DIVERSITY AND STRUCTURE OF BUTTERFLY ASSEMBLAGES ALONG ALTITUDINAL GRADIENT IN TONS VALLEY, WESTERN HIMALAYA

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LIST OF ABBREVIATIONS

ANOSIM: Analysis of Similarity

ANOVA: Analysis of Variance

BF: Broadleaf Forest

***Ca*:** calculated approx

CAF: Conifer and Alpine Forest

DEM: Digital Elevation Model

FRI: Rain Forest Research Institute

MDE: Mid Domain Effect

MDS: Multidimensional Scaling

MRSF: Mixed Riparian and Scrub Forest

NDVI: Normalized Difference in Vegetation Index

NP: National Park

PA: Protected Area

PF: Pine Forest

SAR: Space Area Relationship

SIMPER: Similarity Percentages

WII: Wildlife Institute of India

WLS: Wildlife Sanctuary

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Summary

1. Introduction

As biodiversity on earth is not uniformly distributed, it is required to know the pattern of distribution to identify areas important for conservation. A few areas are highly rich in biodiversity due to several factors. Himalaya, world largest mountain complex and a meeting point to major biogeographical realms is a global biodiversity hotspot and important for conservation. In recent decades, Himalayan ecosystems have been under large threats due to various developmental activities that have led to fragmentation and degradation of remnant forests. As it is impossible to fully inventorize biodiversity in any area, utility of focal taxa has become quite evident within last two decade literature. Assuming that carefully selected focal taxa can serve as a proxy for overall biodiversity. Conservation biologists have proposed to include insects in planning conservation. Insects are a major proportion of animal species (about 60% of all described species) on earth. Several taxa have been tested for their utility as indicators. Butterflies have been suggested as potential indicator of habitat fragmentation and disturbance. By focusing on one biodiversity indicator taxa a large amount of money and time can be saved. Butterflies are also serves as surrogates for other taxon as well. Here, I have examined the distribution pattern of butterflies along elevation gradient along the Tons river valley in the western Himalaya. Two protected areas lies with current study area *viz*. Govind National Park and Govind Wildlife sanctuary and the rest of the area lies within any formal category of protection. The area represents high elevational variation (900 – 6316 m) and a gradient of disturbance regimes and from natural Himalayan forests to highly disturbed villages and agricultural lands. Current study document patterns and processes involved in shaping diversity and distribution of butterflies along an elevation gradient in Tons valley.

2. Inventory and Conservation of Butterflies in Tons Valley

Lepidoptera (butterflies and moths) is a diverse order of class Insecta with about 180,000 described species, more than 10% of all organisms described. Whereas, *ca* 17,500 species of butterflies have so far been reported from the world. The study

deals with inventorization and systematic representation of butterflies recorded in Tons valley. The study began with defining the systematic position of the butterflies and reviewing the available taxonomic literature. It also highlights past faunistic studies on butterflies in India, Indian-subcontinent and major biogeographical regions. This study provides a baseline faunistic inventory of the diversity of butterflies including description of general identification features, their relation to classification and subfamilies and genera of butterflies sampled from the Tons valley during more than four years of observations from April 2008 to October 2012. A total of 189 species representing 98 genera in 5 families were recorded in Tons valley during entire sampling period. Status of butterflies in Indian Wildlife (Protection) Act, 1972 is also discussed, to know 'rare' and 'very rare' species.

3. Diversity and Composition of Butterfly Assemblages

The study deals with comparison of diversity and composition of butterfly assemblages in four habitat types that were sampled in Tons valley. Four butterfly habitats were sampled *viz*. mixed riparian and scrub forest, pine forest, broad leaved forest, conifer and alpine forest. Butterfly species richness, vegetation and microclimatic data was collected on a total of 96 transects between April 2009 - March 2010. A total of 8,432 individuals of butterflies were recorded representing 5 families, 92 genera and 159 species. The pooled accumulation curve reached an asymptote for all the estimators, indicating that sampling was almost complete at regional level. Using Chao1 and Jacknife2 the species richness estimate was 163 ± 4.88 (SD) and 166 species respectively, for the complete dataset. The ratio of observed to estimated (Chao1 and Jacknife2) suggested that inventory was almost complete at regional level (Inventory completeness = 96%). Comparison of different habitats showed that on average, species and composition of same habitat type was much similar within than among different habitat types. Analysis showed that most difference occurred between mixed riparian scrub forest and pine forest and mixed riparian scrub forest and conifer and alpine forest. Eighteen species contributed about 50% of the dissimilarities observed between sites of mixed riparian scrub forest and pine forest. Most differences in family composition occurred between sites of pine forest and mixed riparian and scrub forest and the family Lycaenidae and

Nymphalidae contributing mostly in group differences between pine forests and mixed riparian and scrub forest.

4. Pattern of Butterfly Species Richness along Elevation Gradient

This part of the study deals with the pattern of butterfly species richness along an elevation gradient (900 – 3500 m) in Tons valley, Western Himalaya. First the elevational pattern of species richness and role of geometric constraints and area were examined. Then magnitude and direction of each of the environmental variables on species richness of butterflies were investigated. Further, the validity of Rapoport's rule was tested in butterflies of western Himalaya.

A total of 174 species of butterflies were recorded over the course of the study during April 2010 – August 2011, sampled across 520 transects at 26 sampling sites. Overall inventory completeness was 95% considering highest estimate (Chao1) of species richness. In general bird species richness was highest in 1200 – 2100 m elevation while lowest in between 2900 – 3500 m elevation zones of the study area. Thus butterfly species richness pattern along elevation gradient falls within general pattern of an initial increase, followed by a peak and then a decline with no further increase. Support for mid-domain effect was found. The curves were nearly symmetrical and thus not differed from mid-domain null predictions. A poor but support for Rapoport's rule was found for butterflies of Tons valley. Butterfly species richness was found to be significantly correlated to all the environmental variables. Among climate species richness increased with variable that described water availability (precipitation) and energy related parameter (temperature). Elevation and NDVI were also showed positive relationship with butterfly species richness. At local plot level, environmental variables such as, temperature, plant species richness, shrub and herb density and canopy cover were major positive predictors of butterfly species richness and abundance while elevation, relative humidity and disturbance (fire and livestock abundance) variables showed negative relation. Study also found support for 'water energy balance' hypothesis of species richness gradients which states that the temperature limits the number of species at higher latitude/ altitude and rainfall determines species richness at warmer lower latitudes/ altitudes. Butterfly species richness is also found to be a function of nearly same set of environmental variables (temperature, precipitation and habitat heterogeneity) in Tons valley.

5. Phenology and Seasonality of Butterflies

Phenological and seasonal pattern in butterfly distribution were examined from two locations in the Tons valley *viz.* 'Kedarkanta' and 'Istragad' watersheds during January 2011 - December 2011. A total of 10,445 individuals belonging to 131 butterfly species in 74 genera and five families were recorded during the study period. In general the peak in diversity of butterflies was observed at the end of summer season (dry season) with a second peak in Monsoon season (wet season), while abundance was recorded highest at the end of wet season. The most abundant butterfly family was Nymphalidae with 6,021 individuals during the year, accounting 58% of the total individuals of butterflies recorded in total during the complete year. Family Nymphalidae also accounted for highest number of species occurred every month during the year. Butterfly composition was found to be significantly variable among summer, monsoon and winter seasons, as natural forest sites grouped together and disturbed sites grouped separately. Butterflies were seen in congruence at sites, where water was available in the landscape at the end of dry season.

6. Rapid Assessment of Butterflies: Implications for Conservation

As time and money is limited, explicit, cost-effective, quick and appropriate methods are needed to assist conservation planners and managers for making quick decisions. This is very much required for the areas of biodiversity hotspots like, Himalaya, which are facing rapid biodiversity loss due to habitat degradation and fragmentation. The appeal of using indicator taxa is one of options. By focusing on one particular set of species in a location rather than all of the species, considerable time and limited resources can be saved.

Potential utility of rapid assessment studies using butterflies was tested for assessing quick changes in the habitat as quick and cost effective biodiversity monitoring tool. A 20 days rapid survey was conducted during March - April 2010. The study was able to sample 41.7% (79 species) of all species that were found during complete three year period (2009 - 2012). The survey was continued till June 2010 (45 sampling days) and the inventory completeness was 65%. This degree of inventory completeness can be used in taking conservation decisions regarding habitat change and to monitor diversity in other insect groups. To select and prioritize areas

for biodiversity conservation, rapid assessments of indicator taxa can be an important, helpful and cost effective tool, in time constrained sampling efforts. Butterflies constitute a model system for such large sample long term monitoring studies to test quick biodiversity surveys.

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CHAPTER 1

INTRODUCTION

1.1 Himalaya: Biodiversity Hotspot

The Himalaya are part of the world largest mountain complex and rich repository of unique biodiversity due to a buffer to three major realms *viz.* Oriental, Palearctic and Ethiopian (Mani, 1974). Himalayas cover *ca* 12% of geographical area of India. Himalayan ecosystems faces great conservation challenges under the mounting threats of ill-planned developmental activities, unlimited resource use and uncontrolled grazing by domestic livestock (Kala and Rawat, 1999) and has led to the degradation of remaining wildlife habitats. In recent decades, urbanization, commercial activities and excessive resource use has reduced most natural forest habitats of this area to degraded remnants.

Ongoing climate change over succeeding decades will likely have negative cascading effects on river flows, groundwater recharge, natural hazards, and biodiversity; ecosystem composition, structure, and function; and human livelihoods (Nijssen et al., 2001; Parmesan, 2006; Bates et al., 2008; Ma, et al., 2009). Changes in hydrology can influence biodiversity in a variety of ways; moisture availability governs physiology, metabolic and reproductive processes, phenology, tree-line positions, and the geographic distribution of freshwater and wetland habitats (Holtmeier and Broll, 2005; Parmesan 2006; Bates et al., 2008; He et al., 2008). Potential ecological cascading effects of quick climate change include secondary extinctions triggered by losses of key species in the alpine ecosystems. The endemic-rich Himalayas include many plant species that may not respond successfully to projected rates and scale of climate change (Mutke and Barthlott, 2005; Salick et al., 2009). It is highly likely that climate change will affect the composition and distribution of vegetation types throughout the Greater Himalayas (Jianchu et al., 2008). Within mountain regions, species richness decreases with increasing elevation, but endemism often increases, due partly to topographic isolation (Körner, 2004; Salick et al., 2004), which lead to loss of biodiversity.

The Convention on Biological Diversity (CBD) in its sixth conference in 2002 resolved to significantly reduce biodiversity loss by 2010 at the global, regional and national levels in an effort to alleviate poverty and benefit the Earth (CBD, 2002).

Because of large threats due to development factors, modern studies of biodiversity are critical for conservation of the remaining forests patches in the Himalayas. To reduce biodiversity loss it is necessary to monitor the important areas on a certain timely basis. To fully inventorize or monitor biodiversity in any requires nearly impossible amounts of time, effort, and money (Lawton et al., 1998). To avoid the logistically impossible task of sampling entire communities, past efforts have concentrated on performing rapid inventories (Roberts, 1991), utilizing focal taxa approach (Noss, 1990; Pearson and Cassola, 1992; Pearson, 1994), and developing extrapolation techniques to estimate diversity in different habitats (Colwell and Coddington, 1994; Hammond, 1994; Kiester et al., 1996). Among insects butterflies are such a taxa that have been used as model organism in various field of biological research.

1.2 Role of Insects in Conservation Planning

Invertebrates dominate among multicellular organisms in terms of richness, abundance and often biomass; for example, more than 100,000 species of terrestrial arthropods occupy a single hectare of rain forest in the western Amazon (Erwin et al., 2004) together and over 25% of all described species. Estimates of the number of described insects in the world vary from about 720,000 (May, 2000) through 751,000 (Tangley, 1997), 800,000 (Nieuwenhuys, 2008), 948,000 (Brusca and Brusca, 2003), 950,000 (IUCN, 2004) to more than 1 million (Myers, 2001a). Estimates for the total numbers of insects vary widely from around 2 million (Nielsen and Mound, 2000), 5–6 million (Raven and Yeates, 2007) to around 8 million (Hammond, 1995; Groombridge and Jenkins, 2002). Calculations based on extrapolations from species of Coleoptera and Lepidoptera in New Guinea by Novotny et al. (2002) produced a figure of between 3.7 and 5.9 million for the total number of arthropods in the world. In order to know how and where to protect biodiversity, it is imperative that we learn more about the diversity of terrestrial arthropods, which may comprise 80% or more of the global diversity but have been too often neglected by the resource managers and conservation planners (Wilson, 1988; Kremen et al., 1993; Colwell and

Coddington, 1994; New, 1999; Zamin et al., 2010). Reflecting this neglect, the World Conservation Union's (IUCN) Red List of Threatened Species (IUCN, 2010) lists less than 0.5% of all described arthropods worldwide, when most vertebrates have already been assessed. Of all the species evaluated, the endangered categories occupy similar, if not higher proportions than comparable numbers for vertebrates. Even if such proportions are inflated by the evaluation of species thought a priori to be endangered, the increases are countered by the vast numbers of undescribed species that mostly have restricted distributions and have not yet been collected or diagnosed (Gaston, 1994).

Conservation biologists propose to include insect diversity in planning conservation in tropical forests (Kremen et al., 1993; Meyers et al., 2000; Clark and May, 2002; Leather et al., 2008). Insects are appropriate because they represent a major proportion of animal species in tropical forests (Godfray et al., 1999; Putz et al., 2001; Lewis and Basset, 2007). Assuming that carefully selected focal taxa can serve as a proxy for overall biodiversity (Kerr et al., 2000; Uniyal et al., 2007). Several insect taxa have been tested for their utility as indicators in various ecosystems at multiple spatial scales (McGeoch, 1998).

1.3 Butterflies as Bio-indicators and Model Organism

There are well over one million known species of insects in the world and some experts estimate that there might be as many as 10 million. Lepidoptera is a very large order that includes some of the most beautiful species and some of the most economically important pests in the class Insecta. Many schemes of classification exist for the Lepidoptera. Some divide the order into five suborders. A more informal method divides the order into the Microlepidoptera and the Macrolepidoptera according to average body size of the included species. Another informal scheme divides the Lepidoptera into moths, butterflies, and skippers (Pedigo, 1996). Lepidoptera are beneficial as pollinators, silk producers, indicators of environmental quality, and are appreciated for their aesthetic value. The holometabolous life history of butterflies reveals that Lepidoptera can tolerate a wide range of environmental influences and they are highly sensitive to changes in temperature, humidity and light levels (Vane-Wright and Ackery, 1984; Collins and Thomas, 1989; Kremen, 1992; Chey et. al., 1997). Tropical butterfly assemblages in particular are generally diverse,

with many habitats having large numbers of endemic species, most of which are dependent to some extent on forest ecosystems (Sutton and Collins, 1991). Butterflies fulfill many of the criteria proposed to define useful study groups: they have short generation times, are day-flying, diverse, and easily identifiable (Hill et al., 1992; Spitzer et al., 1993; Beccaloni and Gaston, 1995). Furthermore, butterfly taxonomy, distribution, and natural history are better described than for any other insect taxon (Gilbert and Singer, 1975; Van-Wright and Ackery, 1984; Brown, 1997). This is in contrast to other insect groups in the tropics, where the taxonomy is often poorly known, and morpho-species are often used instead. Butterflies are closely associated with other resource and ecosystem characteristics (Brown, 1991) and are often proposed as bioindicators of forest health and surrogate taxa for various biodiversity groups (Sisk et al., 1994; Hayes et al., 2009). Butterflies have been suggested due to their role as indicators in conservation planning (Ehrlich and Murphy, 1987; Brown, 1991; Kremen et al., 1993; Nelson and Andersen, 1994; DeVries et al., 1997). They also have great potential as indicators to monitor ecosystem properties and local habitats because of their rapid response to change in local vegetation and climate conditions (Kremen, 1992; Murphy and Weiss, 1992; Parmesan, 1996).

Furthermore, butterflies have been suggested as potential bio-indicators of disturbance and fragmentation in both tropical and temperate regions since they demonstrate the most conspicuous responses to changes in environmental conditions. (Gilbert, 1984; Kremen et al., 1993; Spitzer et al., 1997). The dependence of the larval stages on a specific host plant, and the adults role as pollinators for other plants, link butterflies closely to the diversity and health of their habitats (Blau, 1980; Kato, 1996; Ghazoul, 1997). For example host-plant butterfly larvae specificity means that a disturbance-related reduction in hosts will result in a clear reduction in the number of specific species of butterfly, with extinction the worst-case scenario (Koh et al., 2004a, 2004b). Hammond and Miller (1998) conclude that the biodiversity of butterflies is linked to the ecosystem by influencing nutrient cycling, plant population dynamics, and predator prey population dynamics. Butterflies are also very sensitive to changes in temperature, humidity, and light levels, parameters often affected by habitat disturbance (Wood and Gillman, 1998).

However the value of using butterflies as indicators has also been criticized and questions have been raised due to their complexity (i.e. vulnerability to disturbance at different life cycle stages); bias towards the visibility of adults, the most active stage of life and the difficulties of monitoring such highly mobile taxa (Dennis et al., 2006). In forest habitats particularly, species can often go undetected within dense canopies and sampling becomes non-random (Hardy and Dennis, 2005).

1.4 Importance of Studies on Macroecology and Conservation Biology

Variation in number and distribution of species on earth in space and time is not uniform and has been a fundamental theme in biogeography, macroecology and conservation biology in past few decades, majorly after MacArthur's famous work on 'Theory of Island Biogeography'. Perhaps the most studies pattern in spatial ecology is latitudinal gradient in species diversity, in which the number of species, for most of taxa decreases with increasing latitude. However, elevational gradients have often been neglected despite their potential as powerful experimental systems (Körner, 2000; Lomolino, 2001) and they also mirror latitudinal gradient in species diversity. Elevational gradients are nearly as ubiquitous as latitudinal gradients and they offer many characteristics that make them perhaps more suitable to uncover the underlying cause of spatial variation in diversity. Study diversity gradients and their underlying cause, this information is critically important for conservation efforts (Hunter and Yonzon, 1993), especially in the biodiversity hotspots, mountain regions that have been generally poorly explored by the biologists.

1.4.1 Review of Studies on Elevational Species Richness Gradients

In the 1970s and 1980s, ecologists became enamoured by the extraordinarily diverse tropics and attention shifted away from temperate elevational studies. The first tropical elevational gradient study to make a decisive mark on the research community was John Terborgh and colleagues examination of bird communities in the Peruvian Andes (Terborgh and Weske, 1975; Terborgh, 1977, 1985). Based on these results, decreasing elevational diversity became accepted and assumed pattern for all taxonomic groups for more than two decades (Brown and Lomolino, 1998), The uniformity of decreasing richness on elevational gradients was challenged by

Rahbek (1995) presented a series of case studies emphasising that unimodal trends were more common than decreasing patterns.

Recently, there has been a concerted effort to systematically document species richness along elevational gradients around the world for many groups of plants and animals (Heaney, 2001; Kessler et al., 2001; Sanders, 2002; Brehm et al., 2003; Grytnes, 2003; Herzog et al., 2005). Additionally, a series of systematically compiled meta-analyses have been conducted for various taxonomic groups (McCain, 2004, 2005, 2007a, 2007b, 2009, 2010a).

1.5 Objectives

The goal of this study was to document extant of butterfly assemblages that exist in different habitats and to identify the role of elevation, climate and vegetation on the distribution pattern of butterflies in the Tons valley. Following objectives were framed to achieve the aim of the study:

1. To provide inventory of butterfly fauna in different habitats of Tons valley.
2. To compare diversity and community composition of butterflies assemblages in different habitats.
3. To assess the influence of area, elevation, climate, vegetation and disturbance on distribution pattern of butterflies.
4. To investigate the seasonal diversity and structure of butterfly assemblages.
5. To evaluate the benefits of rapid assessments using butterflies as surrogate of insect diversity in conservation decisions.

1.6 Organization of Thesis

Present study adopting the macroecological framework, investigates the spatiotemporal pattern in species richness and distribution of butterflies along an elevational gradient in the Tons valley in western Himalaya. The present thesis is organized into seven chapters that include i.e., the first two introductory sections

followed by four main chapters and a last chapter highlighting applications of quick and cost effective rapid assessment studies to monitor biodiversity in Himalaya:

Chapter 1, introduces the general concepts and focus on biodiversity in Himalayas and highlight the use of butterflies as surrogate biodiversity indicator taxa for biodiversity monitoring and conservation. Followed by highlighting importance of studies in conservation biology and macroecology and presents a brief account on importance of butterflies as model organism. Further, a brief review of the studies on elevation gradients in species richness, international and national review of studies on butterflies is presented and it culminates into objectives and organization of the thesis. Chapter 2, contains a detail description of the Tons valley – the study area of the current experiment, with some information on geography, climate, geology, soil, vegetation, society and wildlife. Chapter 3, deals with the overall faunistic inventory of butterflies sampled in Tons valley with their current taxonomic status. Further, the species which are included in Indian Wildlife (Protection) Act, 1972 are also mentioned. Chapter 4, investigate the diversity and distribution of butterfly assemblage across vegetations and sites. It also discusses the occupancy of butterflies and role of habitat heterogeneity and disturbance on butterfly diversity. Chapter 5, examines the relationship of species richness with elevation and influence of geometric constraints, climate, area and NDVI at landscape level and further explores the effect of habitat, microclimatic and disturbance variables on butterfly communities at plot level sampling. Chapter 6, deals with documentation of seasonal changes in species richness and abundance of butterflies in disturbed and undisturbed habitats. Finally in Chapter 7, importance of cost effective and quick rapid assessment studies is highlighted using butterflies as surrogate indicator taxa to monitor insect biodiversity in Himalayan landscape.

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CHAPTER 2

STUDY AREA

2.1 Tons Valley

The study was conducted over the river Tons in western Himalayan region in the state of Uttarakhand, India. The region falls under bio-geographic province 2B zone of the western Himalayas (Rodgers and Panwar, 1988) and sub-region Garhwal Himalayas (Figure 2.1). The Tons valley covers an area of about 4500 sq. km and flows through 2 Indian states i.e., Uttarakhand and Himachal Pradesh and also constitutes political boundary in between these two states. Due to vastness and inaccessibility of the region, biodiversity in numerous areas still remain underexplored or unexplored. The upper catchment of the Tons valley falling in state Uttarakhand was selected for intensive sampling (Figure 2.1). The average elevation in the study area ranges from 900 - 4500 m but few mountain peaks reaches over 6000 m as well (Plate 1 - 3). As very few species occurs at high elevation so, owing to expansive variability in study region, elevation ranging from 900 – 3500 m was considered for sampling.

2.2 Location and Topography

The Tons valley lies between Latitude - 30° 35’ - 31° 20’ North and Longitude - 77° 49’ - 78° 40’ East and entirely composed of hills and high mountains. The valley is bounded in the north and north-east by Shimla district of Himachal Pradesh, in the south-west by the Chakrata forest division of Dehradun district, and in the east by the Yamuna forest division of Uttarkashi district in the state of Uttarakhand. The total area of the Tons valley is *ca* 4500 sq. km. Its length is 150 km and width is 30 km. The area is composed entirely, of a succession of hills and mountains. The Tons river forms the main drainage system of the valley. Tons river source lies in the 6316 m high Banderpunch glacier zone. The origin of the Tons river is at the convergence of two feeder streams; the Rupin river from the northern part of the Tons catchment near the Himachal Pradesh and the Supin river rises from tributaries from glaciers at north and north-eastern part of Tons catchment. Supin joins Tons at Sankri, which is upstream of confluence of Rupin with Tons at Naitwar (1290 m, asl). These two

feeder streams converge near the mountain hamlet of Naitwar and the channel downstream of Naitwar is known as Tons river. The place is situated in the upstream region of Tuni. The river flow in 'V' shaped valley and has an average bed slope of 11m per Km from Naitwar to Tuni.

Pabber is the major tributary of Tons river and merges in tons at Tuni. It originates from Gangdari ranges of great Himalaya in the state of Himachal Pradesh. The river flows in southwest direction down to Rohru town and further downstream of about 20 km in southeast of Rohru and at place Tuni (Uttarakhand), it joins the Tons river.

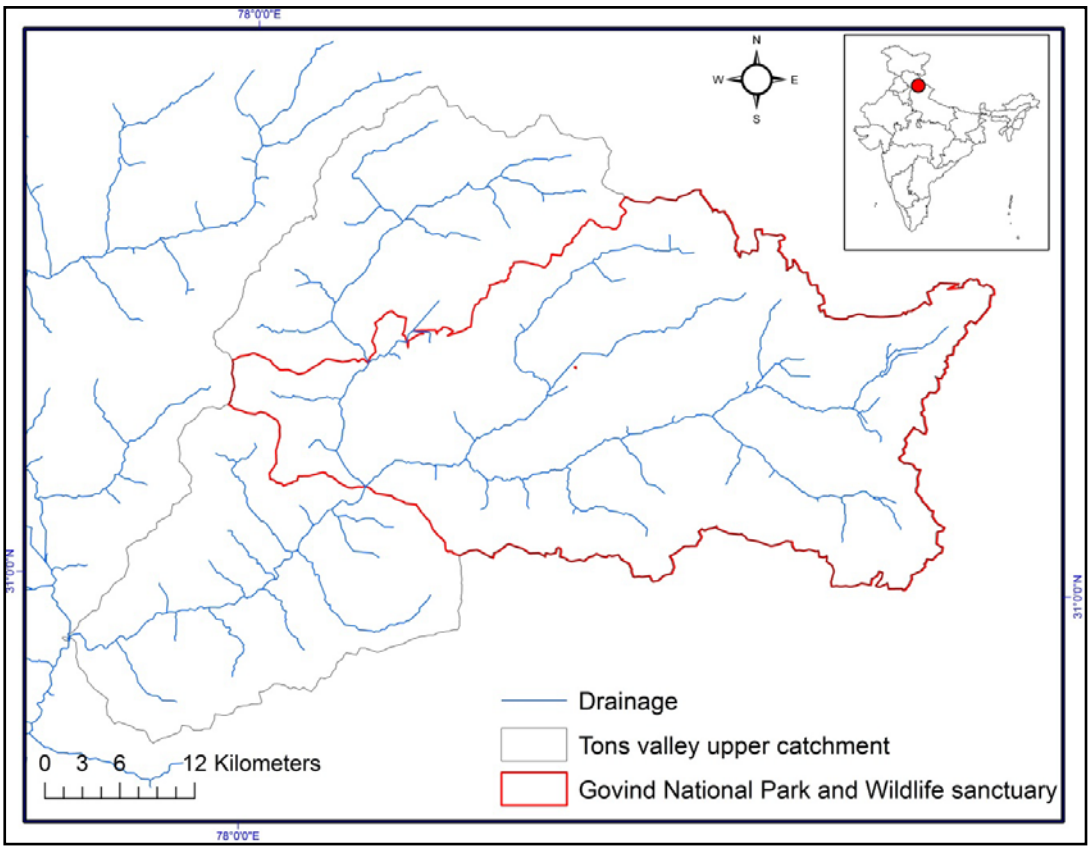

Figure 2.1: Map of the Tons valley (upper catchment) showing major drainage and protected areas (Govind National Park and Govind Wildlife Sanctuary) selected for sampling.

2.3 Geology and Soil

The area forms the knoll belt which extends from Shimla in the northwest upto the Kumaun in the west. In this Himalayan zone, rocks of the area the can be divided into two metamorphic and sedimentary rocks.

Metamorphic rocks are mainly composed of ‘granite and crystalline schist’. Sedimentary rocks are generally of slate, quartzite and conglomerates and include scarlet, green and muddy mica shales, mudstone, silica shales, ferruginous sandstone, brown phyllite and dark coloured slates. These are uncompacted clayey and sandy rocks with bedded structures and ripple marks. The other kinds of rock that are found in the Tons valley are orthoconglomerate, quazrite, grit sandstone. Brown sandy limestone and small amount of phyllite are exposed in the valley. Parallel lamination and ripple marks are common sedimentary structures.

The soil in the valley is fairly deep particularly at the foothills. The soil of this tract can be differentiated into four types; red loam, brown, podsol and meadow soil. The red loams are generally formed along ridges and generally sandy in nature and occurs at sites which received maximum solar radiation. These soils are mostly brownish grey to loamy sand with plenty of undecomposed organic material. The brown forest soil is found in the greater part of the valley and is generally highly organic, finely granular, and clayey and loam, with plenty of undergrowth. The podsol development is met within mils slopes at places in pocket. The meadow soil is usually found near the water streams, cool and low lying shady places. Owing to high ground water table, the soil remains moist and melting of frost covers the soil. These are dark grey, granular, sandy loam, mica sandy soils at greater depth.

Although, the above mentioned soil emerges out of the two parent type rocks, but their development to clear generic types is presumable due to the differences in topographical conditions and weathering agencies like chemical, physical and biochemical and the variation between each of the soil type is numerous.

2.4 Climate

The climate of the area is variable, with subtropical climate in lower part of the valley having hot and more or less humid monsoon season from July to September, pleasant autumn and spring and a cold and dry winter season bracing with clear and bright weather alternating with occasional winter rains and temperate at high elevations. The average rainfall is 1500 mm, with extreme cold and snow during the three to four month winter. Maximum rainfall is experienced during month of July

and August and minimum rainfall during the months of January and October. A permanent snowline occurs at 5000 m elevation.

In summer, maximum temperature reaches 42 - 43°C in areas below 1600 m and 30 - 32°C at 2000 m elevation. At higher elevations, the weather remain cool and pleasant even in June and the precipitation being high. The winter is long and severe with heavy snowfall above 2000 m. Snowfall down to 1500 m, occasionally lower, but melts away rapidly below 2000 m and even above this altitude, it seldom stays long on sunny slopes except at elevations over 2800 m, snow starts falling in November and continues upto February and sometimes upto March. The period from month of December to February is the coldest period. The months of April, May and June are warm, marked by occasional thunderstorms, often accompanied by hail and raining, at all elevations.

2.5 Vegetation and Protected Areas (PAs) Network

Two protected areas (PAs), the Govind National Park (Govind NP) and the Govind Wildlife Sanctuary (Govind WLS) lies in the upper catchment of the Tons valley (WLS) (Figure 2.1). Govind NP and Govind WLS are part of high Western Himalayan highland situated in Purola Tehsil of the Uttarkashi district in Uttarakhand state and lies between Lat - 31° 02' – 31° 20' N and Long - 77° 55' – 78° 40' E (Figure 2.2). Two major rivers, Rupin and Supin, flow through the Govind NP and Govind WLS and merges at Naitwar village, forming the river Tons. The altitude varies from 1290 - 6323 m. The Govind WLS covers 953.12 km^2 of which 472.08 km^2 have been demarcated as National Park encompassing the upper catchment of river Tons.

The forests occur in all aspects and therefore, vary greatly in composition from place to place ranging from river catchments, steep well drained slopes to moist shady ridges and spurs. About 60% of the area of Tons valley is under forest cover. The vegetation of the Tons valley is a mixture of tropical, temperate, sub-alpine, and alpine vegetation. The permanent vegetation is evergreen, intermixed with deciduous species at lower elevations (Champion and Seth, 1968). Following Champion and Seth (1968) forests in study area are classified into six major classes (Figure 2.2) (Appendix 2.1). Detail of groups and subgroups is provided in Appendix 2.1.

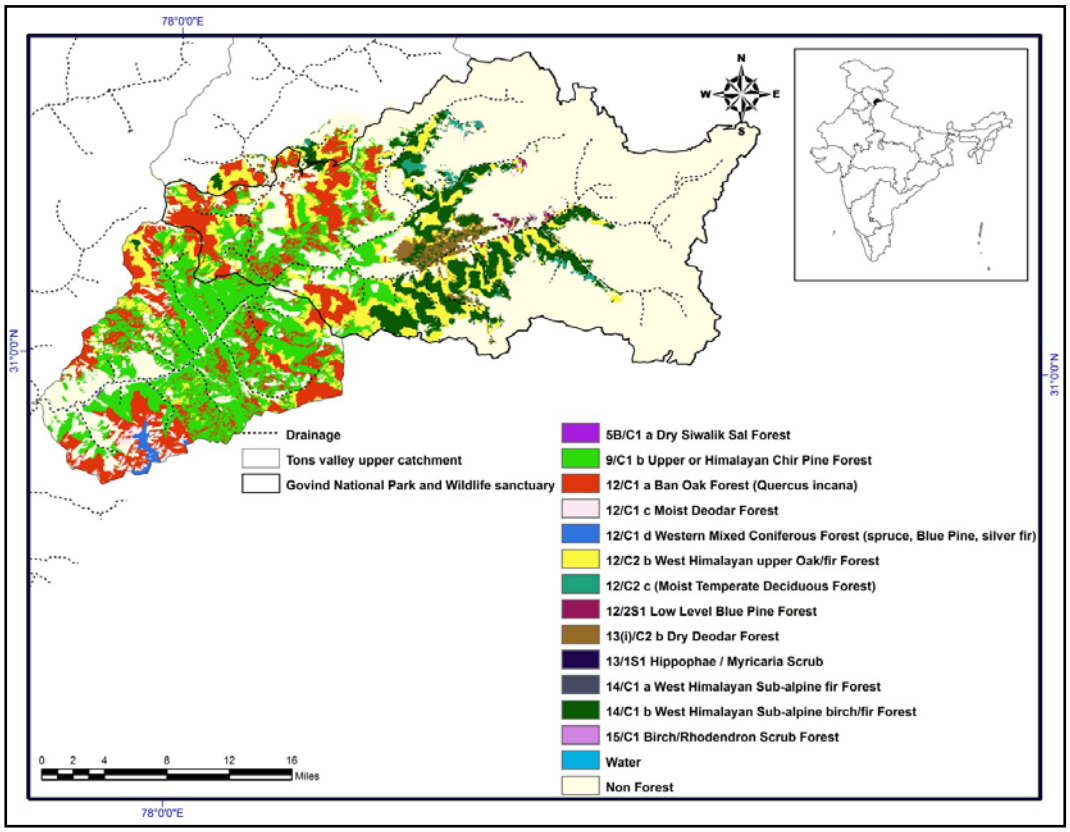

Figure 2.2 Forest types in the Tons valley, according to Champion and Seth (1968) (Source: Forest survey of India, forest cover/type mapping).

The six major types are as follows:

Group 5. Tropical Dry Deciduous Forest

Group 9. Subtropical Pine Forest

Group 12. Himalayan Moist Temperate Forest

Group 13. Himalayan Dry Temperate Forest

Group 14. Sub-alpine Forest

Group 15. Moist Alpine Scrub

The forests in Tons valley are generally dense and the tree height in canopy usually varies from 15 - 30 m. There is an admixture of the species of tropical, temperate and sub-alpine in these forests (Figure 2.2). The deciduous species generally shed their leaves from January to mid March. The forests bordering habitations suffers heavily from lopping and felling. Fortunately, considerable area and parts of the valley forest is not under serious threat and supports luxuriant growth of dense forest. Based on the vegetation composition, Rana et al. (2003) classified the forest of the area into following major types.

(i) Pine Forests

These forests are most widely distributed, occupying the lower slopes in all river catchments, chiefly at the altitudes between 750 – 800 m, occasionally extending above and below this zone. The pine forests go down to about 600 m where these gradually pass into scrub and thorn forests. Towards upper limit these forests extended upto 2300 m, confining to warm exposed aspect, like ridges and spurs. In all pine forests *Pinus roxburghii*, the sole dominant species attains optimum growth in the area. Generally, the pine forests are almost pure, however, at some places *Pinus roxburghii* is associated with trees like *Lyonia ovalifolia*, *Phyllanthus emblica*, *Ougeinia oojeinensis*, *Pyrus pashia*, and in drier rocky places with *Euphorbia royleana*. In shady and moist pockets *Quercus leucotrichophora* and *Alnus nepalensis* are typical associates of pine, however, in upper zone there is an admixture of *Cedrus deodara* and *Pinus wallichiana*.

There is a discontinuous undergrowth of shrubs often so widely scattered that at a very short distance their presence is scarcely observed. Among these are *Rubus ellipticus, Rhus parviflora, Coriaria nepalensis, Berberis lyceum, Indigofera cassiodes* and *Woodfordia fruticosa*.

The ground vegetation is almost negligible, except few species like *Imperata cylindrical, Heteropogon contortus, Anaphalis triplinervis, Lespedeza gerardiana, Conyza candensis, Reinwardtia indica, Archyranthes aspera* and *Artemisia nilagirica*.

(ii) Oak Forests

There are three major species of oak in the Tons Valley *viz.* banj (*Quercus leucotrichophora*), moru (*Q. dilatata*) and kharshu (*Q. semecarpifolia*) which occupy more or less distinct altitudinal zones. The chief characteristic feature of the oak forests are that, soil is usually moist due to high degree of atmospheric humidity throughout the monsoon period, which results in the rich epiphytic flora of mosses, ferns and lichens. The oak forests are dominated by *Quercus leucotrichophora*.

There are few common tree species associated with banj forests such as *Lyonia ovalifolia, Neolitsea umbrosa, Ilex dipyrena, Cornus capitata, Phoebe lanceolata* and *Rhododendron arboretum* are locally common. Among shrub species,

there is altogether a different composition, and the numbers of common shrub species are very large. The commonest among them are *Berberis chitria, Desmodium elegans, Indigofera heterantha, Daphne papyracea, Myrsine africana, Pricepia utilis, Leptodermis lanceolata etc.* The herbs are *Boehmeria macrophyllaa, Geranium mascatense, Artimisia nilagrica* and grasses like *Chrysopogon* sp., *Drepanostachyum* sp. and *Bromus ramosus* are common.

The moru (*Quercus dilatata*) oak forests are sporadically found between 2000 – 2500 m elevations and occupy an intermediate zone between the *Quercus leucotrichophora* and *Q. semecarpifolia*. Other species in these forests are *Acer caesium, Ilex dipyrena, Neolitsea* sp. and *Symplocos paniculata*. The kharsu (*Q. semecarpifolia*) occupies highest zone amongst the oaks and generally found between 2200 – 3500 m elevations. Other competeting species are *Abies pindrow, Quercus dilatata, Taxus baccata, Ilex dipyrena, Acer caesium*. Common shrubs are *Rosa macrophylla, Coteneaster* sp., *Lonicera* sp., and *Wikstroemia canescens.*

(iii) Deodar Forests

The dominating tree in the deodar forests is *Cedrus deodara,* which forms more or less pure formations between 2000 – 3000 m. A few species like *Pinus wallichiana, Abies pindrow, Quercus leucotrichophora, Q. dilatata* are scattered in deodar forests and the undergrowth is usually scanty consisting of *Lonicaera* spp., *Mahonia borealis, Princepia utilis, Sarcococca saligna, Spiraea canescens, Daphne papyracea, Boehmeria macrophylla and Rosa brunonii*. Common herbs are *Justicia* spp., *Plectranthus* spp., *Polygonum capitatum*, *Anaphalis* spp., *Salvia nubicola, Conyza* spp., *Anisomeles indica* and several species of ferns are also dominant on the floor of deodar forest.

(iv) Mixed Forests

The mixed forests being invariably found in the moist depressions upto 1800 m and rarely occur over large continuous areas. The tree species are usually deciduous and found mixed, but at some places *Aesculus indica, Acer caesium* and *Toona serrata*, dominate the vegetation. Other common species found in these forests are *Continus coggygria, Celtis australis, Albizia julibrissin, Olea ferruginea, Symplocos paniculata, Mallotus philippensis, Ougeinia oojeinensis, Viburnum* spp., *Rhus*

parviflora, Lyonia ovalifolia, Hovenia acerba, Phoebe lanceolata, Cinnamonum tamala, Trema politoria, Euonymus tingens, Alnus nepalensis, Prinsepia utilis, Rubus ellipticus. Toona serrata is observed at shady depressions on way to Sankri area.

Common climbers are *Cissampelos pareira, Vitis lanata, Cryptolepis buchananii, Rubia manjith, Clematis monatana, Pueraria tuberosa* and *Aspidopterys willichii*. The ground floor is well covered with the annuals and perennials like *Cyathula tomentosa, Boehmeria macrophylla, Crotalaria prostrate, Euphorbia hirta, Verbascum thapsus, Capsella bursa-pastoris, Solanum surattense, S. nigrum, Justicia* spp. and *Ajuga bracteosa*.

(v) Scrub and Thorn Forests

These forests, being a successional community, resulted due to indiscriminate exploitation of the natural forests, uncontrolled felling and cutting of trees and over-grazing. These forests are found upto 1500 m, due to frequent grazing and biotic disturbances, regeneration of species is very poor and hence vegetation is very sparse.

These forests are characterized by bushy or thorny stunted trees and shrubs with crooked stems. They are usually scattered over the rocky and exposed hill slopes. *Euphorbia royleana* forms the pure patches over rocky hill slopes, it seldom occurs in association with other species. The common species of the scurb and thorny forests are *Rhus parviflora, Zanthoxylum armatum, Murraya koenigii, Rhamnus virgatus, R. procumbens, Vitex negundo, Berberis asiatica, Prinsepia utilis, Abelia triflora, Achyranthes bidentata, Plectranthus rugosus, Holmskioldia sanguine, Adhatoda zeylancia, Elsholtzia fruticosa, Artemisia nilagirica, Eriophorum comosum, Flemingia semialata*, etc., and grasses like *Phragmites karka, Heteropogon contortus, Apluda mutica* and *Arundinella nepalensis*, are very common in the scrub forests.

2.5.1 Seasonal Vegetation

The seasonal vegetation of the valley has been mainly distinguished into rainy, winter and summer vegetations (Rana et. al., 2003).

(i) Rainy Season

During June and July almost all the dried patches begin to green. The species like *Euphorbia prostrate, E. hirta, E. hypericifolia, Cyperus difformis, Phyllanthus fraternus, Arthraxon lancifolius* and *Cynodon dactylon* start appearing in the fallow fields and wastelands. About two or three weeks later, a variety of grasses are sprouted up and the whole ground appears like green carpet. By the end of July and first week of August, several species of other groups are also found growing with grasses. Some of the common species are: *Origanum vulgare, Alysicarpus* spp., *Cassia occidentalis, C. pumila, C. tora, Nasturtium officinale, Kickxia ramosissima, Inula* spp., *Commelina benghalensis, Corchorus aestuans, Portulaca oleracea, Parthenium hysterophorus, Arabidopsis himalaica, A. stricta, Arisaema* spp. and *Cleome viscose*. During the rainy season, optimum temperature and moisture provides the ideal conditions for the plant growth in this area. Most of the species of this season complete their flowering and fruiting by the end of October or November. The bulk of the rainy season vegetation disappears towards the end of November with the same rapidity as it came up during the rains.

(ii) Winter Season

With the commencement of winter season from October to the first week of March, temperature goes down and the top soil as well as the atmosphere becomes dry. By this time, most of the species of temperate regions make their appearance. The common among them are: *Anagallis arvensis, Fumaria indica, Gnaphalium* spp., *Ajuga bracteosa, Anisomeles indica, Verbascum trhapsus, Cyathula tomentosa, Capsella bursa-pastoris, Anemone obtusiloba, Thalictrum foliolosum, Campanula colorata, Conyza aegyptiaca, C. canadensis, Cotula anthemoides, Polygonum capitatum, Rumex dentatus, Euphorbia thymifolia, Setaria pumila* and *Themeda arundinacea* (Rana et. al., 2003).

(iii) Summer Season

The summer is very short starting from April to May or first week of June. The decreasing moisture content and increasing temperature during April and May result in the disappearance of most of herbaceous species except those found in the

moist habitats. The seeds of several annual herbs lie dormant in soil throughout the rainy and winter season.

Major plants in the season are *Argemone mexicana, Stellaria media, Hypericum* spp., *Juncus bufonius, Plumbago zeylanica, Boerhavia diffusa, Geranium nepalense, Conyza japonica, Launaea* spp., *Myriactis nepalensis, Saaussurea heteromalla, Senecio nudicaulis, Taraxacum officinale* and *Tridax procumbens*. Besides this there are lots of herbaceous species associated with the vegetation.

2.5.2 Aquatic and Marshy Vegetation

The aquatic and marshy plants normally grow and develop in water and complete at least a part of their life cycle in water. The common habitats for aquatic and marshland species are rivers, ponds, streams, pools, ditches and depressions along the road and villages, formed during rainy seasons. he maximum diversity in the aquatic flora is noticed during monsoon season.

With the onset of cold weather, coupled with gradual drying up of marshy habitats, a green cover appears on the dried up muddy depressions and monsoonal ponds. Some of the common species inhabiting such as areas are: *Veronica anangallis-aquatica, Houttuniynia cordata, Acorus calamus, Spirodela polyrhiza, Typha angustifolia, Ranunculus sphaerospermus, Mentha arvensis, Nasturtium officinale, Lecanthus penduncularis, Paspalum scrobiculatum, Fimbristylis dichotoma, Cyperus difformis, C. iria* and *C. exaltatus*.

2.5.3 Weeds and Aliens

It is sometimes difficult to distinguish between wild plants and aliens, as wild plants comprise both indigenous species and aliens that have become naturalized. The aliens appear as wild plants but behave as weeds. They are generally found along roadsides, waste places, agricultural fields, gardens etc. Among the common weeds are: *Anagallis arvensis, Asclepias curassavica, Capsella bursa-pastoris, Cannabis sativa, Chenopodium album, C. ambrosioides, Cleome viscose, Commelina benghalensis, Cyperus iria, Euphorbia hirta, Fimbristylis dichotoma, Fumaria indica, Lathyrus sphaericus, Oxalis corniculata, Panicum psilopodium, Stellaria media, Tagetes minuta, Triumfetta rhomboidea, Vicia hirsute, Xanthium indicum, Bedens*

pilosa, Gnaphalium luteo-album, Tridax procumbens, Ageratum conyzoides, Solanum viarum, S. torvum, Physalis minima, Argemone mexicana, Martynia annua, Malvastrum coromandelianum, Parthenium hysterophorus and *Lantana camara*.

2.6 People and Livelihood

About 47 villages are scattered throughout the Govind NP and Govind WLS (Anonymous, 1986). The people subsist mainly on livestock, cultivation, and forest products. The Tons valley is home hold of several tribal communities like *Jaunsaris, Parvatis* and *Gujjars*. Although *Parvatis* are more or less similar to *Jaunsaris* but they are not legally notified as tribes. They are economically weaker than *Jaunsaris. Gujjars* in the area are nomads and they perform transhumance. They move towards high elevation with their livestock during the summer and move back before the onset of the winter. The *Rajputs* of the valley are called *Khasas*. The Khasas have always been referred to as a very powerful race, which are supposed to migrate at a very early period from Central Asia and are supposed to have left their name in Kashgar, Kashkara, the Hindukush, Kashmir and Nepal. The poet Kalhan's chronicle of the Kashmir, the "Rajtaringini" to the ruler of Kashmir is full of references to the Khasas, who were always a continuous source of trouble to the ruler of Kashmir. The "Mahabharata" the "Harivansa" and the epic "Puranas" all mentioned the *Khasas* as a tribe inhabiting the northwest Himalaya (Saksena, 1962). Grieson in 'Linguistic Survey of India' has traced the origin of western *Pahari* and conclude that earliest Aryan-speaking inhabitants of this region were *Khasas*.

Despite primitive way of life, the people of the valley have maintained a balance in the agro-ecosystem with major components comprising crop plants (in terrace farming), the forests and rearing of animals, which they have acquired through age-old traditions. Introduction of apple cultivation is a recent change that has altered the socio-economics of the society. Living close to the forest the people have an understanding of the properties of the flora and fauna, functioning of the ecosystems and ways of using them sustainably. But the recent changes in the global economy has influenced the basic lifestyle of the people of the valley, so they are forced to adopt according to the demand of the recent socioeconomic changes in the society like, social pressure to use electronic devices.

2.7 Wildlife

The fauna of the study area is poorly known and represented in literature other than a few scattered references on the mammals, birds, reptiles, butterflies, dragonflies and damselflies, hymenopterans and chilopods. Dang (1968) published a report on the preliminary survey of Har-ki-dun and adjacent valleys, with special reference to blue sheep and brown bear. A report from Wildlife Institute of India (Anonymous, 1986) reported 11 species of mammals from the study area. Later Sathyakumar (1994) reported about 20 species of large mammals from the Govind Pashu Vihar. Kumar et.al. (2004) published a list of 257 taxa belonging to nine faunal groups (*viz*. Odonata, Lepidoptera, Hymenoptera, Chilopoda, Amphibia, Reptilia, Aves and Mammals.

A total of 115 species of birds and 32 species of mammals have been recorded so far from the area. Major wildlife species are Asiatic Jackal (*Canis aureus*), Red Fox (*Vulpes bengalensis*), Leopard Cat (*Prionailurus bengalensis*), Leopard (*Panthera pardus*), Snow Leopard (*Uncia uncia*), Yellow Throated Marten (*Marets flavigula*), Mountain Weasel (*Mustela altaica*), Brown Bear (*Ursus arctos*), Asiatic Black Bear (*Ursus thibetanus*), Musk Deer (*Moschus chrysogator*), Sambar (*Cervus unicolor*), Barking Deer (*Muntiacus muntjak*), Himalayan Tahr (*Hemitragus jemlahicus*), Bharal (*Pseudois nayaur*), Royale's Pika (*Ochotona roylei*), Red Giant Flying Squirrel (*Petaurista petaurista*) and Indian Crested Porcupine (*Hystrix indica*). The most important avifauna of the area is Himalayan Bearded Vulture (*Gypaetus barbatus*), Western Tragopan (*Tragopan melanocephalus*), Satyr Tragopan (*Tragopan satyra*), Himalayan Monal (*Lophophorus impejanus*), Koklass (*Pucrasia macrolopha*) and Cheer Pheasant (*Catreus wallichii*), which are also scheduled species in Indian Wildlife (Protection) Act, 1972 (Anonymous, 2006).

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CHAPTER 3

INVENTORY AND CONSERVATION OF BUTTERFLIES IN TONS VALLEY

3.1 The Systematics of Butterflies

Lepidoptera (butterflies and moths) is a diverse order of class Insecta with about 180,000 described species, compared with may be 1,413,000 species of all organisms described (Wilson, 1992), around 10% of all described species of living organisms (Kristensen, 1999) in the world. Whereas, a total of 17,500 species of butterflies have so far been reported from the world (Ackery et al., 1999) and rest of them are moths. Butterflies represent around 1% of all species known. Nearly half of all butterflies (about 7500 species) are estimated to be in the new world tropics (Heppner, 1991; Lamas 1997; Robbins and Opler, 1997). A total of 1200-1300 species are found in Oriental region and about 1,677 taxa from India.

It is perhaps ironic that while reviews of the biology of butterflies already fill a substantial volume, two centuries of effort by taxonomists still fail to provide a convincing systematic framework in which to place this wealth of data (Vane-Wright and Ackery, 1984). But there have been few significant advances in the recent years. Wahlberg et al., (2005a) concluded that six families of butterflies were traditionally recognized with the following relationships (Hesperiidae + (Papilionidae + (Pieridae + (Nymphalidae + (Lycaenidae + Riodinidae))))) based on phylogenetic analysis.

This is now confirmed that butterfly superfamilies, Hesperioidea and Papilionoidea together form a monophyletic group. Within the Papilionoidea five families, namely the Papilionidae, Pieridae, Nymphalidae, Lycaenidae and Riodinidae are recognized. At subfamily level there may be broad agreement within the Papilionidae, Pieridae and the Lycaenidae. However, the Nymphalidae remain unconvincingly resolved (Vane-Wright and Ackery, 1984).

3.2 International Studies on Butterflies

3.2.1 Systematics Studies

Reuter (1896) has presented a detailed phylogenetic system for all butterflies and apart from the studies of Ehrlich (1958) and Kristensen (1976). There have been few significant advances in recent years (Wahlberg, et al., 2005a). This is now assured that the butterfly superfamilies Hesperioidea and Papilionoidea together form a monophyletic group. Within the Papilionoidea four families can be recognized with confidence but there is broad agreement about subfamilies within the three of them except Nymphalidae remain unconvincingly resolved. Ashizawa and Muroya (1967), Bernardi (1947), Brown (1971, 1979), Burns (1964), Bryk (1923, 1930), Clark and Dickson (1971), Common and Waterhouse (1981), Cowan (1966, 1967), Ehrlich (1958), Ehrlich and Raven (1965), Eliot (1973), Evans (1937, 1949, 1951, 1952, 1953, 1954, 1955), Field and Herrera (1977), Forbes (1939), Higgins (1975), Kudrna (1977), Lindsey et al. (1931), Munroe and Ehrlich (1960), Munroe (1961), Nabokov (1945), Sibatani and Grund (1978), Stempffer (1967) and Stichel (1928, 1930-31, 1932, 1933, 1938, 1939) work is remarkable to distinguish subfamilies under order Rhopalocera.

3.2.2 Faunistic Studies

The expansive nineteenth century literature still contains valuable information. For the Palaearctic region catalogue works of Higgins (1975) and Korshunov (1972) probably give the widest coverage. To date, Seitz (1907, 1908, 1909) remains the only comprehensive study of this region. For the Afrotropical region although Peters catalogue (1952) remains useful and updated by D'Abera's (1980) and Carcasson (1981). Otherwise only Seitz (1908-25) gives complete coverage of the Afrotropical region.

In the Oriental region area is covered within Seitz (1908-28), the 'IndoAustralian' fauna and also by D'Abrera (1982) in the first part of planned series of volumes on Oriental butterflies. Sevastopulo (1939), Pant and Chatterjee (1950) and Varshney (1977) catalogued the described life histories, local lists and larval host plants of Indian fauna. In the Austro-Oriental fauna Corbet and Pendlebury (1978) for Malaysian butterflies, Roepke work (1935-1942) for Java is helpful.

3.3 Studies on Indian Butterflies

The first account of Indian butterflies was published by Horsfield and Moore (1857), in which many species from Java were included. The next work was by Moore (1865) on lepidopterous insects of Bengal. Later the butterfly fauna of Indian sub-continent have been mainly studied by Moore (1890-1907). Niceville's (1886-90) three volumes contain information on Indian butterflies dealing Papilionidae, Pieridae and Hesperiidae. Colonel Bingham (1905-07) presented two volumes on butterflies in 'Fauna of British India' series containing families Nymphalidae and Riodinidae. Later Bell (1909-27), Antram (1924), Evans (1932), Peile (1937), Talbot (1939, 1947), Wynter-Blyth (1957), Varshney (1977a, 1977b, 1993, 1994, 1997), Mani (1986), D'Abrera (1982, 1985, 1986, 1998), Smith (1989), Gaonkar, (1996), Ghosh (1990), Mondal (1987, 1991, 1998), Haribal (1992) were other researchers, who contributed variously on research on Indian butterflies. In last decades, Kunte (2000) and Kehimkar (2008) presented information on Indian butterflies covering a large number of species. Singh (2011) published account of butterflies mostly from the Himalaya along with their habitat and natural history information.

3.3.1 Studies on Butterflies of Himalaya and Uttarakhand Region

Many workers made the collection of butterflies from Himalayas. Mani (1986) described 377 species of butterflies except Hesperiidae from Himalayas. Collections of A.M. Lang from northwest Himalayas and A.G. Young from Kullu, were included by Major G.F.L. Marshall and de Niceville in The Butterflies of India, Burma and Ceylon (volume 1-3 : 1882-1890). Collections of J.H. Hocking from Kangra district were published by Moore (1882). Subsequently, these were included in publications by Evans (1932), and Talbot (1939, 1947). The butterflies of the Indian region, including those from Uttarakhand in western Himalayas, were named and described by Linnaeus and Fabricius for the first time during the eighteenth century. Doherty (1886) published a list of butterflies, exclusively from Kumaon, for the first time, followed by Hannyngton (1910-11), who published an account of 373 butterflies. Mackinon and de Niceville (1899) published a list of 323 butterflies from Mussoorie and neighbouring region from the western Himalayas followed by Ollenbach (1930-31), who published a list of 143 butterflies from Mussoorie. The other important works referable to the study of Garhwal Himalayas are by Stempffer (1952); Bernardi

(1952) and Lesse (1952). Wynter-Blyth (1957) recorded as many as 415 species from western Himalayas out of which 323 species were listed from Uttarakhand. Subsequently Arora and Mandal (1977) recorded 45 species from Garhwal. Mani (1986) work on Himalayan butterflies is very useful. Arora (1995) recorded 223 species from western Himalayas. Arora (1997) identified 80 species of butterflies collected from Nanda Devi Biosphere. Compiled from the inventory of valid species of butterflies belonging to nine families is somewhere nearly 323 species from Uttarakhand. Detailed assessments based on different bio-geographical regions and landscapes, states, protected areas and forest types were mainly undertaken by Larsen (1978), Arora and Mandal (1981), Gupta and Shukla (1987), Ghosh et al. (1990), Haribal (1992), Mathew (1993), Arora (1994, 1995), Gaonkar (1996) Rose and Sindhu (1997), Gunathilagaraj et al. (1998), Joshi et al. (1999), Rose and Sharma (1999), Singh (1999), Kunte (2000), Singh and Bhandari (2003), Singh and Pandey (2004), and Uniyal (2004).

Mainly Joshi et al. (1999) Joshi and Arya (2007), Joshi (2007), Joshi (2008) and Sharma and Joshi (2010) conducted various studies in protected areas (Rajaji National Park and Nanda Devi Biosphere Reserve) and high altitude areas of Uttarakhand. Various studies on insects and butterflies of Great Himalayan National Park and Himachal Pradesh were published by Uniyal and Mehra (1996), Uniyal (1996, 1999), Uniyal and Kumar (1997), Uniyal and Mathur (1998) and Bhardwaj and Uniyal (2008). Singh and Bhandari (2003) recorded 184 species from lower western Himalaya forests of Doon Valley. Kumar and Gupta (2004) recorded 48 species from Govind Pashu Vihar, Uttarkashi district (which lies within current study area). Singh (2009) published a list of 131 butterflies from Kedarnath Musk Deer Reserve in Garhwal Himalaya. A rarity analysis carried out on 211 species butterflies sampled in six sites in the moist-temperate oak forest zone of Garhwal, including Govind WLS, determined 30 species as both rare and sensitive to habitat disturbance in these forests, thus being species of conservation value (Singh, 2013).

3.4 Inventory and Family Composition of Butterflies in Tons Valley

A total of 189 butterfly species represented by 108 genera in 5 families were recorded in Tons valley (Table 3.1) (Appendix 3.1), (Plate 4 - 14) during entire observation period from April 2008 to October 2012. Of all the species, 46% of all

species were of family Nymphalidae followed by Lycaenidae (23%), Pieridae (13%), Papilionidae (12%) and Hesperiidae (7%).

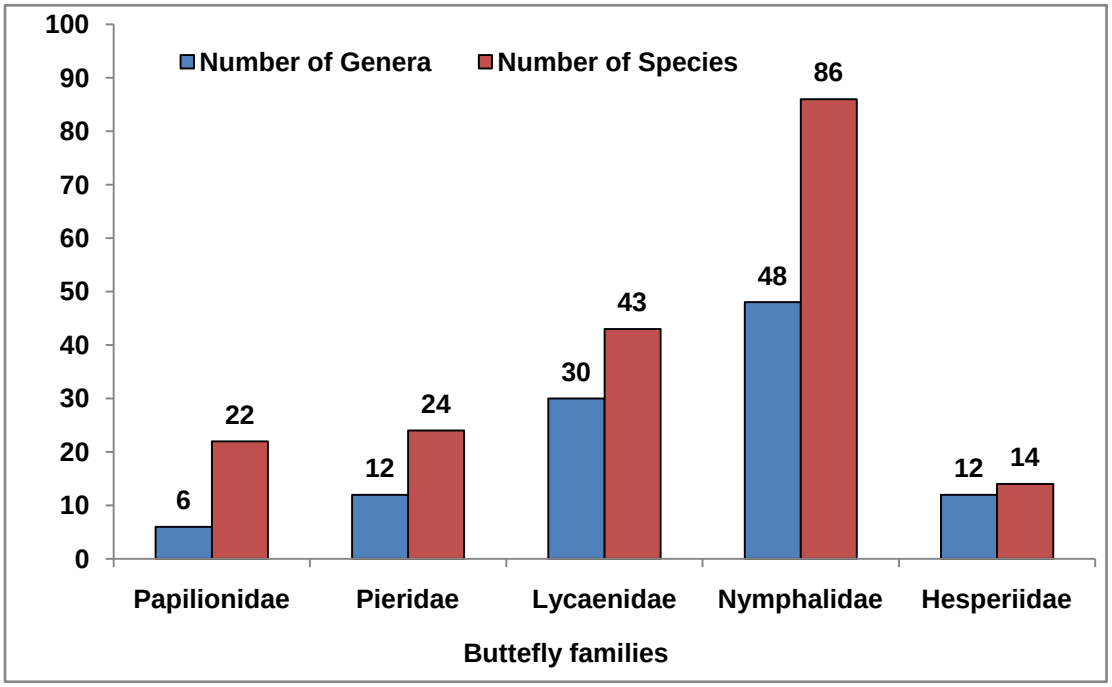

Figure 3.1: Number of genera and species accounted under each of the five butterfly families.

Very low species richness was observed for family Hesperiidae (14 species belonging to 12 genera). Highest species and generic diversity (86 species in 48 genera) were recorded for family Nymphalidae, followed by family Lycaenidae (43 species in 30 genera), family Pieridae (24 species in 12 genera). However family Papilionidae for a total of 22 species but represented by only 6 genera (Figure 3.1) (Table 3.1).

General appearance, natural history, biology and host plants of families and subfamilies of butterfly were recorded fromTons valley are described below is adapted from Evans (1937, 1949, 1951, 1952, 1953, 1955), Talbot (1939, 1947), Ehrlich, (1958), Munroe (1961), Emsley (1963), Miller (1968), Eliot (1969, 1973, 1986), Kristensen (1976) and Common and Waterhouse (1981).

3.4.1 Superfamily Papilionoidea

The true butterflies are composed of five families - Papilionidae, Pieridae, Nymphalidae, Riodinidae and Lycaenidae. There are estimated to be some 13,700

species in the world (Robbins, 1982), distributed on every continent except Antarctica, and most remote oceanic islands as well. The greatest diversity occurs in tropical regions, particularly the Neotropics. Kristensen (1976) suggests two characters for the Papilionoidaea; wing coupling amplexiform in both sexes and antennae with apical clubs. There are four families included as Papilionidae, Pieridae, Lycaenidae and Nymphalidae. The "true" butterflies are composed of five families - Papilionidae, Pieridae, Nymphalidae, Riodinidae and Lycaenidae. There are estimated to be some 13,700 species extant in the world (Robbins, 1982), distributed on every continent except Antarctica, and most remote oceanic islands as well. The greatest diversity occurs in tropical regions, particularly the Neotropics.

3.4.1.1 Family Papilionidae (Swallowtails and Apollos)

The Papilionidae belong to the Superfamily Papilionoidea, the true butterflies. Swallowtails are worldwide in distribution and comprise approximately 625 species (Ackery et al., 1999). About 84 species are reported from Indian region. The family includes the largest butterfly in India; the Golden Birdwing, *Troides aeacus*.

The Swallowtails are large, bright butterflies; many are black and yellow bearing one or two long tail-like extensions off the rear of the hind wing. They are often black and yellow in colour. Members of this family are generally characterized by a unique pattern of wing venation on the fore and hind wing. Pretarsal arolium and pulvilli reduced. Third anal vein of forewing free to the margin and uppermost bundle of thick metathoracic inner dorsal longitudinal muscle almost vertical. Eggs of both Swallowtails and Parnassians are generally round, green, dome-shaped, smooth or obscurely facetted, not as high as wide, somewhat leathery and opaque. The young caterpillars of Swallowtails often look like a bird dropping while older caterpillars are often greenish and marked with large eyespots. They are equipped with an osmeterium, a Y-shaped gland located behind the head which can be pushed out to emit a chemical disagreeable to potential predators. The Parnassian caterpillars vary in appearance but are often black, and they may be equipped with an osmeterium. Swallowtail pupae form no cocoon, often have both a cremaster and a silk girdle, and typically are the overwintering stage. Parnassian pupae generally are in a loose cocoon located on the ground in leaf litter; the egg and the caterpillar are the usual overwintering stages. Other traits of swallowtails include a behaviour called hill

topping, in which males and females congregate at the tops of slopes, trees or ridges in their effort to locate a mate.

I. Subfamily Parnassiinae

There are about 74 currently recognized species in 8 genera, with a largely Holarctic distribution (Ackery et al., 1999). Forewing median spur absent or vestigial and hindwing with one anal vein. Tarsal claws usually asymmetrical in males, sometimes also in females. Spinasternum produced laterally to some extent (Ehrlich, 1958). The Larvae are cylindrical and black, usually with red tubercles. Major host plants of subfamily are Aristolochiaceae, crassulaceae, Fumariaceae and Saxifragaceae etc.

Only one genus (Paranassius) and two species were recorded from the study area.

II. Subfamily Papilioninae

There are about 550 species in 17 genera (Ackery et al., 1999) with an overall cosmopolitan distribution although greatest diversity is in tropics. Forewing with median spur complete or vestigial; if vestigial than extremely pointed. Tarsal claws symmetrical. Larvae are usually dark with red or pale spots and a pale saddle on segment six and seven. Mainly feeds on plants of family Annonaceae, Aristolochiaceae, Lauraceae, Magnoliaceae and Rutaceae.

A total of 5 genera (Papilio, Graphium, Chilasa, Atrophaneura and Troides) were recorded from the study area.

3.4.1.2 Family Pieridae (Whites and Yellows)

Family Pieridae contains about 1,050 species in 74 genera (Ackery et al., 1999) throughout world. The family is characterized by distinctly bifid pre-tarsal claws. Pronotum with medio-posterior membranous cleft. Lateral ‘pre-spiracular bar’ absent in the abdominal base. Wing scales containing pterine-type pigments. Most pierid butterflies are white, yellow or orange in coloration, often with black spots. The Pieridae have the radial vein on the forewing with 3 or 4 branches and rarely with 5 branches. The fore legs are well developed in both sexes, unlike in the Nymphalidae,

and the tarsal claws are bifid unlike in the Papilionidae. The pigments that give the distinct colouring to these butterflies are derived from waste products in the body and are a characteristic of this family. The sexes usually differ, often in the pattern or number of the black markings. Superficially the larvae of the Pieridae look remarkably uniform. A single general description probably suffices - larva cylindrical, slightly tapering posteriorly and also laterally in later instars; shortly setose or pubescent, usually cryptic. Four subfamilies are identified globally (Ehrlich, 1958).

Like the Papilionidae, Pieridae also have their pupae held at an angle by a silk girdle, but running at the first abdominal segment unlike the thoracic girdle seen in the Papilionidae. Males of many species exhibit gregarious mud-puddling behaviour, when they may imbibe salts from moist soils.

I. Subfamily Coliadinae

Although cosmopolitan with about 250 species in 12 genera (Ackery et al., 1999) but greatest diversity is found in the tropics. Second median vein of forewing arise from the end of the cell. Third to fifth radial presents at least one arising from the cell. Humeral vein reduced or absent, tegmen considerably shorter than the uncus and patagia sclerotised (Ehrlich, 1958). Main host plants family are Asteraceae, Fabaceae, and Rhamnaceae. A total of four genera (Eurema, Gonepteryx, Catopsilia and Colias) were recorded from the study area.

II. Subfamily Pierinae

Although cosmopolitan with about 700 species in 55 genera (Ackery et al., 1999) but greatest diversity is found in the tropics. Forewing with vein M_2 arising from the end of the cell. Hindwing with sub-costal and first radial vein not secondarily fused with fifth radial vein. Humeral vein usually long, tegmen longer the uncus and patagia unsclerotised (Ehrlich, 1958). Members of this family mainly feed on plants of Crucifaerae, Capparidaceae, Loranthaceae and Santalaceae.

A total of 10 genera (Colotis, Pareronia, Pieris, Pontia, Ceporia, Prioneris, Aporia, Delias, Leptosia and Belenois) were recorded from the study area.

3.4.1.3 Family Lycaenidae (Blues, Coppers and Hairstreaks)

More than 5,650 species in about 705 genera (Ackery et al., 1999) are found with cosmopolitan distribution although greatest diversity is found in the tropics. There are five main subfamilies represented in India: Polyommatinae, Lycaeninae, Curetinae, Portiinae and Theclinae. A few authorities still include the family Riodinidae within the Lycaenidae. Antennal bases adjacent to the margin of the eye. Frontoclypeus usually less arched than in other butterflies. Patagia entirely membranous and adult individuals often have hairy antenna-like tails complete with black and white annulated appearance. Many species also have a spot at the base of the tail and some turn around upon landing to confuse potential predators from recognizing the true head orientation (false head hypothesis). This causes predators to approach from the true head end resulting in early visual detection. Adults are small, less than 5 cm usually, and brightly coloured, sometimes with a metallic gloss. The male's forelegs are reduced in size and lack claws but full-sized forelegs in females. Most of the Hairstreaks have a thin tail extending from the rear of the hindwing.

Eggs generally appear round and flattened. Caterpillars generally are small, shaped like slugs, and hairy. Larvae are often flattened rather than cylindrical, with glands that may produce secretions that attract and subdue ants. Their cuticles tend to be thickened. Some caterpillars are capable of producing vibrations and low sounds that are transmitted through the substrates they inhabit. They use these sounds to communicate with ants. The caterpillars of many of the species of blues and hairstreaks have a dorsal nectary organ which produces a sugary solution agreeable to ants. The ants feed on the solution and in turn protect the caterpillar from predators (a tending behaviour). Pupae are generally small and round, may have a silk girdle, and are located near or on the ground. Generally no cocoon is formed. The pupa may have a nectary organ as well, allowing it to be tended by ants. Overwintering occurs as the egg, caterpillar, or pupa.

I. Subfamily Portiinae

Species are restricted to Oriental region with approx 530 species in 47 genera (Ackery et al., 1999). Labial sclerite completely sclerotized. Palpi clothed with appressed scales. Male prothoracic coxae not extending spine-like below the

articulation of the trochanter. Male prothoracic legs more than half the length of the pterothoracic legs, with the protarsus fused to a single stubby-tipped segment, meso and metatibiae without terminal spurs. Forewing with 10, 11 or 12 veins, first radial vein anastomosed with sub-costal and sometimes with second radial vein. Hindwing with a very short or indistinct precostal vein; no tail or tornal lobe and no basal vein along the costa; male usually with androconial brands. The larvae are long and thin, barely tapered at either end, and with a dorsal thick covering of hair becoming sparser laterally. Major host plants belong to family Fagaceae.

Only one genus Poritia was recorded from the study area.

II. Subfamily Curetinae

The subfamily is mostly exclusive to the oriental region but a few representatives, just extended into the Palaearctic with 18 species in single genus Curetis (Ehrlich, 1958). Proboscis with a prominent series of sensory hairs on the shaft; terminal papillae strongly developed. Labial sclerite completely sclerotized and palpi normal, clothed with appressed scales. Male prothoracic coxae slightly extended spine like below the articulation of the trochanter. Male prothoracic legs more than half the length of the pterothoracic legs, with the protarsus fused to a single segment and ending in a tapered, down curved point. Meso and metatibiae with incon-spicuous terminal spurs. Forewing with 11 veins; sub-costal, first and second radial vein being free; fifth radial vein ends on the termen. Hindwing tailless and without a basal vein along the coastal margin; male lacking alar androconia. The larvae are smooth, with permanently exerted cylindrical tubercles on the eleventh segment. Host plant of the family is Fabaceae.

Only one genus Curetis was recorded from the study area.

III. Subfamily Theclinae

The subfamily is distributed in all major biogeographic regions with 2,295 species in the world (Ackery et al., 1999). Proboscis often smooth-shafted and labial sclerite completely sclerotized. Male prothoracic legs more than half the length of the pterothoracic legs, with the protarsus usually fuse to a single segment, although segmented, clawed and fully functional in some genera. Forewing with 10-12 veins,

fifth radial vein usually ends on the costa or apex, when only 10 or 11 veins are present. Hindwing without a precostal or a vein along the basal region of the costal margin, sometimes tailless but usually with 1-4 tails, torsal lobe usually well developed. Alar androchonia usually present in males. The larvae are usually more or less onisciform but sometime prominently shouldered or waisted. Subfamily species mainly feeds on plant of family Fagaceae, Loranthaceae, Oleaceae and Santalaceae.

A total of 9 genera (Esakiozephyrus, Arhopala, Loxura, Pratapa, Tajuria, Chliaria, Deudorix, Rapala and Spindasis) were recorded from the study area.

IV. Subfamily Lycaeninae

Overall represented by 4,000 species in 500 genera (Ackery et al., 1999) and most diverse in the Holarctic with weak representation in all other regions. Proboscis smooth shafted and labial sclerite completely sclerotized. Papli clothed with hairy or bristly scales. Male prothoracic coxae not extending spine like below the articulation of the trochanter. Male prothoracic legs more than half the length of the pterothoracic legs, with the protarsus fused to a single segment and ending in a sharp or rounded point; meso and metatibiae spurred. Forewing with 11 veins, fifth radial and first median vein usually narrowly separated, but sometimes connate or with a short stalk. Hindwing tailed at first cubitus vein or tailless; tornus lobed or rounded; costal margin basally lacking a vein. Alar androconia absent in males. The larvae are onisciform. Major host plants of family is Polygonaceae.

Two Genera (Lycaena and Heliophorus) were recorded from the study area.

V. Subfamily Polyommatinae

The subfamily is distributed in all major biogeographic regions with around 1,000 species (Ackery et al., 1999) in the world. Proboscis usually smooth-shafted with the terminal sensory area usually very weakly developed. Labial sclerite completely sclerotized, palpi variable. Male prothoracic coxae not extended spine like below the articulation of the trochanter. Male prothoracic legs more than one half the length of the pterothoracic legs, with the protarsus fused to a single segment and commonly ending in a tapered, down curved point; meso and metatibiae with terminal spurs. Forewing usually with 11 veins; fifth radial and first median vein separates at

their origins with some variations. Hindwing tailless or with a filamentous tail at vein first cubitus only; tornus rounded or occasionally with a vestigial lobe; basally lacking a vein along the costal margin. The larvae are onisciform. Major host plant families are Crassulaceae, Fabaceae, Laminaceae, Myrsinaceae, Primulaceae and Rutaceae.

A total 15 genera (Castallius, Leptotes, Jamides, Lampides, Tarucus, Zizeeria, Pseudozizeeria, Everes, Oreolyce, Acytolepis, Celastrina, Udara, Aricia, Chilades and Polymmatus) were recorded from the area.

VI. Subfamily Riodininae

About 1,250 species in 140 genera (Ackery et al., 1999) in all biogeographic regions but greatest diversity is found in tropics. Labial sclerite completely sclerotized. Male prothoracic legs less than half of prothoracic legs, with unsegmented tarsi and rarely with claws. Hindwing humeral vein usually present and hindwing with a vein along the base of costal margin. Larvae usually onisciform bearing short hairs. The subfamily feeds on the plants of family Asteraceae, Fabaceae and Myrtaceae.

Only two Genera (Abisara and Dodona) were recorded from the study area.

3.4.1.4 Family Nymphalidae (Brush-footed Butterflies)

About 5,600 species in 650 genera (Ackery et al., 1999) are distributed worldwide, approximately 30% of all butterflies and only competed by Family Lycaenidae in species numbers. Male forelegs always atrophied and clawless. Most antennal segments with two ventral grooves and very distinct separation of upper laterocervico-tentotrial muscles into bundles.

Many species are brightly coloured and include popular species such as the emperor, admirals, tortoiseshells and fritillaries. However, the underwings are in contrast often dull and in some species look remarkably like dead leaves, or are much lighter; producing a cryptic effect that helps the butterfly disappears into its surroundings. The forewing has the submedial vein (vein 1) unbranched and in one subfamily forked near base; medial vein with three branches, veins 2, 3 and 4; veins 5 and 6 arising from the points of junction of the discocellulars; subcostal vein and its

continuation beyond apex of cell; vein 7, with never more than four branches, veins 8–11; 8 and 9 always arising from vein 7, 10 and also 11 sometimes from vein 7 but more often free, i.e. given off by the subcostal vein before apex of cell. The hindwing has internal (1a) and peri-osteal veins. The cell in both wings closed or open often closed in the fore, open in the hindwing. Dorsal margin of hind wing channeled to receive the abdomen in many of the forms. Antennae always with two grooves on the underside; club variable in shape. Throughout the family the front pair of legs in the male and with three exceptions (Genus: Libythea, Pseudergolis and Calinaga) and in the female also, is reduced in size and functionally impotent. In some the sub-families atrophy of the forelegs is considerable, e.g. Danainae and Satyrinae. In many of the forms of these subfamilies the forelegs are kept pressed against the underside of the thorax, and often very inconspicuous in males. Pupae usually suspended from cremaster at the abdominal tip.

I. Subfamily Libytheinae

There are only 15 species in 2 genera (Ackery et al., 1999) but their overall distribution is cosmopolitan (Ehrlich and Raven, 1965). Patagia not prominent or rounded and bearing only small lateral sclerotization; metanotum essentially entirely below the mesoscutellum, which covers it. Male prothoracic legs atrophied, in female only slightly so. The generally long labial palps, a ‘traditional’ character for the Libytheines, are short enough in some species to overlap with the lengths found in some other Nymphalids (Ehrlich, 1958). The larvae are smooth, lacking both head capsule ornamentation and bifid tail. Major host plant family is Ulmaceae.

Only one genus Libythea was recorded from the study area.

II. Subfamily Danainae

There are approximately 450 currently recognized species in 62 genera (Ackery et al., 1999), although a few are found in more temperate areas, most are essentially tropical with greatest diversity in the Orient and least in the New world. Mesothoracic episternum absent as a distinct sclerite; mesothoracic pre-episternum at its widest much less than one half the width of the katepisternum. Mesomeron with a prominent caudal bulge. Antennae naked and male with abdominal hairpencil. Female protarsus four-segmented, ankylosed and strongly clubbed. Forewing third anal vein

free at the base. The larvae are smooth and conspicuously patterned, lacking both head ornamentation and a bifid tail; dorsally with between one and nine segmental pairs of fleshy tubercles. Major host plant are of Apocynaceae, Asclepiadaceae and Moraceae.

Four genera Euploea, Parantica, Danaus and Tirumala were recorded from the study area.

III. Subfamily Charaxinae

Around 400 species in 28 genera (Ackery et al., 1999) distributed throughout the tropics, only rarely extending into more temperate regions. Mesothoracic anepisternum present as a distinct sclerite; mesothoracic pre-episternum well developed; pre-episternal suture variable and parapatagia with at least some trace of sclerotization. Forewing veins not swollen at base; Hindwing cell not closed by a tubular vein (Ehrlich, 1958). The larvae are smooth, generally with a bifid tail and an armed head-capsule although at least some Anaea species lack these adornments. Major host plant families are Convolvulaceae, Euphorbiaceae, Fabaceae, Lauraceae, Piperaceae and Sapindaceae.

A total of two genera (Polyura and Charaxes) were recorded from the study area

IV. Subfamily Satyrinae (Browns)

About 2,400 species in 280 genera (Ackery et al., 1999) worldwide with considerable extra-tropical diversity. Mesothoracic anepisternum present as a distinct sclerite mesothoracic pre-episternum usually greatly reduced or separated from the katepisternum by a very weak pre-episternal suture. Forewing third anal vein not free at base and usually with at least one vein basally swollen. Hindwing cell always closed by a tabular vein and precostal cell absent. The larvae are usually smooth with a bifid tail and head capsule occasionally armed with horns. Major host plant families are Arecaceae, Cyperaceae and Poaceae.

A total of 8 genera Melanitis, Lethe, Lasiommata, Elymnias, Mycalesis, Aulocera, Callerebia and Ypthima were recorded from the study area.

V. Subfamily Heliconiinae

A total of about 400 species in 40 genera (Ackery et al., 1999) and dominantly distributed in tropics although distribution is cosmopolitan. Mesothoracic anepisternum absent as a distinct sclerite; mesothoracic pre-episternum at its widest at least one-half the width of the katepisternum. Females with adoriferous glands between abdominal segments eight and nine. Tarsal claws simple, symmetrical. Forewing third anal vein not free at the base. Male hindwing upperside always with androconia present along two or more veins (Ehrlich, 1958; Emsley 1963). The larvae are spinose, with six rows of longitudinal spines, each adorned with stiff bristles. The head is similarly armed with a pair of dorsal spines. Major host plant of the subfamily are of Passifloraceae.

A total of 11 genera (Acraea, Cethosia, Argynnis, Argyreus, Childrena, Fabriciana, Speyeria, Issoria, Cupha, Vagrans and Phalanta) were recorded from the study area.

VI. Subfamily Limenitidinae

Near about 1,000 species in 100 genera (Ackery et al., 1999) in all biogeographic regions.

A total of six genera (Limenitis, Athyma, Pantoporia, Neptis, Euthalia and Tanaecia) were recorded from the study area.

VII. Subfamily Cyrestinae

Near about 1,000 species in 100 genera (Ackery et al., 1999) in all biogeographic regions. A total of three genera (Cyrestis, Pseudergolis and Stibochiona) were recorded from the study area.

VIII. Subfamily Biblidinae

Near about 330 species (Ackery et al., 1999) are found distributed in all biogeographic regions. This subfamily has traditionally been viewed as belonging to the Limenitidinae, which has been shown to be polyphyletic (Wahlberg et al., 2003).

Most of the species of Biblidinae are neotropical, but there are some Old World representatives in Biblidini and Epicaliini.

Only one Genus Ariadne was recorded from the study area.

IX. Subfamily Apaturinae

Near about 430 species in 20 genera (Ackery et al., 1999) of emperors, peacocks and hackberry butterflies and have a cosmopolitan distribution, with a particularly diverse array of species in eastern Asia.

A total of four genera (Apatura, Sephisa, Hestina and Dilipa) were recorded from the study area.

X. Subfamily Nymphalinae

Approximately 350 species in 60 genera (Ackery et al., 1999), and distributed throughout world. Mesothoracic anepisternum absent as a distinct sclerite and tarsal claws simple and symmetrical. Females lack odoriferous glands between the eighth and ninth abdominal segments. Mouthparts usually well developed. Forewing third anal vein usually not free at base. Larvae usually cylindrical and spinose. Major host plants are of family Acanthaceae, Asteraceae, Caprifoliaceae, Euphorbiaceae, Moraceae, Sapindaceae, Ulmaceae, Verbenaceae and Violaceae.

A total 9 genera (Polygonia, Nymphalis, Aglais, Vanessa, Symbrenthia, Kaniska, Junonia, Hypolimnas and Kallima) were recorded from the study area.

3.4.2 Superfamily Hesperioidea

Neither the Papilionoidea nor the Hesperioidea has a convincing array of autapomorphies. Kristensen (1976) provide the following character for the Hesperioidea – forewing with no stalked peripheral veins; forewing with cubito-parietal absent; antennae with subapical thickenings. There is only one included family – Hesperiidae.

3.4.1.5 Family Hesperiidae (Skippers)

At global scale, Hesperiidae is represented by about 3,435 species into 545 genera (Ackery et al., 1999) into six subfamilies, of which 130 are found in oriental region. A total of 14 species are found in study area. Butterflies belong to this family are known as skippers because butterflies exhibit a rapid, erratic, skipping flight pattern. Skippers have the antennae clubs hooked backward like a crochet hook, while the typical butterflies have club-like tips to their antennae, and moth-butterflies have feathered or pectinate (comb-shaped) antennae similar to moths. They also have generally stockier bodies and larger compound eyes than the other two groups, with stronger wing muscles in the plump thorax, in this resembling many moth species.

Some have larger wings, but only rarely as large in proportion to the body as in other butterflies. When at rest, skippers keep their wings usually angled upwards or spread out, and only rarely fold them up completely. There are some with prominent hind wing tails, and others have more angled wings; the skipper' basic wing shape varies not much by comparison to Papilionoidea. However most have a fairly drab coloration of browns and greys; some are more boldly black-and-white. Generally, they lay dome shaped eggs, red or white. Eggs are laid generally singly on the underside of leaves or large grass blades and usually towards tip. Caterpillars in this family are usually with smooth body skin, more or less cylindrical shaped. Their head is large with constricted head and usually live and feed in concealed environment. They live and pupate in shelter build using silk to draw together the leaves of host plant.

I. Subfamily Coeliadinae

All known species are either Austro-Oriental or Afrotropical. Antennae short, less than half the length of the forewing costa, slender clubbed with a sharp-erect, close to the face, and the third segment long and slender, projecting forwards. Hindwing distinctly lobed; sometimes produced at the tornus; second median vein tubular, arising nearer first median than third median vein (Common and Waterhouse, 1981). The larvae are often brightly coloured and patterned with complete or incomplete hoops. Shelters are formed by folding and joining the host plant leaves.

Major host plant families are, Araliaceae, Asclepiadaceae, Euphorbiaceae, Fabaceae, Malpighiaceae, Myristaceae, Sabiaceae and Zingiberaceae

Only two genera (Hasora and Choaspes) were recorded from the study area.

II. Subfamily Pyrginae

Cosmopolitan in distribution with around 1,000 species in 160 genera (Ackery et al., 1999). Papli variable, either erect with the second segment appressed to the face, with third segment protruding in front of the second and mesotibiae without spines. Second median vein of forewing not curved at the base and usually about intermediate between first median and third median vein, or near to first median vein at its origin; cell either long, approximately two-third the length of the costa (Evans, 1952). The larvae may be brightly coloured, or uniformly green, brown or whitish, and slender and pilose. The caterpillars form shelters by folding and joining the leaves of their host plant. Major host plant families are Combretaceae, Fabaceae, Lauraceae, Malvaceae, Myrtaceae, Rosaceae, Sterculiaceae and Verbenaceae.

A total of six genera (Sarangesa, Celaenorrhinus, Spialia, Pseudocoladenia, Tagiades and Odontoptilum) were recorded from the study area.

III. Subfamily Hesperiinae

The subfamily is distributed worldwide, in all major biogeographic regions, with more than 2,000 species in about 325 genera (Ackery et al., 1999). Male lacking hair pencil on the metatibiae. Second median vein of forewing arising nearer third median than first median vein; male forewing upperside with brands or a stigma but never with a costal fold. Wings held erect when at rest (Evans, 1955). The larvae are slender, smooth or finely pubescent, with a well defined neck; commonly pale green, yellowish or whitish. The larvae often construct tunnels of grass stems woven together. Major host plant of the families Agavaceae, Arecaceae, Combretaceace, Cyperaceae, Flagellariaceae, Heliconiaceae, Liliaceae, Musaceae, Pandanaceae, Poaceae (Gramineae), Rubiaceae, Spindaceae and Zingiberaceae.

A total of four genera (Taractrocera, Oriens, Potanthus and Pelopidas) were recorded from the study area.

3.5 Butterflies in Indian Wildlife (Protection) Act, 1972

Also 18 species (Table 3.1) *Papilio machaon* (Common Yellow Swallowtail), *Delias sanaca* (Pale Jezebel), *Portia hewitsoni* (Common Gem), *Pratapa deva* (Tufted White Royal), *Tajuria illurgis* (White Royal), *Rapala varuna* (Indigo Flash), *Spindasis lohita* (Long-Banded Silverline), *Lampides boeticus* (Pea Blue), *Everes diporoides* (Chapman's Cupid), *Libythea lepita* (Common Beak), *Euploea mulciber* (Striped Blue Tiger), *Lethe insana* (Common Forester), *Lethe goalpara* (Large Goldenfork), *Fabriciana adippe (*Highbrown Silverspot), *Neptis narayana* (Broadstick Sailer), *Neptis ananta* (Yellow Sailer), *Dilipa morgiana* (Golden Emperor) and *Hypolimnas misippus* (Danaid Eggfly) found in Tons valley has been listed in various schedules (I, II and IV) of Indian Wildlife (Protection) Act, 1972. In total, these are about 9.5% of total species (189), which were recorded from Tons valley and were listed in Indian Wildlife (Protection) Act (1972) (Anonymous, 2006). These species are highly important from conservation point of view.

Table 3.1: A list of total 189 species of butterflies recorded during April 2008 to October 2012, in Tons valley. Status of butterflies in Indian Wildlife (Protection) Act, 1972 is also provided.

S. No.	Species	Author	Family (Subfamily)	IWPA* Status
1	*Paranassius epaphus*	Oberthür, 1897	**Papilionidae (Parnassiinae)**	-
2	*Paranassius hardwickii*	Gray, 1831		-
3	*Graphium sarpedon*	Linnaeus, 1758	**Papilionidae (Papilioninae)**	-
4	*Graphium cloanthus*	Cramer, 1775		-
5	*Graphium doson*	C. & R. Felder, 1864		-
6	*Graphium* sp.	-		-
7	*Graphium nomius*	Esper, 1798		-
8	*Graphium eurous*	Leech, 1893		-
9	*Chilasa agestor*	Gray, 1832		-
10	*Chilasa clytia*	Linnaeus, 1758		-
11	*Papilio polytes*	Linnaeus, 1758		-
12	*Papilio helenus*	Linnaeus, 1758		-
13	*Papilio protenor*	Cramer, 1775		-
14	*Papilio alcmenor*	C. & R. Felder, 1864		-
15	*Papilio demoleus*	Linnaeus, 1758		-
16	*Papilio machaon*	Linnaeus, 1758		**II**
17	*Papilio paris*	Linnaeus, 1758		-
18	*Papilio polyctor*	Boisduval, 1836		-
19	*Atrophaneura polyeuctes*	Doubleday, 1842		-
20	*Atrophaneura dasarada*	Moore, 1857		-
21	*Atrophaneura aristolochiae*	Fabricius, 1775		-
22	*Troides aeacus*	C. & R. Felder, 1860		-
23	*Eurema blanda*	Boisduval, 1836	**Pieridae (Coliadinae)**	-
24	*Eurema brigitta*	Cramer, 1780		-
25	*Eurema laeta*	Boisduval, 1836		-

S. No.	Species	Author	Family (Subfamily)	IWPA* Status
26	*Eurema hecabe*	Linnaeus, 1758		
27	*Gonepteryx rhamni*	Linnaeus, 1758		-
28	*Gonepteryx mahaguru*	Gistel, 1857		-
29	*Catopsilia pomona*	Fabricius, 1775		-
30	*Catopsilia pyranthe*	Linnaeus, 1758		-
31	*Colias fieldii*	Ménétriés, 1855		-
32	*Colias erate*	Esper, 1805		-
33	*Colotis etrida*	Boisduval, 1836	**Pieridae (Pierinae)**	-
34	*Parenonia valeria*	Cramer, 1776		-
35	*Pieris brassicae*	Linnaeus, 1758		-
36	*Pieris napi*	Linnaeus, 1767		-
37	*Pieris canidia*	Linnaeus, 1768		-
38	*Pontia daplidice*	Linnaeus, 1758		-
39	*Ceporia nerissa*	Fabricius, 1775		
40	*Aporia leucodice*	Eversmann, 1843		-
41	*Aporia agathon*	Gray, 1832		-
42	*Delias belladonna*	Fabricius, 1793		-
43	*Delias sanaca*	Moore, 1857		**I**
44	*Delias eucharis*	Drury, 1773		-
45	*Leptosia nina*	Fabricius, 1793		-
46	*Belenois aurota*	Fabricius, 1793		-
47	*Poritia hewitsoni*	Moore, 1865	**Lycaenidae (Portiinae)**	**II**
48	*Curetis bulis*	Westwood, 1851	**Lycaenidae (Curetinae)**	-
49	*Esakiozephyrus mandara*	Doherty, 1886	**Lycaenidae (Theclinae)**	-
50	*Arhopala amantes*	Hewitson, 1862		-
51	*Arhopala ganesa*	Moore, 1857		-
52	*Loxura atymnus*	Cramer, 1782		-
53	*Pratapa deva*	Moore, 1857		**II**
54	*Tajuria jehana*	Moore, 1883		-
55	*Tajuria illurgis*	Hewitson, 1869		**II**
56	*Chliaria kina*	Hewitson, 1869		-
57	*Deudorix isocrates*	Fabricius, 1793		-
58	*Deudorix perse*	Hewitson,1863		-
59	*Deudorix epijarbas*	Moore, 1858		-
60	*Rapala jarbas*	Fabricius, 1787		-

S. No.	Species	Author	Family (Subfamily)	IWPA* Status
61	*Rapala varuna*	Hewitson, 1863		**II**
62	*Spindasis lohita*	Horsfield, 1829		**II**
63	*Spindasis vulcanus*	Fabricius, 1775		-
64	*Lycaena phlaeas*	Linnaeus, 1761	**Lycaenidae (Lycaeninae)**	-
65	*Lycaena pavana*	Kollar, 1848		-
66	*Lycaena kasyapa*	Moore, 1865		-
67	*Heliophorus brahma*	Moore, 1857		-
68	*Heliophorus androcles*	Westwood, 1851		-
69	*Heliophorus tamu*	Kollar, 1848		-
70	*Heliophorus sena*	Kollar, 1844		-
71	*Castallius rosimon*	Fabricius, 1775	**Lycaenidae (Polyommatinae)**	-
72	*Leptotes plinius*	Fabricius, 1793		-
73	*Jamides celeno*	Cramer, 1775		-
74	*Lampides boeticus*	Linnaeus, 1767		**II**
75	*Tarucus nara*	Kollar, 1848		-
76	*Zizeeria karsandra*	Moore, 1865		-
77	*Pseudozizeeria maha*	Kollar, 1848		-
78	*Everes diporoides*	Chapman, 1909		**II**
79	*Oreolyce vardhana*	Moore, 1874		-
80	*Acytolepis puspa*	Horsfield, 1828		-
81	*Celastrina argiolus*	Linnaeus, 1758		-
82	*Celastrina huegelii*	Moore, 1882		-
83	*Udara dilecta*	Moore, 1879		-
84	*Aricia astrarche*	Bergstrasser, 1779		-
85	*Chilades pandava*	Horsefield, 1829		-
86	*Polymmatus eros*	Ochsenheimer, 1808		-
87	*Abisara echirius*	Stoll, 1790	**Lycaenidae (Riodininae)**	-
88	*Dodona eugenes*	Bates, 1867		-
89	*Dodona durga*	Kollar & Redtenbacher, 1844		-

S. No.	Species	Author	Family (Subfamily)	IWPA* Status
90	*Libythea lepita*	Moore, 1857	**Nymphalidae (Libytheinae)**	**II**
91	*Libythea myrrha*	Godart, 1819		-
92	*Tirumala limniace*	Cramer, 1775	**Nymphalidae (Danainae)**	-
93	*Tirumala septentrionis*	Butler, 1874		-
94	*Danaus genutia*	Cramer, 1779		-
95	*Danaus chrysippus*	Linnaeus, 1758		-
96	*Parantica aglea*	Stoll, 1782		-
97	*Parantica sita*	Kollar, 1844		-
98	*Euploea mulciber*	Cramer, 1777		**IV**
99	*Euploea core*	Cramer, 1780		-
100	*Polyura athamus*	Drury, 1773	**Nymphalidae (Charaxinae)**	-
101	*Charaxes polyxena*	Cramer, 1775		-
102	*Melanitis leda*	Linnaeus, 1758	**Nymphalidae (Satyrinae)**	-
103	*Melanitis phedima*	Herbst, 1796		-
104	*Lethe rohria*	Fabricius, 1787		-
105	*Lethe europa*	Fabricius, 1787		-
106	*Lethe insana*	Kollar, 1844		**II**
107	*Lethe verma*	Kollar, 1844		-
108	*Lethe sidonis*	Hewitson, 1863		-
109	*Lethe goalpara*	Moore, 1865		**II**
110	*Lasiommata schakra*	Kollar, 1844		-
111	*Elymnias hypermnestra*	Linnaeus, 1763		-
112	*Mycalesis francisca*	Stoll, 1780		-
113	*Mycalesis perseus*	Fabricius, 1775		-
114	*Mycalesis myneus*	Linnaeus, 1758		-
115	*Aulocera padma*	Kollar, 1844		-
116	*Aulocera swaha*	Kollar, 1844		-
117	*Aulocera saraswati*	Kollar, 1844		-
118	*Callerebia ananda*	Moore, 1858		-
119	*Callerebia nirmala*	Moore, 1865		-
120	*Callerebia scanda*	Kollar, 1844		-
121	*Ypthima asterope*	Klug, 1832		-

S. No.	Species	Author	Family (Subfamily)	IWPA* Status
122	*Ypthima baldus*	Fabricius, 1775		-
123	*Ypthima nareda*	Kollar, 1844		-
124	*Ypthima sakra*	Moore, 1857		-
125	*Acraea violae*	Fabricius, 1758	**Nymphalidae (Heliconiinae)**	-
126	*Cethosia cyane*	Drury, 1773		-
127	*Argynnis pandora*	Denis & Schiffermüller, 1775		-
128	*Argyreus hyperbius*	Linnaeus, 1763		-
129	*Childrena childreni*	Gray, 1831		-
130	*Fabriciana adippe*	Denis & Schiffermüller, 1775		**II**
131	*Fabriciana kamala*	Moore, 1857		-
132	*Speyeria aglaja*	Linnaeus, 1758		-
133	*Issoria lathonia*	Linnaeus, 1758		-
134	*Cupha erymanthis*	Drury, 1773		-
135	*Vagrans egista*	Cramer, 1780		-
136	*Phalanta phalantha*	Drury, 1773		-
137	*Limenitis trivena*	Moore, 1864	**Nymphalidae (Limenitidinae)**	-
138	*Athyma perius*	Linnaeus, 1758		-
139	*Athyma opalina*	Kollar, 1844		-
140	*Pantoporia hordonia*	Stoll, 1790		-
141	*Neptis yerburyi*	Butler, 1886		-
142	*Neptis hylas*	Linnaeus, 1758		-
143	*Neptis mahendra*	Moore, 1872		-
144	*Neptis sankara*	Kollar, 1844		-
145	*Neptis narayana*	Moore, 1858		**II**
146	*Neptis ananta*	Moore, 1858		**II**
147	*Euthalia aconthea*	Cramer, 1777		-
148	*Euthalia lubentina*	Cramer, 1777		-
149	*Euthalia nais*	Forester, 1771		-
150	*Tanaecia julii*	Lesson, 1837		-
151	*Cyrestis thyodamas*	Boisduval, 1846	**Nymphalidae (Cyrestinae)**	-
152	*Pseudergolis wedah*	Kollar, 1848		-
153	*Stibochiona nicea*	Gray, 1846		-

S. No.	Species	Author	Family (Subfamily)	IWPA* Status
154	*Ariadne merione*	Cramer, 1777	**Nymphalidae (Biblidinae)**	-
155	*Apatura ambica*	Kollar, 1844	**Nymphalidae (Apaturinae)**	-
156	*Dilipa morgiana*	Westwood, 1850		**I**
157	*Hestina nama*	Doubleday, 1844		-
158	*Sephis adichroa*	Kollar, 1844		-
159	*Symbrenthia hypselis*	Godart, 1824		-
160	*Symbrenthia hippoclus*	Cramer, 1779		-
161	*Vanessa indica*	Herbst, 1794	**Nymphalidae (Nymphalinae)**	-
162	*Vanessa cardui*	Linnaeus, 1758		-
163	*Aglais cashmiriensis*	Kollar, 1848		-
164	*Nymphalis xanthomelas*	Esper, 1781		-
165	*Polygonia egea*	Cramer, 1775		-
166	*Kaniska canace*	Linnaeus, 1763		-
167	*Junonia orithya*	Linnaeus, 1758		-
168	*Junonia hierta*	Fabricius, 1798		-
169	*Junonia iphita*	Cramer, 1779		-
170	*Junonia atlites*	Linnaeus, 1763		-
171	*Junonia almana*	Linnaeus, 1758		-
172	*Junonia lemonias*	Linnaeus, 1758		-
173	*Hypolimnas misippus*	Linnaeus, 1764		**II**
174	*Hypolimnas bolina*	Linnaeus, 1758		-
175	*Kallima inachus*	Boisduval, 1846		-
176	*Hasora chromus*	Cramer, 1780	**Hesperiidae (Coeliadinae)**	-
177	*Choaspes benjaminii*	Guerin-Méneville, 1843		-
178	*Spialia galba*	Fabricius, 1793	**Hesperiidae (Pyrginae)**	-
179	*Sarangesa dasahara*	Moore, 1866		-
180	*Sarangesa purendra*	Moore, 1882		-

S. No.	Species	Author	Family (Subfamily)	IWPA* Status
181	*Celaenorrhinus leoucocera*	Kollar, 1844		-
182	*Pseudocoladenia dan*	Fabricius, 1787		-
183	*Tagiades japetus*	Stoll, 1782		-
184	*Tagiades litigiosa*	Möschler, 1878		-
185	*Odontoptilum angulata*	C. & R. Felder, 1862		-
186	*Taractrocera maevius*	Fabricius, 1793	**Hesperiidae (Hesperiinae)**	-
187	*Oriens goloides*	Moore, 1881		-
188	*Potanthus dara*	Kollar, 1844		-
189	*Pelopidas mathias*	Fabricius, 1798		-

*Indian Wildlife (Protection) Act, 1972 (Anonymous, 2006)

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CHAPTER 4

DIVERSITY AND COMPOSITION OF BUTTERFLY ASSEMBLAGES

4.1 Introduction

Our knowledge of global biodiversity and its rate of extinction is very limited, but of the 3 – 100 million species believed to exist, conservative estimates point to about 3000 being lost each year, that is, eight species per day (Wilson, 2003a; González-Oreja, 2008). The vast majority belongs to understudied taxa such as certain groups of arthropods (Evans, 1993; Wilson, 1987). They are subject to the same extinction processes as larger and more familiar organisms, plus a few additional ones, such as co-extinction and extinction of narrow habitat specialists (Dunn, 2005; Dunn et al., 2009). When corrected for knowledge bias, data from invertebrates show even higher extinction rates and proportions of threatened species than those of well-known taxa such as birds and mammals (Stork and Lyal, 1993; Thomas and Morris, 1994; MacKinney, 1999; Moir et al., 2010). Despite of high diversity and importance for humankind, arthropods have largely been neglected in conservation studies and policies worldwide (Kremen et al., 1993; New, 1999; Zamin et al., 2010).

4.1.1 Importance of Butterfly as Indicator of Biodiversity in Conservation Planning

In order to evaluate and monitor biodiversity as well as to implement conservation measures, the development and use of shortcuts is a necessity. Obviously, it is not viable to consider the development of a detailed study for each one of the endangered species. One possible approach is based on diversity measures, but it has several limitations like excluding particular taxonomic information about the communities (Noss, 1990; Dufrêne and Legendre, 1997). The criterion of representative diversity which is based on the recognition of assemblages of species that are typical for specific habitats seems more interesting (Dufrêne and Legendre, 1997). A potentially useful tool is the single species approach based on focal or surrogate species, which can indicate ecological change, patterns of richness or habitat type (Noss, 1990; Caro and O'doherty, 1999; Fleishman et al., 2000). Focal species include umbrella, flagship and different kind of indicator species (Mcgeoch, 1998; Simberloff, 1998).

Some of these species could be used as targets for conservation efforts, assuming their preservation may help to protect other species that share the same habitats. Thus, the use of surrogate species may be a valuable tool for conservation planning, allowing considerable reductions of time and funding costs. Moreover, the use of assemblages instead of single species as indicators enables the enlargement of the focus of the single-species approach to wider ecological situations (Kremen, 1992). Assemblages of species, with determined species richness, level of dominance, and taxonomic composition, can characterize different habitats. The use of a small set of surrogate species allows the inclusion of a broader range of habitats. Using keystone species may be an interesting alternative to surrogate species (Simberloff, 1998). However, the effort and time demanded by this approach in the study of the community processes and the high rate of degradation of the biotic diversity, make the use of other tools necessary (e.g., surrogate species) enabling conservation managers to develop faster responses to the anthropogenic disturbances.

Lepidoptera is a highly diverse order of class Insecta, accounting for more than 150,000 species. It is becoming more widely recognized that conservation biologists should include insect diversity as a data source for planning conservation in tropical forests (Kremen et al., 1993; Meyers et al., 2000; Clark and May, 2002; Leather et al., 2008). Lepidoptera have been proposed as surrogate species by several authors (Kremen, 1992; Beccaloni and Gaston, 1995; Fleishman et al., 2000). Several features of the butterflies make them good candidates for indicator, umbrella and/or flagship species (New, 1997; Fleishman et al., 2000; Maes and Van Dyck, 2001). They have a wide distribution, are relatively easy to sample and identify, both as individuals and species and they show important numbers in different ecosystems (Blair, 1999; Caro and O'doherty, 1999; Ricketts et al., 2002). They are also strongly influenced by local weather and highly sensitive to environmental changes (Spitzer et al., 1997), besides being charismatic insects that could attract the public attention. Finally, some authors have identified patterns of co-variation between the abundance and/or the richness of Lepidoptera and those of other taxonomic groups (Blair, 1999; Swengel and Swengel, 1999). However, these relationships are highly dependent on the taxa and the spatial scale considered (Ricketts et al., 2002).

Butterflies are extremely sensitive to changes in vegetation composition and structure, and different types of vegetation show different butterfly species composition. So, the

butterfly assemblages may be used to characterize different habitats (Erhardt, 1985). Plants are the essential source of nourishment of butterflies; some specific plant species provide the trophic resources for caterpillars, while others provide nectar for adults. The vegetation can also play an important role for butterfly survival offering particular structural elements for sun-basking or mating and determining certain suitable microclimates (Dover et al., 1997). Therefore, it would be expected that butterflies respond more strongly to vegetation gradients than to edaphic gradients (Sawchik et al., 2003). Human disturbance in Himalayan ecosystem has accelerated during last few centuries, resulting in a very high pressure on these ecosystems. An important factor for these changes is drastic changes in landuse. Many of the natural vegetations are being invaded by invasive species, while others suffer fragmentation, deforestation, etc. Moreover, these modifications lead to an increasing isolation of the remaining fragments.

In this chapter a description of diversity and species composition of butterflies as well as their differences between habitat types within study area are provided. The aims of the study were (1) to investigate the butterfly species richness, diversity and composition in different habitats in Tons valley and (2) to compare similarity and dissimilarity between habitat in terms of family and species composition. Further the reasons for differences in butterfly assemblages among habitats were discussed.

4.2 Methods

4.2.1 Study Area

Study was conducted across four habitat types in upper catchment of Tons valley. Sites were distributed between 900 – 3500 m elevations. Study area possessed a gradient of disturbance, such as natural, undisturbed forest to highly disturbed forest land. The study area can be divided into 3 distinct sampling zones *viz.* (1) Govind National Park, (2) Govind Wildlife Sanctuary and (3) Unprotected area (that lies outside any formal protection category) (Figure 4.1). The habitat types contained contagious and relatively homogeneous areas of each vegetation community (Plate 15 - 18). Four habitat types were identified based on apparent differences in vegetation type, physiography, soil conditions and elevation as follows:

(a) Mixed riparian and scrub forest

These forests being invariably found in the moist depressions upto 1800 m, seldom occur over large continuous areas. The tree species were usually deciduous and found mixed, but at some places *Aesculus indica*, *Acer caesium* and *Toona serrata*, dominate the vegetation. Other common species found in these forests are *Celtis australis, Albizia julibrissin, Olea ferruginea, Mallotus philippensis, Ougeinia oojeinensis, Viburnum* spp., *Rhus parviflora, Lyonia ovalifolia, Phoebe lanceolata, Cinnamonum tamala, Alnus nepalensis, Prinsepia utilis, Rubus ellipticus*, etc. Mixed forests were also interspersed with large and small patches of open area, scrub and thorn vegetation upto 1500 m. *Euphorbia royleana* forms the pure patches over rocky hill slopes, it seldom occurs in association with other species. The common species of the scrub and thorny vegetation were *Rhus parviflora, Zanthoxylum armatum, Murraya koenigii, Rhamnus virgatus, R. procumbens, Vitex negundo, Berberis asiatica, Prinsepia utilis, Abelia triflora, Achyranthes bidentata, Plectranthus rugosus, Holmskioldia sanguine, Adhatoda zeylancia,* etc., and grasses like *Phragmites karka, Heteropogon contort* and *Arundinella nepalensis* etc.

(b) Pine forest

These forests are most widely distributed, occupying the lower slopes in all river catchments, chiefly at 750 – 800 m elevation, occasionally extending above and below this zone and extended upto 2300 m, confining to hotter exposed sites. In all pine forests *Pinus roxburghii*, the sole dominant species attains optimum growth in the area but occasionally associated with trees like *Lyonia ovalifolia, Phyllanthus emblica, Ougeinia oojeinensis, Pyrus pashia* at edges and in drier rocky places with *Euphorbia royleana*.

(c) Broadleaf forest

There were three species of Oak in the Tons Valley *viz.* banj (*Quercus leucotrichophora*), moru (*Q. dilatata*) and kharshu (*Q. semecarpifolia*) which occupy more or less distinct altitudinal zones between 1800 – 3500 m. Soil remains usually moist due to high degree of atmospheric humidity throughout the monsoon period, which results in the rich epiphytic flora of mosses, ferns and lichens. Other tree species in broadleaf forests were *Acer caesium, Aesculus indica, Symplocos paniculata, Lyonia ovalifolia, Neolitsea umbrosa, Ilex*

dipyrena, Cornus capitata, Phoebe lanceolata and *Rhododendron arboreum.* The common shrubs were *Berberis chitria, Desmodium elegans, Indigofera heterantha, Daphne papyracea, Myrsine africana, Prinsepia utilis, Leptodermis lanceolata etc.*

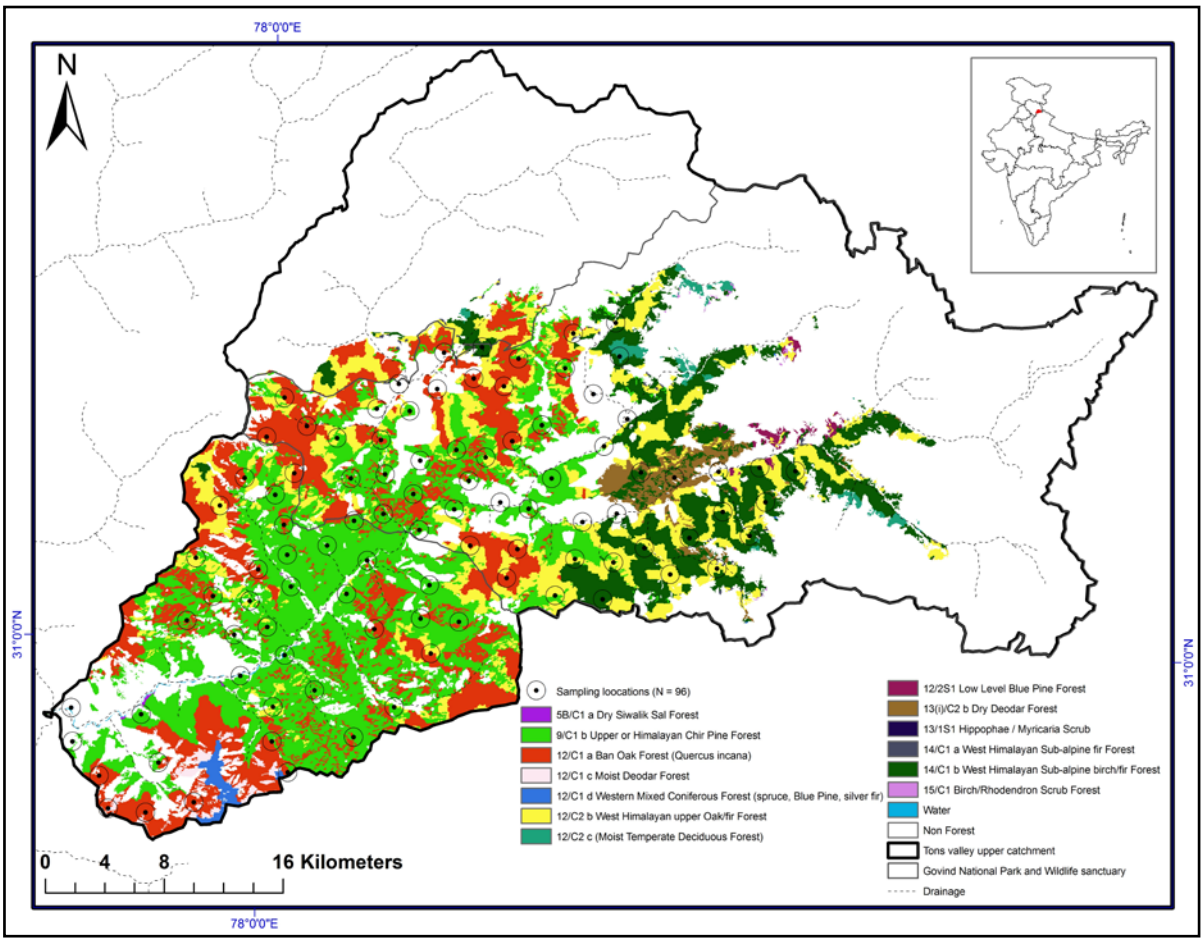

Figure 4.1: Map showing sampling plots (N = 96) laid in different habitats in the Tons valley.

(d) Conifer and alpine forest

The dominating tree in the conifer forests is *Cedrus deodara, Pinus wallichiana, Abies pindrow, Quercus leucotrichophora, Q. dilatata* between 2000 – 3000 m elevation. The alpine forest was found between 2800 – 4000 m. Forest is generally open, dominating vegetation including *Rhododendron campanulatum* scrub above which lie meadows. The zone is dominated by herbaceous species *viz. Cyanthus* sp., *Gentiana* sp., *Danthonia* sp., *Potentilla* sp., *Rhododendron barbatum, Picrorhiza* sp. and *Nardostachys grandiflora*.

4.2.2 Butterflies

Data on species richness and abundance of butterflies in each habitat were collected between April 2009 - March 2010. Butterfly species richness and abundance data was collected on a total of 96 transects (Figure 4.1). Data on 10 transects in each habitat under each protection category was pooled which results in total butterfly species richness in each habitat. Thus the sampling design was as followed (10 transects x 4 habitats x 3 protection categories). Thus, it results into 40 transects in each protection category. However only 16 transect were laid in Govind NP due to unavailability of habitats that were uniformly present in Govind WLS and unprotected area. This was because the available elevation was restricted between 1800 – 6323 m in Govind NP. All transect lengths were 300 m and transects were sampled for 30 min. Data was collected when cloud cover was less than 70% and between 900 - 1300 hrs, the most favorable conditions for butterfly flight. All butterflies seen during the transect walk in an imaginary 5 × 5 × 5 (m) box around the observer were recorded. Butterflies that were too fast or too distant to reliably identify during flight were not counted. Butterflies that could not be readily identified visually were either photographed or captured using a hand held sweep net and were released after identification. The few voucher specimens that were collected deposited at the insect repository of the Wildlife Institute of India (WII) in Dehradun.

All butterflies of Hesperioidea and Papilionoidea (Order: Lepidoptera, Suborder: Rhopalocera) were sampled. Five butterfly families (i.e. Hesperiidae, Papilionidae, Pieridae, Lycaenidae, and Nymphalidae) were recorded in study area and were identified to species level following Evans (1932), Wynter-Blyth (1957), Haribal (1992), Kunte (2000) and Kehimkar (2008).

4.2.3 Analysis

4.2.3.1 Species Richness, Diversity and Inventory Completeness

Species richness estimates (non-parametric) were calculated based on individual-based species accumulation curves (Gotelli and Colwell, 2001) for assessing sampling effort and efficiency using program EstimateS (Colwell, 2009). Program EcoSim (Gotelli and Entsminger, 2004) was used to generate rarefaction curves for comparing species richness

estimates between sites. Many indices have been developed to measure and compare diversity (Magurran, 1988). To sample diverse communities species numbers are not accurate descriptors of diversity (Gotelli and Colwell, 2001). Fisher's alpha of the log series was calculated as measure of total diversity using EstimateS 8.0 (Colwell, 2006). Log series-type distributions commonly occur in nature and measures such as Fisher's alpha are suitable to characterize such datasets. Fisher's alpha has also been extensively used in many other arthropod studies, thus facilitating comparisons between studies (Shochat et al., 2004).

4.2.3.2 Community Composition and Site Similarity Analysis

To look at the differences in butterflies abundance between habitats Kruskal-Wallis test in program Past ver. 1.73 (Hammer et al., 2007) was used.

Analyses for community composition were done with non-parametric tests. The ANOSIM test, (Analysis of similarities - Clarke, 1993) an analogue to the ANOVA, was employed to test for significance in the butterfly species and family composition among sampling sites using PRIMER software (Clarke and Gorley, 2006). The ANOSIM results in dissimilarity values in community composition of compared groups. Importantly, the dissimilarity is calculated using the overlap of species lists and the species abundances, which makes this test appropriate for comparative community composition assessments. This method generates a global *R*-statistic, which is a measure of the distance between groups. A *R*-value that approaches one indicates strongly distinct assemblages, whereas an *R*-value close to zero indicates that the assemblages are barely separable (Clarke, 1993). Before ANOSIM was executed, transformations were applied to the abundance data in order to limit the effect of zeros and the contrast of extreme high and low abundance values. These *R*-values were used to compare butterfly assemblages between habitat types.

Where ANOSIM revealed significant differences between groups, SIMPER analyses (PRIMER) were used to identify those species that contributed most to the observed assemblage differences (Clarke and Gorley, 2001). Similarity percentages (SIMPER) allowed identification of species and guilds important in discriminating between groups that differed significantly from each other. Cumulative contributions were cut arbitrarily at 50%. The

species with the highest dissimilarity to standard deviation ratios were identified as good discriminators for each comparison (Clarke, 1993).

Community-level analysis was performed using MDS (multidimensional scaling) analysis in program Primer (Clarke and Gorley, 2001) to look at the grouping between sites in ordinate space. The ordination was based on Bray–Curtis dissimilarity matrix (single link) (Bray and Curtis, 1957; Krebs, 1989) of ecological distance using both species and guild composition. Bray-Curtis resemblance matrices for butterflies were generated (Bray and Curtis, 1957) and used for differences in sampling plots. The Bray-Curtis resemblance values show plot to plot combinations, and create, e.g., a 96 by 96 matrix (of which half contains values). Furthermore, the Bray-Curtis matrix expresses resemblance values varying between 0 and 1, where 0 is no resemblance and 1 means complete resemblance. Every value reflects the resemblance of one plot with another considering the species list and their abundances.

4.3 Results

4.3.1 Species Richness and Inventory Completeness

A total of 8,432 individuals of butterflies were recorded representing 5 families, 92 genera and 159 species during sampling, which account for 38% of butterfly species recorded in western Himalayan region and about 13% of species in Indian mainland (see Appendix 4.1 for the habitat wise presence absence of butterfly species).

The pooled accumulation curve reached an asymptote for all the estimators (Figure 4.2), indicating that sampling was almost complete at regional level. Regional inventory completeness was around 96% (Table 4.1), which can be suggested as exhaustive sampling. The estimated species richness using Chao1 and Chao2 was 163 ± 4.88 (SE) and using Jacknife2 (166 species) for the complete dataset. The ratio of observed to estimated (Chao1 and Jacknife2) suggested that inventory was almost complete at regional level while 3-5% more species are to be expected in the area than what were actually recorded. The curve of observed species richness start reaching asymptote around 50 samples. After which only six species were observed, while increased sampling upto 91 samples. This means that 40-60 samples are enough to considerably inventorize the butterfly fauna in the study area.

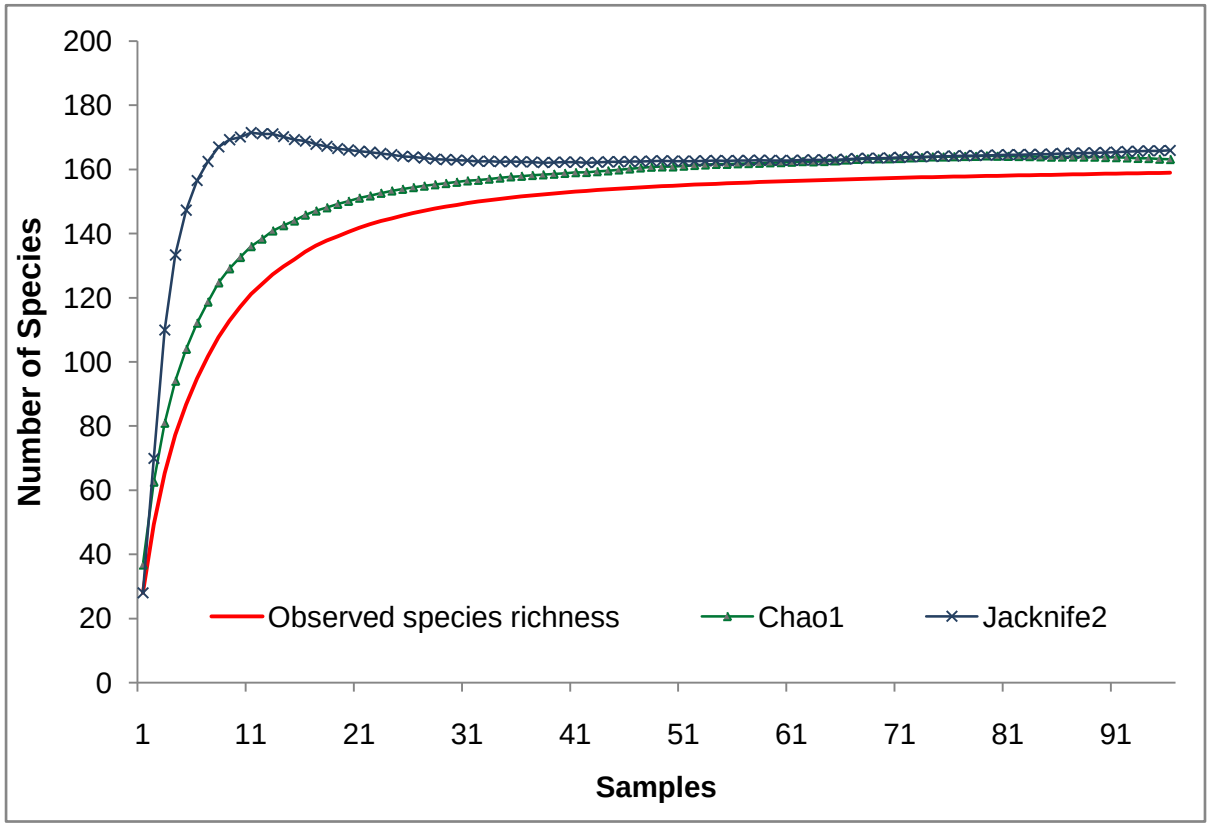

Figure 4.2: Species accumulation curves and non-parametric estimators for the regional (all samples pooled) inventory. Curves are generated from 100 randomizations.

4.3.2 Habitat Diversity and Community Composition

Significant differences were observed in butterflies abundance across habitats (Kruskal-Wallis Test: χ^2 = 5.9, P = 0.05). Average number of species recorded at each site (N = 96) were 28.28 (SE ± 2.09) with a minimum of 5 and a maximum of 83 species. Mean number of butterfly individuals at each site varied from a minimum of 7 to 343 individuals. The most abundant species was *Pieris canidia* (503 individuals) and most individuals were recorded in mixed riparian and scrub forest (201). Highest number of species (149) and individuals (3,885) were recorded from mixed riparian and scrub forest followed by broadleaf forest (103) and pine forest (564 individuals representing 57 species) and lowest in conifer and alpine forest (1,342 individuals representing 42 species). From all the species recorded 28 were singletons (17% of all species) and 15 (9.4% of all species) were doubletons. The highest numbers of singletons were found in conifer and alpine forests. However, there were not many differences in singletons between sites of mixed riparian forest and broadleaf forest.

Mean butterfly diversity at each site was 15.10 (Fisher's alpha) and varied from a minimum of 8.5 at conifer and alpine forest followed by pine forest (9.9) site to a very high of 28.9 at mixed riparian and scrub forest. Diversity was significantly lower in other three butterfly habitats than in mixed riparian and scrub forest (Table 4.1).

At the habitat level, inventory completeness was highest for pine forest (82.4%) followed by mixed riparian and scrub forest (80.9%), broadleaf forest (59.9%) and conifer and alpine forest (37%).

Table 4.1: Species richness, abundance, fisher's alpha, singleton and doubleton species, estimates of species richness and inventory completeness for each habitat type and for the regional dataset.

Habitats	Mixed riparian and scrub forest	Pine forest	Broad leaf forest	Conifer and alpine forest	Regional
No. of Specimens	3885	564	2298	1342	8432
Species richness	131	57	103	42	159
Fisher's alpha	28.96	9.99	16.62	8.56	15.10
Number of Singletons	9	10	7	14	28
Number of Doubletons	13	7	15	11	15
Chao1	156.7 (±5.8)	65.1 (±5.9)	152.45 (±9.1)	102.08 (±16.0)	163
Jacknife2	161.8	69.1	171.8	113.4	166
% Completeness	80.9	82.4	59.9	37.0	95.7

4.3.3 Species Composition and Habitat Similarity

The hierarchical cluster analysis classified all of the 96 sampling sites into four distinct groups with respect to butterfly compositions (Figure 4.3). Among these habitats mixed riparian and scrub forests clustered separately and showed similarity in butterfly composition with broadleaf forest. Sites of pine forest, broadleaf and conifer forests were also clustered separately. Few sites of all habitats grouped into cluster of other habitats, which may be due to edge effect and influences the butterfly composition of neighbour habitats at habitat edges.

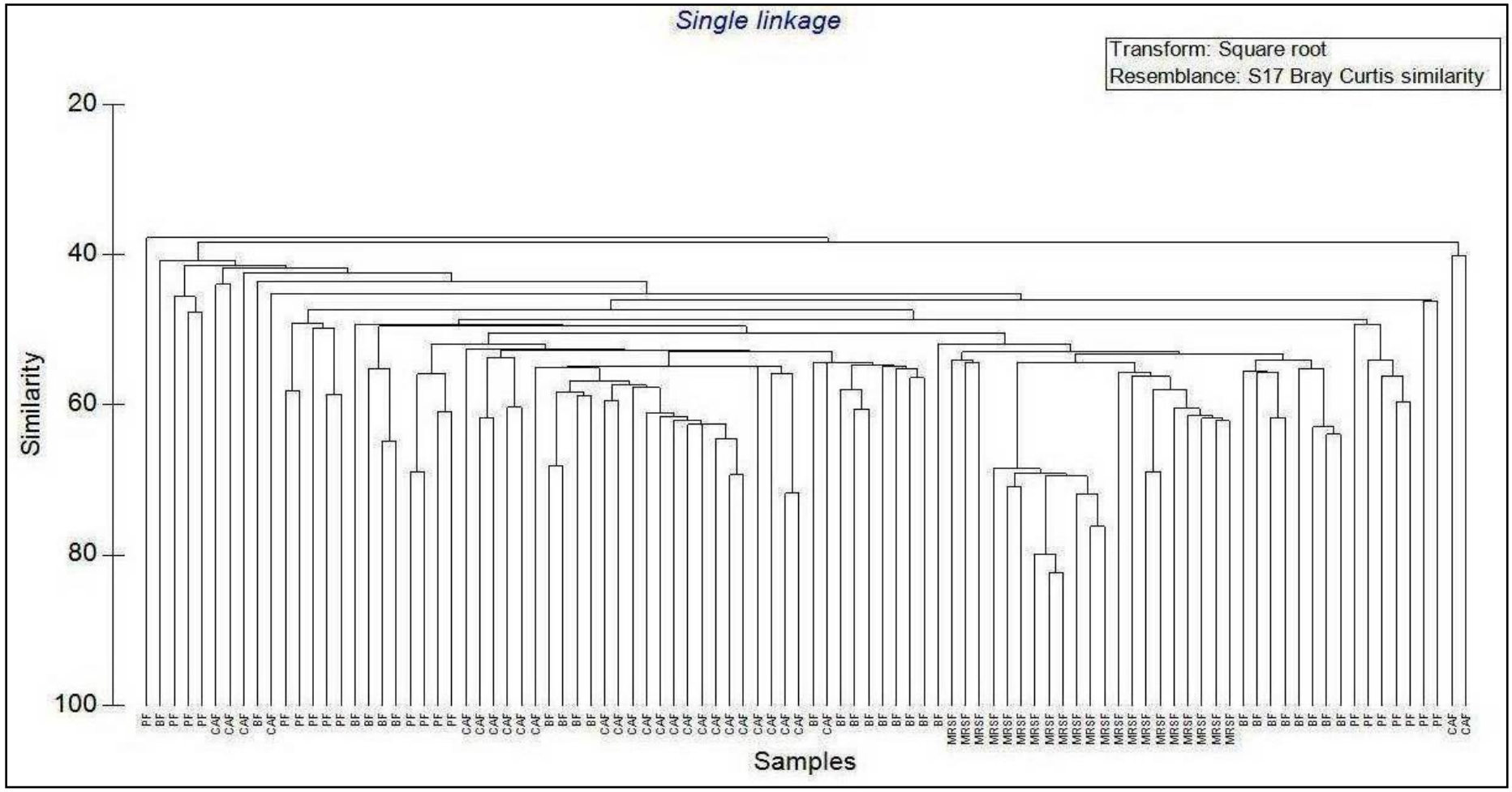

Figure 4.3: Dendrogram showing the classification of sampling plots (N = 96) into four distinct habitat types with respect to butterflies in Tons valley.

Comparison among different habitats showed that on average, species and composition of same habitat type was much similar within than among different habitat types. MDS plots generated from relative abundance of different butterfly species in each habitat type showed that sampling sites in each habitat type clustered together (Figure. 4.4). Sampling sites of more homogeneous habitat like pine forest and conifer and alpine forest were well separated from heterogeneous habitat and clustered separately. Sampling sites in mixed riparian and scrub forest grouped together and showed overlap with sampling sites in broadleaf forest.

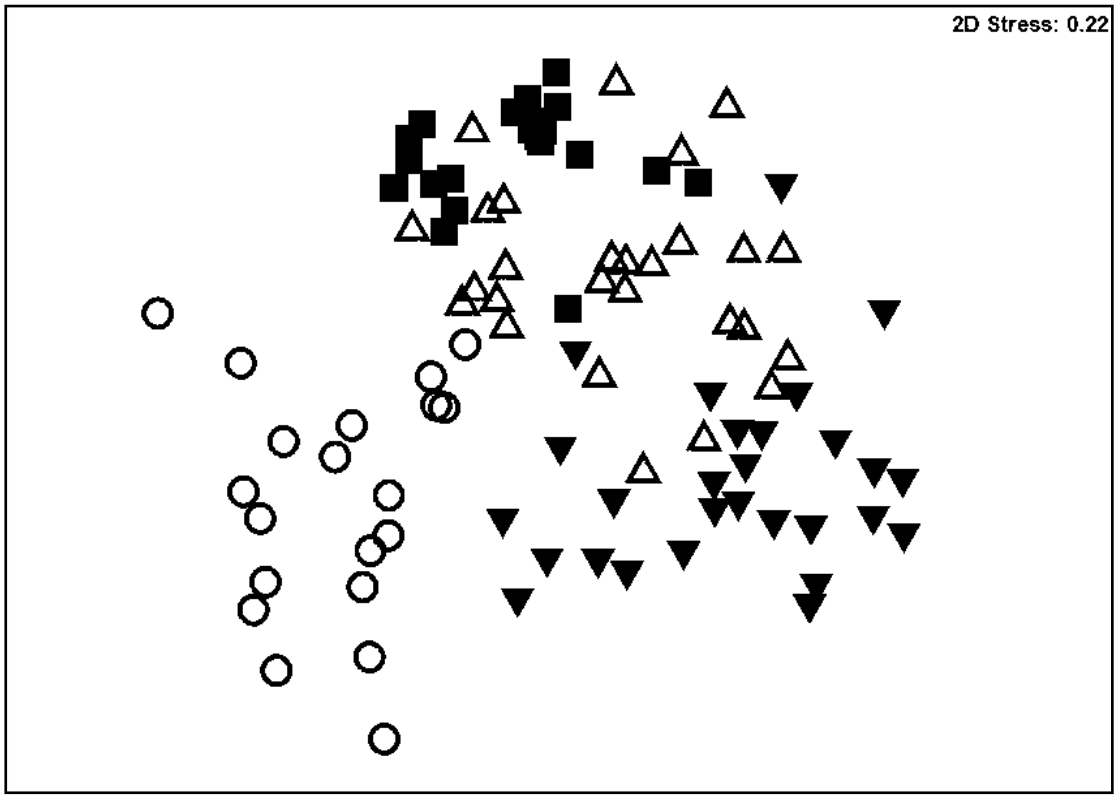

Figure 4.4: MDS ordination plots of sampling sites generated with respect to butterfly species composition and sorted according to habitat types in the Tons valley (closed triangle: Broadleaf forest sites, inverted closed triangle: Conifer and alpine forest, Closed square: Mixed riparian and scrub forest, open circle: Pine forest sites).

Pairwise ANOSIM test showed most difference occurred between mixed riparian scrub forest and pine forest (R = 0.80, P = 0.01) and mixed riparian scrub forest and conifer and alpine forest (R = 0.77, P = 0.01). Least difference was observed between broadleaf forest and conifer and alpine forest (R = 0.39, P = 0.01) and between broadleaf forest and mixed riparian scrub forest (R = 0.37, P = 0.01).

Further comparisons of dissimilarity in butterfly compositions were made to identify the species contributing to the differences between groups of sites that differed most.

Table 4.2: SIMPER analysis of differences in the species of butterfly assemblages contributing to the dissimilarity between most dissimilar habitats types found.

Groups Mixed riparian and scrub forest and Pine forest (Average dissimilarity = 88.54)				
	Mixed riparian and scrub Forest	**Pine Forest**		
Species	**Mean Abundance**	**Mean Abundance**	**Mean Dissimilarity**	**Cumulative Contribution %**
Pieris canidia	10.57	3.4	4.3	4.94
Acytolepis puspa	11.62	0.3	4.21	9.78
Catopsilia pomona	9.19	1.55	4.12	14.51
Pseudozizeeria maha	10.05	0.15	4.07	19.19
Celastrina huegelli	11.24	0.85	3.91	23.68
Gonepteryx rhamni	7.14	1.4	2.99	27.11
Pieris brassicae	6.29	1.8	2.39	29.85
Lampides boeticus	6.1	0.8	2.22	32.41
Eurema laeta	1.76	5.15	2.09	34.81
Aglais cashmiriensis	4.1	0	1.85	36.93
Vanessa indica	4.14	0.25	1.75	38.95
Lycaena phlaeas	3.43	0	1.66	40.86
Heliophorus sena	3.95	0	1.59	42.68
Euploea core	3.14	0.25	1.57	44.49
Belenois aurota	3.33	1.25	1.54	46.26
Chilasa clytia	3	0.3	1.18	47.62
Neptis hylas	2.29	0.35	1.03	48.8
Papilio polytes	2.48	0.1	1.03	49.98

Eighteen species contributed about 50% of the dissimilarities observed between sites of mixed riparian scrub forest and pine forest. These species differed in mean abundance, which was reflected in the degree of group association. Three species of family Lycaenidae and two species of family Pieridae accounted for almost

21% of differences between groups. Around five species of family Lycaenidae, and three species of Nymphalidae were almost absent from sites in pine forest and were present in relatively high abundance in riparian scrub forest, whereas *Eurema laeta* of family Pieridae was present in high numbers in pine forest (Table 4.2).

4.3.4 Family Composition and Habitat Similarity

The most abundant families were Nymphalidae (37% of all individuals recorded) followed by Pieridae (29.5%) and Lycaenidae (24.2%). The other two families were Papilionidae (634 individuals of 20 species accounting 7.5% of total individuals recorded) and Hesperiidae (89 individuals of 9 species accounting 1%).

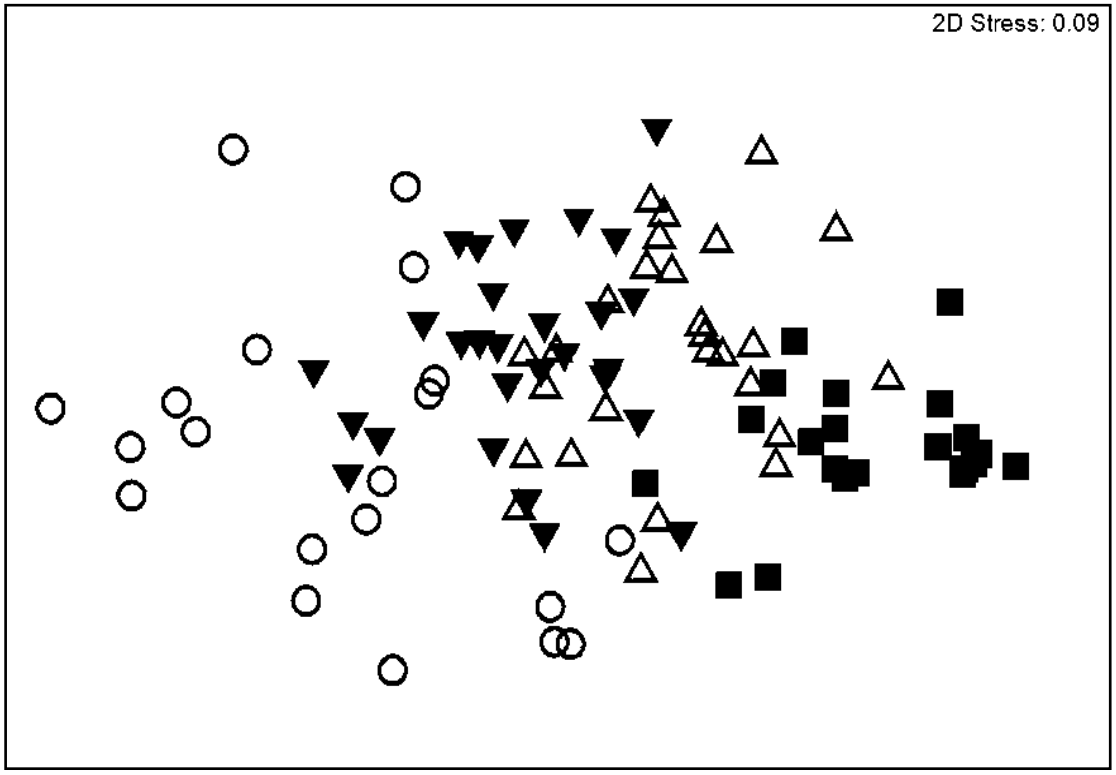

Figure 4.5: MDS ordination plots of sampling sites generated with respect to butterfly family composition and sorted according to habitat types in the Tons valley (open triangle: Broadleaf forest sites, inverted closed triangle: Mixed riparian and scrub forest, Closed square: Conifer and alpine forest, open circle: Pine forest sites).

The MDS plot generated from relative abundance of butterfly families was of no much difference to that generated from butterfly species with respect to habitat association (Figure. 4.4). Sites of pine forests were well separated from sites of broadleaf forest though there was some overlap (five sites) with mixed riparian and

scrub forest. Sites broadleaf forest showed overlapping with mixed riparian scrub forest and conifer and alpine forest. Pairwise ANOSIM test showed that most differences in family composition occurred between sites of pine forest and mixed riparian and scrub forest (R = 0.86, P = 0.01) while the sites of broadleaf forest and conifer and alpine forest showed least difference (R = 0.23, P = 0.01). Results of SIMPER analysis (Table 4.3) showed that family Lycaenidae and Nymphalidae contributing mostly in group differences between pine forests and mixed riparian and scrub forest. Species of family Nymphalidae generally prefer canopy forest with good moisture availability while species of family Lycaenidae found in patches consisting considerable diversity of flowering herbs and shrubs and both conditions are absent in pine forests.

Table 4.3: SIMPER analysis of differences in the families of butterfly assemblages contributing to the dissimilarity between most dissimilar habitats types found.

Groups Mixed Riparian and Scrub Forest and Pine Forest (Average dissimilarity = 75.09)				
	Mixed Riparian and Scrub Forest	**Pine Forest**		
Families	**Mean Abundance**	**Mean Abundance**	**Mean Dissimilarity**	**Cumulative Contribution %**
Lycaenidae	64.52	2.65	24.56	32.7
Nymphalidae	61.95	6.65	23.81	64.42
Pieridae	53.43	16.95	17.67	87.94
Papilionidae	18.19	1.7	7.61	98.08

4.3.5 Habitat Occupancy

Of all the 159 butterfly species recorded, 117 species occupied 1 - 20 sites in the Tons valley and 36 species occupied sites between 21 - 50 sites (Figure. 4.6), while there were only three species that occupied highest number of sites, 61 - 80. There were 13 generalist species that occupied number of sites between 39 – 72: Large Cabbage White, Common Brimstone, Indian Cabbage White, Indian Tortoiseshell, Pioneer, Spotless Grass Yellow, Pale Grass Blue, Common Emigrant, Common Copper, Indian Red Admiral, Plain Tiger and Painted Lady (Table 4.4).

Table 4.4: A list of major butterfly species recorded on both extremes of the habitat-specialization gradient in Tons valley. A total of 96 sites in 4 major habitat types were sampled.

Habitat category	Butterfly species	No. of sites occupied
Habitat Generalists	Large Cabbage White	72
	Common Brimstone	71
	Indian Cabbage White	68
	Indian Tortoiseshell	53
	Pioneer	52
	Spotless Grass Yellow	51
	Pale Grass Blue	48
	Common Emigrant	47
	Common Copper	46
	Indian Red Admiral	44
	Plain Tiger	41
	Painted Lady	39
Habitat Specialists	Blue Tit	4
	Circe	4
	Common Baron	4
	High Brown Silverspot	4
	Himalayan Jester	4
	Indigo Flash	4
	Yellow Sailor	3
	Dark Green Fritillary	3
	Indian Purple Emperor	3
	Large Goldenfork	3
	Broadstick Sailor	2
	Fulvous Pied Flat	2
	Chapman's Cupid	1
	Dusky Yellow-Breasted Flat	1
	Golden Emperor	1
	Great Windmill	1
	Eastern Blue Sapphire	1

Most of the habitat specialist species belong to the families Nymphalidae and Lycaenidae. Species like Golden Emperor, Great Windmill, Chapman’s Cupid and Eastern Blue Sapphire were highly habitat specialist species and were recorded only at one site. While Circe, Blue Tit, Large Golden Fork, Broadstick Sailer, Dark Green Fritillary and Indian Purple Emperor were species that occupied 2 - 4 sites (Table 4.4).

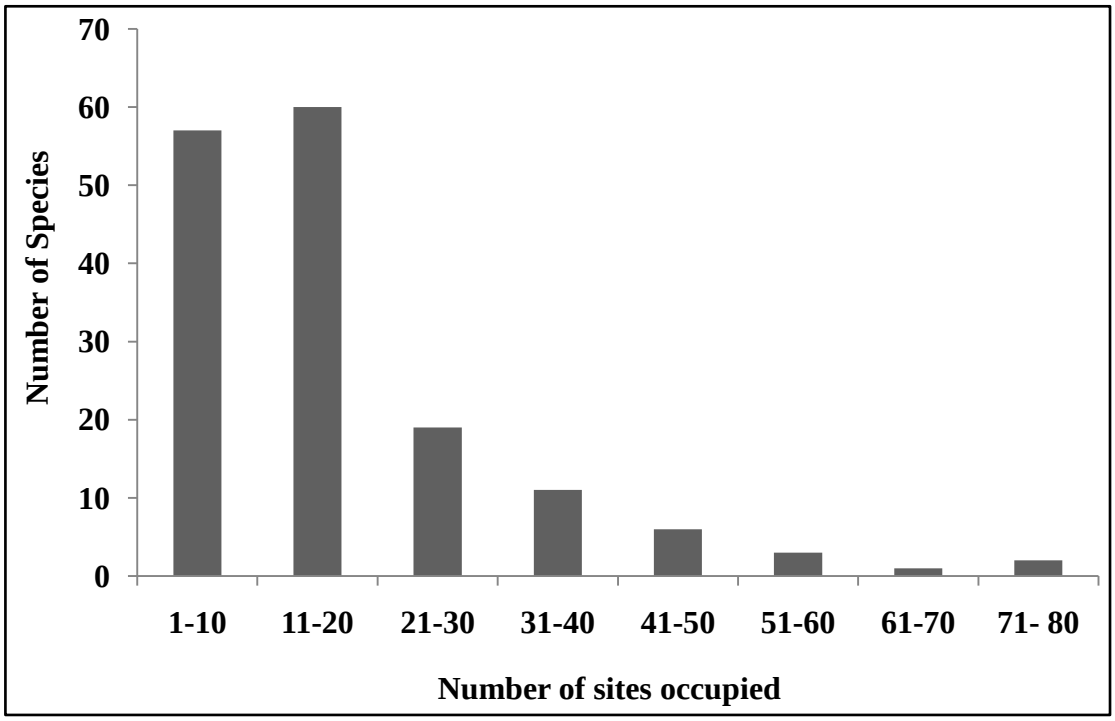

Figure 4.6: Site occupancy rates of butterflies in Tons valley, shown as the number of butterfly species in each class interval of number of sites occupied.

4.4 Discussion

The present study presents a systematic inventory of butterflies, in Tons valley in western Himalayan region. There are approximately 417 species of butterflies in the western Himalayas (Wynter-Blyth, 1957). However 50% of the species that may be found in the western Himalayan region were recorded during present study. It is difficult to precisely know the exact number of regional species. However, based on estimated species richness, the inventory was almost complete at the regional scale (96%) and the study can be described as exhaustive. Undoubtedly species were missed at local scale, since the current study was focus to sample understory layer. Thus, the species that predominantly occur in the canopy were under sampled. Furthermore, sampling efficiency was decreased in dense forests. Therefore, capturing cryptic species (Subfamily: Satyrinae) in dense vegetation habitat is probably less complete than open habitats. Using a sample size independent diversity measures (Fisher's alpha), minimizes distortions of between habitat comparisons (Hayek and Buzas, 1997). The sampling protocol used here provides a comprehensive sampling of local and regional butterfly diversity.

Highest species richness were encountered in mixed riparian and scrub forest and broadleaf forest and inventory completeness was also over 70%, for both of the habitats. These two forest communities support very heterogeneous vegetation assemblages. Major reason for this high species recorded in these forests was because of high plant species richness, moisture availability and a continuous matrix of canopy cover and open patches (due to variability in aspect and slopes and logging) and are explained in Chapter 5 (Table 5.2). It was observed that these two forests support a major butterfly faunal assemblage of the study area. Butterfly diversity was considerably low in pine forests and conifer and alpine forests. Low diversity in pine is obvious as this is a very homogeneous habitat. There are almost very few herb species on the ground floor while shrub and herb species were predominantly present on the edges. The inventory completeness was 82% in pine forests. High proportions of (about 29%) butterfly species were singletons and doubletons in the pine forest. But a high number of butterflies were observed in pine forest than generally expected. This may be because of the fact that butterfly found in this forest may not essentially dependent on the floral resources of the habitat but they might use it as corridor and for shade and for moisture requirements.

A relatively low diversity of butterfly in conifer and alpine forests can be attributed to the differences in temperature, rainfall and historical factors. It was observed that butterfly diversity showed a decreasing pattern from mixed riparian and scrub, broadleaf, pine, to conifer and alpine forest, respectively. Conifer and alpine forests are distributed at higher elevations and as butterflies are ectotherms, a low diversity was found at higher elevation forests. The high butterfly diversity in broadleaf forest may be due to the fact that broadleaf forests are found in mid-elevation zones and may work as a buffer or ecotone habitat between low and high elevation butterfly assemblages, as climatic and resource conditions are in contrast at both ends. High elevation butterfly communities may come down to lower elevations during a large decrease in temperature at higher elevations. Low elevation communities may move up to mid elevations as temperature become very high during dry season. The intermediate disturbance hypothesis (Connell, 1978) might provide an additional explanatory support for the high diversity in mixed riparian and scrub forests and broadleaf forests. According to this hypothesis species diversity is greatest in communities experiencing intermediate levels of disturbance. Disturbance creates

novel opportunities for species not found in undisturbed forest, and the habitat mosaic resulting from regeneration after patchy disturbance further increases the number of niches available. As local communities are dependent on these forests for fodder and fuel wood. This may lead to creation of open patches which butterfly uses for basking and thermoregulation. Logging creates open patches and these patches also maintain relatively high temperature, which may be important for thermoregulation requirements. Similar results were found by Devi and Davidar (2001), Ghazoul (2002), Cleary (2004) and Akite (2008) studying effects of logging on butterfly diversity.

In conclusion, it was observed that despite small differences in geographic distance the landscape was able to support a high amount of butterfly diversity and the processes involved with landscape heterogeneity were strong enough to support a unique butterfly assemblage between forests. Despite enormous pressure from the local communities on these habitats they supported considerably high (64% of butterfly species expected to be found in Uttarakhand state) butterfly diversity in such a small area. These areas along with protected areas (Govind WLS and NP) are important for long term conservation of biodiversity in Tons valley, western Himalaya.

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CHAPTER 5

PATTERNS OF BUTTERFLY SPECIES RICHNESS ALONG ELEVATIONAL GRADIENT

5.1 Introduction

Biodiversity on earth is not uniformly distributed, and understanding these patterns and underlying mechanisms has been central theme in biogeography, macroecology and conservation biology during in recent times. Latitudinal gradient in species diversity is perhaps the best studied, documented and most consistent ecological pattern in spatial ecology (Gaston and Blackburn, 2006), in which the species richness declines (for most of taxa) with increase in distance from equator (Rosenzweig, 1995; Gaston, 2000; Hillebrand, 2004), although there are a few exceptions. Studying latitudinal gradients offers many challenges as to perform studies along latitudes is often very difficult and requires a lot of money. Elevational gradient in species richness are generally mirror latitudinal gradient in species richness and they also offer many features that make them possibly better for studying the species diversity gradients and understanding the underlying processes of variation in species richness in space. Along altitudinal gradients, species richness generally follows decreasing or hump-shaped patterns with increasing elevation but growing consensus suggests that the elevation gradients exhibits peak in richness at some intermediate elevations are more common than uniformly decreasing pattern of species richness. Although differences in unit of sampling, scale of geographic area sampled and post handling of data (Rahbek, 2005; McCain and Grytnes, 2010) are very important factors for differences in species richness patterns. So far, many studies have attempted to study and document elevational patterns in species richness but the consensus on the generality of these patterns is still a topic of discussion (Sanders and Rahbek, 2012).

Understanding elevational patterns in species diversity holds an enormous potential to study the general underlying mechanisms responsible for the distribution of biodiversity on earth, which is critically important for conservation of biodiversity (Hunter and Yonzon, 1993), especially in the montane regions more susceptible to

threats from habitat degradation and climate change, and regions which have been un or under-explored by the biologists (Acharya et al., 2011).

5.1.1 General Patterns of Species Richness

Differences in patterns in species richness along elevational gradients may vary among taxa, geographic regions, unit of sampling and spatial scale and disturbance (Kattan and Franco, 2004; Rowe and Lidgard, 2009; Sanders et al., 2010). Elevational pattern in species richness exhibit four general patterns: mid-elevation peak, decreasing, low plateau and low plateau with a mid-elevational peak (McCain, 2009). These patterns have been variously named and defined but recent one is documented in McCain (2009).

Decreasing richness patterns are those in which species numbers decline generally monotonically with increasing elevation. Low plateau patterns have consecutively high richness across the lower portion of the gradient (4300 m) and thereafter decreasing species richness. Low plateau patterns with a mid-elevational peak have high richness across low elevations (4300 m) with a diversity maximum found more than 300 m from the base. Mid-elevation peaks have a unimodal peak in diversity at intermediate elevations (4300 m) with 25% or more species than at the base and top of the mountain. Rarely, species richness increases with elevation (e.g., for salamanders and lichens in Martin, 1958; Wake et al., 1992; Grytnes et al., 2006). The patterns of elevational species richness reflect the ecology of the taxonomic group in earlier studies (McCain, 2009, 2010). Meta-analyses of terrestrial vertebrate groups found that the predominance of a particular elevational pattern of species richness was clearly linked to taxon. Non-flying small mammals (e.g., rodents, shrews and tenrecs) almost ubiquitously display mid-elevational peaks in diversity (McCain, 2005), whereas bat elevational patterns were evenly split between decreasing to mid-elevational peaks (McCain, 2007b). Birds and reptiles displayed all four common patterns of elevational species richness – evenly for birds (McCain, 2009), and with a predominance of decreasing patterns for reptiles (McCain, 2010). Preliminary analyses for amphibians show that salamanders displayed mostly mid-elevational peaks in species richness, whereas frogs showed all four common patterns in similar frequency. Although no meta-analyses have been completed for plants and insects, the literature shows examples of all four patterns among various groups. Rahbek (2005)

included many plant studies in his overview of scale and species richness, and found most displayed mid-elevational peaks along elevational gradients. There is almost no documentation of elevational patterns of microbe diversity, although one study found a decreasing taxon diversity pattern for bacteria in the Rocky Mountains of Colorado between 2460 – 3380 m (Bryant et al., 2008).

5.1.2 Major Driver of Patterns

As of the more rigorous and extensive work on these patterns in last two decades, there have been a range of hypotheses proposed to explain global variation in species. Climatic, geographical, biological, historical and evolutionary factors impact upon elevation-species richness patterns (Whittaker et al., 2001; Lomolino et al., 2010; McCain and Grytnes, 2010). Hypothesized factors can be grouped majorly into four groups: Climate (temperature and rainfall), space (area and mid-domain effect), evolutionary and biotic factors (niche conservationism, isolation, speciation, endemism and evolutionary processes) (McCain and Grytnes, 2010).

5.1.3 Effect of Space, Geometric Constraints and Mid-Domain Effect

The space area relationship (SAR) suggests that number of species encountered increases as survey area increases (Rosenzweig, 1995). In mountains, the base should harbour more species than regions covering smaller areas like mountain tops. But in watersheds, which are vessel shaped, the area of elevational bands increases with from valley base to valley tops. These are elevational gradients in regions with highly dissected topography where the lowest elevations are within deep ravines and thus cover less area. SAR is based on the assumption that at regional and global scales, extinction rates should increase with area due to increased likelihood of barrier formation and increased population densities. However, Rosenzweig (1995) argued that habitat heterogeneity and its strong relation with the species drives local SAR. The SAR expects a positive relationship between area and species richness.

One factor which is considered as driver for species richness patterns is geometric constraints or mid-domain effects (MDE) (Colwell at al., 2004, 2005). MDE results from random replacement of species range within a bounded geographical space creating a peak of species richness at mid elevations. Though critics argue that the MDE does not provide explanations for elevational species

richness patterns and some MDE might be spurious, the MDE at a minimum provides appropriate null models and should always be interpreted in combinations with biotic, abiotic and historical factors.

5.1.4 Rapoport's Rule

One idea that is persisted in the literature is Rapoport's rule, which states that there is a positive relationship between the latitudinal/ altitudinal geographic range of an organism and latitude/ altitude (Stevens, 1989, 1992). Rapoport's altitudinal rule was explained in terms of the differential ability of a species to attain large range sizes. Species at low elevations are approaching their upper range limits, while species that inhabit higher elevations have comparatively larger climatic tolerances and thus can be found across a greater altitudinal ranges. So far, conclusions on the generality of Rapoport's rule are precluded with random taxonomic and latitudinal representation of organisms (Gaston and Chown, 1999; Willig et al., 2003; Ribas and Schoereder, 2006; Bekhetov, 2009).

5.1.5 Climatic and Environmental Determinants of Species Richness

Climate is a limiting factor and controls the number of species that can survive at different locations and elevations. The control may be the result of physiological tolerance of the species to temperature or rainfall levels or it may put restrictions on the number of individuals by controlling productivity which in turn may limit the total number of individuals in a population and population sizes (Brown, 2001; Hawkins et al., 2003). There may be many aspects of climate that can be important for species survival (e.g., humidity, productivity, solar radiation) but there are three majorly studied climatic factors are temperature, precipitation and productivity.

A positive relationship between temperature and species richness has been strongly evident in literature (Evans et al., 2005). Temperature decreases with increasing elevation (Barry, 2008). If temperature is main determinant of elevational species richness, then predicted pattern is decreasing diversity with increasing elevation (McCain, 2007b). Several hypotheses have been proposed to explain temperature-diversity relationship. But most convincing theory is the metabolic theory of ecology (MTE) which predicts a very specific negative linear relationship between temperature and species richness. Though metabolic theory of ecology explains the

pattern for reptiles worldwide but almost does not support case of vertebrate ectotherms (McCain and Sanders, 2010). Temperature is also a major determinant of productivity and may govern diversity through its effects on productivity.

A positive relationship between precipitation and species richness has been discussed for local and regional diversity patterns (Evans et al., 2005). As precipitation does not change consistently with elevation on all mountains, but varies greatly due to regional mountain and weather conditions (Barry, 2008). Hence, no single diversity pattern would be predicted along elevational gradients, but different patterns on each mountain showing appositive relationship between precipitation and species richness (McCain, 2007b).

Productivity has also been strongly and positively linked to diversity (O'Brien, 1993; Evans, 2005). Climatic productivity depends primarily on regional temperature and precipitation. Therefore, elevational productivity patterns vary among mountains and no single diversity pattern is predicted. The hypothesis usually predicts the positive relationship between diversity and productivity is due to the ability of high productive areas to support more individuals within a community and thus more species (Srivastava and Lawton, 1998). Alternatively, high productivity may result in increased availability of critical resources and therefore support more species.

Other local biotic and abiotic processes have been proposed to explain patterns in species richness, including competition (Terborgh and Weske, 1975), source-sink dynamics and ecotone effects (Terborgh, 1985; Lomolino, 2001) and habitat heterogeneity and habitat complexity (Terborgh, 1977).

Biological interactions like habitat heterogeneity predict positive relationships; whereas completion, predicts negative relationship with diversity. The major difficulty in testing these processes on elevational diversity patterns is due to difficulty in defining critical characteristics as well as measuring these traits for all species along a large spatial gradient (McCain and Grytnes, 2010).

In this study, elevational gradient in butterfly species richness were examined in the upper catchment of Tons river valley in western Himalaya. Specifically the aims were to document, describe and explain the elevational gradient in butterfly diversity. First of all, the butterfly species richness pattern along elevation gradient is

described. Then a set of biotic and abiotic factors were evaluated that might be correlated with butterfly species richness, specially focusing on geometric constraints, space, temperature, precipitation and productivity. Further the role of local habitat heterogeneity in influencing butterfly species diversity was investigated. These parameters broadly represent MDE, climate, productivity and habitat diversity. Finally, the range size distribution pattern of butterflies along the elevation gradient was assessed by examining the elevational range size of each butterfly species and thus applicability of Rapoport's rule in butterflies.

5.2 Methods

5.2.1 Study Area

The study was conducted in upper catchment of Tons valley in Uttarakhand state of India during April 2010 - August 2011. The valley, comprising of three main watersheds i.e. Rupin, Supin and Tons and is predominantly covered with subtropical, temperate, sub-alpine and alpine vegetation, dominated by pine (*Pinus roxburghii*), deodar (*Cedrus deodara*), oak (*Quercus* spp.) and mixed and scrub thorn forest. The average elevation in the study region varies between 900 – 4000 m, while some the mountain peaks exceeds 6000 m.

The entire study area was divided into 26 zones on the basis of 100 m elevational bands between 900 - 3500 m (Figure 5.1). These returns 26 elevational sampling zones and fixed number of transects (N = 20) were laid in each elevation zone, on the basis of physical and phytogeographical features. These 26 sampling zones and the 20 transects at each locations formed the primary sampling units at which butterfly species richness was measured and environmental variables were extracted.

5.2.2 Butterflies

Data on species richness and abundance of butterflies in each sampling zone were collected during April 2010 - March 2011. Butterfly species richness, vegetation and microclimatic data was collected on a total of 520 transects. Data from 20 transects in each elevation zone was pooled which results in total butterfly species richness in each elevation zone.

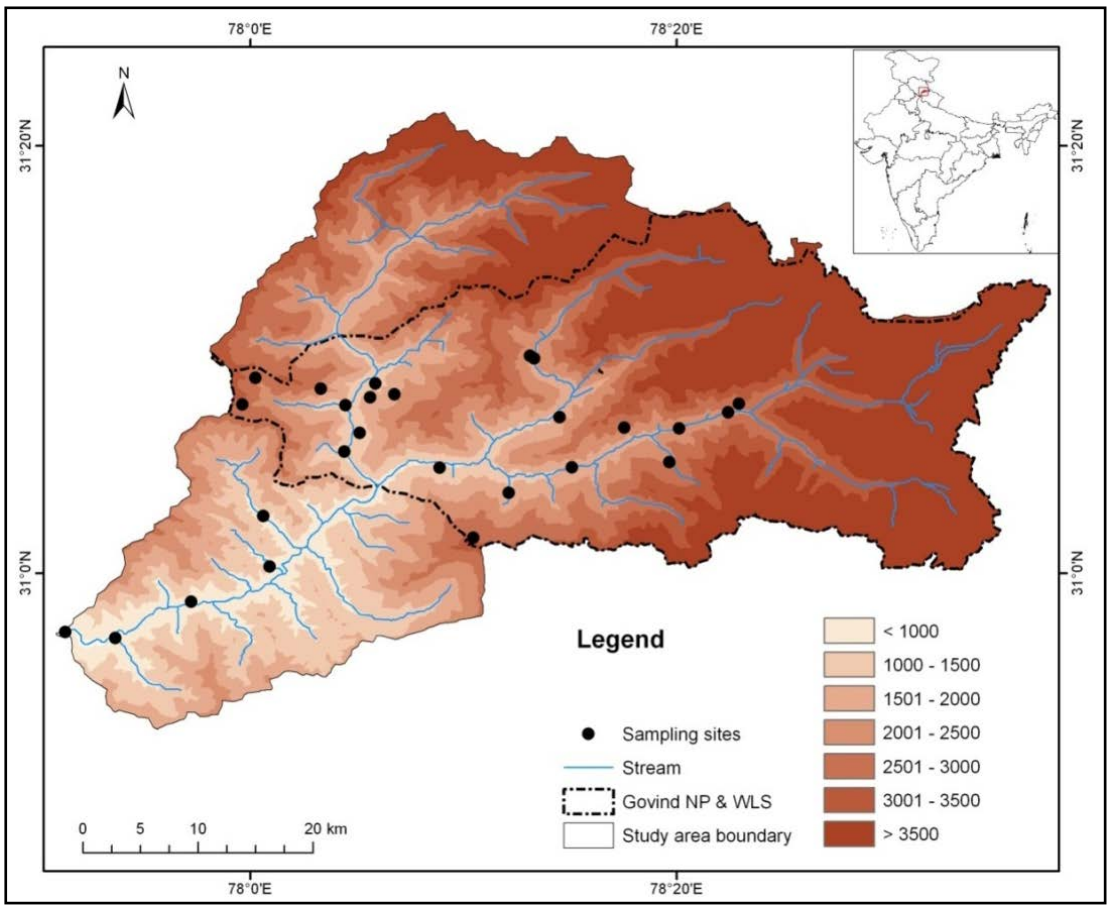

Figure 5.1: Study area showing 26 sampling locations each falling in separate elevational zone between 900 – 3500 m.

All transect lengths were 300 m and transects were traversed on foot in around 30 min. Data was collected when cloud cover was less than 70% and between 0900 and 1300 hrs, the most favorable conditions for butterfly flight. All butterflies seen during the transect walk in an imaginary 5×5×5 (m) box around the observer. Taps baited with a mixture of rotten bananas and beer fermented for 5 days were also employed. Baited traps were alternately placed 5 m to the left and right of transects at every100 m. Thus, there were 3 baited traps on each transect. Specimens captured in these traps were included in the species inventory, but not in species richness estimations. Butterflies that were too fast or too distant to reliably identify during flight were not counted. Butterflies that could not be readily identified visually were either photographed or captured using a hand held sweep net and were released after identification. The few voucher specimens that were collected deposited at the insect repository of the WII in Dehradun.

All butterflies of Hesperioidea and Papilionoidea (Order: Lepidoptera, Suborder: Rhopalocera) were sampled. Total 5 butterfly families (i.e. Hesperiidae, Papilionidae, Pieridae, Lycaenidae and Nymphalidae) in the study area were observed and identified to species level following Evans (1932), Wynter-Blyth (1957), Haribal (1992), Kunte (2000) and Kehimkar (2008).

5.2.3 Sampling Vegetation, Disturbance and Microclimate variables at Plot level

Vegetation data was quantified for each transect using stratified random sampling. Circular plots (10 m radius) were established at the centre of each transect at 100 m intervals to quantify trees. Circular plots (5 m radius) were established on either side (5m from center) of each transect at 100 m intervals to quantify shrubs. In each of these plots, two plots (1 m diameter) were established within the 5 m shrub plot to estimate herb abundance and grass cover. Within each vegetation plot, flowering plant species richness, average density of trees, shrubs, and herbs, grass cover and canopy cover (using canopy densitometer) were measured. Disturbance parameters, including logging, fire signs, and livestock abundance was also quantified. Fire signs (number of signs of past fire inside the plot) and logging (number of logged trees) were recorded in a 10 m radius plot at 100 m intervals at the centre of each transect. Here, livestock abundance refers to number of livestock observed on transects during sampling.

Microclimatic variables, such as temperature, relative humidity (RH), and wind speed, were recorded using a digital thermometer, digital hygrometer, and digital anemometer (Forestry suppliers, USA), respectively. Topographic information, such as altitude, aspect, and slope, were also recorded on transects using an altimeter, compass, and clinometer (Forestry suppliers, USA), respectively.

5.2.4 Data Source for GIS Variables

Data on environmental parameters that represent different spatial themes *viz*. area, topography, climate, primary productivity, were compiled from satellite imageries. The area at 100 m interval within the study region (Figure 5.2) was calculated based on global digital elevation model (DEM, GTOPO30) from the United States Geological survey's Hydro 1k dataset

(http://edcdaac.usgs.gov/gtopo30/hydro), with the resolution of a grid cell of 30 x 30 m. I extracted the map, which contained elevational information of the target region, from the global GTOPO30 data. The area is a product of grid number by grid area. Climatic variables (temperature and precipitation) used in the analysis were downloaded from worldclim online archive (http://www.worldclim.org). These data are available at 1 km resolution and in the form of monthly averaged value of last 50 years (1950 - 2000).

Normalized difference in vegetation index (NDVI) was used as a surrogate for primary productivity and the values were extracted from MODIS terra satellite product, available free from USGS website (http://mrtweb.cr.usgs.gov). MODIS terra satellite products are available at high temporal resolution (one day). The data used here has 1000 m resolution and are averaged for one month (period of maximum vegetation growth) and also the NDVI of August month.

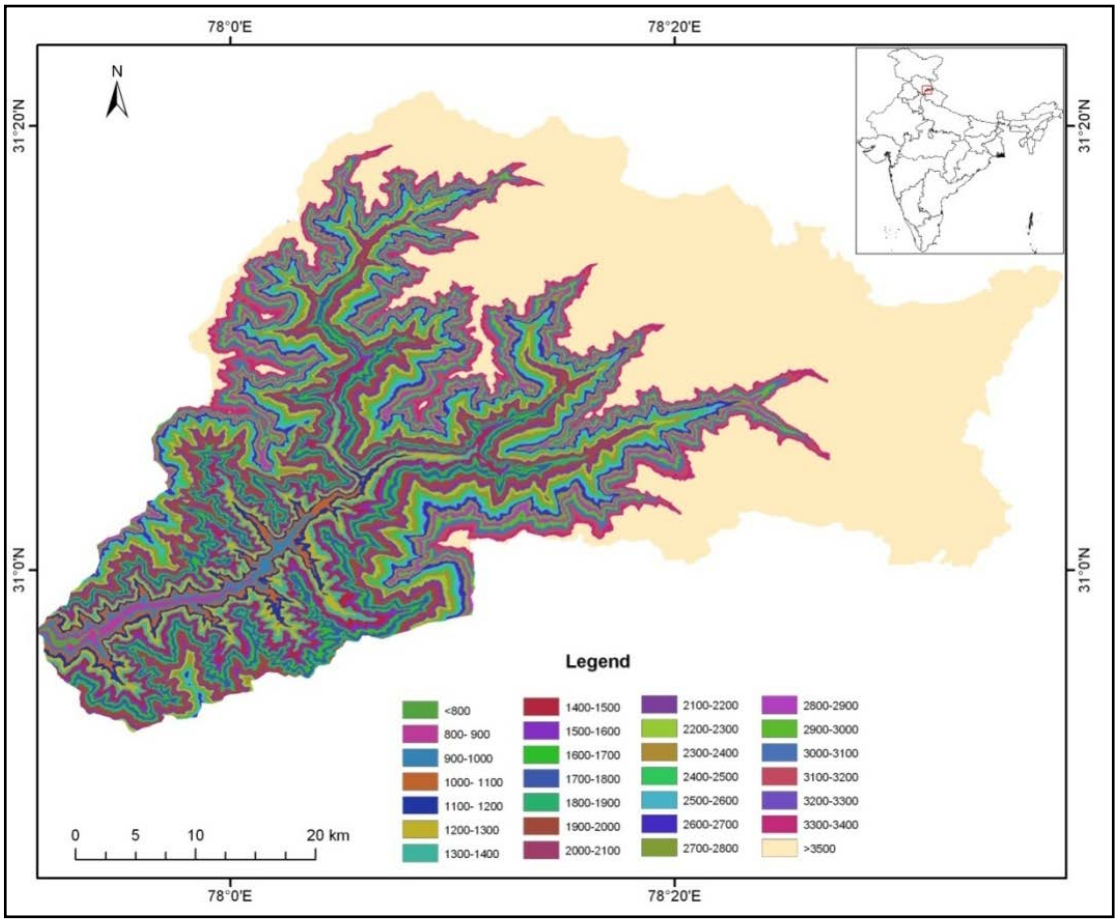

Figure 5.2: Digital Elevation model (DEM) of study area into 26 elevation bands between 900 - 3500 m.

5.2.5 Data Analysis

5.2.5a How Does Species Richness vary with Elevation?

How observed and estimated species richness of butterflies varied with elevation for 26 sampling sites were examined. Observed species richness was the total count of species detected across all sampling period at each of the 26 sampling site. To assess the sampling efficiency at each site species richness estimates (non-parametric) based on individual-based species accumulation curves (Gotelli and Colwell, 2001) were calculated using program EstimateS (Colwell, 2009). Six non-parametric estimators of species richness (Table 5.1) were calculated. However, the Chao1 estimate of species richness produced the largest estimates of species richness in the Tons valley. Suggestions of Sorensen et al. (2002) and Scharff et al. (2003) were followed and used for assessing inventory completeness values, giving the ratio between observed and estimated richness.

5.2.5b Is there any Evidence for Mid-Domain Effect?

Monte Carlo simulations program, mid-domain effect null model (McCain, 2004) was used for testing geometric constraints or mid-domain effects on species ranges. This program uses empirical range sizes or range midpoints within the elevational range and simulates species richness curves based on analytical-stochastic models (Colwell and Lees, 2000).

To test the impact of spatial constraints on species richness, 95% prediction curves were produced based on 50,000 simulations (without replacement) using empirical range sizes. Simulations using range mid-points arbitrarily show better fit to null model because midpoint simulations are too constrained by the empirical data (McCain, 2004). Hence, range size simulation rather than range midpoint simulations are better for assessing fit to MDE null models for geometric constraints of species richness. The empirical species richness curves were compared with the 95% confidence intervals generated from species range sizes. Species richness data were generated at 100 m elevational increments. The average of the predicted number of species was regressed against the observed empirical values to assess whether geometric constraints could contribute to the pattern of butterfly species richness in this system.

5.2.5c What Factors are Correlated with Richness?

Area, temperature, precipitation and NDVI data were used to examine the influence of possible climatic and productivity factors on the patterns of species richness along the elevational gradient. To assess effect of plot level habitat, microclimatic and disturbance variables on butterfly species richness and abundance, I used Pearson correlation coefficients (r) using program SPSS (SPSS 16.0, 2007). All variables were tested for normality. Strongly skewed variables were transformed prior to analyses (i.e. butterfly, species richness, abundance and plant species richness data were square root transformed) to examine associations of butterfly species richness and abundance with microclimatic, habitat and disturbance variables.

5.2.5d Are Range Size and Elevation Correlated?

Range of each species was estimated as the difference between the lowest and highest elevation at which that species was recorded during the study. A species was assumed to have continuous ranges between its minimum and maximum elevational records. To overcome statistical non-independence of the spatial data, 'mid-point method' was used as a measure of the central tendency. The mean between the minimum and maximum elevation reported for each species was used to represent that species elevational range midpoint. The relationship between range size and elevation was assessed by regressing range size of each species against the lower and upper limits of its elevational range, as would be predicted if Rapoport's rule holds in this system.

5.3 Results

5.3.1 Butterfly Species Richness

A total of 174 species of butterflies were recorded over the course of the study sampled across 520 transects at 26 sampling sites. Non parametric estimators (Chao1) yielded higher value compared to observed species richness (Figure 5.3). Overall inventory completeness was 95% considering highest estimate (Chao1) of species richness for compete dataset (Table 5.1).The mean butterfly species richness was 57.6 species (N = 26), with a minimum of 5 species (recorded at 3400 – 3500 m elevation zone) and a maximum of 110 species (recorded between 1200 – 1300 m elevation

zone). In general butterfly species richness was highest in 1200 – 2100 m elevation while lowest in between 2900 – 3500 m elevation zones of the study area (Figure 5.3).

Table 5.1: Species richness estimates of butterflies across study area in Tons valley.

Estimator/Model	Estimate	SE (±)	95% Confidence interval
Observed species richness	174	-	-
Chao1 (Chao, 1984)	184.6	16.9	(161.0 - 232.8)
ACE (Chao and Lee, 1992)	178.6	6.6	(177.5 - 203.8)
1st order jackknife	177.0	7.7	(165.2 - 196.4)

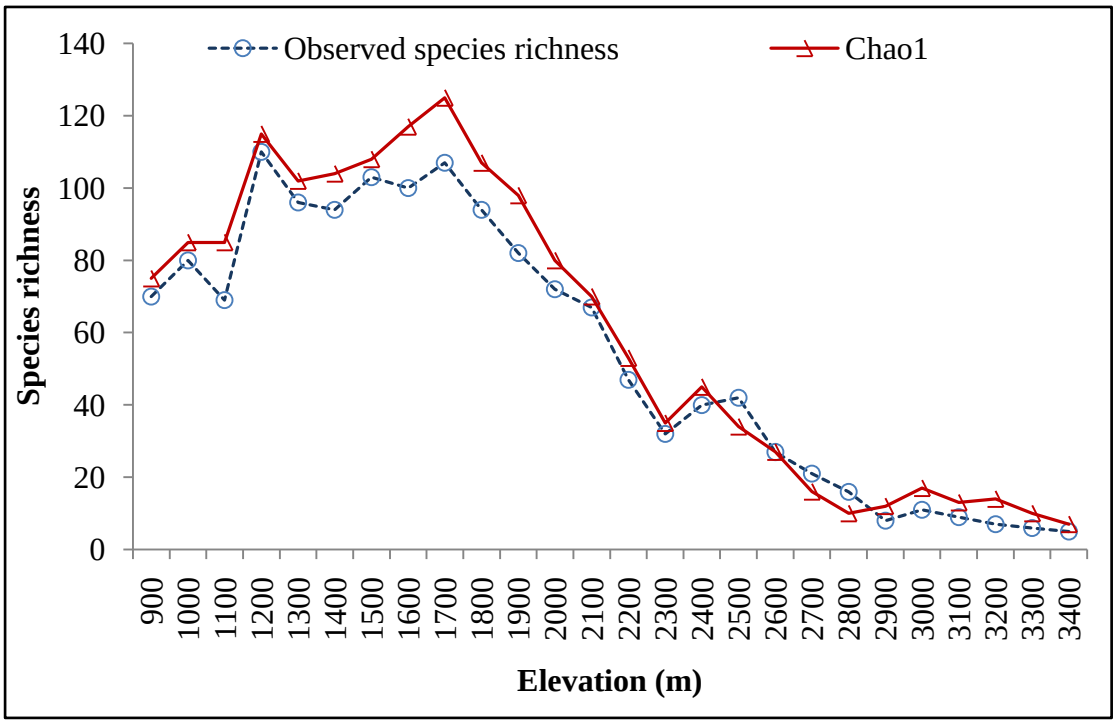

Figure 5.3: Line curves to compare observed species richness with estimated species richness to evaluate sample adequacy at each site along elevation.

5.3.2 Elevational Pattern of Butterfly Species Richness

The pattern of butterfly species richness along elevation gradient in Tons valley is shown in Figure 5.3. The butterfly species richness increases and reaches its peak at 1200 m and shows a hump shaped pattern at middle elevations ranges from 1200 – 1700 m, with the maximum value observed at 1200 m. This value accounted

for 68.9% of total number of butterfly species recorded during study in Tons valley. A second peak was also observed at 1700 m, accounting for total 61.4% of species. Butterfly species richness shows a linear decreasing pattern between elevation ranges from 1700 – 3500 m. Analysis showed a highly significant negative correlation (r = -0.81, N = 26, $P < 0.01$) between elevation and observed species richness of butterflies. Thus butterfly species richness pattern along elevation gradient falls within general pattern of an initial increase in species richness, followed by a peak and then a decline with no further increase in species richness along increasing elevation. The observed and estimated species richness showed strong positive correlation with each other (r = 0.99, N = 26, $P > 0.01$).

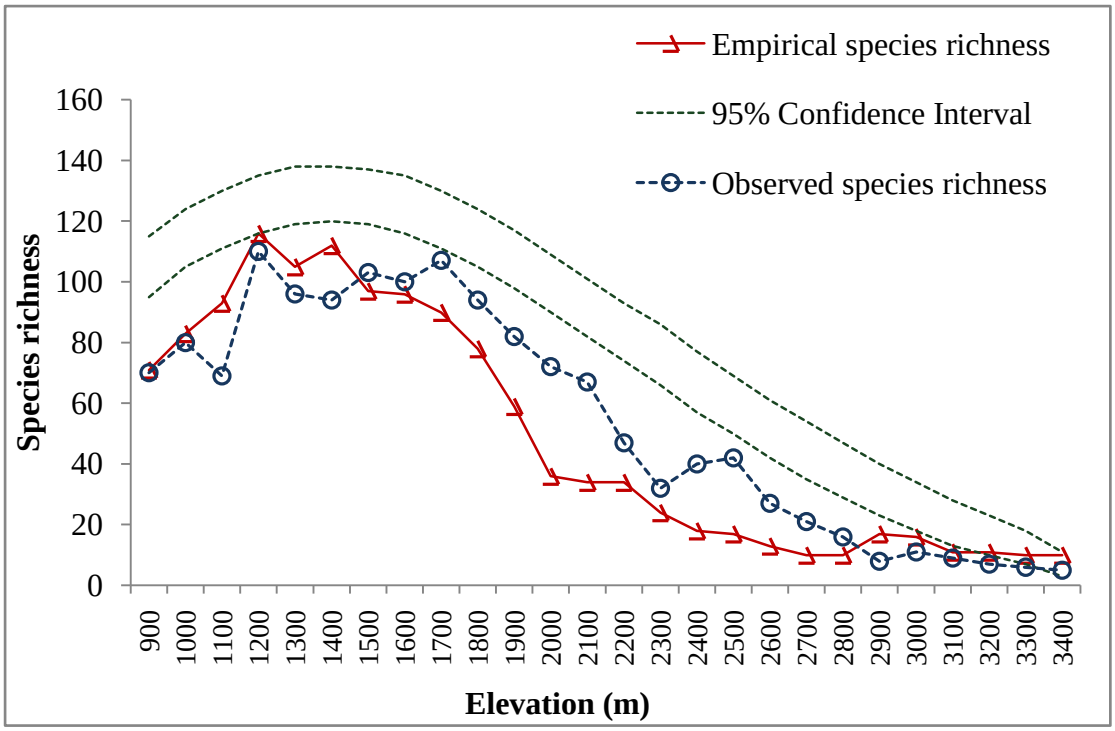

Figure 5.4: Comparison of empirical species richness (line with data points) with 95% prediction curves sampled without replacements from program Mid-domain null (McCain, 2004).

5.3.3 Mid-Domain Null Model

Support for mid-domain effect was found in current study. The curves were nearly symmetrical and thus not differed from mid-domain predictions (Figure 5.4). A comparison of the empirical data with the 95% prediction curves obtained from the 50,000 simulations using range sizes showed that more than 80% (22/26) occurred outside the predicted range of null model (Figure 5.4). Empirical species richness was

significantly correlated with the mean of the predicted richness (r = 0.92, N = 26, *P* > 0.01). Butterfly species richness did not peaked at mid elevation but at the lower elevation (1000 - 1500 m).

5.3.4 Role of Area, Temperature, Rainfall and NDVI

With increasing elevation the area of each elevation band first increased steeply from 900 - 2000 m and then after 2000 m increased very slowly, but a significant correlation was found between area available under each 100 m elevation band and elevation(r = 0.90, N = 26, *P* < 0.0001) (Figure 5.5). Highest area was available between 3000 – 3100 m elevation bands. Finally the area of each point above 3100 m gradually decreased upto 3500 m. The correlation between the species richness of butterflies and the area was significant but negative (r = -0.58, N = 26, *P* < 0.02). Butterfly species richness increases initially upto 1300 m and the relation was symmetrical with an increase in area upto 1700 m. After 1700 m species richness of butterflies gradually decreased with no further increase upto 3500 m while area available under each elevation band increased.

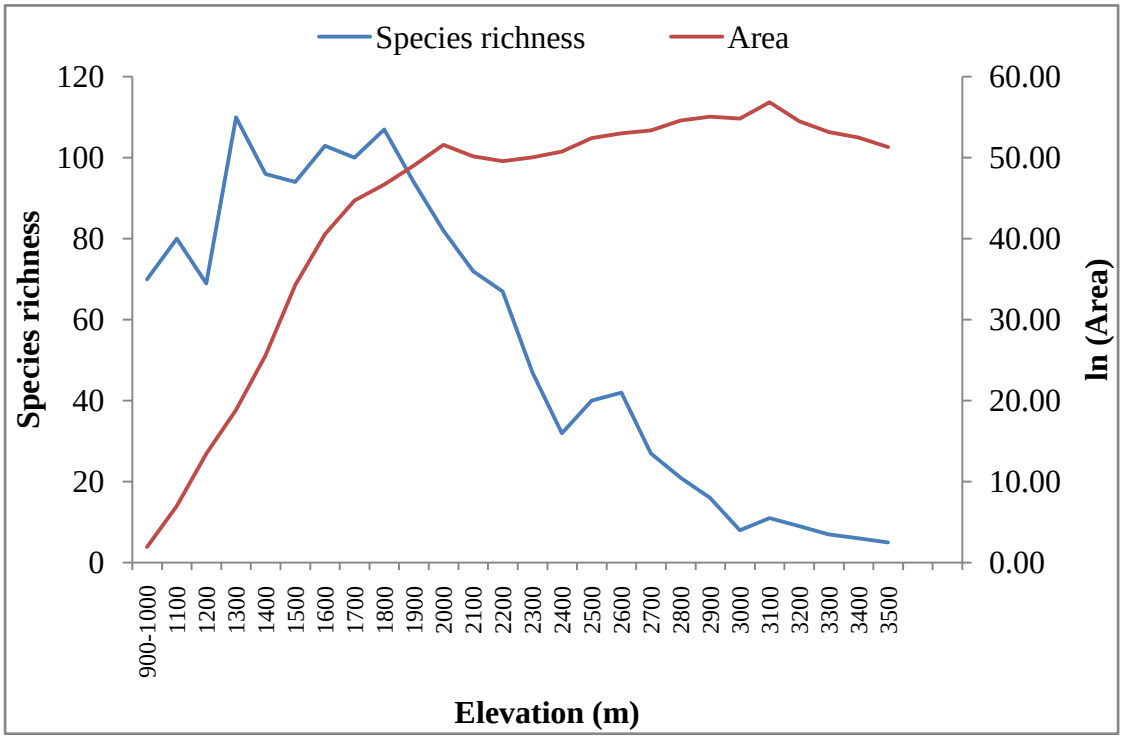

Figure 5.5: Relationship between area of 100 m elevational band and species richness of butterflies.

All the climatic variables were found to be controlled by elevation, as minimum annual temperature and maximum annual temperature were observed to be linear negative relation with elevation (Figure 5.6). There was a strong negative association of maximum temperature with increasing elevation (r = 0.96, N = 26, P < 0.01).

The butterfly species richness was found to be significantly positively correlated with maximum (r = 0.70, N = 26, P < 0.01) and minimum (r = 0.78, N = 26, P < 0.01) temperature (Figure 5.7). Rainfall of dry season was observed to be increased with increasing elevation and species richness found to be significantly negatively correlated with rainfall of dry season (r = -0.81, N = 26, P < 0.01). Species richness was observed to be positively correlated with seasonal rainfall (r = 0.64, N = 26, P < 0.01). NDVI was used as a surrogate of productivity; the relation between elevation and mean NDVI was not very strong and showed a high scatter and a weak positive relationship. Surprisingly mean NDVI and butterfly species richness showed very poor but significant association (r = 0.18, N = 26, P < 0.01) (Figure 5.7). Butterfly species richness showed an average positive relationship with NDVI of August month(r = 0.29, N = 26, P < 0.01) (Figure 5.7).

5.3.5 Effect of Habitat Attributes and Microclimatic Variables at Plot Level

Microclimatic variables, such as temperature, had significant positive influence on species richness (r = 0.69, N = 42, P < 0.01) and abundance (r = 0.74, N = 42, P < 0.01). Relative humidity had a slight negative influence on butterfly species richness (r = -0.35, N = 42, P < 0.05) and a negative association with abundance (r = -0.20, N = 42, P > 0.05). Wind speed did not contribute significantly to either variation in butterfly species richness (r = 0.20, N = 42, P > 0.05) or abundance (r = 0.27, N = 42, P > 0.05) across sampling locations (Table 5.2).

Elevation was an important factor in accounting for variation in butterfly species richness (r = -0.81, N = 42, P < 0.01) and abundance (r = -0.55, N = 42, P < 0.01) across sampling locations.

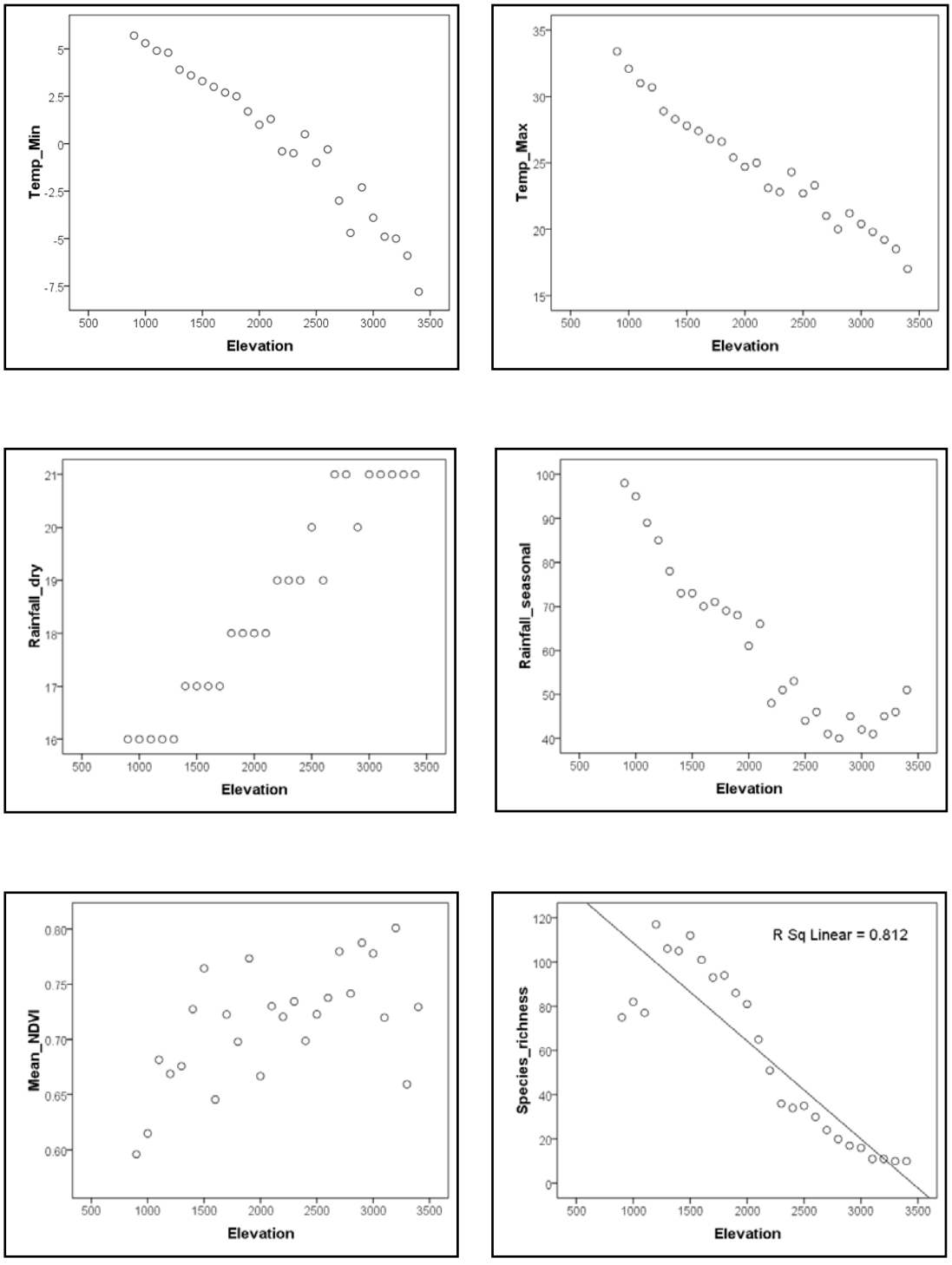

Figure 5.6: Scatterplots showing relationships between elevation and climatic and primary productivity variables in Tons valley (N = 26).

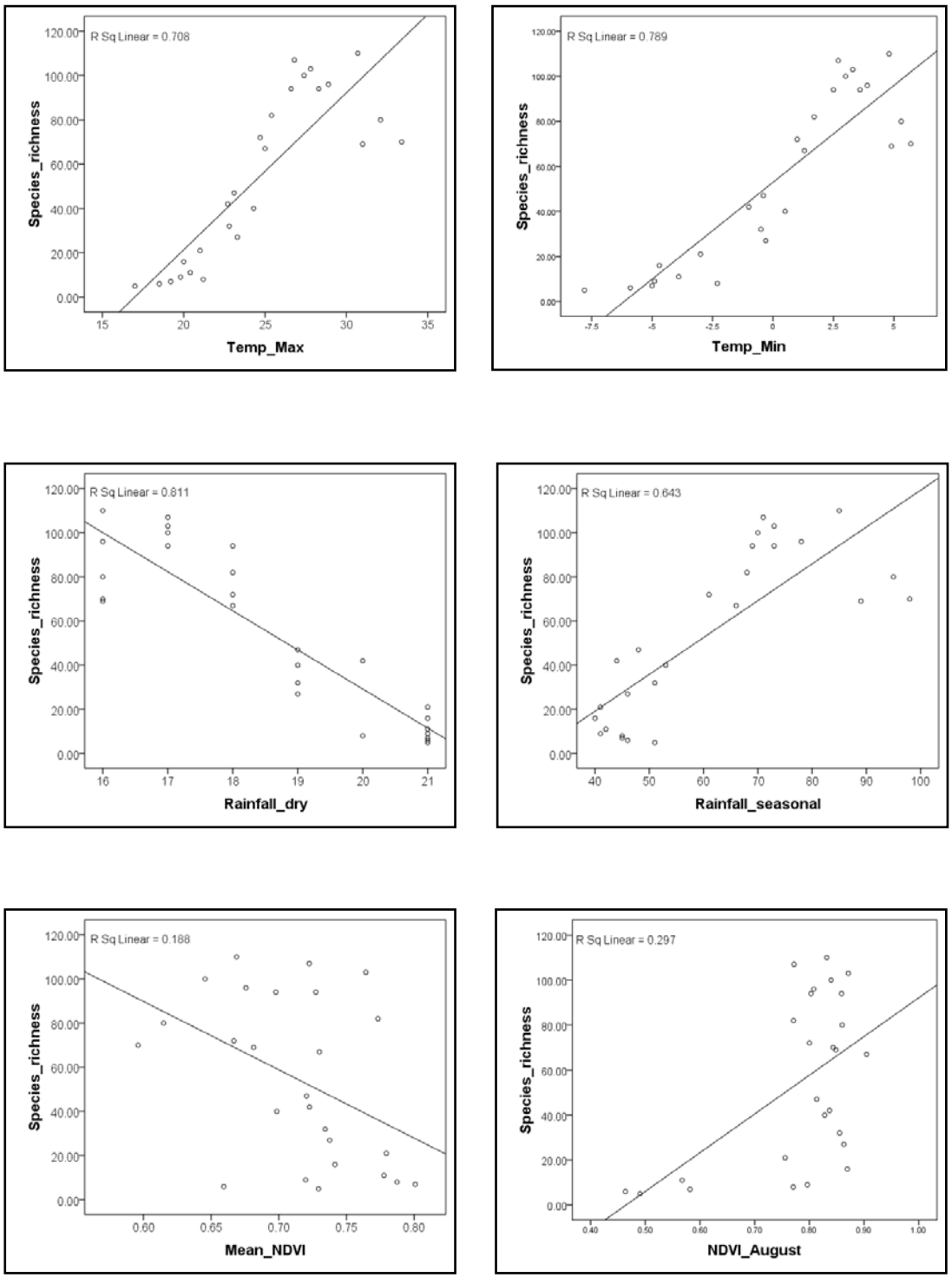

Figure 5.7: Scatterplots showing relationships between butterfly species richness and climatic and primary productivity variables along elevational gradient in Tons valley (N = 26)

The other cardinal variables that were associated with butterfly species richness and habitat specificity involved vegetation cover. Plant species richness was positively associated with butterfly species richness (r = 0.87, N = 42, $P < 0.01$) and abundance (r = 0.65, N = 42, $P < 0.01$). Variation in butterfly abundance and species richness across sampling plots was highly predicted by herb density (Abundance: r = 0.95, N = 42, $P < 0.01$; Butterfly species richness: r = 0.74, N = 42, $P < 0.01$) and shrub density (Abundance: r = 0.82, N = 42, $P < 0.01$; Butterfly species richness: r = 0.69, N = 42, $P < 0.01$), but poorly predicted by canopy cover (Table 5.2).

Fire and livestock abundance were negatively associated with butterfly species richness (Fire signs: r = -0.36, N = 42, $P < 0.05$; Livestock abundance: r = -0.33, N = 42, $P < 0.01$) and abundance (Fire signs: r = -0.49, N = 42, $P < 0.05$; Livestock abundance: r = -0.31, N = 42, $P < 0.05$). Surprisingly, logging activities were positively correlated with butterfly species richness (r = 0.32, N = 42, $P < 0.05$) (Table 5.2).

Table 5.2: Relationship of butterfly species richness and abundance with microclimatic, vegetation, disturbance variables across sampling sites in Tons valley: table presents correlation values (Pearson's *r*) and a level of significance (* < 0.05, ** < 0.01: two tailed).

	Butterfly	
	Species Richness	**Abundance**
Altitude	-0.816**	-0.553**
Temperature	0.693**	0.749**
Relative humidity	-0.359*	-0.208
Wind speed	0.209	0.270
Plant species richness	0.871**	0.659**
Canopy cover	0.538**	0.187
Shrub density	0.693*	0. 823**
Herb density	0.745**	0.999**
Logging	0.328*	0.227
Fire signs	-0.366*	-0.337*
Livestock abundance	-0.493**	-0.312*

5.3.6 Butterfly Range Size

The elevational range size of butterfly increased with increasing elevation upto around 2300 m, but there was high scatter as elevation increases. Hence, there was a very poor positive correlation between the elevational range size and the range mid-points for the butterfly species indicating weak presence of Rapoport's rule (Figure 5.8). Although range sizes of species increased with elevation but the relation was weak (r = 0.19, N =174, $P < 0.05$) (Figure 5.8).

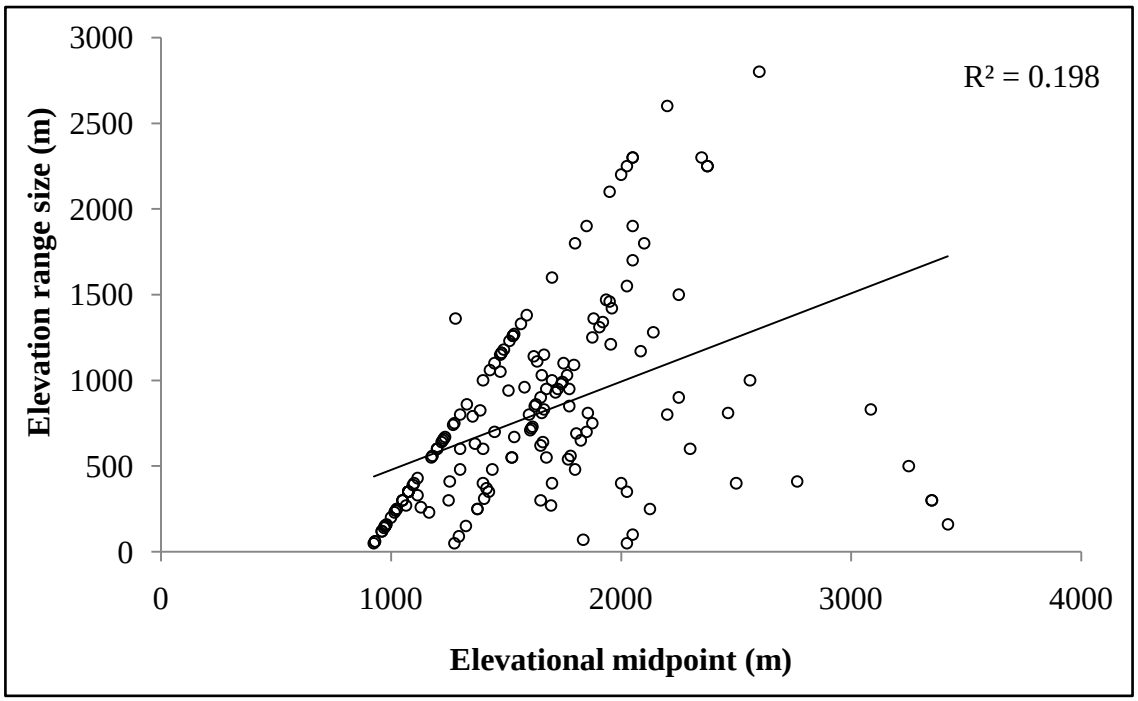

Figure 5.8: Relationship between elevational range midpoints and range size of butterflies.

Species at higher elevation did not have broad ranges. The range size of low elevation species (especially those occurring below 2000 m elevation) tended to increase with increasing elevation (r = 0.29, N = 89, $P < 0.05$), whereas range sizes of high elevation species tended to decrease with elevation (r= 0.02, N = 85, $P < 0.05$) (Figure 5.9). Hence overall a little evidence was found for Rapoport's rule in the butterflies of Tons valley. Elevational range profile of butterflies of Tons valley showed that most of the species occupied very narrow elevational ranges (Figure 5.10).

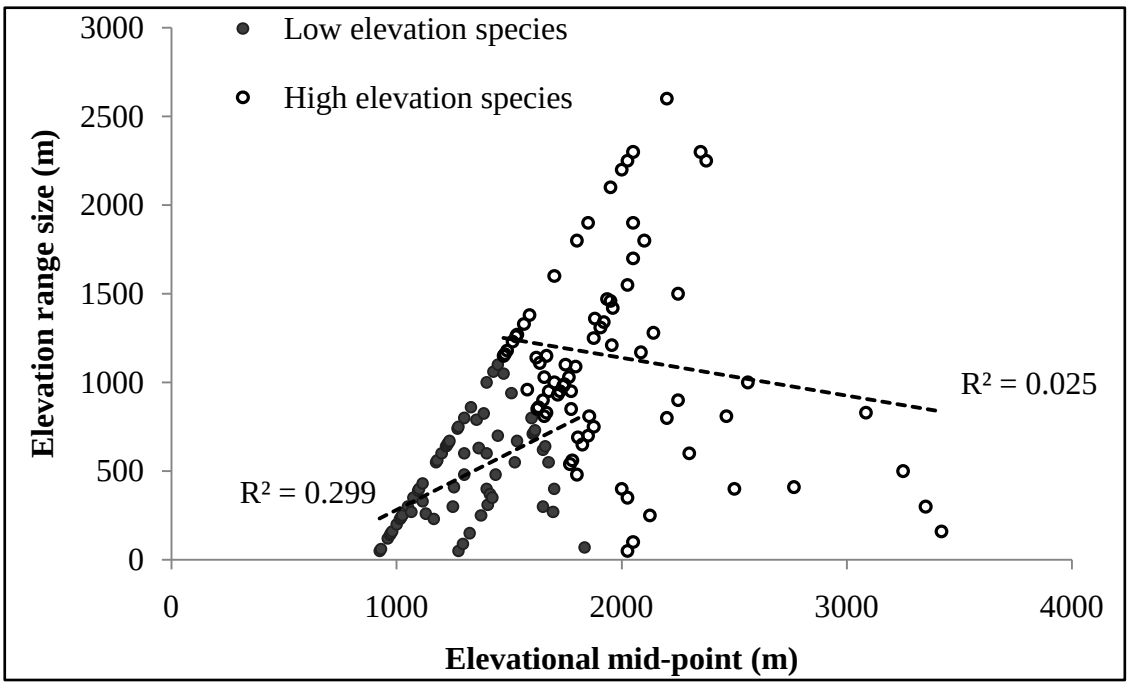

Figure 5.9: Relationship between elevational range midpoints and range size of two groups of butterflies (butterflies occurred upto 2000 m with elevational mid-point between 900 - 2000 m were considered low elevation species, while butterflies elevational mid-point between 2000 – 3500 m and having ranges upto 3500 m were considered high elevation species).

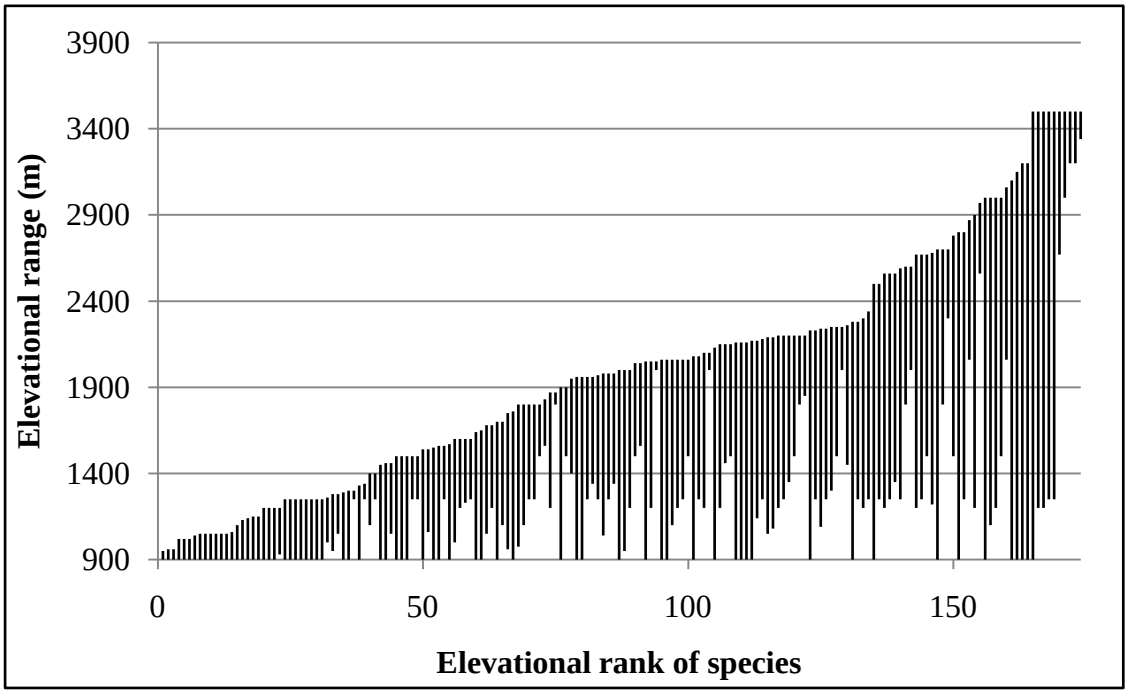

Figure 5.10: Elevational range profiles of butterflies of Tons valley. Vertical bars indicate maximum and minimum range limits of each species. The range of each species was estimated as the difference between lowest and highest elevation, where the species was observed.

There were 89 species (51%), which were observed to have distribution ranges below than 2000 m elevation. Approximately 37% (N = 66) of butterflies had elevational ranges of < 500 m and 4.5% (N = 8) were detected in only a single elevation zone. Ten species had range sizes more than 2000 m (Figure 5.10, Figure 5.11). Only one species (Indian Tortoiseshell *Aglais cashmiriensis*) occurred at each site in the gradient at all elevation (elevation range size = 2600 m) (Figure 5.10).

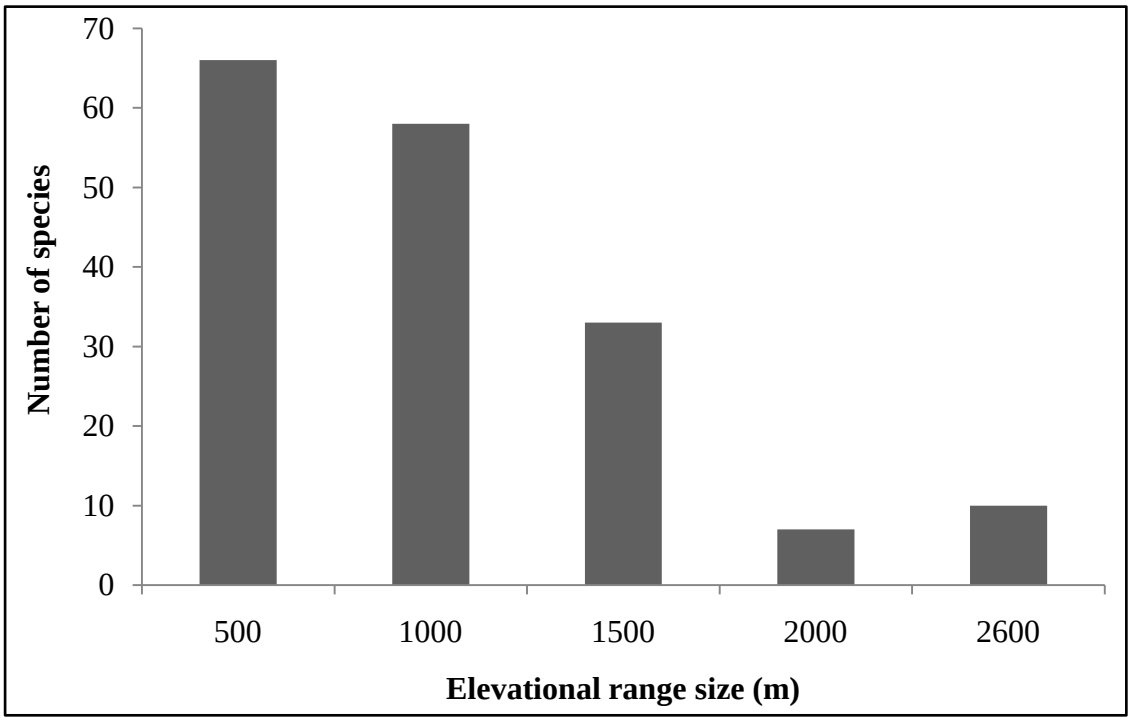

Figure 5.11: Elevational range size distributions of butterflies of Tons valley, western Himalaya.

5.4 Discussion

It is crucial to understand the species richness-altitude relationships for the development of general theory on species diversity. During current study, It was observed that the species richness of butterflies in western Himalaya demonstrated a hump shaped pattern in species richness. Such a pattern is frequently documented in birds (Acharya et al., 2011; McCain, 2009), small mammals (Heany, 2001; McCain, 2004), herpetofauna (Haffer et al., 1999; Fu et al., 2007), invertebrates and plants (Kluge et al., 2006; Sanders et al., 2003; Oommen and Shanker, 2005; Grau et al., 2007). Other taxa in Himalaya and nearby regions also exhibit mid-elevation peaks in

species richness: plant diversity in Central Himalaya, Nepal and Western Himalaya and small mammal diversity in Mt. Qilian, China. Current finding are in consonance with Rahbek's (1995) view that the monotonically inverse relationship between species richness and elevation is not as universal as ecologists generally assumed.

The question of importance is then what produces this pattern. The mid-domain effect is an unavoidable consequence of bounded ranges of variable sizes. As in null model, it is the baseline against which empirical species richness pattern should be compared (Colwell et al., 2003). This has been suggested that an evaluation of biological factors may explain this shift in the peak of richness. Community overlap theory predicts that species richness should peak at the transition zone between two adjacent species rich communities (Lomolino, 2001). In current study the transition zone present between 900 – 1400 m elevations. In current dataset the highest peak occurs at 1100 – 1600 m and the predictions of this theory are supported for present study. Further in these zones secondary peak is also observed. Results of present study are largely in accordance with the prediction of Lomolino (2001) as explained above.

In literature, the SAR has been explained by the theory of island biogeography (MacArthur, 1972) or by the habitat diversity hypothesis. However, these concepts are not mutually exclusive and theoretically may even be complementary because area and habitat diversity are correlated. It has been widely mentioned that larger space can accommodate more species and species richness increases as a function of area (Rahbek, 1997). The influence of area in determining species richness has been shown for different taxa (Kattan and Franco, 2004; Fu et al., 2006). During current study, the area seems to support butterfly species richness upto 2100 m after which species richness gradually decrease and area increase. Nevertheless, the hump-shaped relationship between elevation and butterfly species richness supports the predictions of the SAR theory to some extent. However, the relation of butterfly species richness with area along elevation needs to be seen with change in climate along elevation. This may be possible that temperature and other climatic factors became stronger in explaining butterfly species richness at higher elevation as butterflies are ectotherms and need more energy to support themselves at these higher elevations.

Butterfly species richness in Tons valley was found to respond positively to environmental variables that describes water availability and is negatively associated with climatic parameters. In terms of climatic variables, it then follows that increasing temperature should return more species according species-energy hypothesis.

Butterfly species richness was found be significantly correlated to all the environmental variables. Among climate species richness increased with variable that described water availability (precipitation) and energy related parameter (temperature). Precipitation and temperature emerges as a significant determinant of butterfly species richness in Tons valley at the regional scale. With increasing elevation temperature linearly decreases and the same relation was also observed between elevation and species richness. As it signifies the role of history in the evolution of local species diversity, the ecological significance of precipitation may be considered in the light of global climate change and long term changes in temperature and precipitation may affect biological diversity. Elevation and NDVI also observed to have positive relationship with butterfly species richness. In fact, this was the dominant ides in species-environment studies, till water-energy balance mechanism was proposed and a growing number of investigations at global scale reveal that productivity cannot increase infinitely with solar radiation as temperature would curtail water availability as negative feedback.

At local plot level, a more obvious association of butterfly species richness was observed with vegetation parameters such as, plant species richness, herb and shrub density and canopy cover at plot level. Herb and shrub density were major predictors of butterfly abundance. Anthropogenic factors such as logging were (a moderate amount of logging) found to be positively associated with butterfly species richness and abundance. While forest fire and livestock abundance found to have significant negative influence on butterfly species richness as well as on abundance. As logging creates open patches and these patches also maintain relatively high temperature, which may be important for thermoregulation requirements. Similar results were found by Devi and Davidar (2001), Ghazoul (2002), Cleary (2004) and Akite (2008) studying effect of logging on butterfly diversity. On the other hand, forest fire and livestock grazing directly impacts shrub and herb abundance and shrub and herb abundance was found to be significantly correlated with butterfly abundance

and species richness. As insufficient information is available on the distribution of adult and larval resources, distribution and habitat requirement of generalist and specialist species, interaction and responses of rare species with these factors, flight behaviour, thermal requirement and predation differences in the different habitats, these observations could be used for designing habitat monitoring protocol in the area.

Species ranges results from complex interactions among many factors, including physiological traits, interspecific competition, gene flow and coevolution of species, historical and evolutionary factors and geometric constraints (Case and Taper, 2000). It is still not clear that whether the Rapoport's rule exist for all biological organisms (Grau et. al., 2007). In the present study, elevational; range sizes of butterflies did not increase with increase in elevation, though the relation was poor but it was significant. Although the range size of low elevation species tended to increase with elevation, the relation was weak, and the range sizes of high elevation species decreased with increasing elevation. Rapoport's rule has invited criticisms and whether this rule is a general phenomenon is still a question in macroecology and biogeography (Rhode, 1991; Hernandez et al., 2005). Himalayas is considered as a young mountain system and is still in the course of pronounced differentiation and speciation (Mani, 1974; Johansson et al., 2007).

Present study documents decreasing pattern (with bimodal peaks approximately at 1200 – 1700 m elevation) of butterfly species richness along elevation gradient in Tons valley, Western Himalaya. Butterfly species richness is also found to be a function of nearly same set of environmental variables (temperature, precipitation and habitat heterogeneity) in Tons valley. Study also found support for 'water energy balance' hypothesis of species richness gradients which states that the temperature limits the number of species at higher latitude/altitude and rainfall determines species richness at warmer lower latitudes/altitudes. Given the high richness and small ranges of species, the area needs to be given more protection for the conservation of butterflies and other insect fauna.

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CHAPTER 6

SEASONALITY AND PHENOLOGY OF BUTTERFLIES

6.1 Introduction

Phenology is the study of the sequence of the determined biological events; this type of observation began with the first observation of the agrarians of various cultures (Shapiro et al., 2004). With respect to insects, phenology is defined as the process of appearances of different stages in the life cycle of a taxonomic group over the course of a year and across several seasons (dry and wet or warm and cold periods). Among butterflies, this phenomenon has generally been described based on the appearance of the adult stage or imago of various species. The presence and activity of each generation has been explained as a function of diverse climatic and vegetation factors, such as temperature, precipitation, seasonality of vegetation, food availability and food quality. Phenological patterns in butterflies may be determined by fruitening or flowering plants (Scott, 1986; Wolda , 1987, 1988a), annual humidity distribution (Wolda, 1987; Pozo et al., 2008), cloudiness (Luis and Llorente, 1990), photoperiodic changes (Shapiro, 1975), substrate availability and palatability of larval food plants (Owen et al., 1972).

6.1.1 Seasonality in Insects

As with most other insects, butterfly life cycles are strictly linked to seasonal changes, such as temperature, day length and photoperiod and humidity. Species richness is influenced by climatic factors, which determines reproduction and survival conditions. Therefore, decides the number of individuals documented. Voltinism is the relationship between life cycle, annual climatic behaviour and the number of generation per year. Depending on the number of generation per year, term such as univoltinism, bivoltinism, trivoltinism and mutivoltinism are used to characterise the phenology of a population, specie or a taxon (Gullan and Cranston, 2000). Flight in adults is fundamental to conducting diverse vital actions, such as, feeding, reproduction and oviposition. As butterflies are heliothermic organisms, there flight is dependent on sunlight (Shapiro, 1975).

6.1.1 Phenology in Insects

The phenology of an insect fauna is summarized by the pattern of species emergence throughout the year, which shows records obtained through several generations during several years. When studying phenology, at least three principle components of the insect community can be distinguish. The first component refers to species that are present year after year, regardless of the particular environmental conditions of any given year. The second component consists of species occurring in a given season, generally univoltine species. The third component consists of species whose abundance is too low to determine their seasonality.

In this chapter, phenology and seasonality of butterflies of Tons valley is presented and discussed. First phenology of butterfly species was discussed along the months in a year with peaks in species richness and abundance. Second family level phenology in butterfly species richness and abundance is calculated. Lastly the results are discussed to highlight differences and causes in emergence of seasonal butterfly fauna.

6.2 Methods

6.2.1 Study Area

Study was conducted in Govind WLS in Tons valley. Two sites, (watershed) Istragad and Kedarkanta were selected for sampling (Figure 6.1). Site Istragad has natural forest and the elevation varies from 1500 – 3000 m while site Kedarkanta represents disturbed forest having large anthropogenic disturbance and the elevation varies from 1200 - 3000 m. The butterfly fauna of the sites Kedarkanta and Istragad watershed were surveyed April 2010 - March 2011. Sampling was conducted at sites dominated by the most representative vegetation types in the region mentioned in the Chapter 4. Two approaches such as, line transects and random forest trail/dirt tracts were walked to sample butterflies through three season during January 2011 - December 2011. Transects of 1 km in each mixed forest, oak forest and conifer forest in each natural and disturbed forest were established and sampled across three seasons (pre-monsoon, monsoon and post-monsoon) in each of the two watersheds.

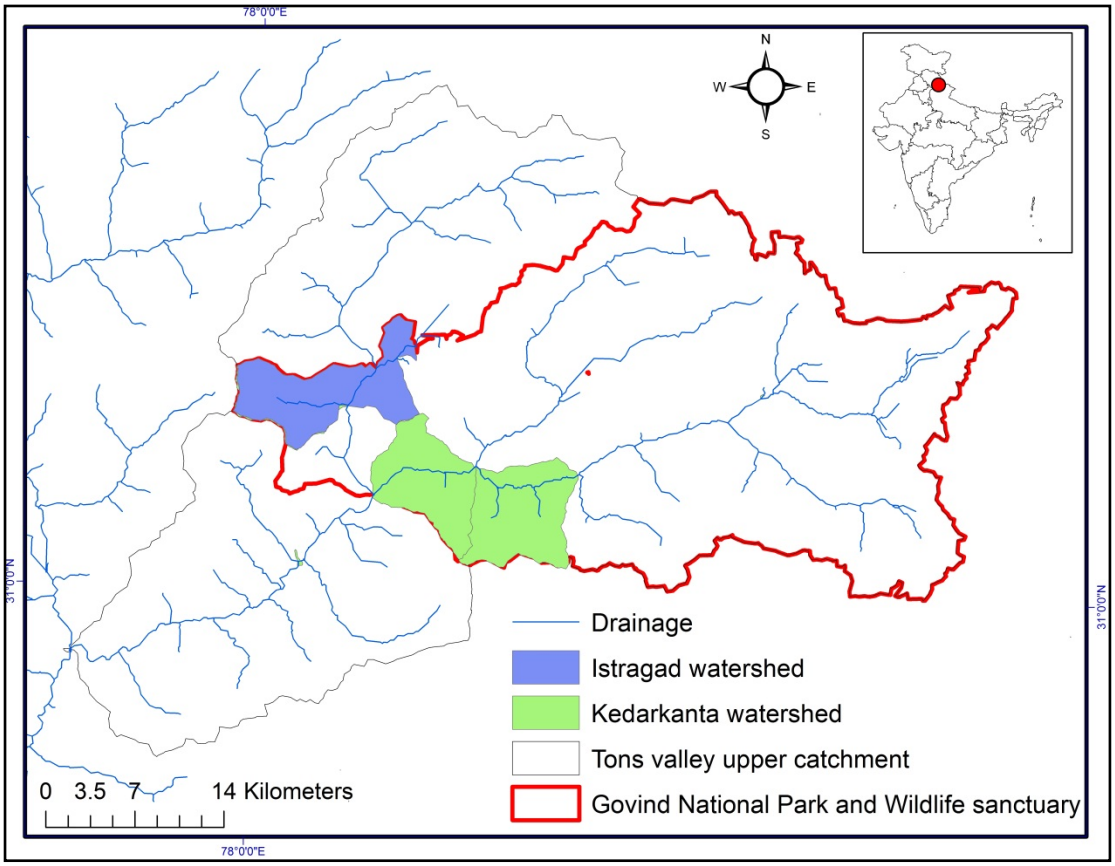

Figure 6.1: Map of study area showing two watersheds (Istragad and Kedarkanta) sampled to evaluate phenology and seasonality for butterflies.

6.2.2 Butterflies

All transects lengths were 1 km (for recording phenology) and transects were traversed on foot by single observer. Abundance data was collected when cloud cover was less than 70% and between 900 - 1700 hrs, the most favorable conditions for butterfly flight. All butterflies seen during the transect walk in an imaginary 5×5×5 (m) box around the observer were recorded. Direct searches were conducted on along or on the dirt tracts and roads. On these, butterflies were searched in sunny gaps, nectar source and damp grounds etc.

6.2.3 Analysis

6.2.3.1 Phenology

Monthly species abundance (phenology) and seasonal distribution (seasonality) data were analysed. In order to describe phenological patterns, total

number of species and individuals were considered and a family level analysis was conducted (Shapiro, 1975).

6.2.3.2 Seasonality

For understanding seasonality, a data matrix was constructed for the year sampling, which recorded the species and their abundance in each season (summer, monsoon and winter) and used to perform community-level analysis using non-metric multidimensional scaling (NMS) analysis in program Past, ver. 1.73 (Hammer et al., 2007) to look at the grouping between sites. The ordination was based on Bray-Curtis dissimilarity matrix (single link) of ecological distance. In order to statistically evaluate differences among groups in each season, an ANOSIM test (Analysis of Similarities) was performed in Primer software, and subsequently SIMPER (SIMilarity PERcentages) analysis was applied to detect species that contributed to 50% of differences among seasonal assemblages.

6.3 Results

6.3.1. Phenology of Butterflies

A total of 10,445 individual butterflies belonging to 131 butterflies species in 74 genera and five families were recorded during the study period. In general the peak in diversity of butterflies was observed at the end of summer season (dry season) with a second peak in wet season (Monsoon season), while abundance was recorded highest at the end of wet season. Reduced species richness and abundance was observed from the end of rainy season to the start of the summer season. The month with the greatest species richness was May with 92 species recorded during that month, while the lowest was during January (28 species) and December (31 species) (Figure 6.2).

Relative abundance peaked during wet season during the month of October with 1,551 individuals (15% of the total abundance recorded in all seasons) and the lowest abundance was recorded during December with 196 individuals (1.8% of the total abundance) (Figure 6.2). Second peak in species richness coincide with the peak abundance. The first peak in species richness was observed from May to June, which corresponds with end of summer season (Dry season) and the second peak in species

richness during August to October corresponds with the rainy season (Monsoon season).

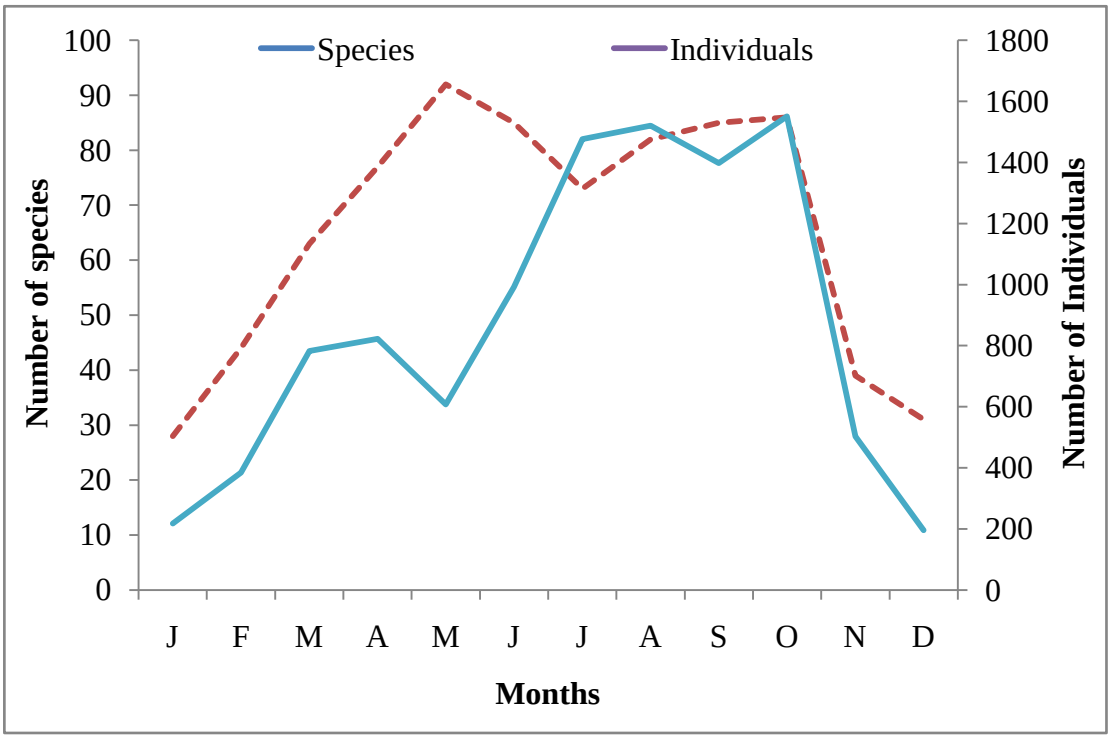

Figure 6.2: Annual occurrence pattern in species richness and abundance of butterflies.

6.3.1.1 Pattern of Species Richness across Families

Family Nymphalidae also accounted for highest number of species occurred every month during the year. This was followed by family Pieridae, Lycaenidae, Papilionidae and Hesperiidae (Figure 6.3). The greatest species richness of family Papilionidae was in May (18 species) and June (14 species) and observed lowest during November (2 species). Species richness of family Pieridae was recorded highest during August (26 species) to September (23 species). Family Nymphalidae shows increased species richness during April to October (with a maximum of 48 species during May and minimum of 33 species during July). Species richness of family Lycaenidae varies from a lowest during December (6 species) to a highest during May and September (14 species). Peak species richness for family Hesperiidae was recorded during May (12 species) to September (10 species).

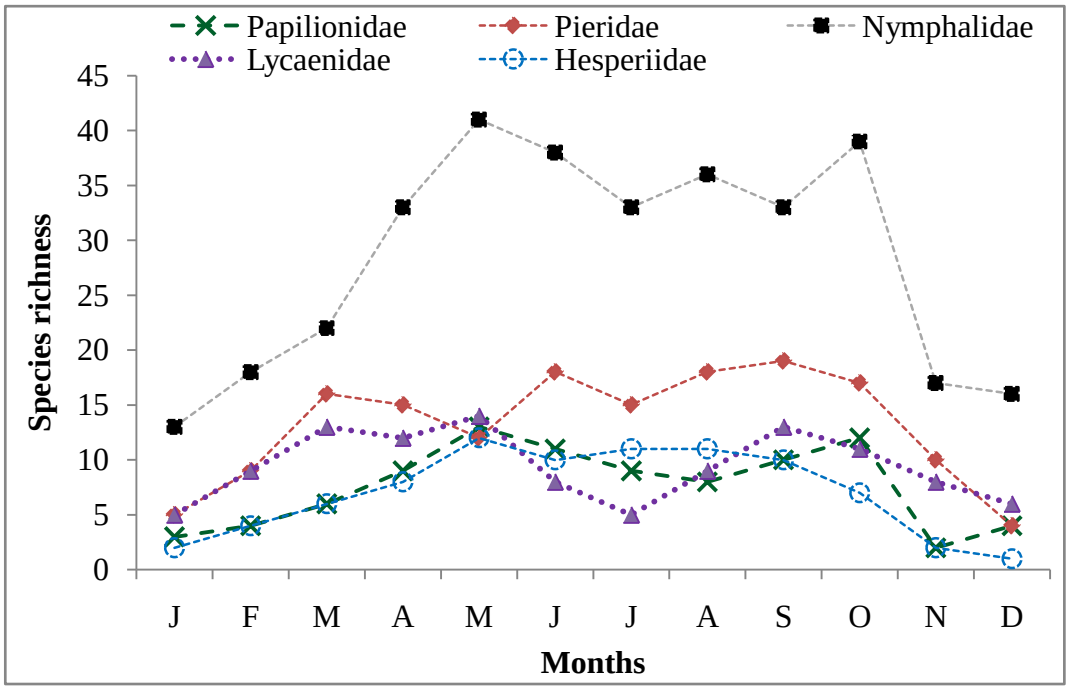

Figure 6.3: Phenological pattern in species richness for five butterfly families.

6.3.1.2 Pattern of Abundance across Families

The most abundant butterfly family was Nymphalidae with 6,021 individuals during the year, accounting 58% of the total individuals of butterflies recorded in total during the complete year. This was followed by family Pieridae, Lycaenidae, Hesperiidae and Papilionidae (Figure 6.4). Proportion of abundance of family Papilionidae and Nymphalidae remain constant for the all months during the year. Family Nymphalidae abundance increases with onset of spring season in proportion to the other families.

Family Papilionidae was composed of few species, most of which are large-bodied, often with small population sizes. Longer survivorship due to their large adult size may allow this family to maintain relatively constant levels of species richness throughout the year. Larger butterflies are good at maintaining their water balance, the greatest problem confronted by insects during the year. The effect of humidity is important with respect to insect body size, and those organisms with small body sizes desiccate more easily than those with medium and large body size in those taxa. In addition, the relatively consistent diversity of family Papilionidae and Pieridae across the seasons could be related to phenological patterns of larval food plants or the availability of adult nectar or mineral resources. In contrast, the Lycaenidae and

Hepseriidae are small sized and thus show fluctuation in their diversity patterns during the year. Family Nymphalidae diversity was highest during post monsoon season followed by the end of dry season.

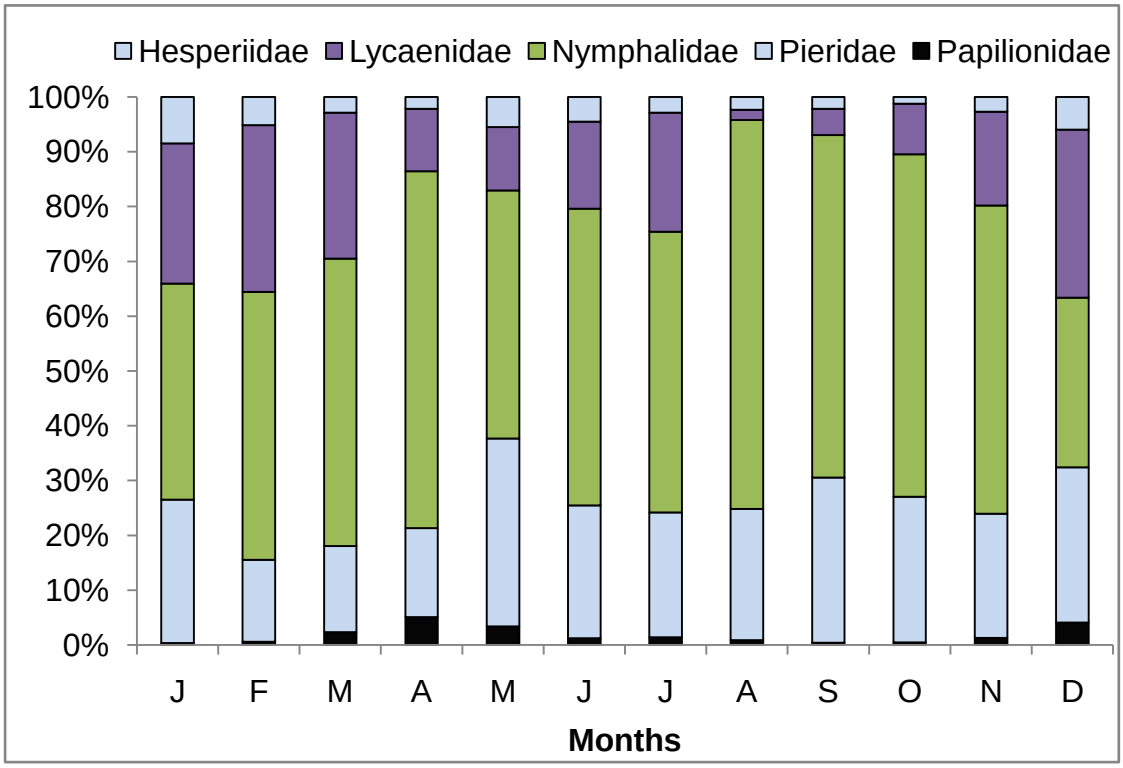

Figure 6.4: Temporal distribution of the relative abundance of butterfly families in Tons valley.

6.3.2 Seasonality of Butterflies

Butterfly composition was found to be significantly variable among dry, rainy and colder seasons at both Istragad (Natural forest site) and Kedarkanta (Natural forest site). As natural forest sites grouped together and disturbed sites group separately. While, the sites were also observed to be group together further by the seasons (Figure 6.5). Butterfly species richness and abundance start increasing with the onset of summer season, while highest species richness was recorded end of the summer season (end of dry season), when water availability was low. Butterflies were seen in congruence at sites, where water was available in the landscape.

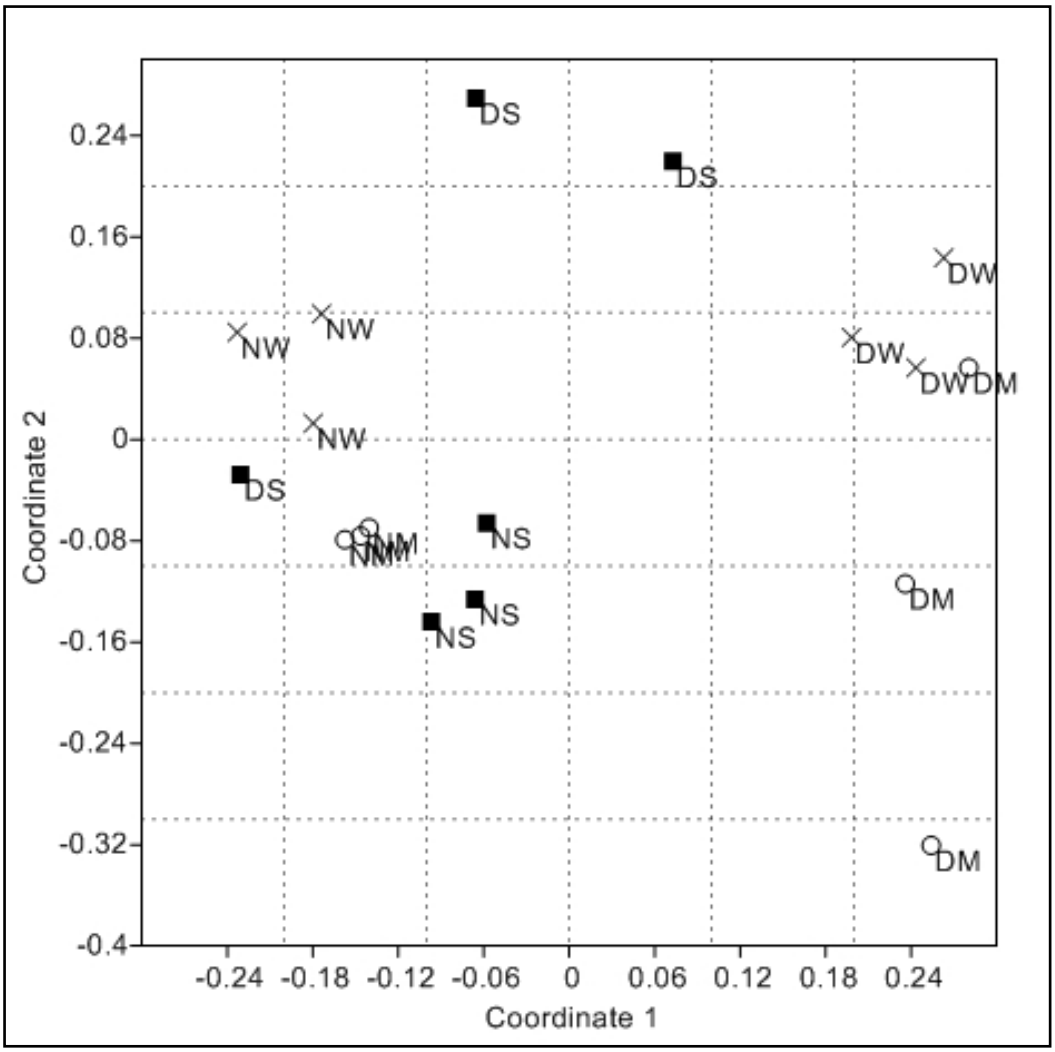

Figure 6.5: MDS ordination plot showing similarities in butterfly composition between 18 sites across three seasons and two disturbance forest categories in the Tons valley. (Abbreviation of sites are as follows:- NS: Natural forest in summer; NM: Natural forest in monsoon, NW: Natural forest in winter, DS: Disturbed forest in summer, DM: Disturbed forest in monsoon, DW: Disturbed forest in winter).

6.4 Discussion

There were differences in phenological patterns of butterflies in Tons valley. Butterfly abundance peaked during dry wet season while multiple peaks in butterfly species richness were observed during late dry season and wet season. Differences have been reported in phenological patterns among insect faunas typical of temperate and tropical areas (Wolda, 1988b). This has been observed that seasonal changes are minimal in tropics and adults of the majority of species should be present throughout the year due to more or less similar climatic conditions throughout the year, which

actually shapes the phenology of flora in the area (Owen, 1971). Whereas in temperate areas adults of most species are restricted to the most conducive seasons (usually spring and summer). Expected observations were made in current study as more than 50% of species appeared and were present during April to July. During wet season a different butterfly assemblage was observed. During the year, the variation in temperature and precipitation was very contrast in summer, monsoon and winter season. Current study indicate a turnover of more than 25% from summer to rainy season and more than 50% from monsoon to winter season. The reason for low abundance in spring/dry summer and high abundance during post monsoon may be that the individuals that emerge in spring after hibernation are able to multiply successfully under favourable climatic conditions and availability of larval food plants in summer, and thus increase their populations to their maximum limits just before the onset of winter when they again go into hibernation or come down to lower valleys. Most of the species here being bivoltine, a very few habitat specialists that are univoltine and many habitat generalists that are tri/multivoltine (skippers). The trend in the graph is for most of the species that have two or three generations.

Among site Kedarkanta and Istragad, butterfly assemblages varied significantly. These differences were probably because of differences in the degree of disturbances, as Istragad watershed represents a natural forest with very low or minimal disturbance while disturbance in Kedarkanta watershed was very high due to many villages inside the region. As there are very few studies conducted in Himalayan region on seasonality of butterflies the results presented here could not be compared. But similar observation in diversity peaks was also observed by Singh and Bhandari (1999) in lower Garhwal, which is not very different in vegetation climate and vegetation from the current study.

Pattern of species richness of Papilionoidea was very similar across the 3 seasons but differed from Hesperiidae. Though family Hesperiidae was represented by very few species in the area but the species richness peaked during May and August. It was observed that differences in phenological pattern among the butterflies generally caused by differences in environmental conditions across seasons. Some studies also suggest that climate is the main factor that controls the emergence and occurrence of butterflies (Brakefield and Shreeve, 1992; Warren, 1992; Gutiérrez and

Menéndez, 1998; Pozo et al., 2008). However, climatic conditions may vary between years and habitats. In current study, phenological similarities were found with respect to species richness throughout seasons. Two period of maximum species richness were observed: the period of greatest diversity during the late summer season and the other peak during monsoon season. Similar observations were also made by Singh and Bhandari (1999), who also documented two peaks in butterfly diversity of tropical moist sal forest of Dehradun valley. Similar observations were made by Pozo et al. (2008). Results of the current study are in consonance with Pozo et al. (2008), which suggests that phenological patterns among butterflies are much more complex than many authors have suggested so far.

Small and medium-sized species show the greatest species turnover across seasons, and many of them are univoltine. As also found by Young (1982), small-sized organisms tend to have their largest populations during the most humid season of the year. Family Hesperiidae, Lycaenidae and Papilionidae were represented by a very few species during dry season, of which Hesperiidae and Lycaenidae were small bodied and most of Papilionidae species were of large body size. Longer survivorship of Papilionidae species due to their large adult size may allow the species of this family to maintain relatively constant levels of species richness throughout year, except extreme cold when most of the area is covered with snow. Larger butterflies are more successful in maintaining their water balance (Janzen and Schoener, 1968), the greatest problem confronted by insects during the dry season. The effect of humidity is important with respect to insect body size, the organisms that have smaller body size desiccates more easily than those with medium and larger sizes (Young, 1982). The phenological pattern of species across the seasons could be related to phenological pattern of larval food plants or the availability of adult nectar or mineral resources. For species with long reproductive lives, availability of nectar resources may be especially important in determining phenological patterns (Gilbert and Singer, 1975). Members of family Lycaenidae and Hesperiidae are characterized by small-sized species and centre their reproductive activities (adult votinism) around larval food plants (New, 1993), in Tons valley this period is most often from March to October. Only few species (e.g., Pale Grass Blue *Pseudozizeeria maha,* Common Hedge Blue *Acytolepis puspa,* Yellow Pansy *Junonia hierta,* Indian Cabbage White *Pieris canidia,* Dark Clouded Yellow *Colias fieldii,* Common Yellow Swallowtail

Papilio machaon, Common Hedge Blue *Acytolepis puspa*, Common Evening Brown *Melanitis leda*, Common Sailer *Neptis hylas* etc.) were observed for most part of the year in Tons valley. Most of the species of family Lycaenidae and Hesperiidae are seasonal and appear only during favourable conditions for reproduction. This was found stands true for most of the species of family Nymphalidae as well (especially for members of subfamily: Satyride). Some species of family Nymphalidae were sighted for a very small period during late of dry season, around water sources and moist habitats. This is the time when humidity is very low and various species can be seen in large congregations, involved in mud-puddling activities near very few remaining water sources in the landscape.

There are very few faunal studies on Lepidoptera of tropical regions based on systematic sampling methods and conducted throughout the year. The information presented here discusses the phenological and seasonal trends of butterfly abundance and species richness and should be useful in future studies on the phenology of this immensely diverse group. In conclusion, current study shows that seasonal variation in the abundance and species richness of the butterfly fauna was high and peaked during summer and end of monsoon season and species richness and abundance of butterflies remain very low during colder season when temperature is very low and plants were in deciduous stage. The majority of seasonal differences were mainly because of the Lycaenidae, Hesperiidae and Nymphalidae species that appeared for a very short durations in specific seasons.

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CHAPTER 7

RAPID ASSESSMENT OF BUTTERFLIES: IMPLICATIONS FOR CONSERVATION

7.1 Introduction

As time and money is limited, explicit, cost-effective, quick, and appropriate methods are needed to assist conservation planners and managers for making quick decisions. Especially in the areas of biodiversity hotspots like, Himalayas facing mounting threats of anthropogenic disturbance to biodiversity. In recent decades, urbanization, commercial activities and unlimited resource use has reduced most of the natural forest habitats of this area to degraded remnants. Because of these threats, modern studies of biodiversity are critical for conservation of the remaining forests patches in the Himalayan ecosystem.

To fully inventorize diversity requires nearly impossible levels of time, effort and money (Lawton et al., 1998) in any area. To avoid the logistically impossible task of sampling entire communities, past efforts have concentrated on performing rapid inventories (Roberts, 1991; Bonebrake and Sorto, 2009), utilizing focal taxa approach (Noss, 1990; Pearson and Cassola, 1992; Pearson, 1994) and developing extrapolation techniques to estimate diversity in different habitats (Colwell and Coddington, 1994; Hammond, 1994; Kiester et al., 1996).

The appeal of using indicator taxa is one of logistics. By focusing on one particular set of species in a location rather than all of the species, considerable time and limited resources can be saved (Gardner et al., 2008). The purpose of this paper was to demonstrate importance of rapid assessment studies, for selecting areas important for insect conservation in the Tons valley, Western Himalaya. With respect to butterflies then, how much sampling effort is required for an adequate assessment of a butterfly community in the western Himalaya landscape?

In the present study butterflies were sampled in five different sites consisting of different natural habitats (mixtures of pine forest, broadleaf forest, conifer forest and alpine meadows) at Tons valley, western Himalaya, India with the following objectives: (1) An integrated approach was used to sample butterfly across multiple

habitats, landuse types, using multiple data collection techniques for assessment of sampling effort. Such an approach is essential for conservation programs aimed at Lepidoptera (Sparrow et al., 1994; Bonebrake and Sorto, 2009). (2) Butterfly diversity and species richness were compared across different sites and assessed the extent to which study was able to inventory the species present at Tons valley. (3) Potential utility of rapid assessment studies was discussed for assessing quick changes in the habitat as quick and cost effective biodiversity monitoring tool. Further, utility of butterflies as surrogate of insect diversity, for boosting insect conservation in the Western Himalaya landscape were discussed.

7.2 Methods

7.2.1 Study Area

The study was conducted in the upper catchment of Tons Valley in Uttarakhand, western Himalaya. The region falls under bio-geographic province 2B zone of Western Himalaya (Rodgers and Panwar, 1988) and sub region Garhwal Himalaya. Five watersheds, Tuni, Istragad, Jakhol, Kedarkanta and Har-ki-Dun were selected for sampling (Figure 7.1) (Table 7.1).

All sites exhibit a range of elevation from a low of 900 - 6323 m and possess a gradient of disturbance from habitats such as natural forest to highly disturbed sites such as, agricultural land. Two sites, Istragad and Kedarkanta, are managed under protection category as Govind WLS. Sites Jakhol and Har-ki-Dun fall within protected area (PA) as Govind NP. While, site Tuni is under high degree of anthropogenic disturbance and lies outside any formally PA.

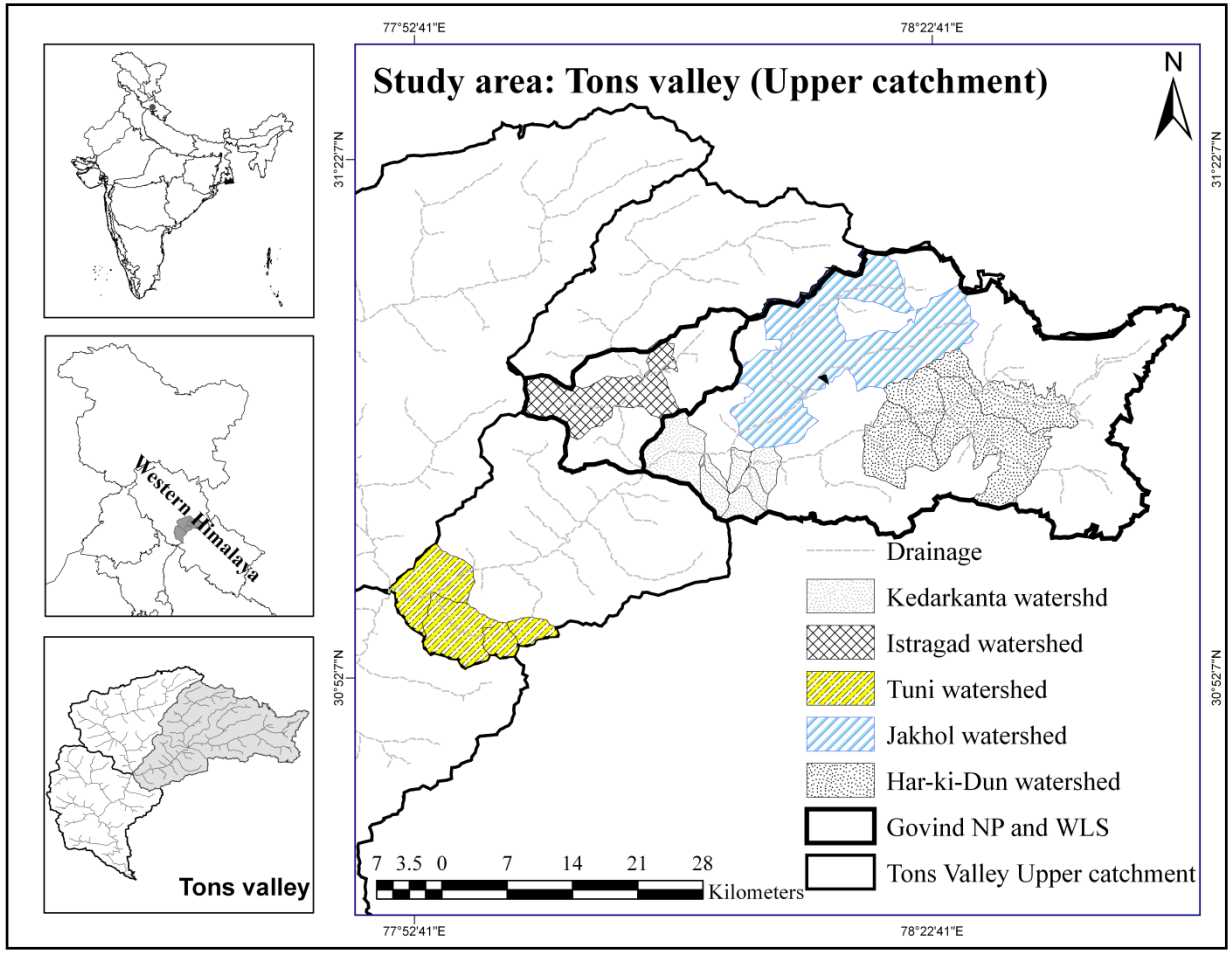

Figure 7.1: Map of Tons valley upper catchment showing locations of five sampling sites. Sites Kedarkanta, Istragad, Jakhol and Har-ki-Dun lies in PAs (Govind NP and WLS), while site Tuni lies in unprotected area.

Table 7.1: Survey details, disturbance characteristics, butterfly species richness, abundance, diversity and unique species recorded, for the five sampling sites in Tons Valley during March - April 2010.

	Istragad	Jakhol	Tuni	Kedarkanta	Har-ki-Dun
Protection category	Govind WLS	Govind NP	Reserve Forest	Govind WLS	Govind NP
Logging intensity	Low	Low	High	Medium	Medium
Fire signs	Low	Medium	High	Medium	High
Livestock abundance	Low	Low	High	High	Medium
Human habitations	Very low	Medium	High	High	Medium
Altitude sampled (m)	1500 - 3500	1800 - 3500	900 - 2400	1250 - 3000	1800 – 3500
Habitats sampled*	6	6	6	6	6
No. of transects/trails	20	16	16	16	16
Effort (km)	6	4.8	4.8	4.8	4.8
Species richness	51	27	27	35	17
Genera richness	40	24	21	26	14
Individuals	488	100	259	540	117
Fisher's alpha	11.17	10.84	7.59	8.37	5.47
Unique species	19	4	11	5	1

** Six butterfly habitats were sampled uniformly across all five sites (e.g. Agriculture land, Mix riparian forest, Mix broadleaf forest, Pine forest, Conifer forest and Alpine meadows).*

7.2.2 Butterflies

Two sampling approaches were used, direct search and indirect search. A total of 42 line transects and 42 random forest trail/dirt tracts were walked to sample butterflies for 20 days during spring season in March - April 2010 and for 50 days during summer season in May - July 2010 and the sampling efficiency of these two sampling periods were compared to complete three year study. Sampling was conducted between 900 - 3,500 m elevations across all sites.

Transect length was 300 m and was traversed on foot within 30 min. All butterflies within 5m×5m (5m around observer) of the transect line were observed using binoculars. Abundance data were collected when cloud cover was less than 70% and between 0900 - 1300 hrs, the most favorable conditions for butterfly flight. I recorded all butterflies seen during transect walk in an imaginary 5 × 5 × 5 (m) box around the observer. Baited traps with rotten bananas and beer mixture fermented for 5 days were also employed. Baited traps were placed in a manner that traps was placed at every 100 m, first 5 m away on left and then on the right side alternatively at each 100 m point on the transect. Thus, there were 3 baited traps on each of transects. Specimens captured in these traps were included in the species inventory but not for species richness estimations. In addition to transect and traps, opportunistic sightings at mud puddles, nectar sources and other resource rich sites were used. Butterflies that were too fast or too distant to reliably identify during flight were not counted. Butterflies that could not be readily identified visually were either photographed or captured using a hand held sweep net and were released after identification in the hand. The few voucher specimens that were collected, deposited at the insect repository of the WII in Dehradun.

Stratified-random sampling design was employed to record butterfly species composition patterns in both dominant and important vegetation types. Broadly six types of butterfly habitats were classified (e.g. agriculture land, mix riparian forest, mix broadleaf forest, pine forest, conifer forest and alpine meadows); only those were considered which were consistent across each of the five sites. Habitats accounting for major proportion of sampling area were one of the criteria of selection. Opportunistic sampling was also conducted at rare habitats to increase species inventory of the area but not included in analysis of rapid assessments.

7.2.3 Analysis

7.2.3a Species Richness Estimates

Species richness estimates were calculated for assessing sampling effort and efficiency using program EstimateS (Colwell, 2009) based on individual-based species accumulation curves (Gotelli and Colwell, 2001). Program EcoSim (Gotelli and Entsminger, 2004) was used to generate rarefaction curves for comparing species richness estimates between sites and habitats.

Another technique for estimating total species richness of the area based on the model developed by Singh and Pandey (2004), which suggests that species proportion of family Papilionidae is an indicator of the total butterfly (Rhopalocera) species richness of an area across Indian subcontinent, for which Papilionidae richness is known, was used. The mean proportion (7.4%) of family Papilionidae was thus used to estimate the total species richness of an area in the Western Himalaya for which Papilionidae species is known.

7.2.3b Species Diversity and Community Composition Analysis

To calculate estimates of evenness, Fisher's alpha index was used to compare diversity between sites using program Past. Community-level analysis with MDS analysis was performed in program Past, ver. 1.73 (Hammer et al., 2007) to look at the grouping between sites and habitats. The ordination was based on a Bray-Curtis dissimilarity matrix (single link) of ecological distance. To test for degree of differences across sites ANOVA (one way) analysis was performed using program SPSS (SPSS, 2007 ver.16.0). Fisher's alpha index was used to compare diversity of butterflies across six habitats (e.g. agriculture land, mix riparian forest, mix broadleaf forest, pine forest, conifer forest and alpine meadows). In this case, butterfly abundance falling under same habitat category from five sampling sites was pooled (e.g. Istragad, Tuni, Jakhol, Kedarkanta and Har-ki-Dun).

7.3 Results

7.3.1 Species Richness and Abundance

A total of 79 butterfly species and 1,504 butterfly individuals on the Tons Valley transects in 20 days over a total of approx 45 sampling hrs (Appendix 7.1) were recorded. Seven individuals of two species, *Elynias hypermnestra* and *Mycalesis perseus,* were only recorded in these traps. Thirteen individuals of seven species (*Heliophorus brahma, Dodona durga, Lethe rohria, Stibochiona nicea, Celanorrhinus leucocera, Celanorrhinus dhanada, Sarangesa purendra*) were only recorded by opportunistic sightings, (not on the transects). A total of 123 butterflies species were recorded during complete season sampling period from the study area and a total of 207 species during entire 3 year study in the Tons valley.

7.3.2 Family Composition across Sites

Across the five sites there was no significant difference in butterfly family (5 families) species richness (one way ANOVA: $F_{4,4} = 2.0$, $P = 0.11$) and genera richness (one way ANOVA: $F_{4,4} = 1.25$, $P = 0.31$) (Table 7.2). A total of 79 butterfly species of 55 genera and five families was recorded. With 14 species the family Papilionidae accounted for an average of 18% (Figure 7.2) of all species recorded at all sites. Kedarkanta (8 species: *Paranassius epaphus, Paranassius hardwickii, Graphium cloanthus, Chilasa clytia, Papilio protenor, Papilio machaon, Papilio polyctor* and *Atrophaneura aristolochiae*) and Istragad (7 species: *Paranassius epaphus, Paranassius hardwickii, Graphium eurous, Chilasa clytia, Papilio polytes, Papilio protenor* and *Papilio machaon*) had the highest number of swallowtail species while, site Har-ki-Dun had only 3 species (*Graphium cloanthus, Papilio protenor* and *Papilio machaon*).

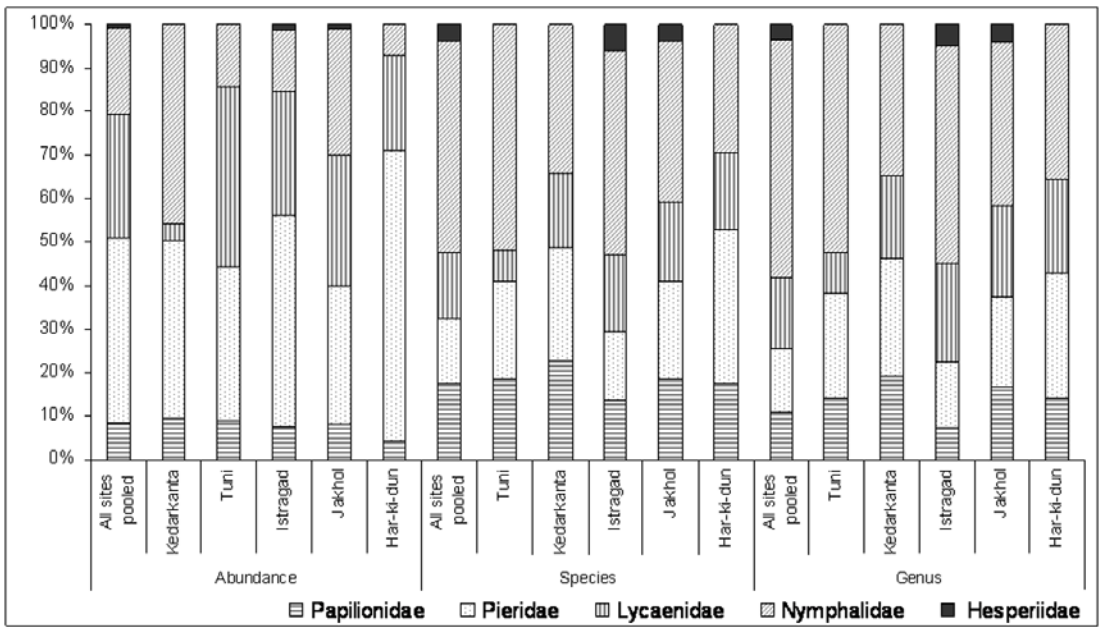

Figure 7.2: Relative compositions of butterfly families in total abundance, number of genus and species across five sampling sites during rapid assessment in Tons valley.

A total 12 species in the family Pieridae comprising 15% of all species found at all sites (Figure 7.2). The highest numbers of Pierid species were recorded at Kedarkanta (9) and the lowest at Istragad (8) accounting for 33% and 30% of total butterfly species at these sites. A total of 12 species (15%) of the family Lycaenidae were recorded. The highest number of species of this family were recorded at Istragad (9 species; 18% of total species at this site) and lowest at Tuni (9 species and 6% of total species at this site) (Figure 7.2). In the family Nymphalidae a total 39 species (49%) was recorded belonging to 30 genera. The highest number of species in this family were recorded at Istragad (9 species; 18% of total species at this site) and lowest at Tuni (9 species; 6% of total species at this site) (Figure 7.2). The family Hesperiidae accounted for a total of 3 species (*Celanorrhinus leucocera*, *Celanorrhinus dhanada* and *Sarangesa purendra*) belonging to 2 genera, 3.7% of the total species recorded at all sites (Figure 7.2).

A significant difference was observed between butterfly families (N = 5) abundance across sites (one way ANOVA*:* $F_{4,4} = 3.91$, $P = 0.009$) (Table 7.2). A total of 1504 butterfly individuals were recorded of which family Pieridae (42.68%) and Lycaenidae (28.45%) accounted for major proportion followed by Nymphalidae (20.07%), Papilionidae (8.24%) and Hesperiidae (0.53%) (Figure 7.2). Family

Pieridae sighting was highest at site Har-ki-Dun and was lowest at site Jakhol (Figure 7.2). Other important observation was taken on family Lycaenidae, which were sighted in very low proportion at site Kedarkanta (4% of total abundance at site).

Table 7.2: Results of Anova (single factor) analysis showing differences in species composition, family abundance, family species richness, family genera richness across five sampling sites in Tons valley. The matrix of family variables is composed of, values under each of the five butterfly families across five sites.

	F	F crit	*P*-value	df	df (denominator)
Species composition	3.38	2.39	0.009	4	78
Family abundance*	3.91	2.62	0.009	4	4
Family species richness**	2.0	2.62	0.11	4	4
Family genera richness***	1.25	2.62	0.31	4	4

*(*Total abundance of all species pooled under each of the 5 butterfly families across 5 sites. **Number of species found under each butterfly family across 5 sites. ***Number of genera accounted by each family across 5 sites)*

7.3.3 Species Richness Estimates and Inventory Completeness

Six estimators of species richness (Table 7.3) were calculated, but the Chao1 estimate of species richness produced the largest estimate of species richness at Tons Valley. Following the suggestions by Sorenson et al. (2002) and Scharff et al. (2003) inventory completeness values were calculated, to assess the ratio between observed and estimated richness. Using the Chao1 estimate, 49% of the estimated species richness was assesses during rapid assessment survey. Estimator Chao2 (lowest estimate of species richness) suggested that 89% of the butterfly fauna was detected.

Continuing sampling to complete season (upto July 2010), a total of 123 butterfly species were detected. Using highest species richness estimates (Chao1), 75-80% of butterfly fauna was sampled at Tons valley (Bhardwaj et al., 2012). While continuing the study upto four years, a total of 189 species were detected in the area. Hence, in 20 day period of rapid assessment a significant of butterfly fauna (41.7% of the total inventory) of Tons valley was sampled.

Table 7.3: Species richness estimates including SD (standard deviation) calculated using program EstimatesS.

Estimates of species richness		
Estimators	**For rapid survey**	**For second sampling period**
ACE	100 (0)	159 (14.2)
ICE	103 (0)	132 (11.7)
Chao1	162 (42.3)	152 (26.7)
Chao2	90 (10.1)	131 (7.3)
Jack1	95 (9.9)	141 (4.2)
Jack2	105 (0)	130 (2.1)

**The ACE is "Abundance-based Coverage Estimator" and the ICE is "Incidence-based Coverage Estimator". Chao1 and Chao2 estimators are based on Chao (Chao, 1987). Jack1 and Jack2 are 1st and 2nd order Jackknife richness estimators. For review see (Magurran, 2004).*

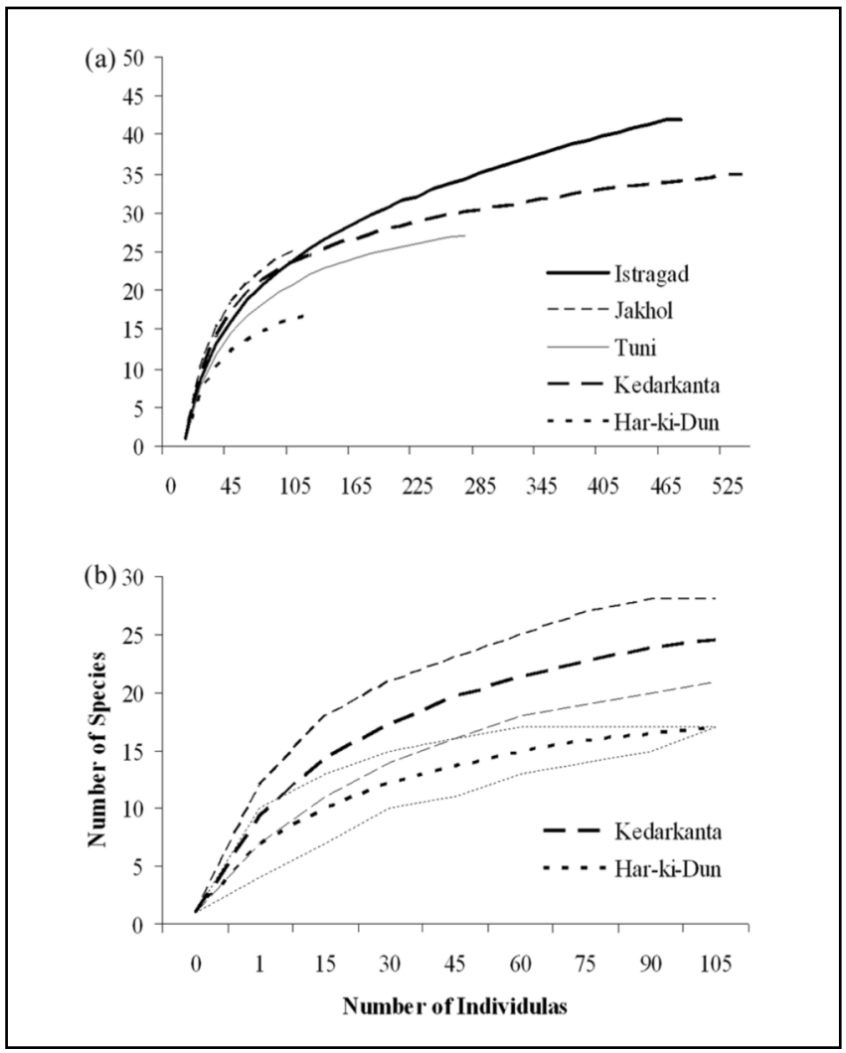

Figure 7.3: (a) Individual based rarefaction curves for five different sites and (b) with 95% confidence intervals for sites Kedarkanta and Har-ki-Dun.

Using family Papilionidae (Singh and Pandey, 2004) proportion (ratio extrapolation) method, the species richness estimate for the Tons valley was 297 species for the rapid assessment survey, which seems an overestimate. Therefore, 26.5% of the estimated species richness was sampled during rapid assessment using this method. Using non parametric methods of species richness estimation, an estimate of around 145 - 220 butterfly species from the study area is provided, which also stands correct at the end of sampling, as a total of 189 species of butterflies were collected during entire 4 year study with 86% of sampling efficiency.

7.3.4 Diversity and Community Analysis

Significant differences (one way ANOVA: $F_{4,78} = 3.38$, $P = 0.009$) (Table 7.2) in species composition across 5 sampling sites were observed. Fisher's alpha was used as a measure of diversity. Fisher's alpha for sites (Table 7.1) was highest for Istragad (11.17) followed by Jakhol (10.8). Sites Kedarkanta (8.36), Tuni (7.58) had the next highest diversity with Har-ki-Dun (5.46) quite similar the pattern found in species richness across sites. Agriculture land (16.2) contained the highest diversity followed by mix riparian forest (15.15), mix broadleaf forest (12.93) while, the diversity was quite low in homogenous habitats such as pine forest (11.64), followed by conifer forest (7.89) and alpine meadows (4.34).

7.3.5 Sites and Habitats Comparison

Two sites, Istragad and Kedarkanta contained higher species richness than any other sites (Figure 7.3a). The 95% confidence intervals for species richness at lowest number of individuals (98) of sites Istragad (19-28 species) and Kedarkanta (20-27 species) was higher than Jakhol (20-25 species) and Tuni (16-23 species). While species richness intervals were significantly lower for Har-ki-Dun (14-17 species).

In non-metric multidimensional scaling (MDS) analysis showed the grouping of sites Istragad and Kedarkanta, Har-ki-Dun and Jakhol grouped together (Figure 7.4). Site Tuni had not group with any of the sites and showed an assemblage pattern different from the other four sites (Figure 7.4). Site Kedarkanta and Istragad lies with Govind WLS, while site Har-ki Dun falls within Govind NP and geographically very close to site Jakhol. There were 36 species that were only found on a single site. Istragad (17) and Tuni (11) had highest number of unique species. Sites Kedarkanta

(5), Jakhol (4) had next highest unique species, while site Har-ki-Dun contained only one unique species (Appendix 7.1).

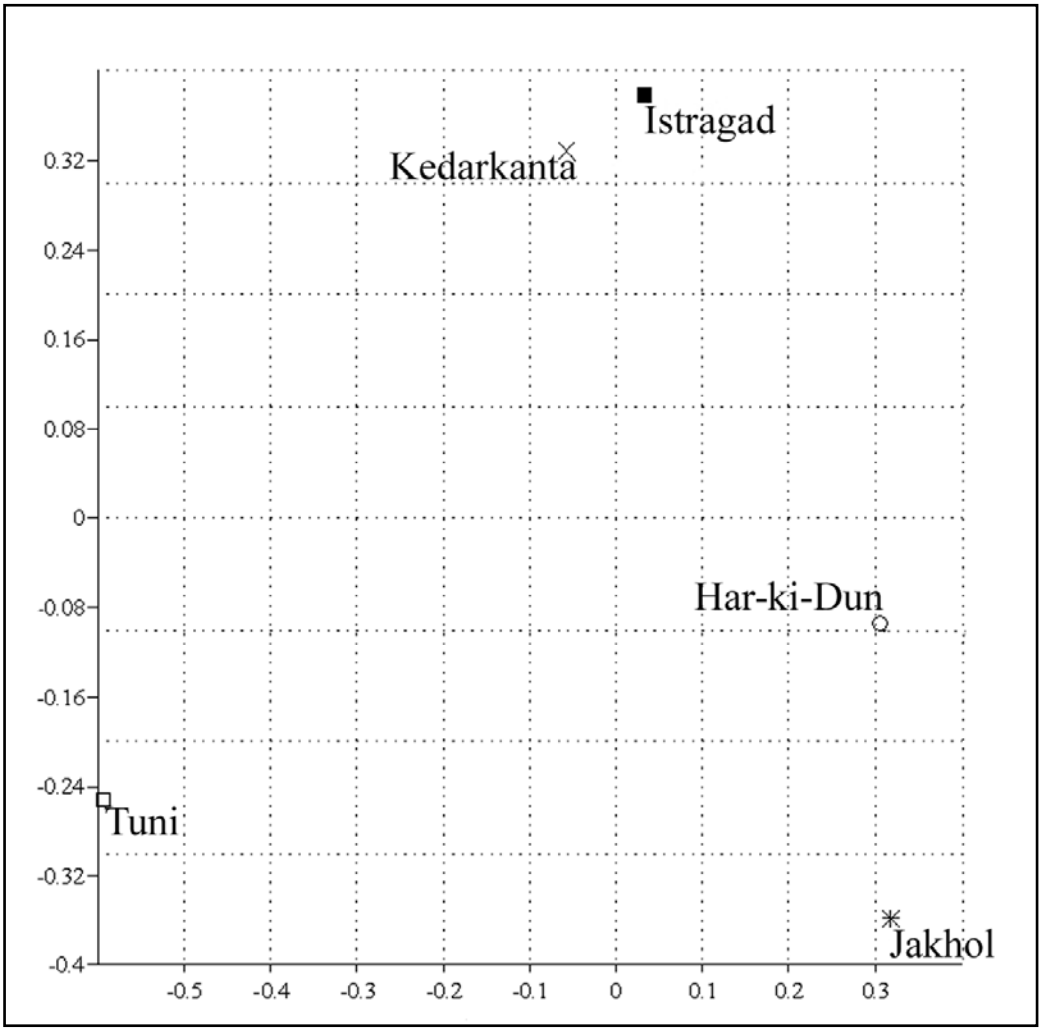

Figure 7.4: MDS ordination for five sampling sites with repect to butterfly composition in Tons valley.

7.4 Discussion

Butterfly assemblages distribution shifts with seasons (dry and wet seasons) and due to change in climatic conditions (snowfall, temperature fluctuations and forest fire etc.) in the Himalayas (Mani, 1986) and make sampling complicated. Thus a complete survey of Tons Valley requires more sampling time. To evaluate this point, sampling was continued upto complete season with double effort than first survey in May - July 2010. However, sampling for whole seasons a total of 123 species were sampled from the area (Bhardwaj et al., 2012). Using highest species

richness estimates, 60% of butterfly fauna was sampled in second study. But on comparing the species inventory to entire study period sampling (4 years), a total of 189 species of butterflies were collected with 86% of sampling efficiency, which is suggested as exhaustive sampling for arthropod inventories (Cardoso, 2009). During rapid assessment survey, 41.71% of total butterfly fauna was sampled and continuing sampling upto complete season 60% of sampling efficiency was achieved, which seems a quick, cost effective method to monitor butterflies and other arthropods in this landscape.

Species richness estimators are based on assumptions that the community being sampled is present at all times of sampling. But due to seasonality effects many butterfly species may not have been flying during the sampled period. As in second sampling 42 more species were recorded which were not recorded during rapid survey and missed 18 species that were present in rapid sampling. Thus because species richness estimators (ICE, Chao1, Chao2, etc.) are sensitive to seasonality problems, it is better to take into account seasonality effects and local migrations in species appearance and disappearance. Solution to this problem can be to sample at pre and late period of seasons and then draw conclusions about estimates of species richness in any area.

The ratio extrapolation approach has its own assumptions and uncertainties. It assumes a strong correlation between finding the focal species and the target species. In this instance, it seems likely that focal species are easier to find than non-focal species given the detection bias towards the focal species. Therefore, it was assured that 297 species (using Papilionidae proportion method) was not an overestimate of species richness, a total of 189 species were recorded during 4 year study. But I feel this proportion varies at local scale, as this figure was an average of large secondary dataset from various part of India (Singh and Pandey, 2004) and thus may provide an overestimated figure in current study area. Approximately, 41.7% of butterfly fauna (of all that was recorded during 4 year) was sampled in 20 days of rapid assessment survey in Tons Valley. Despite the difficulties of sampling such a diverse group in such a short period of time, significant differences in diversity across sites were observed and a reliable estimate of butterfly species richness was provided in the area. Certainly sampling for more time would have improved the estimates of species

richness. For this area was sampled again in during May - July 2010 to account for seasonality effects. With this a total of 123 species were recorded from the Tons Valley. Using the species richness estimates, inventory completeness was approximately 60% (Table 7.3) in the study area, suggested as comprehensive sampling for arthropod inventories (Cardoso, 2009).

To enquire, whether rapid sampling period was sufficient to detect butterfly compositional differences between sites; sites Kedarkanta and Har-ki-Dun differed significantly only after the last 30 - 40 individuals were sampled in rarefaction (Figure 7.3b). Thus, study was able to sample characteristic butterfly composition of sites in rapid assessment. Study was also able to differentiate between sites Har-ki-Dun and Jakhol though there were very less differences in their species richness in given short sampling period.

Baited traps are often recommended as a tool for butterfly inventorization. Two species using these traps were found that were missed by sweep netting sampling method. Opportunistic sightings at ponds and other microhabitats (not on transects), added six more species to the list.

In rapid survey higher butterfly diversity was observed in agriculture land than in any other natural or semi- natural forest habitats, although the numbers of butterfly species were highest in natural forest, such as mix riparian forest. The reason for supporting high diversity may be due to complex habitat conditions and higher resource heterogeneity. Thus this observed diversity in agriculture land may be due to the availability of variety of microhabitats and vegetation, high mineral and resource richness due to anthropogenic activities associated with it (Bhardwaj and Uniyal, 2009; Devi and Davidar, 2001; Spitzer et al., 1993). These results support a growing consensus that human dominated landscape can often support diverse assemblage of butterflies (Barlow et al., 2008; Horner-Devine et al., 2003). However natural sites, such as Istragad and Jakhol contained some of the highest butterfly diversity of the undisturbed sites. But these two sites also contained large number of unique species (23 species, not shared with other sites), indicating that natural forest and undisturbed sites are important for conservation of such species. Both frugivore and non-frugivore butterflies may visit agriculture habitats but rely primarily on resources in the forest for nutrition, mating and reproduction; use adult resources found in the open but

depend on forest fragments for larval host plants; find both adult and larval host plants both in and out of the forest (Horner-Devine et al., 2003). Sites such as, Kedarkanta, Har-ki-Dun and Tuni are highly disturbed sites and generally covered largely by human dominated mix scrub, pine forest, agriculture lands and natural diverse habitats such as mix broadleaf forest and alpine meadows are under immense anthropogenic pressure at these sites. As these habitats support daily livelihood requirements (food, fodder, herbs, livestock grazing etc.) of the villagers. Results support that Istragad and Jakhol are sites that supported a range of forest butterfly species and likely needs more protection.

Site similarities in butterfly composition falling in three protection regimes were well supported by the MDS ordination plot (Figure 7.4). Sites Istragad and Kedarkanta lies in Govind WLS were grouped together as these sites are managed under a lower degree of protection. Sites Jakhol and Har-ki-Dun also grouped together as both lies in the high level of protection regime as Govind NP. Site Tuni fell apart in MDS plot and was unique in that it had areas of high disturbance and low quality forest and protection (managed under reserve forest protection category). Nevertheless, it supported a moderately diverse butterfly assemblage (Table 7.1), made up primarily of widespread and generalist species from high elevation and low elevation areas of the Tons valley. During snowfall at higher elevations species migrate to lower altitude in the area (Personal Observation), while in summer butterflies move here from lower elevations.

Other insect communities were also sampled (moths and beetles) in the area and positive correlation was found in species richness of butterflies, moths and beetles (Uniyal et al., 2011). Patterns of species turnover were correlated for lepidoptera, indicating that the two group community composition shifts similarly across sites (Bhardwaj et al., 2012). In absence of data for more insect communities, this assessment may be used to assume insect species patterns to follow similar patterns as recorded in the butterflies. This may result from overlap in the location of host plants, degree of disturbance or similarity of thermal tolerance. Though correlations between butterflies and other insect groups are decidedly imperfect (Ricketts et al., 2002; Schulze et al., 2004; Singer and Ehrlich, 1991), in the absence of more complete insect data this is suspected that Istragad and Jakhol are likely to be important sites

for general insect conservation in Govind NP and WLS (PA) in Tons Valley. Nonetheless, careful considerations of the conservation issue must be taken into account before butterflies are used as a surrogate for insect biodiversity as the study have not tested for differences in distribution of rare species of butterflies, moths and beetles across sites. The global scale and rapidity of biodiversity destruction (Wilson, 1988) forces most ecologists to accept the practical need for quick surveys of biodiversity in conservation planning and management (Roberts, 1991). However, these can ultimately be justified only by testing their accuracy against large sample; long term studies that partition diversity into spatial and temporal dimensions.

There are about 417 species of butterflies in Western Himalaya (Wynter-Blyth, 1957). This is not expected to record comparable number species at such a small site as the upper catchment of Tons Valley. It lacks representation from lower elevations (500 - 900 m), a major repository of species found in the Western Himalaya. It is extremely difficult to sample biodiversity in a given area, as time and money is limited. To select and prioritize areas for biodiversity conservation, rapid assessments of indicator taxa can be an important, helpful and cost effective tool, in time limited sampling efforts. Butterflies constitute a model system for such large sample long term monitoring studies to test quick biodiversity surveys. In the present study, Istragad and Jakhol managed under different degree of protection regimes (in Govind NP and WLS) are promising sites, supporting a large number of unique forest species and high butterfly diversity as well. These observations are also supported with results of significant positive cross taxa correlation between butterflies, moths and beetles species richness. Thus management practices should be revised, so as to give protection to these sites. Although site Tuni supports large number of generalist butterfly species, it also supports a unique butterfly assemblage. As the site is currently managed under very less degree of protection, effort needs to be given to minimise or check anthropogenic activities (e.g. grazing, logging, looping (collection of leaves for fodder), herb collection, wood cutting, forest fire etc.) leading to habitat degradation. This study also confirms the importance of natural and semi-natural habitats for butterflies in the Tons Valley. Study recommends sweep netting supplemented with fruit baits, opportunistic random search in all possible habitats for inventorization of butterflies in Himalayan landscape. This is expected that results presented here will positively help biodiversity conservation efforts in the area by

giving attention to remaining fragmented habitats facing human alterations. Using rapid assessment methods, which are cost-effective and quick, will help conservation planners and managers in monitoring and taking quick decisions for conservation of biodiversity in Himalaya.

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Appendix 2.1: Classification of major forest types in upper catchment of Tons valley according to Champion and Seth (1968). Note that the codes and notations are followed as given in the source.

Group 5. TROPICAL DRY DECIDUOUS FOREST

5C. Northern tropical dry deciduous forests

C. Dry sal-bearing forest

C1a. Dry Siwalik sal Forest

Group 9. SUBTROPICAL PINE FORESTS

C1. Himalayan subtropical pine forests

C1b. Upper or Himalayan chir pine forest

Group 12. HIMALAYAN MOIST TEMPERATE FOREST

C1. Lower Western Himalayan temperate forests

C1a. Ban oak forest (*Quercus incana*)

C1c. Moist deodar forest (*Cedrus*)

C1d. Western mixed coniferous forest (Spruce, blue pine, silver fir)

C2. Upper West Himalayan temperate forests

2b. West Himalayan upper oak/fir forest

2c. Moist temperate deciduous forest

2S1. Low-level blue pine forest

Group 13. HIMALAYAN DRY TEMPERATE FOREST

(i) Western types

C2. Dry temperate coniferous forest

C2b. Dry deodar forest (*Cedrus*)

1S1. Hippophae-Myricaria scrub

Group 14. SUB-ALPINE FOREST

C1. West Himalayan sub-alpine birch/fir forests (*Betula/Abies*)

C1a. West Himalayan sub-alpine fir forest

C1b. West Himalayan sub-alpine birch/fir forest

Group 15. MOIST ALPINE SCRUB

C1. Birch-Rhododendron scrub forest

Appendix 3.1: List of 189 butterfly species along with their common and scientific names in different families (subfamilies) recorded in the upper catchment of Tons valley during April 2008 to October 2012.

S. No.	Common Name	Scientific Name	Family (Subfamily)
1	Common Red Apollo	*Paranassius epaphus*	**Papilionidae (Parnassiinae)**
2	Common Blue Apollo	*Paranassius hardwickii*	
3	Common Bluebottle	*Graphium sarpedon*	**Papilionidae (Papilioninae)**
4	Glassy Bluebottle	*Graphium cloanthus*	
5	Common Jay	*Graphium doson*	
6	Jay	*Graphium* sp.	
7	Spot Swordtail	*Graphium nomius*	
8	Sixbar Swordtail	*Graphium eurous*	
9	Tawny Mime	*Chilasa agestor*	
10	Common Mime	*Chilasa clytia*	
11	Common Mormon	*Papilio polytes*	
12	Red Helen	*Papilio helenus*	
13	Spangle	*Papilio protenor*	
14	Redbreast	*Papilio alcmenor*	
15	Lime Butterfly	*Papilio demoleus*	
16	Common Yellow Swallowtail	*Papilio machaon*	
17	Paris Peacock	*Papilio paris*	
18	Common Peacock	*Papilio polyctor*	
19	Common Windmill	*Atrophaneura polyeuctes*	
20	Great Windmill	*Atrophaneura dasarada*	
21	Common Rose	*Atrophaneura aristolochiae*	
22	Golden Birdwing	*Troides aeacus*	
23	Three Spot Grass Yellow	*Eurema blanda*	**Pieridae (Coliadinae)**
24	Small Grass Yellow	*Eurema brigitta*	
25	Spotless Grass Yellow	*Eurema laeta*	
26	Common Grass Yellow	*Eurema hecabe*	
27	Common Brimstone	*Gonepteryx rhamni*	
28	Lesser Brimstone	*Gonepteryx mahaguru*	
29	Common Emigrant	*Catopsilia pomona*	
30	Mottled Emigrant	*Catopsilia pyranthe*	
31	Dark Clouded Yellow	*Colias fieldii*	
32	Pale Clouded Yellow	*Colias erate*	
33	Small Orange Tip	*Colotis etrida*	**Pieridae (Pierinae)**
34	Common Wanderer	*Parenonia valeria*	
35	Large Cabbage White	*Pieris brassicae*	
36	Green-Veined White	*Pieris napi*	
37	Indian Cabbage White	*Pieris canidia*	
38	Bath White	*Pontia daplidice*	
39	Common Gull	*Ceporia nerissa*	
40	Himalayan Blackvein	*Aporia leucodice*	

41	Great Blackvein	*Aporia agathon*	
42	Hill Jezebel	*Delias belladonna*	
43	Pale Jezebel	*Delias sanaca*	
44	Common Jezebel	*Delias eucharis*	
45	Psyche	*Leptosia nina*	
46	Pioneer	*Belenois aurota*	
47	Common Gem	*Poritia hewitsoni*	**Lycaenidae (Portiinae)**
48	Bright Sunbeam	*Curetis bulis*	**Lycaenidae (Curetinae)**
49	Indian Purple Hairstreak	*Esakiozephyrus mandara*	**Lycaenidae (Theclinae)**
50	Large Oakblue	*Arhopala amantes*	
51	Tailless Bushblue	*Arhopala ganesa*	
52	Yamfly	*Loxura atymnus*	
53	Tufted White Royal	*Pratapa deva*	
54	Plains Blue Royal	*Tajuria jehana*	
55	White Royal	*Tajuria illurgis*	
56	Blue Tit	*Chliaria kina*	
57	Guava Blue	*Deudorix isocrates*	
58	Large Guava Blue	*Deudorix perse*	
59	Cornelian	*Deudorix epijarbas*	
60	Indian Red Flash	*Rapala jarbas*	
61	Indigo Flash	*Rapala varuna*	
62	Long-Banded Silverline	*Spindasis lohita*	
63	Common Silverline	*Spindasis vulcanus*	
64	Common Copper	*Lycaena phlaeas*	**Lycaenidae (Lycaeninae)**
65	White-Bordered Copper	*Lycaena pavana*	
66	Green Copper	*Lycaena kasyapa*	
67	Golden Sapphire	*Heliophorus brahma*	
68	Green Sapphire	*Heliophorus androcles*	
69	Powdery Green Sapphire	*Heliophorus tamu*	
70	Sorrel Sapphire	*Heliophorus sena*	
71	Common Pierrot	*Castallius rosimon*	**Lycaenidae (Polyommatinae)**
72	Zebra Blue	*Leptotes plinius*	
73	Common Cerulean	*Jamides celeno*	
74	Pea Blue	*Lampides boeticus*	
75	Rounded Pierrot	*Tarucus nara*	
76	Dark Grass Blue	*Zizeeria karsandra*	
77	Pale Grass Blue	*Pseudozizeeria maha*	
78	Chapman's Cupid	*Everes diporoides*	
79	Dusky Hedge Blue	*Oreolyce vardhana*	
80	Common Hedge Blue	*Acytolepis puspa*	
81	Hill Hedge Blue	*Celastrina argiolus*	
82	Large Hedge Blue	*Celastrina huegelii*	
83	Pale Hedge Blue	*Udara dilecta*	
84	Orange Bordered	*Aricia astrarche*	

	Argus		
85	Plains Cupid	*Chilades pandava*	
86	Common Meadow Blue	*Polymmatus eros*	
87	Plum Judy	*Abisara echirius*	**Lycaenidae (Riodininae)**
88	Tailed Punch	*Dodona eugenes*	
89	Common Punch	*Dodona durga*	
90	Common Beak	*Libythea lepita*	**Nymphalidae (Libytheinae)**
91	Club Beak	*Libythea myrrha*	
92	Blue Tiger	*Tirumala limniace*	**Nymphalidae (Danainae)**
93	Dark Blue Tiger	*Tirumala septentrionis*	
94	Striped Tiger	*Danaus genutia*	
95	Common Tiger	*Danaus chrysippus*	
96	Glassy Tiger	*Parantica aglea*	
97	Chestnut Tiger	*Parantica sita*	
98	Striped Blue Tiger	*Euploea mulciber*	
99	Common Crow	*Euploea core*	
100	Common Nawab	*Polyura athamus*	**Nymphalidae (Charaxinae)**
101	Tawny Rajah	*Charaxes polyxena*	
102	Common Evening Brown	*Melanitis leda*	**Nymphalidae (Satyrinae)**
103	Dark Evening Brown	*Melanitis phedima*	
104	Common Treebrown	*Lethe rohria*	
105	Bamboo Treebrown	*Lethe europa*	
106	Common Forester	*Lethe insana*	
107	Straight-Banded Treebrown	*Lethe verma*	
108	Common Woodbrown	*Lethe sidonis*	
109	Large Goldenfork	*Lethe goalpara*	
110	Common Wall	*Lasiommataschakra*	
111	Common Palmfly	*Elymnias hypermnestra*	
112	Liliacine Bushbrown	*Mycalesis francisca*	
113	Common Bushbrown	*Mycalesis perseus*	
114	Dark-Brand Bushbrown	*Mycalesis myneus*	
115	Great Satyr	*Aulocera padma*	
116	Common Satyr	*Aulocera swaha*	
117	Striated Satyr	*Aulocera saraswati*	
118	Ringed Argus	*Callerebia ananda*	
119	Common Argus	*Callerebia nirmala*	
120	Pallid Argus	*Callerebia scanda*	
121	Common Threering	*Ypthima asterope*	
122	Common Fivering	*Ypthima baldus*	
123	Large Threering	*Ypthima nareda*	
124	Himalayan Fivering	*Ypthima sakra*	
125	Tawny Coster	*Acraea violae*	**Nymphalidae (Heliconiinae)**
126	Leopard Lacewing	*Cethosia cyane*	
127	Western Silverstripe	*Argynnis pandora*	

128	Indian Fritillary	*Argyreus hyperbius*	
129	Large Silverstripe	*Childrena childreni*	
130	Highbrown Silverspot	*Fabriciana adippe*	
131	Common Silverstripe	*Fabriciana kamala*	
132	Dark Green Fritillary	*Speyeria aglaja*	
133	Queen of Spain Fritillary	*Issoria lathonia*	
134	Rustic	*Cupha erymanthis*	
135	Vagrant	*Vagrans egista*	
136	Common Leopard	*Phalanta phalantha*	
137	Indian White Admiral	*Limenitis trivena*	**Nymphalidae (Limenitidinae)**
138	Common Sergeant	*Athyma perius*	
139	Himalayan Sergeant	*Athyma opalina*	
140	Common Lascar	*Pantoporia hordonia*	
141	Yerbury's Sailer	*Neptis nata yerburyii*	
142	Common Sailer	*Neptis hylas*	
143	Himalayan Sailer	*Neptis mahendra*	
144	Broad-Banded Sailer	*Neptis sankara*	
145	Broadstick Sailer	*Neptis narayana*	
146	Yellow Sailer	*Neptis ananta*	
147	Common Baron	*Euthalia aconthea*	
148	Gaudy Baron	*Euthalia lubentina*	
149	Baronet	*Euthalia nais*	
150	Common Earl	*Tanaecia julii*	
151	Common Map	*Cyrestis thyodamas*	**Nymphalidae (Cyrestinae)**
152	Tabby	*Pseudergolis wedah*	
153	Popinjay	*Stibochiona nicea*	
154	Common Castor	*Ariadne merione*	**Nymphalidae (Biblidinae)**
155	Indian Purple Emperor	*Apatura ambica*	**Nymphalidae (Apaturinae)**
156	Golden Emperor	*Dilipa morgiana*	
157	Circe	*Hestina nama*	
158	Western Courtier	*Sephis adichroa*	
159	Himalayan Jester	*Symbrenthia hypselis*	
160	Common Jester	*Symbrenthia hippoclus*	
161	Indian Red Admiral	*Vanessa indica*	**Nymphalidae (Nymphalinae)**
162	Painted Lady	*Vanessa cardui*	
163	Indian Tortoiseshell	*Aglais cashmiriensis*	
164	Large Tortoiseshell	*Nymphalis xanthomelas*	
165	Eastern Comma	*Polygonia egea*	
166	Blue Admiral	*Kaniska canace*	
167	Blue Pansy	*Junonia orithya*	
168	Yellow Pansy	*Junonia hierta*	
169	Chocolate Pansy	*Junonia iphita*	
170	Grey Pansy	*Junonia atlites*	
171	Peacock Pansy	*Junonia almana*	
172	Lemon Pansy	*Junonia lemonias*	
173	Danaid Eggfly	*Hypolimnas misippus*	

174	Great Eggfly	*Hypolimnas bolina*	
175	Orange Oakleaf	*Kallima inachus*	
176	Common Banded Awl	*Hasora chromus*	**Hesperiidae (Coeliadinae)**
177	Indian Awlking	*Choaspes benjaminii*	
178	Indian Skipper	*Spialia galba*	**Hesperiidae (Pyrginae)**
179	Common Small Flat	*Sarangesa dasahara*	
180	Spotted Small Flat	*Sarangesa purendra*	
181	Common Spotted Flat	*Celaenorrhinus leoucocera*	
182	Fulvous Pied Flat	*Pseudocoladenia dan*	
183	Common Snow Flat	*Tagiades japetus*	
184	Water Snow Flat	*Tagiades litigiosa*	
185	Chestnut Angle	*Odontoptilum angulata*	
186	Common Grass Dart	*Taractrocera maevius*	**Hesperiidae (Hesperiinae)**
187	Common Dartlet	*Oriens goloides*	
188	Himalayan Dart	*Potanthus dara*	
189	Small Branded Swift	*Pelopidas mathias*	

Appendix 4.1: List of 159 butterfly species along with their habitat occupancy (presence/absence) patterns in four different habitats sampled in Tons Valley during April 2009 - March 2010. (Habitat abbreviations are as follows:- MRSF: Mixed riparian and scrub forest, PF: Pine forest, BF: Broadleaf forest, CAF: Conifer and alpine forest)

S. No.	Species Name	MRSF	PF	BF	CAF
	Papilionidae				
1	*Paranassius epaphus*	0	0	0	1
2	*Paranassius hardwickii*	0	0	0	1
3	*Graphium sarpedon*	1	0	1	0
4	*Graphium cloanthus*	1	1	0	0
5	*Graphium doson*	1	1	0	0
6	*Graphium* sp.	1	0	1	0
7	*Graphium eurous*	1	0	0	0
8	*Chilasa agestor*	1	0	1	0
9	*Chilasa clytia*	1	1	0	0
10	*Papilio polytes*	1	1	0	0
11	*Papilio helenus*	0	0	1	1
12	*Papilio protenor*	1	1	1	0
13	*Palpilio alcemenor*	0	0	1	0
14	*Papilio demoleus*	1	1	0	0
15	*Papilio machaon*	1	0	1	1
16	*Papilio polyctor*	0	1	1	0
17	*Atrophaneura polyeuctes*	0	0	1	0
18	*Atrophaneura dasarada*	0	0	1	0
19	*Atrophaneura aristolochiae*	1	1	0	0
20	*Troides aeacus*	1	0	1	0
	Pieridae				
21	*Eurema blanda*	1	1	1	0
22	*Eurema brigitta*	1	1	0	0
23	*Eurema laeta*	0	1	1	0
24	*Eurema hecabe*	1	0	1	1
25	*Gonepteryx rhamni*	1	1	1	1
26	*Catopsilia pomona*	1	1	0	0
27	*Catopsilia pyranthe*	1	1	1	0
28	*Colias fieldii*	0	0	1	1
29	*Colias erate*	1	0	1	1
30	*Parenonia valeria*	1	1	1	0
31	*Pieris brassicae*	1	1	1	0
32	*Pieris napi*	1	0	1	0

S. No.	Species Name	MRSF	PF	BF	CAF
33	*Pieris canidia*	1	1	1	1
34	*Pontia daplidice*	1	1	1	1
35	*Aporia leucodice*	0	0	1	0
36	*Aporia agathon*	1	0	1	0
37	*Delias belladonna*	1	0	1	1
38	*Delias Sanaca*	1	0	0	0
39	*Belenois aurota*	1	1	1	1
	Lycaenidae				
40	*Poritia hewitsoni*	1	0	1	0
41	*Curetis bulis*	0	0	1	0
42	*Loxura atymnus*	1	0	1	0
43	*Chliaria kina*	1	0	1	0
44	*Deudorix perse*	0	1	1	0
45	*Deudorix epijarbas*	1	0	0	0
46	*Rapala jarbas*	1	0	1	0
47	*Rapala varuna*	0	0	1	0
48	*Spindasis vulcanus*	1	0	0	0
49	*Lycaena phlaeas*	1	0	1	1
50	*Lycaena pavana*	1	1	0	0
51	*Lycaena kasyapa*	1	0	0	0
52	*Heliophorus brahma*	1	0	0	0
53	*Heliophorus androcles*	1	0	0	1
54	*Heliophorus tamu*	0	0	1	0
55	*Heliophorus sena*	1	0	1	1
56	*Castallius rosimon*	1	0	0	0
57	*Jamides celeno*	1	0	1	1
58	*Lampides boeticus*	1	1	0	0
59	*Zizeeria karsandra*	1	0	1	0
60	*Pseudozizeeria maha*	1	1	1	1
61	*Everes argiades diorides*	1	0	0	0
62	*Acytolepis puspa*	1	1	1	1
63	*Celastrina argiolus*	1	1	1	1
64	*Celastrina huegelii*	1	1	1	1
65	*Aricia astrarche*	0	0	1	0
66	*Chilades pandava*	1	0	0	0
67	*Polymmatus eros*	1	0	0	1
68	*Abisara echirius*	1	0	0	1
69	*Dodona eugenes*	1	0	1	0
70	*Dodona durga*	1	0	1	0

S. No.	Species Name	MRSF	PF	BF	CAF
	Nymphalidae				
71	*Libythea lepita*	1	1	1	1
72	*Libythea myrrha*	0	0	1	0
73	*Tirumala limniace*	1	1	1	0
74	*Tirumala septentrionis*	1	0	1	1
75	*Danaus genutia*	1	1	1	1
76	*Danaus chrysippus*	1	1	1	0
77	*Parantica aglea*	1	0	0	0
78	*Parantica sita*	1	0	1	0
79	*Euploea mulciber*	1	1	1	0
80	*Euploea core*	1	1	1	0
81	*Polyura athamus*	1	0	1	0
82	*Melantis leda*	1	1	0	0
83	*Melantis zitenius*	1	1	0	0
84	*Lethe rohria*	1	0	1	0
85	*Lethe europa*	1	0	1	0
86	*Lethe insana*	1	0	0	0
87	*Lethe verma*	1	0	1	0
88	*Lethe sidonis*	1	0	0	0
89	*Lethe goalpara*	1	0	0	0
90	*Lasiommata schakra*	0	0	1	0
91	*Elymnias hypermnestra*	1	0	1	0
92	*Mycalesis francisca*	1	0	1	0
93	*Mycalesis perseus*	1	0	0	0
94	*Mycalesis myneus*	1	1	1	0
95	*Aulocera padma*	0	1	1	1
96	*Aulocera swaha*	1	0	1	0
97	*Aulocera saraswati*	1	0	0	1
98	*Callerebia ananda*	1	1	0	0
99	*Callerebia nirmala*	0	1	1	0
100	*Callerebia scanda*	1	1	0	0
101	*Ypthima asterope*	1	1	1	0
102	*Ypthima baldus*	1	1	0	0
103	*Ypthima sakra*	1	0	1	0
104	*Cethosia cyane*	1	0	1	0
105	*Acraea violae*	1	0	1	0
106	*Argynnis pandora*	0	0	1	1
107	*Arggyres hyperbius*	1	1	0	0
108	*Fabriciana adippe*	0	0	0	1

S. No.	Species Name	MRSF	PF	BF	CAF
109	*Fabriciana kamala*	1	0	1	0
110	*Speyeria aglaja*	0	0	0	1
111	*Issora lathonia*	1	0	1	1
112	*Cupha erymanthis*	1	0	0	0
113	*Palanta phalantha*	1	0	0	0
114	*Limentis trivena*	0	0	1	1
115	*Athyma perius*	1	0	1	0
116	*Athyma opalina*	1	0	1	1
117	*Pantoporia hordonia*	1	1	0	0
118	*Neptis nata yerburyii*	1	0	1	0
119	*Neptis hylas*	1	1	0	0
120	*Neptis ananta*	0	0	1	0
121	*Neptis Mahendra*	1	0	1	1
122	*Neptis sankara*	1	0	1	0
123	*Neptis narayana*	0	1	1	0
124	*Euthalia aconthea*	1	0	0	0
125	*Euthalis nais*	1	1	0	0
126	*Cyrestis thyodamas*	1	0	1	0
127	*Pseudergolis wedah*	1	0	1	0
128	*Stibochiona nicea*	1	0	1	0
129	*Ariadne merione*	1	0	1	0
130	*Apatura ambica*	0	0	1	1
131	*Dilipa morgiana*	0	0	1	0
132	*Hestina nama*	1	0	1	0
133	*Sephisa dichroa*	1	1	1	0
134	*Symbrenthia hypselis*	1	0	1	0
135	*Symbrenthia hippoclus*	1	1	1	0
136	*Vanessa indica*	1	1	1	1
137	*Vanessa cardui*	1	1	1	1
138	*Aglais cashmiriensis*	1	0	1	1
139	*Nymphalis xanthomelas*	1	0	1	1
140	*Polygonia agea*	1	0	1	1
141	*Kaniska canace*	1	1	1	0
142	*Junonia orithiya*	1	1	1	1
143	*Junonia hierta*	1	1	0	0
144	*Junonia iphita*	1	1	1	0
145	*Junonia atlites*	1	0	0	0
146	*Junonia almana*	1	0	0	0
147	*Junonia lemonias*	1	0	0	0

S. No.	Species Name	MRSF	PF	BF	CAF
148	*Hypolimnas misippus*	1	0	0	0
149	*Hypolimnas bolina*	1	0	1	0
150	*Kallima inachus*	1	0	0	0
	Hesperiidae				
151	*Hasora chromus*	1	0	0	0
152	*Choaspes benjaminii*	1	0	1	0
153	*Celaenorrhinus leoucocera*	1	0	1	0
154	*Pseudocoladenia dan*	1	0	0	0
155	*Tagiades japetus*	1	0	0	0
156	*Tagiades japetus*	1	1	0	0
157	*Oriens goloides*	1	1	0	0
158	*Potanthus dara*	0	1	1	1
159	*Pelopidas mathias*	1	0	1	0

Appendix 5.1: List of 174 butterfly species along with their occupancy (presence/absence) patterns in three broad elevation zones during April 2010 – August 2011 in Tons valley.

S. No.	Species Name	Elevation zones (m)		
		900-2000	2000-3000	3000-3500
	Papilionidae			
1	*Paranassius epaphus*	0	0	1
2	*Paranassius hardwickii*	0	1	1
3	*Graphium sarpedon*	1	0	0
4	*Graphium cloanthus*	1	0	0
5	*Graphium doson*	1	0	0
6	*Graphium* sp.	1	0	0
7	*Graphium eurous*	1	0	0
8	*Chilasa agestor*	1	1	0
9	*Chilasa clytia*	1	0	0
10	*Papilio polytes*	1	0	0
11	*Papilio helenus*	1	0	0
12	*Papilio protenor*	1	0	0
13	*Palpilio alcemenor*	1	0	0
14	*Papilio demoleus*	1	0	0
15	*Papilio machaon*	1	1	1
16	*Papilio polyctor*	1	1	0
17	*Atrophaneura polyeuctes*	1	1	0
18	*Atrophaneura dasarada*	1	1	0
19	*Atrophaneura aristolochiae*	1	0	0
20	*Troides aeacus*	1	1	1
	Pieridae			
21	*Eurema blanda*	1	0	0
22	*Eurema brigitta*	1	0	0
23	*Eurema laeta*	1	1	0
24	*Eurema hecabe*	1	1	0
25	*Gonepteryx rhamni*	1	1	0
26	*Catopsilia pomona*	1	1	1
27	*Catopsilia pyranthe*	1	0	0
28	*Colias fieldii*	1	1	1
29	*Colias erate*	1	0	0
30	*Parenonia valeria*	1	0	0
31	*Pieris brassicae*	1	1	1
32	*Pieris napi*	1	0	0
33	*Pieris canidia*	1	1	1

S. No.	Species Name	Elevation zones (m)		
		900-2000	2000-3000	3000-3500
34	*Pontia daplidice*	1	1	0
35	*Ceporia nerissa*	1	0	0
36	*Aporia leucodice*	1	1	0
37	*Aporia agathon*	1	1	0
38	*Delias belladonna*	1	1	0
39	*Delias sanaca*	1	1	0
40	*Delias eucharis*	1	0	0
41	*Belenois aurota*	1	0	0
	Lycaenidae			
42	*Poritia hewitsoni*	1	1	0
43	*Curetis bulis*	1	1	0
44	*Esakiozephyrus mandara*	1	1	0
45	*Arhopala amantes*	1	0	0
46	*Arhopala ganesa*	1	0	0
47	*Loxura atymnus*	1	0	0
48	*Pratapa deva*	1	0	0
49	*Tajuria jehana*	1	0	0
50	*Tajuria illurgis*	1	0	0
51	*Chliaria kina*	1	0	0
52	*Deudorix perse*	1	0	0
53	*Deudorix epijarbas*	1	0	0
54	*Rapala jarbas*	1	1	0
55	*Rapala varuna*	1	0	0
56	*Spindasis lohita*	1	0	0
57	*Spindasis vulcanus*	1	1	0
58	*Lycaena phlaeas*	1	1	1
59	*Lycaena pavana*	1	1	0
60	*Lycaena kasyapa*	1	0	0
61	*Heliophorus brahma*	1	0	0
62	*Heliophorus androcles*	1	1	0
63	*Heliophorus tamu*	1	0	0
64	*Heliophorus sena*	1	1	0
65	*Castallius rosimon*	1	0	0
66	*Leptotis plinius*	1	0	0
67	*Jamides celeno*	1	0	0
68	*Lampides boeticus*	1	1	1
69	*Zizeeria karsandra*	1	0	0
70	*Pseudozizeeria maha*	1	1	0

S. No.	Species Name	Elevation zones (m)		
		900-2000	2000-3000	3000-3500
71	*Everes argiades diorides*	1	0	0
72	*Oreolyce vardhana*	1	1	0
73	*Acytolepis puspa*	1	1	1
74	*Celastrina argiolus*	1	0	0
75	*Celastrina huegelii*	1	1	0
76	*Udara dilecta*	1	0	0
77	*Aricia astrarche*	0	1	0
78	*Chilades pandava*	1	0	0
79	*Polymmatus eros*	0	1	1
80	*Abisara echirius*	1	0	0
81	*Dodona eugenes*	0	1	0
82	*Dodona durga*	1	0	0
	Nymphalidae			
83	*Libythea lepita*	1	1	0
84	*Libythea myrrha*	1	1	0
85	*Tirumala limniace*	1	1	0
86	*Tirumala septentrionis*	1	1	0
87	*Danaus genutia*	1	1	0
88	*Danaus chrysippus*	1	1	0
89	*Parantica aglea*	1	1	0
90	*Parantica sita*	1	1	0
91	*Euploea mulciber*	1	1	0
92	*Euploea core*	1	1	0
93	*Polyura athamus*	1	0	0
94	*Charaxes polyxena*	1	0	0
95	*Melantis leda*	1	0	0
96	*Melantis phedima*	1	0	0
97	*Lethe rohria*	1	1	0
98	*Lethe europa*	1	1	0
99	*Lethe insana*	1	1	0
100	*Lethe verma*	1	1	0
101	*Lethe sidonis*	1	1	0
102	*Lethe goalpara*	1	1	0
103	*Lasiommata schakra*	1	1	0
104	*Elymnias hypermnestra*	1	0	0
105	*Mycalesis francisca*	1	1	0
106	*Mycalesis perseus*	1	0	0
107	*Mycalesis myneus*	1	0	0

S. No.	Species Name	Elevation zones (m)		
		900-2000	2000-3000	3000-3500
108	*Aulocera padma*	1	1	1
109	*Aulocera swaha*	0	0	0
110	*Aulocera saraswati*	1	1	0
111	*Callerebia ananda*	1	0	0
112	*Callerebia nirmala*	1	1	0
113	*Callerebia scanda*	1	1	0
114	*Ypthima asterope*	1	0	0
115	*Ypthima baldus*	1	0	0
116	*Ypthima sakra*	1	1	0
117	*Acraea violae*	1	0	0
118	*Cethosia cyane*	1	1	0
119	*Argynnis pandora*	1	1	0
120	*Arggyres hyperbius*	1	1	1
121	*Fabriciana adippe*	0	0	1
122	*Fariciana kamala*	1	0	0
123	*Speyeria aglaja*	0	1	1
124	*Issora lathonia*	1	0	0
125	*Cupha erymanthis*	1	0	0
126	*Palanta phalantha*	0	0	1
127	*Limentis trivena*	0	0	0
128	*Athyma perius*	1	1	0
129	*Athyma opalina*	1	1	1
130	*Pantoporia hordonia*	1	0	0
131	*Neptis nata yerburyii*	1	1	0
132	*Neptis hylas*	1	1	0
133	*Neptis ananta*	1	0	0
134	*Neptis Mahendra*	1	1	0
135	*Neptis sankara*	1	0	0
136	*Neptis narayana*	1	1	0
137	*Euthalia aconthea*	1	0	0
138	*Euthalis nais*	1	0	0
139	*Cyrestis thyodamas*	1	1	0
140	*Pseudergolis wedah*	1	1	0
141	*Stibochiona nicea*	1	0	0
142	*Ariadne merione*	1	1	0
143	*apatura ambica*	1	1	0
144	*Dilipa morgiana*	1	1	0
145	*Hestina nama*	1	1	0

S. No.	Species Name	Elevation zones (m)		
		900-2000	2000-3000	3000-3500
146	*Sephisa dichroa*	1	1	0
147	*Symbrenthia hypselis*	1	1	0
148	*Symbrenthia hippoclus*	1	0	0
149	*Vanessa indica*	1	1	0
150	*Vanessa cardui*	1	1	1
151	*Aglais cashmiriensis*	1	1	1
152	*Nymphalis xanthomelas*	1	1	1
153	*Polygonia agea*	0	1	1
154	*Kaniska canace*	1	1	0
155	*Junonia orithiya*	1	1	0
156	*Junonia hierta*	1	1	0
157	*Junonia iphita*	1	1	0
158	*Junonia atlites*	1	0	0
159	*Junonia almana*	1	1	0
160	*Junonia lemonias*	1	1	0
161	*Hypolimnas misippus*	1	1	0
162	*Hypolimnas bolina*	1	1	0
163	*Kallima inachus*	1	1	0
	Hesperiidae			
164	*Hasora chromus*	1	0	0
165	*Choaspes benjaminii*	1	1	0
166	*Sarangesa dasahara*	1	1	0
167	*Celaenorrhinus leoucocera*	1	1	0
168	*Spialia galba*	1	1	0
169	*Pseudocoladenia dan*	1	1	0
170	*Tagiades japetus*	1	1	0
171	*Tagiades litigiosa*	1	1	0
172	*Oriens goloides*	1	0	0
173	*Potanthus dara*	1	0	0
174	*Pelopidas mathias*	1	0	0

Appendix 7.1: List of 79 butterfly species along with the number of individuals recorded at each of the five sites during 20 days of sampling during rapid survey in Tons valley.

S. No.	Species	Tuni	Kedarkanta	Istragad	Jakhol	Har-ki-Dun
	Papilionidae					
1	*Paranassius epaphus*	-	1	5	-	-
2	*Paranassius hardwickii*	-	13	9	1	2
3	*Graphium cloanthus*	3	1	-	-	-
4	*Graphium doson*	-	-	-	1	-
5	*Graphium* sp.	1	-	-	-	-
6	*Graphium eurous*	-	-	1	-	-
7	*Chilasa clytia*	-	2	3	-	-
8	*Papilio polytes*	5	-	2	-	-
9	*Papilio protenor*	-	16	12	3	1
10	*Papilio demoleus*	1	-	-	-	-
11	*Papilio machaon*	-	8	5	2	2
12	*Papilio polyctor*	-	2	-	-	-
13	*Atrophaneura aristolochiae*	14	7	-	-	-
14	*Troides aeacus*	-	-	-	1	-
	Pieridae					
15	*Eurema blanda*	5	-	7	-	-
16	*Eurema laeta*	4	2	5	-	-
17	*Gonepteryx rhamni*	-	28	45	3	7
18	*Catopsilia pomona*	19	42	112	-	53
19	*Colias fieldii*	-	17	11	3	4
20	*Colias erate*	-	1	-	-	-
21	*Pieris brassicae*	-	32	16	3	9
22	*Pieris canidia*	68	41	29	15	2
23	*Pieris napi*	-	-	-	-	3
24	*Pontia daplidice*	-	14	12	5	-
25	*Delias belladonna*	4	-	-	-	-
26	*Belenois aurota*	6	12	-	3	-
	Lycaenidae					
27	*Rapala jarbas*	-	-	1	-	-
28	*Lycaena phlaeas*	-	13	1	5	3
29	*Lycaena pavana*	2	3	-	-	-
30	*Heliophorus androcles**	-	-	2	-	-
31	*Heliophorus sena*	-	8	-	1	-
32	*Lampides boeticus*	8	137	78	13	14
33	*Zizeeria karsandra*	-	49	12	6	9

S. No.	Species	Tuni	Kedarkanta	Istragad	Jakhol	Har-ki-Dun
34	*Pseudozizeeria maha*	-	-	1	-	-
35	*Acytolepis puspa*	-	13	41	5	-
36	*Celastrina huegelii*	-	-	1	-	-
37	*Dodona durga**	-	-	2	-	-
	Nymphalidae					
38	*Libythea lepita*	-	-	2	-	1
39	*Tirumala limniace*	-	-	1	-	-
40	*Danaus genutia*	-	-	-	1	-
41	*Danaus chrysippus*	1	2	2	-	-
42	*Parantica sita*	-	-	1	-	-
43	*Euploea mulciber*	-	1	-	-	-
44	*Euploea core*	5	2	-	-	-
45	*Melantis leda*	1	-	-	-	-
46	*Lethe rohria**	-	-	2	-	-
47	*Lethe verma*	-	-	1	-	-
48	*Lasiommata schakra*	9	-	-	-	-
49	*Elymnias hypermnestra^*	-	-	4	-	-
50	*Mycalesis perseus^*	-	-	2	1	-
51	*Aulocera saraswati*	-	-	-	1	-
52	*Ypthima sakra*	-	-	1	-	-
53	*Arggyres hyperbius*	7	1	-	-	-
54	*Fariciana kamala*	-	-	1	-	-
55	*Issora lathonia*	-	17	13	-	2
56	*Palanta phalantha*	-	-	1	-	-
57	*Athyma perius*	-	1	-	-	-
58	*Athyma opalina*	-	-	-	1	-
59	*Neptis hylas*	-	12	-	9	1
60	*Neptis Mahendra*	-	4	-	5	-
61	*Cyrestis thyodamas*	2	-	1	-	-
62	*Pseudergolis wedah*	-	-	2	1	-
63	*Stibochiona nicea**	-	-	1	-	-
64	*Hestina nama*	-	-	-	1	-
65	*Sephisa dichroa*	2	-	1	-	-
66	*Symbrenthia hippoclus*	1	-	-	-	-
67	*Vanessa indica*	-	9	1	-	-
68	*Vanessa cardui*	63	7	6	-	1
69	*Aglais cashmiriensis*	-	21	11	7	3
70	*Nymphalis xanthomelas*	-	-	4	-	-
71	*Kaniska canace*	1	-	2	-	-

S. No.	Species	Tuni	Kedarkanta	Istragad	Jakhol	Har-ki-Dun
72	*Junonia orithiya*	17	1	5	2	-
73	*Junonia hierta*	3	-	-	-	-
74	*Junonia atlites*	2	-	-	-	-
75	*Junonia lemonias*	5	-	2	-	-
76	*Kallima inachus*	-	-	1	-	-
	Hesperiidae					
77	*Celanorrhinus leucocera**	-	-	2	-	-
78	*Celanorrhinus dhanada**	-	-	1	1	-
79	*Sarangesa purendra**	-	-	4	-	-
	Total species richness	**51**	**27**	**27**	**35**	**17**

** Opportunistic sightings: species not recorded on transects*
^ Species only recorded in fruit-baited traps and not by any other method