Study on vegetation ecology of Singalila National Park with reference to indicator species

A Thesis Submitted

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Sikkim University

In Partial Fulfilment of the Requirement for the

Degree of Doctor of Philosophy

By

Bhupen Roka

Under the Supervision of

Prof. D.R. Chhetri

Department of Botany

School of Life Sciences

Sikkim University

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6 माइल, सामदुर, तादोंग - 737102
गंगटोक, सिक्किम, भारत
फोन-03592-251212, 251415, 251656
टेलीफैक्स - 251067
वेबसाइट - www.cus.ac.in

सिक्किम विश्वविद्यालय
SIKKIM UNIVERSITY
(भारत के संसद के अधिनियम द्वारा वर्ष 2007 में स्थापित और नैक (एनएएसी) द्वारा वर्ष 2015 में प्रत्यायित केंद्रीय विश्वविद्यालय)
(A central university established by an Act of Parliament of India in 2007 and accredited by NAAC in 2015)

6th Mile, Samdur, Tadong-737102
Gangtok, Sikkim, India
Ph. 03592-251212, 251415, 251656
Telefax : 251067
Website : www.cus.ac.in

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This is to certify that the Ph.D. thesis entitled "**Study on vegetation ecology of Singalila National Park with reference to indicator species**" submitted to Sikkim University in partial fulfilment for the requirements of the degree of Doctor of Philosophy in Botany embodies the research work carried out by **Mr. Bhupen Roka** at Department of Botany, School of Life Sciences, Sikkim University. It is a record of bonafide investigation carried out and completed by him under my supervision. He has followed the rules and regulations prescribed by the University. The results are original and have not been submitted anywhere else for any other degree or diploma.

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15/12/2022

Prof. D. R. Chhetri
Ph.D. Supervisor
Department of Botany
School of Life Sciences
Sikkim University, Gangtok

Place: Gangtok
Date:

6 माइल, सामदुर, तादोंग - 737102
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It is recommended that this Ph.D. thesis be placed before the examiners for the evaluation.

Prof. N Sathyanarayana
Professor and Head
Department of Botany
School of Life Sciences
Sikkim University, Gangtok

Place: Gangtok
Date: 15.12.2022

6 माइल, सामदुर, तादोंग - 737102
गंगटोक, सिक्किम, भारत
फोन-03592-251212, 251415, 251656
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6th Mile, Samdur, Tadong-737102
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"Study on vegetation ecology of Singalila National Park with reference to indicator species"

Submitted by **Bhupen Roka** under the supervision of Dr. Dhani Raj Chhetri, Professor, Department of Botany, School of Life Sciences, Sikkim University, Gangtok.

Bhupen Roka

(Bhupen Roka)

Ph.D. Scholar

07/12/2022

DHANI RAJ CHHETRI, Ph.D.
Professor
Department of Botany
SIKKIM UNIVERSITY
6th Mile, Tadong, Gangtok

(Prof. Dhani Raj Chhetri)

Ph.D. Supervisor

Vetted by Librarian

DECLARATION

I declare that the present Ph.D thesis entitled **"Study on vegetation ecology of Singalila National Park with reference to indicator species"** submitted by me for the award of the degree of **Doctor of Philosophy** in Botany is a bonafide research work carried out by me at the Department of Botany, Sikkim University under the supervision of **Prof. D. R. Chhetri**.

I also wish to apprise that the thesis does not bear content that has been accepted for degree or diploma of any other University or Institution. Further, the references used to augment the research and the materials obtained have been duly acknowledged.

Bhupen Roka

Bhupen Roka
Registration No.: SU/2014/PhD/19
Department of Botany
School of Life Sciences
Sikkim University, Gangtok

Place: Gangtok
Date: 15.12.2022

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Abbreviations

A	Abundance
A/F	Abundance/Frequency
Bh	Bhutia
cbh	Circumference Breast Height
CCMB	Centre for Cellular and Molecular Biology
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
D	Density
En	English
F	Frequency
IUCN	International Union for the Conservation of Nature and Natural Resources
IVI	Importance Value Index
L	Lepcha
NDVI	Normalized difference vegetation index
Np	Nepali
PNHZ P	Padmaja Naidu Himalayan Zoological Park
RA	Relative Abundance
RD	Relative Density
RDom	Relative Dominance
RF	Relative Frequency
SNP	Singalila National Park
Tb	Tibetan
ZIMS	Zoological Information Management System

Symbols and Units

Symbols	Units
°C	Degree Celsius
km^2	Square Kilometer
π	3.14
m	meter
H'	Shannon-Wiener's Index
ni	number of individuals of a species
N	Sum total of all individual species
In	Log
D	Menhinick's Index
S	Number of individual species
CD	Simpson's Index
J	Pielou's Index
∑	Sum
√	Under root
m^2	Meter square
♂	Male
♀	Female

CONTENTS

Chapter 1
Introduction

1. Introduction

Vegetation ecology is the study of the plant assemblage, ground cover and its associations with the environment. Though large canopy species are important, understory vegetation is the main element that represents ecological changes that occurred during the decades and can depict the differences in disturbance regimes (Dale, 2001; Dale et al., 2002). Variations in species composition and presence and absence of species or their structure often results due to past disturbances in the forest (White, 1979; Veblen, 1989). Forests provide a safe harbour to the wildlife, but in the recent past, developmental activities, encroaching on the forests resulted in a quantitative reduction of wildlife. The structural characteristics of the vegetation cover and spatial distribution are the most important among the various parameters influencing wildlife distribution and its frequency. Increasing pressure on land has resulted in rapid changes in such natural areas. In recent years, there is a growing consciousness amongst the people to protect wildlife. India possesses a rich diversity, history and tradition of conservation. The love and regard for vegetation are part of India’s culture, yet it is confronted with a sad paradox of disappearing vegetation in the country. Himalayan biodiversity is no exception, which is threatened by anthropogenic activities as well as climate change resulting in the extinction of various floral and faunal species. Rapid developmental activities and expanding human population, which depends on the forest for grazing, timber extraction, food, fodder, manure, fuel-wood etc. are the causes of the decline of Himalayan forests.

1.1 Indicator Species

Indicator species is a single species or a group of species of living organisms that depict the environmental condition of particular habitat and which could be monitored effortlessly (Landers, 1988; Cairns, 1993; Markert, 1999; Bartell, 2006;

Siddig, 2016). Indicator species react to particular stress in an ecosystem and represent the responses of the species or the community in the ecosystem. The researchers select them focusing on the crucial facet of the ecosystem that is essential for the evaluation and monitoring of the ecological condition, and it is a recognized practice in ecology (Niemi, 2004; Burger, 2006). Hall (1919) was the first person to use the concept of indicator species whereby animal and plant species may be studied together in relation to a particular life zone (Carignan, 2001). The present study was conducted on the population status, density and distribution of the *Rhododendron arboreum* Smith (*Rhododendron*) and *Ailurus fulgens* Cuvier (red panda) (one plant and one animal indicator) in the Singalila National Park in the Darjeeling Himalayan region.

1.2 Why were *Rhododendron* and red panda selected for the study?

In this study, *Rhododendron arboreum* Smith and red panda (*Ailurus fulgens* Cuvier) have been considered for the study. *Rhododendron arboreum* Smith and red panda are the priority species of the Singalila National Park and is distributed throughout the various altitudinal zones of the park and act as right indicators of climate change and anthropogenic impacts to the local biodiversity. Red panda act as a flagship-umbrella species; therefore, the study and conservation of the species results in the overall conservation of the park's biodiversity. *Rhododendron* is a charismatic and socio-economically influential floral species of the temperate and alpine zone. Its distribution is abundant and can be easily identified and monitored in the wild. Indicator species respond to a particular environmental stress rather quickly and expresses any changes occurring in the area. The red panda is a solitary animal, prefers a high canopy of undisturbed mature forest and is distributed in the less disturbed area. It is a shy animal and in case of any anthropogenic disturbances shifts to less disturbed areas. Its distribution and abundance can give information regarding the status of the vegetation and provide early warning of any changes occurring in the temperate and alpine zone vegetation. *Rhododendron arboreum* and red panda shares similar habitat and both the species are distributed in various altitudinal zone of the Singalila National Park. *Rhododendron arboreum* is one of the most preferred plant species of the red panda. Direct sighting and scat or pellets encountered on *Rhododendron* trees and young shoots indicate that this is one of the preferred plants of the species.

Rhododendron is one of the most diverse species of the family Ericaceae having more than 1000 species distributed in the temperate and alpine regions. In India, 92 species of *Rhododendron* are distributed throughout the Himalayas, starting from Jammu and Kashmir up to Arunachal Pradesh (Paul et al., 2005). The Darjeeling and Sikkim parts of the Himalayas situated on the Eastern side are very rich in *Rhododendron sp.* diversity (Sastry et al., 2010). *Rhododendron arboreum* is a keystone species and is highly sensitive to climate change. The flowering of the species varies with the rise in temperature which affects the growth and survival of the species. Plants get shifted from lower altitude to higher altitude when the temperature rises, in order for it to maintain normal physiological activities. In general, the distributions range of *Rhododendron sp*. is changing in response to global warming and pollution (Ranjitkar, 2012). The temperature of the country has risen by 0.7°C from 1901 to 2018 (Krishnan, 2020); therefore, monitoring and evaluation of the Himalayan ecosystem focusing at the community level are essential to understand the range shift of the species within different geographic ranges. The flowering of the *Rhododendron sp.* is clearly visible which can be used for long term monitoring of the range shift of the species as an indicator of climate change. Therefore, the information on the distribution, density, abundance, and dominance recorded by this study would be essential for long-term monitoring of the ecosystem of the region.

The red panda (*Ailurus fulgens*) is a charismatic and endangered species in worldwide conservation. It is a particular carnivore that has adapted to the herbivore mode of life and is a resident of the Himalayan and Hengduan mountain ranges. This species is mainly distributed between 1500 m and 4800 m in the temperate oak, broadleaf and conifer forests. The main fodder of the species are leaves and shoots of *Yushania maling*, *Thamnacalamus spathiflorus,* young leaves of *Rhododendron sp*., fruits of *Actinidia strigosa*, *Sorbus cuspidata*, *Rosa sericera* etc. The red panda is a protected animal throughout its distribution range, but it faces threats due to forest fragmentation, degradation, forest resource collection, trails and road construction, cattle grazing, attack by feral dogs, and an increasing visitor numbers. In addition, the species' population is declining by anthropogenic activities and climate change.

There is an increasing need to find a simple tool to evaluate the status of the ecosystem. The red panda is an indicator species used to assess the anthropogenic pressure on different species. The species occurrence, abundance, and reproductive success are directly linked to anthropogenic activities. Evidences of the red panda population in the less disturbed area of the park gives a positive indication of ecological integrity i.e. the red panda is negatively associated with the anthropogenic disturbances.

As per the criteria proposed by Carignan (2001), if a species is present frequently in a comparatively less disturbed area, it may be considered a positive indicator of ecological integrity whereas, if a species is present frequently in a moderately disturbed area, it may be considered a negative indicator of ecological integrity. Population trend indicates the qualities of the habitat in which the indicator species thrives. The red panda prefers mature undisturbed forest for survival (Yonzon, 1991b), and it was found more frequently in the relatively less disturbed area in the Singalila National Park. Therefore, red panda is considered a positive indicator of ecological integrity, i.e. the species is negatively associated with anthropogenic disturbances. This animal prefers to remain solitary in the wild except during the breeding period and reacts promptly to the anthropogenic disturbances. The breeding behaviour of the species is directly proportional to anthropogenic disturbances and any disturbance during the mating season results in the population decline. After birth, human disturbances in the habitat also results in the shifting of cubs from one place to another and in the process, cub mortality and predation rate increase ultimately in the population decline. Therefore, population trends of red panda can also help to indicate whether the qualities of the in-situ habitats of the indicator species are showing any change within the period. However, the use of red panda and *Rhododendron* as an indicator species cannot measure all the components of an ecosystem but it may be considered an alternative for directly measuring the habitat which is both economic of cost and time.

1.3 Why Singalila National Park?

The Singalila National Park (SNP) sprawling over an area of 78.6 km^2, is situated in the extreme North-Western boundary of Darjeeling District at an altitude ranging from 2,400 m to 3,650 m. In the Eastern part of the Great Himalayan Range, at the junction of Nepal, West Bengal, and Sikkim, the Singalila Range rises from Kanchenjunga (8,335 m). The Eastern side of the Singalila Range is the Valley of the Teesta river, and the Western (Nepal) side is the Valley of the Tamur river, one of the tributaries of the Kosi river (Management Plan, 1990-1991 to 2000-2001). Its situation is unique, where various phytogeographical and zoo-geographical zones meet. It has sub-alpine grasslands that merge higher up to the snowline beyond Singalila peak (Sikkim). Its temperate forests are contiguous with sub-tropical and tropical forests of Tonglu, Ghoomsimana, Senchal and Chattakpur forests. The physiography of the flora of both the Eastern and Western sides of the Singalila Range is similar.

The Singalila National Park shows a broad climatic and geographic variation which possesses different eco zones exhibiting rich flora and fauna that is unique to this region (Rai, 2013). The variation in altitudinal gradient, rainfall and climate of the park has resulted in the diverse distribution of flora and rich biodiversity. The national park holds an innumerable variety of unique, rare, ethnomedicinal flora and different fauna of the Himalayas. The Singalila National Park houses around 80-90 mammal species and numerous threatened medicinal plants. It is the home for the endangered mammal species red panda and other threatened species like Chinese pangolin, common leopard, Himalayan black bear, Satyr tragopan, blood pheasant, hill partridge etc. The Singalila National Park is the only protected area in India where the captive/zoo born red panda has already been reintroduced in the year 2003 and 2004. Therefore, the study of vegetation ecology of SNP was considered as it is essential to understand the plant diversity, threats and also distribution of the plant species that are used by red panda in the wild.

1.4 Scope and relevance of the work

A number of studies carried out in recent times reinforce the fact that nearly all the natural ecosystems of the world are under pressure due to extensive human use (Gadgil 1990; Kryuchkov, 1993; Mittermeier et al., 2003; Bawa et al., 2004; Imhoff et al., 2004; Cardillo et al., 2006; Bremner et al., 2010; Harris 2010). With the studies confirming the rapid degradation of natural ecosystems and their declining resilience, the need of the new millennia is to enhance and contain ecosystem capacity and conserve and protect biodiversity through legal, political, and socio-ecological interventions, such as the creation and maintenance of Protected Areas (Bruner, 2001; Rodrigues et al., 2004; Chape et al., 2005). So far, negligible work has been conducted in Singalila National Park and its surrounding areas of Darjeeling Himalayas. This research work has been undertaken to understand the vegetation of the park that hold an innumerable variety of unique and rare flora and fauna of the Himalayas. Study parameter like density, relative density, frequency, relative frequency, abundance, relative dominance, IVI value etc. of the different floral species calculated during the study will be instrumental baseline data for further research. The generated data on threat assessment and anthropogenic impact on the Park's vegetation will be helpful in the management of the park. The data points like number, presence and absence of indicator species' helps in the in-situ conservation of the species. The presence of indicator species in certain patches of the park indicates the viability of the species and sustainability of the patches of national park for maintaining indicator species. The baseline data created may help in formulating management and conservation plan on other threatened species in the national park.

The research work presented here on the study of vegetation ecology of Singalila National Park, Darjeeling, West Bengal with reference to indicator species was carried out with the following specific objectives:

1. To study vegetation communities, composition, species distribution, abundance and richness in the Park.
2. Assessment of anthropogenic impact and the vegetation mapping of the Park.

3. To identify the state of the different patches of the park using indicator species *Rhododendron arboreum* and red panda (by presence/absence, population estimation, and plant preference of the indicator species).

Chapter 2
Literature Review

2. Literature Review

2.1 Vegetation Ecology

2.1.1 What is vegetation ecology?

Vegetation ecology is the study of the plant cover and its relationships with the environment and interactions with abiotic and biotic factors. It is a modern science approach for nature management, conservation of biodiversity and identifying the changes occurring in the plant cover. Vegetation is a fundamental part of the ecosystem that interprets the effects of the total environment (Billings, 1952). Interaction between different plants and also between plants and their environment is the main cause of different vegetation types in the forest. It is crucial to understand the plant species' abundance, frequency, presence, absence, and the distribution of plant species for habitat study. Plant species is the main element of vegetation that forms the main component of biodiversity which depends on various factors like topography, geology, slope, climate, soil and anthropogenic aspect of a particular region. According to Kharkwal et al., (2005) plant community is the function of altitude, slope, rainfall, humidity, soil and aspect each of which plays an important role in the formation and composition of plant communities. Forests play a vital role in the developing world because they protect watersheds needed for agriculture, provide timber needed for construction and industrial development, fuelwood for cooking and heating, serve as sources for genetic material and regulate global biogeochemical cycles (Brown et al., 1995). Forests are the energy source and biotic diversity which improves economy and mitigates climate change. They act as a lifeline for the human population residing in the vicinity of the forest and the rural area. Forest composition, diversity structure, and patterns are critical ecological characteristic features that correlate with existing environmental as well as anthropogenic variables (Gairola et al., 2008; Ahmad et al., 2010). The climate and topography of an area are strongly correlated with the forest structure and the species composition (Schall and Pinaka, 1997; Wright, 1983; Currie, 1991). The vegetation within a forest differs due to the differences in the microclimate, aspect, and altitude of the forest (Chaudhary, 1999 and Pande et al., 2002). Several factors influence the species diversity (Gaston, 2000; Li and Zhou, 2002; Lan, 2003; Tang, 2004), especially altitudinal gradient which also influence the species composition, distribution, and structure (Whittaker, 1972). Structural characterization of the vegetation cover and understanding of the green vegetation is required for global and local change monitoring. Proper documentation, information on the forest structure, composition and associations of forest, biotic and abiotic factors, species availability, silvicultural practices, and community involvement can help in designing action plan to invigorate the depleting forests (Ramakrishnan and Toky, 1981; Singh and Singh, 1991). Habitat conservation and forest fragmentation have enormous conservation interest in the long term vegetation cover. Attention is required to maintain a healthy ecosystem and conserve the forest vegetation and biodiversity of the area. Conservation and proper scientific intervention are essential as different flora and fauna inhabiting together depend on each other in the same habitat and maintain the balance of nature. The concept of biodiversity conservation has rapidly gained importance in political, management, public, and scientific arenas (DeLong, 1996). It has emerged as a matter of prime concern because of the rapid extinction of species due to anthropogenic pressure (Ehrlich and Wilson, 1991).

According to Drake (1990) the nature of the ecological community is a fundamental concern in ecology. Scholars have considered communities as integrated, discrete units with evolving structures and functions shaped by species interaction and co-evaluation. Overall, an understanding of ecosystem structure and interaction of biotic and abiotic components are essential for the sustainable management and conservation of forests (Hubbell and Foster, 1983; Ashton et al., 2004). To understand the ecological status, overall health, and sensitivity of an ecosystem, an assessment of the region's biodiversity is essential. As per Singh and Singh (1992), forests have been facing pressure for centuries due to the use of forest products and resources by the inhabitants for their subsistence. There is evidence depicting increased exploitation pressure on the forests over the years (Pandey and Singh, 1984; Ram et al., 2004) which results in canopy disturbances and structural and functional character changes of the forest (Ram et al., 2004; Kumar and Ram, 2005; Gairola et al., 2009, 2015). Rapid decline of biodiversity and complexity of living organisms is causing a threat to the life-supporting system on earth.

Jhariya (2012, 2014) stated that the information regarding the presence of species and their distribution in the region gives a significant idea for prioritizing the area for management and conservation. As per Elourard (1997) proper understanding of the community structure is essential to describe various ecological processes in the forest ecosystem. Various research works have been conducted to understand the community characteristics and distribution patterns along the different altitudinal gradients. The altitudinal gradient plays a vital role in regulating the species richness (Grytnes, 2003; Kessler, 2000; Oommen and Shanker, 2005). Changes in species diversity along the altitudinal gradient have become a significant issue of ecological studies and have explained that the climate, biotic interaction, productivity, and history have played a crucial role (Givnish, 1999; Willig et al., 2003; Qian and Ricklefs, 2004). Conservation actions are based on the number of species that require protection. In the habitat-destructed area, proper knowledge of species richness can estimate the number of species that will be eradicated (May, 1995).

2.1.2 Importance of Vegetation Ecology

Phytosociology or the quantitative study of vegetation depicts the floral type and its distribution pattern and classify it in a meaningful way (Ilorkar and Khatri, 2003). According to Ardakani (2004) and Reddy (2008), species distribution and diversity are helpful in evaluating the ecological significance of an ecosystem. Walker (1988) stated that species richness and species diversity might give ecologists insight into the stability of communities. Tree species is an important component of the forest ecosystem (Rennolls and Laumonier, 2000). Inventory of tree species at a particular site and its minimum diameter classes function as reliable instruments to indicate the floral diversity of a study area (Wattenberg and Breckle, 1995). Tree species diversity is an essential aspect of forest ecosystem diversity and fundamental to tropical forest biodiversity (Rennolls and Laumonier, 2000). Trees provide resources and habitat for other species and are the dominant life form in the forest ecosystems, which are easily identifiable, easy to study, locate and count (Condit et al., 1995). Hartmann and Messier (2011) advocated that trees can influence competitive interactions among individuals because tree growth is influenced by the response to environmental change, competition, and anthropogenic impact, which can eradicate or kill other species from the competitive environment of remaining trees. Trees determine the architecture and play a significant role in the composition of forest communities. Therefore, quantitative floristic studies provide the necessary perspective for planning and long-term ecological research (Phillips et al., 2003).

2.1.3 Vegetation Ecology in the Himalayan Belt

The Himalaya is one of the richest mountain ecosystems covering India, Pakistan, Afghanistan, Nepal, Bhutan, Bangladesh, China, and Myanmar (Semwal et al., 2004). Due to variation in climate and elevation, the Himalayas have a diverse variety of forests as the vegetation community has a direct relationship with altitude (Mani, 1978). The Himalayas possess the most versatile and diverse montane ecosystem on the earth, characterized by a harsh climate, a strong degree of seasonality, and a high diversity of plant communities and species. The Himalayas are young fold mountains and are recognized as a biodiversity hotspot. As per Singh and Singh (1992), the Himalayan forest vegetation ranges from tropical dry forest to the alpine pasture above timberline. Forest composition varies from place to place due to variations in topography, such as plains, foothills, and upper mountains (Singh, 2006). Dhaulkhandi (2008) further added that vegetation in the Himalaya is diverse and is distributed over a wide range due to climatic and topographic variation. Several research works have been conducted to understand the phytosociological parameters and population structure of forests in Himalayan subtropical regions (Ahmed et al., 2006; Kharkwal, 2009; Rawat and Chandhok, 2009; Kharkwal and Rawat, 2010; Shaheen et al., 2011). The Indian Himalayan Region extends from Jammu Kashmir in the North to Arunachal Pradesh in the Eastern region and depicts unique natural and socioeconomically important biodiversity. According to Chatterjee (1962) phytogeographically, the Greater Himalayas has been divided into three main divisions, i.e. Western Himalaya (Kashmir and Himachal Pradesh), Central Himalaya (Uttarakhand to Western Nepal), and Eastern Himalaya (East Nepal to Arunachal Pradesh). Eastern Himalayas comprises the Geographical boundaries of Eastern Nepal, Darjeeling-Sikkim Himalaya, Bhutan, and Arunachal Pradesh (Das, 2004).

The Himalaya plays a pivotal role in regulating the climate and is crucial for the sustainability of the biodiversity that is essential for the wellbeing of the human population (Sharma, 2009). Floral diversity is influenced by the rainfall, altitudinal variation, slopes etc. in the Himalaya. The Himalaya possesses rich floristic zone and different vegetation starting from the tropical vegetation to the alpine vegetation. In the year 2004, IUCN recognized the Eastern Himalaya as important part of biodiversity hotspot. Out of 10,000 vascular plants that have been estimated in the Himalaya, around 31.6% are endemic to the region (Mittermeier, 2011). The topography and the position of the Himalaya i.e. the snow covered peaks in the North and the Gangetic plains in the South does not favour the emigration of other species resulting in high number of endemic flora.

2.1.4 Vegetation Ecology of Singalila National Park, Darjeeling

Darjeeling has rich and diverse flora in comparison to other districts of the Eastern Himalayas. Various factors like physiographic, climatic, rainfall, humidity, and edaphic conditions are responsible for the vegetation types. Altitudinal variation is one of the prominent factors that determine the composition of the region's vegetation. The altitude varies from 130 m in plains to 3660 m at Sandakphu. Vegetation classifications of the region were done earlier by various authors like Gamble (1875), Hooker (1906), Cowan (1929), Kanai (1967) etc. Based on the studies by Bhujel (1996) the vegetation is classified into the following types:

Table 2.1: Vegetation Classification of Darjeeling (Bhujel, 1996)

Sl. No	Vegetation Type	Altitude
1	Tropical and plains	Plains to 300 m (500 m)
2	Sub-tropical	500-1200 m

3	Sub-temperate	1200-1850 m
4	Temperate	1850-3200 m
5	Sub-alpine	3200-3700 m

(1) Tropical and plains: The vegetation of the tropical and plains of the Darjeeling Himalayas were represented by presence of deciduous forest. It can be divided into (i) Riverain forest (ii) Sal Forest (iii) Dry mixed Forest and (iv) Wet mixed forest. The Riverain forest is found in the bank of river/stream such as Balasan, Teesta, Rangeet, Mahanadi etc. where the dominant plant species are *Meliosma pinnata*, *Mikania micrantha*, *Albizia procera*, etc. The Sal forest is covered by the *Shorea robusta* in the loamy plain along with other species like *Terminalia alata, Dillenia pentagyna*, *Schima wallichii*, *Pollinia ciliata* etc. The dry mixed forest is characterized by the presence of *Gmelina arborea*, *Bombax ceiba*, *Tetrameles nudiflora* etc. The wet mixed forest is represented by evergreen species like *Terminalia myricarpa*, *Cinnamorum glaucescens*, *Michelia champaca* etc.

(2) Sub-tropical: The Sub-tropical vegetation possesses tropical genera and species with mainly deciduous character. It is found in the valley of Teesta, Rangit, Baalasan, Neora, Relli, Jaldhaka etc. and is characterized by the presence of *Duabango grandiflora, Schima wallichii, Terminalia alanta, Castanopsis indica, Castanopsis tribuloides* etc.

(3) Sub-temperate: The Sub temperate vegetationis found in the areas like Kurseong-Toong, Mungpoo-Sittong, Peshok-Tukdah, Pedong etc. and it is represented by the presence of *Edgeworthia gardneri*, *Leucosceptrum canum*, *Daphne sureil*, *Schima wallichii*, *Gmelina arborea* etc. In this vegetation, profuse mosses and

lichens which clad the trees are absent compared to other vegetation in temperate vegetation.

(4) Temperate: The temperate vegetation is the most dominant vegetation of the Darjeeling and possesses the largest number of species. The dominant species present in this vegetation type are *Betula alnoides*, *Magnolia campbellii*, *Castanopsis hystrix*, *Alnus nepalensis*, *Quercus lamellose*, *Lithocarpus pachyphyllus*, *Rhododendron arboreum*, *Daphne bholua*, *Tsuga dumosa* etc.

(5) Sub-alpine: The Sub-alpine vegetation of Darjeeling is found in the high altitude region of Singalila National Park which is characterized by the presence of *Abies densa*, *Rhododendron fulgens*, *Acer caudatum*, *Rhododendron cinnabarium* etc.

Few studies were conducted in Singalila National Park by Khaling (1998), Pradhan (1998), Bahuguna, (1998), Pradhan, S (2001), Moktan (2017) etc. which have mainly focused on the faunal aspects of the park.

2.2 Indicator Species

Indicator species may be defined as an organism which indicates the condition of the environment by responding to stress which is inconvenient or expensive to measure. The presence/absence, population density, reproduction success and migration of the species may be used as an index of attribute of indicator species (Landers, 1988; Cairns, 1993; Markert et al., 1999; Bartell, 2006; Burger, 2006; Siddig, 2016; Roka, 2020). Indicator species are used to assess the condition of the environment or forecast the conditions of the environment (Siddig, 2015). They can depict early information about changes in the ecosystem, and the cause of the environmental problem can be diagnosed by using it. The use of indicators has frequently been included in various regulations and policies to check the ecological integrity of forests. The use of indicator species is beneficial as they are time-efficient and cost-effective methods to monitor the changes in the ecosystem (Carignan, 2001).

Sufficient baseline information such as biology, taxonomy, and tolerance of an indicator taxon's measurable characteristics should be understood (Hellawell, 1986; Landers, 1988; Kelly and Harwell, 1990; Regier, 1990; Pearson and Cassola, 1992; Johnson, 1993; Kremen, 1994; Hilty, 1998). The life history of the selected indicator taxa should be such that it will both be able to provide early warning and be effective over a wide range of stress (Soule, 1985; Kelly and Harwell, 1990; Noss, 1990).

According to Kelley and Harwell (1990) with any environmental stress, three concerns are fundamental: how the varieties of the biological components of the ecosystem are exposed to the stress, how the ecosystem responds to the disturbance, and how they adapt or recover with the removal of the stress. Any stress that may be chemical, anthropogenic, or nano-anthropogenic can be considered to characterize ecosystem responses or recovery processes. Response of the biological components and their recovery can be characterized in relation to the stress, which may affect the frequency and presence/absence of the species. Anthropogenic stress can be vital as the ability of the species to face the stress depends on the adaption and how it can recover from the stress. Since the use of indicator species in conservation programs continues to be debated, relying on quantitative criteria during the selection process seems highly desirable compared to more subjective, qualitative criteria.

2.2.1 Red Panda (*Ailurus fulgens* Cuvier)

Red panda (*Ailurus fulgens*) is an unusual carnivore that has adapted to the herbivore mode of life (Roberts, 1984; Glatston, 1994; Wei et al., 1999; Choudhury, 2001; Pradhan, 2001; Roka, 2014). Red panda prefers bamboo forests (Zhang, 2006) between the altitudes 1500 m and 4800 m (Choudhury, 2001) and is mainly confined to the subtropical and temperate forests. A small isolated population is also found in the tropical forest of Meghalaya in India (Choudhury, 2001) at an altitude between 700 m and 1400 m (Choudhury, 1997). Red panda can be distinguished from other carnivores by its reddish-brown or orange-brown coat color and whitish face with reddish-brown tear marks extending from the inferior region of the orbit to the corner of the mouth (Figure 2.1).

It is a living fossil, and its ancestors can be traced back to more than ten million years ago (Kumar, 2016). The red panda mainly feeds on leaves and shoots of local vegetation, mushrooms, bird's egg, and insects (Reid et al., 1991; Yonzon 1991b; Pradhan, 2001; Srivastava, 2010; Dorji, 2012). The number of red panda is decreasing across their habitat due to hunting, poaching, habitat loss, and fragmentation (Wei et al., 1999; Choudhury, 2001; Jha, 2011; Kumar, 2016). Information on the wild red panda has become a matter of great discussion for a long time (Glatston, 1994). It is presumed that the global population of red panda across its range spanning from Nepal to the Sichuan province of China through India (Sikkim, West Bengal and Arunachal Pradesh), Bhutan, and Myanmar (Figure 2.2) could number less than 10,000 individuals (Wang et al., 2008).

Figure 2.1: Red panda (*Ailurus fulgens* Cuvier, 1825)

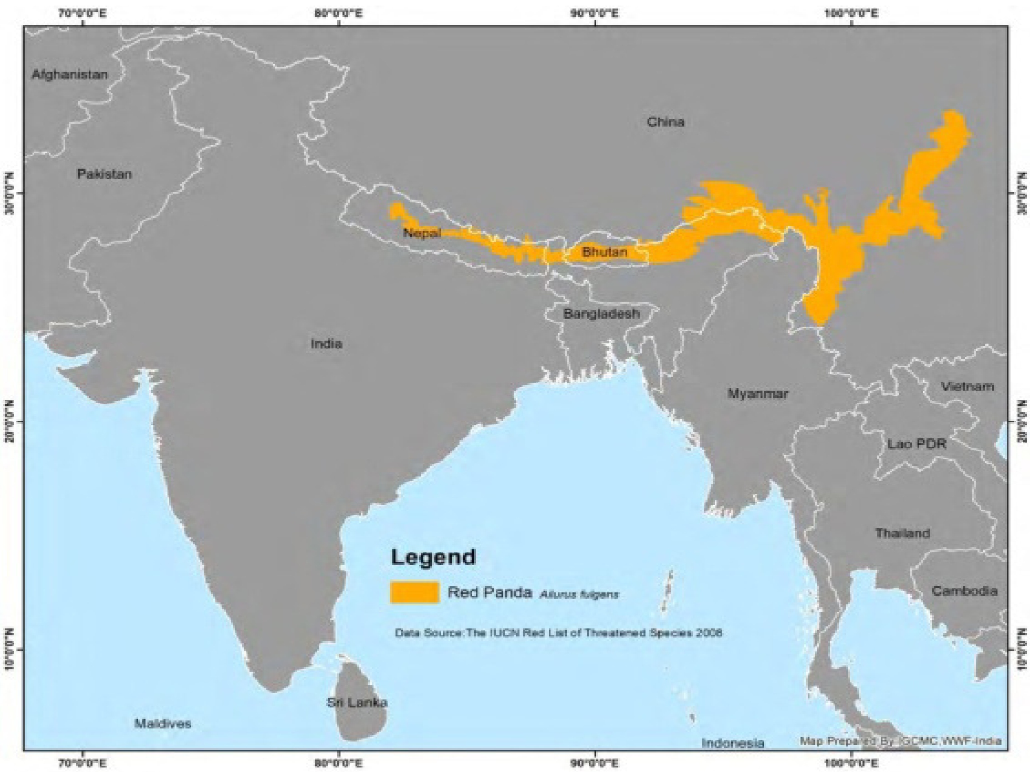

Figure 2.2: Distribution of red panda (Badola, 2020)

2.2.1.1 Taxonomy of the Red Panda

Common name: Red Panda

Local Name: Habra, Puray Kudo, Nighala Ponbo

<u>Scientific Classification</u>

Kingdom: Animalia

Phylum: Chordata

Class: Mammalia

Order: Carnivora

Suborder: Caniformia

Superfamily: Musteloidea

Family: Ailuridae

Genus: *Ailurus*

Species: *A. fulgens*

Species Authority: F. Cuvier, 1825

2.2.1.2 Natural History

The first written report of the red panda was available in the 13th century scroll of the Chou Dynasty. According to Robert (1992), Thomas Hardwicke was the first person to introduce the red panda in Europe. Hardwicke noted “wha” and “Poonya” as two names for the red panda in his description to the Linnaean Society. “Wha” is the sound made by the red panda whenever it encounters other species, and “Poonya” is considered as a local name for a red panda in the dialect spoken by the indigenous people residing between the Himalayan belt of Sikkim and Nepal. Even though M.G.

Hardwick introduced the red panda, it was Frederic Cuvier, a French naturalist, who gave the panda its official scientific name *Ailurus fulgens* (which translated to be a brilliant colored cat) in 1825. For more than 50 years, the red panda was the only known panda in Western countries, but in the year 1869 a larger black and white bear-like animal with similarity in the diet was discovered in China. The animal was named the giant panda and given the scientific name *Ailuropoda melanoleuca* to represent its relatedness to the red panda. After that, *Ailurus fulgens* became the lesser panda, a name that has since become unpopular due to its inferior reference. So the *Ailurus* is now more commonly referred to as the red panda (Jule, 2008). The giant pandas gained the focus of researchers, scientists, and biologists and significantly fewer studies were conducted on the red pandas.

2.2.1.3 Morphology

Red panda can be differentiated from other lesser carnivores by its coat color and face, which possesses white with reddish-brown tear marks extending from the inferior orbit region to the corner of the mouth; the post-cranial dorsal pelage is reddish or orange-brown. The sole of the red panda's feet is covered by hair. The head is rounded, the rostrum shortened and ears large, erect, and pointed, and the tail is long with 12 red rings. Pocock (1921) stated that the red panda of the Eastern region is a more extensive and dark in color. It possesses eight mammae in females that are arranged in two rows. Both hind limbs and forelimbs are equal in length. It uses a forepaw to pick food items, especially the bamboo leaves and shoots. Its bodyweight is around 4.5 kg to 6 kg, and it lives 10 to 14 years in the wild.

2.2.1.4 Reproduction

Red panda gains sexual maturity after 18 months. Mating of the species is seasonal and begins with the arrival of winter, usually between December and mid of

March. The wild birth occurs in the spring and summer, but mainly in June after gestation period of 120-150 days. Several days before parturition, a pregnant female begins to carry nest materials such as sticks, grasses and leaves into suitable nest sites. Within 24 hours of parturition, females become active and move about aimlessly, occasionally pausing to lick the anogenital region or prop the hindquarters against vertical objects as if to strain during abdominal contraction (Roberts, 1981). Mothers move young cubs frequently, presumably in response to nest disturbances; all active nest sites are kept clean by the mother. Lactating females increase food consumption within 24 hours of parturition and continue to do so until weaning. Young cubs are nest bound for approximately 90 days, after which they start consuming solid food. Young cubs attain adult size at approximately 12 months and become sexually mature at approximately 18 months (Roberts, 1975, 1980, 1981).

2.2.1.5 Genetics

Limited information is available on the genetics of the red panda in comparison to other endangered species. The first study of mitochondrial DNA sequence variations in a large sample of red panda was reported by Su Bing et al., (2001) from China, providing information on the distribution and phylogeny of the species. Yibo et al., (2011) also studied genetic structuring and the recent demographic history of the red panda (*Ailurus fulgens*) inferred from microsatellite and mitochondrial DNA. Sarich, 1976 reports the diploid (2n) chromosomal complement of *Ailurus* is 36 including 32 metacentric and sub-metacentric and 2 acrocentrics; one marked pair of satellite sub-metacentric is on the short arm as in other carnivores.

2.2.1.6 Distribution

The red panda is distributed mainly in the broadleaf deciduous and coniferous forests. Its habitat ranges between Himalayan and Hengduan mountain ranges from Nepal to the Min Valley of Sichuan in China, covering India, Nepal, Bhutan and Myanmar, and South China (Dorji, 2011) (Figure 2.2). In India, the red panda is confined to Arunachal Pradesh, Meghalaya, Sikkim, and the Northern region of West Bengal. In Arunachal Pradesh, the red panda is more widely distributed than in any other Indian state. The species is found in the Himalayas and Mishmi Hills, mainly in the following districts- Changlang, Lower Subansiri, Dibang Valley, East Kameng, East Siang, Lohit, Upper Siang and Tawang. The presence of the species was recorded in the Namdapha National Park, Mouling, Dibang, Eaglenest, Mehao, Sessa Orchid, and Kamlang Wildlife Sanctuaries. In Meghalaya, it was reported in Nokrek National Park and Balpakram National Park (Choudhury, 1997). The distribution of red panda was recorded in all the districts of Sikkim, mainly in Barsey Rhododendron Sanctuary, Fambong Lho Wildlife Sanctuary, Kyongnosla Alpine Sanctuary, Kangchendzonga Biosphere Reserve, Shingba Rhododendron Sanctuary and Maenam Wildlife Sanctuary. In West Bengal it is found in the high altitude region of Darjeeling and Kalimpong districts in Singalila and Neora Valley National Park and its adjacent areas (Choudhury, 2001; Pradhan, 2001; Mallik, 2010; Ghosh, 2011).

2.2.1.7 Habit and Habitat

The red panda prefers the temperate oak forest, temperate broadleaf forest, and sub-alpine broad leaf and coniferous forests of the Himalayas above 5000 ft. It is a lazy animal and spends most of the time sleeping and eating bamboo leaves. It rests curled up in the top most branches, with its bushy tail wrapped over its head, or it lies along a branch with its head tucked away under its chest between its forelegs. It remains more active during dusk and dawn time and remains close to the water source (Pradhan, 1998).

2.2.1.8 Conservation status and its role in ecosystem

According to Glatston (1994), the status of the red panda in the wild is not clear. Nevertheless, the IUCN (International Union for the Conservation of Nature and Natural Resources) has reassessed the global status of the red panda and placed it under the endangered category. In India, the red panda is included under Schedule-I of the Indian Wildlife (Protection) Act 1972, but very little is known about its status in the wild. It is also listed in Appendix-I of the Convention on International Trade in Endangered Species of wild fauna and flora (CITES). The red panda is an ecological indicator used to assess the condition of the environment, provide an early warning signal of the change in vegetation ecology, or diagnose the cause of an environmental problem.

The red panda is a flagship species; it helps attracting locals and includes them to support the conservation initiatives and generate funds. It acts as an ambassador and icon for various campaigns and environmental conservation causes. By conservation of this species, other vulnerable species that share similar habitats can be improved. This animal serves as a primary consumer in the food chain. They mainly feed on bamboo leaves and shoots, berries, mushrooms, and occasionally birds and insects. Red panda helps in controlling of overgrowth of bamboo in the natural habitat.

2.2.1.9 Threats

Country-wise threats on the species have been discussed to reveal the past and the present disturbances that have led to a population decline of red panda in the entire distribution range rendering it to be an endangered species.

India: During a questionnaire survey conducted by TRAFFIC in Arunachal Pradesh, old pelts were recorded in Anjaw, Menchuka, and Rouliang areas. Srivastava (2010) found numbers of red panda skin in the Mandla area of Arunachal Pradesh. The respondents further reported the knowledge of poaching of six red pandas in Anjaw District (Badola, 2020), but currently, no targeted poaching is recorded in the area. In Arunachal Pradesh and Meghalaya, the hill tribes practice jhum, a form of shifting slash-and-burn cultivation that destroys large tracts of forest. Forest fire is also a severe problem for red panda habitat degradation. In Western Arunachal Pradesh, fire caused extensive damage to bamboo brakes in 1999 (Choudhury, 2001). Major causes of the red panda habitat destruction in these areas are commercial logging, firewood collection, unsustainable land use pattern, cattle grazing, a monoculture forest plantation etc. (Choudhury, 2001). Though no hunting and poaching are reported from Sikkim and West Bengal, in Sikkim number of tourists visiting the state is increasing rapidly (Mahapatra, 1998), and their requirement for wood for cooking and heating has accelerated habitat loss. In Singalila National Park, West Bengal, exploitation of wildlife mostly occurred prior to 1992 before it was declared a National Park. However sporadic poaching and rabid dogs are still a threat. After 1992 the park was closed for cattle grazing and the cattle station was removed from the area. Nevertheless, the rapid increase in the human population in the surrounding area and dependence on the forest threatens the red panda habitat (Pradhan, 2001).

Bhutan: A study conducted by Dorji (2012) mentions that the expanding road in Bhutan is one of the major causes of the country's loss of wilderness. More than 50% increase in the road network between the year 2002 and 2008 has provided the opportunity for developmental activities in the core red panda habitat resulted in deforestation and damage to the bamboo understory. Population dependent on forest products and the demand for timber and fuelwood is also affecting the red panda habitat. Cattle grazing, lopping and trampling have caused significant habitat degradation (Dorji, 2011; Dorji, 2012). Bamboo is the main component of red panda diet while 42% of the local household in Bhutan uses bamboo for domestic purposes (Dorji, 2011). Thus, bamboo collection is one of the significant threats to the red panda in Bhutan. The tourism industry is also rapidly growing in Bhutan which is directly proportional to habitat degradation. An increase in the tourist flow increases the demand for forest resources for infrastructure development, firewood, etc. During the questionnaire survey it was found that the red panda is being attacked by dogs (Dorji, 2012). Apart from predation, the dog carries canine distemper which is fatal to the red panda. Dhendup (2020) has recorded seven disturbances in Jigme Dorji National Park, Bhutan, these includes dried or dead bamboo, presence of predators, landslide, fallen logs, plant disturbances, livestock and infrastructure development. However, Badola (2020) stated that between July 2010 and July 2019, incidents of illegal trade and poaching of red pandas were not recorded in Bhutan.

China: In China the red panda population has decreased by 40% within 50 years due to habitat loss, increasing anthropogenic pressure, and poaching (Zhang, 2009). Deforestation, hunting and poaching are fundamental threats in China to red panda survival. The bridegroom used to wear red panda skins and fur in the wedding ceremonies of one of the local indigenous peoples of Yunnan Province. Wei (1999) reported that the red panda has disappeared from some parts of Sichuan, Tibet and Yunnan, China. It has also become extinct in China's Gansu, Guizhou, Qinghai and Shaanxi provinces. The trade of live red pandas to zoos was formerly very prevalent. It was found that 141 live red pandas were exported from China between the year 1985 to 1992 (Wei, 1999). A survey conducted by TRAFFIC in April and May 2017 in China found that red panda products were sold in shops in Lijiang, Yunnan Province. Along with traditional clothes, pelt hats were available for the visitors for photography and purchase. In Sichuan, Shaanxi, Jiangsu, Liaoning and Yunnan Provinces, law enforcement agencies made 13 seizures that were involved with illegal red panda trading from 2005 to 2017 and during a raid 35 live and 7 dead red pandas were confiscated (Xu, 2018). However, recently legislation has limited this practice to some extent. Along with habitat fragmentation, the decrease in the genetic diversity causing inbreeding depression is another factor for the decline in the red panda population.

Myanmar: A study conducted in 2003 in Hkakaborazi National Park and Hponkanrazi Wildlife Sanctuary found indirect evidence of the existence of red pandas (Wei, 2014). In 2010, two red pandas were sighted on oak tree in Hkakaborazi National Park. It is worth mentioning that red pandas were recorded on camera traps in Emaw Bum during the Gibbon survey in the year 2011. Glatston (2015) stated that from 1999 to 2000 in the Emaw Bum region in Myanmar, more than 5,000 km^2 of forest was commercially logged, resulting in habitat loss of red panda. Poaching and hunting are other significant threats to red pandas in Myanmar. In the early 1990s, in Myanmar, red pandas were captured and sold illegally for animal collection in China (Glatston, 2015).

Nepal: The possible red panda habitat in Nepal is assessed to be 2652 km^2 which is significantly less than the previous estimation of around 20,400 km^2. 70% of suitable red panda habitat in Nepal is outside the protected area where conservation initiatives are comparatively poor (Bista, 2017). In Nepal, the red panda habitat is threatened by deforestation, habitat degradation, a rise in human population, and forest fire. Bamboo is the primary forest resource of the local residents and is harvested for domestic and commercial purposes, causing a threat to the existence of the red panda (William, 2004). Panthi (2012) found that more than 53% of red panda habitats overlap with human disturbances and cattle grazing. A study conducted by Yonzon (1991) stated that the red panda faces a high mortality rate in Nepal. Predation by leopard and deaths related to anthropogenic activities were also reported in Nepal. Changes in land-use patterns, global climate change and associated threats affect the red panda population and survival (Kandel, 2015). In Nepal, from 2008 to 2015, 56 cases of red panda trafficking were reported (MoFSC, 2016). A study conducted by Bista (2020) reported that 121 pelts were seized from 2008 to 2018 in Nepal. Red panda poaching and illegal trade have increased in Nepal resulting the animal as one of the top five poached animals in Nepal (Dangol, 2015; Bista, 2020).

2.2.1.10 Red panda as an Indicator Species

The red panda is a suitable indicator species to monitor the integrity of the Eastern Himalaya Broadleaf and Conifer Eco-region (Williams, 2003 and Dorji, 2011). Inhaber (1976) states that biological indicator gives us information about the state of environmental quality not obtainable in other ways. Presence, absence, population density and dispersion and reproduction success of the species are used as an index of attributes which are too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest. Red panda (*Ailurus fulgens)* is a charismatic species in worldwide conservation, which can be used to identify the feasibility of the parks for holding different threatened floral and faunal species. It is a solitary and shy animal which respond actively to the anthropogenic stress hence it can be used as an indicator to monitor the ecological integrity and anthropogenic disturbance (Roka, 2020).

2.2.2 *Rhododendron arboreum* Smith

2.2.2.1 Introduction of the species

Rhododendron belongs to the family Ericaceae characterized by more than 1000 species distributed globally (Chamberlain et al., 1996). The genus *Rhododendron* was first described in 1837 by Carl Linnaeus in Genera Plantarum (Tiwari and Chauhan, 2006). *Rhododendron* inhabits the Northern Hemisphere, which extends their distribution to Southeast Asia and North Australasia (Scott, 2010). *Rhododendron* is the most charismatic flowering plant of the mountain region and the largest flowering genera found in Asia (Cullen and Chamberlain, 1978). However, the plant may increase its distribution range due to global warming and pollution (Ranjitkar et al., 2012). Thus presence/absence of *Rhododendron* can indicate the changing environmental parameters of the national park. In the year 1962, the *Rhododendron* (gurans) is declared as the national flower of Nepal by the Government of Nepal. It is the state flower of Uttaranchal and Nagaland and the state tree of Sikkim.

Rhododendron arboreum Smith, locally known as 'lali guras', is the most prominent *Rhododendron* species. The word arboreum means tree as described by Sir James Smith in his Exotic Botany in 1805 (Orwa, 2009). The tree *Rhododendron* reaches up to the height of 15 m and has pinkish-brown bark that exposes a reddish inner layer. The flower color varies from deep red to pink to pure white, which are mistaken as different species in many cases. The flower occurs in the cluster of about 20 flowers. Flowers with tubular, 5 lobed corolla, 4-5 cm long and bell shaped stamens-10, leaves 10-20 cm glossy green above and hair on the under surface (Polunin and Stainton, 1984).

2.2.2.2 Systematic Classification of *Rhododendron arboreum* Smith

Kingdom: Plantae

Phylum: Magnolliophyta

Class: Angiospermae

Order: Ericales

Family: Ericaceae

Genus: *Rhododendron*

Species: *R. arboreum*

2.2.2.3 Natural History

Rhododendron is believed to be the most primitive flowering plant that has flourished 100 million years before in the temperate zone of Northern Hemisphere. The existence of the tree in the primitive age could be found in the reports from Southern China, where Yunnan, Sichuan, and Tibet provinces meet (de Milleville, 2002). A proper scientific study of *Rhododendron* in India was started in the late eighteenth century when Britishers established the Botanical Garden at Calcutta in 1792. Captain Hardwick first identified *Rhododendron arboreum* from the Siwalik Mountain in Jammu and Kashmir in 1796 in India (de Milleville, 2002).

2.2.2.4 Distribution

Rhododendron sp. is distributed in Northeast Asia and Eurasia, North America, and Western Europe (Clinton and Vose, 1996; Colak, 1997). It covers a massive area of North-Western Himalayas from Nepal, India, Northern Myanmar, Eastern Tibet, Bhutan and Western and central China, Thailand, Malaysia, Vietnam, Indonesia, and the Philippine Islands. Above 90% *Rhododendron* population is present in the Himalayan region (Leach, 1961).

In India, *Rhododendron arboreum* distribution ranges from Kashmir to Naga Hills through Nepal, Sikkim, Darjeeling, Bhutan, Arunachal Pradesh, and Khashi Hills (Pradhan and Lachungpa, 1990). Among more than 1000 species of *Rhododendron* globally, 92 species are found in India, distributed throughout the Himalayas (Paul et al., 2005). However Pradhan (2010) has reported that the maximum number of 75 *Rhododendron sp.* is found in Arunachal Pradesh and is followed by Sikkim with 36 species. The Darjeeling Himalayas is also are equally rich in *Rhododendron* diversity (Sastry et al., 2010).

2.2.2.5 Ecology

Rhododendron is generally found in acidic, well drained-aerated soil with rich organic matter containing fewer elements (Ross, 1998; de Milleville, 2002). *Rhododendron* blooms late winter to early summer in temperate climatic conditions, but in the tropical region, it is non-seasonal and blooms throughout the year (Hora, 1981). The humid rainy season occurs for a longer period in the Eastern Himalayas; therefore, *Rhododendron* is the preferred fuelwood in the region (Byers, 2005). Excessive extraction of the wood has caused a decline in the population and is excessively harvested for fuel woods (Krishna, 2002; Chettri, 2007). Climate change has become a significant factor in the change in the diversity of the species. It affects the regeneration and growth of the plant. Forests are degraded due to increasing demand for forest resources which is the consequence of the rapidly expanding human population. Management of forest requires proper understanding of the composition of a particular forest in relation to other forests, consequences of the past on the present status of the forest, and its relation with the surrounding land (Geldenhuys, 1993). It is essential to understand the change or shifts that occurred due to interference caused by the different developmental factors which affect the regeneration and the overall biodiversity, productivity, and sustainability. Increasing pressure on land has resulted in rapid changes in natural areas. Every time lands were cleared, habitat and biodiversity were lost, resulting in the species' decline, and some became extinct. This loss of species, or biodiversity crisis, is one of today's global problems (Williams, 2004). In addition, modern and intensive agriculture is often a threat to biodiversity (Huston, 1980; Bawa, 2007). With the strict Wildlife Protection Act, permanent conversion of forest land has slowed down in the last decade in India.

Uses: *Rhododendron arboreum* is used to prepare a local wine in Singalila National Park, Darjeeling. It is also used against altitude sickness. Dried flowers are used to cure diarrhea and dysentery. Flowers are consumed when fish bone get stuck in throats. The wood is used to prepare khukuri handles, firewood and charcoal. Young leaves are applied to the forehead to cure headaches (Pradhan and Lachungpa, 1990).

2.2.2.6 *Rhododendron* as an Indicator Species

A number of studies conducted globally have produced evidence of changing phenology but nonetheless the persistence of species despite climate change. The flowering of the *Rhododendron arboreum* Smith is considered a prominent biological indicator of climate change (Gaira, 2014). As *Rhododendron* possesses polyphenols and flavonoids which makes it one of the preferred fuelwood as it can burn even in wet conditions. Therefore, change in growth, distribution and decrease in number of

Rhododendron due to excessive extraction may acts an indicator for anthropogenic impacts in the particular vegetation zone.

2.2.3 Forest degradation

Deforestation, forest fragmentation, overuse of forest products, invasive species and global climate change are the primary concern for forest biodiversity loss (Gardner et al., 2009; Morris, 2010). In addition, forests are affected by different factors like grazing, lopping, illicit felling, change in land use pattern, forest fire, and presence of invasive species etc. These factors are causing detrimental consequences causing great loss of biodiversity and ultimately destroying natural vegetation and habitat of the region (Singh and Singh, 1991; Jha and Singh, 1990; Singh, 2002; Singh et al., 2006; Jhariya et al., 2012). Anthropogenic activities have resulted in substantial losses of biodiversity and fragmentation in tropical forest landscape (Buch, 1991; Prasad and Pandey, 1992; Raven and Roy, 1995). Several researchers have advocated that the land-use change may deteriorate ecosystems, eradicate species, and decline natural habitats and ecosystem function, thus finally affecting the biodiversity of the region (Priess et al., 2007; Turner et al., 2007; Ricketts, 2004 and 2008; Steffan, 2008; Lavorel et al., 2007; Martinez et al., 2009). Conservation of biodiversity at the global level can deliver positive ecosystem services, but the benefits of biodiversity conservation and ecosystem services cannot be identified unless ecosystem service is quantified and valued (Naidoo, 2008).

Removal of trees selectively from managed forests has deteriorated the diversity, regeneration, growth, and structure of the forest, essential to maintaining various species' populations (Sukumar, 1992). To conserve biodiversity loss is a prime focus and a challenge for conservationists. According to Wilson (1999) and Berendse (2005) the earth faces the sixth extinction crisis since the beginning of the

Palaeozoic era. Of late, biodiversity conservation, global climate change, ecological balance, and management of various ecosystems have received much attention internationally (Turner et al., 2007; Gullison et al., 2007; Butchart et al., 2010; Strassburg et al., 2010; Frank and Habel, 2011).

The land-use changes and associated biodiversity losses are the major threats to the world's ecological systems (Vitousek, 1997; Carnery and Matson, 2006). Pragasan and Parthasarathy (2010) reviewed that floral inventory is vital for the conservation and management of forest ecosystems. According to Kiester (2001) in most cases, conservation of biodiversity is framed in terms of species diversity to make the public understand the level of diversity.

Throughout the world, all societies are dependent on non-renewable earth resources. Even in this era of post-modernization, people living in the vicinity of the forest areas are using forest recourses extensively for their day-to-day livelihood. In addition, local communities are directly using the resources from the protected area viz., edible items, shelter, firewood, fodders for cattle, and medicine (Dixon and Sherman, 1991; Badola, 1999; Awasthi et al., 2003; Baral and Heinen, 2007; Chandola et al., 2007). Uses of forest products or rather non-consumptive use of the resources from the protected areas have become the subject of studies for several scholars (Badola and Silori, 1999; Campbell, 1999; Archabald and Naughton-Treves, 2001; Stem et al., 2003; Stone and Wall, 2004; Sandbrook, 2010). As per a study carried out by Leroux (2010) at the global level, protected areas do not always represent absolute pristine habitat for the species but they recommended creating new protected areas and maintaining the existing protected areas following IUCN guidelines, because protected areas act as a primary control site for detecting the detrimental effects caused by human beings. From simply conserving the biodiversity for the maintenance of the ecosystem and providing basic needs to the society, the focus has shifted to the broader aspects of managing the pristine ecosystem, which is represented by the protected areas (Dudley and Stolton, 2003; Adams et al., 2004; Kothari, 2006; Holland, 2012). Although there is a continuation of disturbances within the protected areas, the effort for the conservation and the protection of the biodiversity, which are represented by different eco-regions, are acknowledged globally (Brooks et al., 2004; Rodrigues et al., 2004; Chape et al., 2005; Naughton-Treves et al., 2005; Pyke, 2007; Jenkins and Joppa, 2009). Several researchers have discussed the role of protected areas in reducing poverty, maintaining ecological balance to providing livelihood and food security (Holland, 2012). At present, geographical overlap of the protected areas by the local population has become the primary conservation concern. Proper understanding of the conservation having implications on the livelihood of the local people is essential for making conservation initiatives more specific. However, the implications of conservation on the livelihood of the local people still need to be fully understood in a particular regional context due to the heterogeneous nature of the human communities, thus making conservation initiatives more site specific. The diversity of the floral species is one of the significant components of a natural community. For forest conservation, proper floristic inventory and diversity studies help understand the species composition and the diversity status of forests (Gordon and Newton, 2006).

Chapter 3

Materials and Methods

3 Materials and Methods

3.1 Study Area

3.1.1 Singalila National Park

The Singalila National Park (SNP) (Figure 3.1) lies within the latitude 27°31' N to 26°31" N and 88°53' to 87°59' E longitude (Pradhan, 2001). The National park is situated in the extreme North- Western boundary of Darjeeling District, West Bengal. The situation of the National Park ranges between 2400 m to 3650 m above sea level in the Eastern part of the Great Himalayan Range and shares its border with Nepal in the West and Sikkim in the East (Management Plan, 1990-1991 to 2000-2001). The Singalila Range rises from Kanchenjunga (8335 m). Eastern side of the Singalila Range is the valley of the Teesta river, the Western (Nepal) side is the valley of the Tamur river, one of the tributaries of the Kosi river (Figure 3.1). The physiography and the flora of both the Eastern and Western side of the Singalila Range are alike. Its situation is unique, where various phytogeographical and zoo-geographical zones meet. It has sub-alpine grasslands that merge higher and higher up to the snowline beyond Singalila peak (Sikkim). Its temperate forests are contiguous with sub-tropical and tropical forests of Tonglu, Ghoomsimana, and Senchal in Darjeeling Hills. The Singalila National Park represents mainly four type of vegetation namely Broad Leaf Oak Forest that lies between 2400 m to 2800 m, Broad Leaf Deciduous Forest that lies between 2800 m to 3100 m altitude, Broad Leaf Coniferous Forest that lies between 3100 m to 3300 m and Sub Alpine Coniferous Forest that lies between 3300 m to 3600 m altitude above sea level.

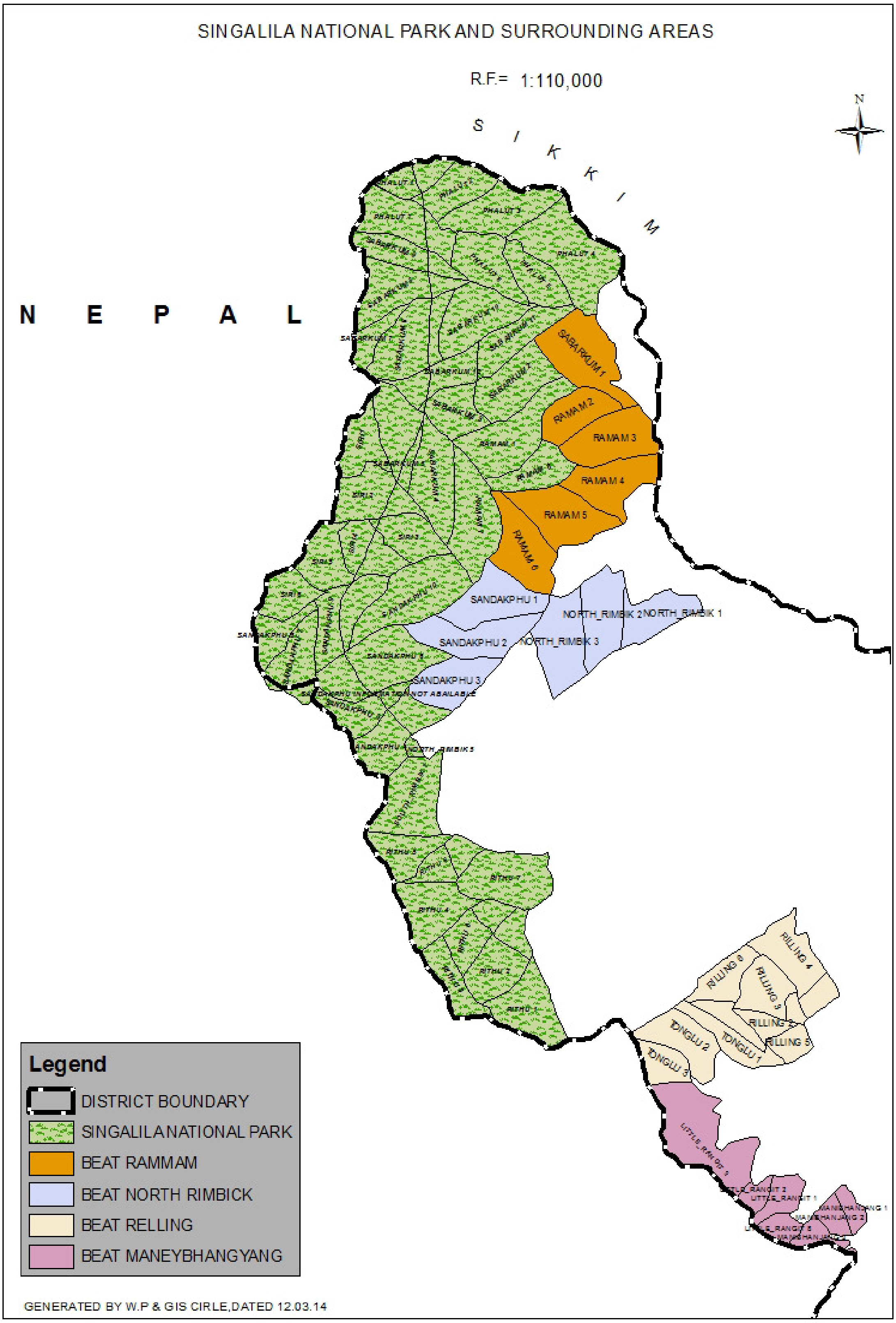

Figure 3.1: Singalila National Park and its surrounding areas (Modified after Roka, 2014)

3.1.2 Constitution

The National Park comprises of the following blocks (Table 3.1):

Table 3.1: Blocks of Singalila National Park (Management Plan, 1990-1991 to 2000-2001)

Block	Compartment*	Area (Ha)
Rithu	1	181.25
	2	161.70
	3	125.45
	4	253.33
	5	136.00
	6	45.66
	7	1.28
	8	115.78
South Rimbick	7	246.86
Sandakphu	4	235.93
	5	210.84
	6	263.86
	7	167.54
	8	143.66
	9	242.00
	10	243.21
Siri	1	170.77
	2	197.49
	3	236.34
	4	192.63
	5	161.47
	6	176.04
Rammam	1	158.64
	7	177.25
	8	198.70

Sabarkum	2	154.19
	3	184.94
	4	178.87
	5	163.09
	6	152.57
	7	153.37
	8	220.55
	9	146.09
	10	219.34
	11	191.42
	12	193.43
Phalut	1	168.35
	2	225.40
	3	212.40
	4	248.07
	5	184.13
	6	212.06
	7	208.41
Total		**7,860.36**

*Compartment is a part of a beat of a National Park

3.1.3 Climate

3.1.3.1 Temperature

The temperate zone has mean temperature between 7°C to 17°C and between -1°C to 10°C in summer and winter respectively. In sub-alpine zone, the mean summer temperature is under 7°C and in winter it is below -1°C. The winter is extremely cold and extends from November to March. The hottest season is between April and June, just before the onset of monsoon. At 3300 m and above, there is a regular incidence of snowfall during winters. Frost is very frequent from December to early days of March in almost 80% of the park area. Atleast, there is some amount of snowfall in the upper reaches at least twice every year. At the higher places the snow persists for up to a month but lower down it seldom remains for more than a few hours to a day or two at the most. The melting snow feeds the streams with water and rejuvenates the marshy valleys. Hail falls occasionally during the months of March and April and does some amount of damage to the trees.

3.1.3.2 Rainfall

Annual rainfall recorded at Sandakphu and Rammam areas of SNP were approximately 330 cm and 315 cm respectively. Records of the monthly rainfall at Sandakphu show that the area receives the maximum rainfall in May, June and August whereas Rammam receives maximum rain during June to September.

3.1.3.3 Humidity

Moist atmospheric condition prevails for a considerable part of the year. Average relative humidity varies from 83% to 96% associated with moderate storms; sometimes also accompanied by hail, especially in the month of April and May. Most of the forests are covered with mist for more than half of the year. Due to this the stems and branches of the trees are thickly covered with mosses. A large number of orchids and epiphytes are also found on the branches and stems as excessive moisture is suitable for their growth.

3.1.4 Water Source

The terrain of the area is mountainous; the rain water is therefore drained very fast. No important natural wetland or marsh except for one at Kalpokhri is present in the region. The rivers, little Rangit and Rammam drain water from Singalila range. Phalut, Sandakphu, Sabarkum and Tonglu blocks from the catchment of Devithan

Khola, Gurdum Khola etc. pass through the park area. Sirikhola and Lodhama Khola drain bulk of water from various blocks of Singalila and Tonglu range. The Rammam river which originates from Phalut, receives water from Singpratap Khola, Siri Khola, Lodhama Khola etc. before it joins the great Rangit river. These kholas (riverlets) and rivers retain water for considerable period of year, which provide water to the wildlife. In the hill slopes, there are large numbers of small springs which ooze out water throughout the year (Management Plan, 1990-1991 to 2000-2001).

3.1.5 Human Settlement

The Singalila forest was notified as Reserved Forests on the 22nd Sept, 1882 under Sec 10 of the Indian Forest Act, 1878 and was declared National Park in the year 1992. Human settlement started gradually in the surrounding areas of National Park and in some pockets of International Boundary with Nepal. There was free access for people across the boundary particularly for grazing, firewood collection and lopping and timber collection before declaration of SNP as national park. The income level of the surrounding people of the National Park area is very low and substantial percentage of the population depends on the forest for their subsistence.

A huge proportion of population of SNP area comprises of SC/ST and OBC belonging to Nepalese community with other tribes forming marginal population. The people are mostly farmers and laborers and most of the population are either landless or subsistence farmers. Their income is supplemented by primitive animal husbandry practices and a large working population is engaged in micro scale agriculture practices.

The Singalila National Park is surrounded by several human settlements. The major settlements near the national parks are Rithu, Gurdum, Sirikhola, Gorkhey, Samanden, Rammam, and Bichgoan. All the settlements except Gorkhey are in the Buffer zone of the National Park.

3.2 Methods

3.2.1 Field study

A preliminary survey of the SNP was conducted to establish the presence/absence of red pandas in different pockets of the park. The rugged terrain of the national park and dense bamboo did not favor drawing transects in the area. The existing patrolling trails and paths present at various altitudes were selected carefully for the study. Based on the field observation, different vegetations were identified for random sampling. GPS readings were taken in the field, and various aspects of habitat variability such as altitude, slopes, presence of tree species, shrub species, and herb species were quantified. Quadrats of 10 m × 10 m were laid randomly within each vegetation type for measuring structure and composition, and numbers of species were noted. Bamboo and other shrub species were quantified in 3 m × 3 m quadrats within the 10 m^2 quadrat. The plant species were identified following Cowan and Cowan (1929) and Tamang and Yonzon (2004). In addition, 1 × 1 m^2 quadrats for herbs were laid within the quadrat in each significant direction to collect information on the ground cover such as herbs, grasses etc. Individuals of the shrubs and herbs species encountered were noted.

3.2.2 Data analysis

The following formulae were used during the study: (Curtis and McIntosh 1950):

$$\text{(a) Density} = \frac{\text{Total number of individuals of the species}}{\text{Total number of quadrats studied}}$$

(b) Relative density = $\dfrac{\text{Density of the species}}{\text{Sum of the density of all the species}} \times 100$

(c) Frequency = $\dfrac{\text{Number of quadrats in which a species occurred}}{\text{Total number of quadrats sampled}} \times 100$

(d) Relative frequency = $\dfrac{\text{Frequency of the species}}{\text{Sum of frequency of all species}} \times 100$

(e) Abundance = $\dfrac{\text{Number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occurred}}$

(f) Relative Abundance = $\dfrac{\text{Abundance of the species}}{\text{Abundance of all the species}} \times 100$

(g) Relative Dominance = $\dfrac{\text{Basal cover of the species}}{\text{Total stand basal cover of all the species}} \times 100$

Basal cover = $(cbh)^2/4\pi$ (Mao, 2009; Moktan, 2017)

Where, cbh is the circumference of the stem at the breast height. The sum of the basal cover of individual plants of a species yields the total stand basal cover of that species.

(h) IVI= Sum of Relative frequency, Relative density, and Relative dominance. (Curtis 1959; Philip 1959)

3.2.3 Diversity Indices

The diversity indices are essential to measure the biodiversity. In the forest community of the Singalila National Park, different indices were measured to understand the diversity of the species. Species diversity was estimated by calculating Shannon-Wiener's Index (1963 and species richness was calculated using Menhinick's Index (1964). Simpson's Index (1949) was used to measure dominance, and species evenness was estimated following Pielou's Index (1966). Formula by Withford (1949) was used to determine the distribution pattern of the species.

3.2.3.1 Shannon-Wiener's Index (1963)

The species diversity shows the community structure and indicates the distribution and complexity of the species in the habitat.

Shannon-Wiener's Index (H') (Shannon and Wiener, 1963) was estimated by the following formula:

$$H' = -\sum [(ni/N)In(ni/N)]$$

ni= number of individuals of a species

N=Sum total of all individual species

In=Log

3.2.3.2 Menhinick's Index (1964)

The species richness is the number of species in a sample per unit area. It is based on the total number of species and the total number of individuals in a sample or habitat.

Menhinick's Index (D) was calculated by the following formula:

$$D = S/\sqrt{N}$$

S is number of individual species

N is sum total of all individual species

3.2.3.3 Simpson's Index (1949)

The Simpson's Index expresses the concentration of dominance. The changes encountered by species during the sampling are determined by Simpson's Index and its value falls between 0 to 1.

Simpson's Index (CD) was calculated by using the following formula:

$$CD= \sum (ni/N)^2$$

ni= number of individuals of a species

N= Sum total of all individual species

3.2.3.4 Pielou's Index (1966)

The species evenness recognizes how close in number each species is in a particular habitat. It is calculated using Pielou's Index (1966).

Pielou's Index (J) was calculated using the following formula:

$$J=H'/InS$$

H' is Shannon-Wiener's Index

S is the number of individual species

3.2.3.5 Whitford Index (1949)

The Spatial distribution was obtained by studying the abundance to frequency ratio (A/F).

The ratio of <0.025 shows the regular distribution

The ratio of 0.025-0.050 shows a random distribution

The ratio of > 0.050 shows the contiguous distribution

3.2.4 Anthropogenic Impact

Qualitative and quantitative data on human settlement and the resource use pattern of the local community residing in the vicinity of the Singalila National Park were done by direct sighting. In order to collect primary data on village profiles on livelihoods and dependency on natural resources and their utilization, Primary Questionnaire and Rural Appraisal (PRA) methods were used during the study. Questionnaire was prepared, and the interviews were conducted at the respondents' homes. Heads of the family (male or female) based to their availability were considered for the questioning or survey as they had more knowledge of the forest and its resources. Questions were asked in local dialect, Nepali. Village leaders and seniors were focused to understand the history of the villages. Group discussions with the small focus group were conducted for better understanding the settlement's history and present resource dependence. The discussions mainly focused on the utilization of forest products (timber and non-timber forest products), farming, land tenure, threats to forest and wildlife, human wildlife conflicts, local developmental issues etc. Preformatted questionnaire were used to obtain data on agriculture practice, human resource, livestock tending practice, income sources, resource collection and uses. During the study the researcher collected data by visiting the houses of the respondents. Emphasis was given to collect 100% data by the researcher during the study but due to unavailability of the respondent and in some cases non participation of some family during the study, 100% house sampling was not possible. Data pertaining to the uses of forest product, household distance from the park, family members, occupation, number of children, age, gender, road network proximity to protected area network, basic health facility, primary educational institute, occupation etc., were collected during the survey. No financial benefits were provided to the respondent during the survey.

3.2.5 Vegetation mapping of SNP

Since vegetation indices have long been used in studying the temporal change associated to vegetation. The Normalized Difference Vegetation Index (NDVI) is a numerical indicator that quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) and is given by the formula:

$$NDVI= (NIR-RED)/(NIR+RED)$$

where NIR is near-infrared and RED is red light.

The multi-temporal satellite data obtained from NASA-Global Land Cover Facility (GLCF) Archive i.e. Landsat (TM) with a spatial resolution of 30m of different years 1992, 2004 and 2016 were used in the present study. The value of the NDVI ranges from -1 to +1. The value close to zero denotes a non-green area or an urban area. It is to be noted that soil and rocks have broader reflection giving NDVI close to '0'. However, if the value is close to +1, it would be the dense green vegetation. The value between 0.1 and 0.6 indicates higher photosynthetic activity and a greater density of the canopy (Tarpley et al., 1984). The Landsat TM derived NDVI imageries were prepared using Arc GIS 10.1 software and compared to study the pattern of vegetation change in different years.

3.2.6 Study of *Rhododendron arboreum* Smith

Presence/absence of the species, density, abundance, and frequency of the species was studied as per the standard taxonomic procedure through collection and identification of plant species by using pre-existing tracks and trails within the forest at various altitudinal zones and following the Quadrat method (10 m × 10 m quadrat for trees). Density and basal area were calculated. The data collected were analyzed for community parameters like frequency, density, abundance, relative frequency, relative density, relative dominance, IVI as per Mishra (1968) and Curtis and McIntosh (1950).

3.2.7 Behaviour observation of red panda

Behaviour of the red panda in captivity was observed following instantaneous sampling (Altman, 1974) and was analyzed at weekly basis at the end of every month. Two red pandas were selected and the behaviour was observed both manually (directly) and through CCTV cameras at PNHZ Park. Thus, one male and one female red panda (1♂:1♀) were observed, dividing a day into four phases i.e., dawn, day, dusk, and night. Animal behaviour was broadly divided into two category-active behaviour and passive behaviour. Activities like walking, running, pacing, feeding, drinking, urinating, defecating, auto grooming, allogrooming, mating, nest building, nursing, climbing, scent marking, fighting, and scratching were considered active behaviours. On the other hand, activities like sleeping, resting, and basking was considered passive behaviour.

3.2.8 Population estimation of red panda

A questionnaire survey was conducted on a set proforma for direct sighting and signs like faecal pellets and reports of any anthropogenic threats. After confirmation of the presence of species, intensive studies were conducted. For field surveys, tracks and trails inside the forest at different altitudinal zones were used, and red panda evidence was searched in the forest. Altogether 20 trails were followed season-wise at a uniform pace and on spotting of the mammals the details like species, number of individuals, group size, activity (like feeding, foraging, resting, moving etc.), distance from the ground, vegetation of the surrounding areas, GPS location of the area, source of water were noted for each sighting. Whenever a pellet group was encountered, the state of the pellet group, the substrate of defecation, number of fresh pellets, the details of the trees used for defecation, water source, and pellets of other animals in the surrounding area were recorded. The fresh pellet of the red panda was collected from the site, and the GPS reading was taken.

3.2.9 Non-invasive Sampling using Polymerase Chain Reaction (PCR) based on DNA amplification (Liu et al., 2005; Zhang et al., 2008)

Red panda fecal samples from the wild were collected to understand the population of red panda in Singalila National Park and its surrounding area. The samples were analyzed at LaCONES, CCMB to estimate the number of individuals of the species. In this approach the gathering of data was done without capturing, handling or otherwise physically restraining individual animals. Sampling is done by gathering data of tracks (pugmarks), scrapes, tree nests, faeces, hair macroscopy (morphology), including the genetic sampling of hairs and scats (Kelly, 2011). After intensive field survey in Singalila National Park, 329 samples were collected, whole samples were picked using disposal gloves and were transferred into a sterile plastic container which later on was stored and preserved in 99% ethanol at -20°C till extraction of DNA. Global Positioning System, date of collection of the samples was noted. DNA was extracted by using QIAGEN DNA Stool Mini Kit. The outer layer of the faeces was peeled off of about 250 mg. Non-invasive genetic methods are less expensive and more efficient than the traditional field methods and overcome most of the limitations related to both sampling and data analysis (Solberg, 2006).

Steps for the Non-Invasive Population estimation

1. Sample collection
2. DNA isolation (Using QIAGEN kit method)
3. Qualitative and quantitative estimation of DNA
4. PCR (Liang et al., 2007).
5. Agarose Gel Electrophoresis
6. Microsatellite genotyping (Liang et al., 2007)

3.2.10 Plant preference of the red panda

For food habit analysis, the year was divided into three seasons, viz., summer, monsoon, and winter. Data analysis and discussion on seasonal changes in vegetation and subsequent change in feeding patterns of indicator species are presented accordingly. Seasonal breaks up of various months were as follows:

Summer:	16 February	– 15 June
Monsoon:	16 June	– 15 October
Winter:	16 October	– 15 February

The commencement of summer and the arrival of monsoon marked the drastic changes in plant phenology and vegetative growth. Most of the plant species attain maximum biomass by monsoon. This is the season in which there is the highest diversity of food plants. Late monsoon has maximum flowering and fruiting. Senescence of vegetation set in winter, limiting forage availability for the species. The following method was used to study the food habits of red panda:

3.2.10.1 Micro histological analysis of fecal pellets

Micro histological analysis of fecal pellets is a very widely used method (Stewart, 1967; Todd and Hansen, 1973; Green, 1987). Two major steps were followed during the study. First, the preparation of reference material of the food plant species to identify the species' epidermal and cellular characteristics, and second, the micro histological examination of fecal material to estimate the frequency of fragments of various plant species. Plant material was collected in the field, air-dried, and then stored in paper bags for later transportation to the laboratory. The plant materials were separated by part, i.e., leaf, stem, and flowers. These materials were ground to a fine powder (to fit a 1 mm mesh). A small quantity of the powdered material was left overnight in 6% hydrogen peroxide to partially remove pigments, which would otherwise obscure the species' characteristic epidermal and cellular patterns. The materials were then washed through a fine sieve under running water to remove traces of hydrogen peroxide. Further, these bleached materials were air-dried. Slides were prepared of these plant materials with DPX mounting medium. The slides were left to dry, until the mounting medium hardened. In the same way, slides were prepared for each of the plant species collected. The slides were viewed under a microscope at 100X magnification, and characteristic epidermal patterns were identified and compared with fragments found in faecal material. Fresh faecal pellets of red panda were collected every month and later combined by season for analysis of the seasonal food habits of the species.

Chapter 4
Results

4 Results

4.1 Vegetation ecology of Singalila National Park

4.1.1 Temperate Oak Forest (2400 m to 2800 m)

4.1.1.1 Tree Layer of Temperate Oak Forest

The Temperate Oak Forest of the Singalila National Park, Darjeeling lies between 2400 m to 2800 m altitude above sea level. The study conducted in the Oak Forest of SNP recorded 46 species and one variety belonging to 32 genus and 20 families. Highest number of species was recorded under the family Ericaceae, Fagaceae and Lauraceae. Each family recorded 6 species each and were followed by Sapindaceae (4 species), Symplocaceae (3 species), Rosaceae (3 species) and Araliaceae (3 species). Other families like Pinaceae (2 species), Pantaphylaceae (2 species), and Magnoliaceae (2 species) recorded two species each (Table 4.1) Total stem density in Oak Forest of the Singalila National Park was estimated to be 1360.7143 individuals ha^{-1}. Highest density was recorded for *Lithocarpus pachyphyllus* (128.571) and was followed by *Rhododendron arboreum var. cinnamomeum* (114.286 ha^{-1}) and *Symplocos dryophila* (78.571). Total estimated abundance in the area was 84.3376 and the species with the highest abundance was *Pinus patula* (3.5) and was followed by *Rhododendron arboretum var. cinnamomeum* (3.048). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the tree species in the Temperate Oak Forest of the National Park showed three classes i.e. A, B and D with species exhibiting 69.39%, 25.532% and 2.128% respectively whereas C and E were nil in the area (Figure 4.1).

The species with the highest frequency recorded was *Lithocarpus pachyphyllus* (75%) and was followed by *Symplocos dryophila* (35.714%). During the study 2 trees species showed random distribution, 1 species showed regular distribution pattern and 43 species and one variety showed contiguous distribution pattern in the Temperate Oak Forest of the national park. *Lithocarpus pachyphyllus* was the most dominant species with the IVI value 56.294 and was followed by *Rhododendron arboreum var. cinnamomeum* and *Quercus lamellose* with 27.661 and 17.672 IVI score respectively (Figure 4.2). The Sannon-Wiener diversity index in the region was estimated to be 3.5213, the concentration of the Dominance was 0.0384, species richness was 1.7026 and evenness of species was 0.9146 (Table 4.4).

Table 4.1: Phytosociological composition of tree layer in the Temperate Oak Forest of SNP area detailing the associated species with their ecological parameters

Sl. No	Scientific Name	Family	F	D^{-1}	A	A/F	R. F	R. D	R. Dom.	IVI
1	*Acer campbellii* Hooker. f. & Thomson ex Hiern	Sapindaceae	16.071	32.143	2	0.124	2.148	2.362	0.954	5.464
2	*Acer caudatum* Wallich	Sapindaceae	5.357	7.143	1.333	0.249	0.716	0.525	0.042	1.282
3	*Acer pectinatum* Wallich ex Nicholson	Sapindaceae	5.357	10.714	2	0.373	0.716	0.787	0.089	1.592
4	*Acer sikkimense* Miquel	Sapindaceae	12.5	28.571	2.286	0.183	1.67	2.1	0.666	4.436
5	*Alnus nepalensis* D. Don	Betulaceae	7.143	10.714	1.5	0.21	0.955	0.787	0.156	1.898
6	*Andromeda villosa* Wall	Ericaceae	14.286	21.429	1.5	0.105	1.909	1.575	0.055	3.539
7	*Castanopsis hystrix* Hook. f. & Thomson ex A. DC.	Fagaceae	14.286	26.786	1.875	0.131	1.909	1.969	1.598	5.476
8	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	12.5	16.071	1.286	0.103	1.671	1.181	0.414	3.266
9	*Cinnamomum bejolghota* (Buch.-Ham.) Sweet	Lauraceae	5.357	5.357	1	0.187	0.716	0.394	0.056	1.165
10	*Cinnamomum impressinervium* Meisn.	Lauraceae	10.714	17.857	1.667	0.156	1.432	1.312	0.292	3.036
11	*Cryptomeria japonica* (Thunb. Ex.L.f)D. Don	Cupressaceae	5.357	10.714	2	0.373	0.716	0.787	0.256	1.759
12	*Endospermum chinense* Benth	Euphorbiaceae	1.786	1.786	1	0.56	0.239	0.131	0.002	0.372
13	*Eurya acuminata* DC.	Pentaphylacaceae	8.929	25	2.8	0.314	1.193	1.837	0.632	3.663

14	*Eurya cerasifolia* (D. Don) Kobuski	Pentaphylacaceae	14.286	16.071	1.125	0.0788	1.909	1.181	0.104	3.195
15	*Gamblea ciliata* Clarke	Araliaceae	3.571	8.929	2.5	0.7	0.477	0.656	0.104	1.238
16	*Ilex fragilis* Hook. f.	Aquifoliaceae	23.214	30.357	1.308	0.056	3.103	2.231	0.541	5.874
17	*Leucosceptrum canum* Sm.	Lamiaceae	5.357	12.5	2.333	0.436	0.716	0.919	0.052	1.687
18	*Lindera assamica* (Meisn.) Kurz	Lauraceae	1.786	1.786	1	0.56	0.239	0.131	0.002	0.372
19	*Lithocarpus fenestratus* (Roxburgh) Rehder	Fagaceae	8.929	21.429	2.4	0.269	1.193	1.575	0.741	3.509
20	*Lithocarpus pachyphyllus* (Kurz) Rehder	Fagaceae	75	128.571	1.714	0.023	10.024	9.449	36.821	56.294
21	*Litsea elongata* (Nees) Hooker. f.	Lauraceae	25	32.143	1.286	0.051	3.341	2.362	0.45	6.153
22	*Litsea sericea* (Wall. ex Nees) Hook. f.	Lauraceae	16.071	32.143	2	0.124	2.148	2.362	0.918	5.428
23	*Lyonia ovalifolia* (Wallichi) Drude	Ericaceae	7.143	10.714	1.5	0.21	0.955	0.787	0.038	1.78
24	*Machilus edulis* King ex Hook.f.	Lauraceae	12.5	17.857	1.429	0.114	1.671	1.312	0.529	3.512
25	*Magnolia campbellii* Hooker f. and Thomson	Magnoliaceae	30.357	32.143	1.059	0.035	4.057	2.362	1.722	8.141
26	*Magnolia globosa* Hook.f. & Thomson	Magnoliaceae	1.786	3.571	2	1.12	0.239	0.262	0.02	0.522
27	*Meliosma dilleniifolia* (Wall. ex Wight & Arn.) Walp.	Sabiaceae	1.786	1.786	1	0.56	0.239	0.131	0.002	0.371
28	*Merrilliopanax alpinus* (Clarke) C.B. Shang	Araliaceae	8.929	12.5	1.4	0.157	1.193	0.919	0.077	2.19
29	*Osmanthus suavis* King ex C.B. Clarke	Oleaceae	17.857	37.5	2.1	0.118	2.387	2.756	0.761	5.904
30	*Prunus undulata* Buch.-Ham. ex D. Don	Rosaceae	12.5	26.786	2.143	0.171	1.671	1.969	1.046	4.685
31	*Pinus patula* Schiede ex Schltdl. & Cham.	Pinaceae	7.143	25	3.5	0.49	0.955	1.837	1.396	4.188

32	*Quercus lamellosa* Smith	Fagaceae	28.571	57.143	2	0.07	3.819	4.199	9.654	17.672
33	*Quercus lineata* Blume	Fagaceae	32.143	51.786	1.611	0.05	4.296	3.806	5.355	13.456
34	*Rhododendron arboreum* Smith	Ericaceae	30.357	57.143	1.889	0.062	4.057	4.199	2.657	10.913
35	*Rhododendron arboreum* var. *cinnamomeum* (Wallich ex G. Don) Lindley	Ericaceae	37.5	114.286	3.048	0.081	5.012	8.399	14.25	27.661
36	*Rhododendron grande* Wight	Eraceae	23.214	62.5	2.692	0.116	3.103	4.593	2.501	10.197
37	*Rhododendron griffithianum* Wight	Eraceae	33.929	53.571	1.579	0.047	4.535	3.937	1.408	9.88
38	*Schefflera rhododendrifolia* (Griff.) Frodin	Araliaceae	21.429	44.643	2.083	0.097	2.864	3.281	0.709	6.854
39	*Sorbus cuspidata* (Spach) Hedl.	Rosaceae	19.643	25	1.273	0.065	2.625	1.837	1.177	5.64
40	*Sorbus vestita* (Wallich ex G. Don) Lodd.	Rosaceae	8.929	12.5	1.4	0.157	1.193	0.919	0.243	2.355
41	*Symplocos dryophila* C.B. Clarke	Symplocaceae	35.714	78.571	2.2	0.062	4.773	5.774	5.486	16.034
42	*Symplocos pinnata* L. (Thunb.) Siebold & Zucc.	Symplocaceae	23.214	37.5	1.615	0.0696	3.103	2.756	1.304	7.163
43	*Symplocos glomerata* King ex C.B. Clarke	Symplocaceae	7.143	19.643	2.75	0.385	0.955	1.444	0.316	2.714
44	*Tsuga dumosa* (D. Don) Eichler	Pinaceae	16.071	23.214	1.444	0.09	2.148	1.706	2.524	6.378
45	*Vitex heterrophylla*	Verbenaceae	21.429	30.357	1.417	0.067	2.864	2.231	1.536	6.631
46	*Wightia speciosissima* (D. Don) Merr.	Paulowniaceae	8.929	16.071	1.8	0.202	1.193	1.181	0.25	2.624
47	*Zanthoxylum armatum* DC	Rutaceae	7.143	10.714	1.5	0.21	0.955	0.787	0.093	1.835

F = Frequency, D^{-1}= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, R. Dom. = Relative Dominance, IVI= Importance Value Index

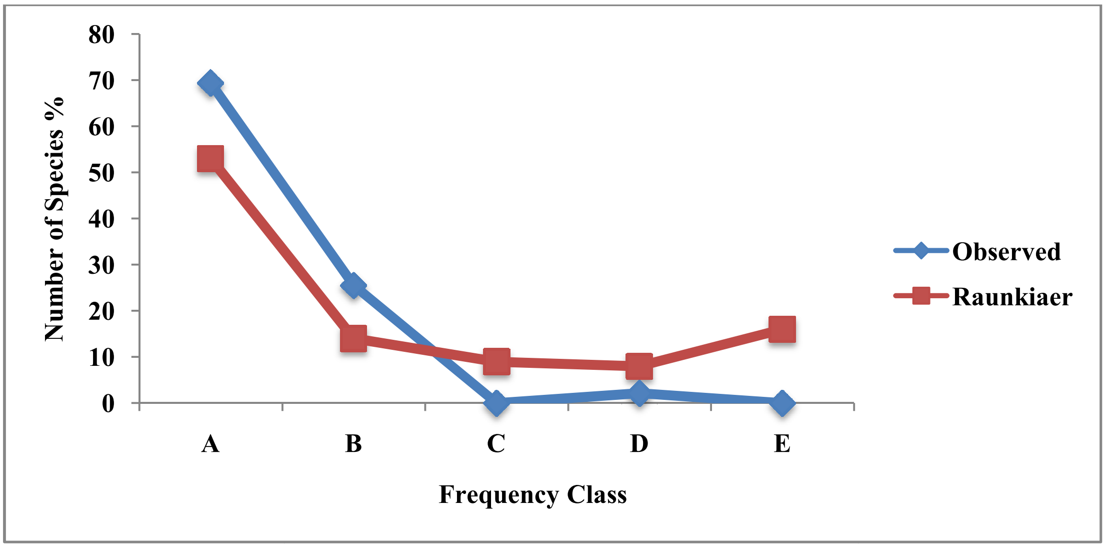

Figure 4.1: Comparison of the Observed frequency of tree layer of Temperate Oak Forest with Raunkiaer's frequency distribution in SNP, Darjeeling

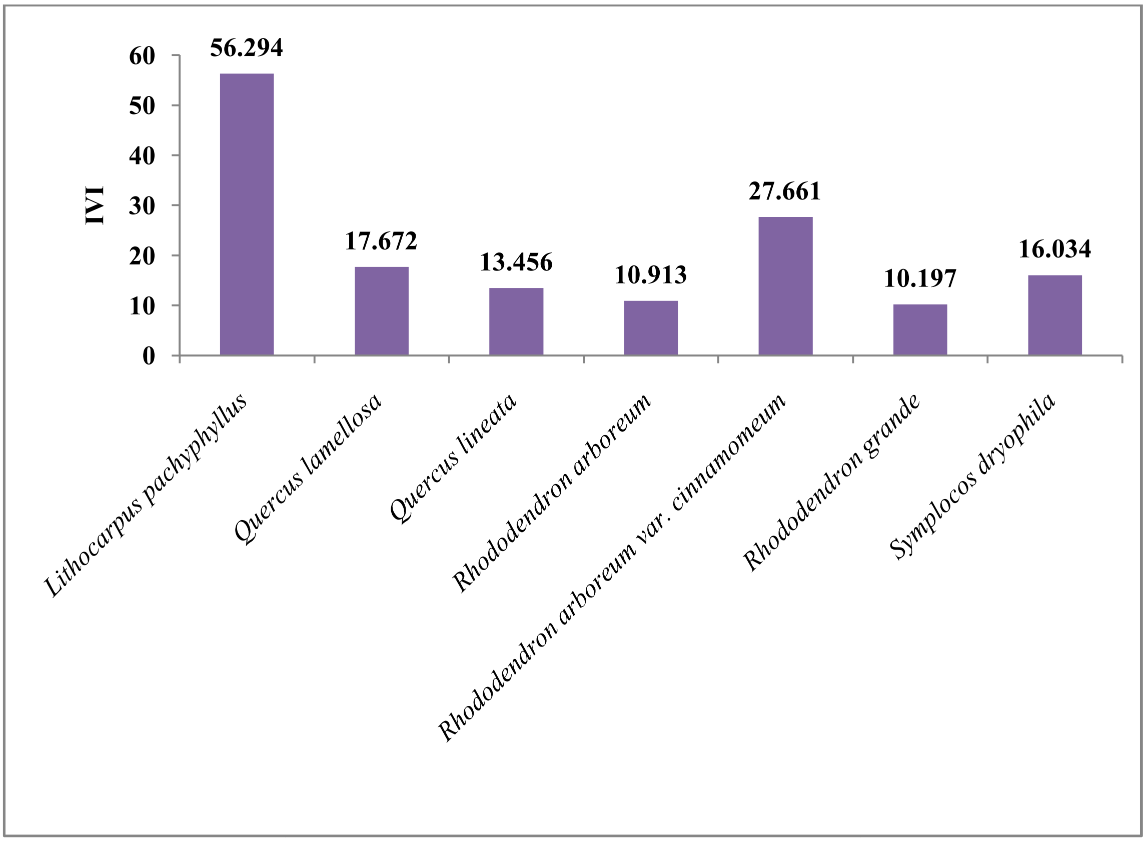

Figure 4.2: Tree species with relatively high Importance Value Index in the Temperate Oak Forest of SNP, Darjeeling

4.1.1.2 Shrub Layer of Temperate Oak Forest

The study conducted in the Temperate Oak Forest of the SNP recorded 24 shrub species belonging to 20 genus and 16 families. Of these, the highest number of species was recorded from the family Rosaceae with 4 species which was followed by Urticaeae with 3 species and Ericaceae, Andoxaceae and Poaceae with 2 species each. Other families like Thymelaeaceae, Liguminaceae, Polygonaceae, Saxifragaceae etc. were represented by 1 species each in the Oak Forest of the park (Table 4.2). The total density of shrub in Oak Forest was estimated to be individuals 46.554. Of these, the highest density was recorded for *Yushania maling* (29.714) which was followed by *Thamnocalamus spathiflorus* (8.839). The total abundance estimated in the area was 146.863 and the species with the highest abundance was again *Yushania maling* (36.173) followed by *Thamnocalamus spathiflorus* (33). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the shrub species in the Oak Forest showed only three classes i.e. A, B and E with species exhibiting 87.5%, 8.33% and 4.17% respectively whereas C and D were nil in the study area (Figure 4.3). The species with the highest frequency recorded was *Yushania maling* with 82.143% followed by *Thamnocalamus spathiflorus* with 26.786% of frequency. *Yushania maling* was the most dominant species with the IVI value 113.874 which was again followed by *Thamnocalamus spathiflorus* with 49.745 IVI score (Figure 4.4). The Sannon-Wiener diversity index in the region was estimated to be 1.3964, the concentration of the Dominance was 0.4455, species richness was 0.47 and evenness of species was 0.4394 (Table 4.4). All the 24 shrub species showed contiguous distribution pattern in the region.

Table 4.2: Phytosociological composition of shrub layer in the Temperate Oak Forest of SNP area detailing the associated species with their ecological parameters

Sl. No	Scientific Name	Family	F	D	A	A/F	RF	R D	RA	IVI
1	*Andromeda formosa* Wall.	Ericaceae	5.357	0.143	2.667	0.498	1.657	0.307	1.816	3.78
2	*Angiopteris* sp	Angiopteridaceae	3.571	0.071	2	0.56	1.104	0.153	1.362	2.62
3	*Astilbe rivularis* Buch.-Ham. ex D. Don	Saxifragaceae	10.714	0.375	3.5	0.327	3.314	0.806	2.383	6.504
4	*Daphne bholua* Buch.-Ham. ex D. Don	Thymelaeaceae	8.929	0.321	3.6	0.403	2.762	0.69	2.451	5.904
5	*Dichroa febrifuga* Lour.	Hydrangeaceae	8.929	0.339	3.8	0.426	2.762	0.729	2.587	6.079
6	*Elsholtzia fruticosa* (D. Don) Rehder	Lamiaceae	3.571	0.161	4.5	1.26	1.105	0.345	3.064	4.514
7	*Gaultheria nummularioides* D. Don	Ericaceae	5.357	0.143	2.667	0.498	1.657	0.307	1.816	3.78
8	*Girardinia diversifolia* (Link) Friis	Urticaceae	7.143	0.304	4.25	0.595	2.21	0.652	2.894	5.756
9	*Heracleum nepalense* D. Don	Apiaceae	10.714	0.464	4.333	0.404	3.315	0.997	2.951	7.263
10	*Ilex sp.*	Aquifoliaceae	5.357	0.161	3	0.56	1.657	0.345	2.043	4.045
11	*Impatiens stenantha* Hook. f.	Balsaminaceae	5.357	0.125	2.333	0.436	1.657	0.269	1.589	3.515
12	*Leycesteria formosa* Wall.	Caprifoliaceae	12.5	0.25	2	0.16	3.867	0.537	1.362	5.766
13	*Piptanthus nepalensis* (Hook.) D. Don	Leguminosae	5.357	0.125	2.333	0.436	1.657	0.268	1.589	3.515
14	*Polygonum molle* D. Don	Polygonaceae	14.286	1.143	8	0.56	4.42	2.454	5.447	12.323
15	*Rubus acuminatus* Sm.	Rosaceae	12.5	0.464	3.714	0.297	3.867	0.997	2.529	7.394
16	*Rubus ellipticus* Sm.	Rosaceae	10.714	0.286	2.667	0.249	3.315	0.614	1.816	5.744
17	*Rubus nepalensis* (Hook. f.) Kuntze	Rosaceae	19.643	0.661	3.364	0.171	6.077	1.419	2.29	9.787

18	*Rubus paniculatus* Sm.	Rosaceae	10.714	0.25	2.333	0.218	3.315	0.537	1.589	5.441
19	*Sambucus adnata* Wall. ex DC.	Adoxaceae	21.429	1	4.667	0.218	6.63	2.148	3.178	11.955
20	*Thamnocalamus spathiflorus* (Trin.) Munro	Poaceae	26.786	8.839	33	1.232	8.287	18.987	22.47	49.745
21	*Urtica dioica* L	Urticaceae	8.929	0.411	4.6	0.515	2.762	0.882	3.132	6.777
22	*Urtica parviflora* Roxb.	Urticaceae	7.143	0.304	4.25	0.595	2.21	0.652	2.894	5.756
23	*Viburnum erubescens* Wall.	Adoxaceae	16.071	0.5	3.111	0.19	4.972	1.074	2.118	8.165
24	*Yushania maling* (Gamble) R.B. Majumdar & Karthik.	Poaceae	82.143	29.714	36.174	0.44	25.414	63.828	24.631	113.874

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, RA = Relative Abundance, IVI= Importance Value Index

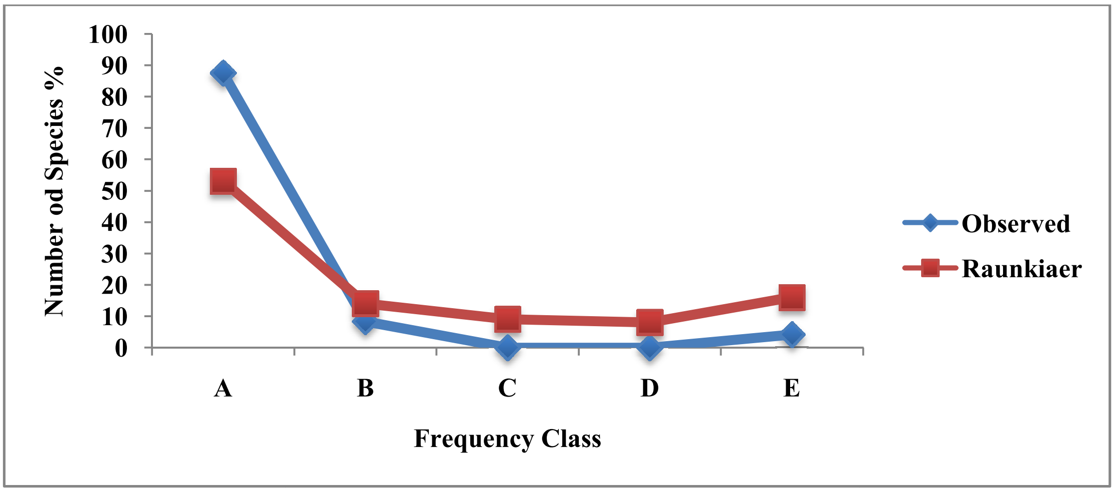

Figure 4.3: Comparison of Observed frequency of the shrub layer of Temperate Oak Forest with the Raunkiaer's frequency distribution in SNP, Darjeeling

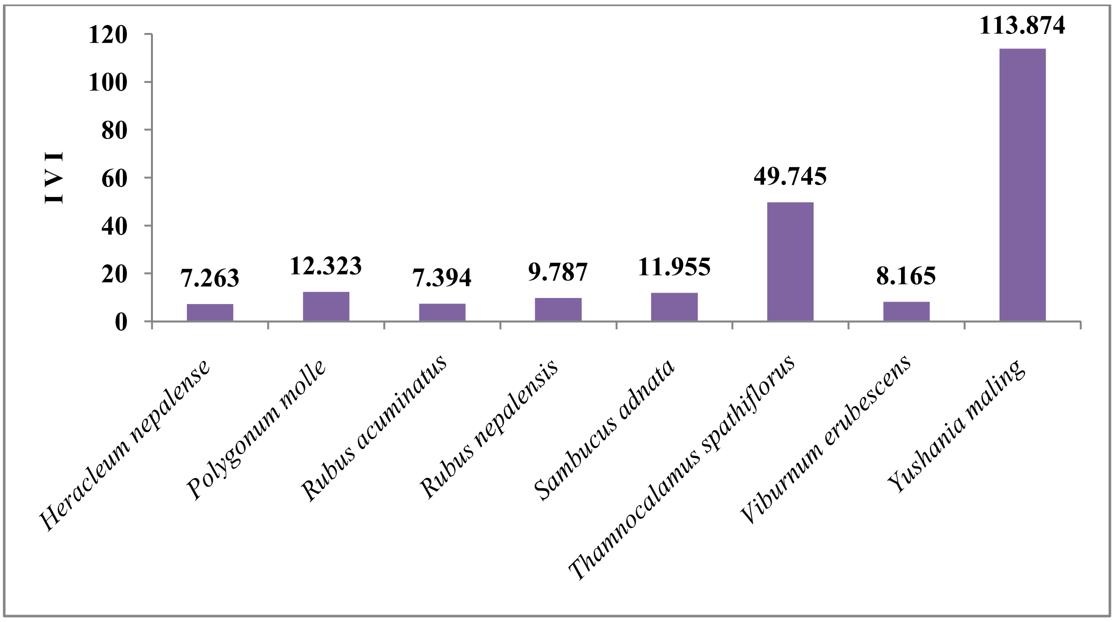

Figure 4.4: Shrub species with relatively high Importance Value Index in the Temperate Oak Forest of SNP, Darjeeling

4.1.1.3 Herb layer of Temperate Oak Forest

The study conducted on the herb layer in the Temperate Oak Forest recorded 61 species belonging to 48 genus and 33 families. Highest number of species were recorded under the family Compositae (8 species) and Polygonaceae (5 species) which was followed by the family Rosaceae (4 species), Urticaceae (3 species), Poaceae (2 species), Begoniaceae (2 species) respectively (Table 4.3). Total density of the herb in Oak Forest was estimated to be 60.625. Highest density was recorded for *Carex decora* (4.848) was followed by *Lepisorus nudus* (4.089) and *Erigeron bellidioides* (2.8) in the forest. Total estimated abundance was 312.87 and the species with the highest abundance was *Erigeron bellidioides* (19.625) and was followed by *Pilea umbrosa* (10.142).Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the herb species in the Oak Forest showed A, B, C, D frequency class. Frequency class A was 72.13%, frequency class B was 22.95%, frequency class C was 3.28%, frequency class D was 1.64% and E was nil in the study area (Figure 4.5). The species with the highest frequency recorded was *Carex decora* (75%) and was followed by *Lepisorus nudus* (58.036%), *Centella asiatica* (52.679%) and *Drymaria cordata* (38.393). *Carex decora* was the most dominant species with the IVI value 17.23 and was followed by *Lepisorus nudus* and *Centella asiatica* with 14.544 and 11.037 IVI score respectively (Figure 4.6). The Sannon-Wiener diversity index in the region was estimated to be 3.67, the concentration of the Dominance was 0.033 species richness was 0.74 and evenness of species was 0.893 (Table 4.4). All the 61 herb species showed contiguous distribution in the region.

Table 4.3: Phytosociological composition of herb layer in the Temperate Oak Forest of SNP area detailing the associated species with their ecological parameters

Sl. No	Scientific Name	Family	F	D	A	A/F	RF	RD	RA	IVI
1	*Ageratina adenophora* (Spreng.) R.M. King & H. Rob.	Compositae	10.714	0.304	2.833	0.264	1.024	0.501	0.906	2.43
2	*Anaphalis adnata* Wall. ex DC	Compositae	16.964	0.875	5.158	0.304	1.621	1.443	1.649	4.713
3	*Anaphalis contorta* (D. Don) Hook. f.	Compositae	10.714	0.563	5.25	0.49	1.024	0.928	1.678	3.63
4	*Anaphalis griffithii* Hook. f.	Compositae	12.5	0.607	4.857	0.389	1.195	1.001	1.552	3.748
5	*Anaphalis triplinervis* var. *triplinervis* (Sims) C. B. Clarke	Compositae	14.286	0.866	6.063	0.424	1.365	1.429	1.938	4.732
6	*Arisaema griffithii* (Wall.) Schott	Araceae	3.571	0.098	2.75	0.77	0.341	0.162	0.879	1.382
7	*Arisaema tortuosum* (Wall.) Schott	Araceae	4.464	0.107	2.4	0.538	0.427	0.177	0.767	1.37
8	*Arisaemia erubescens*	Araceae	5.357	0.08	1.5	0.28	0.512	0.133	0.479	1.124
9	*Artemisia vulgaris* L.	Compositae	4.464	0.143	3.2	0.717	0.427	0.236	1.023	1.685
10	*Asplenium laciniatum* D. Don	Aspleniaceae	25.893	1.205	4.655	0.18	2.474	1.988	1.488	5.951
11	*Begonia picta* Smith	Begoniaceae	11.607	0.232	2	0.172	1.109	0.383	0.639	2.131
12	*Begonia josephi* A.DC.	Begoniaceae	14.286	0.214	1.5	0.105	1.365	0.353	0.479	2.198
13	*Belvisia henryi* (Hieron. ex C. Chr.) Raymond	Polypodiaceae	37.5	1.973	5.262	0.14	3.584	3.255	1.682	8.52
14	*Campylandra aurantica* Baker.	Liliaceae	3.571	0.125	3.5	0.98	0.341	0.206	1.119	1.666
15	*Carex cruciata* Wahlenb.	Cyperaceae	33.929	2.893	8.526	0.251	3.242	4.772	2.725	10.739
16	*Carex decora* Boott.	Cyperaceae	75	4.848	6.464	0.086	7.167	7.997	2.066	17.23
17	*Cautleya gracilis* (Sm.) Dandy	Zingiberaceae	6.25	0.116	1.857	0.297	0.597	0.191	0.594	1.382
18	*Centella asiatica* (L.) Urb.	Apiaceae	52.679	2.661	5.051	0.096	5.034	4.389	1.614	11.037

19	*Clematis montana* Buch.-Ham. ex DC.	Rananculaceae	8.036	0.223	2.778	0.346	0.768	0.368	0.888	2.024
20	*Commelina paludosa* Blume	Commelinaceae	28.571	1.759	6.156	0.215	2.73	2.901	1.968	7.599
21	*Coniogramme intermedia* Hieron.	Pteridaceae	25.893	1.473	5.69	0.22	2.474	2.43	1.819	6.723
22	*Didymocarpus albicalyx* C.B. Clarke	Gesneriaceae	16.964	0.42	2.474	0.146	1.621	0.692	0.791	3.104
23	*Digitaria sanguinalis* (L.) Scop.	Poaceae	29.464	1.509	5.121	0.174	2.816	2.489	1.637	6.942
24	*Diplazium dilatatum* Blume	Athyriaceae	14.286	0.509	3.563	0.249	1.365	0.839	1.139	3.343
25	*Drymaria cordata* Wild	Caryophyllaceae	38.393	2.92	7.605	0.198	3.669	4.816	2.431	10.916
26	*Elatostema platyphyllum* Wedd.	Urticaceae	27.679	1.134	4.097	0.148	2.645	1.87	1.309	5.825
27	*Erigeron bellidioides* (Hook. f.) S.J. Forbes & D.I. Morris	Compositae	14.286	2.804	19.625	1.374	1.365	4.624	6.273	12.262
28	*Fragaria daltoniana* J. Gay	Rosaceae	21.429	1.188	5.542	0.259	2.048	1.959	1.771	5.778
29	*Fragaria nubicola* (Lindl. ex Hook.f.) Lacaita	Rosaceae	25.893	1.313	5.069	0.196	2.474	2.165	1.62	6.26
30	*Gentiana sp.*	Gentianaceae	10.714	0.321	3	0.28	1.024	0.53	0.959	2.513
31	*Geranium polyanthes* Edgew. & Hook. f.	Geraniaceae	11.607	0.339	2.923	0.252	1.109	0.56	0.934	2.603
32	*Geum elatum* Wall. ex G.Don	Rosaceae	30.357	1.232	4.059	0.134	2.901	2.032	1.297	6.231
33	*Hemiphragma heterophyllum* Wall	Plantaginaceae	5.357	0.259	4.833	0.902	0.512	0.427	1.545	2.484
34	*Henckelia dimidiata* (Wall. ex C.B. Clarke) D.J. Middleton & Mich. Moller	Gesneriaceae	16.964	1.143	6.737	0.397	1.621	1.885	2.153	5.66
35	*Hydrocotyle japonica*	Araliaceae	16.964	1.018	6	0.354	1.621	1.679	1.918	5.218
36	*Impatiens stenantha* Hook. f.	Balsaminaceae	6.25	0.17	2.714	0.434	0.597	0.28	0.868	1.745
37	*Impatiens sulcata* Wall.	Balsaminaceae	7.143	0.25	3.5	0.49	0.683	0.412	1.119	2.214
38	*Iris hookeriana* Foster	Iridaceae	5.357	0.214	4	0.747	0.512	0.353	1.278	2.144
39	*Lepisorus nudus* (Hook.) Ching	Polypodiaceae	58.036	4.089	7.046	0.121	5.546	6.745	2.252	14.544
40	*Oxalis corniculata* Linn.	Oxalidaceae	34.821	1.946	5.59	0.161	3.328	3.211	1.787	8.325

41	*Paris polyphylla* Sm.	Melanthiaceae	3.571	0.08	2.25	0.63	0.341	0.133	0.719	1.193
42	*Persicaria campanulata* (Hook. f.) Ronse Decr.	Polygonaceae	20.536	1.241	6.043	0.294	1.963	2.047	1.932	5.941
43	*Persicaria capitata* (Buch.-Ham. ex D. Don) H.Gross	Polygonaceae	16.964	1	5.895	0.347	1.621	1.649	1.884	5.155
44	*Persicaria chinensis* (L.) H. Gross	Polygonaceae	18.75	0.955	5.095	0.272	1.792	1.576	1.629	4.996
45	*Pilea scripta* (D. Don) Weddel	Urticaceae	11.607	1.509	13	1.12	1.109	2.489	4.155	7.753
46	*Pilea umbrosa* Blume	Urticaceae	18.75	1.902	10.143	0.541	1.792	3.137	3.242	8.171
47	*Poa sp.*	Poaceae	9.821	0.527	5.364	0.546	0.939	0.869	1.714	3.522
48	*Polygonum runcinatum* Buch.-Ham. ex D. Don	Polygonaceae	16.071	1.045	6.5	0.404	1.536	1.723	2.078	5.337
49	*Potentilla fulgens* Diels	Rosaceae	16.964	0.955	5.632	0.332	1.621	1.576	1.8	4.997
50	*Primula denticulata* Sm.	Primulaceae	8.036	0.33	4.111	0.512	0.768	0.545	1.314	2.627
51	*Primula sp.*	Primulaceae	6.25	0.259	4.143	0.663	0.597	0.427	1.324	2.349
52	*Rumex nepalensis* Spreng.	Polygonaceae	18.75	1.759	9.381	0.5	1.792	2.901	2.998	7.692
53	*Saxifraga parnassifolia* D. Don	Saxifragaceae	15.179	0.83	5.471	0.36	1.451	1.37	1.749	4.569
54	*Senecio sp.*	Asteraceae	6.25	0.313	5	0.8	0.597	0.515	1.598	2.711
55	*Smilacina oleracea* (Baker) Hook. f	Liliaceae	4.464	0.196	4.4	0.986	0.427	0.324	1.406	2.157
56	*Smilax bracteata* C.Presl	Smilacaceae	5.357	0.232	4.333	0.809	0.512	0.383	1.385	2.28
57	*Swertia chirayita* (Roxb.) Buch.-Ham. ex C.B. Clarke	Gentianeese	11.607	0.286	2.462	0.212	1.109	0.471	0.787	2.367
58	*Taraxacum campylodes* G.E. Haglund	Compositae	3.571	0.161	4.5	1.26	0.341	0.265	1.438	2.045
59	*Thalictrum foetidum* L	Ranunculaceae	5.357	0.259	4.833	0.902	0.512	0.427	1.545	2.484
60	*Vaccinium nummularia* Hook. f. & Thomson ex C.B. Clarke	Ericaceae	23.214	2.438	10.5	0.452	2.218	4.021	3.356	9.595
61	*Valeriana jatamansi* Jones	Caprifoliaceae	7.143	0.205	2.875	0.403	0.683	0.339	0.919	1.94

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, RA= Relative Abundance, IVI= Importance Value Index

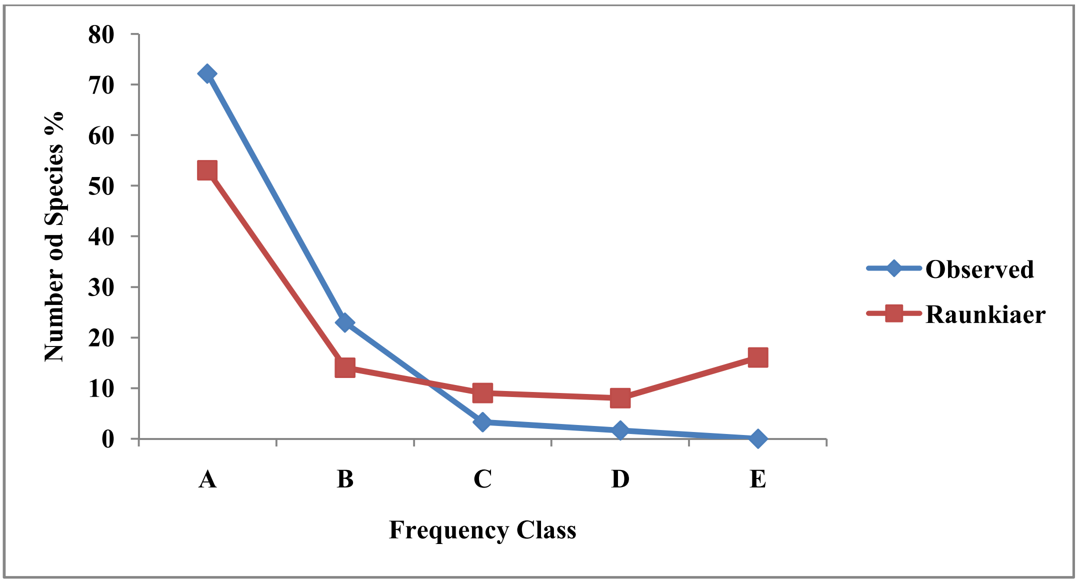

Figure 4.5: Comparison of the Observed Frequency of herb layer of Temperate Oak Forest with the Raunkiaer's Frequency distribution in SNP, Darjeeling

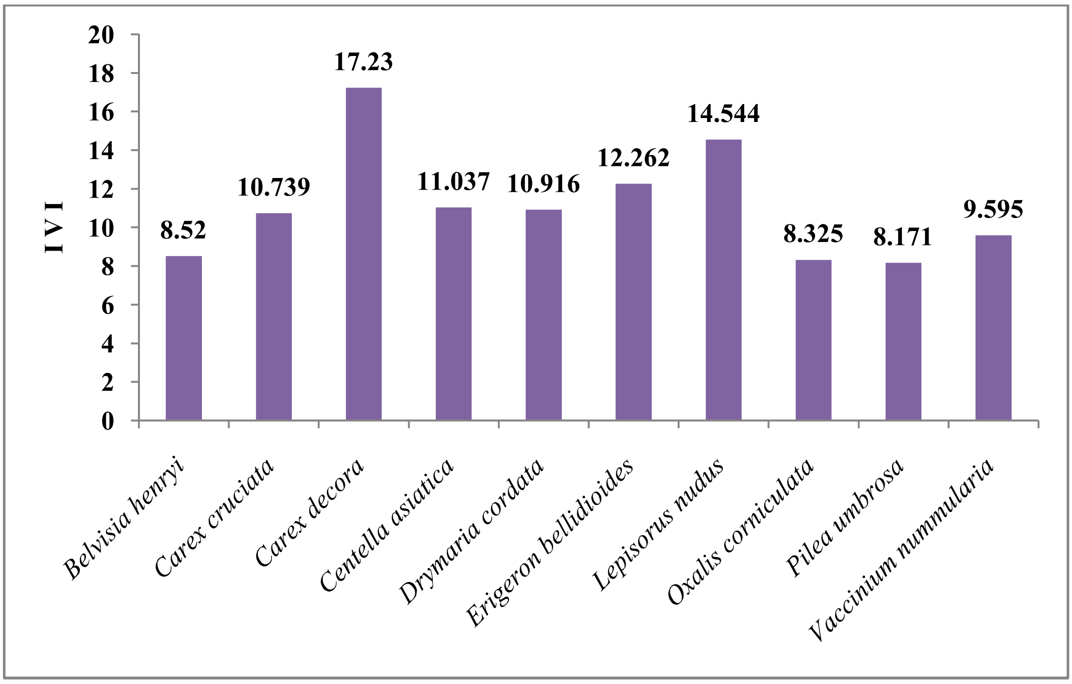

Figure 4.6: Herb species with relatively High Importance Value Index in Temperate Oak Forest of SNP, Darjeeling

Table 4.4: Determinant indices for different group of Temperate Oak Forest of SNP

Layer	Species Diversity (H')	Species richness (D)	Concentration of Dominance (CD)	Species evenness (J')
Tree	3.5213	1.7026	0.0384	0.9146
Shrub	1.3964	0.47	0.4455	0.4394
Herb	3.67	0.74	0.033	0.893

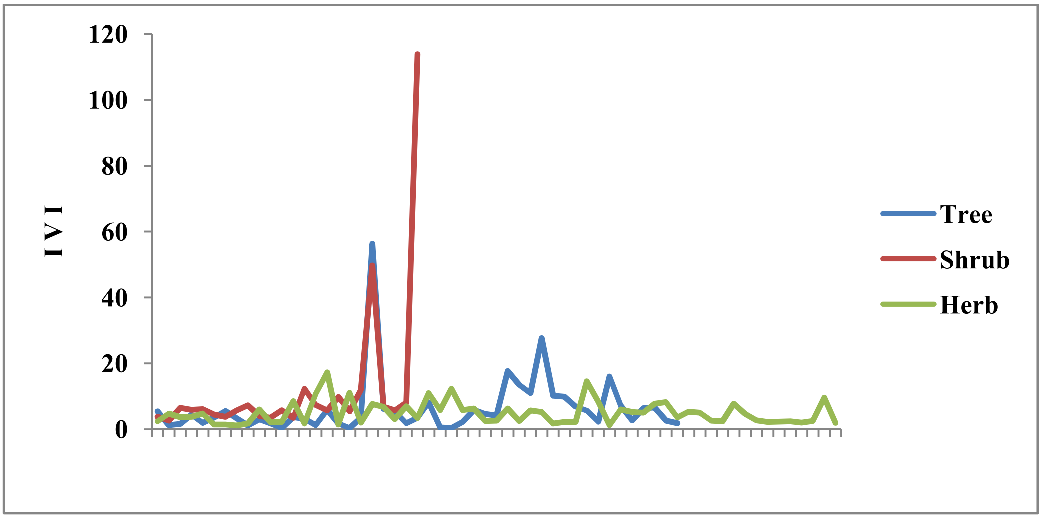

Figure 4.7: Dominance Diversity Curve for all the layers of the Temperate Oak Forest of SNP, Darjeeling

4.1.2 Broad Leaf Deciduous Forest (altitude-2800 m to 3100 m)

4.1.2.1 Tree Layer of Broad Leaf Deciduous Forest

The Broad Leaf Deciduous Forest of the Singalila National Park, Darjeeling lies between 2800 m and 3100 m altitude above sea level. In this study conducted in the Broad Leaf Deciduous Forest of SNP recorded 41 species and one variety belonging to 31 genus and 21 families. Of these the highest number of tree species were recorded from the family Ericaceae (6 species) and was followed by the family Fagaceae (5 species) and Sapindaceae (4 species) respectively. Other families like Lauraceae (3 species), Pinaceae (3 species), Araliaceae (2 species), Betulaceae (2 species), Magnoliaceae (2 species), and Rosaceae (2 species) and other species

Lamiaceae (1 species), Moraceae (1 species) etc. were recorded in the region (Table 4.5). Total stem density in the Broad Leaf Deciduous Forest was estimated to be 1769.643 individuals ha^{-1}. Highest density was recorded for *Rhododendron arboreum* (164.286 ha^{-1}) and was followed by *Symplocos dryophila* (142.857 ha^{-1}). Total estimated abundance in the area was 85.36 and the species with the highest abundance was *Daphniphyllum himalense* (3.667) followed by *Rhododendron arboreum* (3.44) and *Rhododendron falconari* (3.318). The Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the tree species in the Broad Leaf Deciduous Forest showed four classes A, B, C and D with species exhibiting 61.9%, 23.81%, 9.52% and 4.76% frequency respectively whereas E was nil in the study area (Figure 4.8). The species with the highest frequency recorded was *Abies densa* (75.633%) and was followed by *Symplocos dryophila* (67.857), *Rhododendron arboreum* (67.857) and *Sorbus cuspidata* (44.64) respectively. During the study, 8 trees species showed random distribution and 33 species and one variety showed contiguous distribution pattern in the Broad Leaf Deciduous Forest of the SNP. *Rhododendron arboreum* was the most dominant species with the IVI value 37.989 and was followed by *Symplocos dryophila* and *Sorbus cuspidata* with 29.157 and 21.893 IVI score respectively (Figure 4.9). The Sannon-Wiener diversity index in the region was estimated to be 3.4027, the concentration of the Dominance was 0.0425, species richness was 1.334 and evenness of species was 0.9103 (Table 4.8).

Table 4.5: Phytosociological composition of tree layer in the Broad Leaf Deciduous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No.	Trees/ Sc. Name	Family	F	D^{-1}	A	A/F	RF	RD	R. Dom.	IVI
1	*Abies densa* Griffith	Pinaceae	7.143	19.643	2.75	0.385	0.83	1.11	0.813	2.753
2	*Acer campbelli* Hooker f and Thomson ex Hiern	Sapindaceae	41.071	76.786	1.87	0.046	4.772	4.27	4.581	13.623
3	*Acer caudatum* Wallich	Sapindaceae	1.786	1.786	1	0.56	0.207	0.099	0.002	0.309
4	*Acer pectinatum* Wallich ex Nicholson	Sapindaceae	5.357	8.929	1.667	0.311	0.622	0.497	0.046	1.165
5	*Acer sikkimense* Miquel	Sapindaceae	16.071	33.929	2.111	0.131	1.867	1.887	0.891	4.645
6	*Alnus nepalensis* D.Don	Betulaceae	12.5	25	2	0.16	1.452	1.39	0.636	3.478
7	*Andromeda villosa* Wall	Ericaceae	7.143	12.5	1.75	0.245	0.83	0.695	0.029	1.554
8	*Betula alnoides* Buch.-Ham. ex D.Don	Betulaceae	8.929	21.429	2.4	0.269	1.037	1.192	0.335	2.564
9	*Brassiopsic sp.*	Araliaceae	16.071	26.786	1.667	0.104	1.867	1.49	0.237	3.594
10	*Castanopsis hystrix* Hook. f. & Thomson ex A. DC.	Fagaceae	12.5	19.643	1.571	0.126	1.452	1.092	0.462	3.007
11	*Castanopsis tribuloides* (Sm.) A. DC.	Fagaceae	26.786	39.286	1.4667	0.055	3.112	2.185	1.564	6.861
12	*Cinnamomum camphora* (L.) J.Presl	Lauraceae	7.143	16.071	2.25	0.315	0.83	0.894	0.199	1.923
13	*Daphniphyllum himalense*(Bentham) Mueller Argoviensis	Daphiphyllaceae	16.071	58.929	3.667	0.228	1.867	3.277	0.613	5.757
14	*Endospermum chinense* Benth.	Euphorbiaceae	19.643	33.929	1.727	0.088	2.282	1.887	0.121	4.29
15	*Eurya cerasifolia* (D.Don) Kobuski	Pentaphylacaceae	17.857	37.5	2.1	0.118	2.075	2.085	0.452	4.612

16	*Ficus auriculata* Lour.	Moraceae	7.143	10.714	1.5	0.21	0.83	0.596	0.029	1.455
17	*Ilex fragilis* Hooker	Aquifoliaceae	42.857	76.786	1.792	0.042	4.979	4.27	2.679	11.928
18	*Lithocarpus pachyphyllus* (Kurz) Rehder	Fagaceae	42.857	83.929	1.958	0.046	4.979	4.667	11.287	20.934
19	*Litsea sericea* (Wall. ex Nees) Hook. f.	Lauraceae	23.214	51.786	2.231	0.096	2.697	2.88	1.13	6.707
20	*Machilus edulis* King ex Hook. f.	Lauraceae	8.929	21.429	2.4	0.269	1.037	1.192	0.433	2.662
21	*Magnolia campbellii* Hooker f. and Thomson	Magnoliaceae	39.286	48.214	1.227	0.031	4.564	2.681	3.087	10.332
22	*Magnolia globosa* Hook. f. & Thomson	Magnoliaceae	7.143	14.286	2	0.28	0.83	0.794	0.303	1.9278
23	*Meliosma dilleniifolia* (Wall. ex Wight & Arn.) Walp.	Sabiaceae	25	33.929	1.357	0.054	2.905	1.887	0.446	5.237
24	*Merrilliopanax alpinus* (Clarke) C.B. Shang	Araliaceae	14.286	21.429	1.5	0.105	1.66	1.192	0.226	3.078
25	*Osmanthus suavis* King ex C.B.Clarke	Oleaceae	37.5	78.571	2.095	0.056	4.357	4.369	3.35	12.076
26	*Pinus patula* Schiede ex Schltdl. & Cham.	Pinaceae	5.357	10.714	2	0.373	0.622	0.596	0.116	1.3346
27	*Prunus padus* L.	Rosaceae	7.143	17.857	2.5	0.35	0.83	0.993	0.36	2.183
28	*Quercus lamellosa* Smith	Fagaceae	21.429	42.857	2	0.093	2.49	2.383	4.064	8.937
29	*Quercus lineata* Blume	Fagaceae	12.5	17.857	1.429	0.114	1.452	0.993	0.322	2.767
30	*Rhododendron arboreum* Smith	Ericaceae	16.071	55.357	3.444	0.214	1.867	3.078	1.922	6.868
31	*Rhododendron arboreum var. cinnamomeum* (Wallich ex G. Don) Lindley	Ericaceae	67.857	164.286	2.421	0.036	7.884	9.136	20.97	37.989
32	*Rhododendron falconeri* Hook. f.	Ericaceae	39.286	130.357	3.318	0.084	4.564	7.249	5.844	17.658
33	*Rhododendron grande* Wight	Ericaceae	33.929	75	2.211	0.065	3.942	4.171	2.778	10.89
34	*Rhododendron griffithianum* Wight	Ericaceae	5.357	14.286	2.667	0.498	0.622	0.794	0.076	1.493
35	*Sorbus cuspidata* (Spach) Hedl.	Rosaceae	44.643	85.714	1.92	0.043	5.187	4.767	11.939	21.893

36	*Styrax hookeri* C.B. Clarke	Styracaceae	3.571	7.143	2	0.56	0.415	0.397	0.014	0.826
37	*Symplocos dryophila* Clarke	Symplocaceae	67.857	142.857	2.105	0.031	7.884	7.944	13.328	29.157
38	*Symplocos lucida* (Thunb.) Siebold & Zucc.	Symplocaceae	25	66.071	2.643	0.106	2.905	3.674	3.122	9.701
39	*Tsuga dumosa* (D.Don) Eichler	Pinaceae	5.357	14.286	2.667	0.498	0.622	0.794	0.544	1.961
40	*Vitex quinata* (Lour.) F.N. Williams	Lamiaceae	10.714	10.714	1	0.093	1.245	0.596	0.133	1.974
41	*Wightia speciosissima* (D. Don) Merr.	Paulowniaceae	7.143	12.5	1.75	0.245	0.83	0.695	0.165	1.69
42	*Zanthoxylum armatum* DC.	Rutaceae	23.214	28.571	1.231	0.053	2.697	1.589	0.354	4.64

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, R. Dom= Relative Dominance, IVI= Importance Value Index

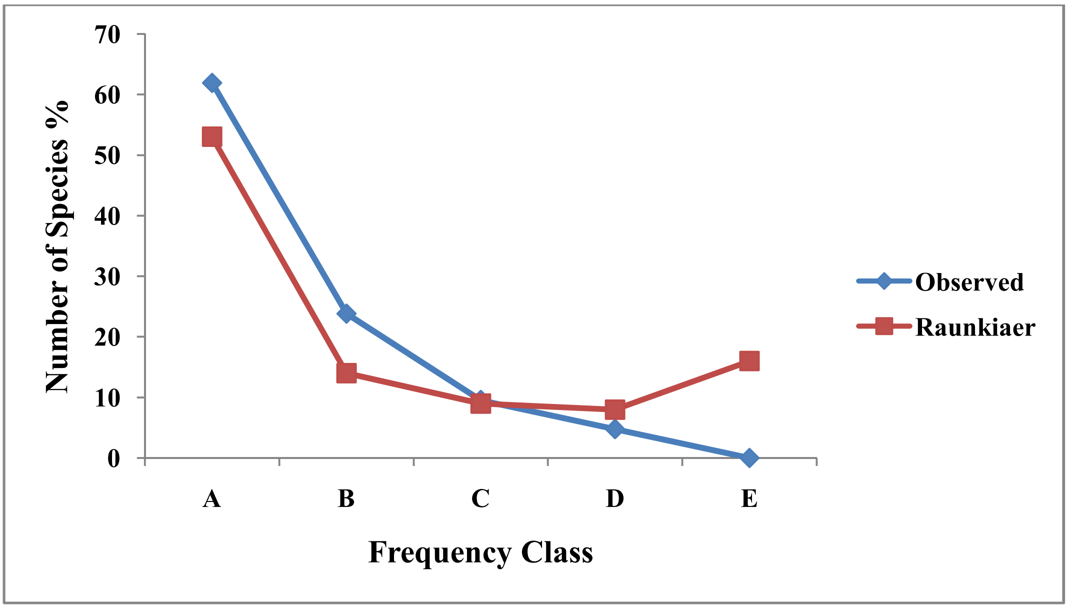

Figure 4.8: Comparison of Observed Frequency of Tree Layer of Broad Leaf Deciduous Forest with Raunkiaer's Frequency distribution in SNP, Darjeeling

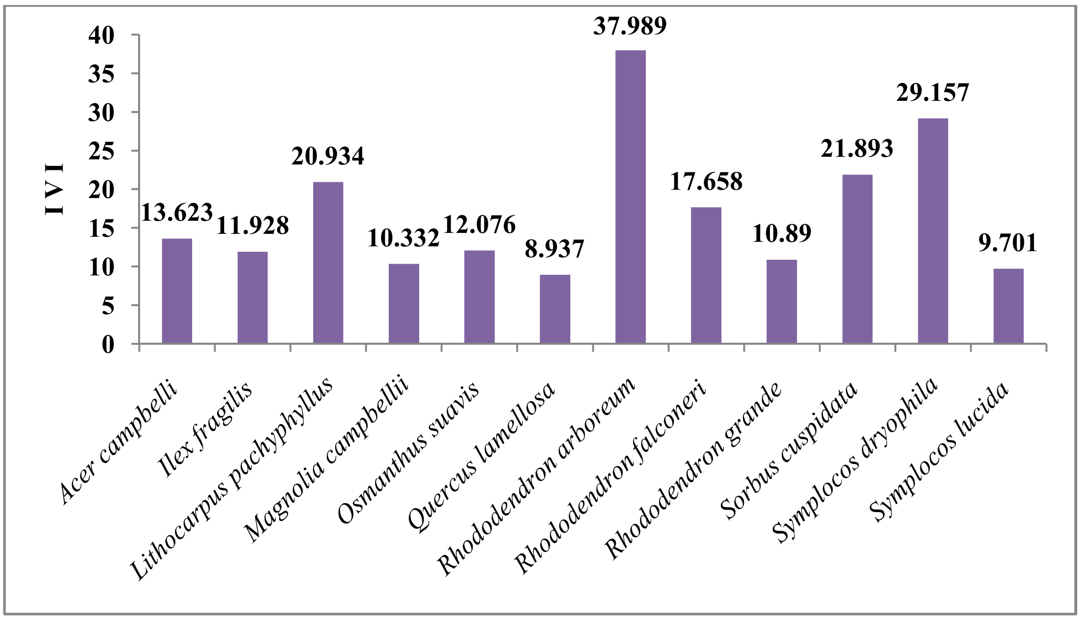

Figure 4.9: Tree species with relatively high Importance Value Index in Broad Leaf Deciduous Forest of SNP, Darjeeling

4.1.2.2 Shrub Layer of Broad Leaf Deciduous Forest

The study conducted in the Broad Leaf Deciduous Forest of SNP recorded 23 shrub species belonging to 17 genus and 12 families. The highest number of species was recorded from the family Rosaceae with 6 species followed by Ericaceae family with 3 species and Andoxaceae, Berberidaceae, Urticaceae and Poaceae with 2 species each. Other families like Thymelaeaceae, Lamiaceae, Apiaceae and Saxifragaceae recorded 1 species each in the Broad Leaf Deciduous Forest (Table 4.6). Total density was estimated to be individuals 21.1964 of which the highest density was recorded for *Yushania maling* (13.071) followed by *Thamnocalamus spathiflorus* (2). Total estimated abundance in the area was 64.261 and the species with the highest abundance was also *Yushania maling* (14.939) which was followed by *Thamnocalamus spathiflorus* (9.333). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the shrub species in the Broad Leaf Deciduous Forest showed only three classes A, B and E with species exhibiting 65.22%, 30.43% and 4.35% respectively whereas C, and D were nil in the study area (Figure 4.10). The species with the highest frequency recorded was *Yushania maling* (87.5%) which was followed by *Daphne bholua and Viburnum erubescens* both with 30.357% frequency. *Yushania maling* was the most dominant species with the IVI value 105.247 and was followed by *Thamnocalamus spathiflorus* with 28.939 IVI score (Figure 4.11). The Sannon-Wiener diversity index in the forest was estimated to be 2.3406, the concentration of the dominance was 0.0189, species richness was 0.6676 and evenness of species was 0.7464 (Table 4.8). All the 23 shrub species showed contiguous distribution pattern in the region.

Table 4.6: Phytosociological composition of shrub layer in the Broad Leaf Deciduous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No.	Scientific Name	Family	F	D	A	A/F	RF	RD	RA	IVI
1	*Andromeda formosa* Wall.	Ericaceae	12.5	0.25	2	0.16	2.905	1.179	3.112	7.196
2	*Astilbe rivularis* Buch.-Ham. ex D. Don	Saxifragaceae	10.714	0.161	1.5	0.14	2.496	0.758	2.334	5.582
3	*Berberis aristata* DC.	Berberidaceae	19.643	0.286	1.455	0.074	4.564	1.348	2.263	8.176
4	*Berberis wallichiana* DC.	Berberidaceae	14.286	0.214	1.5	0.105	3.32	1.011	2.334	6.665
5	*Daphne bholua* Buch.-Ham. ex D.Don	Thymelaeaceae	30.357	0.607	2	0.066	7.054	2.864	3.112	13.031
6	*Elsholtzia fruticosa* (D. Don) Rehder	Lamiaceae	8.929	0.161	1.8	0.202	2.075	0.758	2.801	5.634
7	*Gaultheria fragrantissima* Wall.	Ericaceae	7.143	0.143	2	0.28	1.659	0.674	3.112	5.446
8	*Gaultheria nummularioides* D. Don	Ericaceae	8.929	0.161	1.8	0.202	2.075	0.758	2.801	5.634
9	*Girardinia diversifolia* (Link) Friis	Urticaceae	5.357	0.107	2	0.373	1.245	0.505	3.112	4.863
10	*Heracleum nepalense* D. Don	Apiaceae	16.071	0.393	2.444	0.152	3.734	1.853	3.804	9.392
11	*Ilex sp.*	Aquifoliaceae	5.357	0.143	2.667	0.498	1.245	0.674	4.15	6.069
12	*Polygonum molle* D. Don	Polygonaceae	26.786	0.464	1.733	0.065	6.224	2.19	2.697	11.112
13	*Rosa sericea* Wall. ex Lindl.	Rosaceae	14.286	0.232	1.625	0.114	3.32	1.095	2.529	6.943
14	*Rubus acuminatus* Sm.	Rosaceae	21.429	0.571	2.667	0.124	4.979	2.696	4.15	11.825

15	*Rubus ellipticus* Sm.	Rosaceae	12.5	0.196	1.571	0.126	2.905	0.927	2.445	6.277
16	*Rubus nepalensis* hort.	Rosaceae	14.286	0.214	1.5	0.105	3.32	1.011	2.334	6.665
17	*Rubus paniculatus* Sm.	Rosaceae	12.5	0.161	1.286	0.103	2.905	0.758	2.001	5.664
18	*Rubus sp*.	Rosaceae	21.429	0.339	1.583	0.0739	4.98	1.601	2.464	9.044
19	*Sambucus adnata* Wall. ex DC.	Adoxaceae	21.429	0.571	2.667	0.124	4.979	2.696	4.15	11.825
20	*Thamnocalamus spathiflorus* (Trin.) Munro	Poaceae	21.429	2	9.333	0.436	4.979	9.436	14.524	28.939
21	*Urtica sp.*	Urticaceae	7.143	0.161	2.25	0.315	1.66	0.758	3.501	5.919
22	*Viburnum erubescens Wall.*	Adoxaceae	30.357	0.589	1.941	0.064	7.054	2.78	3.0208	12.855
23	*Yushania maling* (Gamble) R.B. Majumdar & Karthik.	Poaceae	87.5	13.071	14.939	0.171	20.332	61.668	23.247	105.247

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, RA= Relative Abundance, IVI= Importance Value Index

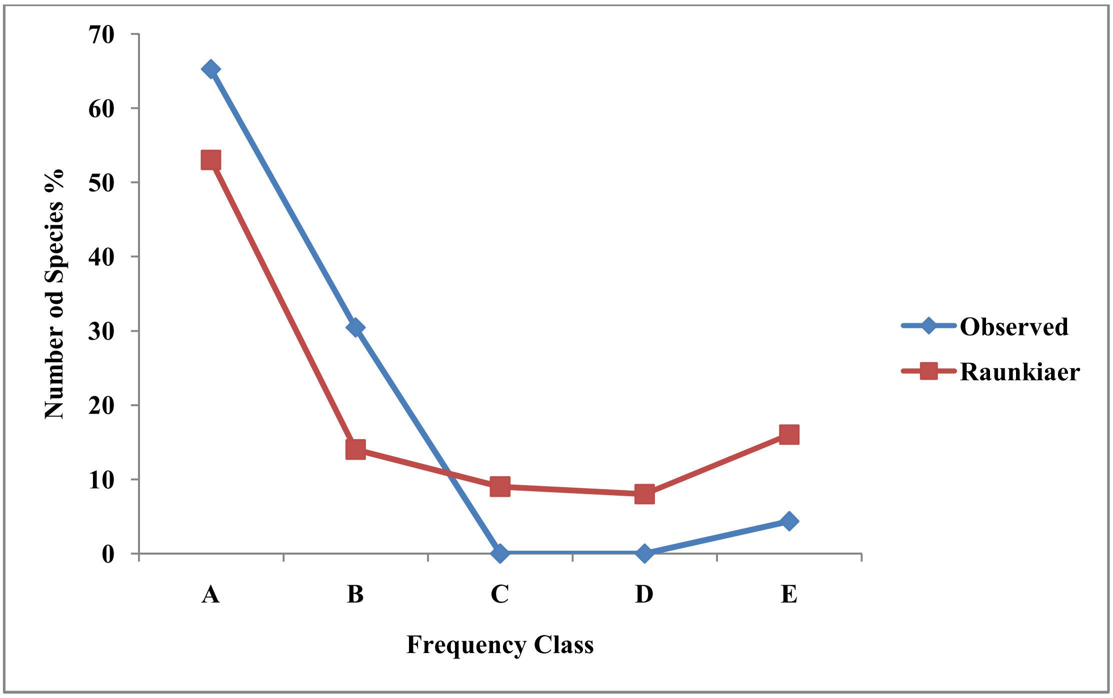

Figure 4.10: Comparison of observed frequency of shrub layer of Broad Leaf Deciduous Forest of SNP with Raunkiaer's Frequency Distribution in SNP, Darjeeling

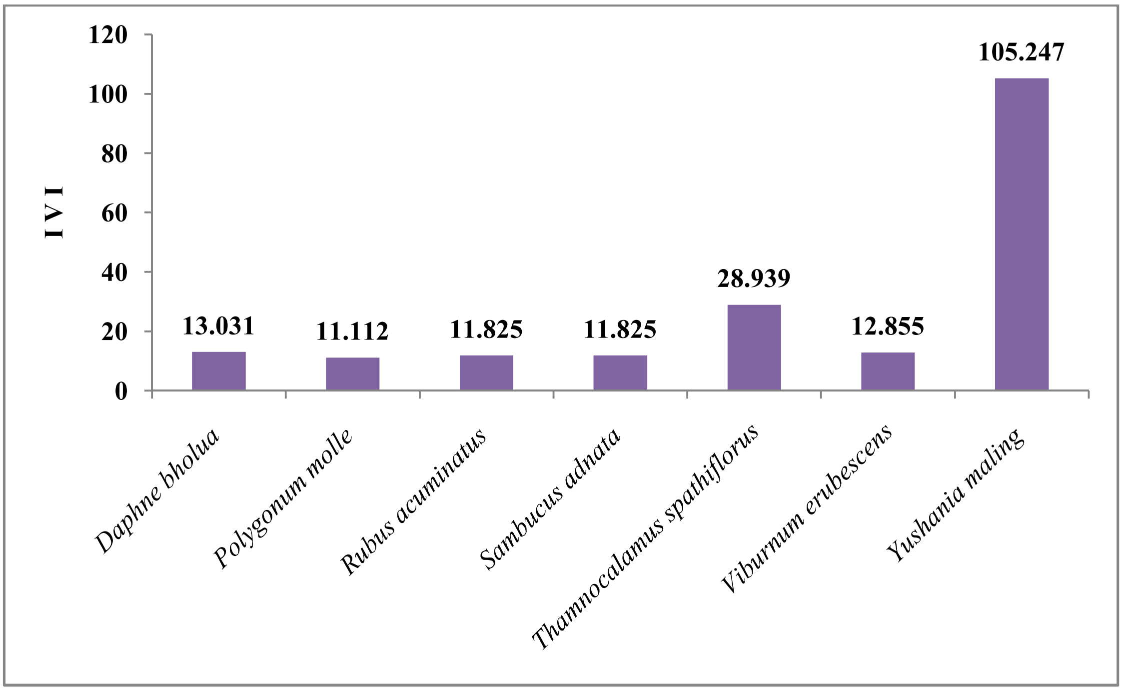

Figure 4.11: Shrub species with relatively high Importance Value Index in Broad Leaf Deciduous forest of SNP, Darjeeling

4.1.2.3 Herb Layer of Broad Leaf Deciduous forest

From the study conducted on the herb layer in the Broad Leaf Deciduous Forest, 53 species belonging to 43 genus and 31 families were recorded. The highest number of species was recorded from the family Compositae (6 species) and Polygonaceae (4 species) which was followed by the family Rosaceae (4 species), Urticaceae (3 species), Poaceae (2 species), Begoniaceae (2 species) etc. (Table 4.7). The total density of the herb in Broad Leaf Deciduous Forest was estimated to be 35.73. The highest density was recorded for *Carex decora* (3.804) followed by *Lepisorus nudus* (2) and *Centella asiatica* (1,723) respectively in the region. Total estimated abundance in the area was 220.8 and the species with the highest abundance was *Erigeron bellidioides* (10.18) and was followed by *Rumex nepalensis* (6.174). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the herb species in the Broad Leaf Deciduous Forest showed A, B, C, D frequency class. Frequency class A was 73.585%, frequency class B was 22.642%, frequency class C was 1.89%, frequency class D was 1.89% and E were nil in the study area (Figure 4.12). The species with the highest frequency recorded was *Carex decora* (72.321%) and was followed by *Centella asiatica* (38.393%) and *Lepisorus nudus* (34.82%) respectively. *Carex decora* was the most dominant species with the IVI value 22.06 which was followed by *Lepisorus nudus* and *Centella asiatica* with 12.55 and 11.65 IVI score respectively (Figure 4.13). The Sannon-Wiener diversity index in the region was estimated to be 3.558, the Concentration of the Dominance was 0.037, species richness was 0.838 and evenness of species was 0.896 (Table 4.8). All the 53 herb species showed contiguous distribution in the forest.

Table 4.7: Phytosociological composition of herb layer in the Broad Leaf Deciduous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No	Scientific Name	Family	F	D	A	A/F	RF	RD	RA	IVI
1	*Anaphalis adnata* Wall. ex DC	Compositae	11.607	0.518	4.462	0.384	1.449	1.449	2.021	4.919
2	*Anaphalis contorta* (D. Don) Hook. f.	Compositae	9.821	0.384	3.909	0.398	1.226	1.075	1.77	4.071
3	*Anaphalis griffithii* Hook. f.	Compositae	9.821	0.384	3.909	0.398	1.226	1.075	1.77	4.071
4	*Anaphalis triplinervis* var. *triplinervis* (Sims) C. B. Clarke	Compositae	14.286	0.866	6.063	0.424	1.784	2.424	2.746	6.953
5	*Arisaema griffithii* (Wall.) Schott	Araceae	2.679	0.063	2.333	0.871	0.334	0.175	1.057	1.566
6	*Arisaema tortuosum* (Wall.) Schott	Araceae	31.25	0.054	0.171	0.006	3.902	0.15	0.078	4.129
7	*Arisaemia erubescens*	Araceae	2.679	0.08	3	1.12	0.334	0.225	1.359	1.918
8	*Asplenium laciniatum* D. Don	Aspleniaceae	43.75	1.08	2.469	0.056	5.463	3.024	1.118	9.605
9	*Begonia picta* Smith	Begoniaceae	5.357	0.134	2.5	0.467	0.669	0.375	1.132	2.176
10	*Begonia josephi* A.DC.	Begoniaceae	9.821	0.188	1.909	0.194	1.226	0.525	0.865	2.616
11	*Belvisia henryi* (Hieron. ex C. Chr.) Raymond	Polypodiaceae	32.143	1.688	5.25	0.163	4.013	4.723	2.378	11.11
12	*Campylandra aurantica* Baker.	Liliaceae	2.679	0.071	2.667	0.996	0.334	0.2	1.208	1.742
13	*Carex cruciata* Wahlenb.	Cyperaceae	34.821	1.375	3.949	0.113	4.348	3.848	1.788	9.985
14	*Carex decora* Boott.	Cyperaceae	72.321	3.804	5.259	0.073	9.03	10.65	2.382	22.06
15	*Centella asiatica* (L.) Urb.	Apiaceae	38.393	1.723	4.488	0.117	4.794	4.823	2.033	11.65
16	*Clematis montana* Buch.-Ham. ex DC.	Rananculaceae	6.25	0.196	3.143	0.503	0.78	0.55	1.423	2.754
17	*Commelina paludosa* Blume	Commelinaceae	11.607	0.384	3.308	0.285	1.449	1.075	1.498	4.022
18	*Coniogramme intermedia* Hieron.	Pteridaceae	9.821	0.33	3.364	0.343	1.226	0.925	1.523	3.674

19	*Didymocarpus albicalyx* C.B. Clarke	Gesneriaceae	2.679	0.098	3.667	1.369	0.334	0.275	1.661	2.27
20	*Digitaria sanguinalis* (L.) Scop.	Poaceae	9.821	0.411	4.182	0.426	1.226	1.149	1.894	4.27
21	*Diplazium dilatatum* Blume	Athyriaceae	6.25	0.116	1.857	0.297	0.78	0.325	0.841	1.946
22	*Drymaria cordata* Wild	Caryophyllaceae	20.536	1.018	4.957	0.241	2.564	2.849	2.245	7.658
23	*Elatostema platyphyllum* Wedd.	Urticaceae	29.464	1.098	3.727	0.127	3.679	3.074	1.688	8.441
24	*Erigeron bellidioides* (Hook. f.) S.J. Forbes & D.I. Morris	Compositae	9.821	1	10.18	1.037	1.226	2.799	4.611	8.636
25	*Fragaria daltoniana* J. Gay	Rosaceae	15.179	0.884	5.824	0.384	1.895	2.474	2.637	7.007
26	*Fragaria nubicola* (Lindl. ex Hook. f.) Lacaita	Rosaceae	16.964	0.875	5.158	0.304	2.118	2.449	2.336	6.903
27	*Geranium polyanthes* Edgew. & Hook. f.	Geraniaceae	9.821	0.277	2.818	0.287	1.226	0.775	1.276	3.277
28	*Geum elatum* Wall. ex G.Don	Rosaceae	16.964	1.08	6.368	0.375	2.118	3.024	2.884	8.026
29	*Hemiphragma heterophyllum* Wall	Plantaginaceae	2.6786	0.098	3.667	1.369	0.334	0.275	1.661	2.27
30	*Henckelia dimidiata* (Wall. ex C.B. Clarke) D.J. Middleton & Mich.Moller	Gesneriaceae	8.036	0.348	4.333	0.539	1.003	0.975	1.963	3.94
31	*Hydrocotyle japonica* Makino	Araliaceae	17.857	0.92	5.15	0.288	2.23	2.574	2.332	7.136
32	*Impatiens stenantha* Hook. f.	Balsaminaceae	3.571	0.125	3.5	0.98	0.446	0.35	1.585	2.381
33	*Iris hookeriana* Foster	Iridaceae	3.571	0.205	5.75	1.61	0.446	0.575	2.604	3.625
34	*Lepisorus nudus* (Hook.) Ching	Polypodiaceae	34.821	2	5.744	0.165	4.348	5.598	2.601	12.55
35	*Oxalis corniculata* Linn.	Oxalidaceae	29.464	1.554	5.273	0.179	3.679	4.348	2.388	10.42
36	*Paris polyphylla* Sm.	Melanthiaceae	1.786	0.027	1.5	0.84	0.223	0.075	0.679	0.977
37	*Persicaria capitata* (Buch.-Ham. ex D. Don) H. Gross	Polygonaceae	19.643	0.946	4.818	0.245	2.453	2.649	2.182	7.284
38	*Persicaria chinensis* (L.) H. Gross	Polygonaceae	16.071	0.83	5.167	0.322	2.007	2.324	2.34	6.671
39	*Pilea scripta* (D. Don) Weddel	Urticaceae	20.536	1.188	5.783	0.282	2.564	3.324	2.619	8.507

40	*Pilea umbrosa* Blume	Urticaceae	18.75	1.098	5.857	0.312	2.341	3.074	2.653	8.067
41	*Poa sp.*	Poaceae	12.5	0.607	4.857	0.389	1.561	1.699	2.2	5.46
42	*Polygonum runcinatum* Buch.-Ham. ex D. Don	Polygonaceae	20.536	1.009	4.913	0.239	2.564	2.824	2.225	7.613
43	*Potentilla fulgens* Diels	Rosaceae	11.607	0.411	3.538	0.305	1.449	1.149	1.603	4.201
44	*Primula denticulata* Sm.	Primulaceae	8.036	0.33	4.111	0.512	1.003	0.925	1.862	3.79
45	*Rumex nepalensis* Spreng.	Polygonaceae	20.536	1.268	6.174	0.301	2.564	3.548	2.796	8.909
46	*Saxifraga parnassifolia* D. Don	Saxifragaceae	11.607	0.438	3.769	0.325	1.449	1.224	1.707	4.381
47	*Senecio sp.*	Asteraceae	7.143	0.196	2.75	0.385	0.892	0.55	1.245	2.687
48	*Smilacina oleracea* (Baker) Hook. f	Liliaceae	3.571	0.143	4	1.12	0.446	0.4	1.812	2.657
49	*Smilax bracteata* C. Presl	Smilacaceae	6.25	0.25	4	0.64	0.78	0.7	1.812	3.292
50	*Taraxacum campylodes* G.E. Haglund	Compositae	3.571	0.116	3.25	0.91	0.446	0.325	1.472	2.243
51	*Thalictrum foetidum* L	Ranunculaceae	4.464	0.17	3.8	0.851	0.557	0.475	1.721	2.753
52	*Vaccinium nummularia* Hook. f. & Thomson ex C.B. Clarke	Ericaceae	21.429	1.08	5.042	0.235	2.676	3.024	2.283	7.983
53	*Valeriana jatamansi* Jones	Caprifoliaceae	6.25	0.196	3.143	0.503	0.78	0.55	1.423	2.754

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, RA= Relative Abundance, IVI= Importance Value Index

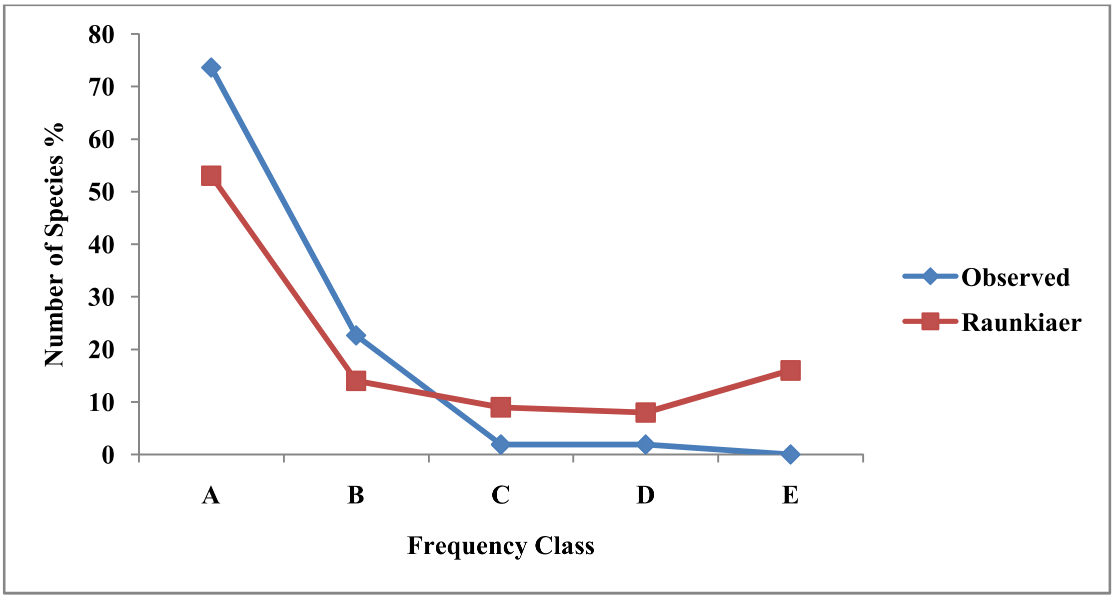

Figure 4.12: Comparison of observed frequency of herb layer of the Broad Leaf Deciduous Forest of SNP with Raunkiaer's Frequency distribution in SNP, Darjeeling

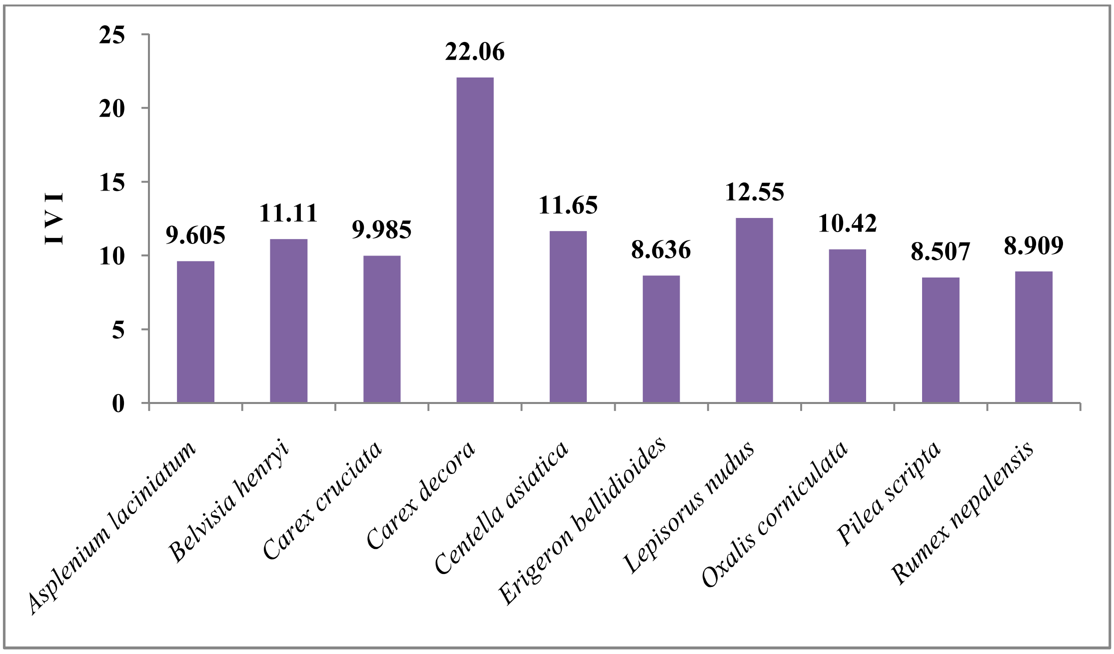

Figure 4.13: Herb species with relatively high Importance Value Index in Broad Leaf Deciduous forest

Table 4.8: Determinant indices for different group of Broad Leaf Deciduous Forest of SNP

Layer	Species Diversity (H')	Species richness (D)	Concentration of Dominance (CD)	Species evenness (J')
Tree	3.402	1.334	0.0425	0.9103
Shrub	2.3406	0.6676	0.0189	0.7464
Herb	3.558	0.838	0.037	0.896

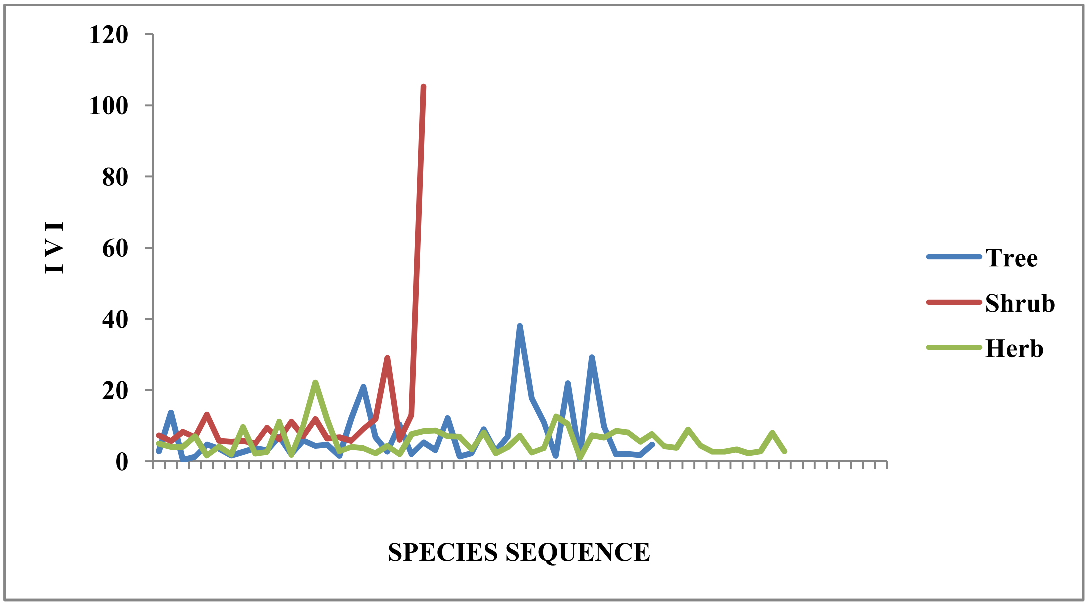

Figure 4.14: Dominance diversity curve for all the layers of Broad Leaf Deciduous forest of SNP, Darjeeling

4.1.3 Broad Leaf Coniferous Forest (altitude 3100 m to 3300 m)

4.1.3.1 Tree Layer of Broad Leaf Coniferous Forest

The Broad Leaf Coniferous Forest of the SNP, Darjeeling lies between 3100 m to 3300 m above sea level. In the study conducted in the Broad Leaf Coniferous Forest of SNP found 20 species belonging to 15 genus and 10 families. The highest number of species were recorded under the family Ericaceae (8 species) followed by the family Pinaceae, Rosaceae, and Fagaceae with 2 species each. Other families i.e. Betulaceae, Daphiphyllaceae, Aquifoliaceae, Lauraceae, Magnoliaceae, and Araliaceae recorded only 1 species each in the region (Table 4.9). Total stem density in Broad Leaf Coniferous Forest was estimated to be 1098.21 individuals ha^{-1}. The highest density was recorded for *Abies densa* (198.214 ha^{-1}) which was followed by *Rhododendron arboreum* (126.786 ha^{-1}) and *Tsuga dumosa* (103.571 ha^{-1}). Total estimated abundance in the area was 60.78 and the species with the highest abundance was *Rhododendron falconeri* (6.5) and was followed by *Rhododendron hodgsonii* (5.4) and *Quercus lamellosa* (4.455). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the tree species in the Broad Leaf Coniferous Forest showed three classes A, B and C with species exhibiting 70%, 15% and 15% frequency respectively whereas D, and E were nil in the study area (Figure 4.15). The species with the highest IVI recorded was *Abies densa* (75.633%) followed by *Tsuga dumosa* (49.182), *Rhododendron arboreum* (31.127%) and *Quercus lamellosa* (23.468) respectively (Figure 4.16). During the study, 19 trees species showed contiguous distribution and 1 species showed random distribution pattern in the Broad Leaf Coniferous Forest of the region. The Sannon-Wiener diversity index was estimated to be 2.702, the Concentration of the Dominance was 0.0842, species richness was 0.8065 and evenness of species was 0.902 (Table 4.12).

Table 4.9: Phytosociological composition of tree layer in the Broad Leaf Coniferous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No	Scientific Name	Family	F	D^{-1}	A	A/F	RF	RD	R.Dom	IVI
1	*Abies densa* Griffith	Pinaceae	58.929	198.214	3.364	0.057	15.278	18.049	42.307	75.633
2	*Andromeda villosa* Wall	Ericaceae	7.143	28.571	4	0.56	1.852	2.602	0.226	4.68
3	*Betula utilis* D.Don	Betulaceae	25	58.929	2.357	0.094	6.481	5.366	2.267	14.1144
4	*Daphniphyllum himalense* (Bentham) Mueller Argoviensis	Daphiphyllaceae	17.857	51.786	2.9	0.162	4.63	4.715	0.702	10.047
5	*Ilex fragilis* Hooker	Aquifoliaceae	8.929	19.643	2.2	0.246	2.315	1.789	0.111	4.215
6	*Lithocarpus pachyphyllus* (Kurz) Rehder	Fagaceae	19.643	57.143	2.909	0.148	5.093	5.203	3.945	14.241
7	*Litsea sericea* (Wall. ex Nees) Hook. f.	Lauraceae	21.429	64.286	3	0.14	5.556	5.854	0.739	12.148
8	*Lyonia ovalifolia* (Wallichi) Drude	Ericaceae	8.929	21.4296	2.4	0.269	2.315	1.951	0.232	4.498
9	*Magnolia campbellii* Hooker f. and Thomson	Magnoliaceae	12.5	28.571	2.286	0.183	3.241	2.602	0.841	6.683
10	*Merrilliopanax alpinus* (Clarke) C.B. Shang	Araliaceae	3.571	5.3571	1.5	0.42	0.926	0.488	0.005	1.419
11	*Prunus undulata* Buch.-Ham. ex D.Don	Rosaceae	3.571	10.714	3	0.84	0.926	0.976	0.076	1.977
12	*Quercus lamellosa* Smith	Fagaceae	19.643	87.5	4.455	0.227	5.093	7.968	10.407	23.468
13	*Rhododendron arboreum* Smith	Ericaceae	46.429	126.786	2.731	0.058	12.037	11.545	7.545	31.127
14	*Rhododendron barbatum* Wallich ex G. Don	Ericaceae	10.714	32.143	3	0.28	2.778	2.927	0.217	5.921
15	*Rhododendron cinnabarnum*	Ericaceae	7.1429	16.0714	2.25	0.315	1.852	1.463	0.023	3.338

16	*Rhododendron falconeri* Hooker. f.	Ericaceae	3.571	23.214	6.5	1.82	0.926	2.114	0.142	3.181
17	*Rhododendron grande* Wight	Ericaceae	30.357	76.786	2.529	0.083	7.87	6.992	1.674	16.536
18	*Rhododendron hodgsonii* Hooker. f.	Ericaceae	8.929	48.214	5.4	0.605	2.315	4.39	0.947	7.652
19	*Sorbus cuspidata* (Spach) Hedl.	Rosaceae	19.643	39.286	2	0.102	5.093	3.578	1.269	9.939
20	*Tsuga dumosa* (D. Don) Eichler	Pinaceae	51.786	103.571	2	0.039	13.426	9.431	26.325	49.182

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, R. Dom= Relative Dominance, IVI= Importance Value Index

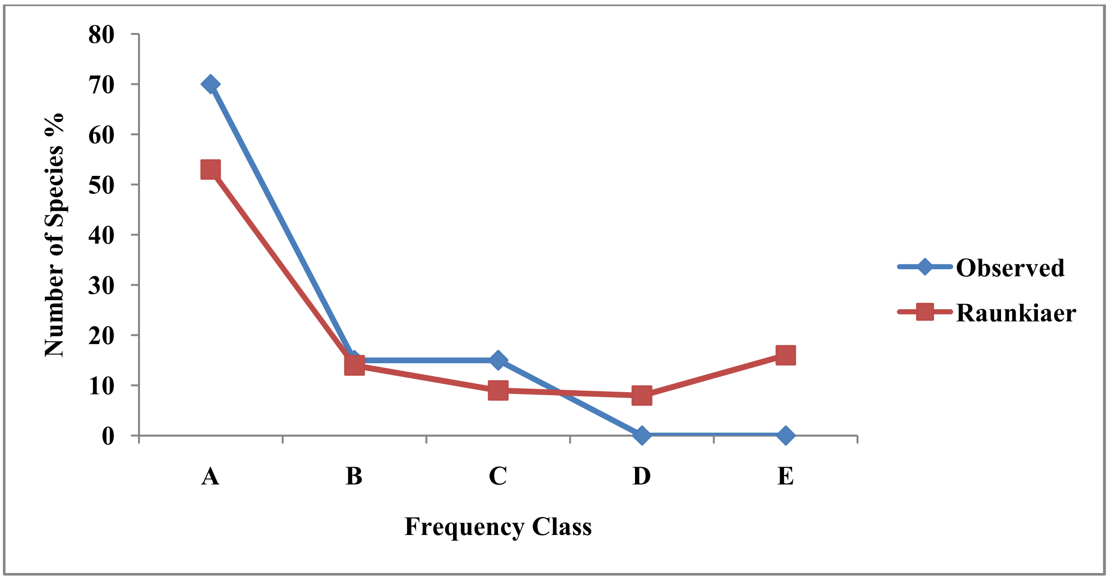

Figure 4.15: Comparison of observed frequency of tree layer of Broad Leaf Coniferous Forest of SNP with Raunkiaer's frequency distribution in SNP, Darjeeling

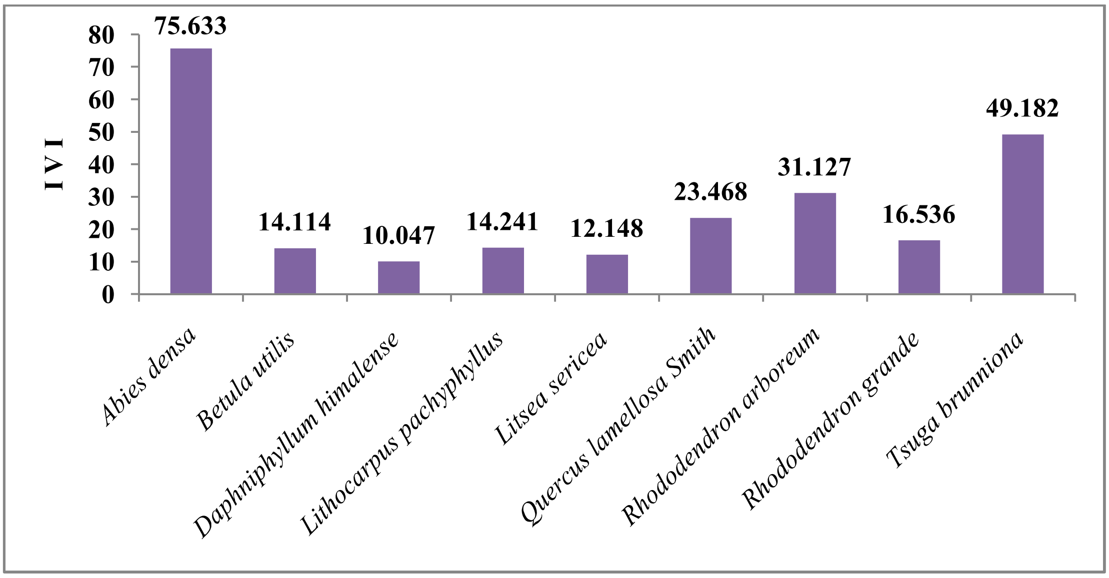

Figure 4.16: Tree species with relatively High Importance Value Index in Broad Leaf Coniferous Forest of SNP, Darjeeling

4.1.3.2 Shrub Layer of Broad Leaf Coniferous Forest

The study conducted in the Broad Leaf Coniferous Forest SNP recorded 21 shrub species belonging to 15 genus and 9 families. Highest number of species was recorded under the family Ericaceae with 7 species each and was followed by

Rosaceae with 4 species. The family Andoxaceae, Berberidaceae and Poaceae recorded 2 species each. Other families like Thymelaeaceae, Compositae, and Grossulariaceae recorded 1 species each in Broad Leaf Coniferous Forest (Table 4.10). Total density was estimated to be individuals 8.8964. The highest density was recorded for *Thamnocalamus spathiflorus* (4.768) and which was followed by *Yushania maling* (1.586). Total estimated abundance in the area was 50.572 and the species with the highest abundance was *Yushania maling* (10.75) and it was followed by *Thamnocalamus spathiflorus* (6.2093). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, shrubs species in the Broad Leaf Coniferous Forest showed only two classes A and D with species exhibiting 95.238 and 4.762% frequency respectively whereas B, C and E were nil in the study area (Figure 4.17). The species with the highest frequency recorded was *Thamnocalamus spathiflorus* (76.786%) and was followed by *Viburnum erubescens* (16.07%), *Rhododendron campanulatum* (14.286%) and *Yushania maling* (14.286%) respectively. *Thamnocalamus spathiflorus* was the most dominant species with the IVI value 100.698 and it was followed by *Yushania maling* (45.16) and *Viburnum erubescens* (12.982) in terms of IVI score respectively (Figure 4.18). The Sannon-Wiener diversity index in the region was estimated to be 1.0814, the concentration of the Dominance was 0.3367, species richness was 0.9516 and evenness of species was 0.3552 (Table 4.12). All the 21 shrub species showed contiguous distribution in the forest.

Table 4.10: Phytosociological composition of shrub layer in the Broad Leaf Coniferous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No	Scientific Name	Family	F	D	A	A/F	RF	RD	RA	IVI
1	*Andromeda formosa* Wall.	Ericaceae	8.929	0.143	1.6	0.179	3.906	1.643	3.164	8.7128
2	*Berberis aristata* DC.	Berberidaceae	7.143	0.125	1.75	0.245	3.125	1.437	3.46	8.023
3	*Berberis wallichiana* DC.	Berberidaceae	7.143	0.107	1.5	0.21	3.125	1.232	2.966	7.323
4	*Daphne bholua* Buch.-Ham. ex D. Don	*Thymelaeaceae*	7.143	0.161	2.25	0.315	3.125	1.848	4.449	9.422
5	*Gaultheria fragrantissima* Wall.	Ericaceae	3.571	0.071	2	0.56	1.563	0.821	3.955	6.339
6	*Gaultheria nummularioides* D. Don	Ericaceae	3.571	0.054	1.5	0.42	1.563	0.616	2.966	5.145
7	*Rhododendron campanulatum* D. Don	Ericaceae	14.286	0.25	1.75	0.123	6.25	2.875	3.46	12.585
8	*Rhododendron lepidotum* Wall. ex G. Don	Ericaceae	3.571	0.054	1.5	0.42	1.563	0.616	2.966	5.145
9	*Rhododendron triflorum* Hook. f.	Ericaceae	3.571	0.071	2	0.56	1.563	0.821	3.955	6.339
10	*Ribes glaciale* Wall.	Grossulariaceae	3.571	0.071	2	0.56	1.563	0.821	3.955	6.339
11	*Rosa sericea* Wall. ex Lindl.	Rosaceae	7.143	0.107	1.5	0.21	3.125	1.232	2.966	7.323
12	*Rubus acuminatus* Sm.	Rosaceae	5.357	0.089	1.667	0.311	2.344	1.027	3.296	6.666
13	*Rubus nepalensis* hort.	Rosaceae	7.143	0.125	1.75	0.245	3.125	1.437	3.46	8.022
14	*Rubus thomsonii* Focke	Rosaceae	5.35714	0.125	2.3333	0.436	2.344	1.437	4.614	8.395
15	*Sambucus adnata* Wall. ex DC.	Adoxaceae	12.5	0.2321	1.8571	0.149	5.469	2.669	3.672	11.81
16	*Schisandra grandiflora* (Wall.) Hook. f. & Thomson	Schisandraceae	7.143	0.107	1.5	0.21	3.125	1.232	2.966	7.323

17	*Senecio scandens* Buch.-Ham. ex D. Don	Compositae	5.357	0.107	2	0.373	2.344	1.232	3.955	7.531
18	*Thamnocalamus spathiflorus* (Trin.) Munro	Poaceae	76.786	4.768	6.209	0.081	33.594	54.826	12.278	100.698
19	*Vaccinium retusum* (Griff.) Hook. f. ex C.B. Clarke	Ericaceae	8.929	0.143	1.6	0.179	3.906	1.643	3.164	8.713
20	*Viburnum erubescens* Wall.	Adoxaceae	16.0714	0.25	1.5556	0.097	7.031	2.875	3.076	12.982
21	*Yushania maling* (Gamble) R.B. Majumdar & Karthik.	*Poaceae*	14.286	1.536	10.75	0.753	6.25	17.659	21.257	45.166

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, RA= Relative Abundance, IVI= Importance Value Index

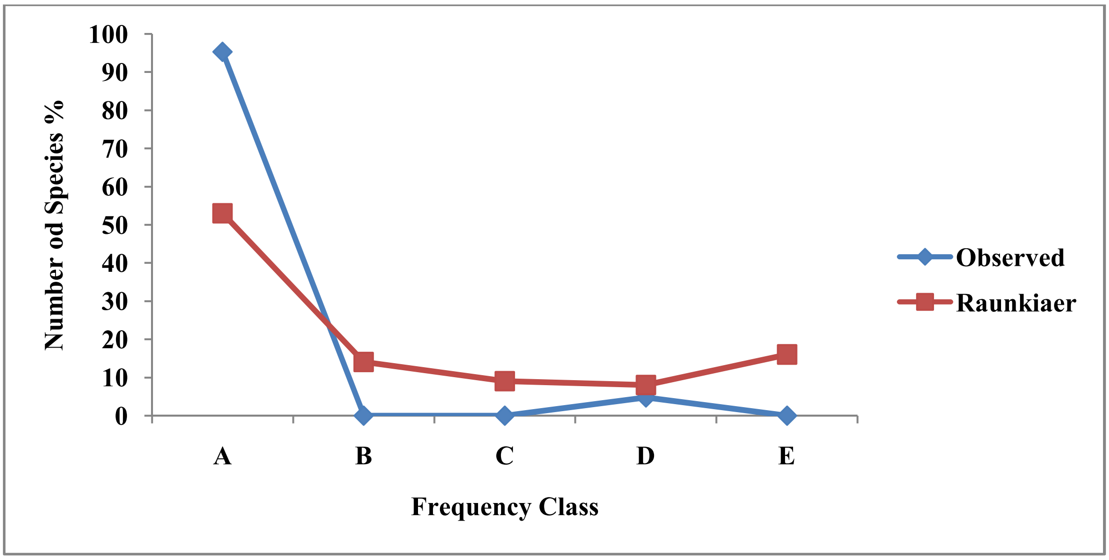

Figure 4.17: Comparison of observed frequency of shrub layer of Broad Leaf Coniferous Forest with Raunkiaer's frequency distribution in SNP, Darjeeling

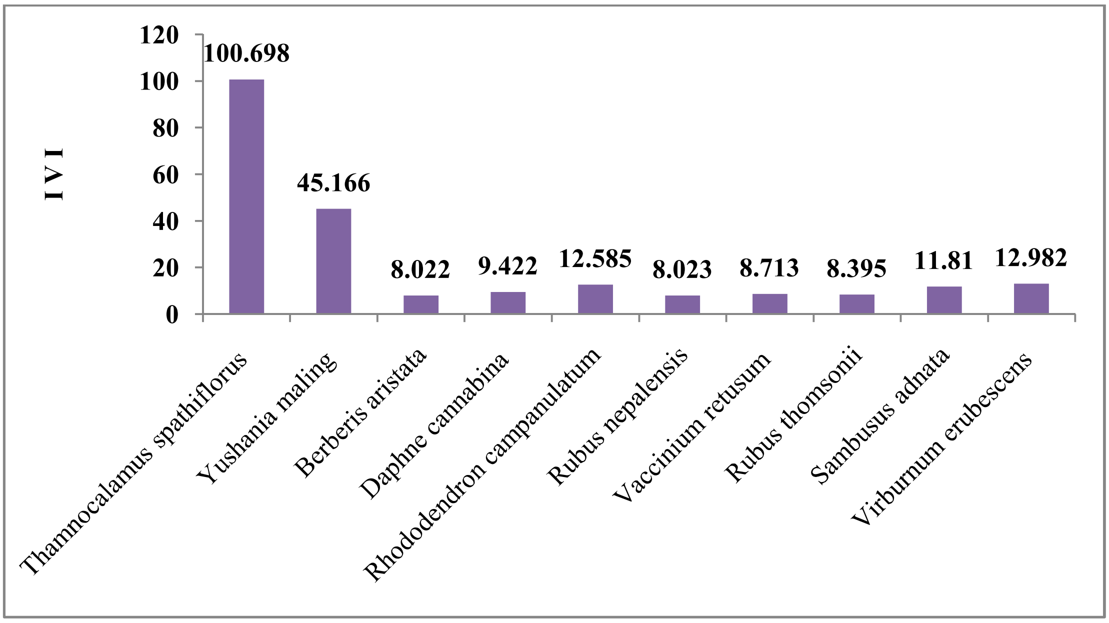

Figure 4.18: Shrub species with relatively High Important Value Index in Broad Leaf Coniferous Forest of SNP, Darjeeling

4.1.3.3 Herb Layer of Broad Leaf Coniferous forest

The study conducted on the herb layer in the Broad Leaf Coniferous Forest recorded 31 species belonging to 27 genera and 18 families. The highest number of species were recorded from the family Polygonaceae (4 species) and Rosaceae (4 species) which was followed by the family Compositae (3 species), Araceae, Asparagaceae, Ranunculaceae and Primulaceae with two species each. Other families like Apiaceae, Cyperaceae, Lamiaceae, Gentianaceae, Melanthiaceae etc. recorded only 1 species each in the region (Table 4.11). Total density in Broad Leaf Coniferous Forest was estimated to be 10.339. The highest density was recorded for *Theropogon pallidus* (1.473), which was followed by *Anaphalis busua* (1.227) and *Gaultheria nummularioides* (1.125) in the forest. Total estimated abundance was 99.248 and the species with the highest abundance was *Anaphalis busua* (8.938) which was followed by *Theropogon pallidus* (8.68) and *Anaphalis contorta* (8.643). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the herb species in the Broad Leaf Coniferous Forest showed only one class A exhibiting 100% frequency class B, C, D and E were nil in the study area (Figure 4.19). The species with the highest frequency recorded was *Theropogon pallidus* (16.964%) which was followed by *Anaphalis busua* (14.286%), *Smilax bracteata* (13.393%) and *Polygonatum verticillatum* (13.393) in descending order. *Theropogon pallidus* was the most dominant species with the IVI value 29.688 and was followed by *Anaphalis busua and Gentiana capitata* with 27.035 and 24.837 IVI score respectively (Figure 4.20). The Sannon-Wiener diversity index in the forest was estimated to be 2.9473, the concentration of the Dominance was 0.0746, species richness was 0.911 whereas the evenness of species was 0.8583 (Table 4.12). All the 31 herb species showed a contiguous distribution in the forest.

Table 4.11: Phytosociological composition of herb layer in the Broad Leaf Coniferous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No	Scientific Name	Family	F	D	A	A/F	RF	RD	RA	IVI
1	*Aconitum ferox* Wall. ex Ser	Ranunculaceae	6.25	0.143	2.286	0.366	2.265	1.413	2.359	6.038
2	*Aconitum heterophyllum* Wall. ex Royle	Ranunculaceae	1.7863	0.036	2	1.12	0.647	0.353	2.064	3.065
3	*Anaphalis busua* (Buch.-Ham.) DC.	Compositae	14.286	1.277	8.938	0.626	5.178	12.633	9.225	27.035
4	*Anaphalis contorta* (D.Don) Hook. f.	Compositae	12.5	1.08	8.643	0.691	4.531	10.689	8.921	24.141
5	*Arisaema erubescens* (Wall.) Schott	Araceae	3.571	0.063	1.75	0.49	1.294	0.618	1.806	3.719
6	*Arisaema griffithii* Schott	Araceae	5.357	0.107	2	0.373	1.942	1.06	2.064	5.066
7	*Belvisia henryi* (Hieron. ex C. Chr.) Raymond	Polypodiaceae	4.464	0.08	1.8	0.403	1.618	0.795	1.858	4.271
8	*Bistorta emodi* (Meisn.) H.Hara	Poygonaceae	5.357	0.098	1.833	0.342	1.942	0.972	1.892	4.806
9	*Carex decora* Boott.	Cyperaceae	9.821	0.295	3	0.305	3.56	2.85	3.096	9.506
10	*Cirsium falconeri* (Hook. f.) Petr.	Compositae	5.357	0.08	1.5	0.28	1.942	0.795	1.548	4.285
11	*Elsholtzia strobilifera* (Benth.) Benth.	Lamiaceae	2.679	0.08	3	1.12	1.942	1.59	3.096	6.628
12	*Fragaria daltoniana* J. Gay	Rosaceae	9.821	0.17	1.727	0.176	0.971	0.795	3.096	4.862
13	Fragaria nilgerrensis Schltdl. ex J. Gay	Rosaceae	9.821	0.768	7.818	0.796	3.56	1.678	1.783	7.021
14	*Gaultheria nummularioides* D.Don	Ericaceae	25	1.125	4.5	0.18	3.56	7.597	8.07	19.227
15	*Gentiana capitata* Buch.-Ham. ex D. Don	Gentianaceae	9.821	0.125	1.273	0.13	9.061	11.131	4.645	24.837
16	*Ilex hookeri* King	Aquifoliaceae	10.714	0.17	1.583	0.148	3.56	1.237	1.314	6.11
17	*Lepisorus nudus* (Hook.) Ching	Polypodiaceae	11.607	0.116	1	0.086	3.883	1.678	1.634	7.196
18	*Microlepia sp.*	Dennstaedtiaceae	11.607	0.286	2.462	0.212	4.207	1.148	1.032	6.388

19	*Paris polyphylla*	Melanthiaceae	3.571	0.071	2	0.56	4.207	2.827	2.541	9.575
20	*Persicaria campanulata* (Hook. f.) Ronse Decr.	Polygonaceae	9.821	0.125	1.273	0.13	1.294	0.707	2.064	4.066
21	*Pilea scripta* (Buch.-Ham. ex D. Don) Wedd.	Urticaceae	5.357	0.161	3	0.56	3.56	1.237	1.314	6.11
22	*Polygonatum verticillatum* (L.) All.	Asparagaceae	13.393	0.304	2.267	0.169	4.854	3.003	2.34	10.197
23	*Potentilla polyphylla* Wall. ex Lehm.	Rosaceae	10.714	0.241	2.25	0.21	3.883	2.385	2.322	8.591
24	*Primula denticulata* Sm.	Primulaceae	3.571	0.063	1.75	0.49	1.294	0.618	1.806	3.719
25	*Primula sp.*	Primulaceae	10.714	0.339	3.167	0.296	3.883	3.357	3.268	10.509
26	*Rubus buergeri* Miq.	Rosaceae	8.036	0.563	7	0.871	2.913	5.565	7.225	15.703
27	*Saxifraga parnassifolia* D. Don	Saxifragaceae	2.679	0.063	2.333	0.871	0.971	0.618	2.408	3.998
28	*Selinum wallichianum* (DC.) Raizada & H.O. Saxena	Apiaceae	11.607	0.125	1.077	0.093	4.207	1.237	1.111	6.555
29	*Smilax bracteata* C. Presl	Smilacaceae	13.393	0.321	2.4	0.179	4.854	3.18	2.477	10.512
30	*Theropogon pallidus* (Wall. ex Kunth) Maxim.	Asparagaceae	16.964	1.473	8.684	0.512	6.149	14.576	8.963	29.688
31	*Vaccinium nummularia* Hook. f. & Thomson ex C.B. Clarke	Ericaceae	6.25	0.161	2.571	0.411	2.265	1.59	2.654	6.51

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, RA= Relative Abundance, IVI= Importance Value Index

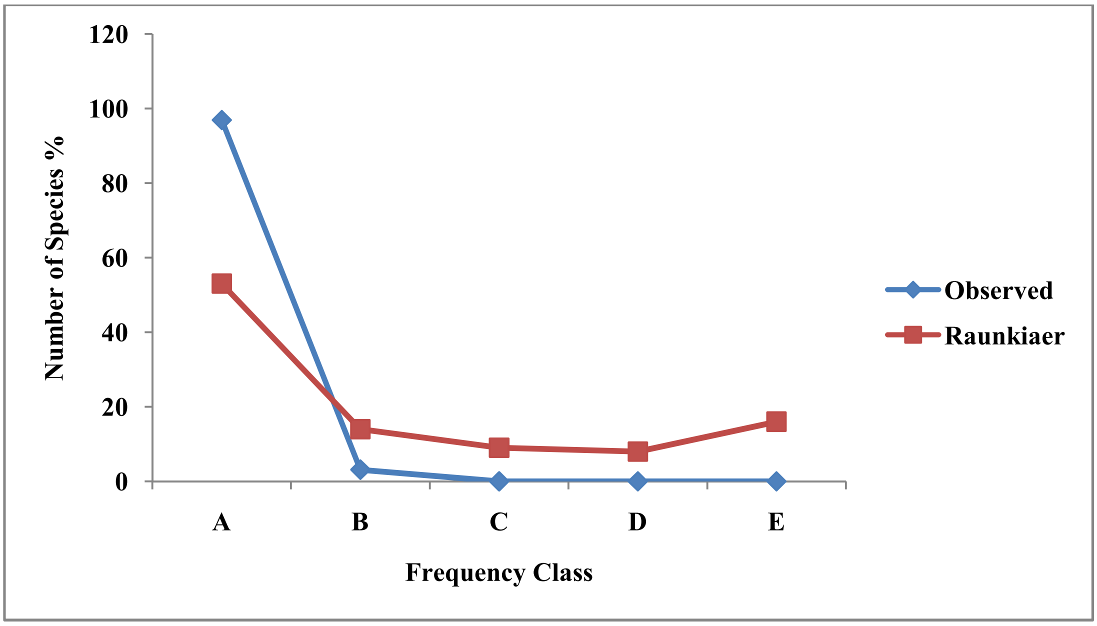

Figure 4.19: Comparison of observed frequency of herb layer of Broad Leaf Coniferous Forest with Raunkiaer's frequency distribution in SNP, Darjeeling

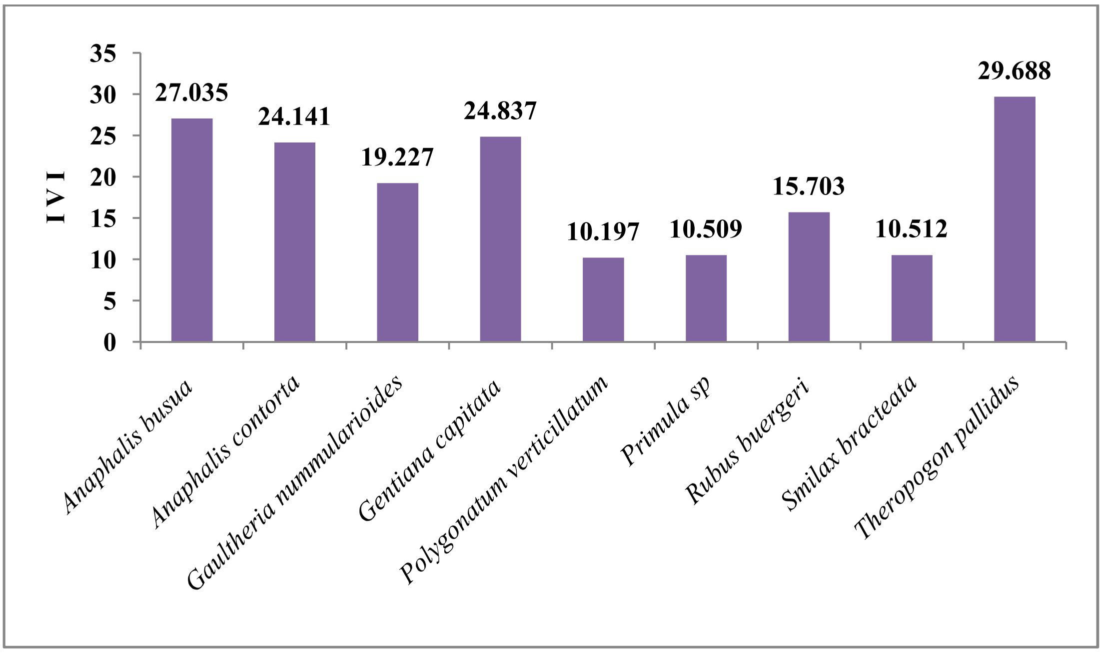

Figure 4.20: Herb species with relatively high Importance Value Index in Broad Leaf Coniferous Forest of SNP, Darjeeling

Table 4.12: Determinant indices for different group of Broad Leaf Coniferous Forest of SNP

Layer	Species Diversity (H')	Species richness (D)	Concentration of Dominance (CD)	Species evenness (J')
Tree	2.702	0.8065	0.0842	0.902
Shrub	1.0814	0.9516	0.3367	0.3552
Herb	2.9473	0.911	0.0746	0.8583

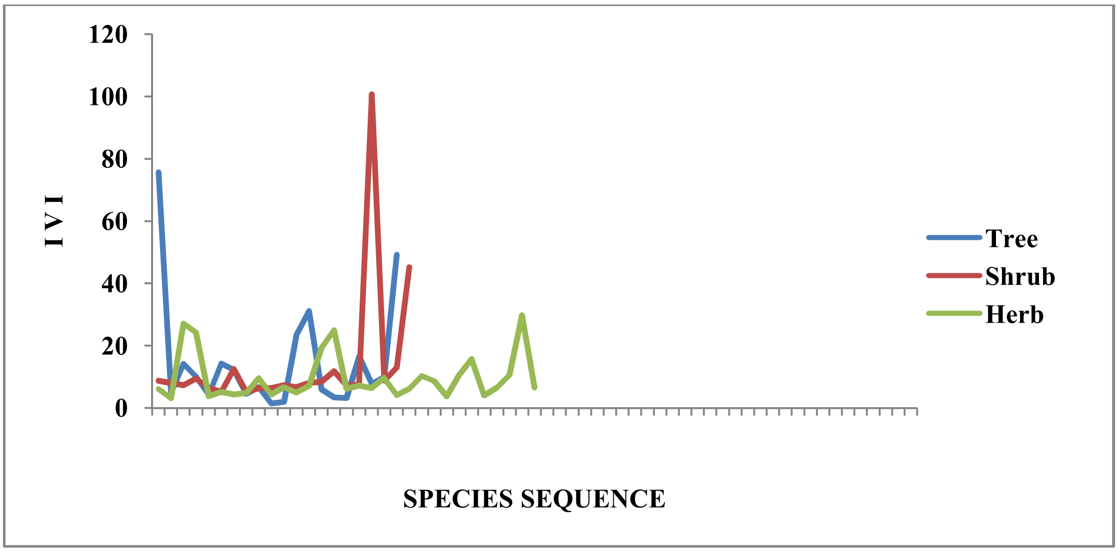

Figure 4.21: Dominance diversity curve of three layers of Broad Leaf Coniferous Forest of SNP, Darjeeling

4.1.4 Sub Alpine Coniferous Forest (altitude 3300 m to 3600 m and above)

4.1.4.1 Tree Layer of Sub Alpine Coniferous Forest

The Sub Alpine Coniferous Forest of the Singalila National Park, Darjeeling lies between 3300 m to 3600 m altitude above sea level. The study conducted during various seasons in the park recorded 12 tree species belonging to 7 genus and 5 families. Highest number of species were recorded under the family Ericaceae (6 species) and was followed by the family Rosaceae (2 species). Other families i.e.

Betulaceae, Daphiphyllaceae, Pinaceae and Sabiaceae recorded 1 species each in the region (Table 4.13). Total stem density in Sub Alpine Coniferous Forest were estimated to be 844.44 individuals ha^{-1}. The highest density was recorded for *Abies densa* (275 ha^{-1}) and it was followed by *Rhododendron arboreum* (219.444 ha^{-1}) and *Betula utilis* (38.889 ha^{-1}) respectively. Total estimated abundance in the area was 32.556 and the species with the highest abundance being that of *Abies densa* (3.808) which was followed by *Rhododendron arboreum* (3.292) and *Rhododendron hodgsonii*. Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the tree species in the Sub Alpine Coniferous Forest showed three classes A, B and D with species exhibiting 75%, 8.33% and 16.67% respectively whereas C, and E were nil in the study area (Figure 4.22). The species with the highest frequency recorded was *Abies densa* (72.22%) which was followed by *Rhododendron arboreum* (66.667%) and *Betula utilis* (38.889%). During the study 10 trees species showed contiguous distribution, one species showed regular and one species showed random distribution pattern in the region. *Abies densa* was the most dominant species with the IVI value 136.521 which was followed by *Rhododendron arboreum* and *Betula utilis* with 64.927 and 33.804 IVI score respectively (Figure 4.23). The Sannon-Wiener diversity index in the region was estimated to be 1.9168, the concentration of the Dominance was 0.2022, species richness was 0.6882 and evenness of species was 0.7714 (Table 4.16).

Table 4.13: Phytosociological composition of tree layer of the Sub Alpine Coniferous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No.	Scientific Name	Family	F	D^{-1}	A	A/F	RF	RD	R.Dom	IVI
1	*Abies densa* Griffith	Pinaceae	72.222	275	3.808	0.053	26.531	32.566	77.425	136.521
2	*Betula utilis* D. Don	Betulaceae	38.889	111.111	2.857	0.073	14.286	13.158	6.361	33.804
3	*Daphniphyllum himalense* Bentham Mueller Argoviensis	Daphiphyllaceae	11.111	36.111	3.25	0.293	4.082	4.276	0.114	8.472
4	*Meliosma dilleniifolia* (Wall. ex Wight & Arn.) Walp.	Sabiaceae	2.778	8.333	3	1.08	1.02	0.987	0.013	2.02
5	*Prunus undulata* Buch.-Ham. ex D. Don	Rosaceae	2.778	5.556	2	0.72	1.02	0.6579	0.017	1.695
6	*Rhododendron arboreum* Smith	Ericaceae	66.667	219.444	3.292	0.049	24.49	25.987	14.45	64.927
7	*Rhododendron barbatum* Wall. ex G. Don	Ericaceae	16.667	44.444	2.667	0.16	6.122	5.263	0.217	11.602
8	*Rhododendron cinnabarinum* Hook. f.	Ericaceae	16.667	38.889	2.333	0.14	6.122	4.605	0.125	10.852
9	*Rhododendron falconeri* Hook. f.	Ericaceae	13.889	36.111	2.6	0.187	5.102	4.276	0.155	9.534
10	*Rhododendron grande* Wight	Ericaceae	5.556	11.111	2	0.36	2.04	1.316	0.015	3.371
11	*Rhododendron hodgsonii* Hook. f.	Ericaceae	11.111	30.556	2.75	0.248	4.081	3.618	0.569	8.269
12	*Sorbus cuspidata* (Spach) Hedl.	Rosaceae	13.889	27.778	2	0.144	5.102	3.289	0.54	8.931

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, Rel. Dom.= Relative Dominance, IVI= Importance Value Index

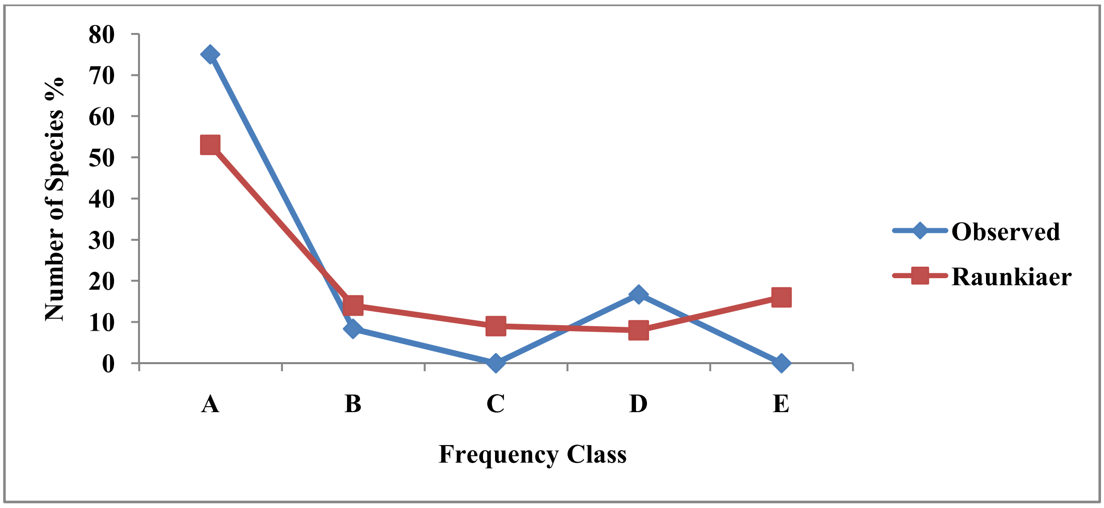

Figure 4.22: Comparison of the observed frequency of tree layer of the Sub Alpine Coniferous Forest with Raunkiaer frequency distribution in SNP, Darjeeling

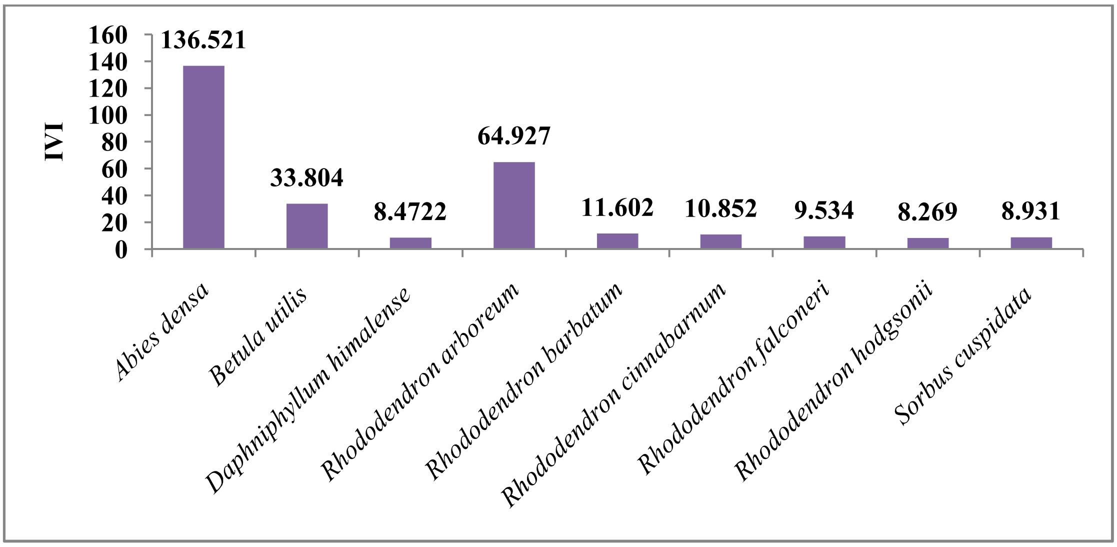

Figure 4.23: Tree species with relatively high Importance Value Index in Sub Alpine Coniferous Forest of SNP, Darjeeling

4.1.4.2 Shrub Layer of Sub Alpine Coniferous Forest

The study conducted in the Sub Alpine Coniferous Forest of SNP recorded 13 species belonging to 10 genera and 7 families. The highest number of species were recorded under the family Ericaceae (5 species) which was followed by the family Berberidaceae and Poaceae with 2 species respectively. Other families such as

Adoxaxeae, Rosaceae, Thymelaeaceae and, Schisandraceae recorded 1 species each in the region (Table 4.14). Total stem density in Sub Alpine Coniferous Forest were estimated to be individuals 8.8861. Highest density was recorded for *Thamnocalamus spathiflorus* (5.944) and was followed by *Yushania maling* (0.889). Total estimated abundance in the area was 50.255 and the species with the highest abundance was *Thamnocalamus spathiflorus* (12.589) and was followed by *Yushania maling* (8). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the shrub species in the Sub Alpine Coniferous Forest showed only two classes A and C with species exhibiting 92.31% and 7.69% respectively whereas B, D and E were nil in the study area (Figure 4.24). The species with the highest frequency recorded was *Thamnocalamus spathiflorus* (47.222%) which was followed by *Rhododendron campanulatum* (16.67%), *Berberis aristata* (11.11%) and *Yushania maling* (11.11%) in descending manner. *Thamnocalamus spathiflorus* was the most dominant species with the IVI value 125.467 and was followed by *Yushania* and *Daphne bholua* with 33.793 and 22.239 IVI score respectively (Figure 4.25). The Sannon-Wiener diversity index in the region was estimated to be 1.3595, the concentration of the Dominance was 0.466, species richness was 0.7279 and evenness of species was 0.53 (Table 4.16). All the 13 shrub species showed contiguous distribution in the forest.

Table 4.14: Phytosociological composition of shrub layer of the Sub Alpine Coniferous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No.	Scientific Name	Family	F	D	A	A/F	RF	RD	RA	IVI
1	*Berberis aristata* DC.	Berberidaceae	11.111	0.222	2	0.18	7.843	2.508	3.98	14.331
2	*Berberis wallichiana* DC.	Berberidaceae	8.333	0.167	2	0.24	5.882	1.881	3.98	11.743
3	*Daphne bholua* Buch.-Ham. ex D. Don	*Thymelaeaceae*	5.556	0.389	7	1.26	3.9216	4.389	13.929	22.239
4	*Gaultheria fragrantissima* Wall.	Ericaceae	5.556	0.111	2	0.36	3.9216	1.254	3.98	9.155
5	*Gaultheria nummularioides* D. Don	Ericaceae	8.333	0.139	1.667	0.2	5.882	1.567	3.316	10.766
6	*Rhododendron campanulatum* D. Don	Ericaceae	16.667	0.306	1.833	0.11	11.765	3.448	3.648	18.861
7	*Rhododendron lepidotum* Wall. ex G. Don	Ericaceae	5.556	0.139	2.5	0.45	3.9216	1.567	4.975	10.464
8	*Rubus thomsonii* Focke	Rosaceae	8.333	0.194	2.333	0.28	5.882	2.194	4.643	12.72
9	*Schisandra grandiflora* (Wall.) Hook. f. & Thomson	Schisandraceae	8.333	0.194	2.333	0.28	5.882	2.194	4.643	12.72
10	*Thamnocalamus spathiflorus* (Trin.) Munro	Poaceae	47.222	5.944	12.589	0.267	33.333	67.084	25.049	125.467
11	*Vaccinium retusum* (Griff.) Hook. f. ex C.B. Clarke	Ericaceae	2.778	0.083	3	1.08	1.961	0.94	5.97	8.871
12	*Viburnum erubescens* Wall.	*Adoxaxeae*	2.778	0.083	3	1.08	1.961	0.94	5.97	8.871
13	*Yushania maling* (Gamble) R.B. Majumdar & Karthik.	*Poaceae*	11.111	0.889	8	0.72	7.843	10.031	15.919	33.793

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, RA= Relative Abundance, IVI= Importance Value Index

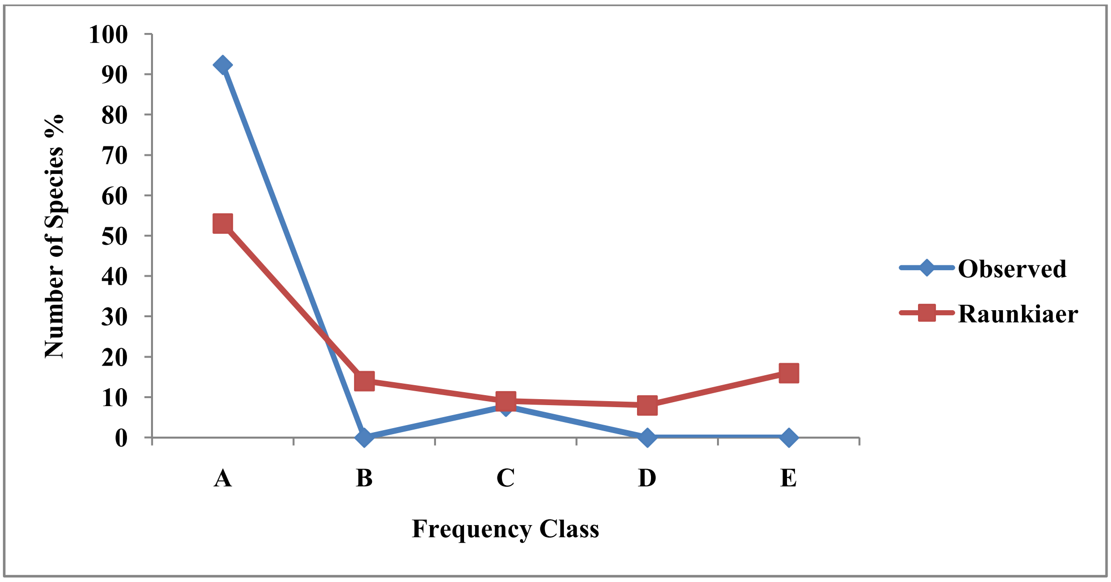

Figure 4.24: Comparison of the observed frequency of shrub layer of Sub Alpine Coniferous Forest with Raunkiaer's frequency distribution in SNP, Darjeeling

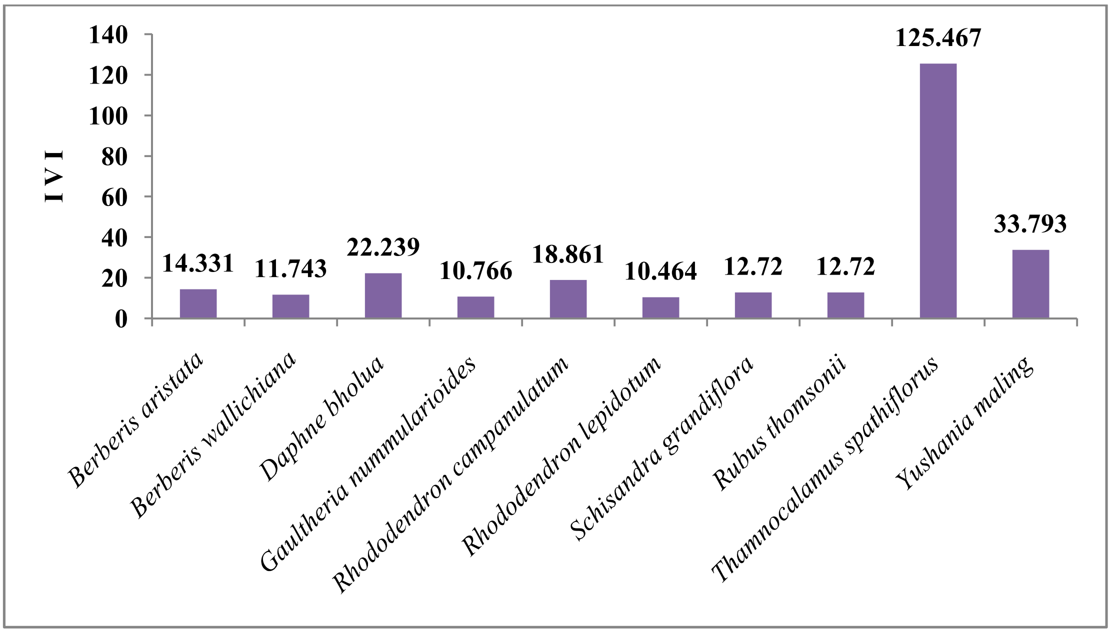

Figure 4.25: Shrub species with relatively High Importance Value Index in Sub Alpine Coniferous Forest of SNP, Darjeeling

4.1.4.3 Herb Layer of Sub Alpine Coniferous Forest

The study conducted on the herb layer in the Sub Alpine Coniferous Forest recorded 21 species of herbs belonging to 18 genus and 14 families. The highest number of species were recorded under the family Compositae (3 species) which was followed by the family Rosaceae, Rananculaceae, Araceae, and Polypodiaceae with two species each. Other families like Lamiaceae, Gentianaceae, Melanthiaceae etc. recorded 1 species each in the region (Table 4.15). Total density in Sub Alpine Coniferous Forest was estimated to be individuals 2.708. Highest density was recorded for *Fragaria daltoniana* (0.194) and *Selinum wallichianum* (0.194) and was followed by *Lepisorus nudus* (0.181). Total estimated abundance in the area was 47.557 and the species with the highest abundance was *Selinum wallichianum* (4.667) and was followed by *Persicaria campanulata* (2.8). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the herb species in the Sub Alpine Coniferous Forest showed only one class i.e. class A exhibiting 100% , frequency class B, C, D and E were nil in the study area (Figure 4.26). The species with the highest frequency recorded was *Fragaria daltoniana* (9.72%) and *Lepisorus nudus* (9.72%) and was followed by *Bistorta emodi* (8.333%), *Cirsium falconeri* (8.333%) and *Gentiana capitata* (8.33%). *Selinum wallichianum* was the most dominant species with the IVI value 20.363 which was followed by *Gentiana capitata* and *Persicaria campanulata* with 18.827 and 18.685 IVI score respectively (Figure 4.27). The Sannon-Wiener diversity index in the region was estimated to be 2.9754, concentration of the dominance was 0.0538, species richness was 1.5038 and evenness of species was 0.9773 (Table 4.16). All the 21 herb species showed contiguous distribution in the forest.

Table 4.15: Phytosociological composition of herb layer of Sub Alpine Coniferous Forest of SNP area detailing the associated species with their ecological parameters

Sl. No.	Scientific Name	Family	F	D	A	A/F	RF	RD	RA	IVI
1	*Aconitum ferox* Wall. ex Ser	Ranunculaceae	5.556	0.111	2	0.36	4.494	4.103	4.205	12.802
2	*Aconitum heterophyllum* Wall. ex Royle	Ranunculaceae	2.778	0.056	2	0.72	2.247	2.051	4.205	8.504
3	*Anaphalis busua* (Buch.-Ham.) DC.	Compositae	5.556	0.167	3	0.54	4.494	6.154	6.308	16.956
4	*Anaphalis contorta* (D. Don) Hook. f.	Compositae	5.556	0.153	2.75	0.495	4.494	5.641	5.783	15.918
5	*Arisaema griffithii* Schott	Araceae	4.167	0.069	1.667	0.4	3.371	2.564	3.505	9.439
6	*Arisaema erubescens* (Wall.) Schott	Araceae	2.778	0.042	1.5	0.54	2.247	1.538	3.154	6.94
7	*Belvisia henryi* (Hieron. ex C. Chr.) Raymond	Polypodiaceae	6.944	0.125	1.8	0.259	5.618	4.615	3.785	14.018
8	*Bistorta emodi* (Meisn.) H. Hara	Poygonaceae	8.333	0.153	1.833	0.22	6.742	5.641	3.855	16.238
9	*Cirsium falconeri* (Hook. f.) Petr.	Compositae	8.333	0.125	1.5	0.18	6.742	4.615	3.154	14.511
10	*Elsholtzia strobilifera* (Benth.) Benth.	Lamiaceae	4.167	0.125	3	0.72	3.371	4.615	6.308	14.294
11	*Fragaria daltoniana* J. Gay	Rosaceae	9.722	0.194	2	0.206	7.865	7.179	4.205	19.25
12	*Gentiana capitata* Buch.-Ham. ex D. Don	Gentianaceae	8.333	0.194	2.333	0.28	6.742	7.179	4.906	18.827
13	*Lepisorus nudus (*Hook.) Ching	Polypodiaceae	9.722	0.181	1.857	0.191	7.865	6.667	3.905	18.437
14	*Microlepia sp.*	Dennstaedtiaceae	4.167	0.111	2.667	0.64	3.371	4.103	5.607	13.081

15	*Paris polyphylla* Sm.	Melanthiaceae	2.778	0.069	2.5	0.9	2.247	2.564	5.257	10.068
16	*Persicaria campanulata* (Hook. f.) Ronse Decr.	Polygonaceae	6.944	0.194	2.8	0.403	5.618	7.179	5.888	18.685
17	*Polygonatum verticillatum* (L.) All.	Asparagaceae	6.944	0.125	1.8	0.259	5.618	4.615	3.785	14.018
18	*Potentilla polyphylla* Wall. ex Lehm.	Rosaceae	6.944	0.125	1.8	0.259	5.618	4.615	3.785	14.018
19	*Primula denticulata* Sm.	Primulaceae	5.556	0.097	1.75	0.315	4.494	3.59	3.68	11.764
20	*Saxifraga parnassifolia* D. Don	Saxifragaceae	4.167	0.097	2.333	0.56	3.371	3.59	4.906	11.867
21	*Selinum wallichianum* (DC.) Raizada & H.O. Saxena	Apiaceae	4.167	0.194	4.667	1.12	3.371	7.18	9.813	20.363

F = Frequency, D= Density, A=Abundance, A/F= Abundance/Frequency, RF= Relative Frequency, RD= Relative Density, RA= Relative Abundance, IVI= Importance Value Index

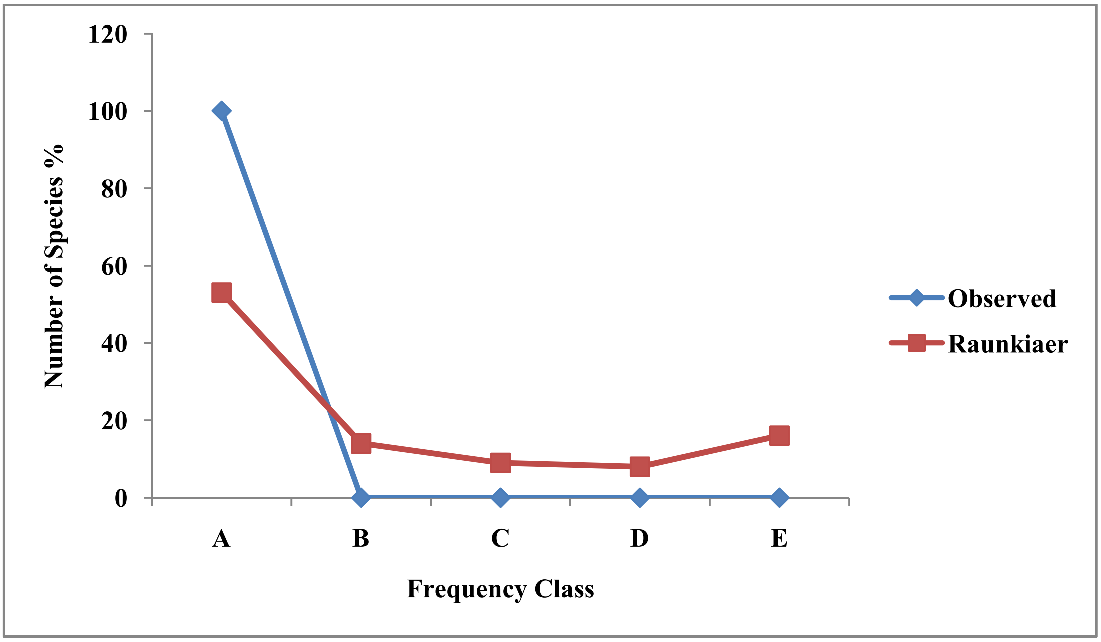

Figure 4.26: Comparison of observed frequency of the herb layer of Sub Alpine Coniferous Forest with Raunkiaer frequency distribution in SNP, Darjeeling

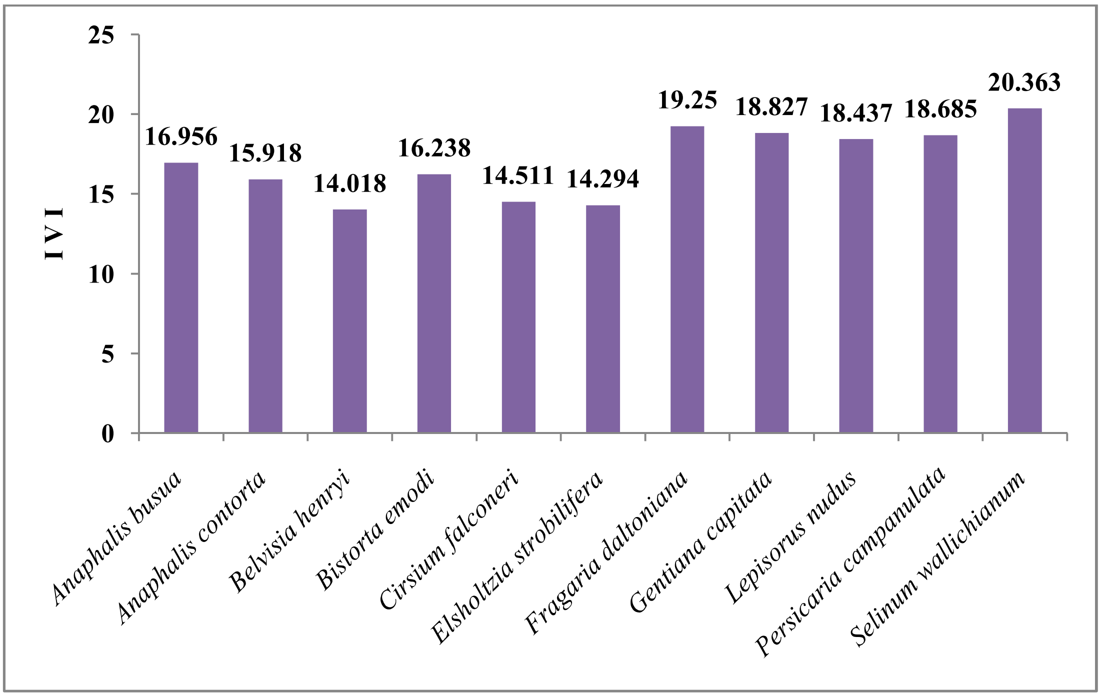

Figure 4.27: Herb species with relatively High Importance Value Index in Sub Alpine Coniferous Forest of SNP, Darjeeling

Table 4.16: Determinant indices for different group of Sub Alpine Coniferous Forest of SNP

Layer	Species Diversity (H')	Species richness (D)	Concentration of Dominance (CD)	Species evenness (J')
Tree	1.9168	0.6882	0.2022	0.7714
Shrub	1.3595	0.466	0.7279	0.53
Herb	2.9754	1.5038	0.0538	0.9773

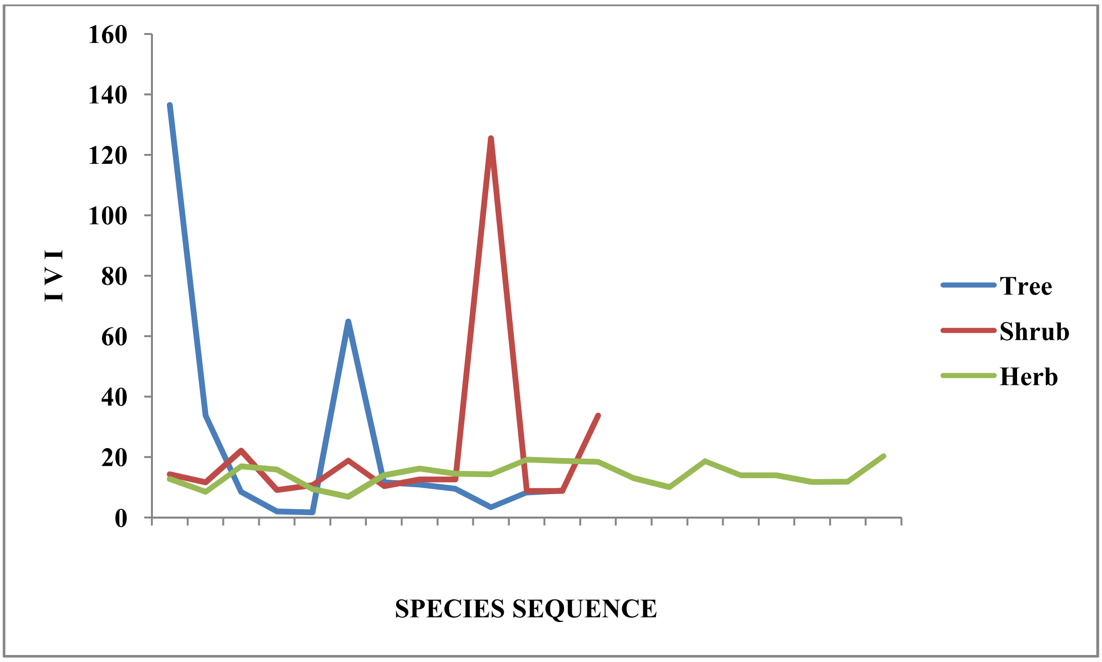

Figure 4.28: Dominance diversity curve for all the three layers of Sub Alpine Coniferous Forest of SNP, Darjeeling

4.2 Assessment of Anthropogenic Impacts and Vegetation mapping of the Singalila National Park

4.2.1 Introduction

Human beings are affected by the physical, chemical, and biological processes of the environment while human biological and social characteristics shape the environment in which they live (Grove and Burch, 1997). Communities residing near the forest area are dependent on the forest for various forest products for their livelihood. The source of income for most of the rural households depends on forest and agriculture throughout the developing world (Teshome, 2015). The sustainability of the forest mainly depends on the human activity, productivity of the forest, and its resilience. Traditionally people residing in the vicinity of the forest have been using the forest resources and sustainably managing them but within few decades' changes have occurred rapidly due to the influence of market forces (Awasthi, 2003). Various protected areas possess human settlement within and adjacent to them that depends on the forest for sustainability or consumption (Silori and Mishra, 2001; Davidar, 2008). The dependence of the local populace on natural resources has a negative impact on the protected areas and its surroundings. The residents of nearby areas of the protected areas are forced to absorb the cost of living with wildlife that many a time leaves a detrimental effect on the conservation efforts. Over harvesting of forest products in a non-sustainable manner has had a severe effect on the forest ecosystem in India (Anitha, 2003). Anthropogenic activities like extraction of forest product, harvesting of particular species, and forest fire change the plant composition. Timber and forest resources are very useful components of the daily life of the forest-dependent population for the construction, fodder plants, wild vegetables, medicines, manures, fire-woods, etc. Both timber and non-timber products are utilized in day-to-day life.

Conservation efforts are highly influenced by the awareness of the local community residing in the vicinity of the protected areas, as it affects the attitude and behaviours of the people regarding conservation (Ntuli, 2019).

4.2.2 Village Settlement

For the study a total of 279 individuals were interviewed, representing 279 households in the study area (Figure 4.29). The population of the village (Figure 4.30) forest belonged to Nepali community comprising a substantial representation from the schedule tribe category belonged to Hindu and Buddhist religions. Most of the populations of the area were marginal farmers and laborers. Based on the participation of the villagers during the survey, it was observed that 1354 people resided in the seven hamlets within and surrounding areas of SNP. Of these, 53.84% of the populations of the villages were male, and 46.16% were female. The sampled household population of the villages was relatively young, with 59.67% of the population being below 30 years (Figure 4.31).

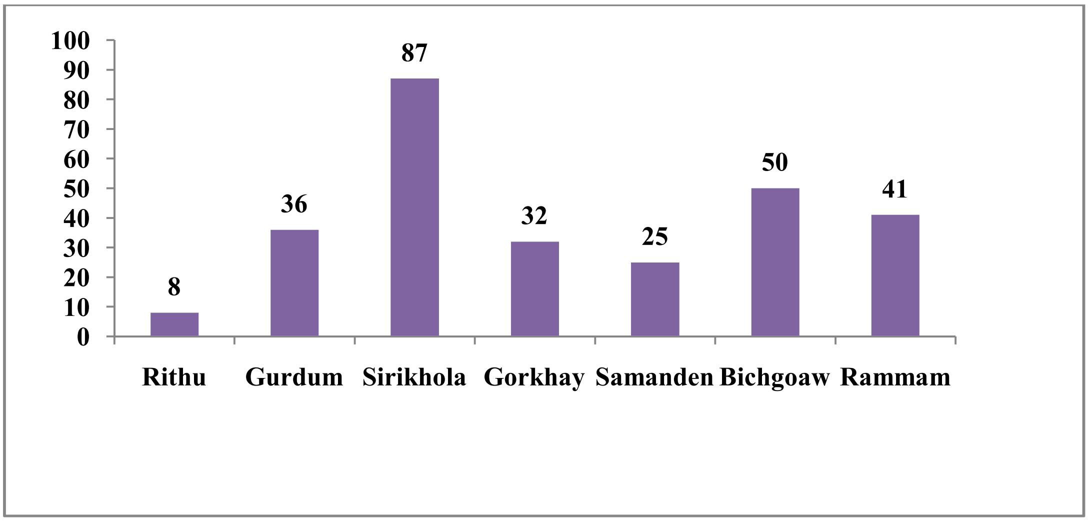

Figure 4.29: Number of household surveyed

Figure 4.30: Village settlement near Singalila National Park

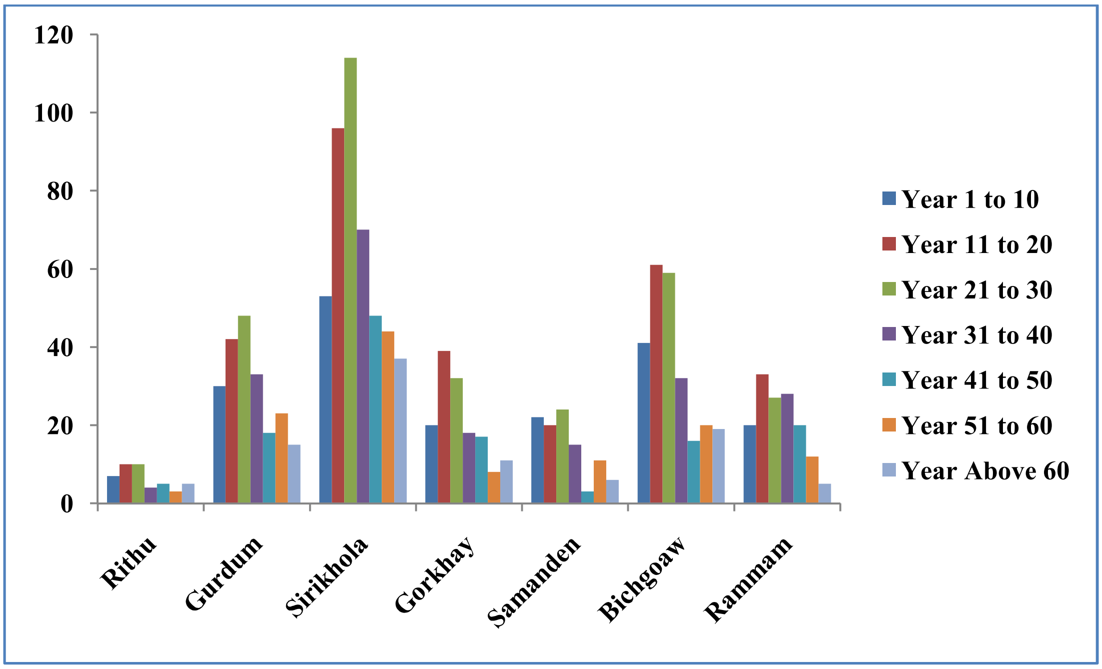

Figure 4.31: Village wise age of the local population

Both male and female actively participated in fulfilling the household needs. The involvement of the females in the agricultural field and livestock rearing was appreciable in the area. The significant population was involved with agriculture, daily wager labor, traditional liquor making, and very few were involved in government jobs in the national park settlements. Livestock was reared for milk and milk products like churpi (traditional cheese), ghee, curd, and meats. Tourism was also one of the primary sources of income in the region. People worked as tourist guides and porters during the tourist seasons. Very few residents were in government service, mainly in the West Bengal Forest Department and defense services. Primary schools were present only in selected areas like Samanden, Rammam, Sirikhola, and Gurdum villages, and only one high school which were located at Siri Khola village (Table 4.17). Most of the teachers in the school were from the urban area of Darjeeling. Population with higher education was comparatively less (Figure 4.32). To obtain higher education and medical facilities, villagers had to travel to the nearby town Darjeeling or the nearby state of Sikkim. People depend on the market for their daily requirements and sell agriculture and farm products. Nevertheless, there were very few small markets near the forest villages of the national park that were connected to Darjeeling and Siliguri by the metalled road. Rimbick and Maney Bhanjayang were the main markets of the region. The source of electricity in most of the areas was solar panels. Since no electric transmission poles were present in the study areas, water turbine based electric generators were used as an alternative source of electricity in some villages like Rithu and Rammam. Firewood was used as energy source in the villages by the entire households. Liquefied Petroleum Gas was also available in the households, however the cost of which was double the cost of that markets price due to high transportation costs.

Table 4.17: Basic facilities in form of educational and health care facilities available in the SNP and surrounding areas

Village cluster	Primary School	Middle School	Public Health Centre (PHC)	Drinking Water
Rithu	-	-	-	+
Gurdum	+	-	-	+
Sirikhola	+	+	-	+
Gorkhay	-	-	-	+
Samanden	+	-	-	+
Bichgoaw	-	-	-	+
Rammam	+	-	+	+

(+ represent present and – represent absent)

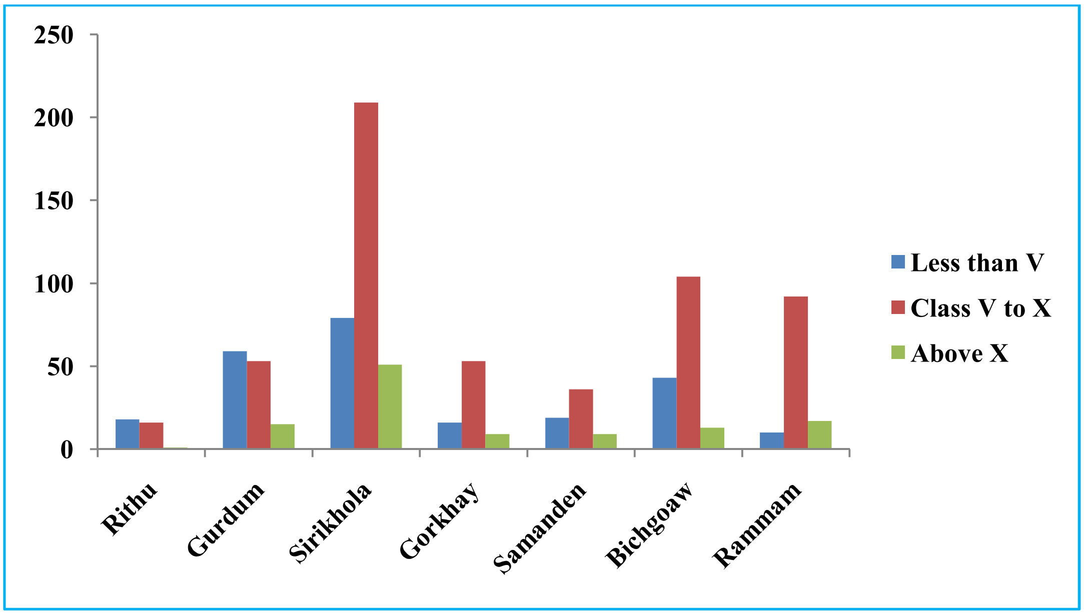

Figure 4.32: Education Qualification of the local population

4.2.3 Households and Economic demography of the study area

People in the settlements surrounding the national park were involved in tourism activities, cattle herding, agriculture, daily labor, liquor making, government jobs, and petty business. Traditional liquor making is also one of the major sources of income for the people settled in and around the study area (Figure 4.33). Liquor was brewed for local consumption and also for commercial purpose and was a profitable occupation. People collected the flowers of *Rhododendron sp.* and *Heracleum sp.* and prepared liquor that has a good market value as recreational and medicinal drinks. During the survey, 7.1% of the people were working in the government service. Darjeeling being the major town in the vicinity has some of the most attractive tourist destination that results in an inflow of a large number of tourists every year. More than 5, 50,000 tourists visit Darjeeling every year. Singalila National Park is one of the vital tourist trekking destinations. The Department of Tourism has constructed several trekkers' huts with suitable accommodation and hospitality facilities in and around the park. Villagers are actively involved in tourism-related activities by providing food and accommodation facilities in their own houses or homestays.

Figure 4.33: Alcohol preparation in the study area

Figure 4.34: Agriculture field in the study area

4.2.4 Agriculture pattern

Agriculture plays a pivotal role in the economic transformation of the rural hamlets and generates employment opportunities. It provides food and income for the socio-economic development of the rural population. The agricultural productivity of the areas was decided by the factors like temperature, rainfall pattern, soil condition, climate, choice of crops, and availability of the groundwater. In the hilly region, agriculture and its associated activities is one of the economic bases that provide employment opportunity as a labor force and contribute to the sustainable livelihood of the rural population. However, inadequate arable land, insufficient irrigation, and transport facilities have caused a decline in the farmers' income in the area. Therefore, agriculture in the hamlets was not for primarily commercial purposes but simply a way of day-to-day life. In the area, family sizes were small, and most were marginal farmers. Terrace framing was predominant, and traditional agriculture practices keeping in mind the varied agro-climatic conditions were practiced by the villagers. Adequate irrigation facilities are not available hence, farmers use pipes and bamboo channels and depend on the nearby streams and springs for the watering in their fields. Agriculture fields were scattered in different valleys and small due to the hilly terrain (Figure 4.34). Crop rotation is a predominant practice, and monoculture was not observed in the area. Crops like maize, potato, carrot, radish, cabbage, garlic, etc. were cultivated. Cultivation season starts from January-February; agriculture fields were prepared through multiple ploughing, applying manure, irrigation and cultivation practice. Harvesting season is July-August, and the harvested crops were taken and sold in nearby markets of Maney Bhanjayang and Rimbick Bazar, and some were stored for future use. The male members of the family were involved in the hard labor and construction works. Participation of female members was also high in agricultural work most of the time. Weeding and harvesting were done mainly by the female members. Labor exchanges known as ‘Parma’ were practiced in the area. Productivity of agriculture was low due to rugged terrain, occasional landslide, irregular rainfall, and lack of irrigation facilities. Good road and transport facilities are not available in the area; hence farmers do not get fair prices for the crops. Modern agriculture practices with the proper scientific intervention were lacking in the area.

4.2.5 Livestock holding pattern

Livestock play a vital role in the life of the rural population by providing nutrition, food, and economic sustainability. They contribute efficiently to crop production through manure that increases soil fertility and the water holding capacity of the soil, and animal power may be used in the agriculture field. In the fringe villages of the Singalila National Park, 58.9% of the livestock was represented by chicken, cow (28.27%), goat (7.77%), horse (2.42%), and pig (2.1%). Only one buffalo was recorded in the area, and increasingly 21 colonies of bees were also present in the area.

4.2.6 Dependency on the forest

During the study, it was found that the local population of the studied hamlets was dependent on the bio-resource for their livelihood. Non-timber forest products were collected for domestic uses only, and no commercial uses were recorded. Cattle were reared by stall feeding in all the studied villages. Cattle grazing were prohibited after 1992 in the area after Singalila was declared a national park. Fodder plants collection was the highest amongst all the forest items collected, followed by the fuel-wood collection. Twenty-two species of fodder plants were collected and was recorded in the area based on the survey conducted. Major fodder plants used were shrubs and herbs (Figure 4.35), and the respective species were *Yushania maling,* *Arundo donax, Persicaria chinensis*, *Pilea anisophylla,* etc. (Table 4.18). Various wild edible plants were available in the forest that was sustainably used by the local population. Few species like *Actindia callosa*, *Duchesna indica*, *Castanopsis hystrix*, *Viburnum erubescens*, etc. were consumed as fruits by humans. Young shoots of *Yushania maling, Thamnocalamus spathiflorus, Arisaema tortuosum*, *Diplazium maximum* etc. are used as vegetables (Table 4.19). While interacting with the village seniors and local healers, they shared their knowledge of the ethnomedicinal plant distributed in the area. Thirty-seven species of medicinal plants were recorded during the survey. Plant families like Ranunculaceae, Ericaceae, Polygonaceae, and Rosaceae were dominant in terms of a total number of medicinal plants. *Abies densa, Aconitum ferox, Betula alnoides, Clematis Montana, Rhododendron arboreum* etc. were some of the important medicinal plants recorded in the area (Table 4.20). In addition, 8 species of cultural and religious importance plants (Table 4.21) and 11 species of ethnoveterinary plants were documented (Table 4.22). However, no extractions of the medicinal plants from the protected areas were recorded as it was prohibited, and people were aware of the law. No significant negative impact on the vegetation of the Singalila National Park has observed during the study, as most of the residents were aware of the conservation of the forest and the charismatic species the red panda.

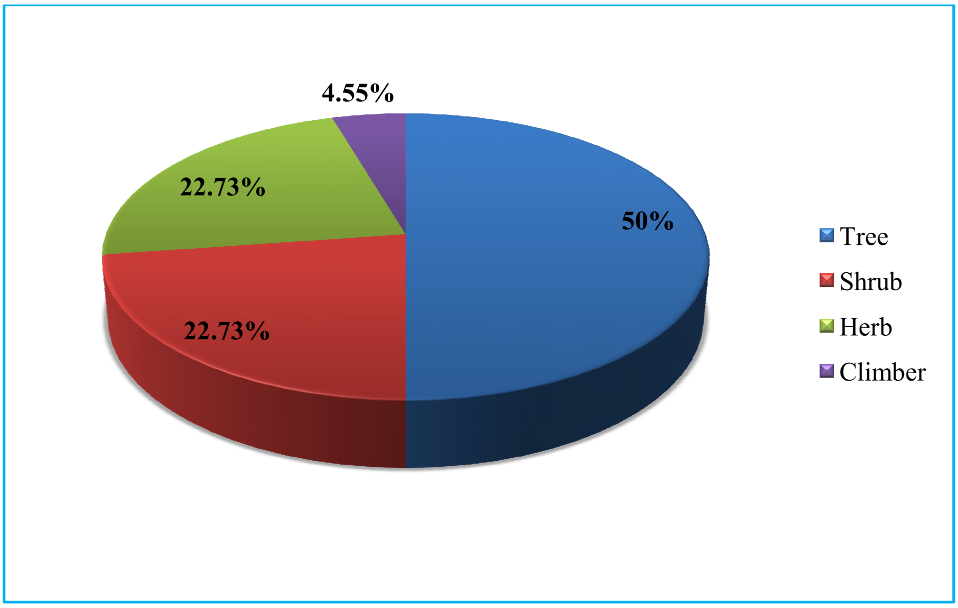

Figure 4.35: Differential habits of the fodder plants used in the SNP area by the local communities

Table 4.18: List of the fodder plants used by the local communities of Singalila National Park area, Darjeeling

Sl. No.	Scientific Name	Local Name	Family	Habit	Part used
1	*Actinidia strigosa* Hook.f.& Thomson	Tekiphal (Np)	Actinidiaceae	Climber	Leaves and fruit
2	*Arundo donax* L	Narkat (Np)	Poaceae	Shrub	Whole plant
3	*Castanopsis hystrix* Hook. f. & Thomson ex A. DC.	Katus (Np)	Fagaceae	Tree	Foliage
4	*Eragrostis gangetica* (Roxb.) Steud.	Bansho (Np)	Poaceae	Herb	Whole plant
5	*Evodia fraxinifolia* (Hook.) Benth.	Khanakpa (Np)	Rutaceae	Tree	Foliage
6	*Ficus neriifolia* Sm.	Dudilo (Np)	Moraceae	Tree	Leaves and twig
7	*Heracleum nepalense* D. Don	Chimphing (Np)	Apiaceae	Shrub	Whole plant
8	*Leucosceptrum canum* Sm.	Cheeongkung (L)	Lamiaceae	Tree	Foliage
9	*Lithocarpus pachyphyllus* (Kurz) Rehder	Bantey (Np)	Fagaceae	Tree	Young Leaves
10	*Litsea sericea* (Wall. ex Nees)	Timber (Np)	Lauraceae	Shrub	Foliage

	Hook.f.				
11	*Litsea elongata* (Nees) Hook.f.	Pahenley (Np)	Lauraceae	Tree	Young Leaves
12	*Meliosma arnottiana* (Wight) Walp.	Dabdabey (Np)	Sabiaceae	Tree	Young Leaves
13	*Pennisetum purpureum* Schumach.	Napier (En)	Poaceae	Herb	Whole plant
14	*Schefflera rhododendrifolia* (Griff.) Frodin	Bhalu chindey (Np)	Araliaceae	Tree	Foliage
15	*Persicaria chinensis* (L.) H. Gross	Ratnaulo (Np)	Polygonaceae	Herb	Whole plant
16	*Pilea anisophylla* (Hook. f.)Wedd.	Bansho (Np)	Urticaceae	Herb	Whole plant
17	*Poa annua* L.	Dubho (Np)	Poaceae	Herb	Whole plant
18	*Polygonum molle* D. Don	Thotney (Np)	Polygonaceae	Shrub	Whole plant
19	*Quercus lineata* Blume	Phalat (Np)	Fagaceae	Tree	Foliage
20	*Symplocos lucida* (Thunb.) Siebold & Zucc.	Kharane (Np)	Symplocaceae	Tree	Foliage
21	*Symplocos dryophila* Clarke	Kharane (Np)	Symplocaceae	Tree	Foliage
22	*Yushania maling* (Gamble) R.B.Majumdar& Karthik.	Malingo (Np)	Poaceae	Shrub	Leaves and young shoot

Local name: Np=Nepali, En=English, L= Lepcha

Table 4.19: Enumeration of wild edible plants used by the local communities in SNP area, Darjeeling

Sl. No.	Scientific Name	Local Name	Family	Uses	Part used
1	*Actindia callosa* Lindl	Thekiphal (Np)	Actinidiaceae	Fruit	Fruit
2	*Arisaema griffithii* Schott	Asek Makai (Np), Dhokayo (Np)	Araceae	Vegetable	Leaves
3	*Arisaema tortuosum* (Wall.) Schott T	Bir bango (Np), whip cord Cobra lily (En)	Araceae	Vegetable	Leaves and stem, and tuber
4	*Castanopsis hystrix* Miq.	Katus (Np)	Fagaceae	Seeds eaten raw and some cases	Seed

				roasted	
5	*Castanopsis tribuloides* (Sm.) A. DC.	Musure Katus (Np)	Fagaceae	Seeds eaten raw and some cases roasted	Seed
6	*Diplazium maximum* (D. Don) C. Chr.	Nakey (Bh)	Woodsiaceae	Vegetable	Young Frond
7	*Duchesna indica* (Andrews) Focke	Indian strawberry (En), Aishalu (Np)	Rosaceae	Fruit	Fruit
8	*Evodia fraxinifolia* (Hook.)Benth.	Khanakpa (Np)	Rutaceae	Pickle	Fruit and seed
9	*Fragaria daltoniana* J.Gay	Bhui Aiselu (Np)	Rosaceae	Fruit	Fruit
10	*Fragaria nubicola* (Lindl. ex Hook.f.) Lacaita	Bhui Aiselu (Np)	Rosaceae	Fruit	Fruit
11	*Girardinia diversifolia* (Link) Friis	Allo (Np) Himalayan Nettle (Eg)	Urticaceae	Vegetable and soup	Flower, leaves and young shoot
12	*Heracleum wallichii* DC	Chimphing (Np)	Apiaceae	Pickle	Seed
13	*Litsea cubeba* (Lour.) Pers.	Siltimur (Np)	Lauraceae	Pickle	Fruit
14	*Oxalis corniculata* L.	Chari Amilo (Np)	Oxalidaceae	Vegetable	Leaves
15	*Pentapanax leschenaultii* (DC.) Seem.	Chinde (Np	Araliaceae	Pickle and vegetable	Tender leaves
16	*Polygonum runcinatum*Buch.-Ham. ex D. Don	Ratnaulo (Np)	Polygonaceae	Vegetable	Whole plant
17	*Rheum australe* D.Don	Padamchal (Np)	Polygonaceae	Consumed as tea	Root
18	*Rheum nobile* Hook. f. &Thoms.	Padamchal (Np)	Polygonaceae	Pickle and vegetable	Whole plant
19	*Rhododendron arboreum* Smith	Lali gurash	Ericaceae	Local wine and	Flower

		(Np)		alcohol	
20	*Rhododendron campanulatum* D. Don	Nilo chimal (Np)	Ericaceae	Raw edible	Nectar
21	*Rosa sericea* Lindl	Sewa (Tb)	Rosaceae	Raw fruits	Fruit
22	*Rubus ellipticus* Sm.	Aeiselu (Np)	Rosaceae	Raw fruits	Fruit
23	*Rumex nepalensis* Spreng.	Halhale (Np)	Polygonaceae	Vegetable	Whole plant
24	*Thamnocalamus spathiflorus* (Trin.) Munro	Ningalo (Np)	Poaceae	Vegetable, pickle	Young shoot
25	*Urtica dioca* L.	Sishnu (Np)	Urticaceae	Vegetable and soup	Flower, leaves and young shoot
26	*Viburnum erubescens* Wall	Asaray (Np)	Adoxaceae	Fruits	Fruit
27	*Yushania maling* (Gamble) R.B.Majumdar& Karthik	Malingo (Np)	Poaceae	Vegetable, pickle	Young shoot
28	*Zanthoxylum armatum* DC	Timur (Np)	Rutaceae	Pickle and spices	Fruit

Local name: Bh=Bhutia, En=English, Np=Nepali, Tb=Tibetan

Table 4.20: Enumeration of medicinal plants in SNP areas used by the local communities for treating different ailments in their traditional medicine systems

Sl. No.	Scientific Name	Local Name	Family	Plant Part	Ailments
1	*Abies densa* Griff.	Gobra salla (Np)	Pinaceae	Leaves	Stomach pain, fever, asthma, bronchitis, tuberculosis, internal hemorrhage
2	*Aconitum ferox* Wall. ex Ser.	Bikh (Np)	Ranunculaceae	Rhizome	Diabetes, abdominal pain, cough, asthma, fever, snakebite, skin diseases.
3	*Aconitum heterophyllum* Wall.ex Royle	Bikh (Np)	Ranunculaceae	Rhizome	Antifertility, stomach-ache, antiperiodic, hysteria, piles, throat diseases, snake bite
4	*Aconitum napellus* L.	Bikuma (Np)	Ranunculaceae	Rhizome	Diabetic, tonsillitis, cough, snake bite, stomachache
5	*Anaphalis adnata* Wall.ex DC.	Buki phul (Np)	*Compositae*	Leaves	Cuts and wounds
6	*Aralia leschenaultii* (DC.) J. Wen	Chindey (Np)	Araliaceae	Flower and young shoot	Stomach disorder and weakness, kidney infection
7	*Artemisia indica* Willd.	Titepati (Np)	Compositae	Leaves and young shoot	Headache, nose bleeding, fever, skin diseases, asthma, injury
8	*Berberis angulosa* Wall. ex Hook. f. & Thomson	Chutro (Np)	Berberidaceae	Leaves	Jaundice, bloody diarrhea
9	*Berberis aristata* DC	Musa Lede (Np)	Berberidaceae	Bark, Root	Jaundice, malaria, fever, diarrhea, dysentery
10	*Betula alnoides* Buch.-Ham.ex D. Don	Saur (Np)	Betulaceae	Bark	Hysteria, antiseptic, snake bite.

11	*Betula utilis* D. Don	Bhujpat (Np)	Betulaceae	Bark	Wounds, antiseptic
12	*Clematis montana* Buch.-Ham. ex DC.	Kaneshi Lahara (Np)	Ranunculaceae	Leaves and stem	Joint pain, head ache, sinusitis, gout
13	*Daphne papyracea* Wall.ex G. Don	Lokta (Np)	Thymelaeaceae	Bark and Root	Fever, intestinal trouble, food poisoning
14	*Drymaria cordata* (L.)Willd.exSchult.	Abijhal (Np)	Caryophyllaceae	Whole plant	Sinus trouble, fever, cold and cough.
15	*Fragaria nubicola* (Lindl. ex Hook. f.) Lacaita	Bhui Aiselu (Np)	Rosaceae	Root	Cold, cough, toothache, bleeding, high altitude sickness
16	*Heracleum nepalense* D.Don	Chimphing (Np)	Apiaceae	Inflorescence and fruit	Influenza, body ache, headache.
17	*Hydrocotyle javanica* Thunb.	Golpatta (Np)	Apiaceae	Leafy shoot	Throat infection, pneumonia
18	*Oxalis corniculata* L.	Chari Amilo (Np)	Oxalidaceae	Leaves	Anemia, piles, poisoning, indigestion, diarrhea, piles
19	*Persicaria capitata* D.Don	Ratnaulo (Np)	Polygonacea	Shoot	Insect bite and Urinary tract infection
20	*Persicaria vivipara* (L.) Ronse Decr.	Ratnaulo (Np)	Polygonaceae	Root	Fever, jaundice, stomach ache
21	*Potentilla lineata* Trevir.	Bajradanti (Np)	Rosaceae	Whole plant	Cough, cold, toothache, fever
22	*Rheum acuminatum* Hook. f. & Thomson	Padamchal (Np)	Polygonaceae	Rhizome	Stomach ache, body ache
23	*Rhododendron arboreum* Smith	Lali Gurash (Np)	Ericaceae	Flower	Throat infection, altitude sickness, dysentery, throat chock by fishbone and chicken bone
24	*Rhododendron barbatum* Wall.	Lal chimal (Np)	Ericaceae	Flower	Blood pressure
25	*Rhododendron campanulatum* D. Don	Nilo chimal (Np)	Ericaceae	Leaves	Cold, chronic rheumatism.
26	*Rhododendron lepidotum* Wall. ex G. Don	Bhale sunpatey (Np)	Ericaceae	Leaves and flower	Lung disease, cold, fever
27	*Rosa sericea* Wall. ex Lindl.	Sewa (Tb)	*Rosaceae*	Fruits and flower	Menstrual disorders, liver disease

28	*Rubia cordifolia* L.	Majito (Np)	Rubiaceae	Root and fruit	Kidney problem, liver ailment, headache, snake bite
29	*Rubus ellipticus* Sm.	Aeiselu (Np)	Rosaceae	Root	Fever, gastric problem, diarrhea
30	*Rumex nepalensis* Sprengel	Halhale (Np)	Polygonaceae	Young shoot and root	Skin diseases, ulcer, hepatitis, hair fall
31	*Swertia chirata* Roxburgh ex Fleming	Chirato (Np)	Gentianaceae	Shoot	Fever, diabetes, skin diseases, constipation, piles
32	*Taxus baccata* L.	Dhangre Salla (Np)	Pinaceae	Leaves	Leaves extract used in breast cancer
33	*Thalictrum reniforme* Wall.	Dampatey (Np)	Ranunculaceae	Root	Jaundice, stomach ache
34	*Urtica parviflora* Roxb.	Sishnu (Np)	Urticaceae	Flower and young leaves	Blood pressure, liver troubles, jaundice, bone fracture and dislocation
35	*Valeriana hardwickii* Wall	Nakkali Jatamansi (Np)	Valerianaceae	Stem, root	Epilepsy, Sore and wound, nerve diseases, urinary trouble
36	*Viola biflora* L.	Ghattey Ghans (Np)	Violaceae	Root, flower, leaf	Vomiting, bacterial and fungal infection, antiseptic
37	*Yushania maling* (Gamble) R.B. Majumdar & Karthik.	Malingo (Np)	*Poaceae*	Root	Ringworm

Local name: Np=Nepali

Table 4.21: Enumeration of ritual plants used by the local communities in SNP area, Darjeeling in their ethno cultural and religious festivals

Sl. No.	Scientific Name	Local Name	Family	Uses	Part used
1	*Abies densa* Griff.	Gobra salla (Np)	Pinaceae	Used as *incense* *Cones used as decorative*	Dried leaves, cone
2	*Daphniphyllum himalense* (Benth.) Müll. Arg.	Chandan (Np)	Daphniphyllaceae	Religious value Used for preparation of local paper	Whole plant
3	*Leontopodium jacotianum* Beauverd	Bhuke Phul, Jhulo (Np)	Compositae	Used as incense	Whole plant
4	*Nephrolepis cordifolia* (L.) C. Presl	Paniamala (Np)	Nephrolepidaceae	Used as decorative	Leaves
5	*Rhododendron lepidotum* Wall.ex G. Don	Bhale sunpatey (Np)	Ericacea	Used as incense	Leaves
6	*Thamnocalamus spathiflorus* (Trin.) Munro	Ningalo (Np)	Poaceae	Religious value; used during offering prayers	Whole plant
7	*Tsuga dumosa* (D. Don) Eichler	Tengre (Np)	Pinaceae	Used as decorative	Cones
8	*Yushania maling* (Gamble) R.B. Majumdar & Karthik.	Malingo (Np)	Poaceae	Religious value; used during offering prayers	Whole plant

Local name: Np=Nepali

Table 4.22: Enumeration of ethno-veterinary plants used by the local communities in SNP area

Sl. No	Scientific Name	Local Name	Family	Uses	Part used
1	*Betula utilis* D. Don	Bhujapat (Np)	Betulaceae	Wounds in cattle	Bark
2	*Daphne bholua* Buch.- Ham. ex D. Don	Lokti (Np)	Thymelaeaceae	Diarrhea and dysentery in goat	Leaves
3	*Iris hookeri* Penny ex G. Don	Lise (Np)	Iridaceae	Wounds in cattle	Stem
4	*Leucosceptrum canum* Sm.	Ghurpis (Np)	Lamiaceae	Bone fracture in cattle	Bark
5	*Rhododendron arboreum* Smith	Lali guras	Ericaceae	Diarrhea and dysentery	Flower
6	*Rubia cordifolia* L	Majito (Np)	Rubiaceae	Post-delivery complication	Whole plant
7	*Rubus ellipticus* Sm	Aeiselu (Np)	Rosaceae	Cold and fever	Tender leaves
8	*Swertia chirayita* (Roxburgh ex Fleming)	Chrato (Np)	Gentianaceae	Fever in cattle	Whole plant
9	*Taxus bacata* L	Dhangre salla (Np)	Taxaceae	Bone fracture	Bark
10	*Thamnocalamus spathiflorus* (Trin.) Munro	Nigalo (Np)	Poaceae	Root used to cure ringworm in cattle Leaves used to cure diarrheal and dysentery	Roots, Leaves and young shoot
11	*Yushania maling* (Gamble) R.B. Majumdar & Karthik.	Malingo (Np)	Poaceae	Root used to cure ringworm in cattle Leaves used to cure Diarrhoea and dysentery	Roots, Leaves and young shoot

Local name: Np=Nepali

4.2.7 Mapping of the National Park

Normalized difference vegetation index (NDVI) was used to understand the change in the vegetation of the Singalial National Park. The vegetation was quantified by measuring the near-infrared and red light. The vegetation strangely reflects near infra-red and red light are the ones that are observed. The value of the NDVI ranges from -1 to +1. The values depict the different components; if it has a negative value, it is likely water. If the value is close to +1, it would be the dense green vegetation. However, the value close to zero denotes a non-green area or an urban area. Values close to 0.2 to 04 represent grassland or shrubs, whereas a high value indicates temperate forest or tropical rainforest. The comparative analysis of the NDVI for the three years 1992, 2004 and 2016 was considered during the study. The Singalila National Park was declared National Park in the year 1992; hence the year was selected as the base year for data collection before the declaration of the National Park, there were practices of cattle grazing in the area. Other points of data collection were considered after the gap of 12 years each for 2 times. The NDVI maps indicate that the value close to 0 was comparatively high during the year 1992 (Figure 4.36) but it was improved in the year 2004 (Figure 4.37) and 2016 (Figure 4.38) respectively. A similar value closer to 1 was higher in the year 2016, which shows the dense vegetation of the park has improved after the declaration of the National Park. Therefore no negative impact was shown in the core area of the Singalila National Park, which supports our survey conducted in the villages of the Singalila National Park and surrounding area.

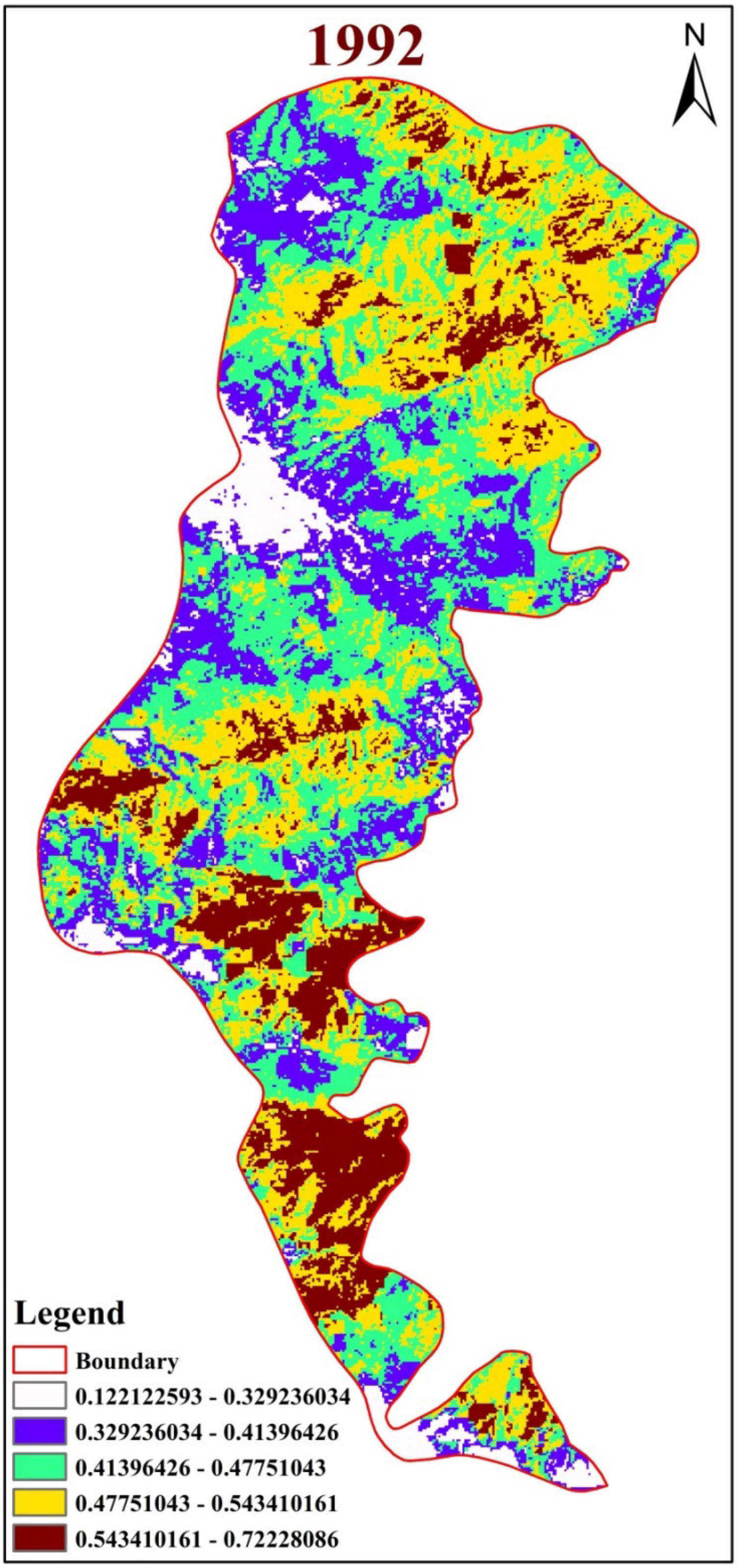

Figure 4.36: NDVI of Singalila National Park for the year 1992

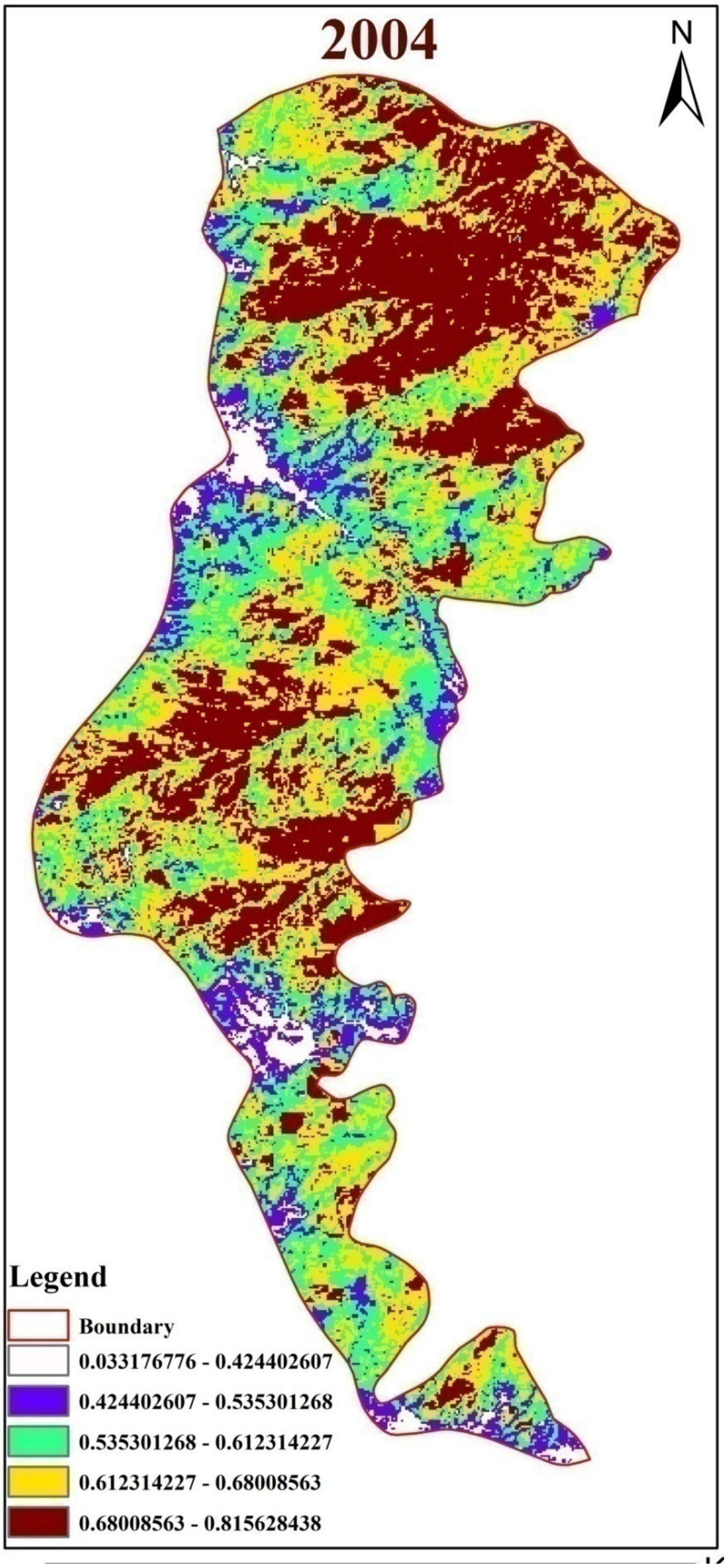

Figure 4.37: NDVI of Singalila National Park for the year 2004

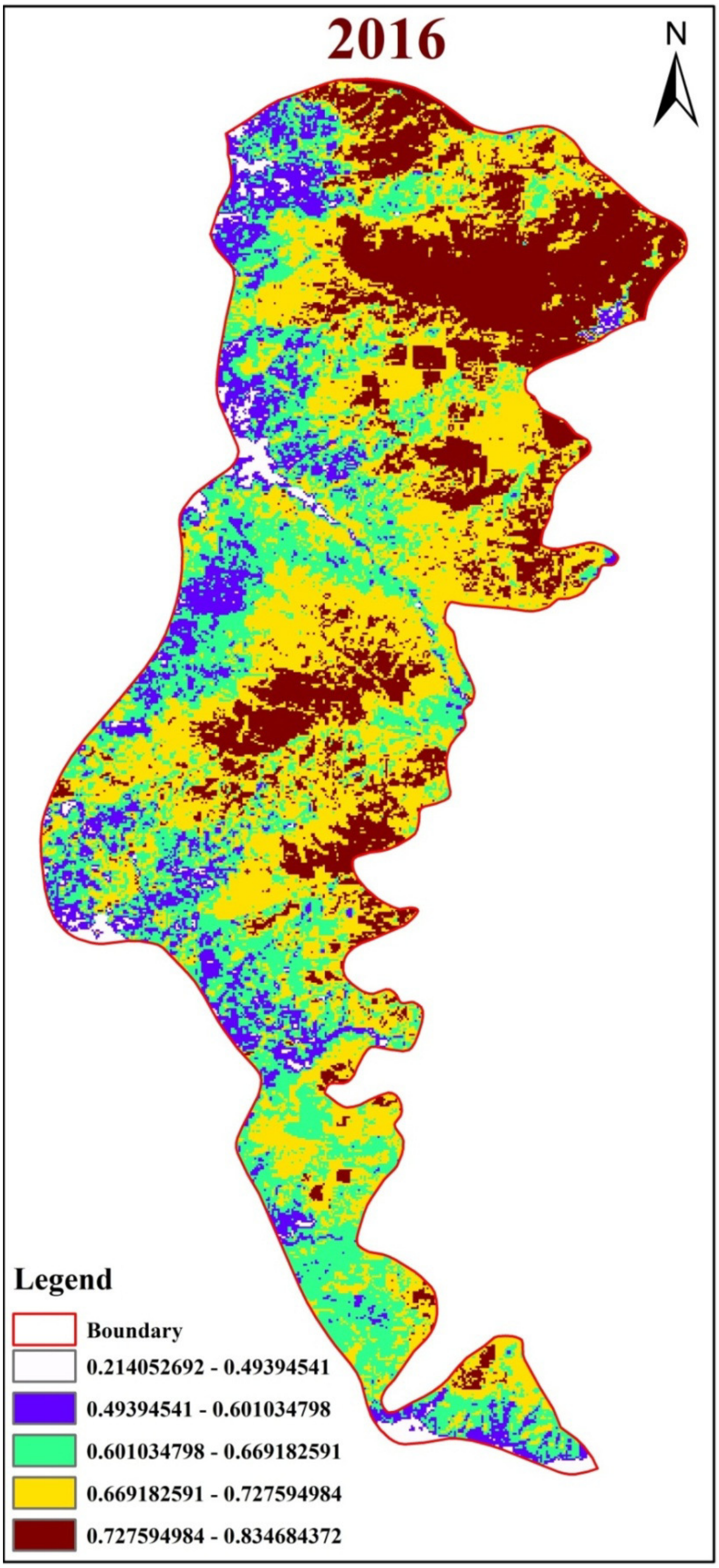

Figure 4.38: NDVI of Singalila National Park for the year 2016

4.3 *Rhododendron arboreum* in Singalila National Park

The *Rhododendron arboreum* Smith is distributed in all four forest types in Singalila National Park. Our study observed that the *Rhododendron arboreum* was distributed throughout the national park from Tumbling, Gairibans, Kaiyakatta, Kalpokahri, Sandakphu, Molle, to Phalut and was very common in the park. The species is evergreen, 4-20 m in height; the bark is greyish-brown in color, with exfoliating flakes. Petioles are 10-25 mm, leaf blades are leathery, oblong-lanceolate, and bases are cuneate or round. The inflorescence dense with around 20 flowers clustered together and the rachis is around 10-15 mm. The flowering of the plant occurred between March to June in the SNP.

4.3.1 Distribution of *Rhododendron arboreum* within Singalila National Park

4.3.1.1 *Rhododendron arboreum* in Temperate Oak Forest (2400 m to 2800 m)

Rhododendron arboreum and *Rhododendron arboreum* var. *cinnamomeum* were recorded along with the two other *Rhododendron* species i.e. *Rhododendron grande* and *Rhododendron griffithianum* in the oak forest. The estimated density of the *Rhododendron arboreum* var. *cinnamomeum* in the area was 114.266^{-1} and *Rhododendron arboreum* Smith was 57.143^{-1} in the Oak Forest along with the other tree species. Density of *Rhododendron grande* and *Rhododendron griffithianum* were 62.5^{-1} and 53.571^{-1} respectively. The dominance of the *Rhododendron* was high in the area as the Importance Value Index of *Rhododendron arboreum* var. *cinnamomeum and Rhododendron arboreum* were 27.661 and 10.931, respectively. IVI of the *Rhododendron grande* and *Rhododendron griffithianum* were 10.197 and 9.88, respectively, in the area. The associated tree species in the area with the *Rhododendron* were mainly *Lithocarpus pachyphyllus, Quercus lamellose*, *Quercus lineata*, *Symplocos dryophila*, *Litsea sericea*, *Magnolia campbellii* etc. The forest was mainly covered by the tree belonging to the family Ericaceae, Fagaceae, and Lauraceae recorded 6 species each and were followed by Sapindaceae (4 species) Lauraceae (3 species), Symplocaceae (3 species), Rosaceae (3 species), and Araliaceae (3 species).

The dominant shrub species associated with *Rhododendron* in the forest were *Yushania maling* and was followed by *Thamnocalamus spathiflorus*, *Polygonum molle*, *Sambucus adnata*, *Viburnum erubescens* etc.

4.3.1.2 *Rhododendron arboreum* in Broad Leaf Deciduous Forest (2800 m to 3100 m)

The *Rhododendron arboreum* Smith and *Rhododendron arboreum* var. *cinnamomeum* were recorded along with the three other species of *Rhododendron* viz. *Rhododendron grande, Rhododendron falconeri* and *Rhododendron griffithianum* in the Broad Leaf Deciduous Forest/*Rhododendron* forest. The estimated density of the *Rhododendron arboreum* var. *cinnamomeum* in the area was 164.286^{-1}, and that of *Rhododendron falconeri* was 130.357^{-1}. The density of *Rhododendron arboreum* Smith was 57.375^{-1}, *Rhododendron grande* was 75^{-1}, and *Rhododendron griffithianum* was 14.286^{-1} in the forest along with the other tree species. The dominance of the *Rhododendron arboreum var. cinnamomeum* was highest among all the tree species in the area with the Importance Value Index of 37.989 as compared to that of *Rhododendron arboreum* Smith was 6.868. The IVI of the *Rhododendron grande*, *Rhododendron falconeri* and *Rhododendron griffithianum* were 10.89, 10.197, and 1.493 respectively in the area. Tree species associated with the *Rhododendron* in the forest were *Lithocarpus pachyphyllus*, *Sorbus cuspidate*, *Acer campbelli, Osmanthus suavis* etc. The highest number of species was recorded under the family Ericaceae (6 species) and was followed by the family Fagaceae (5 species) and Sapindaceae (4 species). The dominant shrub species in the area were *Yushania maling* and was, followed by *Thamnocalamus spathiflorus*, *Polygonum molle*, *Viburnum erubescens* etc.

4.3.1.3 *Rhododendron arboreum* in Broad Leaf Coniferous Forest (3100 m to 3300 m)

During the study in the Broad Leaf Coniferous Forest *Rhododendron arboreum* was recorded along with the five tree species of *Rhododendron* namely *Rhododendron barbatum, Rhododendron cinnabarnum, Rhododendron falconeri, Rhododendron grande* and *Rhododendron hodgsonii* in the Broad Leaf Coniferous forest. The total estimated density of the area was 1098.11^{-1} and the density of the *Rhododendron arboreum* was 126.786^{-1}, density of *Rhododendron grande* was 76.786^{-1}, *Rhododendron barbatum* was 32.143^{-1}, *Rhododendron falconeri* was 23.214^{-1} and *Rhododendron hodgsonii* was 48.2143^{-1}. *Rhododendron arboreum* was one of the dominant species in the area. The importance value index of *Rhododendron arboreum* was 31.127 and that of *Rhododendron grande* was 16.536, *Rhododendron hodsonii* 7.652, *Rhododendron falconeri* was 3.181 *and Rhododendron barbatum* was 5.921 in the forest.

The associated tree species in the area with the *Rhododendron* were mainly *Abies densa*, *Tsuga sp*., *Quercus lamellose*, *Betula utilis*, *Quercus lineata*, *Lithocarpus pachyphyllus, Litsea sericea*, etc. Highest number of species was recorded under the family Ericaceae (8 species) which was followed by the family Pinaceae, Rosaceae, and Fagaceae having 2 species each. Other families i.e., Betulaceae, Daphiphyllaceae, Aquifoliaceae, Lauraceae, Magnoliaceae, and Araliaceae recorded 1 species each in the forest. The dominant shrub species in association with *Rhododendron* in the forest were *Thamnocalamus spathiflorus, Yushania maling* and was followed by *Viburnum erubescens, Sambusus adnata,* etc.

4.3.1.4 *Rhododendron arboreum* in Sub Alpine Conifer Forest (above 3300 m)

The *Rhododendron arboreum* in the Sub Alpine Conifer Forest of the Singalila National Park was recorded along with the *Rhododendron barbatum*, *Rhododendron cinnabarinum*, *Rhododendron falconeri*, *Rhododendron grande* and *Rhododendron hodgsonii.* The stem density estimated for the tree layers in the area was estimated 844.44^{-1}. The stem density of the *Rhododendron arboreum* was 219.44^{-1}, *Rhododendron barbatum* was 44.44^{-1}, *Rhododendron cinnabarinum* was 38.889^{-1}, *Rhododendron falconeri* was 36.111^{-1}, and *Rhododendron grande* was 11.111^{-1}. The importance value index of *Rhododendron arboreum* was 64.927 and that of *Rhododendron barbatum* was 11.6, *Rhododendron hodsonii* was 8.269, *Rhododendron falconeri* was 9.534 and *Rhododendron grande* was 3.371 in the area. The associated tree species in the area with the *Rhododendron* were mainly *Abies densa*, *Betula utilis*, *Sorbus cuspidata* etc. The highest number of species was recorded under the family Ericaceae (6 species) which was followed by the family Rosaceae (2 species). Other families i.e., Betulaceae, Daphiphyllaceae, Pinaceae, and Sabiaceae recorded 1 species in the region. The dominant shrub species associated with *Rhododendron* in the forest were *Thamnocalamus spathiflorus, Yushania maling,* which was followed by *Daphne bholua, Rubus paniculatus* etc. which were slightly less prominent.

Apart from the quadrats studied in the Singalila National Park, few other *Rhododendron* species were sighted as they were either very rare or epiphytic and existed outside the studied quadrats. The lists of the sighted *Rhododendron* in

Singalila National Parks (Figure 4.39 - 4.49) during the study may be seen at Table 4.23.

Table 4.23: Distribution of different species of *Rhododendron* in Singalila National Park area, Darjeeling

Sl. No.	Scientific Name	Altitude	Status in Singalila National Park	Conservation Status
1	*Rhododendron arboreum*	2400-3650	Common	Least Concern
2	*Rhododendron arboreum* var *cinnamomeum*	2400-3650	Common	Least Concern
3	*Rhododendron barbatum*	2900-3600	Common	Vulnerable
4	*Rhododendron campanulatum*	3000-3600	Common	Least Concern
5	*Rhododendron cinnabarinum*	2900-3600	Common	Vulnerable
6	*Rhododendron dicepiens*	3200-3400	Rare	Least Concern
7	*Rhododendron falconeri*	2900-3500	Common	Least Concern
8	*Rhododendron grande*	2400-2900	Common	Least Concern
9	*Rhododendron griffithianum*	2400-2800	Common	Least Concern
10	*Rhododendron hodgsonii*	3300-3600	Common	Least Concern
11	*Rhododendron edgeworthi*	2400-2500	Rare	Least Concern
12	*Rhododendron lepidotum*	3000-3600	Common	Least Concern
13	*Rhododendron lindley*	2400-2500	Very Rare	Least Concern
14	*Rhododendron triflorum*	2400	Rare	Least Concern
15	*Rhododendron dalhousieae*	2400-2600	Common	Least Concern

Table 4.24: Different ethnobotanical uses of various species of *Rhododendron* distributed in SNP area

Sl. No.	Scientific Name	Local Name	Uses	Plant part used
1	*Rhododendron arboreum*	Lali Gurash	It was used as medicinal plant for the treatment of throat ache, anti-diarrheal activity, and anti-microbial activity.	Flowers, leaves, roots and bark for the medicinal value.
			Flowers were used for alcohol and juice preparation. Pickles were also prepared from the flowers in the villages located in the vicinity of the parks.	Logs, branches used for fire wood
			Woods of *Rhododendron arboreum* were one of the preferred hard woods used as firewood.	
2	*Rhododendron arboreum* var *cinnamomeum*	Lali Gurash	It was used as s medicinal plant for the treatment of throat ache, anti-diarrheal activity, and anti-microbial activity.	Flowers, leaves, roots and bark for the medicinal value.
			Flowers were used for alcohol and juice preparation. Pickles were also prepared from the flowers in the villages located in the vicinity of the parks. Woods of *Rhododendron arboreum* were one of the preferred hard woods used as firewood.	Logs, branches used for fire wood

3	*Rhododendron barbatum*	Lal Chimal	It is used for fish poisoning and also used as fire woods. Also used as decorative flowers.	Flowers, leaves, stem and branches
4	*Rhododendron campanulatum*	Nilo Chimal	The plant has medicinal values. It is used for the treatment of in sciatica, Syphilis joint pain, body ache, sore throat, chronic rheumatism, chronic fevers, curing skin diseases, etc.	Leaves, flowers, seed, stem and root
5	*Rhododendron cinnabarinum*	Sano Chimal	Flowers of the species are used as flavouring agent and making of jam. But leaves are Poisonous to animal. It is also used for decoration. Woods are used as fire wood.	Flowers, stem
6	*Rhododendron dicepiens*	Jhukaune Korlingo	Leaves of the species are used for packaging of butter and cheese. It is also used as fire wood.	Leaves, stem
7	*Rhododendron falconeri*	Pahelo Korlingo	Leaves of the species are used for packaging of butter and cheese. It is also used as fire wood.	Leaves, stem
8	*Rhododendron grande*	Patley Korlingo	Fire wood and flowers are used as decoration	Stem and flowers
9	*Rhododendron griffithianum*	Seto Chimal	Leaves of the species are used for packaging of butter and cheese. It is also used as fire wood. Flowers are used for decoration.	Leaves, stem, flowers

10	*Rhododendron edgeworthi*	Edwarthi ko Chimal	It is used for the treatment of the skin diseases	Leaves
11	*Rhododendron lepidotum*	Bhaley Sunpati	The species is used as purgatives or aperients. The leaves of the species have religious and cultural value. It is used as incense in Monastery.	Bark, leaves

Figure 4.39: *Rhododendron lepidotum*

Figure 4.40: *Rhododendron arboreum* var. *cinnamomeum*

Figure 4.41: *Rhododendron arboreum*

Figure 4.42: *Rhododendron fulgens*

Figure 4.43: *Rhododendron hodgsonii*

Figure 4.44: *Rhododendron edgeworthii*

Figure 4.45: *Rhododendron dalhousieae*

Figure 4.46: *Rhododendron griffithianum*

Figure 4.47: *Rhododendron lindley*

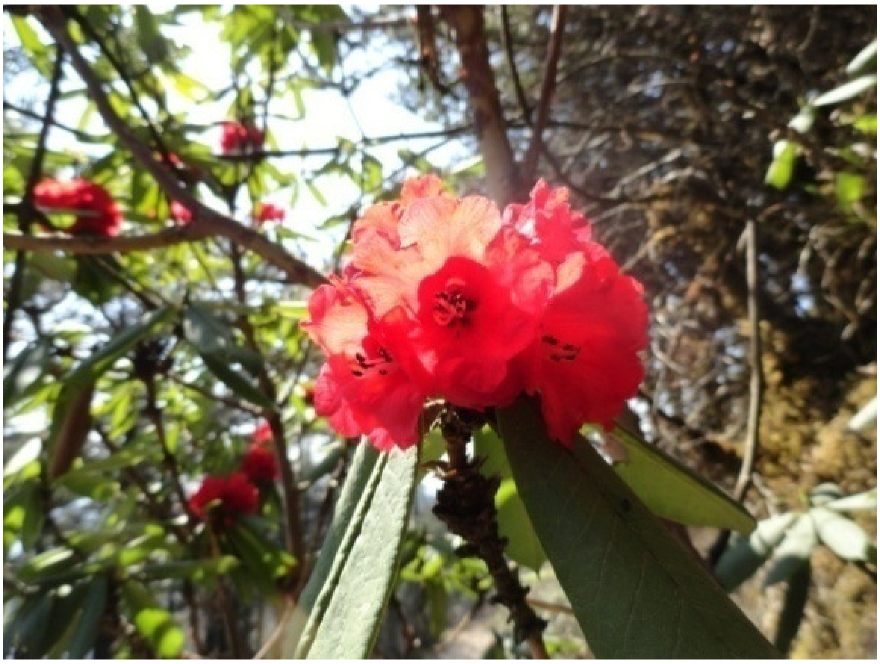

Figure 4.48: *Rhododendron barbatum*

Figure 4.49: *Rhododendron campanulatum*

4.4 Behavioural studies on red panda (*Ailurus fulgens*)

The red panda is one of the endangered and protected animals throughout its in-situ habitat. Before initiating research work in the Singalila National Park the basic behaviour, activity, movement, feeding habit, breeding behaviour, etc. were observed in the ex-situ facility, i.e., in the Conservation Breeding Centre of red panda and display area in Padmaja Naidu Himalayan Zoological Park (Darjeeling Zoo). Activity patterns are vital facets of animal behaviour and help to manage and conserve the animal. Biotic and abiotic factors like anthropogenic impact, food availability, weather condition, prey, and predator affect the activity patterns of the animals (Winne, 2004; James, 2006; Zhang, 2011). Various studies on red pandas have been published to date, but significantly less information is available on the behaviour of red pandas in the wild. Captive studies help understand the basic activity pattern that may not be obtained in other ways. A proper understanding of the behaviour is essential for conserving and managing the species both in captivity and natural habitat. Attempts have been made to highlight some behaviour pattern depicted by a red panda in ex-situ facility, distribution and direct sighting in the wild, and provide input towards better and scientific management ensuring successful breeding of the species.

4.4.1 Observation of behaviour of red panda in captivity

Through behaviour study it was observed that the red panda was more active at dawn, dusk, and night. The red panda spent time resting, basking, and sleeping on the trees and nesting boxes during the daytime. The male activities were higher than the female when the pair was kept in the off-display area. Male spent 53.1% of the total observed time in active behaviour. Male spent most of the time scent marking, feeding, defecating, and moving inside the enclosure. Female red panda showed

34.97% of active behaviour, comparatively lesser than the male (Figure 4.50). The activities of the individuals vary according to the enclosure, visitors, weather, enrichment, breeding, etc. The studied enclosure was adequately enriched, and good numbers of trees were present in it. 14.5% of the time, male red panda went out of sight, whereas female went out of sight for 3.77% of time only in the Conservation Breeding Centre, where visitors were not allowed i.e., less disturbed areas.

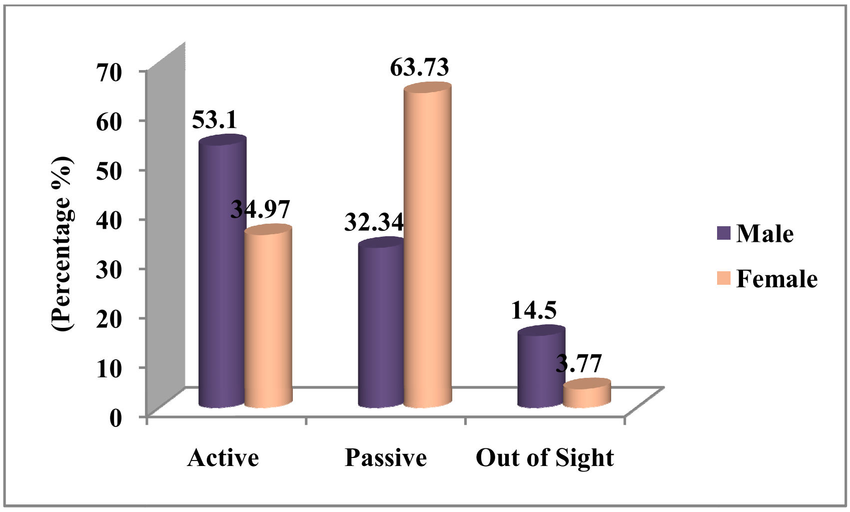

Figure 4.50: Comparative behaviour pattern of male and female red panda as observed during captive breeding programme in PNHZP, Darjeeling

The red panda is a solitary animal, but both the male and female were observed moving, resting and eating within proximity during the mating season. The scent-marking rate was increased, and males spent considerably more time following the trails and urine marking of female. Mating calls were heard before mating, and copulation lasted for 2-3 minutes in February. After 5 weeks of mating, active activities gradually became slow in the female. Before parturition, the female was seen collecting the nest-building material like leaves, twigs, and grasses. After 126 days of gestation, two cubs were born to the female. Post parturition mother spent 91.87% of its time with cubs and covered its cubs by curling over them. After that, the time spent with the cubs gradually decreased. After a fortnight, the female spent 74.78% of the time with the cubs (Figure 4.51). After 30 days, the mother spent 22.92%, after 45 days, 15.17%, and after 60 days, 6.35% of the time was spent with the cubs. Autogrooming and cub grooming were the significant activities while residing with the cubs in the breeding box. During the first week of the parturition mother spent maximum time in cub grooming (46.43%) and slept with the cubs (29.85%) (Figure 4.52). However during 2nd and 3rd week of the birth mother spent 74.78 % but cub grooming was decreased comparatively (32.36%) and mother slept with cub for 35.82% of time (Figure 4.53). Within 4th and 5th week after birth female spent less time with the cubs where the observed behaviour were cub grooming (16.07%), and mother slept with cubs (5.03%) for lesser period (Figure 4.54). Similarly after 6th to 9th week of parturition mother remained away from the cubs (84.83%) and cub grooming was only for 14.9% (Figure 4.55) (Roka, 2015).

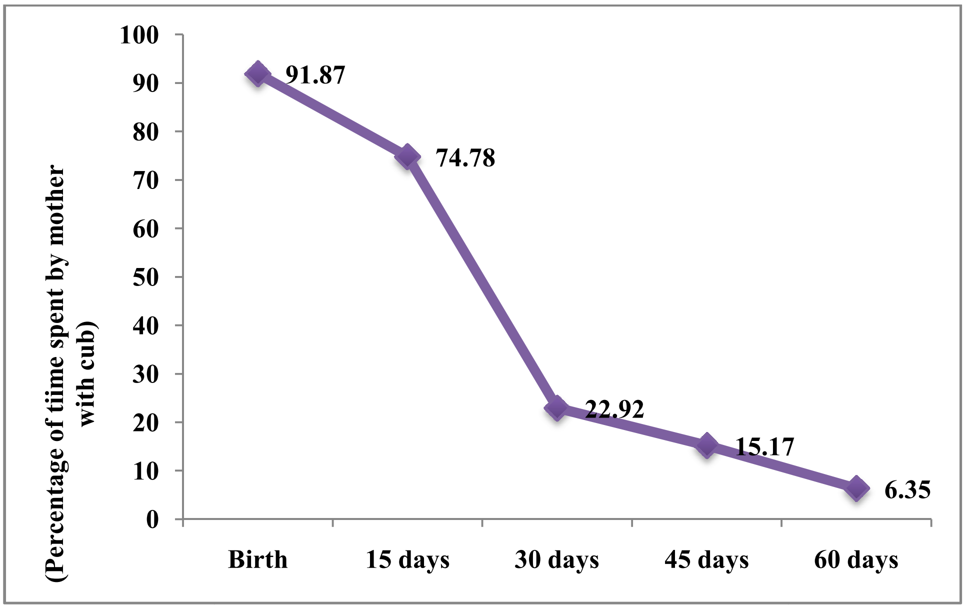

Figure 4.51: Time spent by red-panda mother with cubs

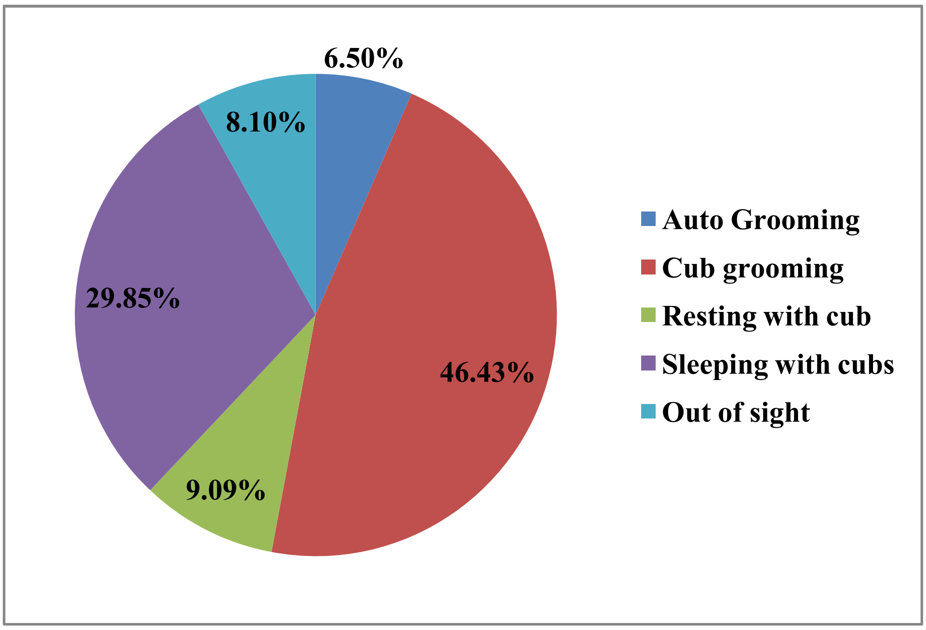

Figure 4.52: Behaviour observation of red-panda female during the first week after birth

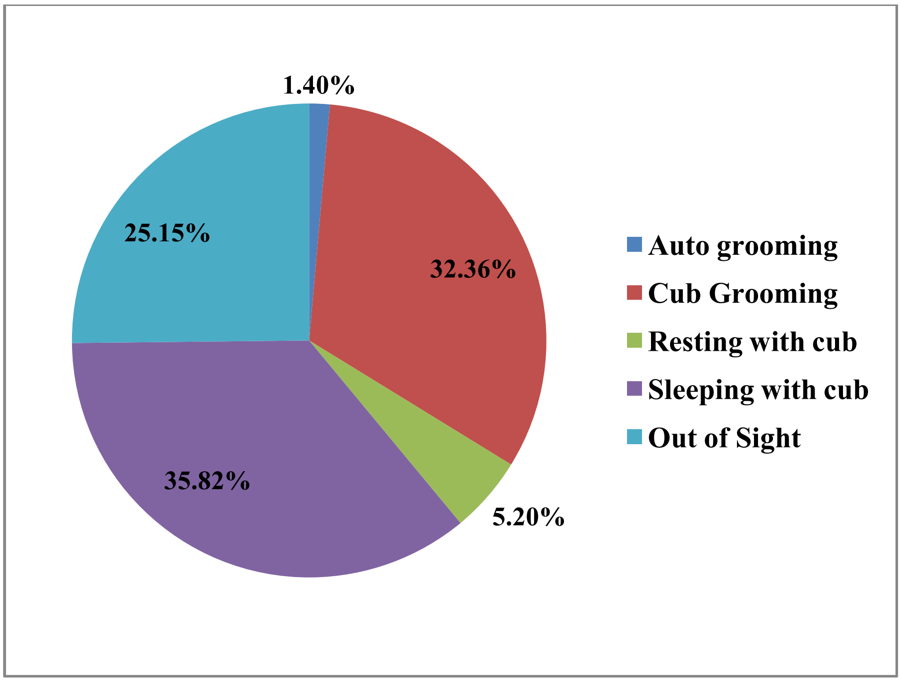

Figure 4.53: Behaviour observation of red-panda female during the 2nd and 3rd Week after birth

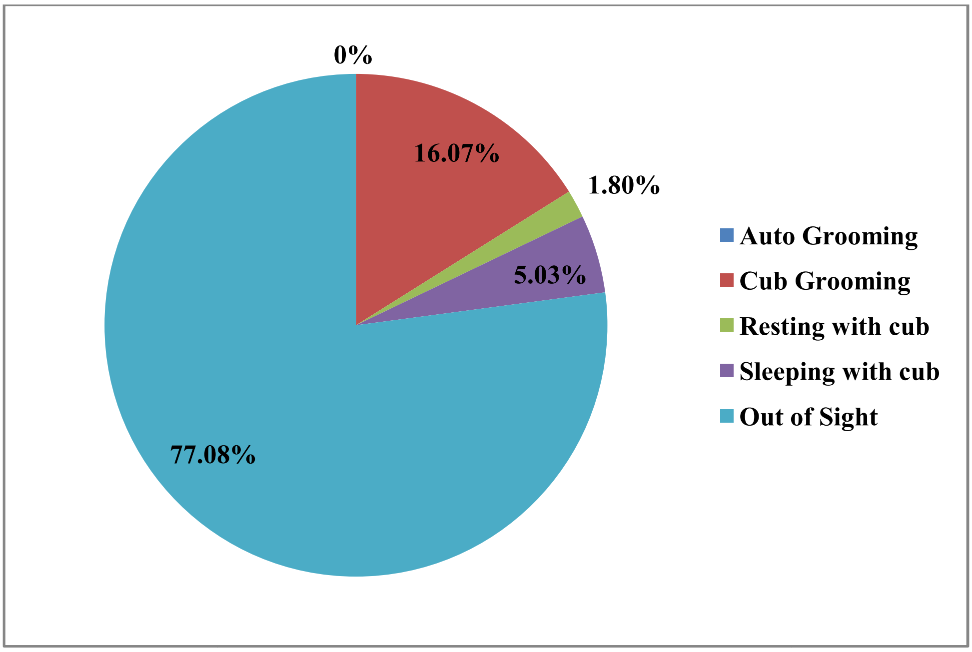

Figure 4.54: Behaviour observation of red-panda female for the 4th and 5th week after birth

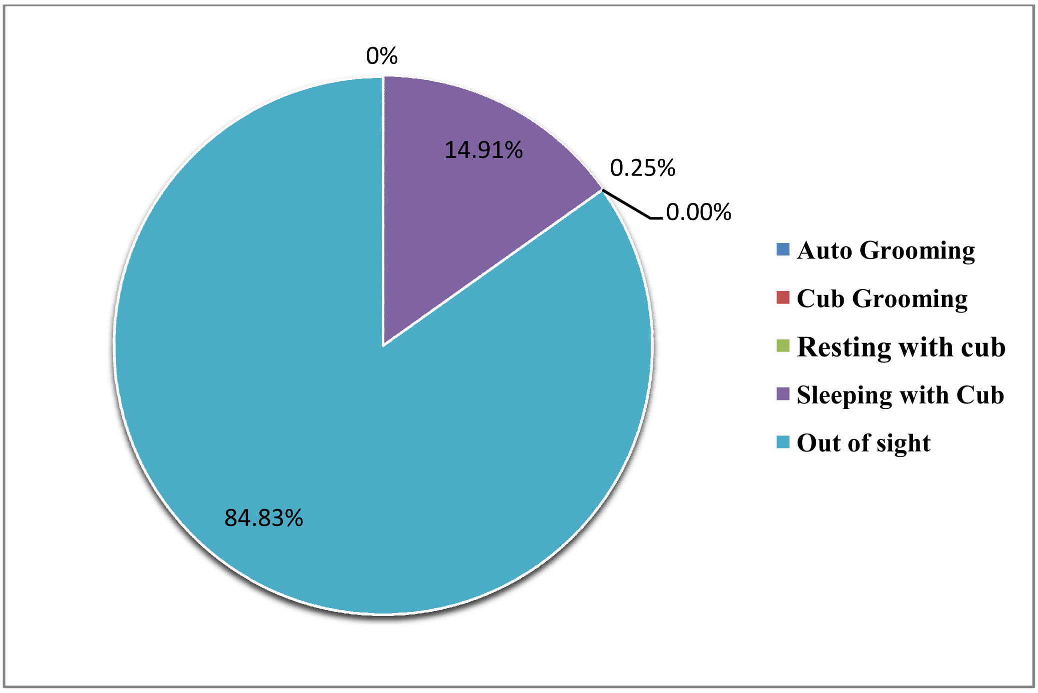

Figure 4.55: Behaviour observation of red panda female for 6th to 9th week after birth

After 14 days of birth, cubs opened eyes, and cub movement inside the nesting/cubbing box increased simultaneously. After 90 days of birth, cubs came outside the nesting box and were found eating bamboo leaves and solid foods. If any disturbances occurred near the breeding/nesting box, the mother started shifting the cubs from one place to another, similar to the cat. During the study on red panda in captivity, various causes of mortality during different ages of maturity were studied as per the available records in PNHZ Park and it was found that the rate of mortality was higher in the younger age (Figure 4.56). The causes of mortality were ill nursing by mother, respiratory failure, bronchopneumonia, old ages, subsequent weakness etc.

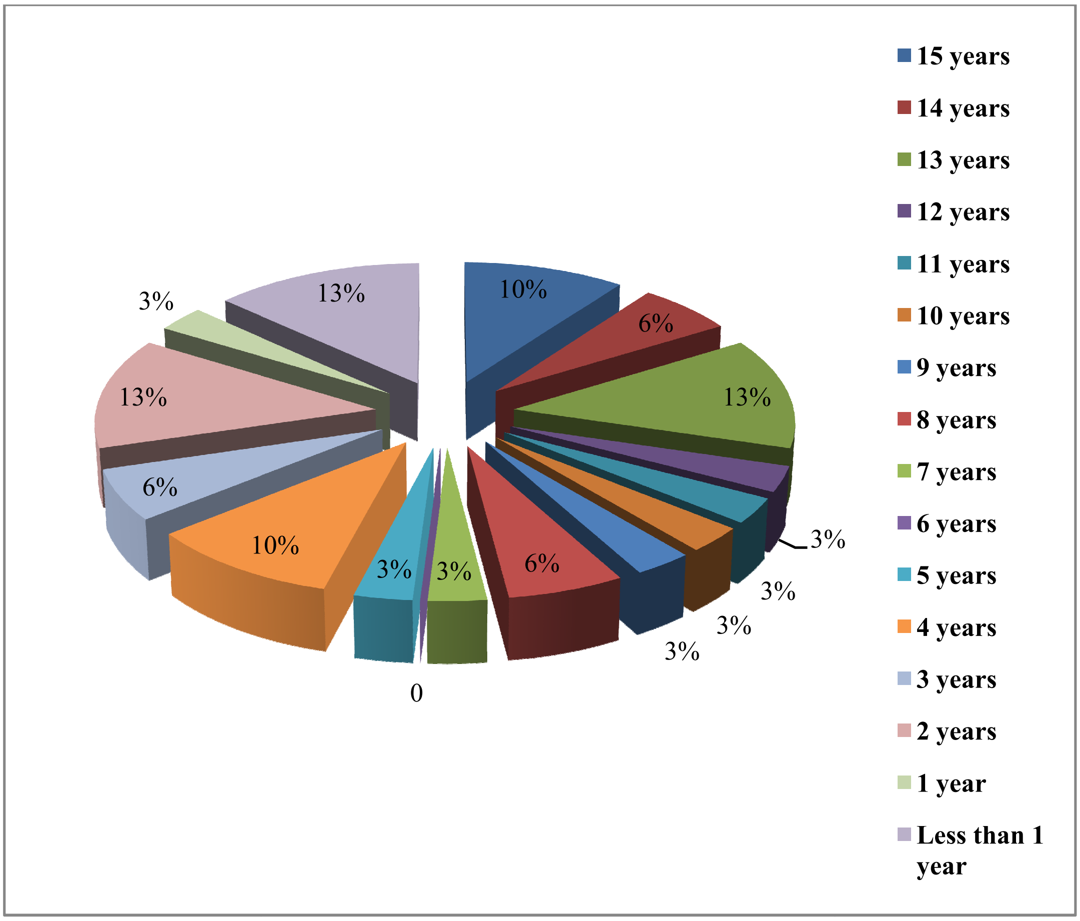

Figure 4.56: Red Panda mortality rate in relation to maturity in age

4.4.2 Genetic assessment of ex situ population of red panda (*Ailurus fulgens*) and population estimation of the wild population in Singalila National Park

In order to understand the genetic assessment of the red panda population of PNHZ Park samples were sent to LaCONES, Centre for Cellular and Molecular Biology, Hyderabad. Faecal samples were collected from the 15 red panda i.e. ten male and 5 females and blood samples were collected from four males and 3 females following all the guidelines without harming the animals. Phenol chloroform method was used for extraction of genomic DNA from blood and QIAamp DNA stool kit was used for the extraction of DNA from faecal samples (Kumar, 2016). All the samples of 15 red panda were genotyped where the average dropout was 9.8% at 14 loci and the successful rate was 89% amplification. All fourteen microsatellites were shown to be polymorphic by Allele frequency analysis in CERVUS 3.0 with mean polymorphism information content (PIC) of 0.64, and 3-7 alleles per locus. Expected (H_E) and Observed (H_O) heterozygosities were 0.714 and 0.681 respectively. Genepop v4 (Rousset, 2008) analysis with default Markov chain parameters showed that all the loci were in Hardy–Weinberg equilibrium ($p<0.001$). Inbreeding and linkage analysis FSTAT (Goudet, 1995) indicated that none of the loci are linked to each other and the red panda population had a mean inbreeding value of 0.048. Deterministic growth rate was 10.3% ($r = 0.103$, $\lambda = 1.109$), with a mean generation time of 4.27 years for both females and males, while retaining only 37% gene diversity after 100 years. Survival probability of this population without any additional intervention is less than 2%. Gene diversity could be maintained at 61% (nearly 90% of the initial diversity of 68%) by supplementing this population with one reproductively active female and male once every 5 years till 100th year.

Out of 329 samples sent to CCMB for DNA analysis, 38 individual red panda were identified in Singalila National Park based on fecal samples collected in Singalila National Park. Microsatellite genotyping was done using nine microsatellite laci (Liang, 2007, Wu 2009) and analyzed with Genemapper 3.1. The highest percentage of the red panda recorded as per DNA Analysis was 26.3% (n=10) in Gairibans Beat which was followed by the Rammam Beat and Maney Bhanjayang Beat i.e. 21.05% (n=8) and 18.42% (n=7) respectively (Figure 4.57). The study showed that distribution of red panda was higher in the core area of Gairibans and Rammam beat (Figure 4.58) where the forest was dominated by the high canopy trees.

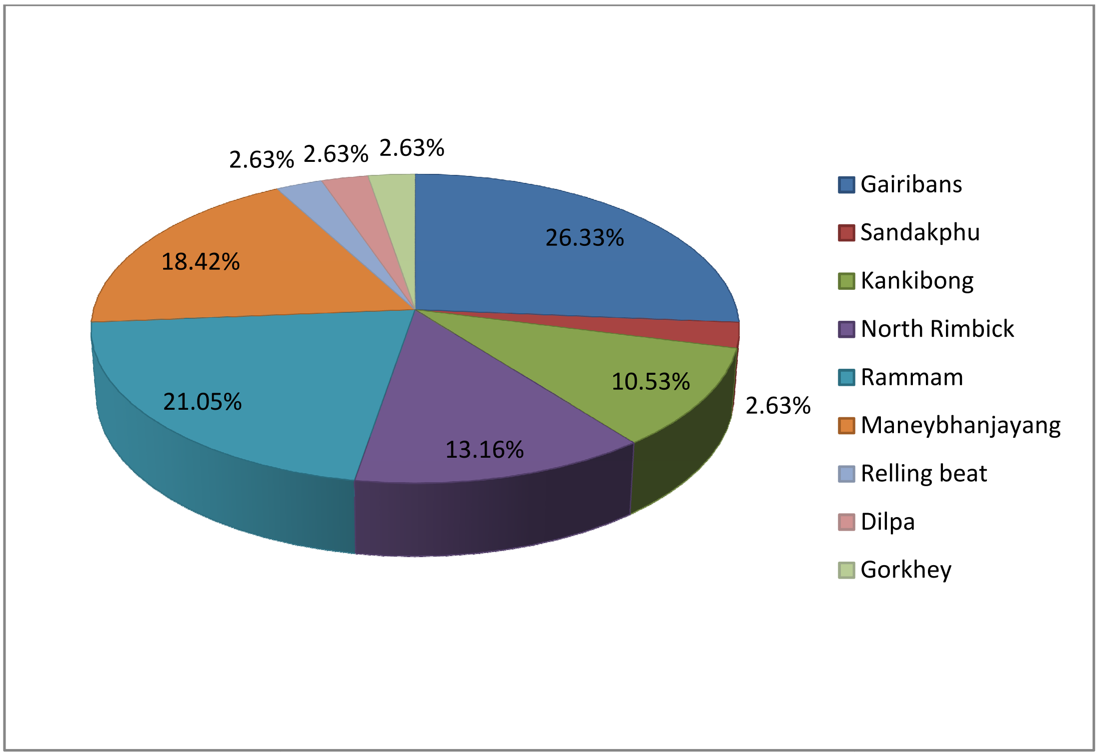

Figure 4.57: Beat wise red panda recorded as per DNA analysis

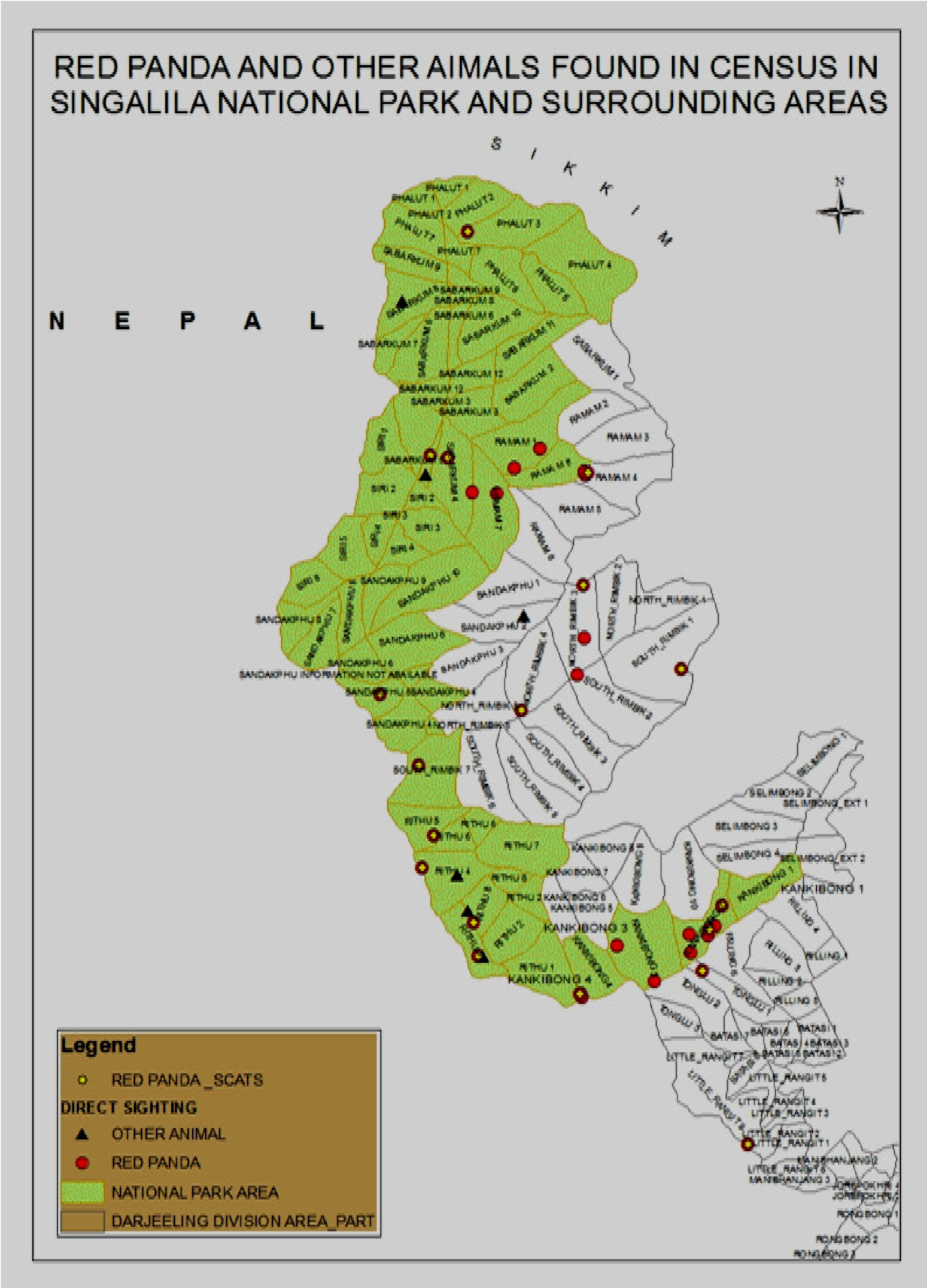

Figure 4.58: Red panda distribution in Singalila National Park area, Darjeeling

4.4.3. Red panda in Singalila National Park

After understanding the basic behaviour of the red panda in the captivity the study in the in-situ habitat i.e. in SNP was conducted. Preliminary study was conducted in the Singalila National Park to know the presence/absence of the animal in different patches of SNP and plant preference in the wild habitat. After confirmation regarding the presence of the animal, an intensive study was conducted in various blocks of the park. Direct sighting of the red panda was rare due to the shy nature of the animal. The study recorded 31 direct sightings of red panda in Singalila National Park during the various seasons. Red panda being a solitary animal in most of the cases single animal was sighted except during the breeding period. In 12.9% (n=4) of the cases red panda sighting occurred within the altitudinal zone of 2801 m to 2900 m, 41.93% (n=13) within 2901 to 3000 m altitudinal zone and 22.58% (n=7) within 3001 to 3100m altitudinal zone in the Broad Leaf Deciduous Forest (Figure 4.59).

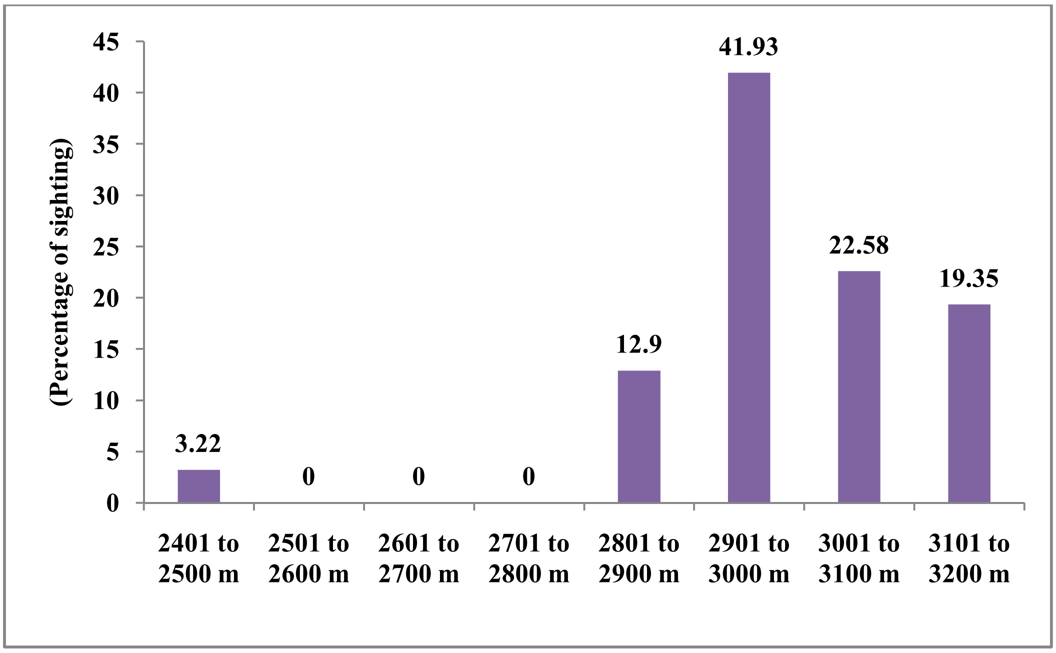

Figure 4.59: Red Panda sighting at different altitudes of SNP, Darjeeling

All the sighted animals were adult in size and were active and seemed healthy. The sightings were for a very short period, and most of the cases the animals were found resting at the top of the trees (Figure 4.60). Water source and canopy covers are most important to red panda (Pradhan*,* 2001). The rate of encounter of the red panda and its scats (Figure 4.61) were highest at the altitude between 2900 m and 3000 m with 56.25% of scat were sighted in the area. 18.75% of scats were sighted in the altitude between 2400 m and 2800 m where the vegetation was dominated by the oak trees. Frequencies of scat samples were high near water sources, greater canopy forest, less disturbed area, and area with a high density of fodder plants and fruits. Sighting was relatively less in the Sub Alpine forest between the altitudes of 3100 to 3600 m in the Singalila National Park.

Figure 4.60: Direct sighting of Red Panda in Singalila National Park

Figure 4.61: Red panda scat/pellets sighted in SNP, Darjeeling

4.4.3.1 Plant preference of Red Panda

During the present study in Singalila National Park, a total of 31 direct sightings of red panda occurred at various seasons. Red panda were sighted on 16 plant species in Singalila National Park. The plant with the direct red panda sightings were *Abies densa* 14.81% (n=4), *Lithocarpus pachyphyllus* 14.18% (n=4), *Rhododendron arboreum* 11.11% (n=3), etc. (Table 4.25). Plants belonging to the family Fagaceae were used maximum for resting and sleeping by red panda during the daytime and were followed by Ericaceae, Pinaceae, and Araliaceae (Figure 4.62). Four red panda were sighted on the ground while feeding on the bamboo leaves. The encounter rate of the red panda has been positively associated with the greater canopy forest, less disturbed area, high density of edible plants, and water.

Table 4.25: Red panda sighted on different plant species of various families in SNP area, Darjeeling

Sl. No.	Scientific Name	Family	Local Name	Percentage of direct sighting
1	*Abies densa* Griffith	Pinaceae	Gobray	14.81% (n=4)
2	*Lithocarpus pachyphyllus* (Kurz) Rehder	Fagaceae	Bantay	14.18% (n=4)
3	*Rhododendron arboreum* var. *cinnamomeum* (Wallich ex G.Don) Lindley	Ericaceae	Lali Gurash	11.11% (n=3)
4	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	Musuray Katus	7.4% (n=2)
5	*Schefflera rhododendrifolia* (Griff.) Frodin	Araliaceae	Bhalu Chinday	7.4% (n=2)
6	*Betula utilis* D.Don	Betulaceae	Bhujapat	7.4% (n=2)
7	*Rhododendron griffithianum* Wight	Ericaceae	Seto Chimmal	3.7 % (n=1)
8	*Ilex fragilis* Hooker	Aquifoliaceae	Lishey	3.7 % (n=1)

9	*Eurya acuminata* DC.	Pentaphylacaceae	Ghinjani	3.7 % (n=1)
10	*Rhododendron falconeri* Hooker f.	Ericaceae	Kurlingo	3.7 % (n=1)
11	*Symplocos lucida* (Thunb.) Siebold & Zucc.	Symplocaceae	Kholmay	3.7 % (n=1)
12	*Vitex negundo* L.	Verbenaceae	Pachpatey	3.7 % (n=1)
13	*Magnolia campbellii* Hooker f. and Thomson	Magnoliaceae	Ghogay chap	3.7 % (n=1)
14	*Acer campbelli* Hooker f and Thomson ex Hiern	Sapindaceae	Kapasi	3.7 % (n=1)
15	*Merrilliopanax alpinus* (Clarke) C.B. Shang	Araliaceae	Phutta	3.7 % (n=1)
16	*Litsea sericea* (Wall. ex Nees) Hook. f.	Lauraceae	Lekh Siltimbur	3.7 % (n=1)

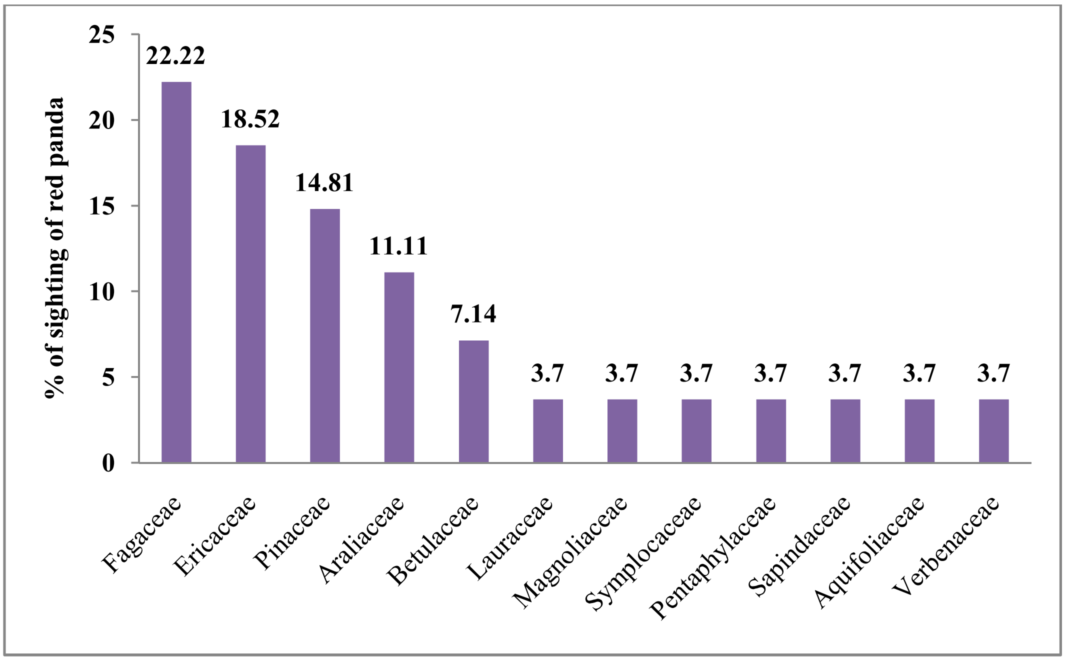

Figure 4.62: Direct sighting of red panda on various plant families in SNP, Darjeeling

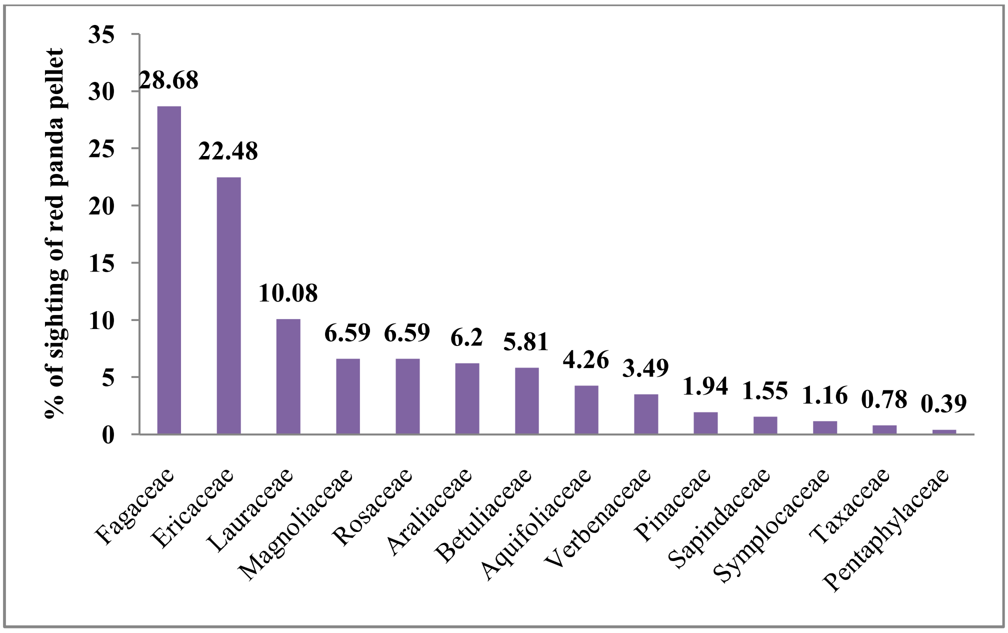

Figure 4.63: Sighting of red panda pellets on various plant families in SNP, Darjeeling

Pellet/scat gives a good indication of the presence and the habitat suitability for the species. In SNP red panda pellets/scats were sighted on 23 different plant species. The plant species with the presence of the group of red panda pellets/scats were *Lithocarpus pachyphyllus* 22.48% (n=58), *Rhododendron arboreum* 12.4% (n=32), *Sorbus cuspidate* 6.59% (n=17), *Magnolia campbellii* 6.59% (n=17) etc. (Table 4.26). Encounters of scats/pellets were highest on the plant species belonging to family Fagaceae, Ericaceae and Lauraceae respectively (Figure 4.63). Frequencies of pellet and direct sighting were most numerous within the 100 m distance of water.

Table 4.26: Sighting of red panda scat on different plant species of various families in SNP area, Darjeeling

Sl. No.	Scientific Name	Family	Local Name	Percentage of sighting
1	*Lithocarpus pachyphyllus* (Kurz) Rehder	Fagaceae	Bantay	22.48% (n=58)
2	*Rhododendron arboreum* var. *cinnamomeum* (Wallich ex G.Don) Lindley	Ericaceae	Lali gurash	12.4% (n=32)
3	*Sorbus cuspidata* (Spach) Hedl.	Rosaceae	Tenga	6.59% (n=17)
4	*Magnolia campbellii* Hooker f. and Thomson	Magnoliaceae	Ghogey chap	6.59% (n=17)
5	*Rhododendron griffithianum* Wight	Ericaceae	Seto chimmal	6.2% (n=16)
6	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	Musuray Katus	6.2% (n=16)
7	*Betula utilis* D.Don	Betulaceae	Bhujapat	5.81 % (n=15)
8	*Merrilliopanax alpinus* (Clarke) C.B. Shang	Araliaceae	Phutta	5.81 % (n=15)
9	*Litsea sericea* (Wall. ex Nees) Hook. f.	Lauraceae	Lekh Siltimbur	5.81% (n=15)
10	*Ilex fragilis* Hooker	Aquifoliaceae	Lishey	4.26 % (n=11)
11	*Litsea elongata* (Nees) Hooker f.	Lauraceae	Pahili	3.88 % (n=10)
12	*Vitex negundo* L.	Verbenaceae	Pachpatey	3.49 % (n=9)
13	*Rhododendron falconeri* Hooker f.	Ericaceae	Kurlingo	3.1 % (n=8)
14	*Tsuga dumosa* (D.Don) Eichler	Pinaceae	Tingray	1.55 % (n=4)
15	*Acer campbelli* Hooker f and Thomson ex Hiern	Sapindaceae	Kapasi	1.55 % (n=4)

16	*Pieris formosa* Wall	Ericaceae	Balu	0.77 % (n=2)
17	*Symplocos lucida* (Thunb.) Siebold & Zucc.	Symplocaceae	Kolmay	0.77 % (n=2)
18	*Taxus baccata* L.	Taxaceae	Dinghray	0.77 % (n=2)
19	*Symplocos dryophila* Clarke	Symplocaceae	Kharanay	0.39 % (n=1)
20	*Schefflera rhododendrifolia* (Griff.) Frodin	Araliaceae	Bhalu Chinday	0.39 % (n=1)
21	*Abies densa* Griffith	Pinaceae	Gobray	0.39 % (n=1)
22	*Eurya acuminata* DC.	Pentaphylacaceae	Ghinjani	0.39 % (n=1)
23	*Machilus edulis* King ex Hook.f.	Lauraceae	Kawlo	0.39 % (n=1)

4.4.3.2 Phytosociological observation as per red panda/scat sightings

The quantification of the diversity of trees is essential to understand the forest dynamics as it influences the energy flow, nutrient cycle and provides suitable habitat for animals. It is also important to study the understory tree species as it shows the species composition of the communities (Sagar, 2008). Phytosociological analysis conducted in the red panda and pellet encountered area revealed a total of 40 tree species belonging to 26 genera and 18 families. The family with the highest number of species was Ericaceae with 11 species that was followed by Betulaceae, Fagaceae, Lauraceae, and Sapindaceae each having 3 species, while family Aralaceae, Pinaceae, Rosaceae, and Symplocaceae had 2 species each (Table 4.27). The rest of the families had a single species. Total stem density for the woody species was estimated to be 1276 individual ha^{-1}. The highest density was recorded for *Lithocarpus pachyphyllus* with 118.27 ha^{-1} and was followed by *Rhododendron arboreum* with 97.12 ha^{-1}, *Rhododendron griffithianum* with 96.15 ha^{-1}, and *Abies densa* with 89.42 ha^{-1}. The total estimated abundance was 89.03, the highest abundance was recorded for

Rhododendron hodgsonii (5.4) and was followed by *Rhododendron barbatum* (5.2) and *Abies densa* (4.43). The highest frequency was recorded for *Lithocarpus pachyphyllus* (45.19%), *Rhododendron arboreum* (41.35%), and *Symplocos dryophila* (35.58%). Comparing the Raunkiaer's frequency distribution for class A, B, C, D and E i.e. 53%, 14%, 9%, 8% and 16% respectively, the tree species in the red panda encountered area showed three classes i.e. A, B and C with species exhibiting 72.5%, 22.5% and 5% observed frequency respectively whereas D and E were nil in the study area (Figure 4.64). The most dominating species as per IVI in the study area was *Lithocarpus pachyphyllus* (47.86) followed by *Abies densa* (33.01) and *Rhododendron arboreum* (22.6) (Figure 4.65). The Shannon-Wiener diversity index (H') was 1.452 and the species richness (D) was 1.098. The species dominance (CD) and evenness for tree species (J') were estimates as 0.045 and 0.907 respectively.

A total number of 19 shrub species belonging to 11 families were recorded in the red panda and its scat sighted area. The family with the highest number of shrubs in the area was Rosaceae with 4 species. Shrubs with the highest density in the area were *Thamnocalamus spathiflorus*, *Yushania maling, Berberis aristata, Polygonum mollee, Rhododendron lepidotum, Rubus ellipticus, Rubus lineatus* and *Viburnum continifolium*. Similarly, *Smilax ovalifolia, Rubus buergeri, Theropogon pallidus,* and *Clematis Montana* were herb species with the highest density in the area. *Actinidia callosa*, *Rubia cordifolia* and *Schisandra grandiflora* were few climber species recorded in the area.

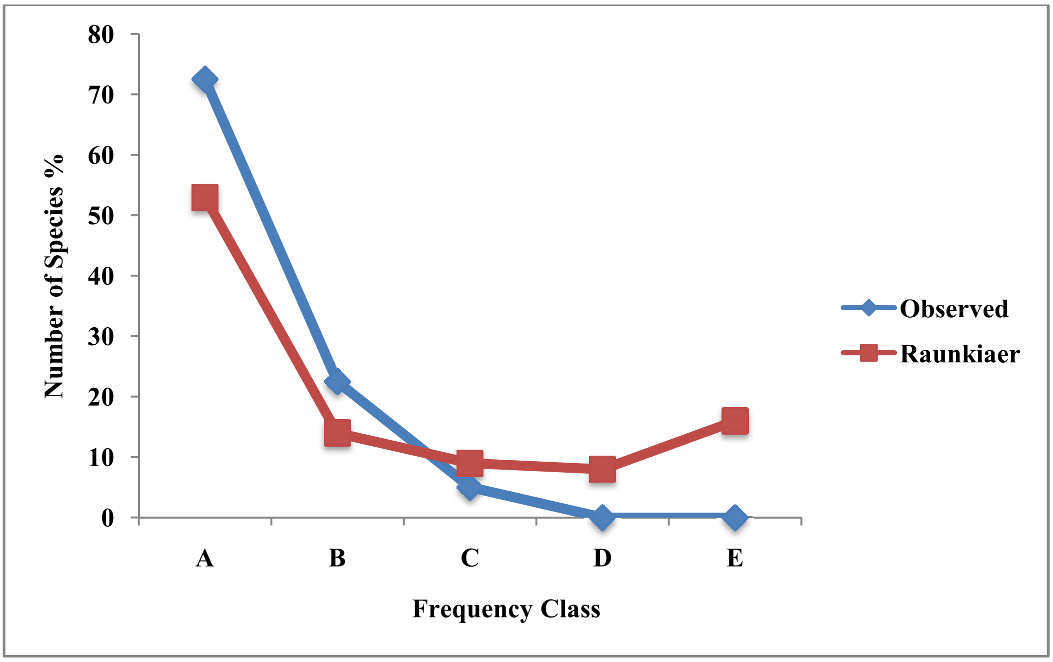

Figure 4.64: Comparison of Observed Frequency of tree layer with Raunkiaer's frequency distribution in SNP, Darjeeling

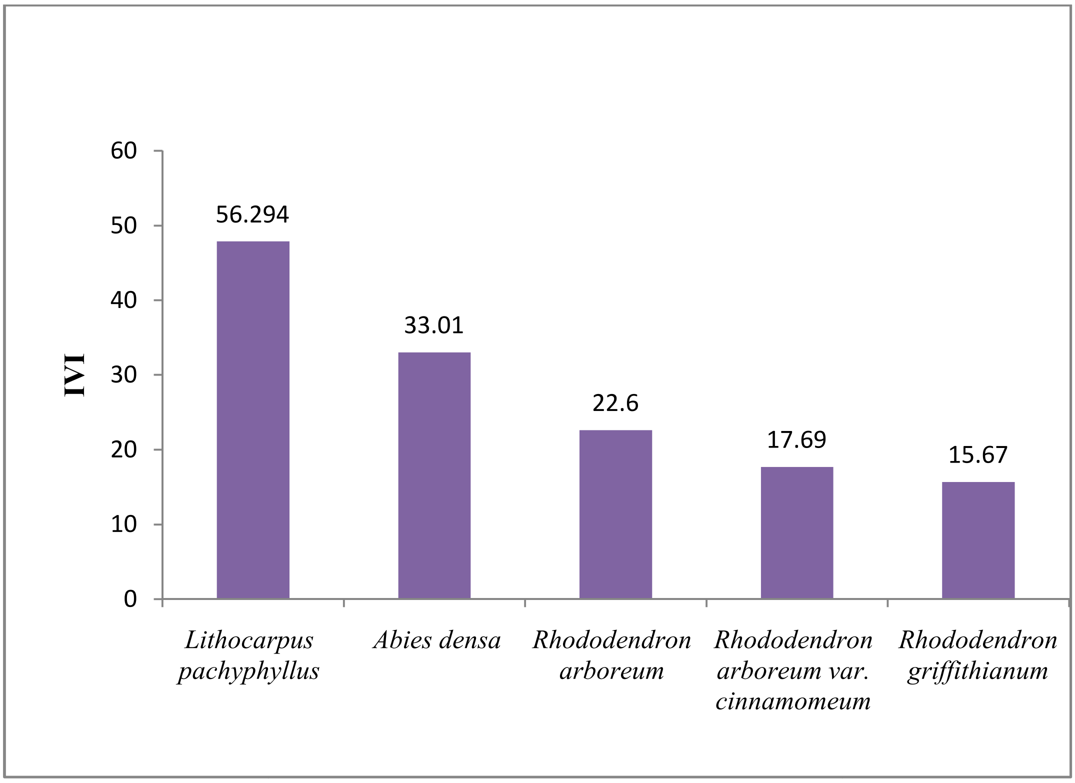

Figure 4.65: Tree Species with relatively High Importance Value in the red panda sighted area of SNP, Darjeeling

Table 4.27: Composition of tree layer in the red panda/scat sighted area of SNP detailing the associated species with their ecological parameters

Scientific Name	Family	F	D	A	R.F.	R.D.	R.Dom.	IVI
Abies densa Griffith	Pinaceae	20.19	89.42	4.43	3.52	7.01	22.48	33.01
Acer campbelli Hooker. f. and Thomson ex Hiern	Sapindaceae	19.23	28.85	1.5	3.36	2.26	0.681	6.3
Acer caudatum Wallich	Sapindaceae	1.92	2.88	1.5	0.34	0.23	0.007	0.57
Acer pectinatum Wallich ex Nicholson	Sapindaceae	0.96	1.92	2	0.17	0.15	0.003	0.32
Alnus nepalensis D. Don	Betulaceae	4.81	9.62	2	0.84	0.75	0.126	1.72
Betula alnoides Buch.-Ham.ex D. Don	Betulaceae	9.62	18.27	1.9	1.68	1.43	1.115	4.22
Betula utilis D.Don	Betulaceae	15.38	33.65	2.19	2.68	2.64	0.472	5.79
Castanopsis hystrix Hook. f. & Thomson ex A. DC.	Fagaceae	0.96	0.96	1	0.17	0.08	0.002	0.25
Castanopsis tribuloides (Sm.) A.DC.	Fagaceae	12.5	19.23	1.54	2.18	1.51	0.514	4.2
Daphniphyllum himalense (Bentham) Mueller Argoviensis	Daphiphyllaceae	9.62	29.81	3.1	1.68	2.34	0.214	4.23
Endospermum chinense Benth.	Euphorbiaceae	8.65	13.46	1.56	1.51	1.06	0.0215	2.59
Eurya acuminata DC.	Pentaphylacaceae	8.65	11.54	1.33	1.51	0.9	0.054	2.47
Ilex fragilis Hooker	Aquifoliaceae	24.04	42.31	1.76	4.19	3.32	1.104	8.61
Lithocarpus pachyphyllus (Kurz) Rehder	Fagaceae	45.19	118.27	2.62	7.89	9.27	30.707	47.86
Litsea elongata (Nees) Hooker f.	Lauraceae	9.62	25	2.6	1.68	1.96	0.273	3.91

Litsea sericea (Wall. ex Nees) Hook.f.	Lauraceae	23.08	33.65	1.46	4.03	2.64	1.076	7.74
Machilus edulis King ex Hook.f.	Lauraceae	5.77	14.42	2.5	1.01	1.13	0.257	2.39
Magnolia campbellii Hooker f. and Thomson	Magnoliaceae	20.19	23.08	1.14	3.52	1.81	0.932	6.26
Meliosma dilleniifolia (Wall. ex Wight & Arn.)Walp.	Sabiaceae	10.58	12.5	1.18	1.85	0.98	0.079	2.9
Merrilliopanax alpinus (Clarke) C.B. Shang	Araliaceae	16.35	18.27	1.12	2.85	1.43	0.098	4.38
Osmanthus suavis King ex C.B.Clarke	Oleaceae	21.15	49.04	2.32	3.69	3.84	1.33	8.86
Prunus undulata Buch.-Ham.ex D.Don	Rosaceae	6.73	8.65	1.29	1.17	0.68	0.144	2
Pieris formosa Wall	Ericaceae	12.5	31.73	2.54	2.18	2.49	0.105	4.77
Quercus lamellosa Smith	Fagaceae	14.42	30.77	2.13	2.52	2.41	2.909	7.84
Quercus lineata Blume	Fagaceae	8.65	15.39	1.78	1.51	1.21	0.799	3.51
Rhododendron arboreum Smith	Ericaceae	41.35	97.12	2.35	7.21	7.61	7.772	22.6
Rhododendron arboreum var. cinnamomeum (Wallich ex G. Don) Lindley	Ericaceae	25	77.89	3.12	4.36	6.1	7.224	17.69
Rhododendron barbatum Wallich ex G. Don	Ericaceae	4.81	25	5.2	0.84	1.96	0.304	3.1
Rhododendron falconeri Hooker. f.	Ericaceae	8.65	28.85	3.33	1.51	2.26	0.252	4.02
Rhododendron grande Wight	Ericaceae	9.62	26.92	2.8	1.68	2.11	0.239	4.03
Rhododendron griffithianum Wight	Ericaceae	32.69	96.15	2.94	5.7	7.54	2.429	15.67
Rhododendron hodgsonii Hooker f	Ericaceae	4.81	25.96	5.4	0.84	2.03	1.695	4.57

Rhododendron campanulatum D. Don	Ericaceae	1.92	1.92	1	0.34	0.15	0.001	0.49
Schefflera rhododendrifolia (Griff.) Frodin	Araliaceae	2.88	11.54	4	0.5	0.9	0.117	1.52
Sorbus cuspidata (Spach) Hedl.	Rosaceae	18.27	26.92	1.47	3.19	2.11	1.392	6.69
Symplocos dryophila Clarke	Symplocaceae	35.58	74.04	2.08	6.21	5.8	4.727	16.74
Symplocos lucida (Thunb.) Siebold & Zucc.	Symplocaceae	25.96	48.08	1.85	4.53	3.77	2.195	10.49
Taxus baccata L.	Taxaceae	5.77	6.73	1.17	1.01	0.53	0.092	1.63
Tsuga dumosa (D.Don) Eichler	Pinaceae	17.31	29.81	1.72	3.02	2.34	5.592	10.95
Vitex negundo L.	Verbenaceae	7.69	16.35	2.13	1.34	1.28	0.488	3.11

(F=Frequency, D= Density, A=Abundance, RF=Relative frequency, RD=Relative density, RA=Relative abundance, R.Dom = Relative dominance, IVI= Importance value index)

4.4.3.3 Food Habit

During the study, pellet samples were collected in pre-monsoon (summer), monsoon and, post-monsoon (winter) seasons. Commencement of summer and arrival of monsoon marked the drastic changes in plant phenology and vegetative growth. Most of the plant species attain maximum biomass by monsoon. This is the season in which the highest diversity of food plants occurs and the late monsoon has the maximum flowering and fruiting in the area. Senescence of vegetation sets in the winter, limiting the availability of forage for the species. Therefore, the pellets were collected in various seasons. *Yushania maling* and *Thamnocalamus spathiflorus* two bamboo species were the main diet of red panda during all the seasons and were highest in the pellets (Table 4.28). Both leaves and shoots were found mostly in the pellets. *Rosa sericea* and *Rubus sp.* were found only in the summer season and *Sorbus cuspidate* and *Actinidia callosa* were found in post monsoon season in the pellet samples. Leaves of *Rhododendron arboreum*, *Polygonum molle* and *Merrilliopanax alpinus* were also present in the pellets during the study. Therefore the red panda distribution in the wild depends on the presence of dense bamboo understory, *Sorbus cuspidate*, *Polygonum molle*, *Rubus sp.* (Figure 4.66) and other edible fruits and fodder.

Table 4.28: Fodder Plant of red panda recorded in Singalila National Park

Season	Scientific Name	Family	Local Name	Part consumed
	Merrilliopanax alnus	Araliaceae	Phutta (Np)	Tender leaves
	Rhododendron arboreum	Ericaceae	Lali gurash (Np)	Tender leaves
Summer	*Rosa sericea*	Rosaceae	Aishalu (Np)	Fruit
	Rubus sp.	Rosaceae	Aishalu (Np	Fruit
	Thamnocalamus	Poaceae	Nigalo (Np)	Leaves and

	spathiflorus			young shoot
	Yushania maling	Poaceae	Malingo (Np)	Leaves and young shoot
	Actinidia callosa	Actinidiaceae	Thekiphal (Np)	Fruit
	Polygonum molle	Polygonaceae	Thotney (Np)	Leaves
	Rhododendron arboreum	Ericaceae	Lali gurash (Np)	Tender leaves
Monsoon	*Thamnocalamus spathiflorus*	Poaceae	Nigalo (Np)	Leaves and young shoot
	Sorbus cuspidate	Rosaceae	Tenga (Np)	Fruit
	Yushania maling	Poaceae	Malingo (Np)	Leaves and young shoot
	Yushania maling	Poaceae	Malingo (Np)	Leaves and young shoot
Winter	*Thamnocalamus spathiflorus*	Poaceae	Nigalo (Np)	Leaves and young shoot
	Rhododendron arboreum	Ericaceae	Lali gurash (Np)	Tender leaves

Abbreviation Np is for Nepali

4.4.3.4 Microhabitat structure and use

During the study, maximum number of red panda evidence either direct or indirect was observed at an altitude level of 2800 m to 3100 m (77.41% i.e. n= 24) where the vegetation was Broad Leaf Deciduous Forest type. The animal was found utilizing mainly the three vegetation type such as Oak Forest, Broad Leaf Deciduous Forest and Broad Leaf Coniferous Forest in the Singalila National Park. The encounter of the red panda scats was higher in the Broad Leaf Deciduous Forest (56.25%) which was followed by the Oak Forest (18.75%). The presences of the species were also influenced by the presence of fodder plants, sources of clean water and disturbance level of the habitat. The dominant plant species in the red panda distributed areas were *Lithocarpus pachyphyllus* (47.86), *Abies densa* (33.01), *Rhododendron arboreum*

(22.6), *Rhododendron griffithianum* (15.67) *Symplocos dryophila* (16.74) etc. the understory vegetation were *Yushania maling, Thamnocalamus spathiflorus, Sorbus cuspidate*, *Actinidia callosa, Rosa sericea* and *Rubus sp.* The plant used by the red panda where the direct red panda sightings occurred were *Abies densa* 14.81% (n=4), *Lithocarpus pachyphyllus* 14.18% (n=4), *Rhododendron arboreum* 11.11% (n=3), *Castanopsis tribuloides* 7.4% (n=2), *Schefflera rhododendrifolia* 7.4% (n=2) etc. (Table 4.26). Similarly, red panda pellets/scats were present on *Lithocarpus pachyphyllus* 22.48% (n=58), *Rhododendron arboreum* 12.4% (n=32), *Sorbus cuspidate* 6.59% (n=17), *Magnolia campbellii* 6.59% (n=17) etc. (Table 4.27). In the SNP, red panda was found most frequently at sites on steeper slopes, with high densities of fallen logs, tree stumps, shrubs, and bamboo culms.

Singalila National Park houses numerous faunal species along with the red panda. Through this study evidences (direct/indirect) of wild high altitude faunal species such as barking deer, yellow throated martin, Asiatic black bear, Himalayan goral, wild boar, common leopard etc. (Table 4.29) were recorded (Figure 4.67). Among these animal, yellow throated martin acts as a natural predator of the red panda which is a natural threat to the species in the SNP. Common leopard also preys on red panda occasionally (Yonzon, 1991). There was no competition on the fodder plant between red panda and other high altitude wild fauna as the distribution of *Yushania maling, Thamnocalamus spathiflorus* were much higher in SNP.

Figure 4.66: Few edible plants of red panda (1. *Yushania maling* 2. *Sorbus cuspidate* 3. *Polygonum molle* 4. *Rubus* sp)

Figure 4.67: Indirect evidence of various faunal species in Singalila National Park (1. Pugmark of Common leopard, 2. Scratches by Himalayan black bear, 3. Marks of Wild boar, 4. Scats of Jungle cat)

Table 4.29: Direct and indirect evidence of faunal Species in Singalila National Park

Sl. No	Common Name	Scientific Name	Compartment*
1	Wild Boar	*Sos scrofa*	Rithu 3
2	Barking Deer	*Muntiacus muntjac*	Giribans
			Gorkhey
3	Yellow Throated Martin	*Martes flavigula*	Gorkhey
4	Himalayan Goral	*Nemorhaedus goral*	Sabarkum
5	Asiatic black bear	*Ursus thibetanus*	Rithu 1
6	Common Langur	*Seminpithecus entellus*	Rithu 1
7	Jungle Cat	*Felis chaus affinis*	Rammam
8	Hill Patridge	*Arborophila torqueola*	Gairibans
9	Satyr Tragopan	*Tragopan satyra*	Sandakphu
10	Kalij Pheasant	*Lophura leucomelana*	Rammam
			Gairibans
11	Red Jungle Fowl	*Gallus gallus*	Gairibans
12	Common leopard	*Panthera pardus*	Rimbick

(*Compartment is a part of a beat of National Park)

Chapter 5
Discussion

5. Discussions

Darjeeling being a part of Himalayan biodiversity hotspot possesses rich floristic diversity that has been attracting researcher, botanists, and tourists from different region of the world. The present research work conducted in various altitudinal zones of SNP in Darjeeling Himalaya made observations on the floral distribution and its association. The varied geomorphologic factors like topography, climate, ecological niche and suitable environment have favored the rich floristic elements and diversity of species similar to other regions of the Eastern Himalaya. The phytosociological analysis of the vegetation of SNP represented rich diversity in various altitudinal zones. Species richness, diversity and the composition of the vegetation is maintained naturally and it appears to be healthy. However, in a few patches closer to road and human habitat, the distribution and ground covers seemed to be comparatively poor in the study area. Herbs displayed the maximum number of species composition throughout the park. The population of the species, its structure and distribution was observed to understand the future stability of the flora (especially tree) in the community, the magnitude of disturbance, and regeneration (Upreti, 1982). It was observed that in the undisturbed forest, the dominant species were the matured trees which indicated that the anthropogenic disturbances were absent in the core area of the National park. The basal area and the density of the tree species were higher in the core area compared to the road side and the buffer vegetation. But in case of shrubs and herbs differences were not distinct. The structure of the forest is contributed by the density and the frequency of the tree species. If a species has same numbers of individuals in all the community it is referred as homogeneously distributed (Yam, 2016) but in this study the species were heterogeneously distributed in the study area. Various factors and magnitude of disturbance are responsible for the species richness and diversity (Raven, 1997). Factors like substrate attribute and topography, micro climate, slope affects the abundance and distribution of the species in the vegetation type in Singalila National Park. Variation in the species richness in different patches was associated with the slope, soil character, topography geomorphology etc. The flora of both the slopes of Singalila National Park was almost similar. Difference in the phytosociological attributes like density, IVI and distribution in SNP indicates the complex plant succession because of various factors of pressure. It was observed that the IVI value was higher in Broad Leaf Deciduous Forest that may be due to favorable ecological requirement needed for the growth and development among the association and community. Holdridge (1971) has opinioned that the species richness is influenced by stress and environmental stress may decrease species richness. The forest of the Himalayan region are protected by the local communities despite their dependency is highly on the forest for livelihood (Sarin, 2001).

The structural characteristics of the vegetation cover and spatial distribution are the most important parameters that influence wildlife distribution and its frequency. Increasing anthropogenic pressure has resulted in rapid depletion of wildlife resulting extinction of various flora and fauna over the years. Knowledge of phytosociological composition of different layers of plant species such as abundance, frequency, presence, absence and the distribution is crucial for the management and conservation of various species. Vegetation composition, floral diversity structure and distribution patterns are vital ecological characteristic that correlates with anthropogenic variables (Gairola et al., 2008). The structure of the forest is represented by the frequency and the distribution of the tree species and understory vegetation. The present study was conducted on the vegetation ecology of Singalila National Park, Darjeeling with reference to indicator species. Through this study, phytosociology of the plant species of Singalila National Park with special reference to red panda and *Rhododendron* was recorded, and quantitative data was derived and analyzed. The present research work was conducted in the four altitudinal vegetation zone of Singalila National Park i.e. (i) Temperate Oak Forest (ii) Broad Leaf Deciduous Forest (iii) Broad Leaf Coniferous Forest and (iv) Sub Alpine Coniferous Forest. Similar vegetation type has been reported by Bhujel (1996) and Pradhan (2001) in the Hill region of Darjeeling and Singalila National Park.

The study conducted in the Temperate Oak Forest of SNP recorded 46 tree species and one variety belonging to 32 genera and 20 families. The dominant family of the tree layer was recorded under the family Ericaceae, Fagaceae and Lauraceae each having 6 species. Total stem density in Oak Forest of the Singalila National Park was estimated to be 1360.7143 individuals ha^{-1}. The vegetation in the Temperate Oak Forest showed the heterogenous distribution where the dominant tree species were *Lithocarpus pachyphyllus*, *Rhododendron arboreum*, *Symplocos dryophila*, *Quercus lamellose*, *Quercus lineate, Rhododendron grande* and *Rhododendron griffithianum*. Maximum tree species (44 No.) showed contiguous distribution pattern in the Temperate Oak Forest of the national park. The shrub layer of the Temperate Oak Forest of SNP recorded 24 shrub species belonging to 20 genera and 16 families. The dominant shrub families in the Oak Forest were Rosaceae (4 species), Urticaeae (3 species), Ericaceae (2 species), Andoxaceae (2 species) and Poaceae (2 species). The dominance and maximum diversity in the shrub layer was expressed by *Yushania maling* (29.714), *Thamnocalamus spathiflorus* (8.839), and *Polygonum molle* (1.143) respectively in that order. In the herb layer in Oak Forest of SNP the dominance and maximum density was expressed by *Carex decora* (4.848), *Lepisorus nudus* (4.089) and *Erigeron bellidioides* (2.8) respectively. Both these shrub and herb species were associated with the larger canopy covered tree species and showed contiguous distribution in the forest. The vegetation of the Temperate Oak Forest showed relatively considerable species richness, diversity and evenness. The herb layer possessed higher species diversity than other two layers in the Oak Forest of SNP, Darjeeling.

In the Broad Leaf Deciduous Forest of the SNP, Darjeeling recorded 41 species and one variety of trees belonging to 31 genus and 21 families. The family with the highest number of tree layer was represented by Ericaceae (6 species) and was followed by the family Fagaceae (5 species) and Sapindaceae (4 species). Total stem density in the Broad Leaf Deciduous Forest was estimated to be 1769.643 individuals ha^{-1}. The dominant tree species in the Broad Leaf Deciduous Forest was *Rhododendron arboreum*, *Symplocos dryophila, Rhododendron falconeri*, *Sorbus cuspidate*, *Lithocarpus pachyphyllus* and *Rhododendron grande*. During the study 34 tree species showed contiguous distribution pattern in the Broad Leaf Deciduous Forest of the SNP. The shrub layer of Broad Leaf Deciduous forest of the SNP recorded 23 shrub species belonging to 17 genera and 12 families. The dominant family with the highest number of species was recorded from the family Rosaceae with 6 species followed by Ericaceae family with 3 species and Andoxaceae, Berberidaceae, Urticaceae and Poaceae with 2 species each. The dominant and maximum diversity of shrub was represented by *Yushania maling* followed by *Thamnocalamus spathiflorus*, *Rubus acuminatus* and *Polygonum molle*. In the herb layer of the Broad Leaf Deciduous Forest of the SNP the dominant species were *Lepisorus nudus* and *Centella asiatica.* All the herb species in the Broad Leaf Deciduous Forest of the SNP showed contiguous distribution.

The study conducted in the Broad Leaf Coniferous Forest of the SNP, Darjeeling recorded 20 tree species belonging to 15 genera and 10 families. The dominant family in the tree layer of the Broad Leaf Coniferous Forest was Ericaceae (8 species) followed by the family Pinaceae, Rosaceae (2 species) and Fagaceae (2 species). Total stem density in Broad Leaf Coniferous Forest was estimated to be 1098.21 individuals ha^{-1}. The dominant species in this forest type was *Abies densa* (IVI 75.633) followed by *Tsuga dumosa* (49.182), *Rhododendron arboreum* (31.127) and *Quercus lamellosa* (23.468). During the study, 19 trees species showed contiguous distribution and 1 species showed random distribution pattern in the forest of the region. Similarly, the shrub layer in SNP recorded 21 shrub species belonging to 15 genus and 9 families in this forest. The dominant shrub family was Ericaceae (7 species) and was followed by Rosaceae (4 species), Andoxaceae, Berberidaceae and Poaceae (2 species each). *Thamnocalamus spathiflorus* was the most dominant species with the IVI value 100.698 and it was followed by *Yushania maling* (45.16) and *Viburnum erubescens* (12.982) in terms of IVI score respectively. The study conducted on the herb layer in the Broad Leaf Coniferous Forest recorded 31 species belonging to 27 genus and 18 families. The most dominant herb species in the Broad Leaf Coniferous Forest were *Theropogon pallidus, Anaphalis busua and Gentiana capitata* as per the IVI score. All the 31 herb species showed a contiguous distribution in the region.

In the Sub Alpine Coniferous Forest of the Singalila National Park, Darjeeling 12 tree species belonging to 7 genera and 5 families were recorded. The dominant family in the tree layer was Ericaceae (6 species), Rosaceae (2 species), Betulaceae, Daphiphyllaceae, Pinaceae and Sabiaceae (1 species each)). The total stem density in Sub Alpine Coniferous Forest was estimated to be 844.44 individuals ha^{-1}. The relatively dominant tree species were *Abies densa* (IVI 136.521) followed by *Rhododendron arboreum* (64.927) and *Betula utilis* (IVI 33.804). 10 trees species showed contiguous distribution, one species showed regular and one species showed random distribution pattern in the region. In the shrub layer 13 species belonging to 10 genera and 7 families were recorded in the Sub Alpine Coniferous Forest. The dominant family with the highest number of species in the shrub layer were Ericaceae (5 species) which was followed by the family Berberidaceae and Poaceae (2 species each). *Thamnocalamus spathiflorus* was the most dominant species with the IVI value 125.467 and was followed by *Yushania maling* and *Daphne bholua* with 33.793 and 22.239 IVI score respectively. All the 13 shrub species showed contiguous distribution in the Sub Alpine Coniferous Forest of the Singalila National Park. In the herb layer 21 species of herbs belonging to 18 genus and 14 families were recorded. The highest number of species were recorded under the family Compositae (3 species) Rosaceae (2 species), Rananculaceae (2 species), Araceae (2 species), and Polypodiaceae (2 species). The most dominant herb species in Sub Alpine Coniferous Forest of the Singalila National Park was *Selinum wallichianum* (IVI value 20.363), *Gentiana capitata* (IVI 18.827) and *Persicaria campanulata* (IVI 18.685). All the 21 herb species showed contiguous distribution in the region.

This study revealed that the vegetation in the Temperate Oak forest that lies between 2400 m to 2800 m altitude above sea were dense and harbors large numbers of trees, shrubs and herbs in SNP. The number of life form was highest at the Oak Forest and was reduced as moved towards higher altitudinal zone. Variation of microclimate as per the topography and the elevation is prime factor for the species distribution in the forest landscape (Chhetri, 2010). The vegetation of the various altitudinal zone of SNP represented healthy plant population where many of them were endemic and few were threatened and endangered. Study conducted by Acharya (2011) in Sikkim, Eastern Himalaya also found that the number of species declined more towards the higher elevation. Very few species such as *Rhododendron* occurred throughout the altitudinal gradient of Singalila National Park however as per the study conducted by Acharya (2011) not a single tree species was distributed throughout the altitudinal gradient of Sikkim. Other studies conducted in the Himalaya by Tripathi (2004) and Behera (2007) have observed hump-shaped pattern of tree species distribution and higher in the middle altitude. Mid elevation patter of species richness was observed in various ecosystems (Rahbek, 2005) if the study is conducted from lower altitude up to 4000 m (approx.). However, in our study, the area of study was from above 2400 m therefore the species richness showed gradual declination which supports the other studies conducted in Himalayas. Mid elevation of the species richness is resulted by the climatic condition, biological interaction, historical and spatial factors (Rahbek, 2005; Li, 2009). Carpenter (2005) has opined that the temperature, soil character, humidity are dominant factor for determining the changes in the plant species richness. However, the distribution range of species were narrow along the elevation gradient and the species number decreased as we move to higher altitudinal zone which is a common phenomenon in the mountainous area (Vetaas, 2002, Cardelus et al., 2006). As per Jetz and Rahbek (2002) various species are unable to thrive and extend distribution range as they are unable to tolerate climatic variation. In Singalila National Park, it was observed that climate plays a crucial factor for the distribution and species richness pattern. Similar observations have been made earlier (Currie et al., 2004; Grytnes et al., 2006, Acharya, 2011) points that evapotranspiration, temperature, water and water availability are important variables that determine the species richness. Tree density is one of the important characteristic features of forest and its variation determines the forest community type, it shows the forest age, condition of the forest and history (Kumar, 2006). It is influenced by the various environmental factors and regeneration of sapling (Sagar and Singh, 2005). In Singalila National Park, tree density was higher in the Broad Leaf Deciduous Forest (1769.643 individual ha^{-1}) where the altitude level was above 2800 m which is close to the finding of Acharya (2011) where he has reported that the tree density was maximum in the temperate coniferous forest (>2800 m) of Sikkim and the highest density was 1675 trees ha^{-1} at 3050 m. The tree density in the lower altitude of mountainous region of Nepal was less because of anthropogenic pressure in lower elevation (Carpenter, 2005). In the Broad Leaf Coniferous and Sub Alpine Coniferous Forest in Singalila National Park the dominant species was *Abies densa*, *Tsuga dumosa* and *Rhododendron.* In the Sub Alpine Coniferous Forest of SNP, the density of few species such as *Abies densa* (275 individual ha^{-1}) and *Rhododendron arboreum* (219.44 individual ha^{-1}) were comparatively high. The increase of density of some species in high altitude compensates for the reduced number of the rare species (Scott, 1976). Trees belonging to Pinaceae family are dominant in the high altitude region because they can tolerate cold climate, strong wind, and less affected by herbivore and have good regeneration potential (Begon, 2006). Similar observation has been made by Sinha (2018) who has opined that the climatic variable favors the growth of *Rhododendron* at 3300 m. In the previous study, Sinha (2018) has reported only 70 species from the area. However, our study recorded much higher number of species i.e. 60 tree species and one variety, 38 shrub species, and 78 herbs in the studied quadrats in SNP, Darjeeling. Species diversity was highest in the temperate oak forest of SNP between 2400 m to 2800 m. This study supports the finding of Sinha (2018) in the Gorkhey in Singalila National Park in Khangchendzonga Landscape where she observed that the highest density of the species was in between 2400 m and 2600 m. Various factors such as climatic variables, habitat availability, competition, local abundance plays significant role in the distribution of species (Gaston 1996, Jetz and Rahbek 2002). As per our study, the basal area was higher in the trees species in the Temperate Oak Forest and Broad Leaf Deciduous Forest. The larger trees were present in the lower altitude region hence higher IVI was attributed. This finding supports the result of Vazquez (1998) stating that from 1500 m to 2500 m elevation the basal area of tree increases.

The Darjeeling hills possess 1876 species of flowering dicots of which there are many endemics (Bhujel, 2002 and Das, 2004). Some of the endemic species of Eastern Himalaya recorded in SNP are *Acer hookeri*, *Carex decora*, *Daphniphyllum himalense*, *Daphne bholua*, *Rhododendron griffithianum*, *Rhododendron falconeri*, *Rhododendron barbatum*, *Clematis napaulensis*, *Rubia charifolia*, *Heracleum wallichi* etc. Various species distributed in the area was socio economically important as medicinal plants, ethno-veterinary plant, food, ornamental and cultural plants preferred by the population residing in the vicinity of the SNP. Thirty-seven species of medicinal plants such as *Abies densa, Aconitum ferox, Betula alnoides, Clematis Montana, Rhododendron arboreum* etc. were recorded in the study area. Darjeeling Himalaya is repository of various socioeconomically important medicinal plants. Earlier Das and Mandal (2003) has reported that 92 species of plants used in folk medicine by the people of Darjeeling Hills. Edible plants like *Actindia callosa*, *Duchesna indica*, *Castanopsis hystrix*, *Viburnum erubescens* etc. were consumed as fruits, young shoots of *Yushania maling*, *Thamnocalamus spathiflorus*, *Arisaema tortuosum*, *Diplazium maximum* etc. were used as vegetables. In addition, 8 species of cultural and religious value plants such as *Abies densa*, *Daphniphyllum himalense*, *Tsuga dumosa, Leontopodium jacotianum*, *Nephrolepis cordifolia*, *Rhododendron lepidotum*, etc. and 11 species of ethnoveterinary plants such as *Betula utilis*, *Iris hookeri*, *Rhododendron arboreum*, *Swertia chirayita*, *Taxus bacata* etc. were recorded during the study. No extractions of the medicinal plants from the protected areas were recorded as it was prohibited, and people were aware of the law. In Singalila National Park, Non Timber Forest Products was used for subsistence whereas in other Himalayan region it is prime source of income. Uprety (2016) has reported that the cross border trade and illegal domestic trade were practiced in the Kangchenjunga Landscape however in Singalila National Park such practice was not found.

In this dissertation, *Rhododendron* and red panda were considered for the study as they share similar habitat and both the species are distributed together in various altitudinal zone of the Singalila National Park. These two species are priority species of the SNP. *Rhododendron arboreum* is one of the most preferred plant species of the red panda and 11.11% (n=3) of direct sighting and 12.4% (n=32) of red panda scats were encountered on *Rhododendron* trees. Young shoots of *Rhododendron* was one of the fodder plants of the species and this was found in the scats of red panda. The direct and indirect evidences of the red panda was higher in the forest covered by *Rhododendron* which supports the finding of Panthi (2012) according to whom the red panda habitat was constituted by 25% *Rhododendron* species in Dhorpatan Hunting Reserve in Nepal. Similarly, Yonzon (1991a) has opined that *Rhododendron* forest was prominently preferred vegetation type by the red panda out of five narrow range of habitats and it was a dominant tree in all the major vegetation like montane, lower subalpine, and upper subalpine zones of Cholang-Dhokache area of Langtang National Park. As in the Eastern Nepal, in Singalila National Park too red panda is recorded in the *Rhododendron* forest and mix broad leaf *Rhododendron* forest (Pradhan, 2001 & Kandel, 2014). Similarly, study conducted by Bista (2017) in Chitwan-Annapurna

Landscape of Nepal has reported that *Rhododendron arboreum* (IVI = 69.30) was one of the significant tree species in the red panda habitat. Dorji (2011) has also observed the evidences of red panda in the forest where one of the dominant tree species was *Rhododendron arboreum*. *Rhododendron arboreum* was also reported in the pellets of red panda during the seasonal food habit analysis of red panda in the Rara National Park in Nepal (Sharma, 2014). It is a known fact that the red panda and *Rhododendron* are the important faunal and floral co-species inhabiting in the temperate and sub alpine vegetation of the Eastern Himalaya. The *Rhododendron* and red panda acts as right indicators of climate change and anthropogenic impacts to the local biodiversity. *Rhododendron* being a socio-economically important floral species of the temperate and alpine zone it was easy to identify and study the species in the wild. An indicator species responds to a particular environmental stress quickly and expresses any changes occurring in the area. It is a proven fact by various researches that the phenology and the persistence of species are affected by the climate change. Red panda being an arboreal animal has shown positive correlation with *Rhododendron* as the plant was highly preferred as fodder plant, substrate for defecation, and sighting on the tree was comparatively high. Canopy cover has always been a positive feature for the presence of red panda in Singalila National Park. The morphology of the species favours it to explore both the ground as well as the arboreal layer. Red panda was associated with the *Rhododendron* because it acts as a food resource, avoid predation risk as the leaves of *Rhododendron* covers the animal from easy sighting. *Rhododendron* reaches the height up to 15 m and it leaves are 10-20 cm in length (Polunin and Stainton, 1984) where red panda can easily hide from predator. Dense forest of *Rhododendron* with proper developed canopy provides safe house and shelter to the species in the wild. Cauha and Vieira (2002) have opined that the arboreal layer used by the animal increases the area of occupancy and provides the resources which are not available on the ground (Rader, 2006). Uses of *Rhododendron sp*. also reduce the competition with other animals in the same habitat and facilitate coexistence with other herbivore. Similarly, various animals are associated with different species, Adler et al., (2012) has reported that *Oecomys rutilus* (arboreal rodent) in French Guiana was associated with lianas and *Micoureus demerarae* showed its association with the number of logs. The morphology of the species favours it to explore both the ground as well as the arboreal layer. Feeding habit of red panda also favours the use of *Rhododendron* as the animal feeds continuously on bamboo and can easily climb on the *Rhododendron* tree. Diet of an animal plays vital role in shaping its population and the behaviour and shaping the niches of the occupancy (Simpson and Raubenheimer, 2012). This study have recorded that out of 31 direct sighting out of which only on four occasion red panda was recorded on the ground. As per Abreu (2014) trees and shrubs close to each other favours connectivity and the naturally developed structure facilitates the movement of arboreal animal between them. In Singalila National Park, *Rhododendron* is one of the dominant plant species and it is distributed in all the four type of vegetation in SNP. Therefore, it was found that *Rhododendron* was highly preferred and is associated with the red panda in its natural habitat. In this study two correlated species red panda and *Rhododendron* was considered for the study with a holistic approach and special emphasis to understand the vegetation with reference to both the floral and faunal components of the National Park. These study on vegetation ecology of SNP with reference to red panda and *Rhododendron* helps to address bio-geographic questions regarding the habitat use, plant preference, distribution of red panda and *Rhododendron*.

Flowering of *Rhododendron arboreum* is considered a prominent biological indicator of climate change (Gaira, 2014). The flowering of *Rhododendron* in Singalila National Park occurred between March to May. Distribution of the *Rhododendron arboreum* was abundant in all the studied forest type in Singalila National Park viz. Tumling, Gairibans, Kaiyakatta, Kalpokahri, Sandakphu, Molle and Phalut. It was observed that the growth rate of *Rhododendron* was very slow compare to other species. The population of the *Rhododendron* in the buffer zone of the protected area and the area near the human settlement were comparatively lesser. *Rhododendron* was one of the most preferred firewood in the high altitude areas. Firewood collections was a significant threat to *Rhododendron* as evident in the border area of the park like Kalpokhari, Sandakphu, Molle and Phalut areas where the large number of tourist visits and stays during the tourist season. The flowering of the *Rhododendron* is clearly visible from distance therefore decrease in the population can be easily monitored. Long term monitoring of flowering time of the *Rhododendron* can act as an indicator of the climate change and the distribution and abundance of *Rhododendron* also gets affected by the temperature. The flowering of the *Rhododendron* varies with the rise in temperature which is important factor for the growth and survival of the species. Plants get shifted from lower altitude to higher altitude when the temperature rises, in order for it to maintain normal physiological activities. This study on *Rhododendron* distribution in the different vegetation type in SNP can be used to check the distribution of *Rhododendron* in future as the distribution range of *Rhododendron* changes in response to global warming and pollution (Ranjitkar, 2012). Monitoring and evaluation of the Himalayan ecosystem focusing at the community level are essential to understand the range shift of the species within different geographic ranges (Krishnan, 2020). Change in growth, distribution and decrease in number of

Rhododendron due to excessive extraction clearly acts as an indicator for anthropogenic impacts in the high altitude regions.

The red panda is one of the endangered and protected animals throughout its in-situ habitat. Anthropogenic activities threaten biodiversity and are the prime cause of the decline in the red panda population across the in-situ habitat (Glatston, 1994; Jha, 2011; Dorji, 2012; Kandel, 2015; Acharya, 2018). An increase in the human population in the surroundings of a protected area, relatively unsound socioeconomic condition, and dependence on forest resources (Pradhan, 2001) has caused degradation of forest, wildlife loss, and erosion in genetic diversity (Sharma, 2008). Red panda is priority species for conservation breeding that has been identified by the Central Zoo Authority, Ministry of Environment, Forest and Climate Change, Government of India as the animal is in the endangered category of IUCN Red List. The ultimate goal of the conservation breeding programme is restocking the animal in the wild habitat. It is the keystone species of the Singalila National Park and that is why initiatives have been undertaken for the conservation of the species. Therefore, the study in Singalila National Park was undertaken to understand the vegetation of the park, population estimation of red panda and its associated indicator tree species, *Rhododendron*, and threats if any as SNP is the in-situ red panda reintroduction site in the country. Conservation involves two key aspects, ex-situ conservation and in-situ conservation (Kasso, 2013). Ex-situ and in-situ conservation are interlinked as without a wild, free-ranging population and pristine in situ habitat, ex-situ conservation makes no sense. Similarly, restocking the genetically healthy population in the wild cannot be ensured without ex-situ conservation. Therefore, study was conducted on red panda in Padmaja Naidu Himalayan Zoological Park (Darjeeling Zoo) prior to the in-situ study. Behaviours of the red panda observation showed that the red panda was more active at dawn, dusk, and night. The male spent 53.1% of the total observed time in active behaviour. Female red panda showed 34.97% of active behaviour, comparatively lesser than the male. The animal was very sensitive to any anthropogenic disturbances and was shy animal. Mating of the animal occurred in the early winter mainly between January to March and after 126 days of gestation, two cubs were born to the female. It was observed that the post parturition mother spent 91.87% of its time with cubs and covered its cubs by curling over them. However, after few days the time spent with the cubs gradually decreased. After a fortnight, the female spent 74.78% of the time with the cubs, after 30 days, the mother spent only 22.92%, after 45 days, 15.17%, and after 60 days, 6.35% of the time was spent with the cubs. The percentage of cub grooming also decreased gradually. After 90 days of birth, cubs came outside the cubbing box and were found eating bamboo leaves and solid food. However, during analyzing the death report of the captive red panda it was observed that the mortality rate was higher in the younger age.

The causes of cub mortality were ill nursing by mother, respiratory failure, bronchopneumonia, subsequent weakness etc. Red panda was very sensitive to disturbance, after parturition if any disturbances occurred near the breeding/cubbing box, the mother started shifting the cubs from one place to another, similar to the cat. Prince and Glatston (2016) have also made similar observation and have noted that in infants, the mortality rate of the captive red panda is highest during the first year of the birth and during the first month of the birth majority of death occurs. Even in the wild, during this period, the chances of cub mortality remain at the maximum. The cubs can be predated or may die due to other factors and is a reason for the high mortality rate in infants and less reproductive success in the species in the wild.

The study on the genetic assessment of captive red panda was an attempt to understand the viability of the captive population of Darjeeling Zoo (PNHZ Park). The heterozygosity observed (HO) level of 0.68 during the study indicated that the captive red panda has genetic variation in the range of wild population (i.e. Singalila National Park and Neora Valley National Park) of red panda (Kumar et al., 2016). As per the study conducted (in CCMB) through viability analysis it was indicated that the population of captive red panda is a slow growing ($r = 0.103$, $\lambda = 1.109$), with a mean generation time of 4.27 years for both females and males, and after 100 years gene diversity will be retained only upto 37% (Kumar et al., 2016). More initiatives are needed for the maintenance of the present genetic diversity of the captive population. Exchange of the animals from other zoos and addition of more red panda with proper analysis of pedigree may contribute up to certain extend will help to maintain and improve genetic diversity. More high altitude zoos such as G B Pant High Altitude Zoo, Nainital, Himalayan Zoological Park (Gangtok Zoo) can contribute in conservation breeding of the species. PNHZ Park and Gangtok Zoo are located in the range of the red panda habitat and the rescued animal may be used for breeding purpose to maintain healthy bloodline following proper guideline of CZA and MoEF, Government of India. Proper record keeping of the species in the captivity and maintenance of national as well as international studbook in the ZIMS database will be fruitful for the exchange programme. In order to estimate the wild population of red panda fecal samples of red panda were collected from different beats of the Singalila National Park and the samples were analyzed at LaCONES, CCMB to estimate the number of individuals of the species. A total of 329 samples were collected, microsatellite genotyping was done. Based on fecal samples collected in Singalila National Park, 38 individual red panda were identified. The highest percentage of the animals recorded as per DNA Analysis was 26.3% (n=10) in Gairibans Beat which was followed by the Rammam Beat and Maney Bhanjayang Beat i.e. 21.05% (n=8) and 18.42% (n=7) respectively. In a study conducted by Pradhan (1998) showed that red panda was not found in Rammam, Lower Gorkhey, and Rimbick. However, our study confirmed the presence of good number of animal in Rammam, Gorkhey, and Rimbick area. The population of the red panda as per our study was higher compared to the study conducted by Bahuguna (1998) which reported 26 red pandas in Singalila National Park. Similarly, another study conducted by Pradhan (2001) has sighted 32 individuals in the Singalila National Park.

Direct sighting of red panda was also recorded in the Singalila National Park with an objective to understand the plant preference, fodder plant and distribution of red panda in SNP. This study recorded 31 direct sightings of red panda in Singalila National Park during various seasons. In 12.9% (n=4) of the cases the red panda sighting occurred within the altitudinal zone of 2801 m to 2900 m, 41.93% (n=13) of cases within 2901 m to 3000 m and in 22.58% (n=7) of cases within 3001 m to 3100 m in the Broad Leaf Deciduous Forest. Similarly, the encounter of the red panda and its scats were highest at the altitudinal level of 2900 m to 3000 m with 56.25% and 18.75% scats samples were sighted in the altitude of 2400 m to 2800 m in the Oak Forest and Broad Leaf Deciduous Forest. Source of water greater canopy forest, less disturbed area, and area with a high density of fodder plants and fruits were other factors for the presence of red panda which was also observed by Pradhan et al., (2001). The sighted animals were adult in size, active and seemed healthy and in most of the cases the animals were found resting at the top of the trees. The finding supported the previous study conducted by Pradhan (2001). Other studies conducted on the habitat of the red panda also recorded the species at an altitudinal range between

1500 m and 4800 m and almost up to 5000 m (Roberts and Gittleman, 1984) concurrently, an abundance of pellets increased up to 3500 m and started declining at higher elevation (Sharma, 2009). Red panda preferred bamboo understory forest as seen earlier between 2800 m to 3900 m (Yonzon, 1989). Pellets give a good indication of the presence and the habitat suitability for the species. The animal used branches, logs, rock surfaces, and ground as a substrate for defecation. Frequencies of scat samples were high near water sources, greater canopy forest, less disturbed area, and area with a high density of fodder plants and fruits which is in consonance with the reports by Yonzon (1991), Pradhan (2001), Bista et al., (2017) and Thapa et al., (2020). The red panda needs mature forest for survival and therefore are indicators of area with mature Eastern Himalayan Broad Leaf forest (Yonzon, 1991b).

The red panda was sighted on the 16 plant species in Singalila National Park. 14.81% (n=4) of direct sighting occurred on *Abies densa*, that was followed by *Lithocarpus pachyphyllus* 14.18% (n=4), *Rhododendron arboreum* 11.11% (n=3), *Castanopsis tribuloides* 7.4% (n=2), *Schefflera rhododendrifolia* 7.4% (n=2), *Betula utilis* 7.4% (n=2) etc. Other plant species with red panda sighting were *Rhododendron griffithianum*, *Ilex fragilis*, *Eurya acuminate, Rhododendron falconeri*, *Symplocos lucida, Vitex negundo, Magnolia campbellii, Acer campbellii, Merrilliopanax alpinus* and *Litsea sericea*. Plants belonging to the family Fagaceae were used maximum for resting and sleeping during the day time and were followed by Ericaceae, Pinaceae, and Araliaceae. Red panda scat gives the evidence of presence of the species and the habitat suitability for the species. The plant species with the presence of red panda scats were *Lithocarpus pachyphyllus* 22.48% (n=58), *Rhododendron arboreum* 12.4% (n=32), *Sorbus cuspidate* 6.59% (n=17), *Magnolia campbellii* 6.59% (n=17), *Rhododendron griffithianum* 6.2% (n=16), *Castanopsis tribuloides* 6.2% (n=16), *Betula utilis* 5.81% (n=15), *Merrilliopanax alpinus* 5.81% (n=15), *Litsea sericea* 5.81% (n=15), *Ilex fragilis* 4.26% (n=11), *Litsea elongate* 3.88% (n=10), *Vitex negundo* 3.49% (n=9), *Rhododendron falconeri* 3.1% (n=8), *Tsuga dumosa* 1.55% (n=4), *Acer campbellii* 1.55% (n=4) and rest of the red panda pellets were encountered on *Pieris formosa, Symplocos lucida, Taxus baccata, Symplocos dryophila, Schefflera rhododendrifolia, Abies densa, Eurya acuminata,* and *Machilus edulis*. Encounters of scats/pellets were highest on the plant species belonging to family the Fagaceae, Ericaceae and Lauraceae respectively. In SNP red panda mostly feed on *Yushania maling, Thamnocalamus spathiflorus, Sorbus cuspidata, Actinidia callosa, Rosa sericea,* tender leaves of *Rhododendron arboreum, Polygonum molle,* and *Rubus sp.* Leaves and shoots of *Yushania maling* and *Thamnocalamus spathiflorus* constitute the main diet of the red panda. *Thamnocalamus spathiflorus* and *Yushania maling* were the dominant plants found in the scats of the red panda during all the seasons. The red panda habitat in Singalila National Park was covered with dense bamboo understory and that mainly determined the abundance and distribution of the red panda. They mainly feed on the bamboo leaves and young shoots. The diet of the species is influenced by anatomical and physiological character and distribution of the plant community, chemical and structural constituent of the plant (Owen-Smith, 1982). It was seen that the red panda mainly feed on bamboo throughout the year; in captivity it consumes around 4 kg bamboo leaves per day which is very high as per its body weight. However plants availability, habitat type and seasons also affect the preference of fodder plants by the species (Crawley, 1983). Wei (1999) highlighted that in China and India bamboos are the main food resource of the species. Previous study also stated that *A. maling* (*Yushania maling*) and *A. aristata* were the main diets of the red panda (Pradhan, 2001). Panthi (2012) reported that *Yushania sp.* comprises the largest portion

(81.7%) of the red panda diet. Red panda fodder plants in Singalila National Park were present abundantly and bamboo was dominant undercover plant in the study area.

Phytosociological analysis conducted in the red panda and pellet encountered area revealed a total of 40 tree species having the total stem density to be 1276 individual ha^{-1} presented the host plants where red panda was directly or indirectly sighted. The most dominating species as per IVI in the study area was *Lithocarpus pachyphyllus* (47.86) *Abies densa* (33.01), *Rhododendron arboreum* (22.6) etc. In the shrub layer dominant species were *Thamnocalamus spathiflorus*, *Yushania maling, Berberis aristata* etc. In the herb layer the dominant species were *Smilax ovalifolia, Rubus buergeri, Theropogon pallidus, Clematis Montana* etc. recorded in the red panda distributed area.

Through this study it was observed that the vegetation with high canopy trees in the Temperate Oak forest, Broad Leaf Deciduous Forests and Broad Leaf Coniferous Forest of Singalila Nation Park was preferred by the red panda. High canopy forest was the dominant in these forests and these are preferred for resting, sleeping, and nest building by the red panda. Tall trees with longer branches provide easy foraging opportunities and also avoid predation (Bista 2019; Dorji 2011). The red panda distribution in the wild depends on the presence of dense bamboo understory, *Rhododendron*, *Sorbus cuspidate*, *Polygonum mollee*, *Rubus sp.* and other edible fruits and their presence were higher in Singalila National Park.

Through questionnaire survey, it was observed that the conservation education and awareness level was relatively high in the resident near SNP and were aware about the basic wildlife laws. A total of 279 households were surveyed in the buffer zone of Singalila National Park where the red panda showed a significant conservation value species of the park. Bamboo was one of the major forest products used by the local population in the area. Bamboo is also a prime fodder of red panda. Study conducted by Dorji (2011) has also reported that 42% of the rural household of Bhutan uses bamboo for the domestic purpose and is one of the major threats to the red panda in Bhutan. Similarly study conducted by William (2004) in Eastern Nepal has reported that the bamboo is the main forest resource of the local residents and is harvested for domestic as well as commercial purposes causing a threat to the existence of red panda. Bamboo being the main food of red panda its loss may be a major threat to the survival of the animals. During the study, it was found that the residents of the area were dependent on the bio-resource for their livelihood. But in Singalila National Park, it was observed that the local population doesn't enter the core area of the park since most of the residents were aware of the conservation of red panda. They were concerned about the importance and the sustainability of the forest. The socio-economic condition of the residents near the protected areas is one of the key factors for the dependence of the rural population on the forest leaving negative effects on the conservation efforts. In the years 2003 and 2004 four female captive-bred red pandas were successfully reintroduced in the Singalila National Park, Darjeeling, and were the first captive-bred red panda reintroduced in India (Jha, 2011). The reintroduction programme was globally acknowledged and was successful to generate public awareness about species. Therefore, all the participants of the questionnaire survey were aware of the red panda and its conservation in the study area.

This study in Singalila National Park indicates that the red panda distribution is supported by the presence of *Rhododendron*. The direct sighting of red panda and scats density were higher in the forest dominated by the *Rhododendron* trees. Red panda traces were present in the forest with larger *Rhododendron* trees with longer branches which depict the habitat preference of red panda and uses. Red panda chooses steeper slopes and prefers places that provide easy access to bamboo leaves. *Rhododendron* trees have long branches that reach the leaves of bamboo and fallen logs (Wei, 2000). *Rhododendron* was one of the most important plants that provided shelter, movement and also a source of food. Foraging strategies and movement of the red panda are vital components that influence its selection of habitat, social interaction, population and reproduction. Therefore, in order to maintain healthy red panda population in its natural habitat, protection of *Rhododendron* forest is essential. *Rhododendron* distribution along with other plant species in SNP may be related to the distribution of red panda hence the habitat restoration by plantation of the *Rhododendron* in the buffer zone and in wildlife corridor may be important for the construction and conservation of red-panda habitat in the Singalila National Park.

The study of just one species each of indicator plant and animal species may not conclusively reveal the entire gamut of ecological conditions and interactions between different biotic and abiotic components of a large area. However, it may amply provide a pointer to all those things. This study indicated that the vegetation of *Rhododendron* is related to the sightings/population of red panda and the presence of red panda in turn was related to the luxurious vegetation of *Rhododendron* in SNP. It may be worthwhile to note that the presence of associated plant species and the particular micro-climatic conditions are critical for the indicator species to flourish. Nonetheless, the study of the particular plant and animal species in relation to each other seems justified.

Chapter 6
Summary

Summary

The vegetation of Singalila National Park (SNP), its structure, and floral diversity was studied as per the standard taxonomic procedure using quadrat method through pre-existing tracks and trails at various altitudinal zones. The study recorded 60 tree species, 38 shrub species and 78 herbs species in all the quadrats in four forest types (Temperate Oak Forest, Broad Leaf Deciduous Forest, Broad Leaf Coniferous Forest and Sub Alpine Coniferous Forest). The vegetation in the Temperate Oak forest that lies between 2400 m to 2800 m altitude above sea was dense and harbors large numbers of trees, shrubs and herbs in SNP. The number of life forms was highest in the oak forest and was gradually reduced as we move towards higher altitudinal zones. The vegetation of the various altitudinal zone of SNP represented healthy plant population where many of them were endemic and few were threatened and endangered. *Rhododendron arboreum* occurred throughout the altitudinal gradient of Singalila National Park. The species richness in SNP showed gradual declination as our study area was between 2400 m to 3650 m above sea level which also supports other studies conducted in the Himalaya. The distribution ranges of the indicator species were narrow along the elevation gradient as the altitude increases and the species number decreased gradually at progressively higher altitudinal zones. In Singalila National Park, tree density was higher in the Broad Leaf Deciduous Forest (1769.643 individual ha^{-1}) where the altitude was between 2800 m and 3100 m. In the Broad Leaf Coniferous and Sub Alpine Coniferous Forest of SNP, the dominant species were *Abies densa*, *Tsuga dumosa* and *Rhododendron sp*. The species diversity was highest in the Temperate Oak Forest of SNP between 2400 m to 2800 m. Various species distributed in the area was socio-economically important as medicinal plants, ethno-veterinary plant, food, ornamental and cultural plants preferred by the population residing in the

vicinity of the SNP. Thirty-seven species of medicinal plants such as *Abies densa*, *Aconitum ferox*, *Betula alnoides*, *Clematis montana*, *Rhododendron arboreum* etc. were recorded in the study area. In addition, 8 species of plants of cultural and religious value such as *Abies densa*, *Daphniphyllum himalense*, *Tsuga dumosa*, *Leontopodium jacotianum*, *Nephrolepis cordifolia*, *Rhododendron lepidotum* etc. and 11 species of ethnoveterinary plants such as *Betula utilis*, *Iris hookeri*, *Rhododendron arboreum*, *Swertia chirayita*, *Taxus bacata* etc. were recorded during the study. It was found that *Rhododendron* and red panda share similar habitat and both the species are distributed together in various altitudinal zones of the SNP. The two indicator species are priority species of the SNP. *Rhododendron arboreum* is one of the most preferred plant species of the red panda and 11.11% (n=3) of direct sighting and 12.4% (n=32) of red panda scats were encountered on *Rhododendron* trees. The *Rhododendron* and red panda acts as right indicators of climate change and anthropogenic impacts to the local biodiversity. Red panda is priority species for conservation breeding that has been identified by the Central Zoo Authority, Ministry of Environment, Forest and Climate Change, Government of India as the animal is in the endangered category of IUCN Red List. The ultimate goal of conservation breeding programme is restocking the animal in the wild habitat. The red-panda is the keystone species of SNP and that is why initiatives have been undertaken for the conservation of the species. Therefore, the present study in SNP was undertaken to understand the vegetation of the park, population estimation of red panda, its associated indicator tree species *Rhododendron,* and threats if any as SNP is important for being the in-situ red panda reintroduction site in the country. In order to estimate the population of wild red panda, a total of 329 samples were collected, and based on the fecal samples collected in Singalila National Park, 38 individual red pandas were identified in SNP area. The highest percentage of the animals recorded as per DNA Analysis was 26.3% (n=10) in Gairibans Beat which was followed by the Rammam Beat and Maney Bhanjayang Beat i.e. 21.05% (n=8) and 18.42% (n=7) respectively. The red panda habitat in SNP was covered with dense bamboo understory and *Rhododendron* and that mainly determined the abundance and distribution of the red panda. As per the direct sighting, 12.9% (n=4) of the cases the red panda sighting was observed within the altitudinal zone of 2801 m to 2900 m, 41.93% (n=13) of cases within 2901 m to 3000 m and in 22.58% (n=7) of cases within 3001 m to 3100 m in the Broad Leaf Deciduous Forest during the study. The red panda in the SNP was sighted on the 16 plant species such as *Abies densa*, *Lithocarpus pachyphyllus*, *Rhododendron arboreum*, *Castanopsis tribuloides*, *Schefflera rhododendrifolia* etc. The animals were found to mostly feed on *Yushania maling, Thamnocalamus spathiflorus, Sorbus cuspidata*, *Actinidia callosa, Rosa sericea* etc. tender leaves of *Rhododendron arboreum, Polygonum molle,* and *Rubus sp.* Through this study, it was observed that the vegetation and high canopy trees in the Temperate Oak Forest, Broad Leaf Deciduous Forest and Broad Leaf Coniferous Forest of SNP was preferred by the red panda. High canopy trees were dominant in these forests which are preferred for resting, sleeping, and nest building by the red panda. Tall trees with longer branches provide easy foraging opportunities and also avoid predation (Bista, 2019; Dorji, 2011). The red panda distribution in the wild depends on the presence of dense bamboo understory, *Rhododendron*, *Sorbus cuspidate*, *Polygonum molle*, *Rubus sp*. and other edible fruits and their presence were higher in SNP. It was also observed that the local human population does not enter the core area of the park since most of the residents were aware of the conservation of red panda. They were concerned about the importance and the sustainability of the forest. Thus, direct anthropogenic threats to red-panda were minimum in the Singalila National Park area.

References

Abreu, M.S.L., & Oliveira, L.R.D. (2014). Patterns of arboreal and terrestrial space use by non-volant small mammals in an Araucaria forest of southern Brazil. *Annals of the Brazilian Academy of Sciences*, http://dx.doi.org/10.1590/0001-376520142013 0063

Acharya, K.P., Shrestha, S., Paudel, P.K., Sherpa, A.P., Jnawali, S.R., Acharya, S., & Bista, D. (2018). Pervasive human disturbance on habitats of endangered red panda Ailurus fulgens in the central Himalaya. *Global Ecology and Conservation*, https://doi.org/10.1016/j.gecco.2018.e00420

Adams, W.M., Aveling, R., Brockington, D., Dickson, B., Elliott, J., Hutton, J., Roe, D., Vira, B., & Wolmer, W. (2004). Biodiversity conservation and the eradication of poverty. *Science*, 306 (5699): 1146-1149. https://doi.org/10.1126/science.1097920

Adler, G.H., Carvajal, A., Davis-Foust, S.L., & Dittel, J.W. (2012). Habitat associations of opossums and rodents in a lowland forest in French Guiana. *Mammalian Biology*, 77: 84-89.

Ahmad, I., Ahmad, M.S.A., Hussain, M., Ashraf, M., Ashraf, M.Y., & Hameed, M. (2010). Spatiotemporal aspects of plant community structure in open scrub rangelands of sub mountainous Himalayan plateaus. *Pakistan Journal Botany*, 42(5), 3431- 3440.

Ahmed, M., Husain, T., Sheikh, A.H., Hussain, S.S., & Siddiqui, M.F. (2006). Phytosociology and structure of Himalayan forests from different climatic zones of Pakistan. *Pakistan Journal of Botany*, 38 (2): 361-383.

Altmann, J. (1974). *Observational study of behaviour: sampling methods*. *Behaviour,* 48: 1-41 (Vol.49 (3): 227-67). https://doi.org/10.1163/156853974x00534

Anitha,V., Muraledharan, P.K., & Binilkumar, A.S. (2003). Natural resources depletion in protected areas: Socioeconomic linkages. *Indian journal of Social Development*, 3(1): 44-59.

Archabald, K. & Naughton-Treves, L. (2001). Tourism revenue-sharing around national parks in Western Uganda: early efforts to identify and reward local communities. *Environmental Conservation*, 28:135–149. http://dx.doi.org/10.1017/S0376892901 000145

Ardakani, M.R. (2004). *Ecology*. Tehran University Press.

Ashton, M.S., Brokaw, N.V.L., Bunyavejchwin, R., Chuyong, G.B. et al. (2004).Floristics and vegetation of the Forest Dynamics Plots. In: Losos EC, Leigh J, Egbert G (eds.) *Tropical forest diversity and dynamism: Findings from a large-scale plot network*. University of Chicago Press, Chicago, USA.pp.90-102.

Awasthi, A., Uniyal, S.K., Rawat, G.S., & Rajvanshi, A. (2003). Forest Resource Availability and Its Utilization by the Migratory Villages of Uttarkashi, Western Himalaya. *Forest Ecology and Management*, 174 (2003)13-24. http://dx.doi.org/10. 1016/S0378-1127(02)00026-9

Badola, R., & Silori, C.S. (1999). *Nanda Devi Biosphere Reserve: A study of socio-economic aspects for sustainable development of dependent population*. First Study Report, Wildlife Institute of India, Dehradun, India.

Badola, S., Fernandes, M., Marak, S.R., & Pilia, C. (2020). *Assessment of illegal trade-related threats to Red Panda in India and selected neighbouring range countries*. TRAFFIC, India office.

Bahuguna, C., Dhundyal, S., Vyas, P., & Singhal, N. 1998. The Red Panda at Singalila National Park and adjoining forest: a status report. *Small Carnivore Conservation*. 19: 11-12.

Baral, N., & Heinen, J.T. (2007). Resource use, conservation attitudes management intervention and park–people relations in the Western Terai landscape of Nepal. *Environmental Conservation*, 2007;34(1):64–72. http://dx.doi.org/10.1017/S0376892907003670

Bartell, S.M. (2006). Biomarkers, bioindicators and ecological risk assessment- a brief review and evaluation. *Environ. Bioindic*, 1, 39-52. https://doi.org/10.1080/15555 270591004920

Bawa, K.S., Joseph, G., & Setty, S. (2007). Poverty, biodiversity and institutions in forest-agriculture ecotones in the Western Ghats and Eastern Himalaya ranges of India. *Agriculture, Ecosystems and Environment*, 121 (2007) 287–295. http://dx.doi.org/ 10. 1016/j.agee.2006.12.023

Bawa, K.S., Kress, W.J., Nadkarni, N.M., Sharachchandra, L., Raven, P.H., Janzen, D.H., Lugo, A.E., Ashton, P.S., & Lovejoy T.E. (2004). Tropical Ecosystems into the 21st Century. *Science,* 306: 227-228. https://doi.org/10.1126/science.306.5694. 227b

Behera, M.D. & Kushwaha, S.P.S. (2007). An analysis of altitudinal behavior of tree species in Subansiri district, Eastern Himalaya. Biodiversity Conservation, 16, 1851-1865. https://doi.org/10.1007/s10531-006-9083-0

Begon, M., Townsend, C.R., & Harper, J.L. (2006). *Ecology: From Individuals to Ecosystems*. Blackwell Scientific Publications, UK.

Berendse, F. (2005). Invited perspective: Impact of global change on plant diversity and vice versa: Old and new challenges for vegetation scientist. *Journal of Vegetation Science*, 16: 613-616. https://doi.org/10.1111/j.1654-1103.2005.tb02403.x

Bhujel, R.B., & Das, A.P. (2002). *Endemic status of the dicotyledonous flora of Darjeeling District In: Perspectives of Plant Biodiversity*. (ed. A.P. Das), Bishen Singh Mahendra Pal Singh, Dehradun. pp. 593 – 609, 2002.

Bhujel, R.B. (1996). *Studies on the Dicotyledonous Flora of Darjeeling District*. Ph.D. Thesis, University of North Bengal.

Billings, W.D. (1952). The environment complex in relation to plant growth and distribution. *The Quarterly Review of Biology*, 27(3): 251–265.

Bing, S.U., Yunxin, F.U., Yingxiang, Wang, Jin, L., & Chakraborty, R. (2001). Genetic diversity and Population History of the Red Panda (Ailurus fulgens) as Inferred from mitochondrial DNA Sequence Variations. *Molecular Biology and Evolution*, Vol.18 pg. 1070-1076.

Bista, D., Baxter, G.S., & Murray, P.J. (2020). What is driving the increased demand for red panda pelts? *Human Dimensions of Wildlife*. 25:4, 324-338. https://doi.org/10. 1080/10871209.2020.1728788

Bista, D., Shrestha, S., Sherpa, P., Thapa, G.J., Kokh, M., Lama, S.T. et al. (2017). Distribution and habitat use of red panda in the Chitwan-Annapurna Landscape of Nepal. *PLoS ONE*,12(10): e0178797.https://doi.org/10.1371/journal.pone. 0178797.

Brautigam, A. (1995). *IUCN Bulletin,* 26 (1), 17.

Bremner, J., Lopez-Carr, D., Suter, L., & Davis, J. (2010). Population, poverty, environment, and climate dynamics in the developing world. *Interdisciplinary Environmental Review*, 11 (2/3): 112-126. http://dx.doi.org/10.1504/IER. 2010.037 902

Brooks, T. M., Bakarr, M.I., Boucher, T. et. al. (2004). Coverage provided by the global protected-area system: Is it enough? *Bioscience,* 54(12):1081-1091.

Brown, K. (1995). Medicinal plants: indigenous medicine and conservation of biodiversity in Ghana. Pp. 201-231 in *Intellectual Property Rights and Biodiversity Conservation*. Edited by T. Swanson. Cambridge University Press, London, U.K.

Bruner, A.G., Gullison, R..E., Rice, R.E., & da Fonseca G.A.B. (2001). Effectiveness of parks in protecting tropical biodiversity. *Science*, 291: 125–128. https://doi.org/10. 1126/science.291.5501.125

Burger, J. (2006). Bio-indicators: types, development, and use in ecological assessment and research. Environ. *Bio-indic*, 1, 22-39. https://doi.org/10.1080/15555270 590 966483

Busha, Teshome, B., Kassa, H., Mohammed, Z., & Padoch, C. (2015): Contribution of Dry Forest Products to Household Income and Determinants of Forest Income Levels in the Northwestern and Southern Lowlands of Ethiopia. *Natural Resources*, 2015, 6, 331-338. https://doi.org/10.4236/nr.2015.65030

Butchart, S.H., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P. et al. (2010). Global biodiversity: indicators of recent declines. *Science*, 2010 May 28; 328(5982):1164-8. https://doi.org/10.1126/science.1187512

Cairns, Jr., & Pratt, J.R. (1993). A history of biological monitoring using benthic macro invertebrates. In: Rosenberg, D.M., Resh, V.H (Eds.), *Freshwater Bio monitoring and Benthic Macro invertebrates*. Chapman & Hall, New York, pp. 10-27.

Campbell, L.M. (1999). Ecotourism in rural developing communities. *Annals of Tourism Research*, 26: 534–553.

Cardelus, C.L., Colwell, R.K. & Watkins, J.E. (2006). Vascular epiphyte distribution patterns: explaining the mid elevation richness peak. *J. Ecol.*, 94, 144-156.

Cardillo, M., Mace, G.M., Gittleman, J.L., & Purvis, A. (2006). Latent extinction risk and the future battlegrounds of mammal conservation. *Proceedings of the National Academy of Sciences of the USA* 103: 4157–4161. https://doi.org/10.1073/pnas. 0510541103

Carignan, V., & Villard, M. A. (2001). Selecting indicator species to monitor ecological integrity: a review. *Environmental Monitoring and Assessment*. 78: 45– 61, 2002.

Carney, K.M., & Matson, P.A. (2006). The Influence of Tropical Plant Diversity and Composition on Soil Microbial Communities. *Tropical Plant Diversity and Soil Microorganisms,* http://dx.doi.org/10.1007/s00248-006-9115-z

Carpenter, C. (2005). The environmental control of plant species density on a Himalayan elevation gradient. *J. Biogeogr*., 32, 999-1018.

Chamberlain, D.F., Hyam, R., Argent, G., Fairweather, G., & Walter, K.S. (1996). The genus Rhododendron, its classification and synonymy. *Royal Botanic Garden, Edinburgh*. Pp. 184.

Chandola, S., Badola, R., & Hussain, S.A. (2007). Factors affecting women's participation in conservation programmes in and around Rajaji National Park, India. *Journal of Indian Anthropological Society,* 42: 11- 21.

Chape, S., Harrison J., Spalding, M., & Lysenko, I. (2005). Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. *Philosophical Transactions of the Royal Society of London*, 360: 443–455.

Chatterjee, D. (1962). Floristic pattern of Indian vegetation. In: Proc. *Summer School of Botany: Darjeeling*, (ed. P. Maheshwari et al.) pp. 30 – 42, 1962.

Chaudhary, R.P.(1999). *Vegetation Pattern*. In: Majpuria T.C. eds. Nepal natuer's paradise. M. Devi, Gwalior, India, 1999.

Chettri, A. (2010). *Effect of forest fragmentation on vascular plant diversity in Khangchendzonga Biosphere Reserve, Sikkim with emphasis on regeneration of some important taxa*. PhD Thesis submitted to North-Eastern Hill University.

Chettri, D.R., & Roy, S.C. (2007). Biochemical diversity in some rhododendron species from Darjeeling and Sikkim Himalayas. *Journal of Hill Research*, 20(2):46-52, 2007.

Choudhury, A. (2001). An overview of the status and conservation of the red panda Ailurus fulgens in India, with reference to its global status. *Oryx*, 35 (3): 250 – 259.

Choudhury, A.U. (1997). Red panda Ailurus fulgens F. Cuvier in the north-east with an important record from Garo hills. *Journal of the Bombay Natural History Society*, 94, 145±147.

Clinton, B.D., & Vose, J.M. (1996). Effects of Rhododendron maximum L. on Acer rubrum L. seedling establishment. *Castanea*, 1996, 61, 38–45.

Colak, A.H. (1997). *Research on the silvicultural characteristics of Rhododendron ponticum L. (forestrose)*. Ph.D. Dissertation. Univ. of Istanbul, Turkey, pp 181.

Condit, R. (1995). Research in large, long-term tropical forest plots. *Trends in Ecology and Evolution*, 10:18-22. https://doi.org/10.1016/S0169-5347(00)88955-7

Cowan, A.M., & Cowan, J.M (1929). *The trees of North Bengal including shrubs, woody climbers, bamboos, palms and tree ferns*. *Calcutta*.

Crawley, M.J. (1983). Herbivory. The Dynamics of Animal-plant interactions. *Studies in Ecology*, Blackwell Scientific publications, Oxford. https://doi.org/10.1177/03 0913338400800409

Cullen, J., & Chamberlain, D. F. (1978). *A preliminary synopsis of the genus rhododendron*. Not. R. Bot. Garden, Edinburgh, 36, 105–126.

Cunha, A.A., & Vieira, M.V. (2002). Support diameter, incline, and vertical movements of four didelphid marsupials in the Atlantic forest of Brazil. *Journal of Zoology*, 258: 419-426 https://doi.org/10.1017/S0952836902001565

Currie, D.J., Mittelbach, G.G., Cornell, H.V., Field, R., Guegan, J.-F., Hawkins, B.A., Kaufman, D.M., Kerr, J.T., Oberdorff, T., O'Brien, E.M., & Turner, J.R.G. (2004). Predictions and tests of climate-based hypotheses of broad scale variation in taxonomic richness. *Ecology Letter*, 7, 1121-1134.

Currie, D.J. (1991). Energy and large scale patterns of animal and plant species richness. *The American Naturalist*, 137 (1): 27–49.

Curtis, J.T., & McIntosh, R.P.(1950). The interrelations of certain analytic and systematic phytosociological character. *Ecology*, 31: Pp 434-455. https://doi.org/10.2307/ 1931497

Curtis, J.T. (1959). *The vegetation of Wisconsin*. Univ. *Wisconsin Press,* Madison.

Cuvier, F. (1825). *Histoire naturelle des mammiferesavec des figures originals, coloreesdesineesd'apris des animauxvivants*. Paris, 1824-42, 2:1-3 Plate 203.

Dale, V.H., & Beyeler, S.C. (2001). Challenges in the development and use of ecological indicators. *Ecological Indicators*, Vol. 1, pp. 3–10. http://dx.doi.org/10.1016/S14 70-160X(01)00003-6

Dale, V.H., Beyeler, S.C., & Jackson, C.B. (2002). Understory vegetation indicators of anthropogenic disturbance in longleaf pine forests at Fort Benning, Georgia, USA. *Ecological Indicators*, 1 (2002) 155–170.

Dangol, B.R. (2015). *Illegal wildlife trade in Nepal: A case study from Kathmandu Valley*. Master Thesis. Norway: Norwegian University of Life Sciences. http://hdl.handle.net /11250/296693

Das, A.P., & Mandal, S. (2003). *Some Medicinal Plants of Darjeeling Hills*. WWF-India, West Bengal State Office, Kolkata.

Das, A.P. (2004). Floristic studies in Darjeeling hills. *Bull. Bot. Surv. India*, 43(1-4): 1 – 18.

Davidar, P., Rajagopal, B., Arjunan, M., & Puyravand, J.P. (2008). The relationship between local abundance and distribution of rain forest trees across environmental gradients in India. *Biotropica,* Vol. 40.Issue 6. Page 700-706. https://doi.org /10.1111/j.1744-7429.2008.00437.x

DeLong Jr., D.C. (1996). Defining biodiversity. *Wildlife Society Bulletin*, 24, 738–749.

Dendup, P., Humle, T., Bista, D., Penjor, U., Lham, C., & Gyeltshen, J. (2020). Habitat requirements of the Himalayan red panda (Ailurus fulgens) and threat analysis in Jigme Dorji National Park, Bhutan. *Ecol Evol.*, 10:9444– 9453. https://doi.org/ 10.1002/ece3.6632

Dhaulkhandi, M., Dobhal, A., Bhatt, S., & Kumar, M. (2008). Community structure and regeneration potential of natural forest site in Gangotri, India. *Journal of Basic and Applied Sciences,* 4(1): 49-52.

Dixon, J.A., & Sherman, P.B. (1991): Economics of Protected Areas. *Ambio*, 20(2): 68-74.

Dorji, S., Vernes, K., & Rajaratnam, R. (2011). Habitat correlates of the Red Panda in the Temperate forests of Bhutan. PLoS ONE 6(10) 1-11.

Dorji, S., Vernes, K., & Rajaratnam, R. (2012). The Vulnerable red panda Ailurus fulgens in Bhutan: distribution, conservation status and management recommendations. *Oryx,* Volume 46/ Issue 04 / October 2012 pp 536 543.

Drake, J.A (1990). The mechanics of community assembly and succession. *Journal of Theoretical Biology*, 147(2): 213–233.

Dudley, N., & Stolton, S. (2003). *Running pure: The importance of importance of forest protected areas to drinking water: a research report for The World Bank/WWF Alliance for Forest Conservation and Sustainable Use*. ISBN 2-88085-262-5, UK.

Ehrlich, P.R., & Wilson, E.O. (1991). Biodiversity Studies: Science and Policy. *Science*, 253, 758-762.

Elourard, C., Pascal, J. P., Pelissier, R., Ramesh, B. R., Houllier, F., Durand, M., Aravajy, S., Moravie, M. A., & Gimaret, C. C. (1997). Monitoring the structure and dynamics of a dense moist evergreen forest in the Western Ghats. *Tropical Ecology*, 38: 193–214.

Frank, E.Z., & Habel, J.C. (2011). Biodiversity Hotspots Distribution and Protection of Conservation Priority Areas. *Springer Berlin,* ISBN 9783642209918.

Gadgil, M. (1990). India's Deforestation: patterns and processes. *Society and Natural Resources*, 3: 131-143. http://dx.doi.org/10.1080/08941929009380713

Gaira, K.S., Rawal, R.S., Rawat, B., & Bhatt, I.D. (2014). Impact of climate change on the flowering of Rhododendron arboreum in central Himalaya, India. *Current Science*, Vol. 106, No. 12, 25.

Gairola, S., Rawal, R.S., & Todaria, N.P. (2008). Forest vegetation patterns along an altitudinal gradient in sub-alpine zone of west Himalaya, India. *African Journal of Plant Science*, 2(6), 42-48.

Gairola, S., Rawal, R.S., & Dhar, U. (2009). Patterns of litter fall and return of nutrients across anthropogenic disturbance gradients in three sub alpine forests of west Himalaya, India. *Journal of Forest Research*, 14(2): 73-80. https://doi.org/10. 1007/s10310-008-0104-6

Gairola, S., Rawal, R.S., & Todaria, N.P. (2015). Effect of anthropogenic disturbance on vegetation characteristics of sub-alpine forests in and around valley of flowers national park, a world heritage site of India. *Trop Ecol*, 56(3): 357-365.

Gamble, J.S (1875). The Darjeeling Forest. *Indian Forester*, Volume-1: 73 – 99, 1875.

Gardner, T.A., Barlow, J., Chazdon, R.L., Ewers, R.M., Harvey, C.A., Peres, C.A., & Sodhi, N.S. (2009). Prospects for tropical forest biodiversity in a human-modified world. *Ecology Letters*, 12: 561-582. https://doi.org/10.1111/j.1461-0248.2009. 01294.x

Gaston, K.J. (2000). Global patterns in biodiversity. *Nature*, 405(6783): 220–226.

Geldenhuys, C.J. (1993). Management of forestry plantations to become effective stepping stones and corridors for forest migration. In: D.A. Everard (Editor), *The Relevance of Island Biogeographic Theory in Commercial Forestry*. FRD, Pretoria, pp. 102-118.

Ghosh, P., & Dutta, P.K. (2011). Status and distribution of Red Panda Ailurus fulgens fulgens in India. In: Glatston AR (ed) *Red panda*. William Andrew Publishing, Oxford, pg 357-373

Givnish, T.J. (1999). On the causes of gradients in tropical tree diversity. *J. Ecol*. 87: 193-210. https://doi.org/10.1046/j.1365-2745.1999.00333.x

Glatston, A., Wei, F., Zaw, T., & Sherpa, A. (2015). Ailurus fulgens (Errata Version Published in 2017). The IUCN Red List of Threatened Species https://doi.org/10.2305/IUCN.UK.2015-4.RLTS. T714A45195924.en

Glatston, A.R. (1994). *Status Survey and Conservation Action Plan for Procyonids and Ailurids: The Red Panda, Olingos, Coatis, Raccoons, and their Relatives*. IUCN, Gland, Switzerland.

Gordon, J.E., & Newton, A.C. (2006). Efficient floristic inventory for the assessment of tropical tree diversity: A comparative test of four alternative approaches. *Forest Ecology and Management*, 237: 564-573.

Green, M.J.B. (1987). Diet composition and quality in Himalayan musk deer based on faecal analysis. *J. Wildl. Manage,* 51: 880-892.

Grove, J.M., & Burch, W.R. (1997). A social ecology approach and applications of urban ecosystem and landscape analyses: a case study of Baltimore, Maryland. *Urban Ecosystems* 1(4): 259-275. https://doi.org/10.1023/A:1018591931544

Grytnes, J. A. (2003). Species richness patterns of vascular plants along seven altitudinal transects in Norway. *Ecography*, 26: 291–300. https://doi.org/10.1034/j.1600-0587.2003.03358.x

Grytnes, J.A., Heegaard, E., & Ihlen, P.G. (2006). Species richness of vascular plants, bryophytes, and lichens along an altitudinal gradient in western Norway. *Acta Oecol*., 29, 241-246.

Gullison, R.E. et al. (2007). Tropical forests and climate policy. *Science*, 316, 985–986.

Hall, H. M., & Grinnell, J. (1919). Life-zone indicators in California. *Proc. Calif. Acad. Sci.* 9, 37–67.

Harris, R.B. (2010). Rangeland degradation on the Qinghai-Tibetan plateau: A review of the evidence of its magnitude and causes. *Journal of Arid Environment*, 74: 1-12. http://dx.doi.org/10.1016/j.jaridenv.2009.06.014

Hartmanna, H., & Messier, C. (2011). Interannual variation in competitive interactions from natural and anthropogenic disturbances in a temperate forest tree species: Implications for ecological interpretation. *Forest Ecology and Management*, 261,11 pg 1936-1944. https://doi.org/10.1016/j.foreco.2011.02.018

Hellawell, J. W. (1986). *Biological indicators in of Freshwater pollution and Environmental Management*. Elsevier Applied Science Publishers, London. https://doi.org/10.1007/978-94-009-4315-5

Hilty, J., & Merenlender, A. (2000). Faunal indicator taxa selection for monitoring ecosystem health. *Biology Conservation,* 92 (2000) 185-197. http://dx.doi.org/10.1016/S0006-3207(99)00052-X

Holdridge, L.R., Grenke, W.C., Hatheway, W.H., Liang, T., & Tosi, J.A., Jr., (1971). *Forest environment in tropical life zones, A pilot study.* Pergamon press, new York: Pp747.

Holland, M.B. (2012): The role of protected areas for conserving biodiversity and reducing poverty. Integrating Ecology and Poverty Reduction. In: Ingram J.C., DeClerck F. & Rumbaitis C. (Eds.). *Integrating ecology and poverty reduction: The Application of Ecology in Development Solutions.* Springer. pp 253-272. https://doi.org/ 10.1007/ 978-1-4614-0186-5_18

Hooker, J.D. (1906). A sketch of the Flora of British India. Oxford, London.

Hora, B. (1981). *The Oxford Encyclopedia of Trees of the world.* Oxford University Press, Conscent Books, New York, http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS. T714A45195924.en

Hubbell, S.P., & Foster, R.B. (1983). Diversity of canopy trees in a neotropical forest and implications for conservation. In: Sutton SL, Whitmore TC, Chadwick AC (eds.) *Tropical Rain Forest: Ecology and Management*. Blackwells, Oxford. pp. 25-41.

Huston, M.A. (1980). Soil nutrients and tree species richness in Costa Rican forests. *J. Biogeogr*, 7, 147–157.

Ilorkar, V.M., & Khatri, P.K. (2003). Phytosociological Study of Navegaon National Park, Maharashtra. *Indian Forester*, 129(3): 377-387.

Imhoff, M.L., Bounoua, L., Ricketts, T., Loucks, C., Harriss, R., & Lawrence, W.T. (2004). Global patterns in human consumption of net primary production. *Nature,* 429: 870-873. https://doi.org/10.1038/nature02619

Inhaber, H. (1976). Change in Canadian National visibility. *Nature,* 260,129-130. https://doi.org/10.1038/260129a0

James, E.O., Sian, W.G., & John, D.A. (2006). Effects of food availability on temporal activity patterns and growth of Atlantic salmon. *Journal of Animal Ecology*, 75:677–685. https://doi.org/10.1111/j.1365-2656.2006.01088.x

Jenkins, C.N., & Joppa, L. (2009). Expansion of the global terrestrial protected area system. *Biological Conservation*, 142, 2166–2174. https://doi.org/10.1016/j.biocon.2009.04.016

Jetz, W., & Rahbek, C. (2002). Geographic range size and determinants of avian species richness. *Science*, 297, 1548-1551.

Jha, A.K. (2011). Release and reintroduction of captive-bred red pandas into Singalila National Park, Darjeeling, India. In: Glatston AR (ed) *Red panda*. William Andrew Publishing, Oxford, pp 435–446.

Jha, C.S., & Singh, J.S. (1990). Composition and dynamics of dry tropical forest in relation to soil texture. *Journal of Vegetation Science*, 1: 609–614.

Jhariya, M.K. (2014). *Effect of forest fire on microbial biomass, storage and sequestration of carbon in a tropical deciduous forest of Chhattisgarh*. Ph.D. Thesis, I.G.K.V., Raipur (C.G.), pp. 259.

Jhariya, M.K., & Oraon, P.R. (2012). Regeneration Status and Species Diversity along the Fire Gradients in Tropical Deciduous Forest of Chhattisgarh. *Journal of Plant Development Sciences*, 4(1):49-54.

Johnson, R. K., Widerholm, T., & Rosenberg, D. M. (1993). Freshwater biomonitoring using individual organisms, populations and species assemblages of benthic macro invertebrates. In: Rosenberg, D.M., Resh, V.H. (Eds), *Freshwater Biomonitoring and Benthic Macro-invertebrates*. Chapman& Hall, New York, pp 40-158.

Jule, K.R., Leaver, L.A., & Lea, S. (2008). The effects of captive experience on reintroduction survival in carnivores. A review and analysis. *Biological conservation*, 141 (2008) 355-363. https://doi.org/10.1016/j.biocon.2007.11.007

Kanai, H. (1966). Phytogeography of Eastern Himalaya. In: *Flora of Eastern Himalaya*. (ed. H Hara), University of Tokyo. pp. 13 – 38.

Kandel, K., Huettmann, F., Suwal, M.K., Regmi, G.R., Nijman, V. et al. (2015). Rapid multi-nation distribution assessment of a charismatic conservation species using open access ensemble model GIS predictions: Red panda (Ailurus fulgens) in the Hindu-Kush Himalaya region. *Biological Conservation*, 181- 150–161. http://dx.doi.org/10.1016/j.biocon.2014.10.007

Kasso, M., & Balakrishnan, M. (2013). Ex Situ Conservation of Biodiversity with Particular Emphasis to Ethiopia. *ISRN Biodiversity*. Volume 2013, Article ID 985037, 11 pages. https://doi.org/10.1155/2013/985037

Kelly, J. R., & Harwell, M. A. (1990). Indicators of ecosystem recovery. *Environmental Management,* 14, 527- 545. https://doi.org/10.1007/BF02394708

Kessler, M. (2000). Elevational gradients in species richness and endemism of selected plant groups in the central Bolivian Andes. *Plant Ecology*, 148: 181–193.

Khaling, S. (1998). *Certain aspect of ecology and behaviour of the satyr Tragopan Tragopan satyra in the Singhalila national Park Darjeeling India*. PhD thesis, North Bengal University, India.

Kharkwal, G., Mehrotra, P., Rawat, Y.S., & Pangtey, Y.P.S. (2005). Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. *Current Science,* 89 (5): 873-878.

Kharkwal, G., & Rawat, Y.S. (2010). Structure and composition of vegetation in subtropical forest of Kumaun Himalaya. *African Journal of Plant Science*, Vol. 4 (4), pp. 116-121.

Kharkwal, G. (2009). Qualitative analysis of tree species in evergreen forests of Kumaun Himalaya. *African Journal of Plant Science*, 4(4): 23-28.

Kiester, A. R. (2001). Species Diversity, Overview. In: *Encyclopedia of Biodiversity*. Vol. 5. Academic Press, NY, pp. 442.

Kothari, A. (2006): Community conserved areas: towards ecological and livelihood security. *Parks*, 16(1): 3-13.

Kremen, C. (1994). Biological inventory using target taxa; case study of the butterflies of Madagascar. *Ecological Applications*, 4: 407-422.

Krishna, A. P., Chhetri, S., & Singh, K. K. (2002). Human dimensions of conservation in the Khangchendzonga Biosphere Reserve. *Mt. Res. Dev*., 24, 328–331. https://doi. org/10.2307/1941946

Krishnan, R, Sanjay, J, Gnanaseelan, C, Mujumdar, M et al. (2020). *Assessment of Climate Change over the Indian Region. A Report of the Ministry of Earth Sciences (MoES), Government of India*. Springer open. ISBN 978-981-15-4326-5.

Kryuchkov, V.V. (1993). Extreme anthropogenic loads and the northern ecosystem condition. *Ecological Society of America,* 3(4): 622-630. https://doi.org/10.2307/ 1942095

Kumar, A., Marcot, B.G., & Saxena, A. (2006). Tree species diversity and distribution patterns in tropical forests of Garo Hills. *Curr. Sci.,* 91, 1370-1381.

Kumar, A., Rai, U., Roka, B., Jha, A.K., & Reddy, A. (2016). Genetic assessment of captive red panda (*Ailurus fulgens*) population. *Springer Plus,* https://doi.org/10. 1186/s40064-016-3437-1

Kumar, A., & Ram, J. (2005). Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, central Himalaya. *Biodivers Conserv,* 14: 309-331. https://doi.org/10.1007/s10531-004-5047-4

Lan, S. (2003). Plant species diversity in Wuyishan national nature reserve. *Scientia Silvae Sinicae,* 2003; 29(1): 36–43.

Landers, P. B., Verners, J., & Thomas, J. W. (1988). Critiques of vertebrate indicator species. *Conservation Biology,* 2, 316-328.

Lavorel, S., Flannigan, M.D., Lambin, E.F., & Scholes, M.C. (2007). Vulnerability of land systems to fire: interactions among humans, climate, the atmosphere, and ecosystems. *Mitigation and Adaptation Strategies for Global Change*, 12 (1),1381–2386 https://doi.org/10.1007/s11027-006-9046-5

Leach, D. G. (1961). *Rhododendrons of the World*. Scribner, New York.

Leroux, S.J., Krawchuk, M.A., Schmiegelow, F., Cumming, S.G., Lisgo, K., Anderson, L.G., & Petkova, M. (2010). Global protected areas and IUCN designations: Do the categories match the conditions? *Biological Conservation,* 143(3): 609-616.

Li, Q., Yang, L., & Zhou, J. (2002). Comparative analysis on species diversity of hillcolsed afforested plant community in Beijing Jiulong Mountain. *Chinese journal of applied ecology,* 2002; 13(9): 1065–1068.

Li, J., He, O., Hua, X., Zhou, J., Xu, H., Chen, J., & Fu, C. (2009). Climate and history explain the species richness peak at mid-elevation for Schizothorax fishes (Cypriniformes: Cyprinidae) distributed in the Tibetan Plateau and its adjacent regions. *Glob. Ecol. Biogeogr.,* 18, 264-272.

Liang, X., Zhang, Z.H., Zhang, L., Zhang, W.P., Shen, F.J., & Yang, Z. (2007). Isolation and characterization of 16 tetranucleotide microsatellite loci in the red panda (*Ailurus fulgens*). *Molecular Ecology Notes,* 7: 1012-1014. https://doi.org/10.1111 /j.1471-8286.2007.01759.x

Liu, Z.J., Zhang, B.W., & Wei, F.W. (2005). Isolation and characterization of microsatellite loci for the red panda, Ailurus fulgens. *Molecular Ecology Notes,* 5:27-29. https://doi.org/10.1111/j.1471-8286.2004.00818.x

Mahapatra, R. (1998). Beauty and biology: the Shangri-la. *Down to the earth*, 7:27-37.

Mallik, J.K. (2010). Status of Red Panda Ailurus fulgens in Neora Valley National Park, Darjeeling District, West Bengal, India. *Small Carnivore Conservation*, Vol. 43:32-36.

Management Plan of Singalila National Park, West Bengal (1990-1991 to 2000-2001). Wildlife Circle (North) Government of West Bengal.

Mani, M.S. (1978). Ecology and Phytogeography of the High Altitude Plants of the North West Himalaya. Oxford & IBH Publishing Company, New Delhi, IN.

Mao, A.A., Yumnan, J.Y, Gogoi, R., & Pinokiyo, A. (2009). Status and distribution of *Rhododendron* species in Temperate and Sub Alpine Hill ranges of Mount Esii and surrounding in Manipur and Nagaland, India. *Indian Forester*.

Markert, B., Wappelhorst, O., Weckert, V., Herpin, U., Siewers, U., & Friese, K. (1999). The use of bioindicators for monitoring the heavy-metal status of the environment. *Journal of Radioanalytical Nuclear Chemistry*, 240(2): 425-429. https://doi.org /10.1007/BF02349387

Martinez, M.L., Maqueo, O.P., Vazquez, G., Campos, G.C., Franco, J.C., Mehltreter, K., Equihua, M., & Landgrave, R. (2009). Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. *Forest Ecology and Management*, 258 (2009) 1856–1863.

Maunder, M., & Byers, O. (2005). The IUCN technical guidelines on the management of ex situ populations for conservation: reflecting major changes in the application of ex situ conservation. *Oryx*, 39, 1: 95–98. https://doi.org/10.1017/S003060 5305000177

May, R.M., Lawton, J.H., & Stork, N.E. (1995). *Chapter 1 of Extinction Rates*, J.H. Lawton and R. M. May, editors. Oxford University Press, New York, NY, USA. https://doi.org/10.1046/j.1420-9101.1996.t01-1-9010124.x

Menhinick, E.F. (1964). A Comparison of some species diversity indices applied to samples of field insects. *Ecology,* (45): 858 – 868. https://doi.org/10.2307/ 1934933

Milleville, R. (2002). *The Rhododendrons of Nepal*. Himal Books, Katmandu.

Mishra, R. (1968). *Ecology Workbook*. Oxford and IBH Publishing Co. New Delhi, India.

Mittermeier, R.A., Mittermeier, C.G., Brooks, T.M., Pilgrim, J.D., Konstant, W.R., da Fonseca, G.A.B., & Kormos, C. (2003). Wilderness and biodiversity conservation. *Proceedings of the National Academy of Sciences USA* 100: 10309–10313. https://doi.org/10.1073/pnas.1732458100

Mittermeier, R.A., Turner, W.R., Larsen, F.W., Brooks, T.M. & Gascon, C. (2011). Global Biodiversity Conservation: The critical role of Hotspots. In: *Biodiversity Hotspots*, (eds. F.E. Zachos & J.C. Habel), Berlin. pp.3 – 22. http://dx.doi.org/10.1007/978-3-642-20992-5_1

MoFSC. (2016). *Red Panda field survey and protocol for community based monitoring*. Kathmandu, Nepal: Ministry of Forests and Soil Conservation. http://dx.doi.org /10.1016/B978-0-12-823753-3.00019-3

Moktan, S. (2017). *Phytosociological characterization of vegetation in Darjeeling hills*. PhD thesis, North Bengal University, India.

Morris, R. (2010). Anthropogenic impacts on tropical forest biodiversity: a network structure and ecosystem functioning perspective. *Phil. Trans. R. Soc. B* , 365, 3709–3718. https://doi.org/10.1098/rstb.2010.0273

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R.E., Lehner, B., Malcolom, T. R.., & Ricketts, T. H. (2008). Global mapping of ecosystem services and conservation priorities. *Proceedings of the National Academy of Science of the United States of America*, 105 (28): 9495-9500. https://doi.org/10.1073/ pnas.0707823105

Nath, A.J., & Das, A.K. (2010). Western Arunachal Pradesh offering prime home to the endangered red panda. *Current Science*, 99, 155.

Naughton-Treves, L., Holland, M.B., & Brandon, K. (2005): The role of protected areas in conserving biodiversity and sustaining local livelihoods. *Annual Review of Environment and Resources,* 30: 219–252. https://doi.org/10.1146/ annurev.energy. 30.050504.164507

Niemi, G. J. & McDonald, M. E. (2004). Application of ecological indicators. *Annual Review of Ecology Evolution and Systematics,* 35:89–111. https://doi.org/10.1146/annurev.ecolsys.35.112202.130132

Noss, R. F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, 4: 355– 64.

Oommen, M. A., & Shanker, K. (2005). Elevational species richness patterns emerge from multiple local mechanisms in Himalayan woody plants. *Ecology*, 86: 3039–3047. https://doi.org/10.1890/04-1837

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Simons, A. (2009). Agroforestree Database: a tree reference and selection guide.

Owen-Smith, N., & Novellie, P. (1982). What should a clever ungulate eat? *Am. Nat.* 119:151-178.

Pande, P.K., Negi, J.D.S., & Sharma, S.C. (2002). Plant species diversity, composition, gradient analysis and regeneration behavior of some tree species in a moist temperate western—Himalayan forest ecosystem. *Indian Forester*, 128(8): 869–886. http://dx.doi.org/10.36808/if%2F2002%2Fv128i8%2F2691

Pandey, U., & Singh, J. S. (1984). Energy flow relationships between agro and forest ecosystems in Central Himalaya. *Environ Conserv*, 11(1): 45-53.

Panthi, S., Aryal, A., Raubenheimer, D., Lord, J., & Adhikari, B. (2012). Summer Diet and Distribution of the Red Panda (*Ailurus fulgens fulgens*) in Dhorpatan Hunting Reserve, Nepal. *Zoological Studies*, 51 (5):701-709.

Paul, A., Khan, M.L., Arunachalam, A., & Arunachalam, K. (2005). Biodiversity and Conservation of rhododendrons in Arunachal Pradesh in the Indo-Burma Biodiversity Hotspot. Curr. *Sci.,* 89(4): 623 – 634.

Pearson, D. L., & Cassola, F. (1992). World-wide species richness patterns of tiger beetles (Coleoptera: Cicindelidae): indicator taxon for biodiversity and conservation studies. *Conservation Biology*, 6 : 376– 391.

Philip, E.A. (1959). *Methods of vegetation study*. Henry Holt & Co., Inc. P.107

Phillips, O.L., Martinez, R.V., Vargas, P.N., et al. (2003). Efficient plot-based floristic assessment of tropical forests. *Journal of Tropical Ecology*, 19: 629-645. https://doi.org/10.1017/S0266467403006035

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Jour. Theo. Biol*., (13): 131 – 44. https://doi.org/10.1016/0022-5193 (66)90013-0

Pocock, R. I. (1921). *The external characters and classification of the Procyonidae*. Proc. Zool. Soc. London, 1921:389-422.

Polunin, O., & Stainton, A. (1984). *Flowers of the Himalaya*. Oxford University Press, Delhi.

Pradhan, K. (2010). *Handbook - Rhododendron of Sikkim*. Logical, Kolkata. Pp. 143.

Pradhan, S. (1998). *Studies on Some Aspects of the Ecology of the Red Panda, Ailurus fulgens (Cuvier, 1825) in the Singhalila National Park, Darjeeling, India*. PhD thesis, North Bengal University, India.

Pradhan, U.C., & Lachungpa, S.T. (1990). *Sikkim- Himalayan Rhododendron*. Primulaceae book, Kalimpong, Darjiling.

Pragasan, L.A., & Parthasarathy, N. (2010). Landscape-level tree diversity assessment in tropical forests of southern Eastern Ghats, India. *Flora*, 205 (2010) 728–737. https://doi.org/10.1016/j.flora.2010.04.011

Prasad, R., & Pandey, R.K. (1992). An observation on plant diversity of sal and teak forest in relation to intensity of biotic impact of various distances from habitation in Madhya Pradesh, A case study. *Journal of Tropical Forestry*, 8(1): 62-83.

Priess, J.A., Mimler, M., Klein, A.M., Schwarze, S., Tscharntke, T., & Steffan-Dewenter, I. (2007). Linking deforestation scenarios to pollination services and economic returns in coffee agroforestry systems. *Ecologial Applications,* 17 (2), 407–417. https://doi.org/10.1890/05-1795

Princee, F., & Glatston, A. (2016). Influence of Climate on the Survivorship of Neonatal Red Pandas in Captivity. *Zoo Biology,* 9999: 1–7. https://doi.org/10.1002/zoo. 21266

Pyke, C. R. (2007). The implications of global priorities for biodiversity and ecosystem services associated with protected areas. *Ecology and Society*, 12(1): 4.

Qian, H., & Ricklefs, R.E. (2004). Taxon richness and climate in angiosperms: is there a globally consistent relationship that precludes region effect? *American Naturalist*. 163: 773-779. http://dx.doi.org/10.1086/383097

Rader, R., & Krockenberger, A. (2006). Does resource availability govern vertical stratification of small mammals in an Australian lowland tropical rainforest? *Wildlife Res,* 33: 571-576. http://dx.doi.org/10.1071/WR04108

Rahbek, C. (2005). The role of spatial scale and the perception of large-scale species richness patterns. *Ecology Letter*, 8, 224-239. https://doi.org/10.1111/j.1461-0248.2004.00701.x

Rai, U., Lama, D., Thapa, N., & Rai, S. (2013). Diversity of Rhododendron Linnaeus (Ericaceae) in Singalila National Park located in Darjeeling part of the Himalayas. *Pleione*, 7(2): 424 - 440. 2013.

Ram, J., Kumar, A., & Bhatt, J. (2004). Plant diversity in six forest types of Uttaranchal, Central Himalaya, India. *Current Science*, 86(7): 975-978.

Ramakrishnan, P.S., Toky, O.P., Mishra, B.K., & Saxena, K.G. (1981). Slash and bum agriculture in north east India. In: Mooney, H.A., Bonnicksen, T.M., Christensen, N.L., Lotan, J.E., and Reiners W.A. (eds.), *Fire Regimes and Ecosystem Properties*. USDA Forest Service, General Tech. Rep. WO-26, pp. 570-587.

Ranjitkar, S., Luedeling, E., Shrestha, K.K., Guan, K., & Xu, J. (2012). Flowering phenology of tree rhododendron along an elevation gradient in two sites in the Eastern Himalayas. *Int J Biometeorol*,http://dx.doi.org/10.1007/s00484-012-0548-4

Raven, A. S., & Roy, P.S. (1997). Satellite remote sensing for ecological analysis of forested landscape. *Plant ecology*, 131: Pp 129-141.

Rawat, V.S., & Chandhok, A. (2009). Phytosociological analysis and distribution patterns of tree spcies-A case study from Govind Pashu Vihar, National Park, Uttarakhand. *New York Science Journal*, 2(4): 58-63.

Reddy, C. S., & Ugle, P. (2008). Tree species diversity and distribution patterns in tropical forest of Eastern Ghats, India: a case study. *Life Science Journal*, 5(4): 87-93.

Regier, H. (1990). Workgroup issue paper: indicators and assessment of the state of fisheries. *Environmental Monitoring and Assessment*, 15, 289-294

Reid, D.G., Jinchu, H., & Hunang, Y. (1991). Ecology of the Red Panda (Ailurus fulgens) in the Woolong Reserve, China. *Journal of Zoology*, 225, pp. 345-364. https://doi.org/10.1111/j.1469-7998.1991.tb03821.x

Rennolls, K., & Laumonier, Y. (2000). Species diversity structure analysis at two sites in the tropical rain forest of Sumatra. *Journal of Tropical Ecology*, 16: 253-270. http://dx.doi.org/10.1017/S0266467400001395

Ricketts, T.H., Daily, G.C., Ehrlich, P.R., & Michener, C.D. (2004). Economic value of tropical forest to coffee production. *Proceedings of the National Academy of Sciences of the United States of America*, 101 (34), 12579–12582. https://doi.org/10.1073/pnas.0405147101

Ricketts, T.H., Regetz, J., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Bogdanski, A., Gemmill-Herren, B., Greenleaf, S.S., Klein, A.M., Mayfield, M.M., Morandin, L.A., Ochieng, A., Viana, B.F., 2008. Landscape effects on crop pollination services: are there general patterns? *Ecology Letters*, 11 (5), 499–515. https://doi.org/10.1111/j.1461-0248.2008.01157.x

Roberts, M.S. (1975). Growth and development of mother reared red pandas. *Internatl. Zoo Year Book*, 15:57-63.

Roberts, M.S. (1992): Red Panda: The fire cat. *Zoo Goer*, 21(2).

Roberts, M. S., & Gittleman, J.L. (1984). Ailurus fulgens. *Mammalian Species,* 222: 1–8.

Roberts, M. S. (1980). Breeding the red panda (*Ailurus fulgens*) at the National Zoological Park. *Zool. Garten*, 50:253-263.

Roberts, M. S. (1981). *The reproductive biology of the red panda, Ailurus fulgens, in captivity*. Unpubl. M.S. thesis, Univ. Maryland, 202 pp.

Rodrigues, A.S.L., Andelman S.J., Bakarr M.I., et al. (2004). Effectiveness of the global protected area network in representing species diversity. *Nature,* 428: 640–643. https://doi.org/10.1038/nature02422

Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Cowling R.M., Fishpool, L.D.C., Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Long, J.S., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., & Yan, X. (2004): Effectiveness of the global protected area network in representing species diversity. *Nature,* 428: 640–643. https://doi.org/10.1038/nature02422

Roka, B., Rai, U., Jha, A.K., & Chhetri, D.R. (2020). Selection of Red Panda (Ailurus fulgens) as an indicator species in Singalila National Park, Darjeeling, India. *Eco. Env.& Cons.*, 26 (1): 2020; pp. (171-176).

Roka, B., & Jha, A. K. (2014a). Census of Red Panda (Ailurus fulgens) at Singalila National Park and its surrounding area, Darjeeling, West Bengal, India. *ZOO's PRINT*. Volume XXIX, Number 4, April 2014.

Roka, B. (2014b). *Study of Red Panda (Ailurus fulgens) in ex situ facilities in corelation with in-situ facilities for conservation breeding*. PNHZP Publication.

Ross, G., (1998). *Botanica. The Illustrated A–Z of over 10000 Garden Plants for Australian Gardens and How to Cultivate Them.* Random House, Australia. 2nd edn, p. 1008.

Sagar, R., Raghubanshi, A.S., & Singh, J. S. (2008). Comparison of community composition and species diversity of understorey and overstorey tree species in a dry tropical forest of northern India. *Journal of Environmental Management,* 88 (4): 1037–1046. https://doi.org/10.1016/j.jenvman.2007.05.013

Sagar, R. & Singh, J.S. (2005). Structure, diversity and regeneration of tropical dry deciduous forest of northern India. *Biodivers. Conserv*. 14, 935-939.

Sandbrook, C.G. (2010). Local economic impact of different forms of nature based tourism. *Conservation Letters*, 3:21–28. https://doi.org/10.1111/j.1755-263X.2009.00085.x

Sarin, M. (2001). Disempowerment in the name of 'Participatory' forestry? Village forests joint management in Uttarakhand. *For Trees People,* 44:26–35

Sastry, A.R.K., & Hajra, P.K. (2010). *Rhododendrons in India: Floral and Foliar Splendour of the Himalayan Flora*. BS Publications/BSP Books. Pp.182.

Schall, J.J., & Pianka, E.R. (1978). Geographical trends in numbers of species. *Science*, 201(4357): 679–686.

Scott, N.J. (1976). The abundance and diversity of the herpetofaunas of tropical forest litter. *Biotropica* 8, 41-58.

Scott. (2010). Nepal's Magnificent Rhododendron. *ECS Nepal*. Issue-104.

Semwal, R.L., Nautiyal, S., Sen, K.K., Rana, U., Maikhuri, R.K., Rao, K.S., & Saxena, K.G. (2004). Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. *Agricultural Ecosystem and Environment*, 102: 81–92. http://dx.doi.org/10.1016/S0167-8809(03)00228-7

Shaheen, H., Qureshi, R.A., & Shinwari, Z.K. (2011). Structural diversity, vegetation dynamics and anthropogenic impact on lesser Himalayan subtropical forests of Bagh district, Kashmir. *Pakistan Journal of Botany*, 43 (4): 1861-1866.

Shannon, C.E., & Wiener, W. (1963). *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, pp. 117.

Sharma, C.M., Gairola, S., Ghildiyal, S.K., & Suyal, S. (2009). Forest resource use patterns in relation to socioeconomic status: A case study in four temperate villages of Garhwal Himalaya. *India. Mount. Res. Dev*., (29): 308 – 319, 2009. https://doi.org/10.1659/mrd.00018

Sharma, E. (2008). Developing a Transboundary Biodiversity Conservation Landscape and Conservation Corridors in the Kangchenjunga Complex. *Biodiversity Conservation in the Kangchenjunga Landscape*. International Centre for Integrated Mountain Development. ISBN 978 92 9115 0885.

Sharma, H.P., & Belant, J.L. (2009). Distribution and observation of red panda (*Ailurusfulgensfulgens*) in Dhorpatan Hunting Reserve, Nepal. *Small Carnivore Conservation,* 40**:** 33-35.

Sharma, H.P., Belant, J.L., & Swenson, J.E. (2014). Effects of livestock on occurrence of the vulnerable red panda Ailurus fulgens in Rara national park, Nepal. *Oryx*, 48 (2), 228-231. https://doi.org/10.1017/S0030605313001403

Siddig, A. H., Ellision, A. M., Ochs, A., Leeman, C. V., & Law, M. K. (2016). How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in Ecological indicators. *Ecological Indicator*. 60-223-230. https://doi.org/10.1016/j.ecolind.2015.06.036

Silori, C.S., & Mishra, B.K. (2001). Assessment of livestock grazing pressure in and around the elephant corridors in Mudumalai Wildlife Sanctuary, South India. *Biodiversity and Conservation*. 10. 2181-2195, 2001. https://doi.org/10.1023/A:1013285910650

Simpson, E.H (1949). Measurement of Diversity. *Nature*, 163 – 188.

Singh, J.S. (2006). Sustainable development of the Indian Himalayan region: Linking ecological and economic concerns. *Current Science,* 90(6): 784-788.

Singh, J.S., & Singh, S.P. (1992). *Forests of Himalaya*. Gyanodaya Prakashan, Nainital, India.

Singh, A.K., Raghubanshi, A.S., & Singh, J.S. (2002). Medical ethnobotany of the tribals of Sonaghati of Sonbhadra district, Uttar Pradesh, India. *Journal of Ethnopharmacology*,81: 31–41.https://doi.org/10.1016/s0378-8741(02)00028-4

Singh, L., & Singh, J.S. (1991). Species structure, dry matter dynamics and carbon flux of a dry tropical forest in India. *Ann. Bot*. 68: 263-273. https://doi.org/10.1093/oxford journals.aob.a088252

Solberg, K.H., Bellemain, E., Drageset, O.M., Taberlet, P., & Swenson, J.E. (2006). An evaluation of field and non-invasive genetic methods to estimate brown bear (*Ursos arctos*) population size. *Biological Conservation,* 128:158-168. https://doi.org/10.1016/j.biocon.2005.09.025

Soule, M. E. (1985). Biodiversity indicators in California; taking nature's temperature. *California Agriculture*, 49 : 40-44.

Srivastava, T., & Dutta, P.K. (2010). Western Arunachal Pradesh offering prime home to the endangered red panda. *Current Science*, Vol. 99, No. 2, 25.

Steffan-Dewenter, I., & Westphal, C. (2008). The interplay of pollinator diversity, Pollination services and landscape change. *Journal of Applied Ecology*, 45 (3), 737–741. https://doi.org/10.1111/j.1365-2664.2008.01483.x

Stem, C., Lassoie, J., Lee, D., Deshler, D., & Schelhas, J. (2003). Community participation in ecotourism benefits: the link to conservation practices and perspectives. *Society and Natural Resources,* 16:387–413. http://dx.doi.org/10.1080/08941920309177

Stewart, D.R.M. (1967). Analysis of plant epidermis in faeces: a technique for studying food preferences of grazing herbivores. *J. Appl. Ecol.,* 4 (1): 83- 111. https://www. jstor.org/stable/2401411

Stone, M., & Wall, G. (2004). Ecotourism and community development: case studies from Hainan, China. *Environmental Management,* 33:12–24. http://dx.doi.org/10.1007/s00267-003-3029-z

Strassburg, B.B.N. et al. (2010). Global congruence of carbon storage and biodiversity in terrestrial ecosystems. *Conservation Letters*, 2010;3:98–105. https://doi.org/10. 1111/j.1755-263X.2009.00092.x

Su, B., Fu, Y., Wang, Y., Jin, L., & Chakraborty, R. (2001). Genetic diversity and Population History of the Red Panda (Ailurus fulgens) as inferred from mitochondrial DNA Sequence Variations. Mol Biol Evol. https://doi.org/ 10.1093/oxfordjournals.molbev.a003878

Sukumar, R., Dattaraja, H.S., Suresh, J., Radhakrishnan, R., Vasudeva, S., Nirmala, & Joshi, N.V. (1992). Long-term monitoring of vegetation in a tropical deciduous forest in Mudumalai, Southern India. *Current Science*, 62:608-616.

Tamang, K.K., & Yonzon, G.S. (2004). *Dictionary of flowering plants of Darjeeling-Sikkim Himalaya*.

Tang, Z., Fang, J., & Zhang, L. (2004). Patterns of woody plant species diversity along environmental gradients on Mt.Taibai, Qinling Mountains. *Biodiversity Science,* 12(1): 115–122. http://dx.doi.org/10.17520/biods.2004014

Tarpley, J. D., Schneider, S. R., & Money, R. L. (1984). Global Vegetation Indices from the NOAA-7 Meteorological Satellite. *J. Clim. Appl. Meteor*., 23 (3): 491-494.

Thapa, A., Hu, Y., Aryal, P. C., & Singh, P. (2020). The endangered red panda in Himalayas: Potential distribution and ecological habitat associates. *Global Ecology and Conservation*, 21 (2020) -00890. https://doi.org/10.1016/j.gecco. 2019.e00890

Tiwari, O., & Chauhan, U.K. (2006). Rhododendron conservation in Sikkim Himalaya. *Current Science*, Vol. 85, No. 5.

Todd, J.W., & Hansen, R.M. (1973). Plant fragments in the faeces of bighorns as indicators of food habits. *Journal of Wildlife Management,* 37: 363-366. https://doi.org/10.2307/3800127

Tripathi, O.P., Pandey, H.N., & Tripathi, R.S. (2004). Distribution, community characteristics and tree population structure of sub-tropical pine forest of Meghalaya, northeast India. *International Journal of Ecology and Environmental Sciences*, 30, 207-219.

Turner, W.R., Brandon, K., Brooks, T.M., Costanza, R., da Fonseca GAB, & Portela, R. (2007). Global conservation of biodiversity and ecosystem services. *BioScience*, 57: 868–873. https://doi.org/10.1641/B571009

Upreti, N. (1982). *A Study on Phytosociology & State of Regeneration of Oak-Forest at Nainital.* Ph.D. Thesis, Kumaum University, Nainital.

Uprety, Y., Poudel, R.C., Gurung, J., Chettri, N., & Chaudhary, R.P. (2016). Traditional use and management of NTFPs in Kangchenjunga Landscape: implications for conservation and livelihoods. *Journal of Ethnobiology and Ethnomedicine*, 12:19. https://doi.org/10.1186/s13002-016-0089-8

Vazquez, G.J.A., & Givnish, T.J. (1998). Altitudinal gradients in tropical forest composition, structure, and diversity in the Sierra de Manantlan. *J. Ecol.*, 86, 999-1020.

Veblen, T.T. (1989). Tree regeneration response to gaps along transandean gradient. *Ecology*, 70: Pp 539-576.

Vetaas, O.R., & Grytnes, J.A. (2002). Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology and Biogeography,* 11:291-301.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., & Melillo, J.M. (1997). Human Domination of Earth's Ecosystems. *Science* 277, 494. https://doi.org/10.1126/science.277.5325.494

Walker, D. (1988). Diversity and stability, in: Cherrett, J.M. (Ed.), *Ecological concepts: the contribution of ecology to the understanding of the natural world*. Blackwell Scientific Publications, Oxford, pp. 115–145.

Wang, X., Choudhry, A., Yonzon, P., Wozencraft, C., & Than, Z. (2008). *Ailurus fulgens*, in: IUCN2009. IUCN Red List of Threatened Species. Version 2009.2.

Wattenberg, I., & Breckle, S.W. (1995). Tree species diversity of a premontane rain forest in the Cordillera de Tilaran, Costa Rica. *Ecotropica*, 1: 21-30.

Wei, F., Feng, Z., Wang, Z., & Hu, J.(2000). Habitat use and separation between the giant panda and the red panda. *Journal of Mammalogy*, 81(2):448–455.

Wei, F., Feng, Z., Wang, Z., & Hu, J. (1999). Current distribution, status and conservation of wild red pandas Ailurus fulgens in China. *Biological Conservation*, 89: 285 – 291. https://doi.org/10.1016/S0006-3207(98)00156-6

Wei, F.W., Traylor-Holzer, K., Leus, K., & Glatston, A. (2014). *Red Pandas in China Population and Habitat Viability Assessment Workshop Final Report*. IUCN SSC Conservation Breeding Specialist Group, Apple Valley, MN.

White, P.S. (1979). Pattern, process and natural disturbance in vegetation. *Botanical review*, 45: Pp 229-299. https://www.jstor.org/stable/4353953

Whitford, P.B. (1949). Distribution of woodland plants in relation to succession and clonal growth. *Ecol*., (30): 199 – 208. https://doi.org/10.2307/1931186

Whittaker, R.H. (1972). Evolution and measurement of species diversity. *Taxon*, 21(2/3): 213–251. https://www.jstor.org/stable/1218190

Williams, B. (2003). Red panda in eastern Nepal: how do they fit into ecoregional conservation of the eastern Himalaya. *Conserv. Biol. Asia*, 16, 236-250.

Williams, B. (2004). *The status of Red Panda in Jamuna and Mabu Village of Eastern Nepal*. M.Sc. Thesis submitted to San Jose State University.

Willig, M.R., Kaufman, D.M., & Stevens, R.D. (2003). Latitudinal gradients of biodiversity: pattern process, scale and synthesis. *Annu. Rev. Eco. Evol. Sys*., 34: 273-309. https://doi.org/10.1146/annurev.ecolsys.34.012103.144032

Wilson, E. O. (1999). *The diversity of life*. Reissue ed. W.W. Norton and Company, New York, NY. US.

Winne, C.T., & Kech, M.B. (2004). Daily activity patterns of Whiptail Lizards (Squamata: Teiidae: Aspidoscelis): A proximate response to environmental conditions or an endogenous rhythm? *Function Ecology*, 18:314–321. https://doi.org/10.1111/j. 0269-8463.2004.00819.x

Wright, D.H. (1983). Species–energy theory: an extension of species–area theory. *Oikos*, 41(3): 496–506. https://www.jstor.org/stable/3544109

Wu, Z.Y., Raven, P.H., & Hong, D.Y. (eds.) (2005). *Flora of China*. Vol. 14 (Apiaceae through Ericaceae). *Science Press, Beijing, and Missouri Botanical Garden Press, St. Louis*. Pp. 260 – 517.

Xu, L., & Guan, J. (2018). Red panda market research findings in china. *TRAFFIC* briefing paper. https://www.traffic.org/site/assets/files/10540/red-panda-briefing-en.pdf

Yam, G., & Tripathi, O.P. (2016). Tree diversity and community characteristics in Talle Wildlife Sanctuary, Arunachal Pradesh, Eastern Himalaya, India. *Journal of Asia-Pacific Biodiversity*, 9 (2016) 160-165. https://doi.org/10.1016/j.japb. 2016.03.002

Yibo, Hu., Yu, Guo., Dunwu, Qi. et al. (2011). Genetic structuring and recent demographic history of red pandas (*Ailurus fulgens*) inferred from microsatellite and mitochondrial DNA. *Molecular Ecology*, 20, 2662-2675. https://doi.org/10.1111/j.1365-294x.2011.05126.x

Yonzon, P.B., & Hunter. (1989). *Ecological study of the red panda in the Nepal-Himalayas*. University of Maine.

Yonzon, P.B., & Hunter, M.L. (1991a). Cheese, tourists, and red pandas in the Nepal Himalayas. *Conservation Biology*, 5, 196–202. https://doi.org/10.1111/j.1523-173 9.1991.tb00124.x

Yonzon, P. B. (1991b). Conservation of the Red Panda (Ailurus fulgens). *Biological Conservation*, 57 (I):1-11. http://dx.doi.org/10.1016/0006-3207(91)90104-H

Zhang, Z.J., Wei, F.W., Li, M., & Hu, J.C. (2006). Winter microhabitat separation between giant and red pandas in Bashania faberi bamboo forest in Fengtongzhai Nature Reserve. *Journal of Wildlife Management*, 70:231–235. https://www.jstor. org/stable/3803565

Zhang, L., Liang, X., Zhang, Z.H. et al. (2008). Identification and characterization of ten polymorphic microsatellite loci in the red panda Ailurus fulgens. *Conservation Genetics*, 9:787-790. https://doi.org/10.1007/s10592-007-9396-x

Zhang, Z., Hu, J., Han, Z., & Wei, F. (2011). Activity patterns of wild red pandas in Fengtongzhai Nature Reserve, China. *Italian Journal of Zoology*, 78(3): 398–404. https://doi.org/10.1080/11250003.2011.563248

Zhang, Z., Hu, J., Yang, Z., Li, M., & Wei, F. (2009). Food habits and space-use of red pandas Ailurus fulgens in the Fengtongzhai Nature Reserve, China: food effects and behavioural responses. *Acta Theriologica,* 54 (3): 225–234. http://dx.doi.org/ 10.4098/j.at.0001-7051.017.2008

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RESEARCH ARTICLE

A study on plant preferences of red panda (*Ailurus fulgens*) in the wild habitat: foundation for the conservation of the species

Bhupen Roka[1], Alankar K. Jha[2], Dhani Raj Chhetri[1]

1 *Department of Botany, Sikkim University, 6th Mile, Tadong, Gangtok 737102, Sikkim, India*
2 *Padmaja Naidu Himalayan Zoological Park, Jawahar Parbat, Darjeeling, West Bengal 734101, India*

Corresponding author: Bhupen Roka (bhupenroka2012@rediffmail.com)

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Abstract
The red panda is a lesser carnivore that has adapted to the herbivore diet and is distributed in the Himalayan and Hengduan mountain ranges. The study conducted on red panda in Singalila National Park recorded the highest encounter of the species within the altitude of 2800 to 3200 meters in the broad leaf deciduous and broad leaf coniferous forest. 22.22% of direct sightings of red pandas occurred on plant species belonging to the family Fagaceae and were followed by the family Ericaceae (18.52%). The plant species mostly preferred by the red panda in Singalila National Park were *Lithocarpus pachyphyllus*, *Rhododendron arboreum*, *Abies densa*, and *Betulia utilis*. During all seasons, the dominant plants found in the red panda pellets were *Arundinaria maling* and *Arundinaria aristata*. The distribution of the red panda is influenced by the presence of the preferred plant species, therefore, through this studies effort has been made to document the plant species used by the red panda in the wild habitat.

Keywords
Conservation, plant preference, red panda, wild

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RESEARCH Open Access

Genetic assessment of captive red panda (*Ailurus fulgens*) population

Arun Kumar[1], Upashna Rai[2], Bhupen Roka[2], Alankar K. Jha[2] and P. Anuradha Reddy[1*]

Abstract

Red panda *(Ailurus fulgens)* is threatened across its range by detrimental human activities and rapid habitat changes necessitating captive breeding programs in various zoos globally to save this flagship species from extinction. One of the ultimate aims of ex situ conservation is reintroduction of endangered animals into their natural habitats while maintaining 90 % of the founder genetic diversity. Advances in molecular genetics and microsatellite genotyping techniques make it possible to accurately estimate genetic diversity of captive animals of unknown ancestry. Here we assess genetic diversity of the red panda population in Padmaja Naidu Himalayan Zoological Park, Darjeeling, which plays a pivotal role in ex situ conservation of red panda in India. We generated microsatellite genotypes of fifteen red pandas with a set of fourteen loci. This population is genetically diverse with 68 % observed heterozygosity (H_O) and mean inbreeding (F_{IS}) coefficient of 0.05. However population viability analysis reveals that this population has a very low survival probability (<2 %) and will rapidly loose its genetic diversity to 37 % mainly due to small population size and skewed male-biased sex ratio. Regular supplementation with a pair of adult individuals every five years will increase survival probability and genetic diversity to 99 and 61 % respectively and will also support future harvesting of individuals for reintroduction into the wild and exchange with other zoos.

Keywords: Red panda, Captive breeding, Genetics, Population viability

Background

Red panda (*Ailurus fulgens*), also known as the lesser panda, is one of earth's living fossils and its ancestors can be traced back to more than ten million years ago across Eurasia (Mayr 1986). Presently red panda populations are sporadically distributed in bamboo forests of Himalayan and Heng-Duan mountains in Nepal, India, Bhutan, Myanmar and Southwestern China (Su et al. 2001; Li et al. 2005). These populations continue to drastically decline across their habitats due to hunting, poaching, habitat loss and fragmentation (Wei et al. 1999; Choudhury 2001; Jha 2011). Red panda is classified as vulnerable by IUCN and is listed in Appendix I of CITES (Convention on International Trade in Endangered Species of Wild Flora and Fauna) since its wild population is estimated to be less than 10,000 mature individuals (Wang et al. 2008). Although endemic to eastern Himalayas and a flagship species for conservation of this fragile ecosystem, little is known about the genetic diversity of red panda in the wild, as it is shy, scansorial and dwells in altitudinal ranges of 1500–4800 m making it a very difficult animal to study (Choudhury 2001). Recent research on demography, phylogeography and genetic diversity of red panda (Su et al. 2001; Li et al. 2005; Hu et al. 2011) opens more opportunities to study current trends in wild red panda populations.

Several ex situ breeding programs have been initiated worldwide to protect this iconic species as its future survival relies on implementation of active conservation measures. Ex situ management and captive breeding for species conservation have grown enormously in recent years, and are the ultimate alternatives to in situ conservation, for preservation and recovery of endangered species aiming towards their reintroduction in the wild (Ballou 1992; Snyder et al. 1996; Ramirez et al. 2006) along with other aspects like education, research and fund raising. Founding and managing populations

*Correspondence: anuradha@ccmb.res.in
[1] CSIR-Centre for Cellular and Molecular Biology, Uppal Road, Hyderabad 500 007, India
Full list of author information is available at the end of the article

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Selection of Red Panda (*Ailurus fulgens*) as an indicator species in Singalila National Park, Darjeeling, India

Bhupen Roka[1,2]*, Upashna Rai[1], A.K. Jha[1] and Dhani Raj Chhetri[2]

[1]Padmaja Naidu Himalayan Zoological Park, Darjeeling, West Bengal, India
[2]Department of Botany, Sikkim University, Gangtok, Sikkim, India

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ABSTRACT

Indicator species is an organism which indicates the condition of the environment or response to stress that is inconvenient or expensive to measure and the population density, presence/absence, reproduction success and migration of the species may be used as an index of attribute. It is mainly use to assess environmental condition as an early warning of the problem and the ecological changes occurring in the nature. In this study, effort has been made to consider red panda (*Ailurus fulgens*) as indicator species in the Singalila National Park, Darjeeling, India. Red panda is an endangered, charismatic carnivore which has converted into herbivore mode of diet. It is found in Himalayan and Hengduan mountain ranges mainly at the temperate conifer and the adjacent broad leaf forest with mainly bamboo dominance within the altitude of 1500m and 4800m above sea level. Anthropogenic pressure and rising human population is damaging the health of ecosystem and creating pressure on forest. Red panda is a solitary and shy animal and respond actively to the anthropogenic stress. Being a flagship, priority species and endemic to the region, red panda can be considered as an indicator species to monitor the ecological integrity and anthropogenic disturbance in the Singalila National Park, Darjeeling.

Key word : *Red panda, Indicator species, Singalila National Park*

Introduction

Indicator species is a living organism that can be easily monitored and their status reflects the condition of the environment where they are found (Landers, 1988; Cairns, 1993; Markert *et al.*, 1999; Bartell, 2006; Burger, 2006; Siddig, 2016). Response of the indicator species to a particular stress represents for the community in the ecosystem. They are sensitive to pollution, habitat fragmentation or other stress. Indicator species are developed by the researcher, scientist and managers that focus on the important facet of ecosystem which are essential for the assessment of the ecological condition (Niemi, 2004). The use of indicator species to evaluate and monitor the environmental condition is an established tradition in ecology, environmental toxicology, pollution control, agriculture, forestry and wildlife. Using indicator species to monitor and evaluate the environmental impact on animals and plants is one of the most easy and cheaper way (Noss, 1990; Lien 2007). Hall (1919) was the first person to use the concept of indicator species by associating plant and animal species to particular life zone (large geographic area with similar structure and compositional characteristics) (Carignan, 2001). According to Carignan (2001) the use of indicator species has been incorporated in the policies

***Corresponding author's email:** bhupenroka2012@rediffmail.com

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Red Panda (*Ailurus fulgens*) on the Verge of Extinction: Threat and Conservation

Bhupen Roka[1]* and Dhani Raj Chhetri[1]

[1]Department of Botany, Sikkim University, Gangtok, Sikkim, India

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ABSTRACT

The red panda is a charismatic animal that acts as an icon to attract and encourage the public in support of conservation action. Forest fragmentation, habitat degradation, forest resource collection, cattle grazing, and increasing visitor number in protected areas are the prime threat to the red panda population. Confiscation of red panda pelts in different countries shows an increase in illegal trade in recent years. Various research articles, conference reports, chapters and books, management plans, and thesis on red panda were referred for the study. This study aimed to understand the threat to a red panda in the wild habitat and highlights the requirement of conservation initiatives. Collaborative study on red panda population, prey-predator density, habitat, food availability, floral diversity and, threat assessment in the entire habitat can contribute immensely in framing and formulation conservation strategies for long-term management of the species and maintaining the viable population in the wild.

Key word : *Red panda, Anthropogenic impact, Threat, Conservation*

Introduction

The red panda (*Ailurus fulgens*) also known as a lesser panda is an endangered living fossil (Kumar, 2016) residing in the Himalayan and Hengduan mountain ranges (Bista, 2019). Its habitat ranges from western Nepal to Sichuan Province in China through Sikkim, West Bengal, Arunachal Pradesh, Meghalaya, Bhutan, and some northern parts of Myanmar (Dorji, 2011; Panthi, 2019) within the altitude of 1500 m and 4800 m (Choudhury, 2001). Anthropogenic activities are a crucial threat to biodiversity and are causing the decline in the red panda population across the distribution range (Jha, 2011; Dorji, 2012; Kandel, 2015; Acharya, 2018). Weather condition, increase in the human population, prey and predator density and food availability affect the population and habitat of the animals (Winne, 2004; James *et al*., 2006; Zhang, 2011). In the last three generations, the red panda population has declined by 50% (Kappelhof, 2020) and IUCN has placed red panda under the endangered category (Glatston, 2015). It is presumed that the in-situ population of the red panda across its range could be 14,500 to 15,000 individuals (Xu, 2018). Various studies on red pandas have been published to date but comparatively less information is available on the threat throughout the range. Therefore, the proper understanding of the threat is essential for the conservation and management of the wild population. The effort has been made in this paper to highlight some major threats recorded throughout the distribution range of red panda.

Methodology

Systematic reviews of the literature related to red panda were carried out during the study. Various

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Study of red panda (*Ailurus fulgens fulgens*) in ex situ facility for conservation breeding at Padmaja Naidu Himalayan Zoological Park, Darjeeling

Bhupen Roka[1*], Piar Chand[2], Upashna Rai[3], Dhani Raj Chhetri[4]
[1, 2, 3] Padmaja Naidu Himalayan Zoological Park, Darjeeling, West Bengal, India
[1, 4] Department of Botany, Central University of Sikkim, Sikkim, India

Abstract
Red panda (*Ailurus fulgens fulgens*) is a solitary, nocturnal and scansorial carnivore which has adapted to the herbivore mode of life. It is a monotypic member of the family *Ailuridae* which is included in the animal collection of the zoos across America, Asia, Australia, Europe and South Africa. Each of these regions have developed their own captive husbandry protocols further strengthening it with the Global Species Management Plan which is involved with the shaping up of the husbandry and veterinary issues for the species welfare in captivity. With an aim to promote captive breeding, an effort has been made to examine how red pandas are kept and managed in captivity. This paper provides information on successful captive management of red panda during the last twenty-six years at Padmaja Naidu Himalayan Zoological Park. The other issues that paper highlights are housing, feeding, social behaviour, breeding and behavioural management of the species in captivity.

Keywords: red panda conservation breeding programme, captive management

Introduction

Ex-situ conservation deals with the planned breeding of the species, where the ultimate goal is to reintroduce the animals in the wild. Threats to the ecosystem continue to increase worldwide for which the conservation of species has become a big concern. Ex-situ conservation plays key role in conservation through education, fundraising and research as well as breeding for the reintroduction into the wild (Hutchins, 1995) [5]. Conservation breeding is not an alternative but can be considered as a complement to in-situ conservation and the protection of the wildlife habitat. Conservation breeding in some cases is the only hope for the species near extinction in the wild (Hakansson, J. 2007) [4].

Red panda is a solitary and nocturnal animal which is adapted to cool and moist environment and is found in Himalayan and Hengduan mountain ranges (Roberts and Gittleman, 1984; Glatston, 1994; Wei *et al*., 1999; Choudhury, 2001; Pradhan, 2001) [9, 3, 10, 2, 7]. The red panda (*Ailurus fulgens fulgens*) is an endangered animal and is priority species of the conservation breeding programme of Central Zoo Authority, Government of India. The animal shares its name with giant panda *Ailuropoda melanoleuca*, despite their popular name the two species are not closely related. The red panda is now placed in a monotypic family Ailuridae (Glatston, 1994) [3]. According to Choudhary, 2001 [2] red panda is found in the Himalayan belt of Nepal, India, Bhutan, Myanmar and Southern China. Populations of the species are confined to isolated mountain ranges ranging in altitude between 1,500 m and 4,800 m (Glatston, 1994; Choudhury, 2001) [3, 2]. Status of the red panda in wild has also been a matter of great discussion and speculation for over a long period (Glatston, 1994) [3]. International Union for the Conservation of Nature and Natural Resources has reassessed the global status of red panda and placed it under the endangered category. In India too, though red panda is included under the Schedule - I of Indian Wildlife (Protection) Act 1972 and very little is known about its status in the wild. It is also listed in Appendix 1 of the Convention on International Trade for Endangered Species of wild fauna and flora (CITES). Anthropogenic activities and associated global climate change are threatening the biodiversity in the Himalayas and have led to the extinction of many species of flora and fauna. Rapid growth and expanding human population which depends on the forest for livestock grazing, timber extraction, food, fodder, fertilizer, fuel-wood are the causes for the erosion of the Himalayan forest and decrease in number of red panda in the region.

Study Area

Padmaja Naidu Himalayan Zoological Park (PNHZP) in Darjeeling, established in year 1958 is dedicated to the conservation of endangered Himalayan fauna. The zoo is situated in a patch of virgin forest at an altitude of 6,874 ft above sea levels. The annual rainfall in this area varies between 100 and 115 inches and the daily temperature range from nearly freezing in the winter to about 20^0C in summer. Winter snowfall can be quite heavy at times (about once every 3-4 years) and frosts are common. The 67 acres of the Birch Hill Forest where the zoo is located are the remnants of the original woodlands of the region. This is the only specialized zoo in the country and is internationally recognized for its conservation breeding program of red panda, snow leopard, Tibetan wolf and other highly endangered animal species of Eastern Himalayan.

Ex-situ conservation breeding of Red Panda

Red panda is a local animal of Darjeeling and it was housed at

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TECHNICAL NOTE

Molecular sex identification of red panda (*Ailurus fulgens*) suitable for noninvasive genetic studies

Arun Kumar[1] · Bhupen Roka[2] · Upashna Rai[2] · P. Anuradha Reddy[1]

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Abstract Molecular sexing of wild animals is feasible with differential amplification of X- and Y-homologous regions of various genes. We present a simple and robust technique for sex identification of red panda suitable for noninvasive studies based on sex-specific fragment size polymorphism in amelogenin (*AMEL*) gene. Sequence analysis of *AMELX* and *AMELY* revealed an 18-bp deletion in Y fragment which was used to differentially amplify 217 bp of X and 199 bp of Y fragments. The designed primer pair is very sensitive and exhibits polymerase chain reaction (PCR) success rates of 89 and 78 % at 0.1 and 0.01 ng template DNA concentrations, respectively. Further, we amplified poor quality faecal DNA with 94 % success rate and average dropout rate of 15.6 %. In silico analysis shows that these primers can also be used to identify sex of a sympatric species, giant panda.

Keywords Red panda · Sex identification · Amelogenin · DNA

Communicated by M. Scandura

Electronic supplementary material The online version of this article (doi:10.1007/s10344-015-0928-2) contains supplementary material, which is available to authorized users.

✉ P. Anuradha Reddy
anuradha@ccmb.res.in

1 CSIR-Centre for Cellular and Molecular Biology, Uppal Road, Hyderabad 500 007, India

2 Padmaja Naidu Himalayan Zoological Park, Darjeeling 734101, India

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Introduction

Noninvasive genetics has led to remarkable changes in population studies of endangered species (Beja-Pereira et al. 2009). This approach is especially useful in generating large-scale molecular data on elusive species without handling or even seeing them, from shed samples like hair, skin, feathers and faeces (Beja-Pereira et al. 2009; Reddy et al. 2012). Major challenges of working with such samples are low quality and quantity of DNA, genotyping errors and low amplification success rates (Taberlet et al. 1996). These issues are effectively addressed in studies which identify and quantify target DNA (Morin et al. 2001), use multi-tube method (Taberlet et al. 1996) and use multiplex DNA amplification (Arandjelovic et al. 2009), making noninvasive DNA analysis a robust method for assessing population parameters of wild animals.

Sex identification and sex ratio assessment provide crucial data on population dynamics of wild animals (Xu et al. 2010). Sex can be assessed by karyotyping, presence of Y-antigen, X-linked enzymes and polymerase chain reaction (PCR), of which PCR is a reliable, accurate and sensitive technique (Fernández Feijóo et al. 2010). PCR-based identification can be achieved by amplifying Y-specific SRY gene (Woods et al. 1999); however, an amplification failure can result in a false inference of a male as a female (Bidon et al. 2013). Internal mitochondrial controls can be used to address this problem (Kamimura et al. 1997), but there exists an inherent risk of preferential amplification, as mitochondrial sequences occur in higher copy numbers than Y-chromosome sequences (Durnin et al. 2006). Therefore, the most preferred technique is differential amplification of alleles located on homologous regions of sex chromosomes (Xu et al. 2010), such as zinc finger locus (*ZnF*) and amelogenin gene (*AMEL*) (Pilgrim et al. 2005). Length polymorphisms in *AMEL* and *ZnF* have been used in molecular sexing of free ranging animals like

Appendix B: List of Conferences/Seminar attended

13th Annual Convention of
Association of Indian Zoo & Wildlife Veterinarians
&
International Conference on
"Advancements in Veterinary Sciences for Wildlife Conservation"
(13-15 November, 2019)
Organized By
Laboratory for the Conservation of Endangered Species (LaCONES),
CSIR- Centre for Cellular and Molecular Biology (CCMB), Hyderabad

CSIR - CCMB

Certificate

This is to certify that Dr./ Mr./ Ms.......Bhupen Roka.................. has participated and presented a paper (~~oral~~/poster) in the 13th Annual Convention of Association of Indian Zoo & Wildlife Veterinarians & International Conference on "Advancements in Veterinary Sciences for Wildlife Conservation".

(Sadanand D. Sontakke)	(B. Sambasiva Rao)	(B. M. Arora)
Convener	Convener	President AIZWV

13th Annual Convention of
Association of Indian Zoo & Wildlife Veterinarians
&
International Conference on
"Advancements in Veterinary Sciences for Wildlife Conservation"
(13-15 November, 2019)

CSIR - CCMB

Organized By
Laboratory for the Conservation of Endangered Species (LaCONES),
CSIR- Centre for Cellular and Molecular Biology (CCMB), Hyderabad

Certificate

This is to certify that Dr./ Mr./ Ms. ...Bhupen Roka.................has presented a paper entitled "Study of Red Panda in Singalila National Park, Darjeeling with reference to conservation"..........in oral/poster session and secured First/ Second/ Third place.

(Sadanand D. Sontakke)	(B. Sambasiva Rao)	(B. M. Arora)
Convener	Convener	President AIZWV

Certificate of Participation

Bhupen Roka

participated and presented paper/poster paper in International Conservation Conference held at Aligarh Muslim University, Aligarh, U.P., India during 21st to 23rd October 2019. The title of the presentation was

Status Distribution and Conservation of Red Panda; Case study in Singalila N.P, Darjeeling.

DR. AFIFULLAH KHAN
Conference Director

DR. ORUS ILYAS
Conference Co-ordinator

Organized by

Department of Wildlife Sciences, AMU
and
Wildlife Institute of India, Dehradun