, 128(2)*, pp.294-302.

Hillebrand, H. 2004. On the generality of the latitudinal diversity gradient. *The American Naturalist*, *163*(2), pp.192-211.

Hilt, N. and Fiedler, K. 2005. Diversity and composition of Arctiidae moth ensembles along a successional gradient in the Ecuadorian Andes. *Diversity and Distributions, 11(5)*, pp.387-398.

Hilt, N., Brehm, G. and Fiedler, K. 2006. Diversity and ensemble composition of geometrid moths along a successional gradient in the Ecuadorian Andes. *Journal of Tropical Ecology, 22(2)*, pp.155-166.

Hodkinson, I.D. 2005. Terrestrial insects along elevation gradients: species and community responses to altitude. *Biological Reviews, 80(3)*, pp.489-513.

Holloway, J.D. 1993. The moths of Borneo: Family Geometridae, subfamily Ennominae. *Malayan Nature Journal, 47,* pp.1-19.

Holloway, J.D. 1996. The moths of Borneo: Family Geometridae, Oenochrominae, Desmobathrinae and Geometrinae. *Malayan Nature Journal, 49*, pp.147-326.

Holloway, J.D. 1997. The moths of Borneo: Family Geometridae, subfamilies Sterrhinae and Larentiinae. *Malayan Nature Journal, 51*, pp.1-242.

Holloway, J.D. and Barlow, H.S. 1992. Potential for loss of biodiversity in Malaysia, illustrated by the moth fauna. *Pest management and the environment in 2000*, pp.293-311.

Holloway, J.D. 1985. Moths as indicator organisms for categorizing rain-forest and monitoring charges and regeneration processes. In *Tropical rain-forest: the Leeds Symposium*. Leeds Philosophical and Literary Society.

Hou, Z.E., Li, Z. and Li, S.Q. 2009. Identifying Chinese species of Gammarus (Crustacea: Amphipoda) using DNA barcoding. *Current Zoology 55(2),* pp.158–164.

Hubert, N., Hanner, R., Holm, E., Mandrak, N.E., Taylor, E., Burridge, M., Watkinson, D., Dumont, P., Curry, A., Bentzen, P. and Zhang, J. 2008. Identifying Canadian freshwater fishes through DNA barcodes. *PLoS one, 3(6)*, p.e2490.

Huemer, P., Mutanen, M., Sefc, K.M. and Hebert, P.D.N. 2014. Testing DNA barcode performance in 1000 species of European Lepidoptera: large geographic distances have small genetic impacts. *PLoS One, 9(12)*, p.e115774.

Humboldt Von, A. and Bonpland, A. 1807. Ideen zu einer Geographie der Pflanzen nebst einem Naturgema¨ lde der Tropenla¨ nder, Schoell andCotta

Humboldt Von, A. 1849. *Aspects of nature, in different lands and different climates; with scientific elucidations*. Lea and Blanchard.

Intachat, J., Chey, V.K., Holloway, J.D. and Speight, M.R. 1999. The impact of forest plantation development on the population and diversity of geomeirid moths (lepidoptera: Geometridae) in malaysia. *Journal of Tropical Forest Science*, pp.329-336.

Ivanova, N.V., Dewaard, J.R. and Hebert, P.D.N. 2006. An inexpensive, automation-friendly protocol for recovering high-quality DNA. *Molecular Ecology Resources, 6(4)*, pp.998-1002.

James, A.N., Gaston, K.J. and Balmford, A. 1999. Balancing the Earth's accounts. *Nature, 401(6751)*, p.323-324.

Janzen, D.H., Hajibabaei, M., Burns, J.M., Hallwachs, W., Remigio, E. and Hebert, P.D.N. 2005. Wedding biodiversity inventory of a large and complex Lepidoptera fauna with DNA barcoding. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *360(1462)*, pp.1835-1845.

Janzen, D.H., Hallwachs, W., Blandin, P., Burns, J.M., Cadiou, J., Chacon, I., Dapkey, T., Deans, A.R., Epstein, M.E., Espinoza, B. and Franclemont, J.G. 2009. Integration of DNA barcoding into an ongoing inventory of complex tropical biodiversity. *Molecular Ecology Resources*, *9*(s1), pp.1-26.

Jetz, W. and Rahbek, C. 2001. Geometric constraints explain much of the species richness pattern in African birds. *Proceedings of the National Academy of Sciences, 98(10)*, pp.5661-5666.

Jin, Q., Han, H., Hu, X., Li, X., Zhu, C., Ho, S.Y., Ward, R.D. and Zhang, A.B. 2013. Quantifying species diversity with a DNA barcoding-based method: Tibetan moth species (Noctuidae) on the Qinghai-Tibetan Plateau. *PloS one, 8(5)*, p.e64428.

Joly, S., Davies, T.J., Archambault, A., Bruneau, A., Derry, A., Kembel, S.W., Peres-Neto, P., Vamosi, J. and Wheeler, T.A. 2014. Ecology in the age of DNA barcoding: the resource, the promise and the challenges ahead. *Molecular Ecology Resources*, *14*(2), pp.221-232.

Jurado-Rivera, J.A., Vogler, A.P., Reid, C.A., Petitpierre, E. and Gómez-Zurita, J. 2009. DNA barcoding insect–host plant associations. *Proceedings of the Royal Society of London B: Biological Sciences*, *276(1657)*, pp.639-648.

Kaila, L. and Albrecht, A. 1994. The classification of the Timandra griseata group (Lepidoptera: Geometridae, Sterrhinae). *Insect Systematics & Evolution, 25(4)*, pp.461-479.

Kandari, O.P. 1982. Nanda Devi-India's highest national park. *Cheetal*, *24*, pp.29-36.

Kandpal, V. 2010. Evaluating threatened species in relation to anthropogenic pressures and their management strategy in Nanda Devi Biosphere Reserve, Western Himalaya. (Doctoral dissertation, Forest Research Institute University, Dehradun).

Kaur, H. and Sharma, K. 2017. COI-based DNA barcoding of some species of Pentatomidae from North India (Hemiptera: Heteroptera). *Mitochondrial DNA Part A, 28(5)*, pp.756-761.

Kearns, C.A. 1992. Anthophilous fly distribution across an elevation gradient. *American Midland Naturalist*, pp.172-182.

Kekkonen, M., Mutanen, M., Kaila, L., Nieminen, M. and Hebert, P.D.N. 2015. Delineating species with DNA barcodes: a case of taxon dependent method performance in moths. *PLoS One, 10(4)*, p.e0122481.

Kerr, K.C., Stoeckle, M.Y., Dove, C.J., Weigt, L.A., Francis, C.M. and Hebert, P.D.N. 2007. Comprehensive DNA barcode coverage of North American birds. *Molecular Ecology Resources, 7(4)*, pp.535-543.

Kessler, M., Herzog, S.K., Fjeldså, J. and Bach, K. 2001. Species richness and endemism of plant and bird communities along two gradients of elevation, humidity and land use in the Bolivian Andes. *Diversity and distributions, 7(1-2)*, pp.61-77.

Khachar, L.K. 1978. The Nanda Devi Sanctuary. J. *Bombay. Nat. His. Soc.,753*, pp. 868-886

Kim, K.C. 1993. Biodiversity, conservation and inventory: why insects matter. *Biodiversity & Conservation, 2(3)*, pp.191-214.

Kimura, M. 1980. A simple method for estimating evolutionary rates of base substitutions through comparative studies of nucleotide sequences. *Journal of molecular evolution, 16(2)*, pp.111-120.

Kirti, J.S., Goyal, T. and Kaur, M. 2007. A preliminary report on the Geometrid moths of District Solan (Himachal Pradesh*). Bionotes, 9 (3)*, pp 91.

Kirti, J.S., Goyal, T. and Kaur, M. 2009. Morphology of the external male genitalia of five Indian geometrid species (Lepidoptera). *Journal of Threatened Taxa, 1(9)*, pp.484-487.

Kirti, J.S., Kaur, M. and Goyal, T. 2008a. Economic importance of the Geometrid Ennominae moths in Himachal Pradesh. *Bionotes, 10 (2),* pp.56-57.

Kirti, J.S., Kaur, M. and Goyal, T. 2008b. Studies on genitalic structures of six commonly known Geometrid species (Lepidoptera) from Himachal Pradesh. *J. ent. Res., 32 (2)*, pp.161-169.

Kirti, J.S., Mandeep, K. and Tarun, G. 2011. Studies on Internal Genitalic Structures of Two Indian Species of Genus Agathia Guenee (Lepidoptera: Geometridae: Geometrinae). Indian Journal of Entomology (India).

Kirti, J.S., Singh, N. and Saxena, A. 2014. Seven New Records of Geometrid Moths (Lepidoptera: Geometridae) From India. *J. Appl. Biosci, 40(2)*, pp.113-116.

Kitching, R.L., Orr, A.G., Thalib, L., Mitchell, H., Hopkins, M.S. and Graham, A.W. 2000. Moth assemblages as indicators of environmental quality in remnants of upland Australian rain forest. *Journal of applied Ecology, 37(2)*, pp.284-297.

Körner, C. 2003. Alpine plant life: functional plant ecology of high mountain ecosystems; with 47 tables. Springer Science & Business Media. 345pp.

Körner, C. 2004. Mountain biodiversity, its causes and function. *Ambio*, pp.11-17.

Körner, C. 2007. The use of 'altitude'in ecological research. *Trends in ecology & evolution, 22(11)*, pp.569-574.

Kress, W.J., Erickson, D.L., Jones, F.A., Swenson, N.G., Perez, R., Sanjur, O. and Bermingham, E. 2009. Plant DNA barcodes and a community phylogeny of a tropical forest dynamics plot in Panama. *Proceedings of the National Academy of Sciences, 106(44)*, pp.18621-18626.

Kress, W.J., García-Robledo, C., Uriarte, M. and Erickson, D.L. 2015. DNA barcodes for ecology, evolution, and conservation. *Trends in ecology & evolution, 30(1)*, pp.25-35.

Kristensen, N.P. 1999. Phylogeny of endopteryygote insects, the most successful lineage of living organisms. *European Journal of Entomology*, *96*, pp.237-254.

Kroupa, M., Spitzer, K. and Novak, I. 1990. The heavy metals content in melanic and typical forms of Biston betularia (Lepidoptera, Geometridae) and its bioindicator significance. *Acta Entomologica Bohemoslovaca, 87(4)*, pp.249-252.

Kumar, K., Oli, B.P., Joshi, B.M. and Samant, S.S. 2001. The faunal diversity of Nanda Devi Biosphere Reserve in Western Himalaya, Himalayan Biosphere Reserve. 3 (I &II), pp.18-57

Kumar, N.P., Rajavel, A.R., Natarajan, R. and Jambulingam, P. 2007. DNA barcodes can distinguish species of Indian mosquitoes (Diptera: Culicidae). *Journal of medical entomology*, *44*(1), pp.1-7.

Kumar, N.P., Srinivasan, R. and Jambulingam, P. 2012. DNA barcoding for identification of sand flies (Diptera: Psychodidae) in India. *Molecular Ecology Resources*, *12*(3), pp.414-420.

Kuzmina, M.L., Johnson, K.L., Barron, H.R. and Hebert, P.D.N. 2012. Identification of the vascular plants of Churchill, Manitoba, using a DNA barcode library. *BMC ecology, 12(1)*, p.25.

Lakra, W.S., Verma, M.S., Goswami, M., Lal, K.K., Mohindra, V., Punia, P., Gopalakrishnan, A., Singh, K.V., Ward, R.D. and Hebert, P.D.N. 2011. DNA barcoding Indian marine fishes. *Molecular Ecology Resources, 11(1)*, pp.60-71.

Lamarre, G., Decaëns, T., Rougerie, R., Barbut, J., Dewaard, J.R., Hebert, P.D.N., Herbin, D., Laguerre, M., Thiaucourt, P. and Bonifacio Martins, M. 2016. An integrative taxonomy approach unveils unknown and threatened moth species in Amazonian rainforest fragments. *Insect conservation and diversity, 9(5)*, pp.475-479.

Lamba, B.S. 1987. Status survey report of fauna: Nanda Devi National Park. Records of the Zoological Survey of India, Occasional Paper No. 103.

Larsen, T.H., Escobar, F. and Armbrecht, I. 2011. Insects of the tropical Andes: diversity patterns, processes and global change. *Climate Change and Biodiversity in the Tropical Andes. Inter-American Institute of Global Change Research (IAI) and Scientific Committee on Problems of the Environment (SCOPE), São José dos Campos and Paris*, pp.228-244.

Laskar, B.A., Bhattacharjee, M.J., Dhar, B., Mahadani, P., Kundu, S. and Ghosh, S.K. 2013. The species dilemma of northeast Indian mahseer (Actinopterygii: Cyprinidae): DNA barcoding in clarifying the riddle. *PloS one, 8(1)*, p.e53704.

Laurance, W.F., Useche, D.C., Shoo, L.P., Herzog, S.K., Kessler, M., Escobar, F., Brehm, G., Axmacher, J.C., Chen, I.C., Gámez, L.A. and Hietz, P. 2011. Global warming, elevational ranges and the vulnerability of tropical biota. *Biological Conservation, 144(1)*, pp.548-557.

Laurance, W.F. and Bierregaard, R.O. eds. 1997. *Tropical forest remnants: ecology, management, and conservation of fragmented communities*. University of Chicago Press.

Lavkumar, K. 1979. Nanda Devi Sanctuary-A naturalist's report. *The Himalayan Journal*, *35*, pp.191-209.

Lawton, J.H. 1996. Patterns in ecology. *Oikos*, *75*(2), pp.145-147.

Leather, S.R., Basset, Y. and Hawkins, B.A. 2008. Insect conservation: finding the way forward. *Insect Conservation and Diversity*, *1*(1), pp.67-69.

Lee, M.S. 2002. Online database could end taxonomic anarchy. *Nature, 417(6891)*, p.787-788.

Lees, D.C., Kawahara, A.Y., Rougerie, R., Ohshima, I., Kawakita, A., Bouteleux, O., Prins, J. and Lopez-Vaamonde, C. 2014. DNA barcoding reveals a largely unknown fauna of Gracillariidae leaf-mining moths in the Neotropics. *Molecular Ecology Resources, 14(2)*, pp.286-296.

Lennon, J.J., Koleff, P., Greenwood, J.J.D. and Gaston, K.J. 2001. The geographical structure of British bird distributions: diversity, spatial turnover and scale. *Journal of Animal Ecology, 70(6)*, pp.966-979.

Lipscomb, D., Platnick, N. and Wheeler, Q. 2003. The intellectual content of taxonomy: a comment on DNA taxonomy. *Trends in Ecology & Evolution, 18(2)*, pp.65-66.

Liu, J.U.N., Li, Q.I., Kong, L., Yu, H. and Zheng, X. 2011. Identifying the true oysters (Bivalvia: Ostreidae) with mitochondrial phylogeny and distance-based DNA barcoding. *Molecular Ecology Resources, 11(5)*, pp.820-830.

Lomolino, M.V. 2001. Elevation gradients of species-density: historical and prospective views. *Global Ecology and biogeography, 10(1)*, pp.3-13.

Lomov, B., Keith, D.A., Britton, D.R. and Hochuli, D.F. 2006. Are butterflies and moths useful indicators for restoration monitoring? A pilot study in Sydney's Cumberland Plain Woodland. *Ecological Management & Restoration, 7(3)*, pp.204-210.

Longino, J.T. and Colwell, R.K. 2011. Density compensation, species composition, and richness of ants on a neotropical elevational gradient. *Ecosphere, 2(3)*, pp.1-20.

Lund, M.P. and Rahbek, C. 2002. Cross-taxon congruence in complementarity and conservation of temperate biodiversity. In *Animal Conservation forum* (Vol. 5, No. 2, pp. 163-171). Cambridge University Press.

Luo, A., Lan, H., Ling, C., Zhang, A., Shi, L., Ho, S.Y. and Zhu, C. 2015. A simulation study of sample size for DNA barcoding. *Ecology and evolution*, *5*(24), pp.5869-5879.

MacArthur, R.H. and Wilson, E.O. 1967. *The theory of island biogeography*. Princeton University Press. 224pp.

MacArthur, R.H. 1972. Geographical Ecology: Patterns in the Distribution of Species. Harper, New York. 288pp.

Maleque, M.A., Maeto, K. and Ishii, H.T. 2009. Arthropods as bioindicators of sustainable forest management, with a focus on plantation forests. *Applied entomology and zoology, 44(1)*, pp.1-11.

Malhotra, A. and Thorpe, R.S. 2004. Maximizing information in systematic revisions: a combined molecular and morphological analysis of a cryptic green pitviper complex (Trimeresurus stejnegeri). *Biological Journal of the Linnean Society, 82(2)*, pp.219-235.

Mallet, J. and Willmott, K. 2003. Taxonomy: renaissance or Tower of Babel? *Trends in Ecology & Evolution, 18(2)*, pp.57-59.

Mani, M.S. 1968 (republished 2013). Ecology and biogeography of high altitude insects (Vol. 4). Springer Science & Business Media. 539pp.

Matheson, C.D., Muller, G.C., Junnila, A., Vernon, K., Hausmann, A., Miller, M.A., Greenblatt, C. and Schlein, Y. 2008. A PCR method for detection of plant meals from the guts of insects. *Organisms Diversity & Evolution, 7(4)*, pp.294-303.

Mathew, G. and Rahmathulla, V.K. 1995. Biodiversity in the Western Ghats-A study with reference to moths (Lepidoptera: Heterocera) in the silent valley National Park, India. *Entomon-Trivandrum-, 20,* pp.25-34.

May, R.M. 1988. How many species are there on earth? *Science, 241(4872)*, pp.1441-1449.

McCain, C.M. and Grytnes, J.A. 2010. Elevational gradients in species richness. *eLS*, pp.1-10.

McCain, C.M. 2007a. Could temperature and water availability drive elevational species richness patterns? A global case study for bats. *Global Ecology and biogeography, 16(1)*, pp.1-13.

McCain, C.M. 2007b. Area and mammalian elevational diversity. *Ecology, 88(1)*, pp.76-86.

McCoy, E.D. 1990. The distribution of insects along elevational gradients. *Oikos*, pp.313-322.

McNaughton, S.J. 1989. Ecosystems and conservation in the twenty-first century. *Conservation for the Twenty-first Century. Oxford University Press, New York*, pp.109-120.

Meier, R. and Dikow, T. 2004. Significance of specimen databases from taxonomic revisions for estimating and mapping the global species diversity of invertebrates and repatriating reliable specimen data. *Conservation Biology, 18(2)*, pp.478-488.

Meier, R., Shiyang, K., Vaidya, G. and Ng, P.K. 2006. DNA barcoding and taxonomy in Diptera: a tale of high intraspecific variability and low identification success. *Systematic biology, 55(5)*, pp.715-728.

Meinertzhagen, C.R. 1928. Some Biological Problems comected with the Himalaya. *Ibis, 70(3)*, pp.480-502.

Menzel, A., Sparks, T.H., Estrella, N., Koch, E., Aasa, A., Ahas, R., Alm-Kübler, K., Bissolli, P., Braslavská, O.G., Briede, A. and Chmielewski, F.M., 2006. European phenological response to climate change matches the warming pattern. *Global change biology, 12(10)*, pp.1969-1976.

Merckx, T., Feber, R.E., Dulieu, R.L., Townsend, M.C., Parsons, M.S., Bourn, N.A., Riordan, P. and Macdonald, D.W. 2009. Effect of field margins on moths depends on species mobility: field-based evidence for landscape-scale conservation. *Agriculture, ecosystems & environment, 129(1-3)*, pp.302-309.

Merckx, T., Feber, R.E., Mclaughlan, C., Bourn, N.A., Parsons, M.S., Townsend, M.C., Riordan, P. and Macdonald, D.W. 2010. Shelter benefits less mobile moth species: the field-scale effect of hedgerow trees. *Agriculture, ecosystems & environment, 138(3-4)*, pp.147-151.

Merckx, T., Marini, L., Feber, R.E. and Macdonald, D.W. 2012. Hedgerow trees and extended-width field margins enhance macro-moth diversity: implications for management. *Journal of Applied Ecology, 49(6)*, pp.1396-1404.

Merriam, C.H. 1890. Results of a biological survey of the San Francisco Mountain region and desert of the Little Colorado in Arizona. *North American Fauna*, pp.1-4.

Meyer, C.P. and Paulay, G. 2005. DNA barcoding: error rates based on comprehensive sampling. *PLoS biology, 3(12)*, p.e422.

Miller, M.A., Müller, G.C., Kravchenko, V.D., Amy, J., Vernon, K.K., Matheson, C.D. and Hausmann, A. 2006. DNA-based identification of Lepidoptera larvae and plant meals from their gut contents. *Russian Entomological Journal, 15(4)*, pp.427-432.

Miller, S.E., Hausmann, A., Hallwachs, W. and Janzen, D.H. 2016. Advancing taxonomy and bioinventories with DNA barcodes. *Phil. Trans. R. Soc. B, 371(1702)*, p.20150339.

Minet, J. 1983. Etude morphologique et phylogenetique des organcs tympaniques des Pyraloidea. 1. Generalites et homologies. (Lep. Glossata). *Annales de la' Societi Enromologiquede France, 19*, pp.175-207.

Mondal, D.K. and Ghosh, S.K. 1997. Fauna of West Bengal, Part-7, Zoological Survey of India, pp. 91-532.

Mora, C., Tittensor, D.P., Adl, S., Simpson, A.G. and Worm, B. 2011. How many species are there on Earth and in the ocean? *PLoS biology, 9(8)*, p.e1001127.

Morinière, J., Hendrich, L., Hausmann, A., Hebert, P., Haszprunar, G. and Gruppe, A., 2014. Barcoding Fauna Bavarica: 78% of the Neuropterida fauna barcoded! *PLoS One, 9(10)*, p.e109719.

Moritz, C. and Cicero, C. 2004. DNA barcoding: promise and pitfalls. *PLoS biology, 2(10)*, p.e354.

Munch, K., Boomsma, W., Willerslev, E. and Nielsen, R. 2008. Fast phylogenetic DNA barcoding. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363(1512)*, pp.3997-4002.

Mutanen, M., Hausmann, A., Hebert, P.D., Landry, J.F., de Waard, J.R. and Huemer, P. 2012. Allopatry as a Gordian knot for taxonomists: Patterns of DNA barcode divergence in arctic-alpine Lepidoptera. *PLoS One, 7(10)*, p.e47214.

Mutanen, M., Kivelä, S.M., Vos, R.A., Doorenweerd, C., Ratnasingham, S., Hausmann, A., Huemer, P., Dincă, V., van Nieukerken, E.J., Lopez-Vaamonde, C. and Vila, R. 2016. Species-level para-and polyphyly in DNA barcode gene trees: strong operational bias in European Lepidoptera. *Systematic Biology, 65(6)*, pp.1024-1040.

Nakamura, A., Catterall, C.P., House, A.P., Kitching, R.L. and Burwell, C.J. 2007. The use of ants and other soil and litter arthropods as bio-indicators of the impacts of rainforest clearing and subsequent land use. *Journal of Insect Conservation, 11(2)*, pp.177-186.

Negi, A.S. 2002. The World Heritage Site, Nanda Devi Biosphere Reserve, Chamoli, India. Chief Wildlife Warden Uttaranchal, India. Shiva Offset Press, Dehra Dun.

New, T.R. and Samways, M.J. 2014. Insect conservation in the southern temperate zones: an overview. *Austral Entomology, 53(1)*, pp.26-31.

New, T.R. 2004. Moths (Insecta: Lepidoptera) and conservation: background and perspective. *Journal of Insect Conservation, 8(2-3)*, pp.79-94.

Niemelä, J., Langor, D. and Spence, J.R. 1993. Effects of Clear-Cut Harvesting on Boreal Ground-Beetle Assemblages (Coleoptera: Carabidae) in Western Canada. *Conservation biology, 7(3)*, pp.551-561.

Nogués-Bravo, D., Araújo, M.B., Romdal, T. and Rahbek, C. 2008. Scale effects and human impact on the elevational species richness gradients. *Nature, 453(7192)*, pp.216-219.

Nöske, N.M., Hilt, N., Werner, F.A., Brehm, G., Fiedler, K., Sipman, H.J. and Gradstein, S.R. 2008. Disturbance effects on diversity of epiphytes and moths in a montane forest in Ecuador. *Basic and Applied Ecology, 9(1)*, pp.4-12.

Novotny, V. & Weiblen, G. D. 2005.From communities to continents: beta-diversity of herbivorous insects. *Annal. Zool. Fenn. 42*, pp.463–475.

Novotny, V., Miller, S.E., Hulcr, J., Drew, R.A., Basset, Y., Janda, M., Setliff, G.P., Darrow, K., Stewart, A.J., Auga, J. and Isua, B. 2007. Low beta diversity of herbivorous insects in tropical forests. *Nature, 448(7154)*, pp.692-695.

Ødegaard, F. 2006. Host specificity, alpha- and beta-diversity of phytophagous beetles in two tropical forests in Panama. *Biodivers. Conserv. 15*, pp 83–105.

Ødegaard, F. 2000. How many species of arthropods? Erwin's estimate revised. *Biological Journal of the Linnean Society, 71(4)*, pp.583-597.

Olson, D.M. and Dinerstein, E. 2002. The Global 200: Priority ecoregions for global conservation. *Annals of the Missouri Botanical garden*, pp.199-224.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V., Underwood, E.C., D'amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C. and Loucks, C.J. 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience, 51(11)*, pp.933-938.

Õunap, E. 2010. *Systematic studies on the subfamily Sterrhinae (Lepidoptera: Geometridae)* (Doctoral dissertation, University of Tartu, Estonia).

Õunap, E., Javois, J., Viidalepp, J. and Tammaru, T. 2011. Phylogenetic relationships of selected European Ennominae (Lepidoptera: Geometridae). *European Journal of Entomology, 108(2)*, pp.267-273.

Õunap, E., Viidalepp, J. and Saarma, U. 2008. Systematic position of Lythriini revised: transferred from Larentiinae to Sterrhinae (Lepidoptera, Geometridae). *Zoologica Scripta*, *37*(4), pp.405-413.

Õunap, E., Viidalepp, J. and Saarma, U. 2005. Phylogenetic evaluation of the taxonomic status of *Timandra griseata* and *T. comae* (Lepidoptera: Geometridae: Sterrhinae). *European Journal of Entomology, 102(4)*,pp.607-615.

Pajni, H.R. and Walia, V.K. 1984a. On a new species of genus *Chloeres* Turner with comments on Indian species. *Geobios new Reports, 3*, pp.139-141.

Pajni, H.R. and Walia, V.K. 1984b.Taxonomic studies on Indian Geometridae I. Genus Chlorissa Stephens (Subfamily: Geometrinae). *Entomon, 9 (1)*, pp.39-46.

Pandit, M.K., Sodhi, N.S., Koh, L.P., Bhaskar, A. and Brook, B.W. 2007. Unreported yet massive deforestation driving loss of endemic biodiversity in Indian Himalaya. *Biodiversity and Conservation, 16(1)*, pp.153-163.

Papadopoulou, A., Bergsten, J., Fujisawa, T., Monaghan, M.T., Barraclough, T.G. and Vogler, A.P. 2008. Speciation and DNA barcodes: testing the effects of dispersal on the formation of discrete sequence clusters. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363(1506)*, pp.2987-2996.

Patterson, B.D. 1984. Mammalian extinction and biogeography in the southern Rocky Mountains. In: Nitecki MH (ed) Extinctions. *Univ Chicago Press, Chicago,* pp. 247-293

Paudel, P.K. and Šipoš, J. 2014. Conservation status affects elevational gradient in bird diversity in the Himalaya: A new perspective. *Global Ecology and Conservation*, *2*, pp.338-348.

Paudel, P.K., Šipoš, J. and Brodie, J.F. 2018. Threatened species richness along a Himalayan elevational gradient: quantifying the influences of human population density, range size, and geometric constraints. *BMC ecology*, *18*(1), p.6.

Pearce, J.L. and Venier, L.A. 2006. The use of ground beetles (Coleoptera: Carabidae) and spiders (Araneae) as bioindicators of sustainable forest management: a review. *Ecological indicators, 6(4)*, pp.780-793.

Pearson, D.L. and Cassola, F. 1992. World-wide species richness patterns of tiger beetles (Coleoptera: Cicindelidae): indicator taxon for biodiversity and conservation studies. *Conservation Biology, 6(3)*, pp.376-391.

Peters, M.K., Hemp, A., Appelhans, T., Behler, C., Classen, A., Detsch, F., Ensslin, A., Ferger, S.W., Frederiksen, S.B., Gebert, F. and Haas, M. 2016. Predictors of elevational biodiversity gradients change from single taxa to the multi-taxa community level. *Nature communications*, *7*, p.13736.

Pianka, E.R. 1966. Latitudinal gradients in species diversity: a review of concepts. *The American Naturalist, 100(910)*, pp.33-46.

Pimm, S.L. and Gittleman, J.L. 1992. Biological diversity: where is it? *Science*, *255*(5047), pp.940-941.

Pimm, S.L., Russell, G.J., Gittleman, J.L. and Brooks, T.M. 1995. The future of biodiversity. *Science, 269(5222)*, pp.347-350.

Pires, A.C. and Marinoni, L. 2010. DNA barcoding and traditional taxonomy unified through Integrative Taxonomy: a view that challenges the debate questioning both methodologies. *Biota Neotropica, 10(2)*, pp.339-346.

Pitkin, L.M. 1996. Neotropical Emerald moths: a review of the genera (Lepidoptera: Geometridae, Geometrinae). *Zoological Journal of the Linnean Society, 118(4)*, pp.309-440.

Pitkin, L.M. 2005. Moths of the Neotropical genera Ischnopteris, Stegotheca and Rucana (Lepidoptera: Geometridae: Ennominae). *Systematics and Biodiversity, 3(1)*, pp.13-96.

Pons, J., Barraclough, T.G., Gomez-Zurita, J., Cardoso, A., Duran, D.P., Hazell, S., Kamoun, S., Sumlin, W.D. and Vogler, A.P. 2006. Sequence-based species delimitation for the DNA taxonomy of undescribed insects. *Systematic biology, 55(4)*, pp.595-609.

Pramual, P., Wongpakam, K. and Adler, P.H. 2010. Cryptic biodiversity and phylogenetic relationships revealed by DNA barcoding of Oriental black flies in the subgenus Gomphostilbia (Diptera: Simuliidae). *Genome, 54(1)*, pp.1-9.

Prendini, L. 2005. Comment on "Identifying spiders through DNA barcodes". *Canadian Journal of Zoology, 83(3)*, pp.498-504.

Price, T., Zee, J., Jamdar, K. and Jamdar, N. 2003. Bird species diversity along the Himalaya: a comparison of Himachal Pradesh with Kashmir. *J. Bombay Nat. Hist. Soc*, *100*, pp.394-409.

Price, T.D., Mohan, D., Tietze, D.T., Hooper, D.M., Orme, C.D.L. and Rasmussen, P.C. 2011. Determinants of northerly range limits along the Himalayan bird diversity gradient. *The American Naturalist*, *178*(S1), pp. S97-S108.

Quasin, S. 2011. Systematics and Diversity of Spiders (Araneae) in Nanda Devi Biosphere Reserve, Uttarakhand, India (Doctoral dissertation, Saurashtra University, India).

Rahbek, C. 1995. The elevational gradient of species richness: a uniform pattern? *Ecography, 18(2)*, pp.200-205.

Rahbek, C. 2005. The role of spatial scale and the perception of large-scale species-richness patterns. *Ecology letters, 8(2)*, pp.224-239.

Rao, K.S., Nautiyal, S., Maikhuri, R.K. and Saxena, K.G. 2000. Management conflicts in the Nanda Devi biosphere reserve, India. *Mountain Research and Development, 20(4)*, pp.320-323.

Ratnasingham, S. and Hebert, P.D.N. 2007. BOLD: The Barcode of Life Data System (http://www. barcodinglife. org). *Molecular Ecology Resources, 7(3)*, pp.355-364.

Ratnasingham, S. and Hebert, P.D.N. 2013. A DNA-based registry for all animal species: The Barcode Index Number (BIN) system. *PloS one, 8(7)*, p.e66213.

Raupach, M.J., Hendrich, L., Küchler, S.M., Deister, F., Morinière, J. and Gossner, M.M. 2014. Building-up of a DNA barcode library for true bugs (Insecta: Hemiptera: Heteroptera) of Germany reveals taxonomic uncertainties and surprises. *PLoS One, 9(9)*, p.e106940.

Rawat, G.S., Adhikari, B.S. and Chandola, S.K. 2004. Manual for Rapid Inventory and Mapping of the Medicinal and Aromatic Plants in Uttaranchal. Uttaranchal Medicinal and Aromatic Plant Board.

Raxworthy, C.J., Ingram, C.M., Rabibisoa, N. and Pearson, R.G. 2007. Applications of ecological niche modeling for species delimitation: a review and empirical evaluation using day geckos (*Phelsuma*) from Madagascar. *Systematic biology, 56(6)*, pp.907-923.

Reed, T.M. 1979. A contribution to the ornithology of the Rishi Ganga valley and the Nanda Devi Sanctuary. *Bombay Nat. Hist. Soc.*, pp.275-282.

Regier, J.C., Zwick, A., Cummings, M.P., Kawahara, A.Y., Cho, S., Weller, S., Roe, A., Baixeras, J., Brown, J.W., Parr, C. and Davis, D.R. 2009. Toward reconstructing the evolution of advanced moths and butterflies (Lepidoptera: Ditrysia): an initial molecular study. *BMC Evolutionary Biology, 9(1)*, p.280.

Régnier, C., Achaz, G., Lambert, A., Cowie, R.H., Bouchet, P. and Fontaine, B. 2015. Mass extinction in poorly known taxa. *Proceedings of the National Academy of Sciences, 112(25)*, pp.7761-7766.

Reynolds, B.C. and Crossley Jr, D.A. 1997. Spatial variation in herbivory by forest canopy arthropods along an elevation gradient. *Environmental Entomology, 26(6)*, pp.1232-1239.

Ricketts, T.H., Daily, G.C., Ehrlich, P.R. and Fay, J.P. 2001. Countryside biogeography of moths in a fragmented landscape: biodiversity in native and agricultural habitats. *Conservation biology, 15(2)*, pp.378-388.

Ricklefs, R.E. and Schluter, D., eds. 1993. Species diversity in ecological communities: historical andgeographical perspectives. University of Chicago Press, Chicago. 575pp.

Rodgers, W.A., Panwar, H.S. and Mathur, V.B. 2000. Wildlife Protected Area Network in India: A Review. Wildlife Institute of India. 44pp.

Rohde, K. 1992. Latitudinal gradients in species diversity: the search for the primary cause. *Oikos*, pp.514-527.

Rose, H.S. 1986. A new species of the genus *Chlorissa* Stephens from North India (Geometridae: Lepidoptera). *J. Bombay nat. Hist. Soc., 82 (3)*, pp.614- 616.

Saitou, N. and Nei, M. 1987. The neighbor-joining method: a new method for reconstructing phylogenetic trees. *Molecular biology and evolution, 4(4)*, pp.406-425.

Salick, J., Anderson, D., Woo, J., Sherman, R.E., Cili, N., Yin, X.Z., Na, A. and Dorje, S. 2004. Tibetan ethnobotany and gradient analyses, menri (medicine mountains), eastern Himalayas. *The millennium ecosystem assessment. Bridging* *scales and epistemologies: linking local knowledge and global science in multi-scale assessments. Alexandria, Egypt*.

Samant, S.S. and Joshi, H.C. 2003. Floristic diversity, community patterns and changes of vegetation in Nanda Devi National Park. *Biodiversity Monitoring Expedition. Uttaranchal Forest Department*, pp.39-44.

Sanders, N.J. 2002. Elevational gradients in ant species richness: area, geometry, and Rapoport's rule. *Ecography, 25(1)*, pp.25-32.

Sanders, N.J., Moss, J. and Wagner, D. 2003. Patterns of ant species richness along elevational gradients in an arid ecosystem. *Global ecology and biogeography, 12(2)*, pp.93-102.

Sanyal, A.K. 2015. Diversity and distribution of moth assemblages along altitudinal gradient in gangotri landscape (Doctoral dissertation, Saurashtra University, India)

Sanyal, A.K., Dey, P., Uniyal, V.P., Chandra, K. and Raha, A. 2017. Geometridae Stephens, 1829 from different altitudes in Western Himalayan Protected Areas of Uttarakhand, India. (Lepidoptera: Geometridae). *SHILAP Revista de Lepidopterología, 45(177)*, pp.143-163.

Sanyal, A.K., Uniyal, V.P., Chandra, K. and Bhardwaj, M. 2011. Diversity and indicator species of moth (Lepidoptera: Heterocera) assemblages in different vegetation zones in Gangotri Landscape, Western Himalaya, India. *ENVIS Bulletin: Arthropods and their Conservation (Insects & Spiders), 14(1)*, pp.116-132.

Sanyal, A.K., Uniyal, V.P., Chandra, K. and Bhardwaj, M. 2013. Diversity, distribution pattern and seasonal variation in moth assemblages along altitudinal gradient in Gangotri landscape area, Western Himalaya, Uttarakhand, India. *Journal of Threatened Taxa, 5(2)*, pp.3646-3653.

Sathyakumar, S. 1993. Status of mammals in Nanda Devi National Park. *Scientific and Ecological Expedition to Nanda Devi. A Report. Dehradun, Wildlife Institute of India*, pp.5-15.

Sathyakumar, S. 2004. Conservation status of Mammals and Birds in Nanda Devi National Park: An assessment of changes over two decades. *Biodiversity Monitoring Expedition Nanda Devi*, pp.1-14.

Schelhas, J. and Greenberg, R.S. eds. 1996. *Forest patches in tropical landscapes*. Island press.

Schlick-Steiner, B.C., Steiner, F.M., Seifert, B., Stauffer, C., Christian, E. and Crozier, R.H. 2010. Integrative taxonomy: a multisource approach to exploring biodiversity. *Annual review of entomology*, *55*, pp.421-438.

Schmidt, S., Schmid-Egger, C., Morinière, J., Haszprunar, G. and Hebert, P.D.N. 2015. DNA barcoding largely supports 250 years of classical taxonomy: identifications for Central European bees (Hymenoptera, Apoidea partim). *Molecular Ecology Resources, 15(4)*, pp.985-1000.

Schulze, C.H. 2000. Auswirkungen anthropogener Störungen auf die Diversität von Herbivoren —Analyse von Nachtfalterzönosen entlang von Habitatgradienten in Ost-Malaysia. (Doctoral Dissertation, University of Bayreuth, Germany).

Scoble, M.J. and Hausmann, A. [update 2007]: Online list of valid and nomenclaturally available names of the Geometridae of the World. [http://www.lepbarcoding.org/cl_geometridae.php]

Scoble, M.J., Gaston, K.J. and Crook, A. 1995. Using taxonomic data to estimate species richness in Geometridae. Utilizando datos taxonómicos para estimar la riqueza de especies en Geometridae. *Journal of the Lepidopterists' Society., 49(2)*, pp.136-147.

Scotland, R., Hughes, C., Bailey, D. and Wortley, A. 2003. The Big Machine and the much-maligned taxonomist. *Systematics and Biodiversity, 1(2)*, pp.139-143.

Shah, S.K., Mitra, B., Das, A. and Mishra, P. 2017. A Report on Moth Fauna (Insecta: Lepidoptera) in Neora Valley National Park, West Bengal, India. *Journal of Environment and Sociobiology, 14(2)*, pp.179-186.

Shankaran, R. 1993. An ornithological survey of Nanda Devi National Park. *Scientific and ecological expedition Nanda Devi*, *2*.

Sharma, E., Tse-ring, K., Chettri, N. and Shrestha, A. 2008, November. Biodiversity in the Himalayas–trends, perception and impacts of climate change. In *Proceedings of the International Mountain Biodiversity Conference Kathmandu*.

Sihvonen, P. 2003. Diversity and classification of the Scopulini (Lepidoptera: Geometridae, Sterrhinae) (Doctoral dissertation, University of Helsinki, Finland).

Sihvonen, P. 2005. Phylogeny and classification of the Scopulini moths (Lepidoptera: Geometridae, Sterrhinae). *Zoological Journal of the Linnean Society*, *143*(4), pp.473-530.

Sihvonen, P., Mutanen, M., Kaila, L., Brehm, G., Hausmann, A. and Staude, H.S. 2011. Comprehensive molecular sampling yields a robust phylogeny for geometrid moths (Lepidoptera: Geometridae). *PloS one, 6(6)*, p.e20356.

Silori, C.S. 2004. Socio-economic and ecological consequences of the ban on adventure tourism in Nanda Devi Biosphere Reserve, western Himalaya. *Biodiversity & Conservation, 13(12)*, pp.2237-2252.

Silva-Brandao, K.L., Lyra, M.L. and Freitas, A.V. 2009. Barcoding Lepidoptera: current situation and perspectives on the usefulness of a contentious technique. *Neotropical entomology, 38(4)*, pp.441-451.

Simpson, G.G. 1943. Mammals and the nature of continents. *American Journal of Science, 241(1)*, pp.1-31.

Singh, N. and Ranjan, R. 2016. Additions to the moth fauna of Dalma Wildlife Sanctuary, Jharkhand (India). *Rec. Zool. Surv. India, 116(4)*, pp.323-336.

Sites Jr, J.W. and Marshall, J.C. 2003. Delimiting species: A Renaissance issue in systematic biology. *Trends in Ecology & Evolution, 18(9)*, pp.462-470.

Sites Jr, J.W. and Marshall, J.C. 2004. Operational criteria for delimiting species. *Annu. Rev. Ecol. Evol. Syst.*, *35*, pp.199-227.

Sivasankaran, K., Gnanasekaran, S., Parandhaman, D. and Ignacimuthu, S. 2011. Diversity of Noctuid moths (Lepidoptera: noctuidae) in TamilNadu part of Western Ghats (Nilgiris biosphere and Kodaikanal hills), *India. Elixir. Bio. Diver, 38*, pp.4131-4134.

Slade, E.M., Merckx, T., Riutta, T., Bebber, D.P., Redhead, D., Riordan, P. and Macdonald, D.W. 2013. Life-history traits and landscape characteristics predict macro-moth responses to forest fragmentation. *Ecology, 94(7)*, pp.1519-1530.

Smetacek, P. 1994. The hawkmoths (Lepidoptera: Sphingidae) of Kumaon, N. India: A probable cause of faunal drift. *Records of the Zoological Survey of India, Calcutta. Occasional papers 156*, pp.56.

Smetacek, P. 2004. *Corymica* Walker, Lepidoptera: Geometridae, in the Kumaon Himalaya, with the description of a new form of *C. deducata caustolomaria* Moore. *J. Bombay nat. Hist. Soc., 101 (1)*, pp.173-176.

Smetacek, P. 2008. Moths recorded from different elevations in Nainital district, Kumaon Himalaya, India. *Bionotes, 10(1)*, pp.5-15.

Smith, M.A., Woodley, N.E., Janzen, D.H., Hallwachs, W. and Hebert, P.D.N. 2006. DNA barcodes reveal cryptic host-specificity within the presumed polyphagous members of a genus of parasitoid flies (Diptera: Tachinidae). *Proceedings of the*

National Academy of Sciences of the United States of America, 103(10), pp.3657-3662.

Soberón, J.and LlorenteB, J.1993. The use of species accumulation functions for the prediction of species richness. *Conservation biology, 7(3)*, pp.480-488.

Sondhi, Y. and Sondhi, S. 2016. A partial checklist of moths (Lepidoptera) of Dehradun, Mussoorie and Devalsari in Garhwal, Uttarakhand, India. *Journal of Threatened Taxa, 8(5)*, pp.8756-8776.

Spehn, E.M. and Korner, C. eds. 2009. *Data mining for global trends in mountain biodiversity*. CRC Press.

Stevens, G.C. 1992. The elevational gradient in altitudinal range: an extension of Rapoport's latitudinal rule to altitude. *The American Naturalist, 140(6)*, pp.893-911.

Stork, N.E. 1997. Measuring global biodiversity and its decline. *Biodiversity II: Understanding and protecting our biological resources*, *41*, pp.41-68.

Strutzenberger, P., Brehm, G. and Fiedler, K. 2012. DNA barcode sequencing from old type specimens as a tool in taxonomy: a case study in the diverse genus *Eois* (Lepidoptera: Geometridae). *PLoS One, 7(11)*, p.e 49710.

Stüning, D. and Walia, V.K. 2009. The genus *Astygisa* Walker, 1864 in India, with description of a new species from Western Himalaya (Lepidoptera: Geometridae: Ennominae). *Tinea, 21 (1),* pp.9-22

Summerville, K.S. and Crist, T.O. 2004. Contrasting effects of habitat quantity and quality on moth communities in fragmented landscapes. *Ecography, 27(1)*, pp.3-12.

Summerville, K.S. 2005. Functional groups and species replacement: testing for the effects of habitat loss on moth communities. *Journal of the Lepidopterists' Society*, *58*, pp.114-117.

Summerville, K.S., Boulware, M.J., Veech, J.A. and Crist, T.O. 2003. Spatial variation in species diversity and composition of forest Lepidoptera in eastern deciduous forests of North America. *Conservation Biology, 17(4)*, pp.1045-1057.

Summerville, K.S., Ritter, L.M. and Crist, T.O. 2004. Forest moth taxa as indicators of lepidopteran richness and habitat disturbance: a preliminary assessment. *Biological Conservation, 116(1)*, pp.9-18.

Tak, P.C. and Kumar, G. 1987. Wildlife of Nanda Devi National Park: an update. *Indian journal of Forestry, 10(13)*, pp.184-190.

Tak, P.C. and Lamba, B.S. 1984. Field observations on abundance of some smaller mammals at Nanda Devi National Park. *Indian journal of forestry,10*, pp.184-190.

Tattersfield, P., Warui, C.M., Seddon, M.B. and Kiringe, J.W. 2001. Land-snail faunas of afromontane forests of Mount Kenya, Kenya: ecology, diversity and distribution patterns. *Journal of Biogeography, 28(7)*, pp.843-861.

Tautz, D., Arctander, P., Minelli, A., Thomas, R.H. and Vogler, A.P. 2003. A plea for DNA taxonomy. *Trends in Ecology & Evolution, 18(2)*, pp.70-74.

Terborgh, J. and Weske, J.S. 1975. The role of competition in the distribution of Andean birds. *Ecology, 56(3)*, pp.562-576.

Terborgh, J. 1977. Bird species diversity on an Andean elevational gradient. *Ecology, 58(5)*, pp.1007-1019.

Terborgh, J. 1985. The role of ecotones in the distribution of Andean birds. *Ecology, 66(4)*, pp.1237-1246.

Thomas, J.A., Telfer, M.G., Roy, D.B., Preston, C.D., Greenwood, J.J.D., Asher, J., Fox, R., Clarke, R.T. and Lawton, J.H. 2004. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science*, *303*(5665), pp.1879-1881.

Uniyal, V.P. 2004. Butterflies of Nanda Devi National Park-a world heritage site. *Indian Forester, 130(7)*, pp.800-804.

van Klink, R., van der Plas, F., van Noordwijk, C.G.E., Wallis DeVries, M.F. and Olff, H. 2015. Effects of large herbivores on grassland arthropod diversity. *Biological Reviews, 90(2)*, pp.347-366.

Veldman, S., Otieno, J., Gravendeel, B., van Andel, T. and de Boer, H. 2014. Conservation of endangered wild harvested medicinal plants: use of DNA barcoding. *Nov. Plant Bioresour. Appl. Food Med. Cosmet.*, pp.81-88.

Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. 1997. Human domination of Earth's ecosystems. *Science, 277(5325)*, pp.494-499.

Wahlberg, N., Snäll, N., Viidalepp, J., Ruohomäki, K. and Tammaru, T. 2010. The evolution of female flightlessness among Ennominae of the Holarctic forest zone (Lepidoptera, Geometridae). *Molecular Phylogenetics and Evolution, 55(3)*, pp.929-938.

Walia, V.K. 1988. Studies on the Geometridae (Lepidoptera) of North-West India - Subfamily Geometrinae. *Res. Bull. (Sci.) Pb. Univ., 39 (1/2)*, pp.101-107.

Walia, V.K. 2005. Insecta: Lepidoptera: Geometridae (Moths). *Zoological Survey of India, Fauna of Western Himalaya, 2*, pp.181-190.

Walia, V.K. and Anju 2005. A new species of *Chlororithra* Butler from Himachal Pradesh in India, with comments on its taxonomic status (Lepidoptera: Geometridae: Geometrinae). *Pol. Pis. Ent., 74 (1),* pp.73-80.

Walia, V.K. and Pajni, H.R. 1987. Studies on the Geometridae (Lepidoptera) of North West India - Subfamily Scopulinae. *Res. Bull. (Sci.) Pb. Univ., 38 (3-4)*, pp.9-14.

Wallace, A.R. 1876. The geographical distribution of animals, with a study of the relations of living and extinct faunas as elucidating the past changes of the earth's surface, 2 volumes. Macmillan, London.

Wallace, A.R. 1878. Tropical nature and other essays. Macmillan, New York.

Ward, R.D., Zemlak, T.S., Innes, B.H., Last, P.R. and Hebert, P.D.N. 2005. DNA barcoding Australia's fish species. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *360(1462)*, pp.1847-1857.

Warren, S.D., Harper, K.T. and Booth, G.M. 1988. Elevational distribution of insect pollinators. *American Midland Naturalist*, pp.325-330.

Warren, W. 1889. On Lepidoptera collected by Major Yerbury in Western India in 1886 and 1887. *Proceeding of the scientific meetings of the Zoological Society, London*, pp. 292-339

Webb, J.M., Jacobus, L.M., Funk, D.H., Zhou, X., Kondratieff, B., Geraci, C.J., DeWalt, R.E., Baird, D.J., Richard, B., Phillips, I. and Hebert, P.D.N. 2012. A DNA barcode library for North American Ephemeroptera: progress and prospects. *PloS one, 7(5)*, p.e38063.

Wheeler, Q.D. 2004. Taxonomic triage and the poverty of phylogeny. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *359(1444)*, pp.571-583.

Wheeler, Q.D. 2007. Invertebrate systematics or spineless taxonomy. *Zootaxa, 1668(1)*, pp.11-18.

Whittaker, R.H. and Niering, W.A. 1965. Vegetation of the Santa Catalina Mountains, Arizona: a gradient analysis of the south slope. *Ecology*, *46(4)*, pp.429-452.

Whittaker, R.H. 1952. A study of summer foliage insect communities in the Great Smoky Mountains. *Ecological monographs, 22(1)*, pp.1-44.

Whittaker, R.H. 1960. Vegetation of the Siskiyou mountains, Oregon and California. *Ecological monographs, 30(3)*, pp.279-338.

Wiens, J.J. and Penkrot, T.A. 2002. Delimiting species using DNA and morphological variation and discordant species limits in spiny lizards (*Sceloporus*). *Systematic biology, 51(1)*, pp.69-91.

Wiens, J.J. 1998. Combining data sets with different phylogenetic histories. *Systematic Biology, 47(4)*, pp.568-581.

Wiens, J.J., Chippindale, P.T. and Hillis, D.M. 2003. When are phylogenetic analyses misled by convergence? A case study in Texas cave salamanders. *Systematic Biology, 52(4)*, pp.501-514.

Wilson, E.O. 1985. The biological diversity crisis. *BioScience, 35(11)*, pp.700-706.

Wilson, E.O. 2000. A global biodiversity map. *Science, 289 (5488),* p.2279.

Wilson, E.O. 2002. *The future of life*. Vintage. 256pp.

Wilson, E.O. 2004. Taxonomy as a fundamental discipline. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *359(1444)*, pp.739-739.

Winfree, R., Bartomeus, I. and Cariveau, D.P. 2011. Native pollinators in anthropogenic habitats. *Annual Review of Ecology, Evolution, and Systematics*, *42*, pp.1-22.

Wong, L.L., Peatman, E., Lu, J., Kucuktas, H., He, S., Zhou, C., Na-Nakorn, U. and Liu, Z. 2011. DNA barcoding of catfish: species authentication and phylogenetic assessment. *PLoS One, 6(3)*, p.e17812.

Wright, D.H. and Reeves, J.H. 1992. On the meaning and measurement of nestedness of species assemblages. *Oecologia, 92(3)*, pp.416-428.

Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y.U.N. and Wilkes, A. 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. *Conservation Biology, 23(3)*, pp.520-530.

Yamamoto, S. and Sota, T. 2007. Phylogeny of the Geometridae and the evolution of winter moths inferred from a simultaneous analysis of mitochondrial and nuclear genes. *Molecular phylogenetics and evolution, 44(2)*, pp.711-723.

Yang, Z., Landry, J.F. and Hebert, P.D.N. 2016. A DNA Barcode Library for North American Pyraustinae (Lepidoptera: Pyraloidea: Crambidae). *PloS one, 11(10)*, p.e0161449.

Yela, J.L. and Holyoak, M., 1997. Effects of moonlight and meteorological factors on light and bait trap catches of noctuid moths (Lepidoptera: Noctuidae). *Environmental Entomology, 26(6)*, pp.1283-1290.

Yoder, A.D., Olson, L.E., Hanley, C., Heckman, K.L., Rasoloarison, R., Russell, A.L., Ranivo, J., Soarimalala, V., Karanth, K.P., Raselimanana, A.P. and Goodman, S.M. 2005. A multidimensional approach for detecting species patterns in Malagasy vertebrates. *Proceedings of the National Academy of Sciences*, *102*(suppl 1), pp.6587-6594.

Young, C.J. 2006. Molecular relationships of the Australian Ennominae (Lepidoptera: Geometridae) and implications for the phylogeny of the Geometridae from molecular and morphological data. *Zootaxa, (1264)*, pp.1-147.

Zahiri, R., Lafontaine, J.D., Schmidt, B.C., Zakharov, E.V. and Hebert, P.D.N. 2014. A transcontinental challenge—a test of DNA barcode performance for 1,541 species of Canadian Noctuoidea (Lepidoptera). *PloS one, 9(3)*, p.e92797.

Zahiri, R., Lafontaine, J.D., Schmidt, B.C., Zakharov, E.V. and Hebert, P.D.N. 2017. Probing planetary biodiversity with DNA barcodes: The Noctuoidea of North America. *PloS one, 12(6)*, p.e0178548.

Zenker, M.M., Rougerie, R., Teston, J.A., Laguerre, M., Pie, M.R. and Freitas, A.V. 2016. Fast census of moth diversity in the Neotropics: a comparison of field-assigned morphospecies and DNA barcoding in tiger moths. *PloS one, 11(2)*, p.e0148423.

Zhang, A.B., He, L.J., Crozier, R.H., Muster, C. and Zhu, C.D. 2010. Estimating sample sizes for DNA barcoding. *Molecular Phylogenetics and Evolution, 54(3)*, pp.1035-1039.

Zhou, X., Adamowicz, S.J., Jacobus, L.M., DeWalt, R.E. and Hebert, P.D.N. 2009. Towards a comprehensive barcode library for arctic life-Ephemeroptera, Plecoptera, and Trichoptera of Churchill, Manitoba, Canada. *Frontiers in zoology, 6(1)*, p.30.

Zhou, X., Robinson, J.L., Geraci, C.J., Parker, C.R., Flint Jr, O.S., Etnier, D.A., Ruiter, D., DeWalt, R.E., Jacobus, L.M. and Hebert, P.D.N. 2011. Accelerated construction of a regional DNA-barcode reference library: caddisflies (Trichoptera) in the Great Smoky Mountains National Park. *Journal of the North American Benthological Society, 30(1)*, pp.131-162.