A STUDY ON FLORISTIC DIVERSITY AND PLANT FUNCTIONAL TYPES ACROSS VARIOUS LANDFORMS IN UPPER DHAULI VALLEY, NANDA DEVI BIOSPHERE RESERVE, WESTERN HIMALAYA

THESIS

SUBMITTED TO THE

FOREST RESEARCH INSTITUTE (DEEMED) UNIVERSITY

DEHRADUN, INDIA

FOR

THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

FORESTRY

(FOREST ECOLOGY AND ENVIRONMENT)

BY

AMIT KUMAR

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2016

This work is dedicated to...

My Family,

Ph.D. Supervisors

&

My Village

Caragana versicolor Benth. - A keystone species of the Trans-Himalaya

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Dr. B.S. Adhikari Ph.D.
Scientist F & HoD
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CERTIFICATE

This is to certify that the thesis entitled "**A Study on Floristic Diversity and Plant Functional Types Across Various Landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya**", submitted by Mr. **Amit Kumar** (Reg. no. 11Ph.D198) to Forest Research Institute (Deemed) University, Dehradun for the award of the degree of **Doctor of Philosophy in Forestry (Forest Ecology and Environment)** is a record of bonafide research work carried out by him under my supervision. No part of this thesis has been submitted for any other degree and it fulfills all the requirements laid down in the ordinance of Forest Research Institute (Deemed) University, Dehradun for this purpose.

Place: Dehradun
Date: 4th July, 2016

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This is to certify that Mr. **Amit Kumar,** enrolment no **11Ph.D198** carried out research work under the supervision of **Dr B.S. Adhikari,** Scientist-F & HoD and Co-Supervision of **Dr. G.S. Rawat**, Dean, FWS of **Wildlife Institute of India, Dehradun**. The topic of the research registered with Forest Research Institute (Deemed) University, Dehradun was **"A Study on Floristic Diversity and Plant Functional Types Across Various Landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya"**. The scholar presented his work in the pre-thesis submission seminar held on **17.06.2016** and the Research Advisory Committee found the work to be satisfactory and approves the work to be presented in the form of thesis for evaluation by examiners for "Award of Ph.D. Degree" by Forest Research Institute (Deemed) University.

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DECLARATION

I hereby declare that the thesis entitled "**A Study on Floristic Diversity and Plant Functional Types Across Various Landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya**" submitted by **Mr. Amit Kumar** (Reg. no. 11Ph.D198) to Forest Research Institute (Deemed) University, Dehradun, for the award of the degree of **Doctor of Philosophy in Forestry (Forest Ecology and Environment)**, is a record of original research work carried out by me under the supervision of Dr. B.S. Adhikari and Dr. G.S. Rawat, Wildlife Institute of India, Dehradun and it has not formed the basis for the award of any other degree or diploma. I also declare that the thesis embodies my own work, observation and analysis and in that respects the investigation appears to advance knowledge in the subject.

[Amit Kumar]

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Sub:- Registration for Doctor of Philosophy Degree in Forestry.

Dear Sir/Madam,

In response to your application dated 19.04.2011 for enrolment as Research Scholar for the Degree of Doctor of Philosophy in Forestry in this Institute, it is to inform you that the following decisions have been taken:-

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2. Your Enrolment number is : - 11Ph.D198
   (For all further correspondence please quote your enrolment number.)
3. Name of Research Centre :- **Wildlife Institute of India, Dehradun**
4. The Topic of research approved by the FRI University: **"A Study on Floristic Diversity and Plant Functional Types Across Various Landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya".**
5. Name of Discipline :- **Forest Ecology & Environment**
   (As per clause 3.3 of the Ph.D. Ordinance)

6. (i) Name of Supervisor :- **Dr. B.S. Adhikari**

   (ii) Name of Co-Supervisor :- **Dr. Gopal S. Rawat**

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Encl: **1. Fee receipt No. 979 dated 09.11.2012 for Rs. 18,500/-**
2. Format of progress report

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1. Dr. K. Sankar, Nodal Officer, Wildlife Institute of India, P.B. No.18, Chandrabani Dehradun – 248 001 for information and necessary action.
2. Dr. B.S. Adhikari, (Supervisor of the Scholar), Scientist-E, Department of Habitat Ecology, Wildlife Institute of India, Dehradun, for information and necessary action.
3. Dr. Gopal S. Rawat, (Co-Supervisor of the Scholar) Scientist-G, Wildlife Institute of India, Dehradun, for information and necessary action.

(Dr. A.K. Tripathi)
Registrar
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ACKNOWLEDGEMENTS

Though this thesis has my name on its cover, the work is a result of contribution of great many people who helped me throughout the journey. I owe my gratitude to all those people who have made this work possible. I would like to acknowledge many people for this but if I forget to mention any names here then I beg your apologies.

First and foremost, I am indebted to my family without whom none of this would have been possible. This thesis is dedicated to my family who has been a constant source of love, support and strength for all these years. I am short of words to express my heart-felt gratitude to my parents who, in-spite of whatever little education they had, supported and encouraged all their children to study and achieve their dreams. I am grateful to my brothers and sisters who have aided and encouraged me all the way through this endeavor.

I express my deepest gratitude to my supervisor Dr. B.S. Adhikari, Scientist-F & HoD, Wildlife Institute of India for his consistent guidance from writing the synopsis to the end of this thesis and kind support in every way throughout the work. He has been my mentor since last five years and has advanced my understanding of vegetation ecology.

I am extremely grateful to Dr. G.S. Rawat, Dean, FWS, Wildlife Institute of India, for continuous support, guidance and giving his precious time in terms of sharing his field experiences in Himalayan Mountains, long hour discussions on landscape features, vegetation ecology, mountain ecology, rangeland management, floral associations, botany, ethnobotany and pastoralism.

I wish to acknowledge Dr. V.B. Mathur, Director and Dr. P.K. Mathur, former Dean, Wildlife Institute of India (WII), Dehradun for providing necessary support, infrastructure and encouragement. I would also like to thank our former Director Sh. P.R. Sinha for facilitating work during initial period of the study.

I extend my sincere thanks to Dr. V.P. Uniyal, Nodal Officer, Dr. B.C. Sinha, Research Co-ordinator and Dr. K. Sankar, former Research Co-ordinator, WII for facilitating my Ph.D and research work.

I would like to acknowledge all the respected faculties at WII for their explicit help and encouragement. I am especially grateful to Dr. S. Sathyakumar, Sh. Qamar Qureshi, Dr. S.P. Goyal, Dr. K. Sivakumar, Dr. Parag Nigam, Dr. K. Ramesh, Dr. Gopi G.V. and Dr. Bilal Habib for their valuable inputs and shaping my thoughts. I would like to thank Sh. Salvador

Lyngdoh for all the discussions that we had on various aspects of ecology which helped in developing my scientific acumen.

I wish to acknowledge the support of Ministry of Environment, Forests and Climate Change, Govt. of India, New Delhi for providing funds at the earlier stage of my work. Both, University Grant Commission, New Delhi, under Rajiv Gandhi National Fellowship scheme and World Wide Fund for nature (WWF-INDIA)-Small Grant Programme deserve a special mention here, for funding my thesis at later stage when I was stuck in the middle due to lack of resources.

I also wish to acknowledge Uttarakhand State Forest Department; Sh. Rajiv Dhiman, Divisional Forest Officer, Joshimath for necessary permissions, support and hospitality. I would like to thank Sub-divisional Magistrate, Joshimath for issuing Inner-line permit and Indo-Tibetan Border Police Force and Indian Army for providing necessary accommodations and assistance.

I would like to thank my field companion Ms. Monideepa Mitra for her consistent help in field as well as at the institute in analyzing and interpretation of the data.

I am also thankful to Sh. Prakash, Sh. Dinesh and Sh. Amit for assisting us in the field. A special thank goes to Sh. Prakash Bhai and his family who were a constant source of support in all possible ways during my field work. He accompanied me during the long and strenuous treks of the landscape, never complaining about anything and always appreciating our efforts with a smile.

I am extremely thankful to Ms. Upma Manral for her consistent help, valuable suggestions and extending her advice whenever I needed it. I am highly indebted to her advices in the improvement of my synopsis, writing research articles and this thesis.

Thanks are also due to Dr. Ishwari Rai for sparing his precious time for helping in identification of plants and a number of discussion sessions on various aspects of vegetation ecology and phyto-taxonomy.

I am also highly indebted for time to time help from Drs. Pankaj Kumar, Gajendra Singh, Umesh Tiwari, Amit Kotia, Ninad Raut, Sutirtha Dutta, Mukesh Thakur, Tapajit Bhattacharya, Sabuj Bhattacharya and Kaushik Banerjee for valuable suggestions and guidance in data analysis and interpretation of results.

I also would like to thank Ms. Mansa Srivastav and Mr. Sanjay Bhakhuni for assisting in the field.

I want to extend my sincere thanks to Sh. P.L. Saklani and Sh. Shyam Lal from herbarium section and Sh. Ajay ji, Sh. Rakesh ji, Sh. Vinod ji and Sh. Ram from laboratory for their consistent support since the initiation of the work.

I am also grateful to the competent team of WII library staff particularly Sh. Y.S Verma ji for providing all library facilities. Special thanks to Sh. Kishan ji, Smt. Sashi Uniyal and Smt. Sunita Agarwal for the pains they took for searching the required books, reprints and journals.

I am also thankful to Shri Umed ji, Shri Madan ji, Shri Mahesh ji and Shri Virender ji for the help they provided. I am also thankful to Sh. Dubey ji and Sh. Rajeev ji (Finance), Sh. Rajesh ji, Dr. Manoj Aggarwal, Dr. Panna Lal, Sh. Dinesh ji, Sh. Muthu ji (Computer staff) and Sh. Virendra ji (DTP) for extending helps in various ways.

I also thank my seniors Mr. Vipin Rao, Mr. Prabhat Kumar, Mr. Akshay Verma, and friends and colleagues Sachin, Manas, Akhato, Manthan, Jis, Manisha, Sasmita, Jiju J.S., Samaresh, Akanksha, Pallavi, Gurpreet, Sharmila, Shruti, Vandana, Paromita, Soni, Anu, Monika, Kartikeya, Roopa, Ravi, Dipak, Rathore, Kesav, Swapnali, Urjit and Prashant for all the support.

The sincere appreciation goes to the *Bhotiya's* of Niti Valley for their wonderful hospitality, cooperation and help throughout the work. It had become a home for me up in the mountains.

[Amit Kumar]

Scrub steppe in Geldung, Ganesh Ganga watershed

EXECUTIVE SUMMARY

In ecological systems, vegetation communities are shaped by various physiographic and edaphic factors which determine their structural and functional attributes. In Trans-Himalayan region of the state of Uttarakhand, limited studies on linkages of floristics, patterns of diversity in various vegetation communities and landforms are available. The region faces disturbances due to various natural and anthropogenic causes. The present research work attempts to assess the diversity of vascular plants, plant community structure and plant functional types (PFTs) in various landforms and physiognomic units in Upper Dhauli Valley, a cold-arid region and buffer of Nanda Devi Biosphere Reserve. This research work has not only generated information on the baseline ecological characteristics of various plant species and communities but also provides valuable management implications. The study is summarized in the following paragraphs.

1. The Upper Dhauli Valley (UDV; ca. 727.7 km^2; 30°46-54'N and 79°45-51'E) in Nanda Devi Biosphere Reserve was selected for intensive study. The UDV was added as a part of buffer zone of NDBR in 2002 and among the least studied valleys of the region with respect to floristics, floral assemblages and vegetation structure. It has three major watersheds namely, Amrit Ganga, Satyagad and Ganesh Ganga. The present study is based on the extensive surveys of various landscape features, landforms and physiognomic units. Reconnaissance survey in the entire valley was conducted in the year 2011. The field work comprised of floristic survey, systematic collection and record of plant specimens, vegetation quantification and collection of soil samples followed by laboratory analysis. For the study of PFTs, direct field observations as well as descriptions or figures or photographs in the literature, each species (in the sampled sites) across landforms and physiognomic units was critically analyzed and classified in one of the life form, growth form and clonality categories following Cornelissen et al. (2003) and Harguindeguy et al. (2013). The area was surveyed extensively for aforementioned field activities throughout the growing season during 2012, 2014 and 2015.

2. A total of 495 species of vascular plants (476 angiosperms, 10 gymnosperms and 9 pteridophytes) belonging to 267 genera and 73 families were recorded. Of the recorded angiospermic plants species, 383 were dicots and 93 monocots. The valley comprises 62% of the vascular plants of NDBR and 35% of the flora of cold deserts of Western Himalaya. The

ratio of monocots to dicots in respect of families, genera and species is 1:5.6, 1:4.7 and 1:4, respectively. Asteraceae, Poaceae, Lamiaceae, Fabaceae, Brassicaceae, Rosaceae, Polygonaceae, Apiaceae, Ranunculaceae and Orchidaceae were ten dominant families.

The study also updates the flora of the Nanda Devi Biosphere Reserve with addition of 189 species of vascular plants. New distributional records of *Anemone demissa* (Ranunculaceae) and *Anthoxanthum flexuosum* (Poaceae) for Western Himalaya and *Potentilla pamirica* (Rosaceae), *Carex sagaensis* (Cyperaceae) and *Dontostemon glandulosus* (Brassicaceae) for Uttarakhand are noteworthy. The present record of these species could be attributed to their extended range of distribution or limited botanical excursions in these interior valleys. The current report on the presence of only a few individuals of these species indicates their rarity in the region. Further, floristic surveys would be required to assess the population status of these species.

3. Of identified major landforms (moraine, river bed and scree), scree slopes are reasonably absent in Amrit Ganga watershed. In Satyagad watershed, due to comparatively narrow and dry and rugged terrain, the moraine and river bed were reasonably absent. Towards interior areas of the valley such as, Kalazowar in Satyagad watershed and Geldung in Ganesh Ganga, plant species show affinities with the Trans-Himalayan regions due to increasing aridity. However, Amrit Ganga watershed is comparatively rich in Greater Himalayan flora due to reasonably moist conditions and has affinities with it especially in lateral moraines, open riverine tracts and mixed herbaceous formations. Therefore, based on the existence of phyto-elements from the Trans and Greater Himalayan regions, it is concluded that UDV has close affinities with the flora of both the regions. Hence, the valley forms a transition zone in terms of floristic elements between the two.

4. The present study provides a general procedure to identify various habitats. It suggests that the habitats which are categorized by their geo-morphological or physical attributes such as elevation, slope, orientation, stratification, rock exposure and soil type must be referred to as a 'landform', for example moraine, scree, river bed, table land, plateau, gorge and ridge. The habitats that are defined by their vegetation attribute or type of vegetation present such as herbaceous meadow, scrub steppe, scrublands, alpine grassland, alpine dry scrub, alpine meadow and riverine scrub must be referred as a 'physiognomic or landscape unit'.

5. Among three major landforms identified, the species richness was highest in moraine (99) followed by scree (88) and river bed (44). The species richness among various physiognomic units was highest in scrub steppe (97) followed by herbaceous meadow (76), livestock

camping site (52) and tussock formations (20). Species diversity across three watersheds for herbs was highest for scrub steppe in Ganesh Ganga (9.4) followed by scrub steppe in Amrit Ganga (8.5) and scree in Ganesh Ganga (8.3). The diversity values were least in case of river bed of Ganesh Ganga (1.3) and livestock camping site in Satyagad (1.8). For shrubs, diversity was highest for scrub steppe in Amrit Ganga (3.7) followed by scrub steppe in Ganesh Ganga (3.5) and livestock camping site in Amrit Ganga (2.7). The diversity values were least in case of herbaceous meadow in Ganesh Ganga (0.2). Higher species diversity and richness in scrub steppe and moraine could also be relative to land area, the larger an area is, the more species it can support, which results in larger populations. The highest diversity in scrub steppe appears to be due to edge effect and intermingling of forest and meadow species. The lower diversity in river bed and livestock camping sites are due to high livestock pressure resulting into prevalence of homogenized species such as *Rumex nepalensis*, *Polygonum* spp. and *Impatiens* spp. Species richness across three watersheds was highest in scrub steppe of Ganesh Ganga (92) followed by scrub steppe (77) and moraine (71) of Amrit Ganga. In Satyagad, highest richness was recorded in scrub steppe (46). The least richness was recorded in livestock camping site of Satyagad with 12 species, river bed in Ganesh Ganga (15) and 20 species each in tussock formation of Amrit Ganga and herbaceous meadow in Satyagad. Among various landforms and physiognomic units, species richness was highest in scrub steppes (46-92) while, least in livestock camping sites (12-38). Evenness across three watersheds for herbs was highest (0.8 each) in tussock formation and river bed of Amrit Ganga and herbaceous meadow of Satyagad. In Ganesh Ganga evenness varied from 0.2 to 0.7, whereas in Satyagad it was 0.7-0.8 and in Amrit Ganga, it varied from 0.6-0.8. Equability in tussock formation, river bed and herbaceous meadow was higher mainly due to contagious distribution of the individuals. Unstable river course in river bed of Ganesh Ganga, might be a cause of lower evenness.

6. A total of 39 plant communities in three landforms were identified using TWINSPAN statistical package in three landforms across the watersheds. Highest number of communities (18) was recorded in screes followed by 11 in moraines and 10 in river beds. Additionally, a total of 52 plant communities in four physiognomic units were segregated. Scrub steppe supported highest number of communities (28) followed by herbaceous meadow (12) and livestock camping site (10), tussock formation (2). Of total, highest number of communities (23; 18 herb and 5 shrub) were recorded in Ganesh Ganga, followed by Amrit Ganga (16; 13 herb and 3 shrub) and Satyagad watershed (13; 10 herb and 3 shrub).

7. Among the landforms, moraine and scree in Ganesh Ganga watershed showed maximum similarity (0.54). Also, moraine of Amrit Ganga watershed had similarity with moraine (0.50) and scree (0.48) of Ganesh Ganga watershed. Among the physiognomic units, livestock camping site of Amrit Ganga and scrub steppe of Satyagad watershed showed maximum similarity (0.54). The similarity within landforms and physiognomic units was found maximum (0.54) between moraine and scrub steppe of Amrit Ganga watershed followed by moraine of Ganesh Ganga and scrub steppe of Satyagad watershed (0.52).

8. Among three landforms, the Nitrogen (N) content in soil was highest in scree (0.19%) followed by moraine (0.10%) and river bed (0.07%). Phosphorus (P) was highest in scree (0.17%) followed by river bed (0.12%) and moraine (0.11%). Potassium (K) was highest in scree (0.63%) followed by moraine (0.49%) and river bed (0.20%). Higher nutrient percentage in scree could be attributed due to accumulation of soil and rock debris resulted due to weathering at the scree slopes. Lower nutrient percentage in moraine could be due to leaching of nutrients. Organic Carbon (OC) was highest in river bed (2.28%) followed by scree (1.92%) and moraine (1.71%). Sodium (Na) was highest in scree (0.43%) followed by river bed (0.40%) and moraine (0.35%). Soil pH was highest in scree (6.94) followed by river bed (6.15) and moraine (5.82). Across different physiognomic units, the N content in soil was highest in livestock camping site (0.35%) followed by herbaceous meadow (0.30%) and scrub steppe (0.25%). P was highest in livestock camping site (0.25%) followed by herbaceous meadow (0.22%) and scrub steppe (0.16%). K was highest in livestock camping site (0.72 %) followed by herbaceous meadow (0. 62%) and scrub steppe (0.60%). Highest nutrient concentration of N, P, K and Na in livestock camping site could be attributed due to the livestock dung which adds higher nutrient concentration. OC was highest in herbaceous meadow (4.25%) followed by livestock camping site (4.19%) and scrub steppe (2.29%). Na was recorded highest in livestock camping site (0.62%) followed by scrub steppe (0.44%) and herbaceous meadow (0.42%). Soil pH was recorded highest in scrub steppe (6.94) followed by livestock camping site (5.99) and herbaceous meadow (5.58).

9. The biological spectrum of the flora (495 species) revealed the dominance of hemicryptophytes (61%) followed by phanerophytes (12%), therophytes and geophytes (11% each) and chamaephytes (5%), which indicate 'hemicryptophytic' phytoclimate of the Upper Dhauli Valley. The presence of chamaephytes (5.1%) such as *Caragana* spp., *Krascheninnikovia* sp., *Devendraea* spp., *Lonicera* spp., *Juniperus* spp., and high proportion of hemicryptophytes (61.4%) and geophytes (10.5%) indicates the flora of the region above

3800 m is similar to desert steppe and steppe. In landforms such as moraine, scree and river bed, hemicryptophytes dominated strongly followed by chamaephytes, geophytes, phanerophytes and therophytes.

10. Of the total 495 species recorded, semi basal and erect leafy growth forms showed dominance representing 30% and 29% species, respectively, followed by short basal (22%), shrub (7%), dwarf shrub and tree (4% each) and climber (2%). In moraine (99 species) and scree (88 species), short basal growth form was dominant (33% and 30% species, respectively) followed by semi basal (20% and 29% species respectively), erect leafy (17% species each), dwarf shrub (16.4% and 12.6% species) and shrub (8% and 7% species). In scrub steppe (97 species), erect leafy and short basal growth form were dominant (25.3% and 24.6% species respectively) followed by semi basal (20.7%), shrub (13%), dwarf shrub (9.2%), tree (3%) and climber (2.3%). In herbaceous meadow (76 species), short basal were dominant (42% species) followed by semi basal (23.6%), erect leafy (18.4%), dwarf shrub (5.2%) and cushion (2.6%). In livestock camping sites (52 species), short basal were dominant (33.3% species) followed by erect leafy (29.4%), semi basal (19.6%), shrub (9.8%) and dwarf shrub (7.8%). In tussock formations (20 species), short basal was represented by 60% species, semi basal by 26.6% and erect leafy and tussock by 6.6% species each.

11. Of the total 495 species recorded, non-clonal forms prevailed strongly represented by 387 species (78%). Among 108 clonal species (22% of total species), maximum (49%) dominance was of clonal (e.g. mostly grasses) followed by clonal- rhizome (32.4%), clonal-bulb and clonal- tuber (6.5% each) and clonal- stolon (5.6%). In landforms, non-clonal forms were higher in scree (78 species; 20.2% of total non-clonal species) and moraine (75 species; 19.4%) followed by river bed (40 species; 10.3%). Among clonal forms, rhizome form was represented by seven species (20% of total clonal species) in moraine, six species (17%) in scree and four pecies (11.4%) in river bed. Bulb form was represented by two species namely, *Arisaema jacquemontii* and *Allium carolinianum* in moraine and one species (*Allium carolinianum*) in scree. Stolon form was represented by two species, *Androsace sarmentosa* and *Saxifraga flagellaris* in scree and one species (*Androsace sarmentosa*) in moraine. In physiognomic units, non-clonal forms were higher in scrub steppe (87 species; 22.4% of total non-clonal species) followed by herbaceous meadow (60 species; 15.5%), river bed (49; 12.6% of total) and tussock (11 species; 2.8%). Among clonal forms, rhizome was represented by six species (5.5% of total clonal species) in herbaceous meadow, five species (4.6%) in scrub steppe and two species (2%) each in livestock camping site and tussock

formation. Stolon form was represented by three species (2.7%) in scrub steppe and two species (2%) each in herbaceous meadow and tussock formation. Interestingly, compared to other Trans-Himalayan regions, higher proportion of non-clonal species and low proportion of clonal plants in Upper Dhauli Valley could be chiefly due to the transition zone and the affinity of floral characteristics from Greater and Trans-Himalayan region.

12. The discovery of phyto-elements yet from cold arid areas that are characterized by sparse vegetation cover, low primary productivity and short growing season indicate need of such detailed floral inventorization in other interior areas of Himalaya. Extensive floristic surveys are also required to assess the population status of rare and threatened species. Further, in general, a consolidated and comprehensive vegetation map for the entire Trans-Himalaya is needed. Geospatial analysis of alpine arid rangelands showing the distribution of certain keystone species such as *Caragana versicolor* and *Kraschenninikovia ceratoides* would be needed for better management and conservation planning. Restoration of heavily degraded sites by reseeding *Caragana* and participatory monitoring with the help of herders would be the most practical way forward to restore degraded sites. In order to conserve the herbaceous meadows, the most grazed feeding grounds of livestock and critical and most preferred wild ungulates habitats, integrated rangeland management plans based on participatory processes are necessary to developed.

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ABBREVIATIONS

APG – Angiosperm Phylogeny Group

BSD – Herbarium: Botanical Survey of India, Dehradun

CCA – Canonical Correspondence Analysis

CITES – Convention on International Trade in Endangered Species of Wild Fauna and Flora

DD – Herbarium: Forest Research Institute, Dehradun

E – Evenness

H' – Shannon diversity

HP – Himachal Pradesh

ITH – Indian Trans-Himalaya

IUCN – International Union for Conservation of Nature

J & K – Jammu and Kashmir

K – Potassium

MPs – Medicinal plants

N – Nitrogen

NDBR – Nanda Devi Biosphere Reserve

NDNP – Nanda Devi National Park

NP – National Park

OC – Organic Carbon

P – Phosphorus

PCA – Principal Component Analysis

PFTs – Plant Functional Types

S – Species richness

SK – Sikkim

TWINSPAN – Two way indicator species analysis

UDV – Upper Dhauli Valley

UK –Uttarakhand

VoFNP – Valley of Flowers National Park

WH – Western Himalaya

WII – Wildlife Institute of India

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Palaeorecords suggest that life on land started out in sheltered, warm and moist environments, and gradually expanded into more demanding habitats where water is rare, thermal energy is either low or overabundant or where mechanical disturbance is high (Korner 1999). The ability to survive low temperature extremes opened the highlands of the earth to plants. Plant survival in cold as well as hot deserts, the two thermal extremes on the globe, thus may have common evolutionary roots, although life under such contrasting thermal conditions requires many additional, rather different metabolic and developmental adaptations (Korner 1999). With continued orogenies and accelerated evolution during the Cenozoic, much of our modern alpine vascular flora at the generic and species levels has come into existence since Miocene times. Migrations and barriers due to mountain building and glaciations during the Pleistocene and up to the present time have speeded up the development of alpine floras (Billings 1974). The tertiary (and still ongoing) uplift of mountain ranges strongly accelerated the evolution of alpine taxa (Billings 1974, Agakhanyantz and Breckle 1995).

The mighty Himalaya, the youngest and highest mountain chain is known for its inimitable and rich biological diversity. It has very diverse vegetation types from sub-tropical moist forests to open alpine arid rangelands. Primary reasons for such varied biological diversity are great variability in climate, sharp gradients of elevation and varied landforms and habitats. This region has also been described as the 'third pole', due to diverse climatic conditions prevailing in the region (Negi 1995) and has the largest concentration of glaciers outside the polar region (Bajracharya et al. 2007). It starts from Nanga Parbat, ca. 8126 m above mean sea level (amsl) in north-west and passes through Pakistan, India (Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh), Nepal, Bhutan and China and ends in Namche Barwa (ca. 7842 m amsl) in the East (Ahluwalia and Gerner, 1985).

At present, the Himalayan region harbour Austro-Polynesian, Malayo-Burman, Sino-Tibetan, Euro-Mediterranean, and African elements. Interestingly, of the three phyto-geographic regions, the Euro-Mediterranean affinities are well represented in the Western Himalayan (west of 77°E long.) and the Chinese and Malaysian affinities are evident in the Eastern Himalayan region (east of 84°E long.). The Central Himalayan region contains an assortment of these two regions (Singh and Singh 1987); though, the proportion of endemic taxa is substantial in the entire region. Physiographically, the Himalayan region broadly comprises of four incredibly diverse forest types viz., sub-tropical, temperate, sub-alpine and alpine forests (Champion and Seth 1968). Although, the lower ranges in the Eastern Himalayan region supports luxuriant broadleaved forests which are often referred to as tropical rain forests and the elevation varies considerably, from ca. 300 m to more than 5000 m (Singh and Singh 1987).

1.2 Alpine biome: a case for ecological convergence

The uppermost vegetated areas in the Himalaya are alpine regions. These regions represent one of the most fascinating biomes, well known for their biological, geo-hydrological, aesthetic and cultural values (Rawat 2007). These occupy nearly 33% of the geographical area in the Himalayan region, of which about 25.88% area is vegetated and remaining 7.12% area falls under perpetual snow (Lal et al. 1991). The most striking feature of the alpine vegetation is lack of tree life form, stunted vegetation, pasture lands and abundance of grasses and other herbaceous plants exhibiting interesting patterns of adaptations to harsh and cold environments with short growing season (Korner 1999; Vishnu-Mittre 1984). These areas remains under snow for six months during winter and the flowering of plants starts after snow melts in late April or early May and continues till early September (Uniyal et al. 2007). The alpine meadows have had an intimate association with local inhabitants in terms of cultural, religious and economic dependence from time immemorial. More importantly, this region forms the upper catchment of majority of the Himalayan Rivers, which support millions of people in the lower hills as well as in the Indo-Gangetic plains. The health of alpine ecosystem is closely linked with the environmental stability and human welfare in the entire region. Ecologically, this area is of much interest due to adaptability of organisms to climatic extremes, vegetation processes, phytogeography and convergence of specialized life forms (Mani 1978). The richness of organismic taxa including the alpine plant diversity decreases with increasing elevation (Rawat 2011) however, the species diversity within each zone varies considerably (Kala et al. 1998).

The high altitude pastures locally called as '*bugyals*' or '*payar*' are the characteristic vegetation of the alpine regions. This region is demarcated by a distinct treeline towards lower elevation that lies around 3300±200 m amsl in the Western and 3800±200 m amsl in the Eastern Himalaya (Rawat 2007). The area immediately above natural treeline is usually occupied by *Krummholz* (stunted forest or crooked wood, German) formations comprising of *Rhododendron campanulatum* in Western Himalaya. The alpine zone above 4000 m is characterized by low productivity, high intensity of solar radiation and high degree of resource seasonality. This zone is often dominated by scrub or desert steppe and other types of herbaceous vegetation with remarkable adaptations, such as reduced leaves, stunted growth, deep tap root system and xerophytic nature, thus, referred to as 'Cold-arid region of the Himalaya'.

1.3 Cold-arid region: extremes of adaptive strategies

Geographically, the Himalaya forms three parallel zones, such as the Great Himalaya, Lesser Himalaya (Middle or Inner Himalaya) and the Sub-Himalayan foothills or Shiwalik and the adjacent Terai and Duar plains (Karan 1966). The arid mountainous tracts lying extreme north and parallel to the Great Himalayan range, constituting the sediments of the Tethyan sea bed are referred to as Trans-Himalaya. The area is not affected by Indian monsoon as they are positioned in the rain shadow of the main Himalayan region. The areas come under cold deserts and constitute a unique ecosystem characterized by extreme climatic conditions, such as diurnal fluctuations in temperatures, scanty and erratic rainfall, heavy winds and snowfall. Most of the flora is perennial, as the growing season is very short that leads to less plant growth. The annuals complete their life cycle in a very short time. The vegetation is most conspicuously characterized by the cushion like habit that protects them from heavy dry winds (Murti 2001).

The Indian Trans-Himalaya (ITH) usually described as High Altitude Cold Desert Zone (Zone 1) is broadly divisible into three biogeographic provinces, such as Ladakh mountains in the north-west constituting Kargil, Nubra and Zanskar in Jammu and Kashmir and Lahul and Spiti in Himachal Pradesh (1A); eastern plains of Ladakh (Changthang plateau), adjacent parts of Spiti and small pockets of Uttarakhand along northern frontiers (1B) and Sikkim Plateau (1C; Rodgers et al. 2000; WII 2015 unpublished). The region in India is thought to be an extension of Tibetan plateau having an average elevation ranging from 2500 m to 4500 m. The region is generally considered as floristically impoverished as compared to the areas of same altitudes in the main Himalayan ranges (Mani 1978, Schweinforth 1984). It covers only about 2% of the total geographical area of India. The total area of cold desert ecosystem is approximately 98,660 km^2, with 83.7% lying in Jammu & Kashmir, 15% in Himachal Pradesh and 1% (ca.1000 km^2) in Uttarakhand State. In the state of Uttarakhand, it falls in the Uttarkashi (Nilang valley), Chamoli (Mana and Niti valleys) and Pithoragarh districts (Johar valley).

These areas have a unique physical and biological setting that is markedly different from that of the adjoining areas in Himalaya. Considering its hydrological significance into account, the entire cold arid region in ITH is drained by hundreds of small and large rivers and streams. The valleys of cold-arid region of the state of Uttarakhand, is thought to be an extension of Tibetan plateau and contributes 1% (ca.>1000 km^2) of the total Trans-Himalayan region of India (ca.

98,660 km^2). These valleys are home to rivers such as Jadh Ganga, Vishnu Ganga, Girthi Ganga and Dhauli Ganga, which originates from the inner dry valleys of the Garhwal Himalaya and drains into the Bhagirathi-Alaknanda river system and contributes a major part to the total volume of the Ganga River. Gori Ganga River originates from Milam glacier in Johar valley, Kumaon Himalaya and drains into the Sharda River where the later demarcates Nepal's western border with India. Teesta River flowing almost across the entire length of the Sikkim forms main river system of the state.

The vegetation of ITH has been described as *Caragana-Lonicera-Artemisia* formation (Osmaston 1922), alpine steppe (Schweinfurth 1959), dry alpine scrub (Champion and Seth 1968) and alpine stony deserts (Puri et al. 1989). The vegetation of these regions reveal a geo-chamaephytic (cold winter) phyto-climate with a high proportion of therophytes (reflect the aridity) and the vegetation can be classified as alpine mesophytes, oasitic vegetation and desert vegetation (Sapru and Kachroo 1979, Murti 2001, Srivastava 2010). The flora of Tsokar basin in Changthang plateau reflects the dominance of hemi-cryptophytes and chamaephytes (Rawat and Adhikari 2005). Most of the plants have spinous tipped leaves and stunted growth often dominated by scrub or desert steppe. Though by large the plant species are adaptive in nature, increasing human pressures and activities such as grazing have posed serious threat to the survival of these ecosystems.

1.4 Plant Functional Types

Plant Functional Types (PFTs) can be defined as groups of plants, which show similar responses to environmental conditions with similar effects on the dominant ecosystem processes (Walker 1992; Noble and Gitay 1996; Diaz and Cabido 1997). Plants are grouped on the basis of their functions in the ecosystem and their utilization of various resources such as water, soil nutrients and substrate (Smith et al. 1997). There is a growing recognition of classifying terrestrial plant species on the basis of their 'functional types' rather than their higher taxonomic identity (Cornelissen et al. 2003).

The concept of PFTs has been recognized particularly by the modelers to know the response of vegetation with respect to climate change (Smith et al. 1997). However, in recent years, more attempts have been made to predict plant responses to disturbances such as grazing by studying plant functional types (Diaz et al. 2001; Vesk et al. 2004; De Bello et al. 2005; Diaz et al. 2007; Golodets et al. 2009). This approach has become a promising way forward for tackling important ecological questions at the ecosystem, landscape or biome level (Cornelissen et al.

2003). The concept of plant functional type has been given priority in international research agendas, mainly because of two reasons, first, in modelling vegetation under changing climatic conditions there is a need to move away from single-leaf to whole-plant approaches (Bazzaz 1993; Korner 1993), and in doing so, the enormous complexity of individual species and population needs to be summarized into a relatively small number of general recurrent patterns (Walker 1992; Grime et al. 1996).

A worldwide protocol for standardized and easy measurement of plant functional traits suggests growth form, life form, plant height, clonality, spinescence, flammability, leaf life-span and leaf phenology as vegetative traits (Cornelissen et al. 2003). Growth form is mainly determined by canopy structure and canopy height that may be associated with plant's strategy to various climatic factors and land use. The height and positioning of the foliage may be adaptations and responses to grazing by different herbivores, rosettes and prostrate growth forms being associated with high grazing pressure by mammalian herbivores. Raunkiaer (1910) developed a simple life form system strictly based on renewal of buds in relation to the soil surface, which became widely accepted and applied in comparative vegetation studies. Although, Raunkiaer's system with basic categories (Phanerophytes, Chamaephytes, Hemi-cryptophytes, Geophytes and Therophytes) was often refined by several workers *viz*., Ellenberg and Muller-Dombois (1967), Muller-Dombois and Ellenberg (1974) and Barkman (1988). The height is a fundamental functional trait of plants and most frequently used PFT to assess species response to pasture management, thereby recognized as important trait for competitive performance and acquiring carbon (Westoby et al. 2002). A set of traits that can be used in combination with height are related to shoot architecture (i.e. distribution of leaves along the plant stem, or biomass per unit height) or life cycle. Clonal plants are defined as the plants that multiply vegetatively on a regular basis, consisting of potentially independent ramets or spreading by vegetatively originated propagules. Non-clonal plants include annual and perennial species with a main (tap) root of the primary root system and without adventitious roots and buds. Pleiocorm plants are those with short belowground branches bearing very few or no roots and apomicts lack other mode of vegetative multiplication (Klimes 2003).

PFTs have been used recently to address a wide range of ecological questions such as to parameterize carbon, land management models, global vegetation models, nutrient and water budget models, predicting impacts of environmental change including climate change, to find vegetation change along physical gradients, to predict plant effects on ecosystem function and resilience, to test evolutionary and phylogenetic relationships among species and to evaluate many additional hypotheses by various workers (Westoby et al. 2002; Cornelissen et al. 2003; Reich et al. 2003; McGill et al. 2006; Westoby and Wright 2006).

1.5 Present Study

Due to increase in human population, demand and supply for economic natural resources has caused their over exploitation and habitat degradation, which has led to the rapid loss of these resources. The prioritization of habitats and their communities in the course of qualitative and quantitative assessment of vegetation is prerequisite for initiating any conservation and management programme (Singh and Samant 2010). Moreover, the knowledge of plant diversity patterns within different vegetation types provides a first sound basis for the potential assessment of conservation priorities and monitoring schemes (Dhar et al. 2000). In India, numerous vegetational surveys and assessments have been conducted to understand the landscape or habitat types and different plant communities in the Himalayan regions. However, the current levels of pressure or patterns of biodiversity are under explored or unexplored even from well established protected areas. Noteworthy, the Great Himalayan range has been thoroughly explored by the botanists and ecologists, very few floristic surveys in the equally important areas i.e. the Trans-Himalayan regions have been conducted, especially in the state of Uttarakhand. The present research work aimed to address the floristics, habitat ecology of plant species and plant functional types (PFTs) in Upper Dhauli Valley of Nanda Devi Biosphere Reserve (NDBR). The reserve has recently been reorganized by adding additional buffer area in 2002, which was the least studied area with respect to the floristic diversity and floral assemblages. The botanical explorations covering some extent of this area were conducted by Naithani (1984a,b) and Rawat (2005) and on monocotyledonous plants by Murti (2001). Hence, in order to obtain a comprehensive account on the floristics, the need was felt to assess the diversity of vascular plants, patterns of floristic diversity across various landforms. Apart from this, no attempts have been made so far to study various life forms, growth forms and clonal as well as non-clonal forms in the cold-arid region of Uttarakhand. Additionally, there is a dearth of large-scale quantification of how well plant functional types actually determine ecological outcomes and the ecological role of species. Therefore, in order to understand how the PFTs are distributed across the various landforms, a systematic understanding of PFTs particularly in the newly added buffer and cold-arid landscape of the reserve was needed.

1.6 Objectives of the Study

The principle aim of the current study was to understand the ecological setting of the cold-arid landscape of the Upper Dhauli Valley in Nanda Devi Biosphere Reserve, Western Himalaya. The study focused on the assessment of phyto-diversity, patterns of floristic diversity across various landforms and plant functional types, which provides a comparative account on the inventory of flora, vegetation structure and composition across various landforms, proportionality and habitat preferences of life forms (phanerophytes, chamaephytes, hemi-cryptophytes, geophytes, helopytes, hydrophytes and therophytes), growth forms (tall forbs, short forbs, short basal, long basal, cushions, tussocks, climbers, dwarf shrubs, shrubs, trees, leafless shrubs or trees, epiphytes, succulents) and clonal (aboveground and belowground) as well as non-clonal forms in buffer zone and cold-arid region of the Nanda Devi Biosphere Reserve, Western Himalaya.

The objectives of this study are as follows:

1. To assess the diversity of vascular plants in Upper Dhauli Valley,
2. To assess the plant community structure and composition in various landform units, and
3. To assess the plant functional types (PFTs) in various landform units.

1.7 Organization of the Thesis

Chapter one describes background, objectives, literature review on the floristics, vegetation ecology, structural and functional aspects of the Himalayan forests and scope of the study. It also includes the literature review on the same aspects from Indian Trans-Himalayan region and intensive study area.

Chapter two covers the description and introduction of the study area including its location, topography, climate, geology and soil, vegetation, fauna, local community and land use practices.

Chapter three deals with first objective, to assess the diversity of vascular plants in Upper Dhauli Valley. This chapter gives an account on the diversity of vascular plants and threatened taxa in the study area.

Chapter four focuses on second objective, to assess the plant community structure and composition in various landforms. This chapter gives an elaborate account on the structural attributes such as vegetation structure, plant community composition and other phyto-sociological characteristics and functional attributes (soil chemical properties) across major landforms and physiognomic units in three major watersheds (Amrit Ganga, Satyagad and Ganesh Ganga) of Upper Dhauli Valley, a cold arid region and buffer zone of Nanda Devi Biosphere Reserve, Western Himalaya.

Chapter five deal with objective three, to assess the plant functional types (PFTs) across various landforms. This chapter focuses on the identified growth forms, life forms and clonality across various landforms.

Chapter six discusses about major findings of the study and their conservation implications.

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CHAPTER 2
STUDY AREA

2.1 General Introduction

The Indian Trans-Himalaya usually described as 'High Altitude Cold Desert' lies in the rain shadow areas of the main Himalayan range. It covers only about 2% of the total geographical area of India. The large chunk of cold desert area lies in Ladakh region in Jammu & Kashmir, Lahul & Spiti and Kinnaur (small northern portion of Kalpa and Baspa valleys) in Himachal Pradesh and small portions of Uttarkashi (Nelang valley), Chamoli (Mana and Niti valleys) and Pithoragarh (Johar valley) districts in Uttarakhand.

The total area of cold desert ecosystem is ca. 98,660 km^2, i.e. 83.7% in Jammu & Kashmir, 15% in Himachal Pradesh and 1% (ca.1000 km^2) in Uttarakhand. The Nelang valley (Uttarkashi district), above Mana and Niti valley beyond Malari (also known as Upper Dhauli valley; Chamoli district) is in Zanskar range and Johar valley in Pithoragarh. The average elevation of the area is between 4000 and 6000 m above mean sea level (amsl). Niti and Girthi valleys are located in the rain shadow areas of Dhauli Ganga catchment, consequently the region receives very low amount of precipitation and remains dry and dusty. Girthi and Dhauli rivers form the drainage system of western part of Nanda Devi Biosphere Reserve (NDBR).

2.2 Nanda Devi Biosphere Reserve

The protected area network in Indian Himalayan region consists of 7 Biosphere Reserves including Nanda Devi Biosphere Reserve, 31 National Parks and 111 Wildlife Sanctuaries (WII, 2015 unpublished). Located in the state of Uttarakhand, NDBR (30°08' to 31°02'N Lat, 79°12' to 80°19'E Long) falls in the Western Himalayan biotic province (2B; Rodgers et al. 2000). The reserve was second to be declared in India and first in Himalaya (1988). It has two core zones, Nanda Devi National Park (NDNP; ca. 630 km^2) and the Valley of Flowers National Park (VoFNP; ca. 87.5 km^2), listed together as a World Natural Heritage site. These two core zones are the least disturbed areas of the entire BR and have the distinction of being the only PAs in the Western Himalaya that have not been subjected to extensive livestock grazing in recent decades.

The reserve is spread across higher reaches of Chamoli, Bageshwar and Pithoragarh districts of Uttarakhand. It is spread across ca. 6407.03 km^2 area divided into core area (ca. 712.12 km^2); buffer zone (ca. 5148.57 km^2) and transition zone (ca. 546.34 km^2) and has an elevational range from 1800-7,816 m. The highest point is the Nanda Devi peak, considered as the world's second toughest peak to climb (Kaur 1982), which lies within the core area of NDNP and is the second highest peak (ca. 7,816 m) within the Indian Territory. The buffer and transition zone are inhabited by 47 and 52 villages respectively. The buffer zone covers most of Alaknanda and entire Rishi Ganga catchments (the sub-catchments of the river Ganga). A large area of the reserve lies above tree line and is covered with snow for more than 6 months in a year. Thus, about 81% of the core zone and 60% of the buffer zone remain snow bound by glaciers throughout the year (Sahai and Kimothi 1996). The areas above 2500m amsl are accessible only for a limited period from late May to early October. Average annual rainfall is 930 mm and about 48% of annual rainfall occurs over a short period of two months (July-August; Sahai and Kimothi 1996). The maximum temperature ranges from 11^{0}C to 24^{0}C and minimum from 3^{0}C to 7.5^{0}C. The region is characterized by temperate forests, alpine meadows, high altitude lakes, glaciers, and perpetual snow (Sahai and Kimothi 1996). Dramatic changes in elevation have resulted in the existence of a number of unique vegetation types such as temperate forests and alpine meadows, distributed over a variety of topographical and climatic zones. As per Champion and Seth's (1968) classification, the vegetation of NDBR falls under three categories such as temperate forests (2000-2800 m) with two sub-categories, broadleaved montane forests and coniferous montane forests, sub-alpine forests (2800-3500 m), alpine scrublands (3800-4500 m) and alpine meadows and moraines (>3500 m).

A total of 801 species of vascular plants have been recorded from the reserve (Hajra and Balodi 1995). However, according to Samant (2001), the reserve supports over 1000 species of plants including fungi, lichen and bryophytes. The reserve supports 29 species of mammals including Blue sheep or Bharal (*Pseudois nayaur*), Himalayan musk dear (*Moschus chrysogaster*), Himalayan tahr (*Hemitragus jemlahicus*), Serow (*Nemorhaedus sumatrensis*), Himalayan black bear (*Ursus ursus*), Himalayan brown bear (*Ursus arctos*) and Snow leopard (*Panthera uncia*) (Sathyakumar, 2004; Bhattacharya et al. 2006; Bhattacharya et al. 2009 and Kandpal 2010). Apart from these, 228 birds, 229 species of arthropods, 14 mollusks, 8 amphibians and 6 annelids are also recorded from the reserve (Kumar et al. 2001; Prajapati 2005). Due to heavy exploitation in some pockets, populations of numerous plant and animal species have declined in their natural habitats (Rao et al. 2000).

2.3 Intensive Study Area

The present study was conducted in the buffer zone of NDBR covering Upper Dhauli Valley (UDV; **Figure 2.1**) in Chamoli district. UDV also known as 'Niti Valley' is named after the river Dhauli Ganga that forms one of the major catchments of river Alaknanda (a sub-catchment of the river Ganga). The picturesque landscape of valley comes under Trans-Himalayan region of Uttarakhand. The valley with an average elevation ranging from 3500 to 5000 m is spread over ca. 727.7 km^2. **Figure 2.2** shows the aspect and slope map of the valley.

The valley has three sub-watersheds namely, Amrit Ganga, Satyagad and Ganesh Ganga. The Amrit Ganga watershed is situated in western side of valley, enroute an alpine pasture known as Dhaman (3800 m). Frank S. Smythe with his team while returning from successful expedition of Mount Kamet (7,756 m) discovered the famous 'Valley of Flowers' from this route. A stream, Satyagad merges with Dhauli Ganga about 2 km before Niti village from eastern side that originates from Kalajowar (4200 m) and Chotahoti (4400 m) area, while Ganesh Ganga watershed forms the extreme northern side of the valley forming border between India and China. The alpine pastures are Bamplas (4000 m), Rekhana (base of Mount Kamet; 4400 m), Gothing (4000 m) and Geldung (4600 m).

2.3.1 Climate, Geology and Soil

This area is situated in the rain-shadow zone and dryness increases towards upper reaches of the Dhauli and adjacent Girthi Valley, which remain snow bound for more than 6 months in a year. Summer is very short and generally lasts from June to August. The region receives low amount of precipitation and remains dry and dusty above 3200 m.

The surface overburden is largely gravely and immature over the larger part of the tract, poor in nutrients and moisture and is marked by unstable slopes. The soil of the area is largely acidic and sandy gravely derived as a result of fluvial and glacial action. Among three different landforms, present study reports highest soil pH in scree (6.94) followed by river bed (6.15) and moraine (5.82). Among three physiognomic units, pH was recorded highest in scrub steppe (6.94) followed by livestock camping site (5.99) and herbaceous meadow (5.58). The detailed description of the nutrients concentrations including soil pH across landforms and physiognomic units of the study area is given in the Chapter 4.

2.3.2 Vegetation

In general, the vegetation in the region comprises of dry temperate to dry alpine types. The flora is of steppe nature and rich at lower elevations. The alpine meadows are large undulating grassy plains and shrubby vegetation is found on ridges and rocky slopes. The major woody elements are *Cedrus deodara, Pinus wallichiana, Picea smithiana, Betula utilis, Fraxinus xanthoxyloides* and *Juniperus semiglobosa.*

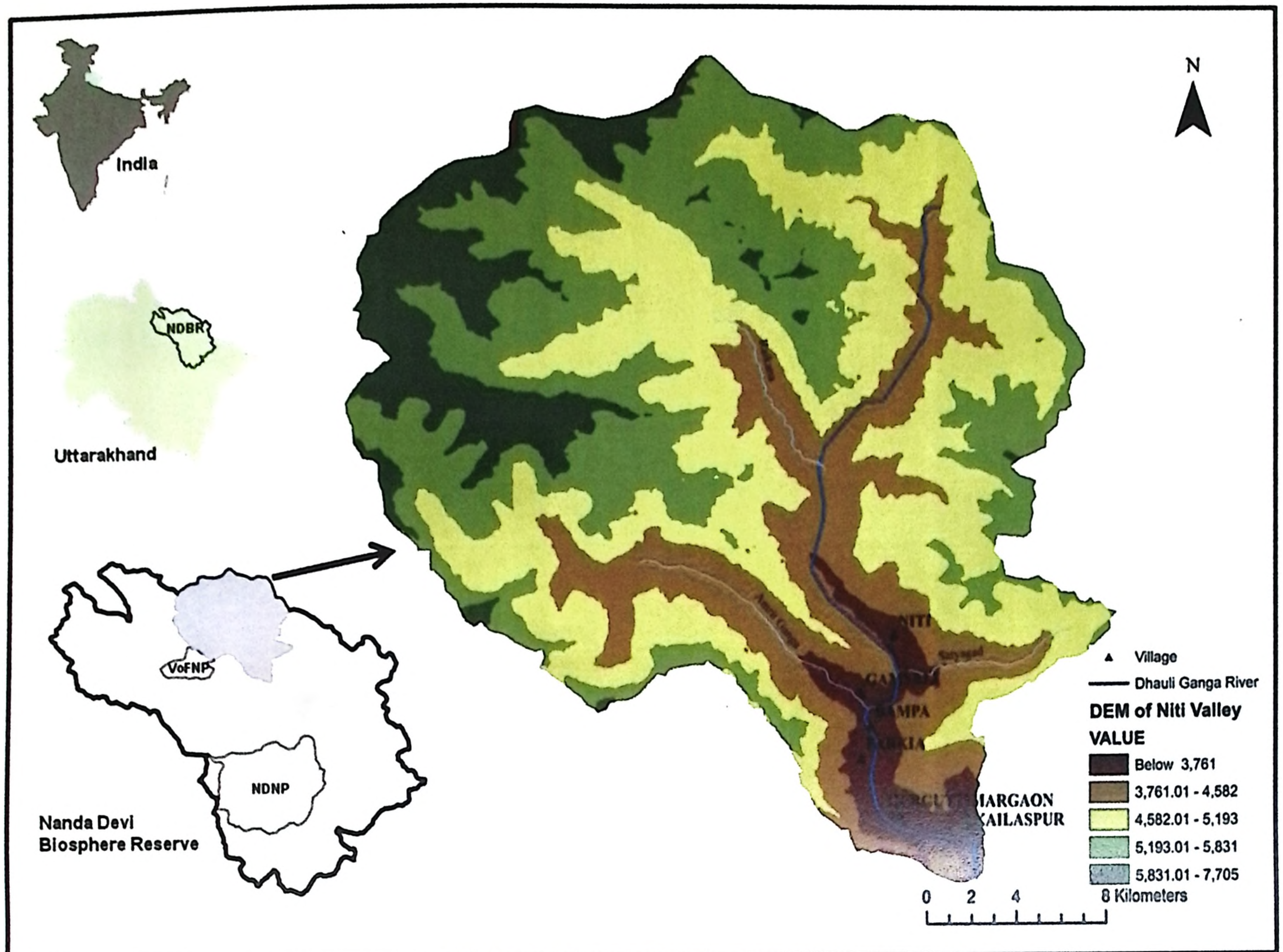

Figure 2.1 Map showing the location of Upper Dhauli or Niti Valley in Nanda Devi Biosphere Reserve, Western Himalaya.

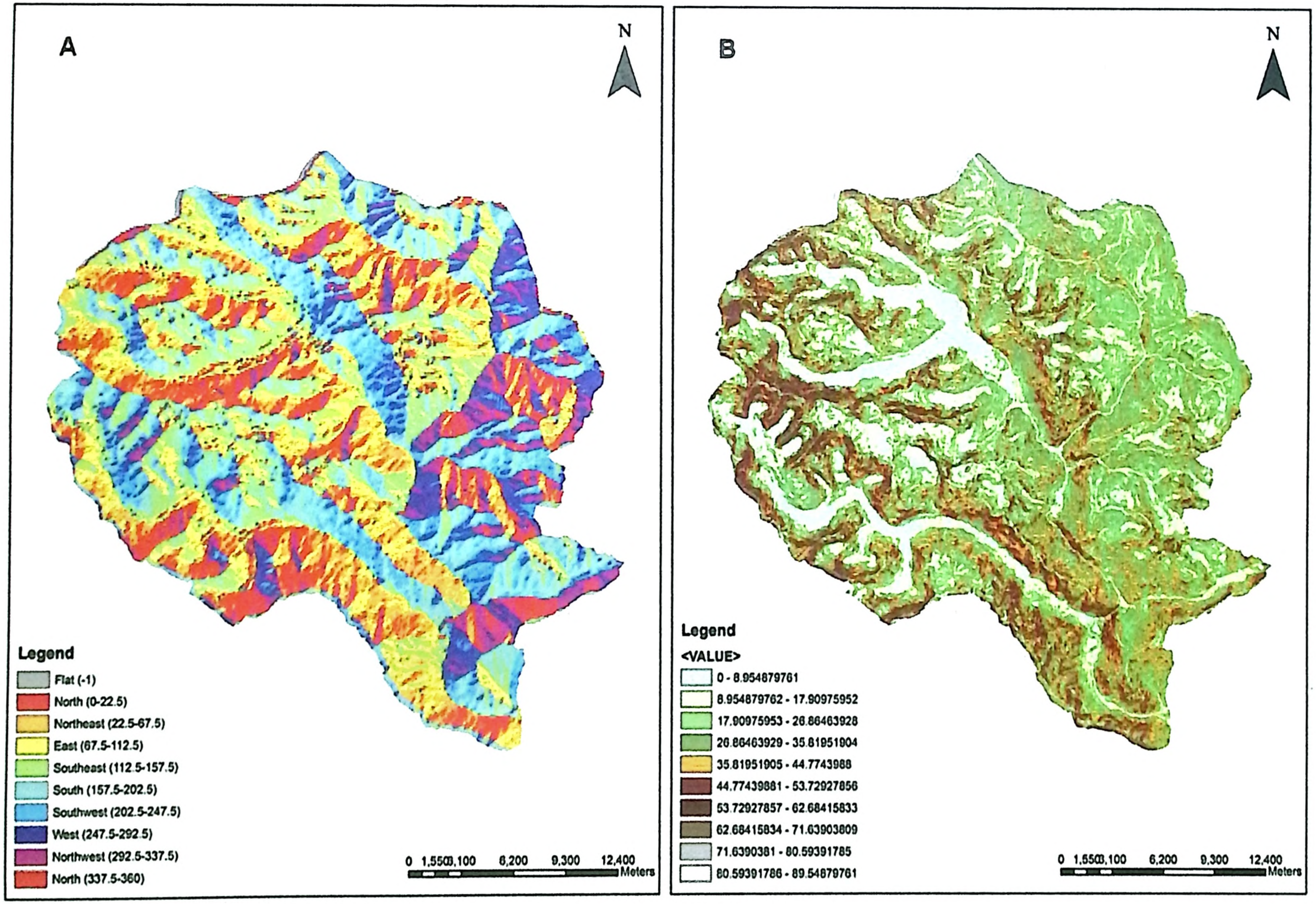

Figure 2.2 Aspect (A) and slope (B) map of Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya.

Species of *Juniperus, Hippophae, Ephedra, Caragana*, *Potentilla rigida, Krascheninnikova, Lonicera, Rosa, Berberis, Rhododendron, Cotoneaster*, and *Salix* forms the shrubby growth. The alpine vegetation comprised by herbaceous formations includes species of *Astragalus, Potentilla, Sibbaldia, Poa, Kobresia*, *Carex, Danthonia, Anemone, Androsace* and *Aconogonum*. The detailed description of flora and vegetation composition is given in the Chapter 3 and 4.

2.3.3 Fauna

The mammalian fauna inhabiting the valley include Blue sheep (*Pseudois nayaur*), Himalayan marmot (*Marmota himalayana*), Himalayan musk deer (*Moschus chrysogaster*), Himalayan tahr (*Hemitragus jemlahicus*), Snow leopard (*Panthera uncia*), Red fox (Vulpes vulpes), Royle's Pika (*Ochotona roylei*) and Tibetan woolly hare (*Lepus oiostolus*).

2.3.4 Local community and Land use Practices

Upper Dhauli Valley is inhabited by two clans of Bhotiya community, locally known as Tolchhas and Marchhas. Of the 47 villages present within the buffer zone of NDBR, seven migratory villages namely, Mahargaon, Kailashpur, Gurgutti, Pharkia, Bampa, Gamsali and Niti are present in the UDV. Niti (3500 m) is the last village in the valley that borders to China. The Bhotiya ethnic community of Indo-Mongoloid origin has their own unique customs, folklore and religious beliefs. Additionally, this indigenous community has its own perspective on conservation which manifests itself through local archetypes (Kumar et al. 2013b). They depend on natural resources from the adjacent forests and alpine pastures for sustenance and livelihood, and the area continues to be used for transhumant pastoralism (Mitra et al. 2013). Due to lack of education facility and socio-economic transformations, the practice of utilizing medicinal plants in the local healthcare system of Bhotiyas is sharply declining and has lead to lack of knowledge as well as transfer of knowledge to younger generations (Kumar et al. 2015b).

Prior to 1962, residents of this valley carried cross-border trade with Tibet, primarily in salt and wool which was their main source of income. In recent decades, livestock (sheep and goat) rearing and weaving of woolen items such as pankhi (shawl), chutka or gudma (mattress), dann or kalin (carpet), topi (cap), fatuli (vascot) and baniyan (sweater) has become a more reliable source of income for locals, though at present it is restricted to a few families. As per Census India (2011), the total number of households in the area is 292 with a total population of 864 people (47.5% males and 52.5% females) and the average family size was 4-5 persons.

The inhabitants have two dwellings; in cold-arid region of UDV, between 3000 to 3600 m amsl, where they stay during the summer and the other in the lesser Himalaya, a permanent dwelling between 1000-1500 m amsl. In UDV, most of the families are engaged in small scale farming where Kidney bean (*Phaseolus vulgaris*), Potato (*Solanum tuberosum*), Pea (*Pisum sativum*) and Fapar (*Fagopyrum esculentum*) are the major agricultural crops while Apricot (*Prunus armeniaca*), Akhrot (*Juglans regia*) and Apple (*Malus domestica*) are the major horticultural crops.

The biotic pressure on the alpine rangelands is mainly due to heavy use by livestock grazing. The total number of livestock with eight herder groups recorded in 2012 was 5,777, of which 65% were sheep and 35% goats (Mitra et al. 2013). The heavily grazed alpine pastures are Dhaman, Kalazowar, Bamplas, Rekhana, Gothing and Geldung. The transhumant herders using the area belong to the lower elevations of the Himalaya, who bring their herds to higher alpine meadows during summers (June-September) for grazing.

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PLATE 2.1 AMRIT GANGA WATERSHED

Herbaceous meadow amidst *Danthonia cachemyriana* tussocks

Riverine habitat towards Dhaman Payar

PLATE 2.2 SATYAGAD WATERSHED

Scrub steppe on the way to Kalazowar

Dry scree slope (>4000 m)

PLATE 2.3 GANESH GANGA WATERSHED

Glacial accumulation near Kharbasiya nallah along Dhauli Ganga river

Scrub vegetation along the Dhauli Ganga River

2.4 FAUNA IN THE STUDY AREA

Snow leopard (*Panthera uncia*)

Blue sheep (*Pseudois nayaur*)

Himalayan marmot (*Marmota himalayana*)

Royle's Pika (*Ochotona roylei*)

Bright green underwing

Alpine or Yellow-billed chough

CHAPTER 3
FLORISTIC DIVERSITY

3.1 Introduction

Mountainous regions of the world are fascinating as they cover an ample range of biological diversity over smaller areas (Dash and Saxena 2012). The mighty Himalaya is the youngest and highest mountain chain, known for its inimitable and rich biological diversity. It harbours a rich array of the floral diversity across diverse habitats in mountain systems expanding as parallel chain from Shivaliks to the alpine arid rangelands. In Indian Himalayan region, the alpine zone occupies nearly 33% of the total geographical area, of which about 25.98% area is vegetated and remaining 7.1% area falls under perpetual snow (Lal et al. 1991). The alpine zone above 4000 m is characterized by low productivity, high intensity of solar radiation and high degree of resource seasonality. Of the estimated 10,000 plant species in the Himalaya, 71 genera and ca. 3160 species are endemic. It represents about 61% of endemic species and 49% of the endemic genera of flowering plants in India (Nayar 1996). The Himalaya Hotspot is divided in to Eastern and Western Himalaya, of which Eastern region is considered as one of the centres of the evolution and most of the Western Himalayan plants are found in this region. It forms a distinct biogeographic eco-region with large variation in topography and climate (Olson et al. 2001).

The arid tracts lying extreme north and parallel to the Greater Himalayan range, constituting the sediments of Tethyan sea bed, are referred as Trans-Himalaya (Rawat 2007, Chandola 2009). These areas are not affected by the Indian monsoon as they are positioned in the rain shadow of the main Himalayan region and are characterized by extreme climatic conditions, such as diurnal fluctuations in temperature, scanty and erratic rainfall, heavy winds and snowfall.

The Indian Trans-Himalaya (ITH) usually described as 'High Altitude Cold Desert Zone' (Zone 1) spreads into three biogeographic provinces: 1A, Ladakh mountains: Kargil, Nubra and Zanskar in Jammu and Kashmir and Lahul and Spiti in Himachal Pradesh); 1B, Tibetan plateau: Changthang region of Ladakh and northern parts of the states of Uttarakhand; and 1C, Sikkim Plateau (Rodgers et al. 2000; WII 2015, unpublished). The vegetation of ITH has been described as *Caragana-Lonicera-Artemisia* formation (Osmaston 1922), alpine steppe (Schweinfurth 1957), dry alpine scrub (Champion and Seth 1968) and alpine stony deserts (Puri et al. 1989). The extreme north of the state of Uttarakhand contributes approximately

1% (ca. >1,000 km^2) of the total Trans-Himalayan region of India (ca. 98,660 km^2) covering Nilang, Niti and Mana valleys (Nanda Devi Biosphere Reserve) and Johar valley in Uttarkashi, Chamoli and Pitthoragarh districts, respectively.

3.2 Review of Literature

3.2.1 Floristic Studies in Indian Trans-Himalaya

The Indian Trans-Himalaya has been extensively surveyed in terms of floristics by several workers. According to Srivastava (2010), the cold deserts of Western Himalaya are represented by ca. 1405 species belonging to 490 genera under 98 families of flowering plants. Murti (2001) reported about 347 species, belonging to 103 genera under 16 families of monocotyledons from the same region. A number of workers have documented the richness of vascular plants from Indian Trans-Himalaya, based on extensive floristic studies (Kachroo et al. 1977; Klimes 2003; Klimes and Dickore 2005, 2006). Rawat and Adhikari (2005) recorded 232 species of vascular plants and identified several plant communities such as *Caragana-Artemisia, Artemisia-Krascheninnikovia* and *Artemisia-Tanacetum* from ca. 300 km^2 area in Changthang region of Ladakh. Rawat (2007) estimated that a total of over 1800 species of flowering plants occur within the alpine region of Western Himalaya in an area of ca. 157,671 km^2. Joshi et al. (2006) recorded 414 species of vascular plants from Nubra Valley, Ladakh. In Ladakh, Kala and Mathur (2002) studied distribution of plant species in eight landscape types and found that the table lands have highest species diversity followed by undulating areas and river beds. In Trans-Himalayan region of Himachal Pradesh, Aswal and Mehrotra (1994) recorded 985 species from Lahaul-Spiti. In recent floristic surveys of the cold arid regions of the state, Sekhar and Srivastava (2009) recorded 513 plant species belonging to 243 genera under 64 families from Pin Valley National Park while Chawla et al. (2012) reported 911 species of vascular plants from Kinnaur, Himachal Pradesh. The cold arid regions of Uttarakhand include Nilang, Mana and Niti valleys in Garhwal and Johar, inner Darma and Byans valleys in Kumaun regions. Very few studies have been done on the floristics of these valleys. Naithani (1988) reported ca. 170 species of flowering plants from Nilang valley. However, Chandola (2009) recorded 441 species of vascular plants belonging to 229 genera and 72 families from the same valley. Kumar and Mitra (2015) recorded a total of 469 species belonging to 73 genera under 261 families of vascular plants from Niti valley, Nanda Devi Biosphere Reserve, Uttarakhand. A perusal of literature on floristics of the ITH by various workers has been provided in **Table 3.1.**

Table 3.1. Details of floristic studies carried out in the Indian Trans-Himalaya.

Eco-floristic region and State	Area (km^2)	Family	Genera	Species	Elevation range (m)	Author (s)
Western Himalaya; J&K, H.P., UK	98,980	98	490	1405	4500-6000	Srivastava (2010)
Western Himalaya; J&K, H.P., UK	1,57,671	--	--	1810	3300-5600	Rawat (2007)
Ladakh, J&K	97,782	51	190	611	2900-5900	Kachroo et al. (1977)
Ladakh, J&K	1,00,000	--	--	1180	3000-6000	Klimes and Dickore (2006)
Lower Ladakh, J&K	400	--	--	355	2750-4100	Klimes and Dickore (2005)
Western Ladakh, J&K	6,523	51	159	301	2700-5300	Angmo (2013)
Eastern Ladakh, J&K	10,227	--	--	404	4180-6000	Klimes (2003)
Eastern Ladakh, J&K	6,912	43	127	272	4180-6670	Dvorsky et al. (2011)
Nubra Valley, J&K	22,656	56	202	414	2800-5400	Joshi et al. (2006)
Tso Kar Basin, Changthang, J&K	300	38	101	232	4400-5500	Rawat and Adhikari (2005)
Lahaul and Spiti, H.P.	12,210	79	353	985	2000-6600	Aswal and Mehrotra (1994)
Pin Valley National Park, H.P.	1,825	64	243	513	3300-6600	Sekar and Srivastava (2009)
Kinnaur, H.P.	6,400	114	450	911	--	Chawla et al. (2012)
Sangla Valley, H.P.	--	99	321	639	1800-4600	Devi et al. (2014)
Nilang Valley, UK	1,360	72	229	441	3000->6000	Chandola (2009)
Milam Valley, UK	--	39	95	181	3132-4235	Sekar et al. (2014)
Niti Valley, UK	727	73	267	495	3200->5000	Kumar et al. (2016a)
Khangchendzonga National Park, Sikkim	1,784	67	243	585	4000-5000	Tambe (2007)

[Abbreviations used: J&K: Jammu and Kashmir, H.P: Himachal Pradesh, UK: Uttarakhand].

3.2.2 Floristic Studies in Nanda Devi Biosphere Reserve

Located in the state of Uttarakhand, Western Himalaya, the Nanda Devi Biosphere Reserve (NDBR) is among the few well surveyed Protected Areas in terms of flora in the country. Collection of plant species from the area started as far back as 1846 by R. Strachey and J. E. Winterbottom (Kala 2004a). Frank S. Smythe, who is credited with the discovery of the Valley of Flowers, had reported 262 plant species belonging to 150 genera under 45 families (Smythe 1938). Subsequently, Ghildiyal (1957), Shah (1974) and Awasthi (1975) were among the first plant explorers of the reserve. The major floristic works from the reserve include Hajra (1983), Naithani (1984a,b), Balodi (1993), Samant (1993), Samant (1999), Hajra and Balodi (1995), Kala (1998), Joshi et al. (2011a,b), Rawat (2013) and Kumar et al. (2016a). Ghildiyal (1957) recorded 96 species of vascular plants from Valley of Flowers. An account on the flora of Chamoli district, which covers maximum area of the NDBR, was made by Naithani (1984a,b). The most comprehensive collection of plants from the entire reserve was made by Hajra and Balodi (1995) who recorded 801 species of vascular plants (406 genera; 120 families) covering the then area of reserve (*ca.* 2000 km^2). Negi (2000) recorded 56 species of mosses (38 genera; 24 families) for the first time from the reserve. According to Samant (2001), the reserve supports over 1000 plant species including bryophytes, fungi and lichens. Hajra (1983) recorded 312 species of vascular plants (81 genera; 199 families) from the Nanda Devi National Park (NDNP). Later, Samant (1993) reported 620 species (344 genera; 116 families) of vascular plants from the same region and added 308 species (145 genera; 35 families) to the previous works. Joshi and Samant (2004) reported 76 woody species from Lata-Tolma-Phagti area of NDBR. Samant and Joshi (2005) recorded 490 species of spermatophytes from the NDNP. Samant and Joshi (2003) recorded 568 vascular plant species (314 genera; 110 families) from NDNP. Negi and Gadgil (1996) reported 76 macrolichens from western NDBR, the least studied taxa in the region. Kala (1998), Kala et al. (1998), Kala and Rawat (2004) and Kala (2005) reported a total of 521 species of vascular plants (248 genera; 72 families) from the Valley of Flower National Park. Murthy (2011) prepared a pictorial field guide for VoFNP covering 287 species (190 genera; 63 families). Sekar et al. (2009) reported a new species of *Arnebia* from Bageshwar region of NDBR. Awasthi (1975) recorded 122 species (38 genera; 18 families) of lichens from Pindari area. Joshi et al. (2011a) recorded 283 lichen species from the Pindari valley. Rawat (2013) recorded 451 species of vascular plants from Pindar and Dhauli Ganga Valley. Rawat and Upreti (2014) recorded 82 lichen species (39 genera; 16 families) from seven sites of

Chamoli. Rawat et al. (2015a,b) recorded 451 species of vascular plants from Pindari-Sunderdhunga-Kafni and Lata-Tolma-Phagti area of the reserve. Details on the floristic studies conducted in the reserve are given in **Table 3.2.**

Though, the Great Himalayan range has been thoroughly explored by the botanists, very few floristic surveys in the equally important areas, such as the Trans-Himalayan region of Uttarakhand state have been conducted. Additionally, flora of NDBR has been extensively surveyed by various workers albeit highly confined to the core zones. Therefore, the present study was conducted to assess the diversity of vascular plants in the Upper Dhauli Valley (also known as Niti Valley), an extended buffer zone of the Biosphere Reserve which represents the cold arid landscape.

Table 3.2: Details on the floristic studies carried out in the Nanda Devi Biosphere Reserve.

Study area	Plant group	Family	Genera	Species	Author (s)
Valley of Flowers National Park	Vascular plants	45	150	262	Smythe (1938)
Valley of Flowers National Park	Vascular plants	-	-	96	Ghildiyal (1957)
Valley of Flowers National Park	Vascular plants	72	248	521	Kala (1998); Kala et al. (1998); Kala and Rawat (2004); Kala (2005)
Nanda Devi National Park	Vascular plants	81	199	312	Hajra (1983)
Nanda Devi National Park	Vascular plants	116	344	620	Samant (1993)
Nanda Devi National Park	Angiosperms	85	274	480	Samant and Joshi (2003)
	Gymnosperms	4	7	10	
	Pteridophytes	21	33	78	
Nanda Devi National Park	Angiosperms	85	274	480	Samant and Joshi (2005)
	Gymnosperms	4	7	10	
Nanda Devi Biosphere Reserve	Vascular plants	120	406	801	Hajra and Balodi (1995)
Nanda Devi Biosphere Reserve	Lichens	-	33	87	Upreti and Negi (1995)
Nanda Devi Biosphere Reserve	Lichens	-	-	76	Negi and Gadgil (1996)
Nanda Devi Biosphere Reserve	Vascular plants	-	-	656	Samant (1999)
Nanda Devi Biosphere Reserve	Mosses	24	38	56	Negi (2000)
Pindar Valley	Lichens	18	38	122	Awasthi (1975)
Pindar Valley	Lichens	35	77	283	Joshi et al. (2011a,b)
Pindar and Dhauli Valley	Vascular plants	94	-	451	Rawat (2013); Rawat et al. (2015a,b)
Niti Valley	Vascular plants	73	267	495	Kumar et al. (2016a)

3.3 Methodology

3.3.1 Field survey and data collection

Systematic survey of vascular plants was done during the growing season from May to October in 2012, 2014 and 2015. The entire valley was traversed on foot to cover all the landscape features, which included alpine arid tracts, along water channels, ridges, exposed and unexposed sites, riverside tracts, valley bottoms, grasslands, agricultural fields, near human habitations and various habitats in and around forests. The voucher specimens were dried, pressed and mounted on herbarium sheets following Jain and Rao (1976) and deposited in the herbarium of Wildlife Institute of India, Dehradun (WII) for future reference and records. To supplement the process of correct identification, the information on parameters such as elevation, aspect, important taxonomic characters including habit and habitat of the species were also gathered. The identity of plant specimens was cross-checked with specimens housed in herbaria (BSD, DD and WII) and based on field characters with the aid of existing florula's and literature (Naithani 1984a,b; Hajra and Balodi 1995; Chandola 2009; Pusalkar and Singh 2012). The currently accepted botanical names and authorities were updated following www.ipni.org and the families were updated following APG III (2009). Certain plant species including threatened and common, which were easily identified in the field, were only photographed. The threat status of species was determined with the aid of existing literature or sources (Nayar and Sastry 1987–90; Walter and Gillett 1998; Ved et al. 2003; Hedge et al. 2003; Srivastava 2010 and IUCN 2015). Species richness was determined as the total number of the species in an area.

3.4 Results

3.4.1 Floristic diversity and richness

The systematic floristic survey and detailed inventory of the entire area revealed presence of 495 species of vascular plants (angiosperms, gymnosperms and pteridophytes) belonging to 267 genera and 73 families (Adhikari et al. 2012; Kumar et al. 2016a; **Table 3.3**). Of the recorded species, 383 were dicots, 93 monocots, 9 pteridophytes and 10 gymnosperms. The valley comprises 62% of the vascular plants of NDBR and 35% of the flora of cold deserts of Western Himalaya. The ratio of monocots to dicots in respect of families, genera and species is 1:5.6, 1:4.7 and 1:4, respectively. The ratio of family to genera is 1:3.65, family to species is 1: 6.78 and genera to species is 1:1.85.

Table 3.3 Analysis of floristic diversity under various taxonomic groups.

Plant group	Family	Genera	Species
Dicotyledons	52 (71.2)	208 (78)	383 (77.3)
Monocotyledons	10 (13.6)	43 (16)	93 (18.7)
Pteridophytes	8 (10.9)	9 (3.3)	9 (1.8)
Gymnosperms	3 (4.1)	7 (2.6)	10 (2)
Total	**73**	**267**	**495**

*Values in parentheses are percent contribution of the total.

The dominant families in terms of high species richness in the valley were Asteraceae (32 genera with 58 species) followed by Poaceae (22 genera with 41 species) and Lamiaceae (15 genera with 19 species; **Figure 3.1**). 52% of total species found in the present study belongs to these ten dominating families. The presence of families such as Asteraceae, Poaceae, Lamiaceae, Fabaceae, Brassicaceae, Rosaceae, Polygonaceae, Apiaceae, Ranunculaceae and Orchidaceae could be attributed to the mesic conditions in the valley. Among gymnosperms, three major families (Pinaceae, Ephedraceae and Cupressaceae) were recorded, of which Pinaceae had five species, Cupressaceae had four species and Ephedraceae had only one species. A total of nine species (eight families with nine genera) of pteridophytes were recorded from the valley, with the family Athyriaceae having two species. Altogether, 24 families (Adiantaceae, Aspleniaceae, Betulaceae, Bignoniaceae, Cannabaceae, Celastraceae, Dioscoreaceae, Dryopteridaceae, Ephedraceae, Equisetaceae, Hydrangeaceae, Hypericaceae, Iridaceae, Juglandaceae, Nartheciaceae, Nyctaginaceae, Oleaceae, Phytolaccaceae, Polemoniaceae, Polypodiaceae, Pteridaceae, Santalaceae, Sapindaceae and Thelypteridaceae) were represented by single species in Niti valley. Among the different growth forms, herbs contributed 70.7% followed by shrubs (11.3%), grasses (7.2%), sedges (4.3%) trees (2.6%), climbers and ferns (1.8% each). The list of species including currently accepted name, author citation, family, habit and voucher specimen's number for each species is given in Kumar et al. (2016a).

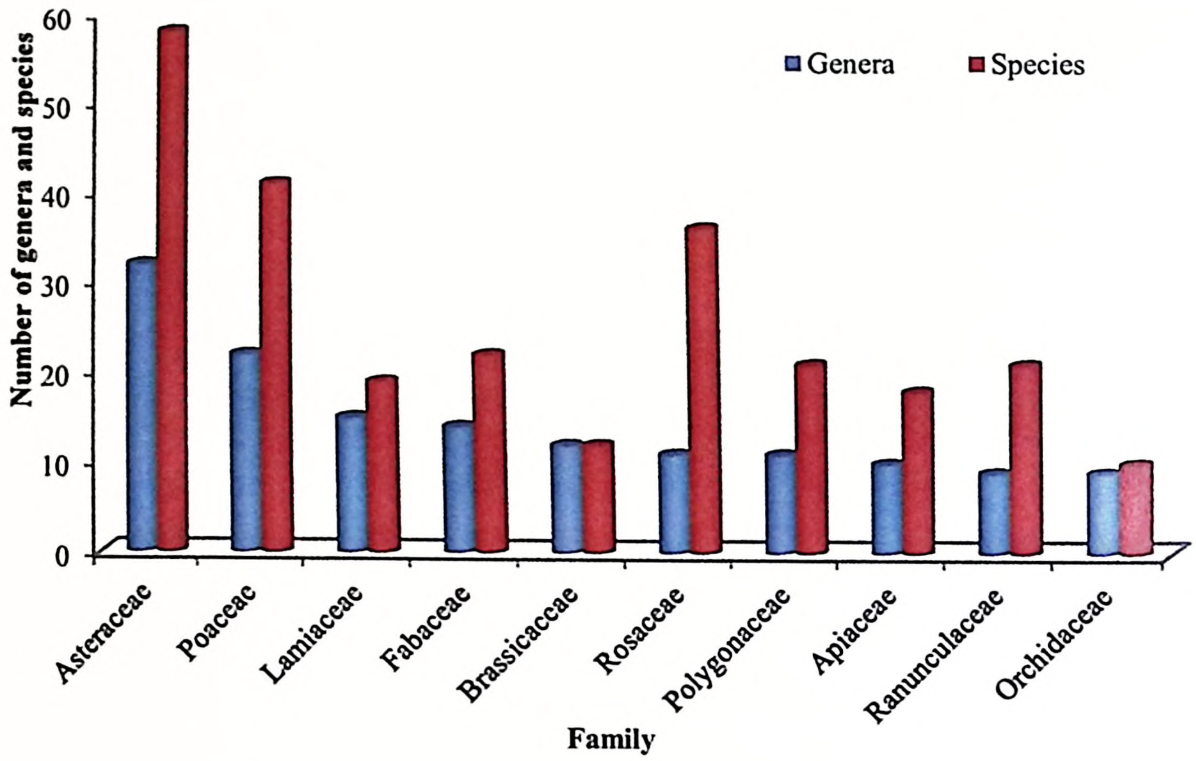

Figure 3.1 Dominant families with number of genera and species in Niti valley, Nanda Devi Biosphere Reserve, India.

Potentilla was the dominant genus with 12 species, including one shrub species (*Potentilla rigida*), followed by the monocotyledons (*Carex* and *Kobresia*) with nine species each, and dicotyledons such as *Artemisia, Corydalis* and *Silene* (seven species each) and *Astragalus* and *Poa* (six species each). The other common herbaceous vegetation was *Anaphalis* spp., *Oxytropis* spp., *Danthonia* sp., *Pedicularis* spp., *Androsace* spp., *Saxifraga* spp. and *Rhodiola* spp. Among the shrubs, *Cotoneaster* with seven species followed by *Lonicera* (five) dominated the valley, while *Juniperus indica*, *J. communis*, *Caragana versicolor*, *Krascheninnikovia ceratoides*, *Potentilla rigida*, *Devendraea* spp., *Rosa* spp., *Ephedra gerardiana*, *Rhododendron anthopogon*, *R. lepidotum*, *Hippophae* sp. and *Salix* spp. were common. The major trees found in the valley were *Pinus wallichiana*, *Cedrus deodara*, *Picea smithiana*, *Betula utilis*, *Fraxinus xanthoxyloides* and *Juniperus semiglobosa*. *Pinus wallichiana*, *Pinus-Cedrus,* and *Pinus-Cedrus-Picea* were the major forest communities in the lower reaches of the valley. Additionally, *Betula utilis* dominated the community alongside steep ridges protruding towards hill tops. *Rumex nepalensis*, locally known as *khoksya,* was found growing excessively in open riverine and alpine tracts of Amrit Ganga (Dhaman payar), animal resting places, near human habitations and agricultural fields throughout the valley. An overview of the study area with some specific habitats, rare and important medicinal plants in the region are described in Kumar et al. (2016a). The predominance of major families in the Western Himalaya is given in **Table 3.4.**

Table 3.4. Comparison of dominant plant families in the Western Himalaya.

Western Ladakh, J & K (Angmo 2013)	**Eastern Ladakh, J & K** (Dvorskey et al. 2011)	**Lahaul & Spiti, H.P.** Aswal and Mehrotra (1994)	**Pin Valley, H.P.** Sekar and Srivastava (2009)	**Nilang Valley, UK** (Chandola 2009)	**Valley of Flowers NP** (Kala et al. 1998)	**Nanda Devi NP** Samant and Joshi (2003)	**Present Study**
Asteraceae	Asteraceae	Asteraceae	Poaceae	Poaceae	Asteraceae	Rosaceae	Asteraceae
Fabaceae	Poaceae	Poaceae	Asteraceae	Asteraceae	Rosaceae	Asteraceae	Poaceae
Ranunculaceae	Brassicaceae	Brassicaceae	Fabaceae	Brassicaceae	Ranunculaceae	Ranunculaceae	Lamiaceae
Polygonaceae	Fabaceae	Fabaceae	Brassicaceae	Lamiaceae	Orchidaceae	Poaceae	Fabaceae
Caryophyllaceae	Cyperaceae	Rosaceae	Polygonaceae	Apiaceae	Apiaceae	Apiaceae	Brassicaceae
Apiaceae, Poaceae	Chenopodiaceae	Scrophulariaceae	Scrophulariaceae	Fabaceae	Poaceae	Orchidaceae	Rosaceae
Brassicaceae, Rosaceae	Caryophyllaceae	Ranunculaceae	Caryophyllaceae	Polygonaceae	Scrophulariaceae	Fabaceae	Polygonaceae
Primulaceae, Lamiaceae	Ranunculaceae	Apiaceae	Ranunculaceae	Caryophyllaceae	Brassicaceae	Polygonaceae	Apiaceae
Boraginaceae, Cyperaceae	--	Polygonaceae	Lamiaceae	Rosaceae	Polygonaceae	Saxifragaceae	Ranunculaceae
Amaranthaceae, Papaveraceae	--	Cyperaceae	Boraginaceae	Scrophulariaceae	Liliaceae	Lamiaceae	Orchidaceae

Abbreviations used: J & K- Jammu and Kashmir, H.P. - Himachal Pradesh, UK- Uttarakhand, NP- National Park

Asteraceae, the most diverse family recorded in the current study conforms to Western Ladakh, Eastern Ladakh, Lahaul & Spiti and VoFNP. Poaceae in VoFNP and NDNP have sixth and fourth rank respectively, whereas it represented as second dominant family in UDV, Eastern Ladakh and Lahaul & Spiti, indicating moist conditions in former and arid in later. Subsequently, Orchidaceae in VoFNP and NDNP have fourth and sixth rank respectively, whereas it represented as tenth dominant family in UDV (**Table 3.4**). Therefore, based on the prevalence of families, it can be concluded that the UDV has close affinities with the flora of the Great and Trans-Himalaya.

3.4.2 Threatened taxa

Saussurea costus (locally known as *kuth*; cultivated) and *Juniperus semiglobosa* were recorded from the region, which are listed as Critically Endangered and Least Concern, respectively (IUCN 2015). *Allium stracheyi* (wild as well as cultivated) and *Aconitum lethale* were reported as Vulnerable and Indeterminate, respectively, as per Walter and Gillett (1998). *Allium carolinianum* (Vulnerable), *Thermopsis barbata* (Vulnerable), *Thylacospermum caespitosum* (Endangered) and *Viola kunawurensis* (Critically Endangered) are threatened species of cold-arid regions as per Srivastava (2010). *Allium stracheyi* has been recorded as Vulnerable as per Nayar and Sastry (1987–90) while *Dioscorea deltoidea* is listed in the Appendix II of CITES (2003). Additionally, the valley also harbours 23 threatened plants, which fall under various threat categories as per Conservation Assessment and Management Prioritization of selected medicinal plants in Western Himalaya (Ved et al. 2003). Of these, 35%, 35%, 22% and 8% plants were Endangered, Vulnerable, Near Threatened and Critically Endangered, respectively (Kumar et al. 2016a). Moreover, despite the presence of suitable habitats in Amrit Ganga watershed, the authors did not find any individuals of *Dactylorhiza hatagirea* from the valley. However, local inhabitants of the valley mentioned its presence in the valley, though the identity of this plant is mostly confused among locals with *Gymnadenia orchidis*.

3.4.3 Update to the flora of Nanda Devi Biosphere Reserve

The present investigation updates the existing flora of Nanda Devi Biosphere Reserve (Hajra and Balodi (1995); 801 species) with new distributional records of 183 species (Kumar et al. 2013a, 2016a).

3.4.4 New species records for the flora of Uttarakhand

The present floristic inventories has also led to discovery of *Dontostemon glandulosus, Potentilla pamirica* and *Carex sagaensis* for the first time from the state of Uttarakhand and hence are additions to the state flora (Kumar et al. 2016b; **Table 3.5**).

3.4.5 New species records for the flora of Western Himalaya

During recent botanical explorations, few interesting species such as *Anthoxanthum flexuosum* (syn. *Hierochloe flexuosa*) and *Anemone demissa* from the Upper Dhauli Valley, NDBR were recorded. After detailed scrutiny of literature and herbarium specimens, their identities were ascertained and thereby report them as additions to the flora of Western Himalaya (**Table 3.5**).

Table 3.5 Details of new records obtained from the Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

Botanical name	Habit	Family	New record for	Earlier distribution
Anthoxanthum flexuosum (Hook.f.) Veldkamp	Grass	Poaceae	Western Himalaya	Sikkim and [Nepal]
Anemone demissa Hook.f. & Thomson	Herb	Ranunculaceae	Western Himalaya	Sikkim, Arunachal Pradesh, [China, Nepal, Bhutan and Myanmar]
Carex sagaensis Y.C.Yang	Sedge	Cyperaceae	Uttarakhand	Eastern Ladakh, [China]
Dontostemon glandulosus (Kar. & Kir.) O.E.Schulz	Herb	Brassicaceae	Uttarakhand	Jammu & Kashmir and Sikkim, [China, Kazakhstan, Nepal, Russia and Tajikistan.]
Potentilla pamirica Th.Wolf	Herb	Rosaceae	Uttarakhand	Ladakh, [China, Tajikistan, SW Mongolia, Afghanistan, Iran and Pakistan.]

3.5 Discussion

The flora of Himalaya, Tibet and west China had a common origin and they radiated into distinct eco-floristic zones gradually as the Himalaya and Tibetan Plateau rose from sea level to become the highest region in the world (Kashyap 1932). A large number of Western Himalayan alpine floras in the Garhwal and Kumaon region seem to have come from Tibet, west China and adjoining north-east Asia (Rau 1975). The Upper Dhauli Valley, due to its geographical location, edge effect and intermingling of floral elements of Greater and Trans-Himalaya, shows high landscape diversity and resultant plant species diversity. The presence of 495 species of vascular plants (angiosperms, gymnosperms and pteridophytes) belonging to 267 genera and 73 families in an area of ca. 727 km^2 indicates rich floral diversity and it can be said that Upper Dhauli Valley has high species richness as compared to Nilang (441 species; 1,360 km^2) and Milam (181 species), the adjacent cold desert valleys in the state of Uttarakhand. Naithani (1984a,b) reported 1934 species of vascular plants from Chamoli, 26% of which are recorded in the UDV. Of total species recorded from NDBR, the present study area accounted 50.3% species.

During recent floristic surveys, new species or distributional record for the Western Himalaya and the state of Uttarakhand could be attributed to its extended distributional range or restrained botanical excursions in these interior valleys. The current report on presence of few individuals of these species indicates their rarity in the region. Further, floristic surveys would be required to assess the population status of these species. Additionally, current update of 189 species of vascular plants to the flora of the Nanda Devi Biosphere Reserve indicates need of such detailed inventorization in other areas of Himalaya.

In UDV, Asteraceae and Poaceae were the most diverse families and eight to nine of the ten dominant families were common to different regions of the Western Himalaya. Notably, Asteraceae, which is the most represented family in present study area, Western Ladakh (Angmo 2013), Eastern Ladakh (Dvorskey et al. 2011), Pin Valley (Sekar and Srivastava 2009), Nilang Valley (Chandola 2009), VoFNP (Kala et al. 1998) and Lahaul and Spiti (Aswal and Mehrotra 1994), ranks second in Western Himalaya (Rau 1975), fourth in Eastern Himalaya (Hara and Hohashi 1966-1974) and seventh in the Flora of British India (Hooker 1904). Orchidaceae, a prominent family in the Eastern Himalaya and the Flora of British India, ranks fourth, sixth, ninth and tenth in VoFNP, NDNP, Western Himalaya and UDV respectively.

Towards inner side of the valley such as, Satyagad (Kalazowar) and Ganesh Ganga watersheds has a similar climate as that of the Ladakh and Tibetan Plateau. Species to name a few for example, *Caragana versicolor*, *C. gerardiana*, *Cousinia thomsonii*, *Ephedra gerardiana*, *Festuca tibetica*, *Hippophae tibetana*, *Juniperus semiglobosa*, *Kraschenninikovia ceratoides*, *Melica persica* and *Rheum tibeticum* show affinities with these Trans-Himalayan regions due to increasing aridity. The mosaics of *Caragana* scrub alone and amidst *Kraschenninikovia ceratoides*, *Devendraea spinosa* and *Potentilla rigida* add a peculiar appearance to the landscape in the Geldung and Kalazowar regions. Moreover, the presence of cushioned dwarf herbs, to name a few, such as *Thylacospermum caespitosum* on east and southeast slopes near Geldung Lake (above 5000 m) and *Arenaria festucoides* and *Androsace globifera* in Kalajowar (above 4000 m) were among the typical Trans-Himalayan floral elements. However, situated adjacent to the Valley of Flowers National Park, Amrit Ganga watershed (Dhaman payar) is comparatively rich in flora due to reasonably moist conditions and has affinities of floral characteristics with the Greater Himalayan region, especially in lateral moraines, open riverine tracts and mixed herbaceous formations with species of *Rhododendron campanulatum*, *R. lepidotum*, *Cassiope fastigiata*, *Trachydium roylei*, *Potentilla*, *Anaphalis*, *Gentiana*, *Rosa*, *Sorbus*, *Primula* and *Pedicularis* to name a few. Therefore, based on the existence of phyto-elements from the Trans and Greater Himalayan regions, it can be concluded that the area has close affinities with the flora of both the regions. Hence, the Upper Dhauli Valley forms a transition zone.

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CHAPTER 4

VEGETATION STRUCTURE AND COMPOSITION

4.1 Introduction

The Indian Trans-Himalaya (ITH), located in the rain shadow zone beyond Greater Himalaya is characterized by sparse treeless vegetation, often dominated by scrub, desert steppe or mixed herbaceous formations. Owing to extensive use of these areas for livestock grazing, they are often referred as rangelands. This region is also home to a large number of threatened species of flora and fauna. It is spread across three biogeographic provinces such as, Ladakh Mountains in the north-west (1A), Tibetan plateau comprising of Eastern Ladakh, adjacent parts of Spiti, small pockets of Uttarakhand along northern frontiers (1B) and Sikkim Plateau (1C; Rodgers et al., 2000; WII, 2015; unpublished). These provinces are usually located 4000 m above mean sea level and represent characteristic ecology and biogeography. The Trans-Himalayan rangelands are least influenced by summer monsoon and characterized by low productivity, extreme climatic conditions, high diurnal fluctuation in temperatures, scanty and erratic rainfall (<50mm), heavy winds and snowfall during winter. The region is generally considered floristically impoverished as compared to adjacent high altitude areas of Greater Himalaya (Mani, 1978; Schweinfurth, 1984). These areas are quite distinct from the moist meadows of the Greater Himalaya in terms of physiognomy, plant community composition, primary productivity and patterns of seasonal use by the wild as well as domestic ungulates (Kumar et al. 2015a). The vegetation of this region has been described by various authors as *Caragana-Lonicera-Artemisia* formation (Osmaston, 1922), Alpine steppe (Schweinfurth, 1959), Dry alpine scrub (Champion and Seth, 1968) and Alpine stony deserts (Puri et al., 1989).

The ITH has a unique physical and biological setting that is markedly different from that of the adjoining areas in the Greater Himalaya. The plant species in these areas exhibit several features such as reduced leaves, stunted growth, deep tap root system and xerophytic nature. The area forms upper catchment of several rivers such as Indus, Chenab, Satluj, Jahnavi or Jad Ganga, Alaknanda, Gori Ganga, Lasser Yangti, Kutti Yangti, and Teesta. Several factors such as topography and altitude, moisture availability, anthropogenic factors and phytogeographic affinities play important role in determining the vegetation structure and plant community composition in these areas (Kumar et al. 2015a). Additionally, these areas are of considerable ecological and conservation significance which is crucial for pastoral production for the local herders as well as other ecosystem functions.

4.2 Review of Literature

4.2.1 Vegetation structure and composition in ITH

Most of the published studies on the plant community structure and composition pertaining to the ITH are from the Ladakh Mountains, North-West Himalaya. Dvorsky et al. (2011) identified eight distinct vegetation types and found scree as well as alpine grasslands as the most species-rich and reported altitude, soil moisture and salinity as the most important environmental factors influencing the species composition in Eastern Ladakh. In Ladakh, Rawat (2008) identified eight special habitats, such as moist meadows, marsh meadows, craggy rock surfaces, scree bases, scrub steppe and sub-nival zones and remnant woodlands which harbour unique plant assemblages including some rare and threatened plants, such as *Colchicum luteum, Inula rhizocephala, Saussurea medusa, Allium przewalskianum* and *Arnebia euchroma.* In a comprehensive effort covering Trans-Himalayan region of North-West and Western Himalaya, Rawat (2007) identified eleven major vegetation communities, of which *Lonicera spinosa-Caragana versicolor-Oryzopsis lateralis* and *Thalictrum alpinum-Saussurea gnaphaloides-Trisetum aenium* showed highest diversity (H'=2.27 and H'=2.37, respectively) and lowest (H'=1.12) by *Phragmites australis-Lycium ruthenicum* community. Rawat and Adhikari (2005) reported *Stipa-Alyssum-Oxytropis* and *Caragana-Poa* as the most extensive communities with respect to the aerial coverage among 16 plant communities observed in Tso-Kar Basin of Changthang Plateau, Eastern Ladakh. Kala and Mathur (2002) identified six communities in western Ladakh, such as *Ephedra-Artemisia, Poa annua-Ranunculus hirtellus-Pedicularis oederi, Caragana brevifolia-Cotoneaster, Hippophae rahmnoides-Myricaria germanica, Artemisia-Salsola collina-Krascheninnikovia ceratoides* and *Agropyron-Trisetum-Oryzopsis-Carex.* In Nubra valley of Ladakh, Joshi et al. (2006) reported that herbaceous meadows on the gentle slopes had higher species diversity (H'=2.29) followed by fell fields (H'=2.08) and least diversity was observed on scree slopes and on lower eroded slopes (H'=0.68). The study also revealed that nearly 78-80% of plant species are restricted to the valley bottoms.

Of the 14 forest communities recorded from Lahaul valley by Singh and Samant (2010), tree density was found maximum for *Hippophae salicifolia* community (1850 individuals ha^{-1}), followed by *Fraxinus xanthoxyloides* (1000), *Juglans regia-Ulmus wallichiana-Acer* *acuminatum* mixed (760), *Abies pindrow-Pinus wallichiana* mixed (640), *Juniperus polycarpos-Cedrus deodara* mixed (600) while *Cedrus deodara-Acer cappadocicum* mixed community had lowest density (171). Further, these authors have prioritized 15 habitats and 14 forest communities distributed between 2490-4000 m in the Lahaul Valley, Cold Desert Biosphere Reserve for conservation. Jishtu and Goraya (2008) identified six unique habitats, such as moist meadows, Juniper woodland and sub-alpine scrub, alpine dry scrub, alpine mixed communities and riverine scrub with respect to taxa of high conservation significance in cold deserts of Lahaul and Spiti Valley and part of Pooh sub-division in Kinnaur, Himachal Pradesh.

In Niti and Nilang valleys of Uttarakhand state, the dry and undulating slopes in interior areas exhibit characteristic scrub steppe dominated by *Caragana versicolor, Devendraea spinosa* and *Potentilla rigida* and at places by *Krascheninnikovia ceratoides*. The unstable scree slopes harbour a distinct community characterized by *Aconogonum tortuosum, Eriophyton rhomboideum, Cicer microphyllum* and *Cousinia thomsonii,* to name a few (Chandola et al. 2008; Kumar and Mitra 2015).

In alpine meadows of north Sikkim, Tambe and Rawat (2008) reported the dominance of sedges namely *Kobresia nepalensis* on smooth slopes, *Kobresia duthiei* on broken slopes and *Kobresia pygmaea* and *Kobresia schoenoides* in dry meadows. Based on numerical classification, the study also identified 11 vegetation types in the alpine landscape namely,'*krummholz*' thicket, Juniper scrub, *Rhododendron* scrub, morainic scrub, *Salix sikkimensis* riverine thicket, *Myricaria rosea* riverine scrub, *Kobresia nepalensis* moist meadow, *Kobresia duthiei* moist meadow, *Kobresia pygmaea* moist meadow, *Deschampsia caespitosa* marsh meadow and *Anaphalis xylorhiza* dry meadow. The details on the various landforms and landscape units described by various workers in the ITH are given in **Table 4.1**.

Table 4.1 A comparative account of landforms and landscape units defined by various authors in the Indian Trans-Himalaya.

Landform or landscape unit	J&K					HP		UK		SK	WH
	Angmo (2013)	Dvorsky (2011)	Joshi et al. (2006)	Rawat and Adhikari (2005)	Kala and Mathur (2002)	Singh and Samant (2010)	Sekar (2009)	Kumar and Mitra (2015)	Chandola (2009)	Tambe (2007)	Rawat (2007)
	Westen Ladakh	Eastern Ladakh	Nubra Valley	Tso Kar	Ladakh	Lahul Valley	Pin Valley NP	Niti Valley	Nilang Valley	Khangchendzonga NP	Western Himalaya
Agricultural fallow									√		
Alpine dry scrub											√
Alpine meadow/Herbaceous meadow	√		√				√	√		√	
Alpine grassland/Grassland		√				√					
Animal resting/Camping site/Livestock camping area		√				√		√			
Avalanche trap									√		
Bouldary slope/Bouldary	√	√				√		√			
Crags and ridges//Ridge line					√				√		
Degraded						√					
Dry						√					
Dry scrub on eroded slope/Eroded slope			√						√		
Dry scrub on the plateau			√								
Embeded rocky/Rocky outcrop								√	√		
Fell-fields			√	√							√
Field margin	√										
Forest/Forested area/Plantations			√			√		√			

Gentle slope									√		
Marsh meadow/Marshy	√		√	√		√					
Mesic localities											√
Moist meadows				√							
Moraine/Moraine scrub	√				√			√	√	√	
Narrow gorges					√						
Near settlements						√					
Parasitic						√					
Plateau/Table lands	√				√						
Riverbeds/Riverine scrub/Riverine/River bed			√		√	√		√	√	√	√
Road side						√					
Rocks and cliff/Rocky	√					√					
Salt marshes		√									
Sandy plains				√							
Scree/Scree slope	√	√			√			√	√		
Scrub on alluvial fans/Alluvial fan			√						√		
Scrublands		√									
Semi-deserts and steppes/Alpine scrub/Scrub steppe		√		√			√	√		√	√
Shady moist						√					
Shrubberies						√					
Stabilized debris								√			
Stable slope	√										
Steep slope									√		
Stream courses/Water courses				√		√			√		
Subnival zone		√									
Undulating land areas/Undulating land mass					√				√		
Water bodies/Wetlands		√			√				√		

Abbreviations used: J&K: Jammu and Kashmir, H.P: Himachal Pradesh, UK: Uttarakhand, SK: Sikkim, WH: Western Himalaya, NP: National Park.

4.2.2 Vegetation structure and composition in Nanda Devi Biosphere Reserve

A number of studies on different aspects of vegetation have been conducted in Nanda Devi Biosphere Reserve (NDBR), such as Singh (1992) found that the proportion of foliage in total net primary productivity was higher in kharsu oak forest compared to silver fir, deciduous and low-rhododendron forests in Pindar catchment, a buffer zone of NDBR. Naithani et al. (1992) suggested that ban on grazing in the VoFNP has led to overdominance of fast growing and taller species resulting in the suppression of a number of less aggressive species. Rastogi (1993) studied the conservation status of forests in Peng, Tolma, Phagti and Dunagiri village. Adhikari et al. (1995a) recorded total vegetation biomass of 593 t ha^{-1} in kharsu oak forests followed by 566 t ha^{-1} in silver fir and 505 t ha^{-1} horse chestnut forests in the Pindar catchment. Of the total nutrients recorded in the system, soil, litter and vegetation, respectively accounted 66.5, 0.6 and 33% in horse chestnut, 61.4, 0.8 and 37.85 in silver fir and 58.1, 0.8 and 41.1% in kharsu oak forests (Adhikari et al. 1995b). Singh et al. (1996) identified seven major tree communities and found that the total basal area at timberline was about one-seventh of the maximum basal area in silver fir forest in the Pindar catchment. The study also reported that the β-diversity was greater (8.13) in forests between elevational range of 2300-3300 m as compared to low elevation forests (4.21) and the forest biomass of Low-*Rhododendron* community was found to have low (41 t ha^{-1}) while it was higher in Kharsu oak forest (593 t ha^{-1}). Negi and Gadgil (1996) recorded highest lichen species diversity between 2700-3700 m. Kala (1998) and Kala et al. (1998) identified 24 plant communities, of which highest number (10) of communities were found in lower alpine zone while 7 each in subalpine and higher alpine zones. Kala (1999) studied the phenology of 95 flowering plant species in VoFNP and found that the vegetative phase peaked between June to August.

Based on visual interpretation of thematic mapper and satellite imagery, Bisht (2000) showed that the forest cover has increased for the period of 1988-96 in NDBR. Negi (2000) revealed that the microhabitats (rock, soil and wood), rather than altitude, seem to govern the local patterns of abundance and richness of the moss communities. Negi (2001) gave a detailed account on the community ecology of lichens and mosses. Purohit et al. (2001) found that the growth and survival of *Taxus baccata* declined significantly when the bark was removed beyond a limit of average bark thickness (0.43cm). Nautiyal et al. (2001b) found that habitat of bushes/thorny bushes are expanding in strictly protected sites in comparison to the buffer zone and all pastures. The rate of change in vegetation dynamics is very rapid and indicates a threat to the diversity. Negi (2002) found highest composite conservation value of macrolichens in alpine meadows of NDBR. Kala et al. (2002) compared the effects of sheep and goat grazing on the species diversity in the alpine meadows of GHNP and VoFNP and found that the areas in VoFNP devoid of domestic livestock grazing had higher species diversity. As per Kala (1998), forest gaps were most diverse (H'=3.23), followed by lower slopes (H'=2.81), tree-line (H'=2.68), valley bottom (H'=2.56), plateau (H' =2.52) and sub-alpine meadows (H'= 2.47) in the Valley of Flowers National Park. However, the scrubby slopes (H' =1.48) and stony deserts (H' =1.88) at higher altitudes were the poorest in species diversity. The species richness was highest in forest gaps (67) followed by valley bottom (62) and river beds (50). Stony deserts (19) and scrubby slopes (12) were the poorest in species richness. Samant et al. (2005) identified 12 habitat types of pteridophytes in NDBR and found highest species richness in rocks/boulders/walls while highest species diversity in forests. Singh and Rai (2004) highlighted the significance of grazing pressure in the management of alpine meadows of NDBR. Adhikari (2004) and Silori (2004) suggested that the ban on adventure tourism in NDBR would significantly improve the forest cover and density. Kala and Srivastava (2004); Kala, (2004b) studied Himalayan knotweed (*Polygonum polystachyum*) distribution to clarify its ecological role in the Himalayan alpine meadows and found that eradication of Himalayan knotweed provides open space for balsam to thrive instead of assisting biodiversity conservation and concluded that knotweed is a successional species and its increase after cessation of pastoral grazing does not threaten native biodiversity. Joshi and Samant (2004) identified 13 forest communities and 5 habitats (dry, moist, bouldery, degraded and riverine) in Lata-Tolma-Phagti, the buffer zone of the reserve and found that *Pinus wallichiana* community had highest conservation value as well as highest economic importance. Samant and Joshi (2005) studied altitudinal distribution and habitat diversity identifying 13 habitats in NDNP and compared these with that of VoFNP and Great Himalayan National Park. Joshi et al. (2008) studied change in the lichen flora of Pindari Glacier Valley during the last three decades. The study on current status of threatened species in relation toanthropogenic pressures in Upper Pindar catchment of Nanda Devi Biosphere Reserve was carried out by Kandpal (2010). Kala (2010) revealed that effect of migratory livestock grazing is species-specific and the species diversity of natural herbaceous communities does not depend on livestock grazing in the VoFNP. Rawat et al. (2010) studied the habitat characteristics and ecological status of *Paeonia emodi* in Pindari region and found it to be present in only 3 of 14 possible habitats predicting that it is on the edge of threat status. Joshi et al. (2011b) observed that the corticolous lichen dominates (~90%) in temperate and temperate-alpine transition and saxicolous lichens dominate (98%) in the alpine zone of Pindari Glacier Valley. Based on remote sensing analysis of Landsat MSS and TM images, Bharti et al. (2011) have concluded that there has been no geographical shift in the timberline, while the subalpine forest's canopy has increased substantially. Kandari et al. (2011) examined the distribution pattern of four rhizomatous medicinal and aromatic plant species (MAPs), such as *Angelica glauca*, *Pleurospermum angelicoides*, *Rheum emodi* and *Arnebia benthamii* in the Dhauli Ganga catchment and found them to be contagiously distributed. Furthermore, these authors have reported an increase in subalpine forest and most of the changes were associated with forests at lower elevation as compared to timberline. Majumdar and Adhikari (2012) studied eight vegetation communities and their diversity patterns in Chenab valley, the buffer zone of NDBR. Rajwar and Kumar (2011) stated that maximum number of trees (29 and 31% for Lata and Dunagiri villages, respectively) belonged to disturbance class 1 (1–20% lopping) followed by the class 2 (20–40%). Tiwari and Joshi (2013) found higher moisture holding capacity of litter in composite leaf litter (19.73%) and lowest in the *Cedrus* leaf litter (8.20%). Mitra et al. (2013) studied transhumant pastoralism in the Niti Valley and found that stopovers experience maximum anthropogenic pressure during livestock migrations adversely affecting vegetation. Rawat et al. (2014) analysed the forest vegetation of Pindari-Sunderdhunga-Kafni for structure, composition and development of future compositional patterns and found that they exhibited progressive structures suggesting long term persistence of the communities or species. Rawat and Upreti (2014) revealed that lower altitudes (<3000 m) having anthropogenic pressure had less lichen biomass than the localities situated in undisturbed higher temperate and alpine regions (>3000 m). Rawat (2013) and Rawat et al. (2015a) found mixed Silver fir-*Rhododendron*-Maple community in Pindari-Sunderdhunga-Kafni and *Taxus wallichana*- *Abies pindrow* mixed community in Lata-Tolma-Phagti across 60 sites that supports maximum richness and density of native and endemic species.

The studies on plant community structure and composition reflect the ecosystem properties and ecological conditions of an area, which form the bases for further scientific research and management of an area (Lindenmayer and Franklin 1997). The constituent elements of vegetation such as plant species and their assemblages also form the component of the biodiversity of a region that depends on various factors such as elevation, aspect, soil, geology, topography, orography and anthropogenic pressures. This chapter deals with the second objective, 'to assess the plant community structure and composition in various landforms' so as to address 'What is the distribution pattern of species with respect to landforms?'. It gives an elaborative account on the structural attributes such as vegetation structure, plant community composition and other phyto-sociological characteristics along with soil chemical properties across major landforms and physiognomic units in three major watersheds (Amrit Ganga, Satyagad and Ganesh Ganga) of Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

4.3 Methodology

4.3.1 Sampling design and data collection

The present study is based on the extensive survey of various landscape features, landforms and physiognomic units. The reconnaissance survey in the entire valley was conducted in the year 2011. The field work comprised of floristic survey, systematic collection and record of plant specimens, vegetation quantification and collection of soil samples. The area was surveyed extensively for aforesaid field activities throughout the growing season during the years 2012, 2014 and 2015. The valley was traversed on foot to cover various landscape features such as ridges, bouldary areas, along streams, exposed and un-exposed sites. The habitats which are characterized by their geo-morphological or physical attributes such as elevation, slope, orientation, stratification, rock exposure, and soil type are referred as a 'landform', for example moraine, scree, river bed, table land, plateau, gorge and ridge. Subsequently, the habitats which are characterized and defined by their vegetation, such as herbaceous meadow, scrub steppe, scrublands, alpine grassland, alpine dry scrub, alpine meadow and riverine scrub are referred as a 'physiognomic unit', sometimes also referred as a landscape unit. Based on reconnaissance survey in the current study, three major landforms, such as moraine, scree and river bed and four major physiognomic units, such as herbaceous meadow, scrub steppe, livestock camping site and tussock formation were identified and selected for extensive floristic surveys and vegetation sampling **(Table 4.2-4.3)**.

Table 4.2 Classification and characteristics of major landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya.

Landform	Characteristic features
Moraine	Any glacially formed accumulation of unconsolidated glacial debris (soil and rock). These landforms are consisted of weathered rocks with a high proportion of stones bigger than >20 cm in diameter.
River bed	Essentially river banks and valley bottoms characterized by deposition of sand and sand stones.
Scree	Steep slopes with unstable substrate accumulation of broken rock fragments at the base of mountain cliffs, crags or valley shoulders. Landforms associated with these materials are sometimes called as 'Scree slopes'.

Table 4.3 Classification and characteristics of major physiognomic units in Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya.

Physiognomic unit	Characteristic features
Habitats characterized and defined by their vegetation	
Herbaceous meadow	Areas characterized by presence of relatively dense herbaceous formations because of high moisture and nutrient availability due to snow or glacial seepages. These formations are favourite grazing grounds for wild as well as domestic animals.
Scrub steppe	The areas comprising of pure or associations of scattered scrub vegetation such as *Caragana* spp., *Krascheninnikovia ceratoides*, *Juniperus* spp., *Lonicera* spp., *Ephedra* sp., and *Potentilla rigida* that are especially adapted to withstand harsh and dry climatic conditions as well as heavy browsing pressure. Landforms associated with these materials are also reffered as 'scrublands'.
Tussock formation	The areas comprising of tussock and bunch grasses that usually grow as singular plants in clumps, tufts, hummocks or bunch in meadows, grasslands and prairies.
Habitats characterized and defined by the human or livestock interference	
Livestock camping site	Camping sites, also known as 'animal resting places' used by the shepherds or pastoralists.

Selection of a particular landform or physiognomic unit to be sampled was decided as per the accessibility and extent of the area available. A minimum area of one hectare was considered as one landform or physiognomic unit, whereas it was >2500m^2 area for livestock camping site. The data was collected following standard vegetation sampling methods such as Misra (1968), Mueller-Dombois and Ellenberg (1974), Kent and Coker (1992), Korner (2003), Rawat and Adhikari (2005). Using stratified random sampling method, one 50m×50m plot was selected for sampling for the areas dominated by scrub vegetation, grasses and herbs. In order to uniformly sample the selected area within each plot, 10, 5m×5m quadrats were laid for shrubs and 25, 1m×1m quadrats were laid for herbs and grasses (ground layer).

In each sampling site, the information on the habitat parameters, such as elevation, geographic coordinates (latitude and longitude), slope (degree), aspect (0-359°), habit, habitat characteristics, vegetation cover (%) and total number of species was recorded. The specimens were collected and recorded systematically following Jain and Rao (1976) and submitted at the WII herbarium. The plant specimens were identified with the aid of existing florula and literature (Naithani 1984a, 1984b; Hajra and Balodi 1995; Chandola 2009; Pusalkar and Singh (2012). The unidentified specimens were cross-checked with authentic specimens housed in herbaria (BSD, DD and WII). The rare and threatened plants which were easily identified in the field were only photographed. For nutrient analysis, a composite soil sample was made out of the four soil samples taken down to 20cm (0-20cm) from each site. In order to study the relationship between vegetation and environmental variables following parameters were recorded and assessed: elevation through Global Positioning System (GPS; Garmin etrex 12); inclination of slope (degree) and aspect through compass cum clinometer; rock cover (total rock or boulders percentage in the site through visual observation), soil temperature through soil thermometer, soil pH was measured with the help of pH meter and soil moisture using hot air oven.

4.3.2 Data analysis

4.3.2.1 Species diversity, richness and evenness

Species diversity and richness was computed using EstimateS (Colwell, 2013) for Shannon diversity index (Magurran, 2004), Fisher's α diversity index (Magurran, 2004) and Chao 1 richness estimator (Chao, 1984), respectively. To estimate the number of additional species that will be discovered with further effort, species discovery curves were prepared following Chao and Shen (2004). To assess, how evenly the species are distributed, evenness (equability index) was calculated using the Pielou's (1966) equation. The value ranges between 0 and 1. If the evenness value is higher, the variation in habitats between the species would be less and *vice-versa*.

4.3.2.2 Vegetation structure and plant community composition

The structural aspects of vegetation were quantitatively analyzed for density, frequency and abundance based on Curtis and Mclntosh (1950) Misra (1968) and Muller-Dombois and Ellenberg (1974). The ratio of abundance to frequency (A/F) for different species was determined by eliciting the distribution pattern, such as regular (<0.025), random (0.025–0.05) and contiguous (>0.05) distribution (Curtis and Cotton, 1956). Two way indicator species analysis (TWINSPAN in PC-ORD, version 4.34 software) following Hill (1979) was done for plant community classification.

4.3.2.3 Similarity among different landforms and physiognomic units

The Classic Sørensen's Index (Sørensen 1948, Magurran 2004) was used to compute similarity among various habitats. Any quantitative phyto-sociological character is taken into consideration to determine this index. In this analysis similarity between different habitats was calculated based on richness of the species using formula:

$$S = \frac{2c}{a + b}$$

Where, S = Similarity

c = Total number of species common in both the habitats

a = Total number of species in habitat 'a'

b = Total number of species in habitat 'b'

4.3.2.4 Environmental variables

4.3.2.4.1 Inter-relationship between environmental variables

Principal Component Analysis (PCA, Jolliffe 2002) was used for the multivariate data analysis and for the estimation of correlation structure of the variables and inter-relationship among them. It also shows the influence of exploratory variable on the objects (sampling plots or sites). PCA was performed using software R (version 3.2.4). Interpretation was done based on importance and loadings of principal components and biplot. The graphic interpretation of biplot gives a clear frame to understand the influence of variables on the species, sites and interrelationship among the exploratory variables.

4.3.2.4.2 Relationship between vegetation and environmental variables

In order to evaluate the relationships between vegetation and environmental variables, a Canonical Correspondence Analysis (CCA) was performed using XLSTAT (version 2015). CCA is a direct gradient ordination technique to cluster species abundance with environmental variables (ter Braak 1986). As required by CCA, the data is set into two distinct matrices: the species matrix and the matrix of environmental variables. Interpretation was done based on the weighted average of the variables and loading of the component on primary and secondary axes. The graphic interpretation of biplot gives a clear frame to understand the distribution of the species with respect to different independent environmental variables.

4.3.2.5 Soil nutrient analysis

Nutrient concentration in the soil was estimated following well established methods. Total Nitrogen (N) was estimated using Kjeltec-2300 following Micro-Kjeldahl application of Peach and Tracey (1956) and Mishra (1968). Phosphorus (P) was determined by UV Spectrophotometer and exchangeable Potassium (K) by Flame Photometer after proper digestion of the samples. Organic Carbon (OC) in the soil was estimated by titration method.

4.4 Results and Discussion

4.4.1 Sampling sites and adequacy

A total of 84 sites comprising of 2100 plots (1m×1m) for herbs and 64 sites (640 plots; 5m×5 m) for shrubs were laid in three landforms (33 sites) and four physiognomic units (52 sites) across different watersheds, namely Amrit Ganga, Satyagad and Ganesh Ganga (**Table 4.4-4.5**).

Table 4.4 Total number of sampling sites selected across different landforms.

Landform	Watershed						
	Amrit Ganga		Satyagad		Ganesh Ganga		Total
	Herb	Shrub	Herb	Shrub	Herb	Shrub	(33)
Moraine	10	9	-	-	5	4	15
River bed	3	3	-	-	1	1	04
Scree	-	-	6	5	8	8	14

Table 4.5 Total number of sampling sites selected across different physiognomic units.

Physiognomic unit	Watershed						
	Amrit Ganga		Satyagad		Ganesh Ganga		Total
	Herb	Shrub	Herb	Shrub	Herb	Shrub	(51)
Herbaceous meadow	3	-	2	-	4	-	09
Scrub steppe	6	6	4	4	21	21	31
Livestock camping site	5	3	2	-	2	-	09
Tussock formation	2	-	-	-	-	-	02

The relationship between the area of a habitat and the number of species found within that area was predicted through Coleman rarefaction curves (Coleman, 1981) using EstimateS (Colwell, 2013). **Figure 4.1** shows the species-area curves separately for herbs and shrubs sampling in each watershed.

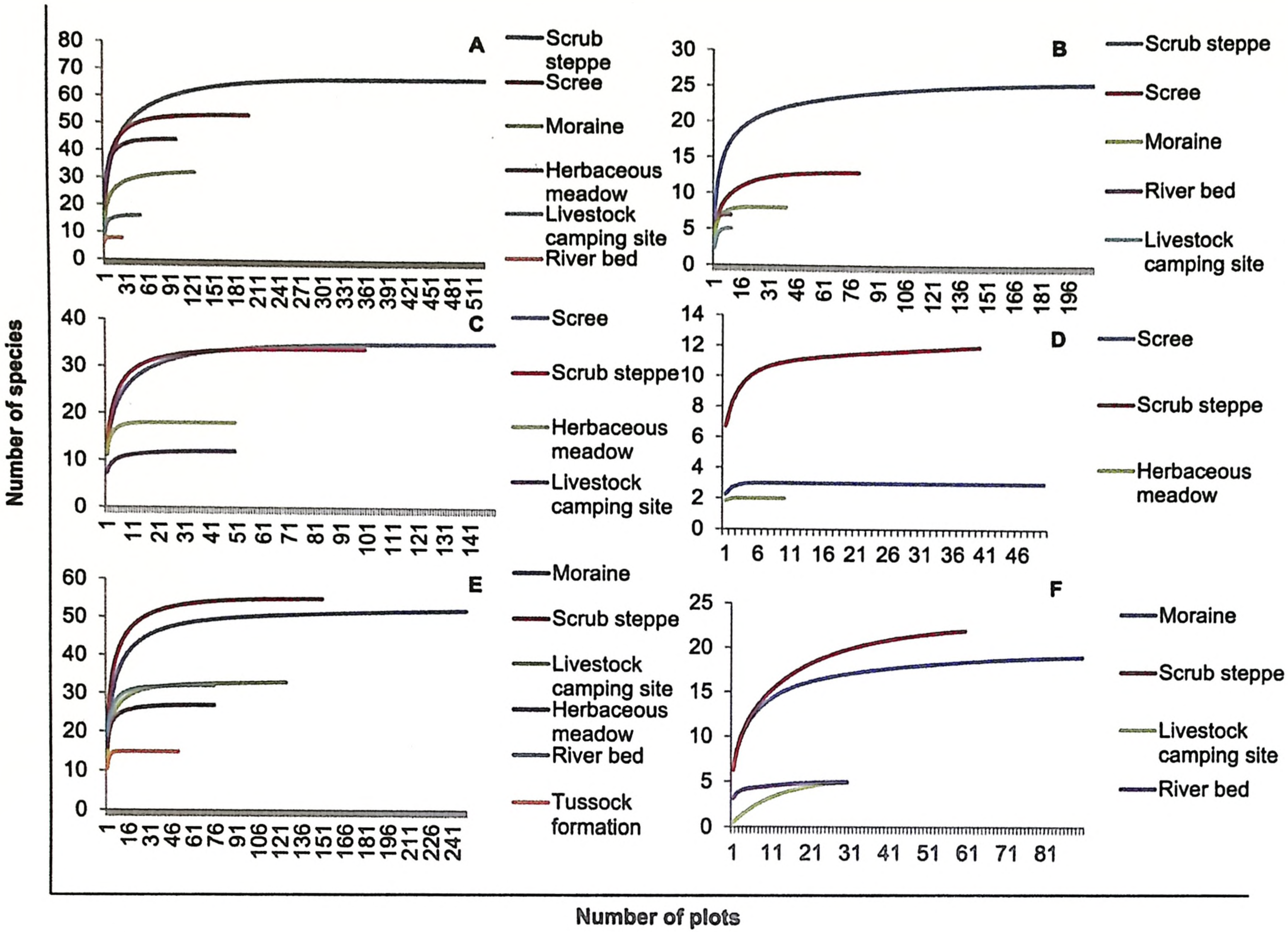

Figure 4.1 Species-area curves: A-herbs and B-shrubs in Ganesh Ganga; C-herbs and D-shrubs in Satyagad; E-herbs and F-shrubs in Amrit Ganga.

4.4.2 Species richness across landforms and physiognomic units in the valley

Moraine and scrub steppe were most frequent habitats in the entire valley. The species richness was 99 in moraines followed by scrub steppe (97), scree (88), herbaceous meadow (76) livestock camping site (52) and river bed (44; **Figure 4.2**). Moraines being a dynamic landform support higher species richness due to presence of multiple micro-habitats. The micro-habitats in these landforms are resultant of continuous process of glaciations and stabilization of the debris over the period with several successional stages. Moreover, high species diversity and richness in moraines is directly proportional to land area, the larger an area, more species it can support, which results in larger populations. Scrub steppes, which are found in comparatively stable slopes along with rich soil nutrients, might contribute to its rich diversity. Species richness among various landforms with respect to herb species was 74 species in scree slopes, herbaceous meadow (72), moraines (71), scrub steppe (69) and livestock camping site (44; **Figure 4.2**). Shrubs species richness was recorded with 28 species each in scrub steppe and moraines followed by scree slopes (14; **Figure 4.2**). The species discovery curve for herbs and shrubs, respectively across the major landforms and physiognomic units for seven sampling sites are shown in **Figures 4.3** and **4.4**.

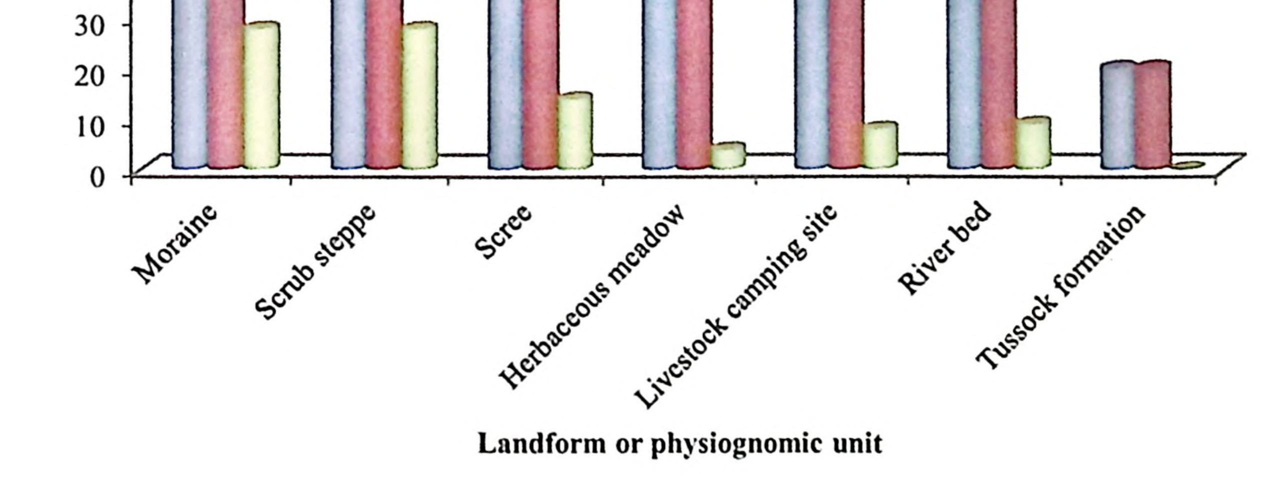

Figure 4.2 Species richness across various landforms and physiognomic units in the valley.

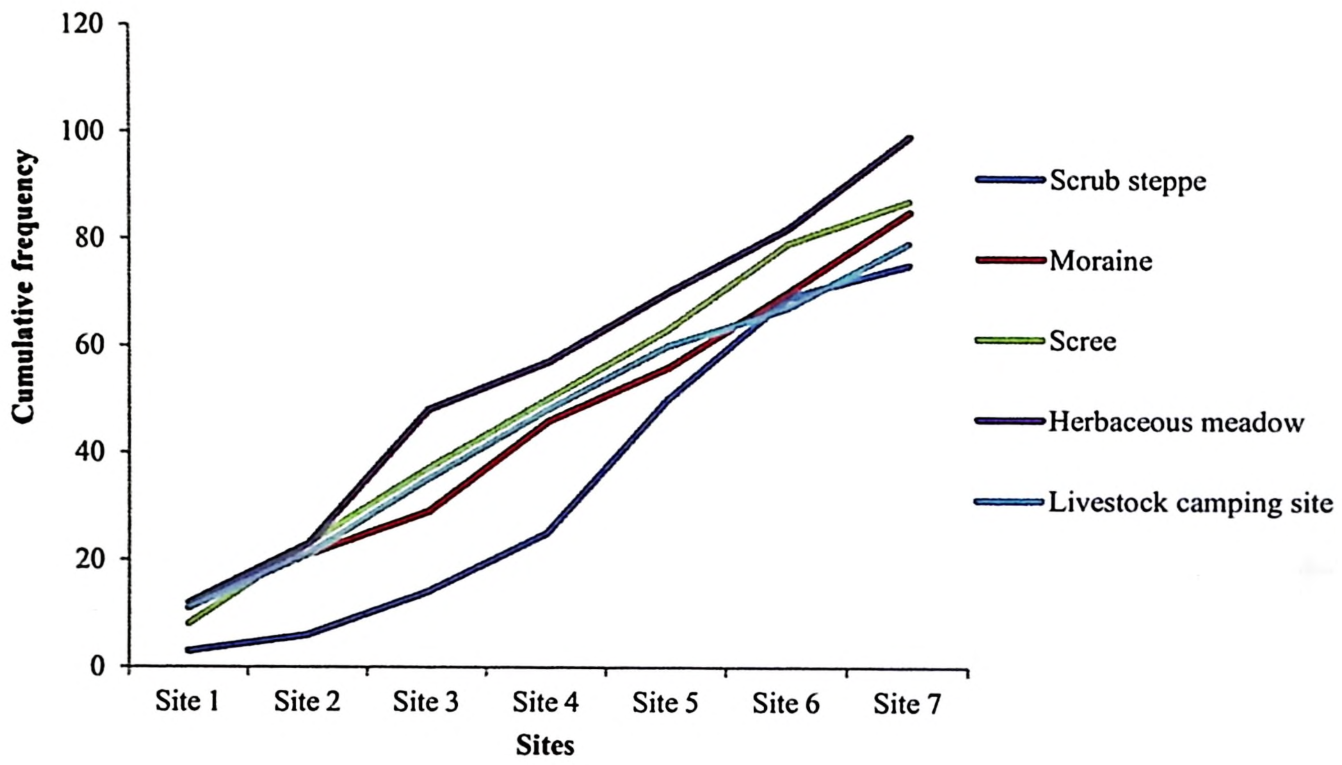

Figure 4.3 Species discovery curve for herbs across major landforms.

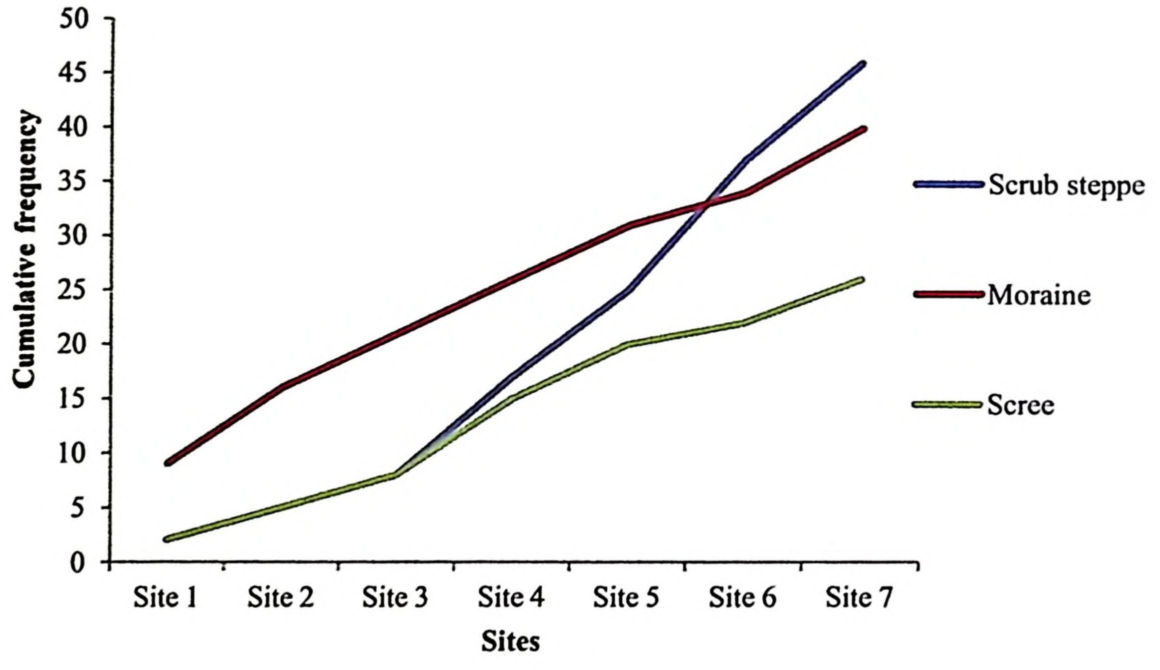

Figure 4.4 Species discovery curve for shrubs across major landforms.

4.4.3 Species diversity, richness and evenness across three watersheds in the valley

Species diversity, richness and evenness were calculated separately for herbs and shrubs across different landforms and physiognomic units in three watersheds (**Figure 4.5** and **Table 4.6**).

Fisher's diversity index (α) varied from 1.3 to 9.4 for herbs and 0.2 to 3.7 for shrubs. For herbs, α diversity was recorded 9.4 for scrub steppe in Ganesh Ganga followed by scrub steppe (α=8.5) in Amrit Ganga and scree (α=8.3) in Ganesh Ganga. The diversity values were recorded lower in case of river bed (α=1.3) of Ganesh Ganga and livestock camping site (α=1.8) in Satyagad. For shrubs, α diversity was recorded 3.7 for scrub steppe in Amrit Ganga followed by scrub steppe (α=3.5) in Ganesh Ganga and livestock camping site (α=2.7) in Amrit Ganga. The diversity values were recorded lower in case of herbaceous meadow (α=0.2) in Ganesh Ganga and scree and herbaceous meaow of Satyagad (α=0.4). The highest diversity in scrub steppe appears to be due to edge effect and intermingling of forest and meadow species. The lower diversity in river bed and livestock camping sites are due to high livestock pressure resulting into prevalence of homogenized species such as *Rumex nepalensis*, *Polygonum* spp. and *Impatiens* spp.

The total number of species reported during the growing season in different landforms varied from 12 to 92. The species richness was recorded 92 species in scrub steppe of Ganesh Ganga followed by scrub steppe (77) and moraine (71) of Amrit Ganga. In Satyagad, highest richness (46) was recorded in scrub steppe. The richness was recorded lower in livestock camping site of Satyagad with 12 species, river bed in Ganesh Ganga (15) and 20 species each in tussock formation of Amrit Ganga and herbaceous meadow (Satyagad). Among various landforms and physiognomic units, species richness was highest in scrub steppe (46-92) while, lowest in livestock camping site (12-38). Higher species diversity and richness in scrub steppe and moraine could also be relative to land area, the larger an area is, the more species it can support, which results in larger populations. However, due to contagious distribution of individuals for example, *Rumex nepalensis* and *Polygonum plebeium* in livestock camping sites; bunch grass which usually grow as singular plants in clumps or tufts (*Danthonia cachemyriana*) in tussock formation and *Carex* spp., *Kobresia* spp. in riverbed doesn't tag on the aforesaid statement.

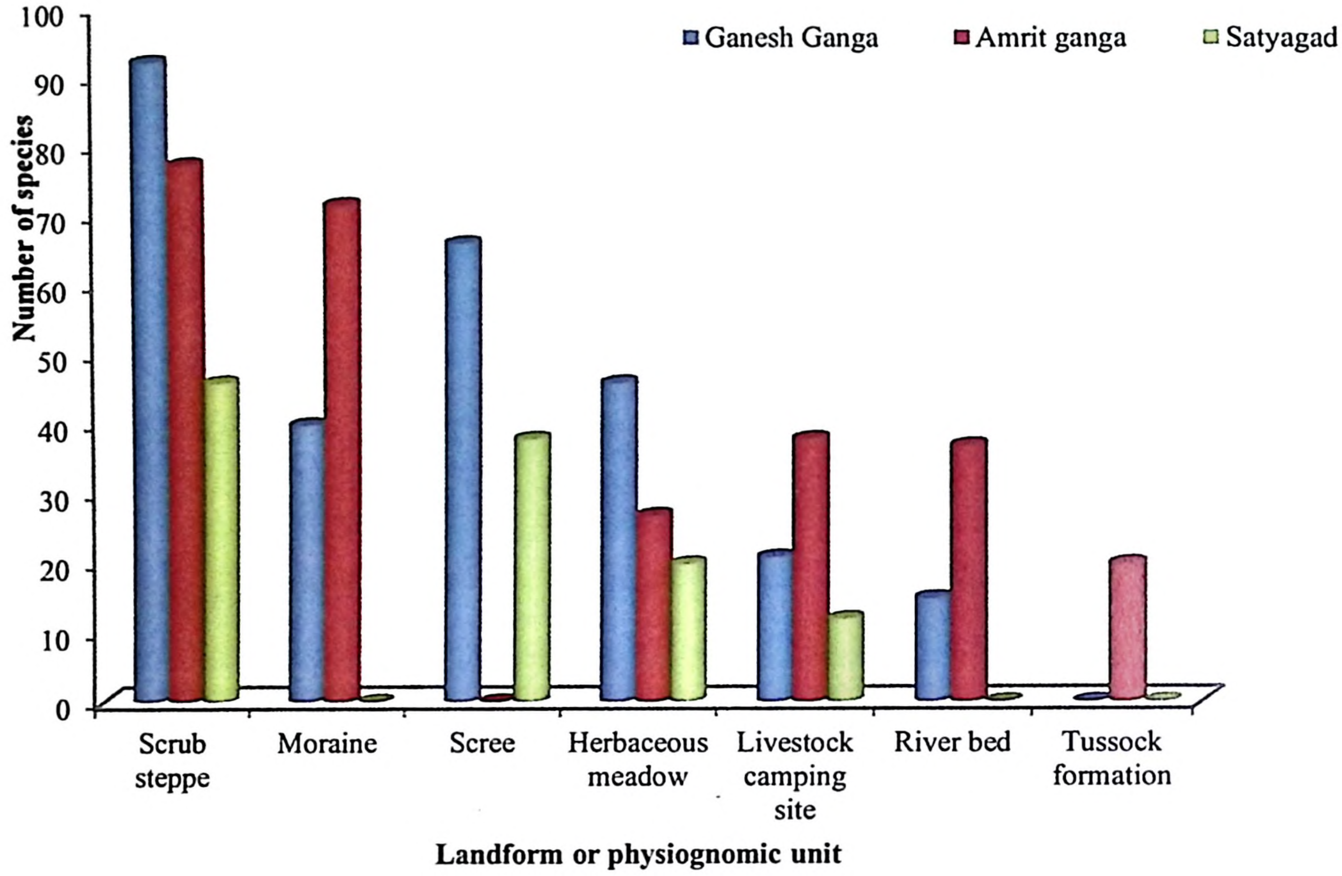

Figure 4.5 Species richness across landforms or physiognomic units in different watersheds.

Evenness (E) varied from 0.2 to 0.8 for herbs and 0.3 to 0.9 for shrubs. For herbs, E was recorded 0.8 each in tussock formation and river bed of Amrit Ganga and herbaceous meadow of Satyagad. In Ganesh Ganga evenness varied from 0.2 to 0.7, whereas in Satyagad (E=0.7-0.8) and Amrit Ganga (E=0.6-0.8). Equability in tussock formation, river bed and herbaceous meadow was higher mainly due to contagious distribution of the individuals. Unstable river course in river bed of Ganesh Ganga, might be a cause of lower evenness (E=0.2).

Table 4.6 Richness, evenness and diversity indices in three different watersheds.

Landform or physiognomic unit	Watershed	Richness			Evenness		α diversity	
		H	S	T	H	S	H	S
Moraine	Ganesh Ganga	32	8	40	0.6	0.7	4.6	1.4
	Satyagad	-	-	-	-	-	-	-
	Amrit Ganga	52	19	71	0.6	0.4	7.0	2.7
River bed	Ganesh Ganga	8	7	15	0.2	0.7	1.3	1.2
	Satyagad	-	-	-	-	-	-	-
	Amrit Ganga	32	5	37	0.8	0.6	4.5	0.8
Scree	Ganesh Ganga	53	13	66	0.7	0.4	8.3	2.0
	Satyagad	35	3	38	0.7	0.3	5.3	0.4
	Amrit Ganga	-	-	-	-	-	-	-
Herbaceous meadow	Ganesh Ganga	44	2	46	0.7	0.3	6.4	0.2
	Satyagad	18	2	20	0.8	0.8	2.8	0.4
	Amrit Ganga	27	-	27	0.6	-	3.4	-
Livestock camping site	Ganesh Ganga	16	5	21	0.5	0.7	2.1	1.7
	Satyagad	12	-	12	0.7	-	1.8	-
	Amrit Ganga	33	5	38	0.7	0.9	4.5	2.7
Scrub steppe	Ganesh Ganga	67	25	92	0.7	0.6	9.4	3.5
	Satyagad	34	12	46	0.7	0.7	5.3	2.0
	Amrit Ganga	55	22	77	0.7	0.5	8.5	3.7
Tussock formation	Ganesh Ganga	-	-	-	-	-	-	-
	Satyagad	-	-	-	-	-	-	-
	Amrit Ganga	20	-	20	0.8	-	2.3	-

Abbreviations: H=herb, S=shrub, T=total.

4.4.4 Vegetation structure and plant community composition across various landforms

Compared to Ganesh Ganga and Satyagad watersheds, Amrit Ganga watershed is comparatively moist and has affinities of floral characteristics with Greater Himalayan region, especially in moraine and river bed. Presence of tussocks of *Danthonia cachemyriana* towards Sagar glacier (4000-4400 m) and mixed herbaceous formations at Dhaman Payar (3800 m) compliments the aforesaid statement. Approximately, 70% of the area is comprised under moraine (fairly moist) and river bed (10%). Of identified major landforms (moraine, river bed and scree), scree slopes are reasonably absent in Amrit Ganga watershed. The characteristic species in this watershed were comprised of *Cassiope fastigiata, Rhododendron campanulatum, Gaultheria trichophylla, Juniperus indica, J. communis, Myricaria rosea, Potentilla cuneifolia, P. argyrophylla, Trachydium roylei, Thalictrum alpinum, Sibbaldia parviflora, Anaphalis royleana, Euphrasia himalayica* and *Bistorta affinis*.

In Satyagad watershed, due to comparatively narrow and dry and rugged terrain, the moraine and river bed were reasonably absent. Scree slopes alone contribute approximately 60% of the total area of this watershed. *Caragana gerardiana, Astragalus candolleanus, Juniperus* spp., *Devendraea spinosa* towards Sailsala (3800 m), *Arenaria festucoides, Corydalis nana* and *Androsace globifera* in Kalajowar (4200-4500 m) represents some of the characteristic Trans-Himalayan floral elements. In scree slopes, *Potentilla cuneifolia, Bistorta affinis, Geranium wallichianum, Thymus linearis, Leontopodium brachyactis, Delphinium densiflorum* and *Potentilla argyrophylla* were the major species.

Towards inner side of the valley, for example, Geldung area (>4000m) in Ganesh Ganga watershed, *Caragana versicolor, Krascheninnikovia ceratoides, Devendraea spinosa, Potentilla rigida, Thymus linearis, Potentilla bifurca, Scutttularia prostrata, Cousinia thomsonii, Hippophae tibetana, Melica persica* and *Festuca tibetica* were some of the characteristic species which show affinities with Trans-Himalayan region due to increasing aridity. The mosaics of *Caragana* scrub alone and amidst *Krascheninnikovia ceratoides, Devendraea spinosa* and *Potentilla rigida* add peculiar appearance to the landscape. The characteristic species found in scree slopes were *Thymus linearis, Geranium wallichianum, Potentilla cuneifolia, Scutttularia prostrata, Aconogonum tortuosum, Cousinia thomsonii, Lamium rhomboideum* and *Cicer microphyllum*.

Two way indicator species analysis (TWINSPAN) for the major landforms, such as moraine, river bed and scree, which contributes ca. 75% of the total geographical area of the valley, resulted in 39 plant communities. Of these, 12, 09 and 18 were major plant communities in Amrit Ganga, Satyagad watershed and Ganesh Ganga, respectively. All the plant communities across various landforms along with total number of sampling sites and plots, species diversity and richness, and their co-dominant species are discussed below.

4.4.4.1 Moraine

Amrit Ganga watershed: A total of 250 plots (1m×1m) across 10 sites and 90 plots (5m×5m) across 9 sites were sampled and species richness of 52 for herbs and 19 for shrubs was recorded. Evenness was recorded 0.6 and 0.4 for herbs and shrubs, respectively. Diversity was recorded 7 and 2.7 for herbs and shrubs, respectively. In herbs, density was found highest in *Thymus linearis* (8.2±1.1) followed by *Potentilla cuneifolia* (8.1±0.7), *Sibbaldia parviflora* (4.4±1.1), *Leontopodium brachyactis* (3.4±1.1) and *Bistorta affinis* (3.1±0.6). Frequency was recorded highest for *Potentilla cuneifolia* (51.2%) followed by *Thymus linearis* (45.2%), *Leontopodium brachyactis* (24.4%), *Sibbaldia parviflora* and *Bistorta affinis* (24% each) and *Androsace sarmentosa* (22.8%). Abundance of *Gaultheria trichophylla* was recorded highest (76) followed by *Viola biflora* (45.3), *Sibbaldia parviflora* (18.3), *Thymus linearis* (18.1) and *Potentilla cuneifolia* (15.7). The distribution of herb species was contiguous (a/f ratio=>0.05). The structural aspects of vegetation, such as density and frequency for herbs are given in the **Table 4.7.** The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Cassiope fastigiata* (330) followed by *Rhododendron campanulatum* (37), *Devendraea myrtillus* (34), *Salix denticulata* (21), *Juniperus indica* (12) and *J. communis* (8.5).

Vegetation communities: A total of four herb and two shrub communities were identified in the moraine of this watershed. **Figure 4.6-4.7** shows dendrogram of the identified plant communities of herbs and shrubs.

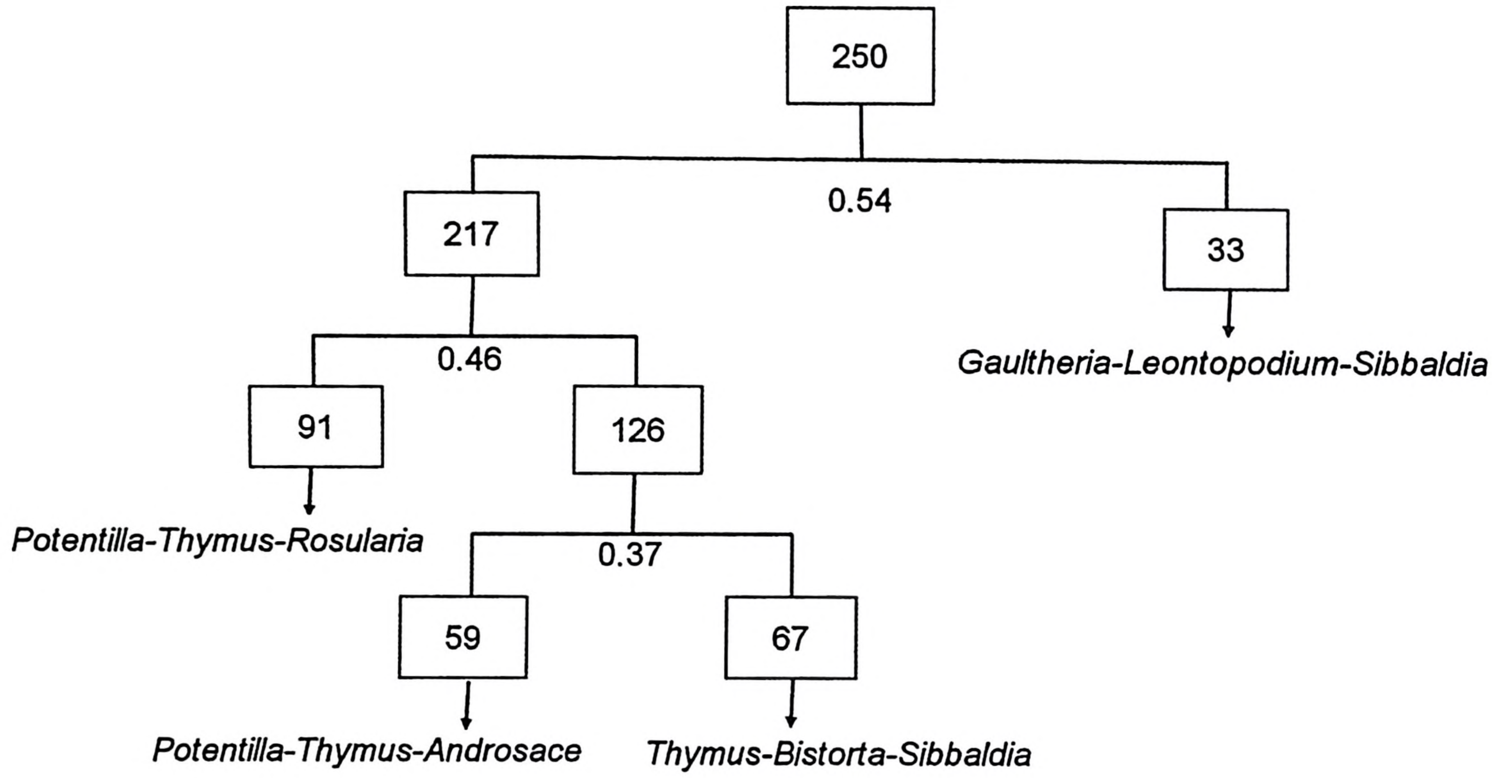

Figure 4.6 Dendrogram of herb communities in moraine of Amrit Ganga.

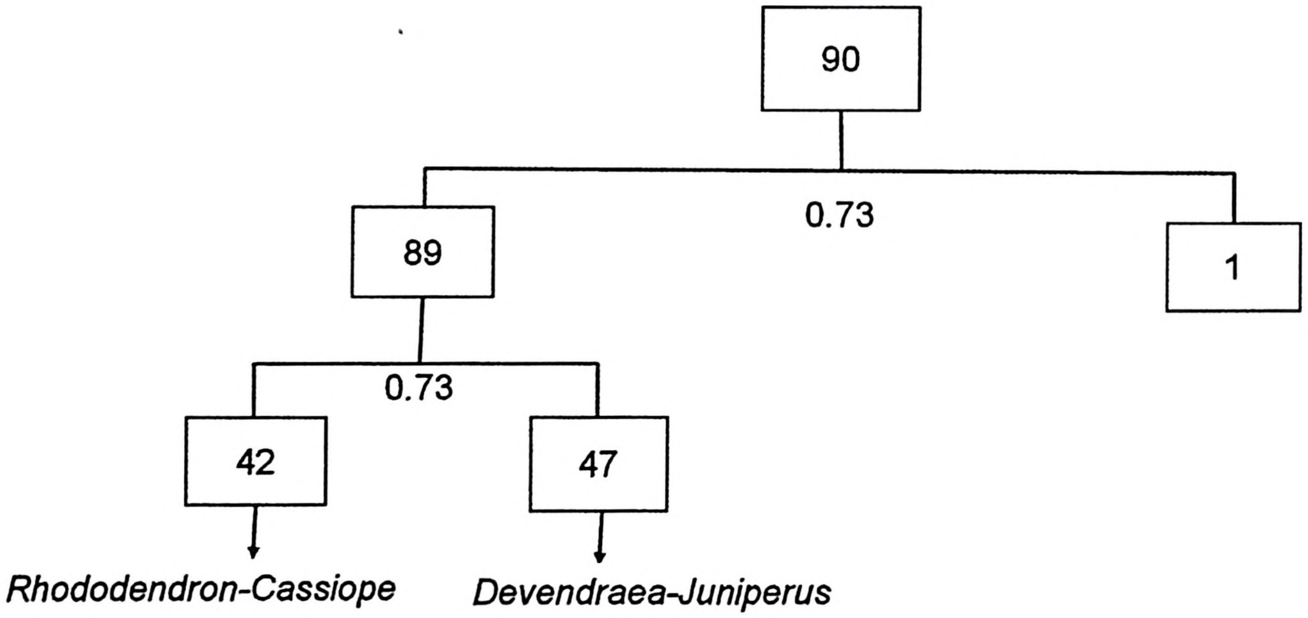

Figure 4.7 Dendrogram of shrub communities in moraine of Amrit Ganga.

Ganesh Ganga watershed: A total of 125 plots (1m×1m) across 5 sites and 40 plots (5m×5m) across 4 sites were sampled and species richness of 32 species for herbs and 8 for shrubs was recorded. Evenness was recorded 0.6 and 0.7 for herbs and shrubs, respectively. Diversity was recorded 4.6 and 1.4 for herbs and shrubs, respectively. In herbs, density was found highest in *Thymus linearis* (15.3±1.6) followed by *Potentilla cuneifolia* (4.5±0.5), *Geranium wallichianum* (2.9±0.4), *Scuttelaria prostrata* (2.7±0.4) and *Astragalus* sp. (2.6±0.4). Frequency was recorded highest for *Thymus linearis* (63.2%) followed by *Potentilla cuneifolia* (58.4%), *Cousinia thomsonii* (47.2%), *Geranium wallichianum* (43.2%)

and *Astragalus* sp. (42.4%). Abundance of *Thymus linearis* was recorded highest (24.3) followed by *Anaphalis royleana* (21.3), *Bistorta affinis* (18), *Potentilla bifurca* (16.5) and *Potentilla cuneifolia* (7.8). The distribution of herb species was contiguous (a/f ratio=>0.05). The structural aspects, such as density and frequency for herbs are given in the **Table 4.7.** The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Potentilla rigida* (198), followed by *Devendraea spinosa* (59), *Juniperus communis* (46), *J. indica* (27) and *Hippophae tibetana* (22).

Vegetation communities: A total of three herb and two shrub communities were identified in the moraine of this watershed. **Figure 4.8-4.9** shows dendrogram of the identified plant communities of herbs and shrubs.

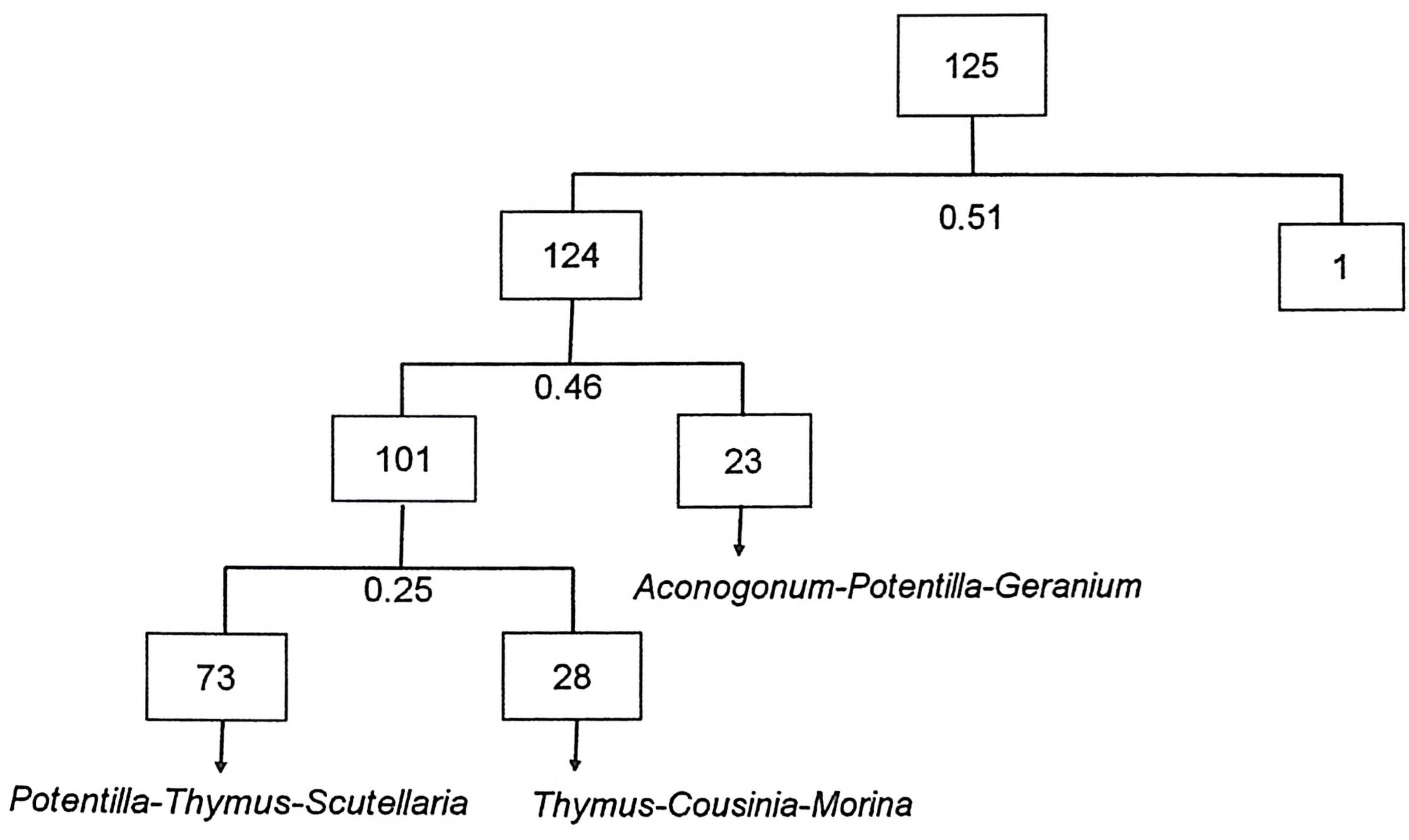

Figure 4.8 Dendrogram of herb communities in moraine of Ganesh Ganga.

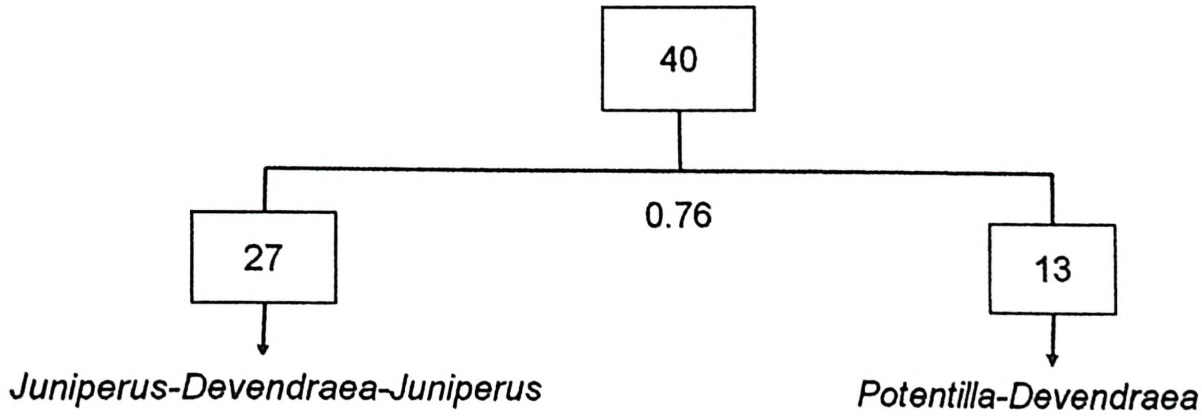

Figure 4.9 Dendrogram of shrub communities in moraine of Ganesh Ganga.

Table 4.7 Structural aspects of dominant herbs in moraine of Amrit Ganga and Ganesh Ganga watersheds.

Species	Amrit Ganga		Ganesh Ganga	
	Density (ind. $m^{-2} \pm$ SE)	Frequency (%)	Density (ind. $m^{-2} \pm$ SE)	Frequency (%)
*Gaultheria trichophylla**	10.3±3.3	13.6	-	-
Thymus linearis	8.2±1.1	45.2	15.3±1.6	63.2
Potentilla cuneifolia	8.1±0.7	51.2	4.5±0.5	58.4
Sibbaldia parviflora	4.4±1.1	24.0	0.4±0.3	8.0
Leontopodium brachyactis	3.4±1.1	24.4	-	-
Bistorta affinis	3.1±0.6	24.0	1.6±0.7	8.8
Androsace sarmentosa	1.7±0.2	22.8	-	-
Rosularia alpestris	0.8±0.2	17.6	-	-
Viola biflora	0.7±3.5	1.6	-	-
Anaphalis royleana	0.7±0.3	10.8	1.2±1.4	5.6
Potentilla argyrophylla	0.7±0.1	22.4	1.2±0.2	36.8
Geranium wallichianum	0.6±0.2	11.6	2.9±0.4	43.2
Picrorhiza scrophulariiflora	0.5±0.3	5.6	-	-
Euphrasia himalayica	0.5±0.3	5.2	-	-
Scuttelaria prostrata	-	-	2.7±0.4	41.6
Astragalus sp.	-	-	2.6±0.4	42.4
Cousinia thomsonii	-	-	1.1±0.2	47.2
Aconogonum tortuosum	-	-	0.9±0.9	11.2
Potentilla bifurca	-	-	0.8±0.4	4.8
Iris kemaonensis	-	-	0.4±0.1	20.0

*= dwarf shrub

In Amrit Ganga, species richness (S), diversity (H') and evenness (E), respectively among the communities ranged between 12 to 42, 1.1 to 2.4 and 0.45 to 0.65 in herbs, while 11 to 12, 0.8 to 1.8 and 0.35 to 0.71 in shrubs. Of the four herb communities recorded, species richness, diversity and evenness, respectively 42, 2.4 and 0.65 was recorded highest in *Thymus linearis-Bistorta affinis-Sibbaldia parviflora*, while lowest in *Gaultheria trichophylla-Leontopodium brachyactis-Sibbaldia parviflora* (12, 1.1 and 0.45). Of the two shrub communities recorded, species richness, diversity and evenness, respectively 12, 1.8 and 0.71 was recorded highest in *Rhododendron campanulatum-Cassiope fastigiata,* while lowest (11, 0.8 and 0.35) in *Devendraea myrtillus-Juniperus indica* **(Table 4.8)**.

In Ganesh Ganga, S, H' and E, respectively among the communities ranged between 13 to 21, 1.7 to 2 and 0.57 to 0.78 in herbs, while 5 to 7, 0.5 to 1.7 and 0.32 to 0.89 in shrubs. Of three herb communities, species richness was recorded highest (21) in *Potentilla cuneifolia-Thymus linearis-Scutellaria prostrata* and lowest in *Aconogonum tortuosum-Potentilla argyrophylla-Geranium wallichianum* (13). H' was recorded highest (2) in *Aconogonum tortuosum-Potentilla argyrophylla-Geranium wallichianum* and *Potentilla cuneifolia-Thymus linearis-Scutellaria prostrata,* while lowest in *Thymus linearis-Cousinia thomsonii-Morina coultriana* (1.7). E was found highest (0.78) in *Aconogonum tortuosum-Potentilla argyrophylla-Geranium wallichianum,* while lowest in *Thymus linearis-Cousinia thomsonii-Morina coultriana* (0.57). Of the two shrub communities recorded, species richness, diversity and evenness, respectively 12, 1.7 and 0.89 was recorded highest in *Juniperus communis-Devendraea spinosa-J. indica*, while lowest (5, 0.5 and 0.32) in *Potentilla rigida-Devendraea spinosa* (**Table 4.8**).

Table 4.8 Plant communities in moraine across Amrit Ganga and Ganesh Ganga watersheds.

Watershed and Community	S	H'	E	Co-dominant species
Amrit Ganga				
Gaultheria trichophylla-Leontopodium brachyactis-Sibbaldia parviflora	12	1.1	0.45	*Picrorhiza scrophulariiflora, Bistorta affinis, P. argyrophylla, Aconogonum tortuosum, Taraxacum officinale*
Thymus linearis-Bistorta affinis-Sibbaldia parviflora	42	2.4	0.65	*Potentilla cuneifolia, P. argyrophylla, Rosularia alpestris, Scutellaria prostrata, Geranium wallichianum*
Potentilla cuneifolia-Thymus linearis -Rosularia alpestris	32	2.1	0.61	*Anaphalis royleana, Trigonella emodi, Artemisia maritima, A. cappilaris, P. argyrophylla*
Potentilla cuneifolia-Thymus linearis-Androsace sarmentosa	30	2.2	0.64	*Leontopodium brachyactis, P. argyrophylla, Sibbaldia parviflora, Bistorta affinis, Geranium wallichianum*
Rhododendron campanulatum-Cassiope fastigiata	12	1.8	0.71	*Salix denticulata, Pinus wallichiana, Devendraea myrtillus, Juniperus communis, J. indica*
Devendraea myrtillus-Juniperus indica	11	0.8	0.35	*Juniperus communis, Ephedra gerardiana, Lonicera obovata, Berberis pseudumbellata, Astragalus candolleanus*
Ganesh Ganga				
Aconogonum tortuosum-Potentilla argyrophylla-Geranium wallichianum	13	2	0.78	*Cousinia thomsonii, Bupleurum candollei, Nepeta laevigata, Oxytropis* sp., *Allium carolinianum*
Potentilla cuneifolia-Thymus linearis-Scutellaria prostrata	21	2	0.67	*Cousinia thomsonii, Astragalus* sp., *Potentilla argyrophylla, Geranium wallichianum, Iris kemaonensis*
Thymus linearis-Cousinia thomsonii-Morina coultriana	20	1.7	0.57	*Potentilla cuneifolia, Scutellaria prostrata, Astragalus* sp., *Anaphalis royleana, Taraxacum officinale*
Juniperus communis-Devendraea spinosa-J. indica	7	1.7	0.89	*Hipphophae tibetana, Devendraea myrtillus, Lonicera obovata, Cotoneaster microphyllus*
Potentilla rigida-Devendraea spinosa	5	0.5	0.32	*Juniperus communis, J. indica, Cotoneaster microphyllus*

Abbreviations used: S= Species richness, H'= Species diversity, E= Evenness

4.4.4.2 River bed

Amrit Ganga watershed: A total of 75 plots (1m×1m) across 3 sites and 30 plots (5m×5m) across 3 sites were sampled and species richness of 32 species of herbs and 5 of shrubs was recorded. Evenness was recorded 0.8 and 0.6 for herbs and shrubs, respectively. Diversity was recorded 4.8 and 0.8 for herbs and shrubs, respectively. In herbs, density was found highest in *Equisetum diffusum* (14.7±4.8) followed by *Trachydium roylei* (8.4±6.3), *Sibbaldia parviflora* (7.9±1.6), *Potentilla cuneifolia* (6.1±2.5) and *Ranunculus pulchellus* (5.8±8.4). Frequency was recorded highest for *Sibbaldia parviflora* (42.7%) followed by *Rumex nepalensis* (40%), *Potentilla cuneifolia* (38.7%), *Anaphalis royleana* (36%), *Taraxacum officinale* (34.7%) and *Plantago himalaica* (33.3%). Abundance of *Trachydium roylei* was recorded highest (70.2) followed by *Ranunculus pulchellus* (62.4), *Equisetum diffusum* (52.5), *Tibetia himalaica* (47.8), *Galium asperuloides* (45) and *Primula denticulata* (32). The distribution of herb species was contiguous (a/f ratio=>0.05). The structural aspects, such as density and frequency for herbs are given in the **Table 4.9.** The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Myricaria rosea* (127), followed by *Hippophae tibetana* (40), *Juniperus indica* (18) and *Devendraea myrtillus* (10).

Vegetation communities: A total of four herb and two shrub communities were identified in river bed of this watershed. **Figure 4.10-11** shows dendrogram of the identified plant communities of herbs and shrubs.

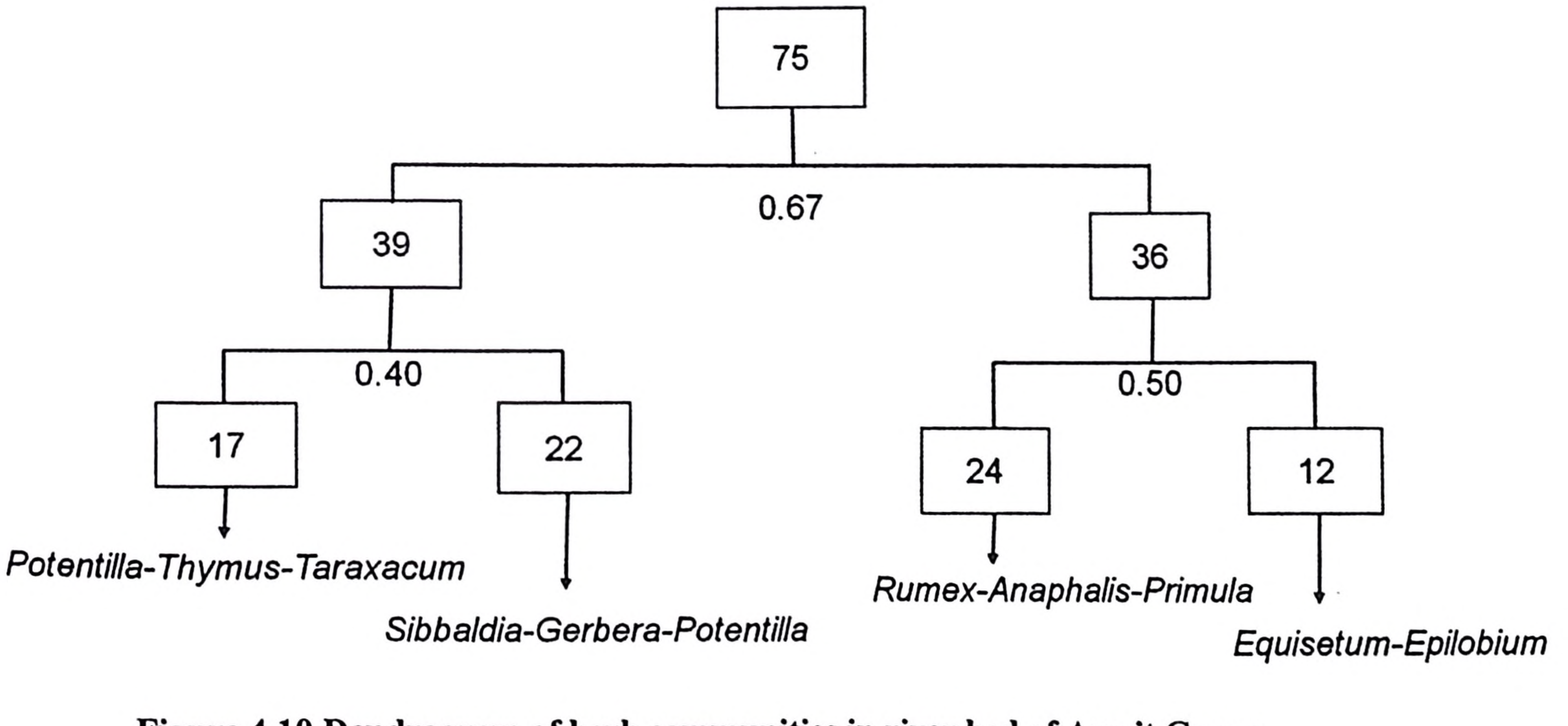

Figure 4.10 Dendrogram of herb communities in river bed of Amrit Ganga.

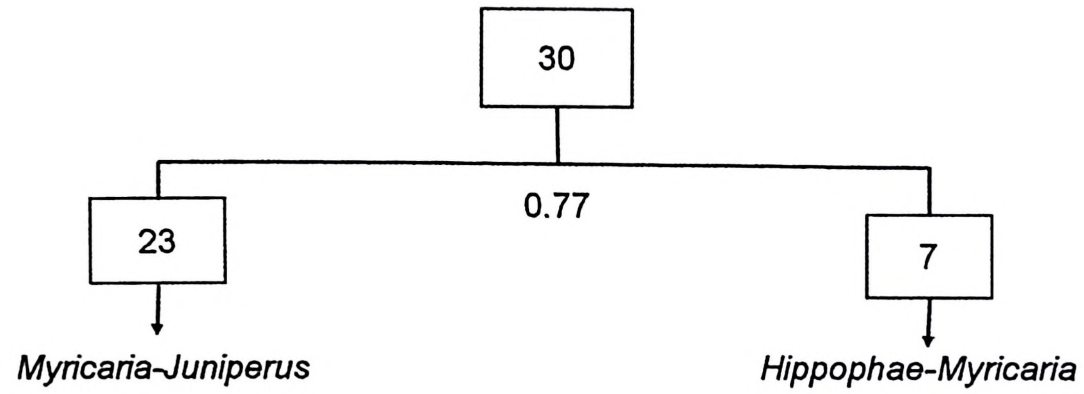

Figure 4.11 Dendrogram of shrub communities in river bed of Amrit Ganga.

Ganesh Ganga watershed: A total of 25 plots (1m×1m) across one site and 10 plots (5m × 5m) across one site were sampled and eight species of herbs and seven of shrubs were recorded. Evenness was recorded 0.2 and 0.7 for herbs and shrubs, respectively. Diversity was recorded 1.3 and 1.2 for herbs and shrubs, respectively. In herbs, density was recorded highest in *Potentilla cuneifolia* (7.1±1.6) followed by *Thymus linearis* (5.1±1.0), *Anaphalis royleana* (4.4±1.0), *Bistorta affinis* (3.2±0.8) and *Geranium wallichianum* (2.5±0.4). Frequency was recorded highest for *Cousinia thomsonii* (48) followed by *Potentilla cuneifolia* and *Anaphalis royleana* (44% each), *Thymus linearis* (40%), *Geranium wallichianum* (36%) and *Rosularia alpestris* (32%). Abundance of *Bistorta affinis* was recorded highest (16.2) followed by *Potentilla cuneifolia* (16.1), *Thymus linearis* (12.8), *Anaphalis royleana* (10) and *Geranium wallichianum* (7). The distribution of herb species was contiguous (a/f ratio=>0.05). The structural aspects, such as density and frequency for herbs are given in the **Table 4.9.** The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Hippophae tibetana* (337), followed by *Potentilla rigida* (112), *Myricaria rosea* (97), *Devendraea spinosa* (59), *Berberis pseudumbellata* (32) and *Ephedra gerardiana* (25).

Vegetation communities: A total of two herb and two shrub communities were identified in moraine of this watershed. **Figure 4.12-4.13** shows dendrogram of the identified plant communities of herbs and shrubs.

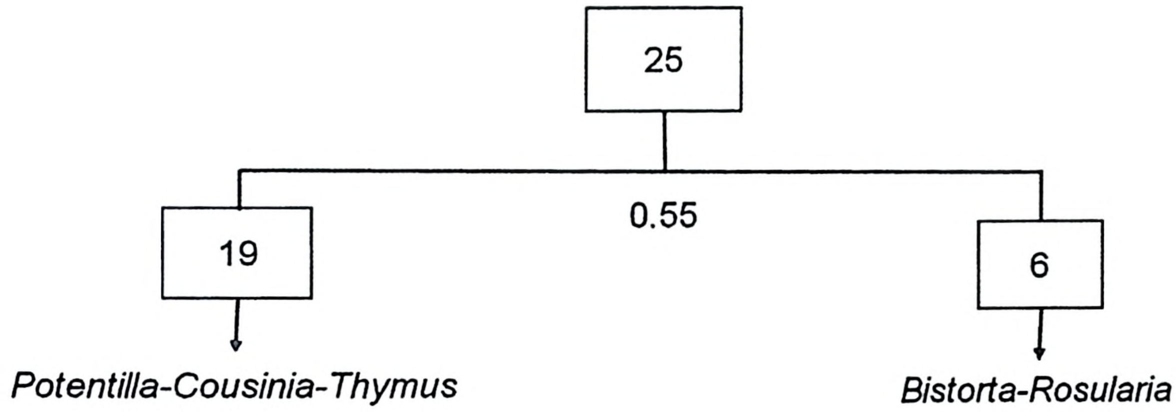

Figure 4.12 Dendrogram of herb communities in river bed of Ganesh Ganga.

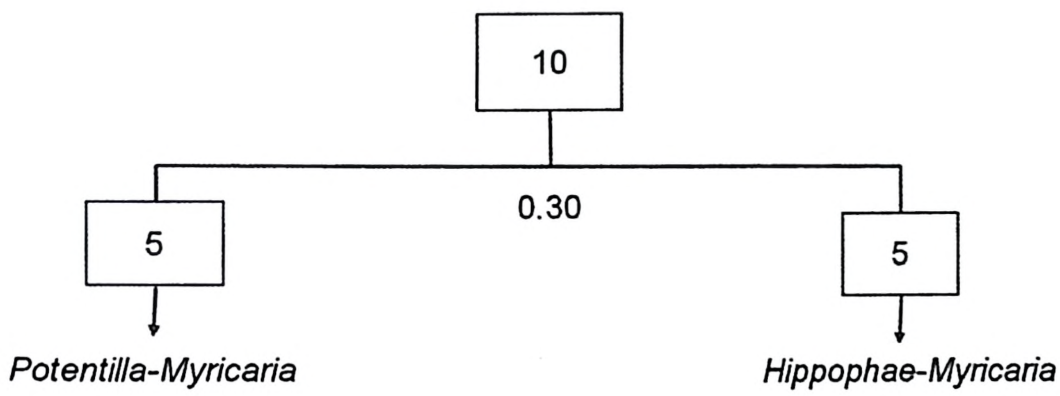

Figure 4.13 Dendrogram of shrub communities in river bed of Ganesh Ganga.

Table 4.9 Structural aspects of dominant herbs in river bed of Amrit Ganga and Ganesh Ganga watersheds.

Species	Amrit Ganga		Ganesh Ganga	
	Density (ind. m^{-2}± SE)	Frequency (%)	Density (ind. m^{-2}± SE)	Frequency (%)
Equisetum diffusum	14.7±4.8	28.0	-	-
Trachydium roylei	8.4±6.3	12.0	-	-
Sibbaldia parviflora	7.9±1.6	42.7	-	-
Potentilla cuneifolia	6.1±2.5	38.7	7.1±1.6	44
Ranunculus pulchellus	5.8±8.4	9.3	-	-
Anaphalis royleana	3.7±1.5	36.0	4.4±1.0	44
Gerbera gossypina	3.2±1.3	29.3	-	-
Primula denticulata	3.0±4.4	9.3	-	-
Plantago himalaica	2.9±0.6	33.3	-	-
Primula involucrata	2.6±1.1	26.7	-	-
Tibetia himalaica	2.5±8.7	5.3	-	-
Thymus linearis	1.9±0.4	22.7	5.1±1.0	40
Bistorta affinis	1.9±0.8	10.7	3.2±0.8	20
Taraxacum officinale	1.8±0.7	34.7	-	-
Herminium monorchis	1.6±0.9	12.0	-	-
Rumex nepalensis	1.6±0.3	40.0	-	-
Epilobium laxum	1.1±0.4	20.0	-	-
Euphrasia himalayica	0.6±1.9	4.0	-	-
Galium asperuloides	0.6±0.0	1.3	-	-
Geranium wallichianum	-	-	2.5±0.4	36
Cousinia thomsonii	-	-	1.0±0.2	48
Rosularia alpestris	-	-	0.8±0.3	32
Arenaria festucoides	-	-	0.4±0.3	16

In Amrit Ganga, species richness (S), diversity (H') and evenness (E), respectively among the communities ranged between 13 to 23, 1.3 to 2.4 and 0.52 to 0.81 in herbs, while 3 to 4, 0.6 each and 0.42 to 0.56 in shrubs. Of the four herb communities recorded, species richness and diversity, respectively 23 and 2.4 was recorded highest in *Sibbaldia parviflora-Gerbera gossypina-Potentilla cuneifolia*, while lowest in *Equisetum diffusum-Epilobium laxum* (13 and 1.3). E was recorded highest (0.81) in *Rumex nepalensis-Anaphalis royleana-Primula involucrata* and lowest (0.52) in *Equisetum diffusum-Epilobium laxum.* Of the two shrub communities recorded, species richness was recorded four in *Hippophae tibetana-Myricaria rosea* and three in *Myricaria rosea-Juniperus indica* (**Table 4.10**). H' was 0.6 in both the communities. E was 0.56 in *Myricaria rosea-Juniperus indica* and 0.42 in *Hippophae tibetana-Myricaria rosea.*

In Ganesh Ganga, species richness (S), diversity (H') and evenness (E), respectively was 7, 1.5 and 0.79 each in two herb communities, while 5 and 7, 0.9 and 1.8 and 0.56 and 0.90 in two shrub communities (**Table 4.10**).

Table 4.10 Plant communities in river bed across Amrit Ganga and Ganesh Ganga watersheds.

Watershed and Community	S	H'	E	Co-dominant species
Amrit Ganga				
Potentilla cuneifolia-Thymus linearis-Taraxacum officinale	19	2.3	0.79	*Potentilla argyrophylla, Gerbera gossypina, Plantago himalaica, Anaphalis royleana, Bistorta affinis*
Sibbaldia parviflora-Gerbera gossypina-Potentilla cuneifolia	23	2.4	0.75	*Herminium monorchis, Plantago himalaica, Taraxacum officinale, Anaphalis royleana, Rumex nepalensis*
Rumex nepalensis-Anaphalis royleana-Primula involucrata	17	2.3	0.81	*Sibbaldia parviflora, Plantago himalaica, Taraxacum officinale, Equisetum diffusum, Trachydium roylei*
Equisetum diffusum-Epilobium laxum	13	1.3	0.52	*Ranunculus pulchellus, Rumex nepalensis, Primula involucrata, Corydalis govaniana*
Myricaria rosea-Juniperus indica	3	0.6	0.56	*Devendraea myrtillus*
Hippophae tibetana-Myricaria rosea	4	0.6	0.42	*Juniperus indica, J. communis*
Ganesh Ganga				
Potentilla cuneifolia-Cousinia thomsonii-Thymus linearis	7	1.5	0.79	*Anaphalis royleana, Geranium wallichianum, Arenaria festucoides, Rosularia alpestris*
Bistorta affinis-Rosularia alpestris	7	1.5	0.79	*Geranium wallichianum, Potentilla cuneifolia, Anaphalis royleana, Thymus linearis*
Potentilla rigida-Myricaria rosea	7	1.8	0.90	*Devendraea spinosa, Berberis pseudumbellata, Ephedra gerardiana, Juniperus indica, Hippophae tibetana*
Hippophae tibetana-Myricaria rosea	5	0.9	0.56	*Potentilla rigida, Devendraea spinosa, Juniperus indica*

Abbreviations used: S= Species richness, H'= Species diversity, E= Evenness

4.4.4.3 Scree

Satyagad watershed: A total of 150 plots (1m×1m) across six sites and 50 plots (5m×5m) across five sites were sampled and 35 species of herbs and three of shrubs were recorded. Evenness was recorded 0.7 and 0.3 for herbs and shrubs, respectively. Diversity was recorded 5.3 and 0.4 for herbs and shrubs, respectively. In herbs, density was recorded highest in *Potentilla cuneifolia* (6.5±0.5) followed by *Bistorta affinis* (5.5±0.6), *Geranium wallichianum* (1.7±0.2), *Thymus linearis* (1.4±0.4) and *Leontopodium brachyactis* (1.1±0.2). Frequency was recorded highest for *Potentilla cuneifolia* (52%), followed by *Potentilla argyrophylla* and *Androsace globifera* (39.3% each), *Geranium wallichianum* (35.3%), *Bistorta affinis* (29.3%) and *Delphinium densiflorum* (19.3%). Abundance of *Bistorta affinis* was recorded highest (18.8) followed by *Potentilla cuneifolia* and *Thymus linearis* (12.4 each), *Potentilla bifurca* (10.3), *Eriophyton rhomboideum* (9.7) and *Sibbaldia parviflora* (8.6). The distribution of herb species was contiguous (a/f ratio=>0.05). The structural aspects, such as density and frequency for herbs are given in the **Table 4.11.** The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Rhododendron lepidotum* (303), followed by *Caragana gerardiana* (20) and *Juniperus indica* (12).

Vegetation communities: A total of six herb and three shrub communities were identified in the moraine of this watershed. **Figure 4.14-4.15** shows dendrogram of the identified plant communities of herbs and shrubs.

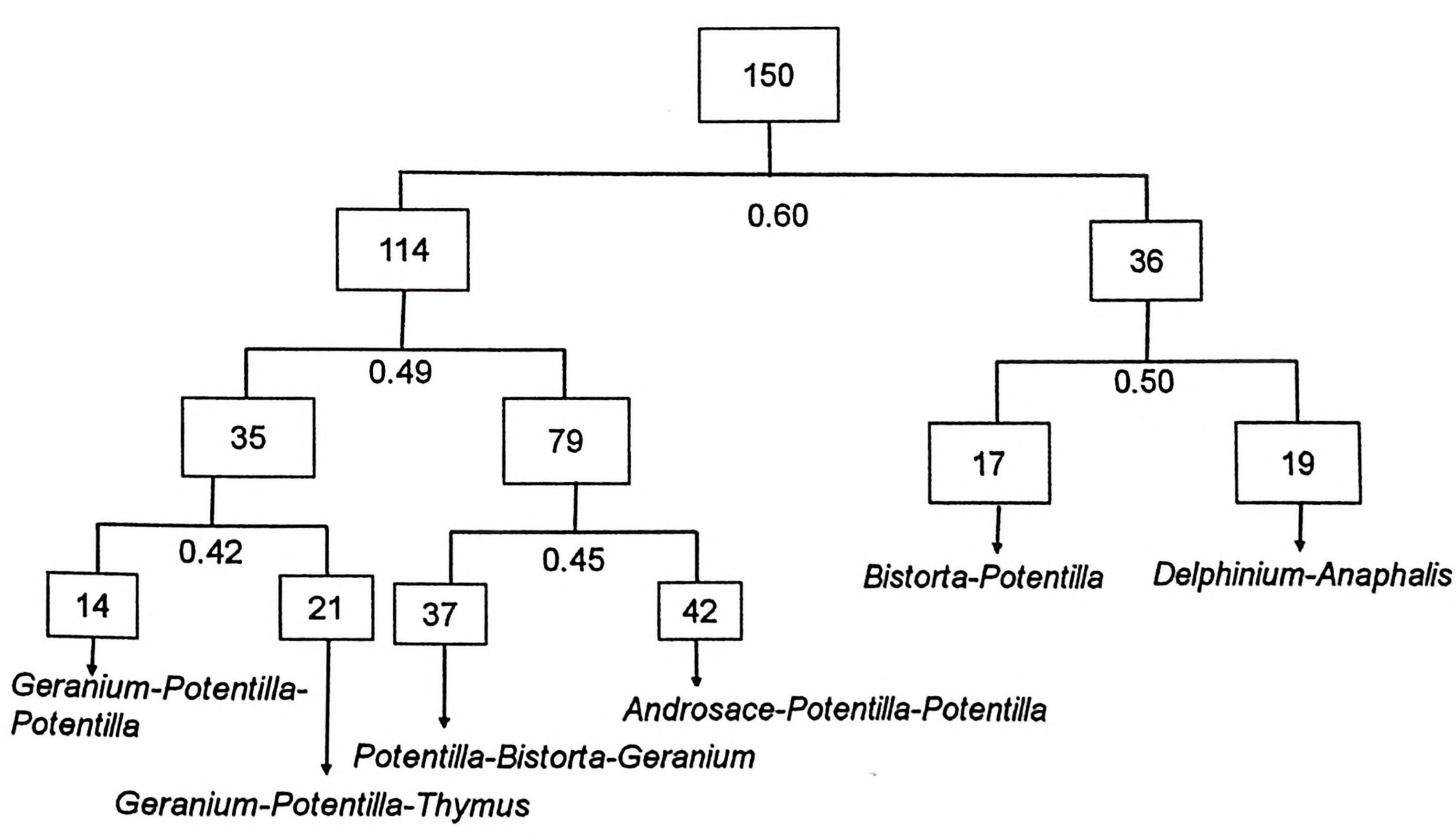

Figure 4.14 Dendrogram of herb communities in scree of Satyagad watershed.

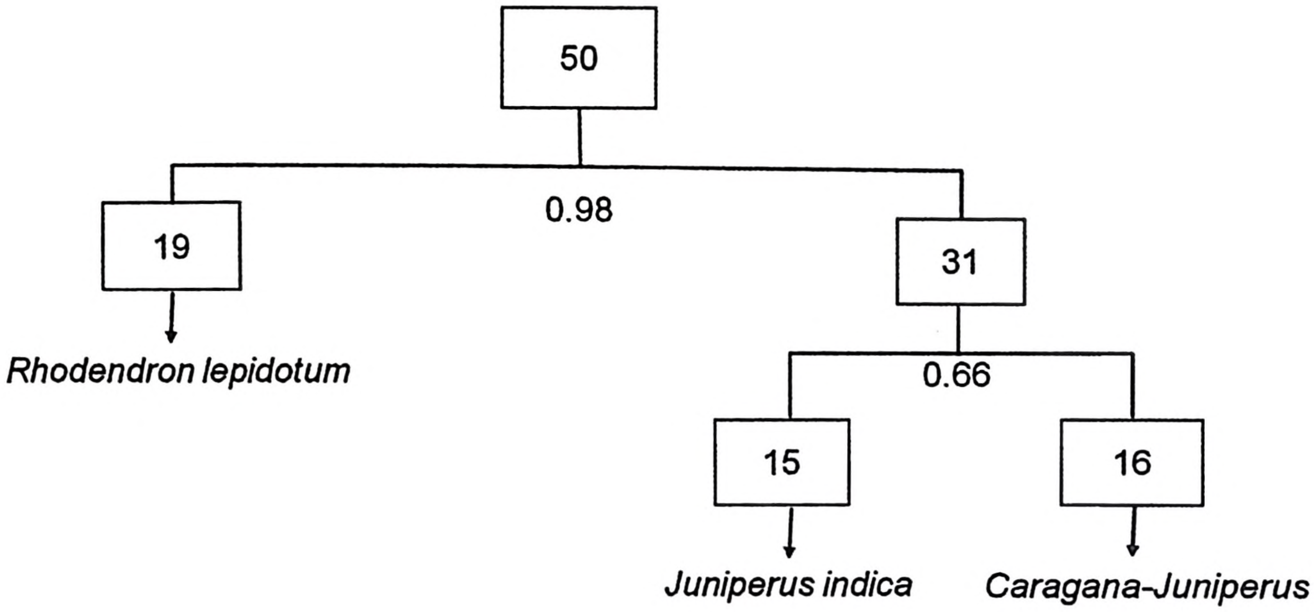

Figure 4.15 Dendrogram of shrub communities in scree of Satyagad watershed.

Ganesh Ganga watershed: A total of 200 plots (1m×1m) across eight sites and 80 plots (5m×5m) across eight sites were sampled and 53 species of herbs and 13 of shrubs were recorded. Evenness was recorded 0.7 and 0.4 for herbs and shrubs, respectively. Diversity was recorded 8.3 and 2 for herbs and shrubs, respectively. In herbs, density was recorded highest in *Thymus linearis* (5.9±1.5) followed by *Geranium wallichianum* (1.6±0.4), *Potentilla cuneifolia* (1.6±0.3), *Scuttelaria prostrata* (1.5±0.3) and *Bistorta affinis* (1.4±0.3). Frequency was recorded highest for *Thymus linearis* (33.5%), followed by *Cousinia thomsonii* (26%), *Aconogonum tortuosum* (24.5%), *Geranium wallichianum* (23.5%) and *Scuttelaria prostrata* (22%). Abundance of *Trachydium roylei* was recorded highest (23.5) followed by *Thymus* linearis (17.7), *Bistorta affinis* (16.6), *Polygonum plebeium* (12.2) and *Potentilla bifurca* (11.3). The distribution of herb species was contiguous (a/f ratio=>0.05). The structural aspects, such as density and frequency for herbs are given in the **Table 4.11.** The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Potentilla rigida* (1576), followed by *Devendraea spinosa* (578), *Lonicera obovata* (122), *Berberis pseudumbellata* (110), *Juniperus indica* (74), *Caragana versicolor* (52) and *Rosa sericea* (52).

Vegetation communities: A total of five herb and four shrub communities were identified in the moraine of this watershed. **Figure 4.16-4.17** shows dendrogram of the identified plant communities of herbs and shrubs.

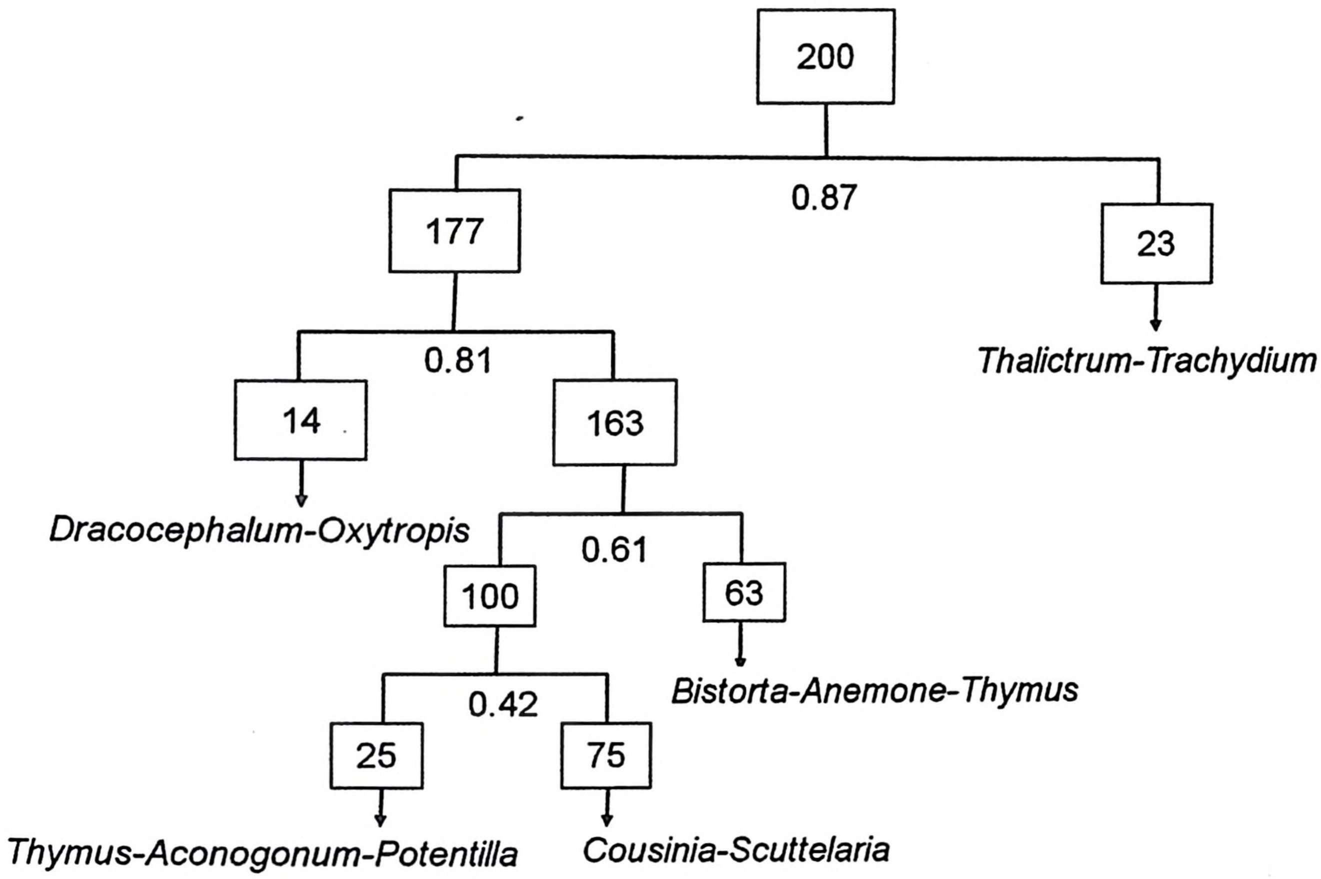

Figure 4.16 Dendrogram of herb communities in scree of Ganesh Ganga watershed.

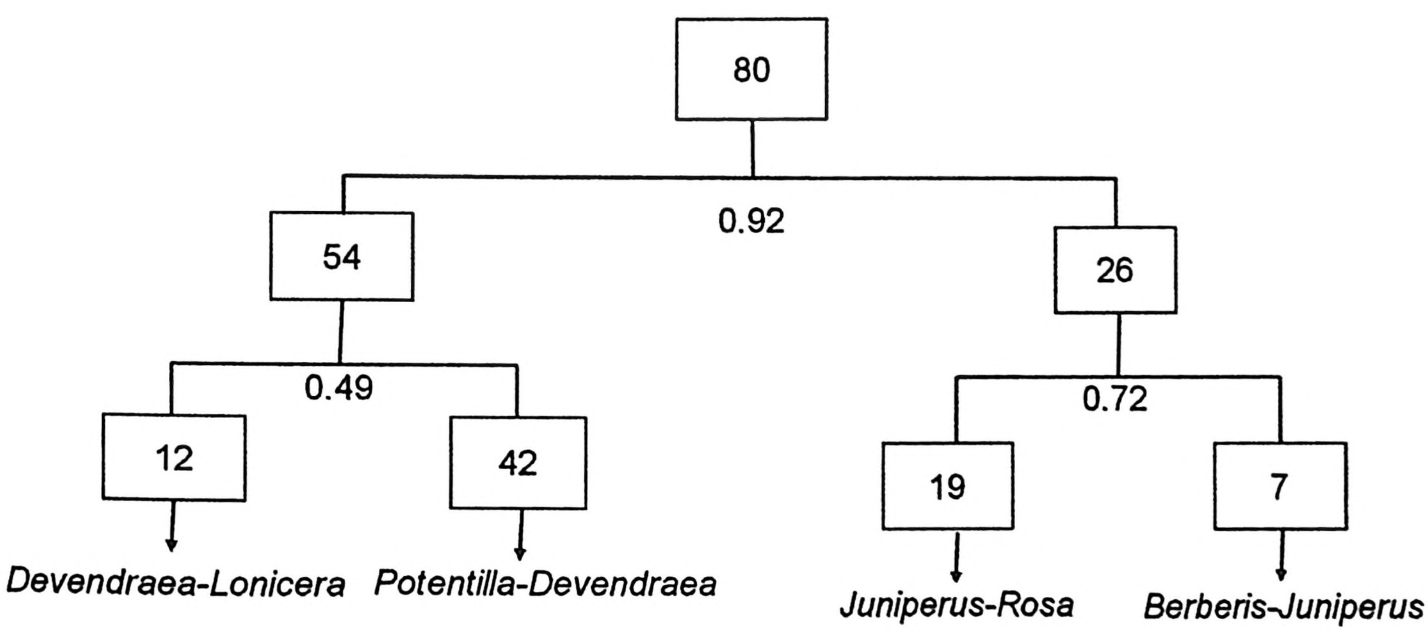

Figure 4.17 Dendrogram of shrub communities in scree of Ganesh Ganga watershed.

Table 4.11 Structural aspects of dominant herbs in scree of Satyagad and Ganesh Ganga watersheds.

Species	Satyagad		Ganesh Ganga	
	Density (ind. $m^{-2}\pm$ SE)	Frequency (%)	Density (ind. $m^{-2}\pm$ SE)	Frequency (%)
Potentilla cuneifolia	6.5±0.5	52	1.6±0.3	18.5
Bistorta affinis	5.5±0.6	29.3	1.4±0.3	8.5
Geranium wallichianum	1.7±0.2	35.3	1.6±0.4	23.5
Thymus linearis	1.4±0.4	11.3	5.9±1.5	33.5
Leontopodium brachyactis	1.1±0.2	16.7	-	-
Delphinium densiflorum	1.0±0.3	19.3	-	-
Potentilla argyrophylla	1.0±0.1	39.3	-	-
Androsace globifera	1.0±0.1	39.3	-	-
Sibbaldia parviflora	0.8±0.3	9.3	-	-
Anaphalis royleana	0.7±0.3	11.3	0.9±0.3	12
Potentilla bifurca	0.6±0.4	6	0.6±0.5	5.0
Eriophyton rhomboideum	0.5±0.2	4.7	-	-
Scuttelaria prostrata	-	-	1.5±0.3	22
Trachydium roylei	-	-	1.3±1.4	5.5
Astragalus sp.	-	-	0.9±0.2	18.5
Aconogonum tortuosum	-	-	0.9±0.2	24.5
Cousinia thomsonii	-	-	0.7±0.2	26
Polygonum plebeium	-	-	0.7±0.5	5.5
Thalictrum elegans	-	-	0.6±0.3	6.5
Bergenia stracheyi	-	-	0.6±0.2	5.5
Iris kemaonensis	-	-	0.5±0.1	16.5

In Satyagad, species richness (S), diversity (H') and evenness (E), respectively among the communities ranged between 11 to 28, 1.1 to 2.5 and 0.42 to 0.80 in herbs, while 11 to 12, 0.8 to 1.8 and 0.35 to 0.71 in shrubs. Of the six herb communities recorded, species richness, and diversity, respectively 28 and 2.5 was recorded highest in *Androsace globifera-Potentilla cuneifolia-P. argyrophylla*, while lowest in *Delphinium denudatum-Anaphalis royleana* (11 and 1.1). E was ecorded highest (0.80) in *Geranium wallichianum-Potentilla biflora-Potentilla cuneifolia* and lowest (0.42) in *Bistorta affinis-Potentilla argyrophylla. Rhodendron lepidotum, Juniperus indica* and *Caragana gerardiana-Juniperus indica* were the shrub communities in this watershed **(Table 4.12)**.

In Ganesh Ganga, species richness (S), diversity (H') and evenness (E), respectively among the communities ranged between 12 to 26, 1.7 to 2.3 and 0.68 to 0.72 in herbs, while 3 to 10, 0.7 to 2 and 0.36 to 0.89 in shrubs. Of the five herb communities recorded, species richness, diversity and evenness, respectively 26, 2.3 and 0.72 was recorded highest in *Thymus linearis-Aconogonum tortuosum-Potentilla cuneifolia* followed by *Cousinia thomsonii-Scuttelaria prostrata* (25, 2.3 and 0.72) and *Bistorta affinis-Anemone rupicola-Thymus linearis* (25 2.2 and 0.68). Of the four shrub communities recorded, species richness, diversity and evenness, respectively 10, 2 and 0.89 was recorded highest in *Juniperus indica-Rosa sericea* **(Table 4.12)**.

Table 4.12 Plant communities in scree across Satyagad and Ganesh Ganga watersheds.

Community and Watershed	S	H'	E	Co-dominant species
Satyagad				
Bistorta affinis-Potentilla argyrophylla	14	1.1	0.42	*Delphinium denudatum, Anaphalis royleana, Erigeron alpinum, Androsace globifera, Potentilla argyrophylla*
Delphinium denudatum-Anaphalis royleana	11	1.9	0.78	*Phlomis bracteata, Oxytropis* sp., *Bistorta affinis, Potentilla argyrophylla, Androsace globifera*
Geranium wallichianum-Potentilla biflora-Potentilla cuneifolia	17	2.3	0.80	*Eriophyton rhomboideum, Nepeta laevigata, Androsace globifera, Mentha longifolia, Thymus linearis*
Geranium wallichianum-Potentilla cuneifolia-Thymus linearis	13	1.8	0.72	*Galium asperuloides, Spongiocarpella nubigena, Potentilla microphylla, P. argyrophylla, Rheum moocraftianum*
Potentilla cuneifolia-Bistorta affinis-Geranium wallichianum	20	1.6	0.54	*Androsace globifera, Potentilla argyrophylla, Phlomis bracteata, Oxytropis* sp., *Leontopodium brachyactis*
Androsace globifera-Potentilla cuneifolia-P. argyrophylla	28	2.5	0.74	*Leontopodium brachyactis, Sibbaldia parviflora, Tibetia himalaica, Geranium wallichianum, Veronica lanosa*
Rhodendron lepidotum	2	0	0.01	*Juniperus indica*
Juniperus indica	1	0	0	*Juniperus communis*
Caragana gerardiana-Juniperus indica	2	0.6	0.84	*Juniperus communis*
Ganesh Ganga				
Thalictrum elegans-Trachydium roylei	13	1.7	0.68	*Corydalis meifolia, Delphinium denudatum, D. cashmerianum, Viola biflora, Oxytropis* sp.
Dracocephalum heterophyllum-Oxytropis sp.	12	1.7	0.70	*Potentilla argyrophylla, Anemone rupicola, Allium carolinianum, Geranium wallichianum, Potentilla bifurca*
Bistorta affinis-Anemone rupicola-Thymus linearis	25	2.2	0.68	*Geranium wallichianum, Cousinia thomsonii, Rheum webbianum, Potentilla cuneifolia, Sibbaldia parviflora*
Thymus linearis-Aconogonum tortuosum-Potentilla cuneifolia	26	2.3	0.72	*Anaphais royleana, Atremisia maritima, Polygonum plebeium, Nepeta laevigata, Scrophularia dentata*
Cousinia thomsonii-Scuttelaria prostrata	25	2.3	0.72	*Thumus linearis, Iris kemaonensis, Astragalus* sp., *Geranium wallichianum, Morina coultriana*
Devendraea spinosa-Lonicera obovata	3	0.7	0.65	*Cotoneaster integrifolius*
Potentilla rigida-Devendraea spinosa	6	0.7	0.40	*Caragana versicolor, Juniperus indica, Krascheninnikovia ceratoides*
Juniperus indica-Rosa sericea	10	2	0.89	*Rosa webbiana, Spiraea arguta, Cotoneaster integrifolius, Ephedra gerardiana*
Berberis pseudumbellata-Juniperus communis	7	0.7	0.36	*Rosa sericea, Juniperus indica*

Abbreviations used: S= Species richness, H'= Species diversity, E= Evenness

4.4.5 Vegetation structure and plant community composition across physiognomic units

Of the identified physiognomic units such as livestock camping site, herbaceous meadow, scrub steppe and tussock formation across three watersheds, tussock formations were reasonably absent in Satyagad and Ganesh Ganga watersheds. In Amrit Ganga, the dominant species in scrub steppe were *Juniperus indica, J. communis, Devendraea myrtillus, Devendraea spinosa, Ephedra gerardiana, Rosa* spp., *Cotoneaster* spp, *Thymus linearis, Sibbaldia parviflora, Thalictrum alpinum, Trachydium roylei* and *Bistorta affinis.* In livestock camping sites, *Plantago himalaica, Trachydium roylei, Rumex nepalensis, Taraxacum officinale, Sibbaldia parviflora* and *Potentilla bifurca* were the foremost species. In Satyagad watershed, the dominant species in scrub steppe were *Caragana gerardiana, Astragalus candolleanus, Juniperus indica, J. communis, Thymus linearis, Potentilla bifurca, Galium asperuloides, P. cuneifolia, Scuttelaria prostrata* and *Geranium wallichianum.* Subsequently, *Bistorta affinis, Anaphalis royleana, Potentilla cuneifolia, Sibbaldia parviflora, P. argyrophylla, B. tenuifolia* and *Trachydium roylei* were the dominant species in herbaceous meadow. In Ganesh Ganga watershed, scrub steppe comprised of the dominant species which showed affinities with Trans-Himalayan region due to increasing aridity were *Caragana versicolor, Krascheninnikovia ceratoides, Devendraea spinosa, Potentilla rigida, Thymus linearis, Potentilla bifurca, Scuttelaria prostrata, Cousinia thomsonii, Hippophae tibetana, Melica persica* and *Festuca tibetica.* In herbaceous meadow, *Bistorta affinis, Sibbaldia parviflora, Thymus linearis, Scuttelaria prostrata, Potentilla argyrophylla, Crucihimalaya himalaica* and *Leontopodium brachyactis* were the dominant species. The structural aspects of vegetation, such as density and frequency for herbs across various physiognomic units are given in the **Table 4.13-4.16.** The identified plant communities across various physiognomic units are given in the **Table 4.27.**

4.4.5.1 Livestock camping site

In Amrit Ganga watershed, a total of 125 plots (1m×1m) across five sites and 30 plots (5m×5m) across three sites were sampled and 33 species of herbs and five of shrubs were recorded. Evenness was recorded 0.7 and 0.9 for herbs and shrubs, respectively. Diversity was recorded 4.5 and 2.7 for herbs and shrubs, respectively. In herbs, density was recorded highest in *Plantago himalaica* (9.6±2.8) followed by *Trachydium roylei* (9.3±3.6), *Rumex nepalensis* (8.0±0.6), *Taraxacum officinale* (6.8±1.8) and *Sibbaldia parviflora* (5.4±1.9). Frequency was recorded highest for *Rumex nepalensis* (81.6%) followed by *Taraxacum officinale* (41.6), *Plantago himalaica* (32.8%), *Sibbaldia parviflora* (24.8%) and *Potentilla argyrophylla* (24%). Abundance of *Thalictrum alpinum* was recorded highest (135) followed by *Trachydium roylei* (61), *Plantago himalaica* (29.1), *Galium asperuloides* (28) and *Sibbaldia parviflora* (22). The distribution of herb species was contiguous (a/f ratio=>0.05).

In Satyagad watershed, a total of 50 plots (1m×1m) across two sites were sampled and 12 herb species were recorded. The shrub species were reasonably absent in the sampled sites. Evenness and diversity was recorded 0.7 and 1.8, respectively. The density was recorded highest in *Geranium wallichianum* (7.5±2.7) followed by *Urtica parviflora* (6.5±0.7), *Potentilla bifurca* (5.8±1.0), *Chenopodium opulifolium* (3.6±0.9), *Mentha longifolia* (1.8±0.9) and *Rumex nepalensis* (1.8±0.3). Frequency was recorded highest for *Urtica parviflora* (80%) followed by *Rumex nepalensis* (56%), *Potentilla bifurca* (52), *Geranium wallichianum* and *Chenopodium opulifolium* (40% each) and *Mentha longifolia* (30%). Abundance of *Geranium wallichianum* was recorded highest (18.9) followed by *Potentilla bifurca* (11.2), *Chenopodium opulifolium* and *Potentilla cuneifolia* (9 each), *Urtica parviflora* (8.2) and *Mentha longifolia* (6.1). The distribution of species was contiguous (a/f ratio=>0.05).

In Ganesh Ganga watershed, a total of 50 plots (1m×1m) across two sites were sampled and 16 herb and five shrub species were recorded. Evenness was recorded 0.5 and 0.7 for herbs and shrubs, respectively. Diversity was recorded 2.1 and 1.7 for herbs and shrubs, respectively. In herbs, density was recorded highest in *Chenopodium opulifolium* (34.8±10.3) followed by *Potentilla bifurca* (19.2±11.5), *Polygonum plebeium* (8.0±3.6), *Geranium wallichianum* (2.2±1.4) and *Rumex nepalensis* (1.5±0.4). Frequency was recorded highest for *Potentilla bifurca* (42%) followed by *Rumex nepalensis* (40%), *Chenopodium opulifolium* (36%), *Malva verticillata* and *Geranium wallichianum* (18% each) and *Potentilla* *argyrophylla* (16%). Abundance of *Chenopodium opulifolium* was recorded highest (96.7) followed by *Potentilla bifurca* (45.7), *Polygonum plebeium* (30.7), *Geranium wallichianum* (12.2) and *Mentha longifolia* (10.5). The distribution of herb species was contiguous (a/f ratio=>0.05). The density and frequency of herbs in livestock camping site of Amrit Ganga, Satyagad and Ganesh Ganga watersheds is given in the **Table 4.13.**

Table 4.13 Structural aspects of dominant herbs in livestock camping site across three watersheds.

Species	Amrit Ganga		Satyagad		Ganesh Ganga	
	Density (ind. m^{-2}±SE)	Frequency (%)	Density (ind. m^{-2}±SE)	Frequency (%)	Density (ind. m^{-2}±SE)	Frequency (%)
Plantago himalaica	9.6±2.8	32.8	-	-	-	-
Trachydium roylei	9.3±3.6	15.2	-	-	-	-
Rumex nepalensis	8.0±0.6	81.6	1.8±0.3	56	1.5±0.4	40
Taraxacum officinale	6.8±1.8	41.6	-	-	-	-
Sibbaldia parviflora	5.4±1.9	24.8	-	-	-	-
Potentilla bifurca	2.2±0.4	18.4	5.8±1.0	52	19.2±11.5	42
Galium asperuloides	1.6±1.8	5.6	0.4±0.3	10	-	-
Bistorta affinis	1.3±0.6	8.8	-	-	-	-
Thalictrum alpinum	1.1±0.0	0.8	-	-	-	-
Potentilla cuneifolia	1.0±0.3	16.8	0.4±0.0	4	-	-
Thymus linearis	0.8±0.1	14.4	-	-	0.5±0.3	8
Potentilla argyrophylla	0.6±0.1	24	-	-	0.7±0.3	16
Iris kemaonensis	0.6±0.7	5.6	-	-	-	-
Polygonum plebeium	0.5±0.2	4.8	-	-	8.0±3.6	26
Mentha longifolia	0.5±0.6	4	-	-	0.8±0.7	8
Geranium wallichianum	-	-	7.5±2.7	40	2.2±1.4	18
Urtica parviflora	-	-	6.5±0.7	80	0.7±0.4	10
Chenopodium opulifolium	-	-	3.6±0.9	40	34.8±10.3	36
Mentha longifolia	-	-	1.8±0.9	30	-	-
Artemisia salsoloides	-	-	0.6±0.2	24	-	-
Artemisia capillaris	-	-	0.5±0.3	14	-	-
Malva verticillata	-	-	-	-	0.9±0.4	18

4.4.5.2 Herbaceous meadow

In Amrit Ganga watershed, a total of 75 plots (1m×1m) across three sites were sampled and 27 herb species were recorded. Evenness and diversity was recorded 0.6 and 3.4, respectively. The density was recorded highest in *Thalictrum alpinum* (35±4.4) followed by *Trachydium roylei* (27.6±6.6), *Sibbaldia parviflora* (17.5±2.7), *Gaultheria trichophylla* (7.3±3.5) and *Anaphalis royleana* (7.1±7.3). Frequency was recorded highest for *Sibbaldia parviflora* (50%), followed by *Thalictrum alpinum* (42%), *Potentilla argyrophylla* and *Taraxacum officinale* (31), *Euphorbia strachyei* (24%) and *Euphrasia himalaica* (22%). Abundance of *Trachydium roylei* was recorded highest (90.1) followed by *Anaphalis royleana* (75.6), *Thalictrum alpinum* (62.5), *Gaultheria trichophylla* (45.8) and *Polygonatum graminifolium* (34.5). Distribution of the species was contiguous (a/f ratio=>0.05).

In Satyagad watershed, a total of 50 plots (1m×1m) across two sites were sampled and 18 herb species and two shrub species were recorded. Evenness was recorded 0.8 each for herbs and shrubs. Diversity was recorded 2.8 and 0.4 for herbs and shrubs, respectively. The density was recorded highest in *Bistorta affinis* (7.5±1.1) followed by *Anaphalis royleana* (3.2±0.4), *Potentilla cuneifolia* (2.3±1.0), *Sibbaldia parviflora* (2.3±0.3) and *Potentilla argyrophylla* (2.1±0.3). Frequency was recorded highest for *Potentilla argyrophylla* (64%), followed by *Bistorta affinis* (60%), *Anaphalis royleana* (56%), *Leontopodium brachyactis* (40%) and *Bistorta tenuifolia* (36%). Abundance of *Trachydium roylei* was recorded highest (13) followed by *Bistorta affinis* (12.5), *Viola biflora* (10), *Potentilla cuneifolia* (9.7) and *Sibbaldia parviflora* (8.3). The distribution of herb species was contiguous (a/f ratio=>0.05).

In Ganesh Ganga watershed, a total of 100 plots (1m×1m) across four sites were sampled and 44 herb species and two shrub species were recorded. Evenness was recorded 0.7 and 0.3 for herbs and shrubs, respectively. Diversity was recorded 6.4 and 0.2 for herbs and shrubs, respectively. The density was recorded highest in *Bistorta affinis* (12.3±1.4) followed by *Sibbaldia parviflora* (7.7±2.4), *Arenaria* sp. (6.7±3.1), *Thymus linearis* (5.4±1.6) and *Scuttelaria prostrata* (4.9±0.9). Frequency was recorded highest for *Potentilla argyrophylla* (67%), followed by *Bistorta affinis* (48%), *Crucihimalaya himalaica* (35%), *Rosularia alpestris* (32%), *Scuttelaria prostrata* (31%) and *Tanacetum tomentosum* (29%). Abundance of *Arenaria* sp. was recorded highest (134.4) followed by *Sibbaldia parviflora* (42.6), *Bistorta affinis* (25.7), *Thymus linearis* and *Potentilla cuneifolia* (21.8 each) and *Scuttelaria prostrata* (15.9; **Table 4.14**). The distribution of herb species was contiguous (a/f ratio=>0.05).

Table 4.14 Structural aspects of dominant herbs in herbaceous meadow across three watersheds.

Species	Amrit Ganga		Satyagad		Ganesh Ganga	
	Density (ind. m^{-2}±SE)	Frequency (%)	Density (ind. m^{-2}±SE)	Frequency (%)	Density (ind. m^{-2}±SE)	Frequency (%)
Thalictrum alpinum	35±4.4	42	-	-	-	-
Trachydium roylei	27.6±6.6	23	2.1±0.4	16	-	-
Sibbaldia parviflora	17.5±2.7	50	2.3±0.3	28	7.7±2.4	18
*Gaultheria trichophylla**	7.3±3.5	12	-	-	-	-
Anaphalis royleana	7.1±7.3	7	3.2±0.4	56	-	-
Euphrasia himalaica	5.4±1.9	22	-	-	0.8±0.7	7
Potentilla argyrophylla	2.8±0.9	31	2.1±0.3	64	3.8±0.4	67
Euphorbia strachyei	2.7±0.8	24	-	-	0.5±0.2	12
Bupleurum longicaule	2.5±2.3	10	-	-	-	-
Hermenium monorchis	2.1±2.6	11	-	-	-	-
Potentilla bifurca	1.4±0.7	8	-	-	-	-
Taraxacum officinale	1.3±0.4	31	-	-	-	-
Primula denticulata	1.3±1.3	5	1.3±0.3	28	-	-
Gentiana argentea	1.2±0.9	12	-	-	-	-
Polygonatum graminifolium	0.9±3.8	2	-	-	-	-
Thymus linearis	0.7±0.5	8	-	-	5.4±1.6	25
Plantago himalaica	0.6±0.4	7	-	-	-	-
Bistorta affinis	0.5±1.1	2	7.5±1.1	60	12.3±1.4	48
Potentilla cuneifolia	-	-	2.3±1.0	24	1.1±0.7	5

Bistorta tenuifolia	-	-	2.1±0.2	36	-	-
Leontopodium brachyactis	-	-	2.0±0.2	40	2.2±0.5	20
Saxifraga brunonis	-	-	1.0±0.2	24	-	-
Oxytropis sp.	-	-	1.0±0.3	28	-	-
Viola biflora	-	-	0.8±0.3	8	-	-
Spongiocarpella nubigena	-	-	0.5±0.2	24	-	-
Arenaria sp.	-	-	-	-	6.7±3.1	5
Scuttelaria prostrata	-	-	-	-	4.9±0.9	31
Crucihimalaya himalaica	-	-	-	-	3.6±0.5	35
Rosularia alpestris	-	-	-	-	2.2±0.3	32
Tanacetum tomentosum	-	-	-	-	2.2±0.4	29
Polemonium caeruleum	-	-	-	-	1.6±1.6	12
Parrya nudicaulis	-	-	-	-	1.2±0.6	22
Geranium wallichianum	-	-	-	-	1.2±0.3	13
Aconitum violaceum	-	-	-	-	0.8±0.4	11

*=dwarf shrub

4.4.5.3 Scrub steppe

In Amrit Ganga watershed, a total of 150 plots (1m×1m) and 60 plots (5m×5m) across six sites were sampled and 55 herb and 22 shrub species were recorded. Evenness was recorded 0.7 and 0.5 for herbs and shrubs, respectively. Diversity was recorded 8.5 and 3.7 for herbs and shrubs, respectively. The density was recorded highest for *Thymus linearis* (7.6±0.7) followed by *Sibbaldia parviflora* (3.9±1.3), *Thalictrum alpinum* (3.4±1.4), *Trachydium roylei* (2.1±3.2) and *Bistorta affinis* (1.7±0.5). Frequency was recorded highest for *Thymus linearis* (50%), followed by *Iris kemaonensis* (20%), *Thesium himalense* and *Lotus corniculatus* (19.3 each), *Scuttelaria prostrata* (18.6) and *Thalictrum alpinum* (17.3%). Abundance of *Trachydium roylei* was recorded highest (62.2) followed by *Sibbaldia parviflora* (25.2), *Thalictrum alpinum* (20), *Thymus linearis* (15.2) and *Polygonatum graminifolium* (12.6). The distribution of herb species was contiguous (a/f ratio=>0.05). The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Ephedra gerardiana* (184), followed by *Juniperus indica* (127), *Devendraea myrtillus* (45), *Rosa sericea* (38) and *Berberis pseudumbellata* (16).

In Satyagad watershed, a total of 100 plots (1m×1m) and 40 plots (5m×5m) across four sites were sampled and 34 herb species and 12 shrub species were recorded. Evenness was recorded 0.7 and 0.7 for herbs and shrubs, respectively. Diversity was recorded 5.3 and 2 for herbs and shrubs, respectively. The density was recorded highest for *Thymus linearis* (9.9±1.2) followed by *Potentilla bifurca* (4.2±1.8), *Galium asperuloides* (2.2±0.6), *Potentilla cuneifolia* (1.9±1.5) and *Scuttelaria prostrata* (1.9±0.6). Frequency was recorded highest for *Thymus linearis* (69%), followed by *Scuttelaria prostrata* (34%), *Potentilla bifurca* and *Geranium wallichianum* (30% each), *Iris kemaonensis* (22%) and *Galium asperuloides* (19%). Abundance of *Thymus linearis* was recorded highest (14.3) followed by *Potentilla bifurca* and *P. cuneifolia* (13.9 each), *Dubyaea hispida* and *Potentilla microphylla* (12.5 each) and *Anaphalis royleana* (12.2). The distribution of herb species was contiguous (a/f ratio=>0.05). The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Caragana gerardiana* (134), followed by *Astragalus candolleanus* (78), *Devendraea spinosa* (60), *Juniperus communis* (51), *Berberis pseudumbellata* (20) *Potentilla rigida* (13) and *Juniperus indica* (12).

In Ganesh Ganga watershed, a total of 100 plots (1m×1m) and 40 plots (5m×5m) across four sites were sampled and 34 herb species and 12 shrub species were recorded. Evenness was recorded 0.7 and 0.7 for herbs and shrubs, respectively. Diversity was recorded 5.3 and 2 for herbs and shrubs, respectively. The density was recorded highest for *Thymus linearis* (4.8±0.3) followed by *Potentilla bifurca* (2.0±0.3), *Potentilla cuneifolia* (1.4±0.2), *Bistorta affinis* (1.4±0.4) and *Scuttelaria prostrata* (1.1±0.1). Frequency was recorded highest for *Thymus linearis* (43.8%), followed by *Potentilla argyrophylla* (31.4%), *Scuttelaria prostrata* (25.5% each), *Cousinia thomsonii* (25.1%) and *Potentilla cuneifolia* (18.7%). Abundance of *Trachydium roylei* was recorded highest (73.3) followed by *Cassiope fastigiata* (63.2), *Thalictrum alpinum* (39.3), *Bistorta affinis* (13.5) and *Potentilla bifurca* (12.2). The distribution of herb species was contiguous (a/f ratio=>0.05). The density (individuals ha^{-1}) of scrub vegetation was recorded highest for *Potentilla rigida* (1100), followed by *Caragana versicolor* (450), *Devendraea spinosa* (364), *Krascheninnikovia ceratoides* (358), *Rhododendron lepidotum* (91), *Juniperus indica* (79), *Astragalus candolleanus* (76), *Berberis pseudumbellata* (54), *Devendraea myrtillus* (54), *Lonicera obovata* (54), *Cotoneaster integerifolius* (48) and *Ephedra gerardiana* (48). The density and frequency of herbs in scrub steppe of Amrit Ganga, Satyagad and Ganesh Ganga watersheds is given in the **Table 4.15.**

Table 4.15 Structural aspects of dominant herbs in scrub steppe across three watersheds.

Species	Amrit Ganga		Satyagad		Ganesh Ganga	
	Density (ind. m^{-2}±SE)	Frequency (%)	Density (ind. m^{-2}±SE)	Frequency (%)	Density (ind. m^{-2}±SE)	Frequency (%)
Thymus linearis	7.6±0.7	50	9.9±1.2	69	4.8±0.3	43.8
Sibbaldia parviflora	3.9±1.3	15.3	-	-	0.8±0.3	8.6
Thalictrum alpinum	3.4±1.4	17.3	-	-	0.9±1.8	2.3
Trachydium roylei	2.1±3.2	3.3	-	-	1.1±2.3	1.5
Bistorta affinis	1.7±0.5	15.3	1.2±0.4	12	1.4±0.4	10.1
Polygonatum graminifolium	1.5±0.4	12	-	-	-	-
Cicerbita macrorhiza	1.3±0.7	12.7	-	-	-	-
Scuttelaria prostrata	1.2±0.5	18.7	1.9±0.6	34	1.1±0.1	25.5
Cassiope fastigiata	1.1±0.4	10	-	-	0.6±1.6	1
Iris kemaonensis	1.1±0.4	20	1.4±0.4	22	-	-
Thesium himalense	1.0±0.2	19.3	-	-	-	-
Lotus corniculatus	0.9±0.2	19.3	-	-	-	-
Gentiana argentea	0.9±0.3	12.7	-	-	-	-
Oreganum vulgare	0.8±0.3	12	-	-	0.5±0.3	6.3

Trigonella emodi	0.7±0.2	16.7	-	-	-	-
Anaphalis royleana	0.6±0.7	5.3	0.6±0.4	5	-	-
Nepeta laevigata	0.5±0.2	14	-	-	-	-
Astragalus sp.	0.5±0.2	9.3	-	-	-	-
Potentilla bifurca	-	-	4.2±1.8	30	2.0±0.3	16.8
Galium asperuloides	-	-	2.2±0.6		-	-
Potentilla cuneifolia	-	-	1.9±1.5	14	1.4±0.2	18.7
Geranium wallichianum	-	-	1.6±0.6	30	0.8±0.1	14.5
Dubyaea hispida	-	-	0.6±1.0	5	-	-
Leontopodium brachyactis	-	-	0.6±0.3	5	-	-
Nepeta laevigata	-	-	0.5±0.2	13	-	-
Potentilla microphylla	-	-	0.5±0.7	4	-	-
Euphrasia himalaica	-	-	0.5±0.4	9	-	-
Potentilla argyrophylla	-	-	-	-	0.9±0.1	31.4
Cousinia thomsonii	-	-	-	-	0.7±0.1	25.1

4.4.5.4 Tussock formation

In UDV, the areas comprising of tussock and bunch grass, *Danthonia cachemyriana* are confined mostly to Amrit Ganga watershed. A total of 50 plots (1m×1m) across two sites were sampled and 20 herb species were recorded. Evenness and diversity was recorded 0.8 and 2.3, respectively. The density was recorded highest in *Bistorta affinis* (7.4±2.6) followed by *Danthonia cachemyriana* (3.7±0.3), *Androsace sarmentosa* (3.1±0.6), *Nepeta laevigata* (2.9±0.4) and *Potentilla argyrophylla* (2.8±0.3). Frequency was recorded highest for *Danthonia cachemyriana* (92%), followed by *Potentilla argyrophylla* (76%), *Nepeta laevigata* (68), *Androsace sarmentosa* (52%) and *Bistorta affinis* (50%; **Table 4.16**). Abundance of *Bistorta affinis* was recorded highest (14.8) followed by *Thymus linearis* (8.7), *Taraxacum officinale* and *Bergenia stracheyi* (6.7), *Androsace sarmentosa* (6) and *Anaphalis royleana* (5). Distribution of the species was contiguous (a/f ratio=>0.05).

Table 4.16 Structural aspects of herbs in tussock formation of Amrit Ganga watershed.

Species	Density (ind. m^{-2}±SE)	Frequency (%)
Bistorta affinis	7.4±2.6	50
Danthonia cachemyriana	3.7±0.3	92
Androsace sarmentosa	3.1±0.6	52
Nepeta laevigata	2.9±0.4	68
Potentilla argyrophylla	2.8±0.3	76
Thymus linearis	2.1±0.8	24
Anaphalis royleana	1.5±0.5	30
Bergenia stracheyi	1.2±0.4	18
Euphrasia himalaica	0.9±0.3	28
Campanula aristata	0.8±0.4	26
Taraxacum officinale	0.8±0.9	12
Gypsophila cerastioides	0.8±0.4	18
Potentilla cuneifolia	0.7±0.4	18
Gentiana argentea	0.4±0.2	16
Sibbaldia parviflora	0.3±0.1	12

4.4.6 Similarity

4.4.6.1 Similarity within landforms

Maximum similarity (0.54) was found between moraine and scree in Ganesh Ganga watershed. Also, moraine of Amrit Ganga watershed had similarity with moraine (0.50) and scree (0.48) of Ganesh Ganga watershed (**Table 4.17; Figure 4.18**).

4.4.6.2 Similarity within landforms and physiognomic units

Maximum similarity (0.54) was found between moraine and scrub steppe in Amrit Ganga watershed followed by moraine of Ganesh Ganga and scrub steppe of Satyagad watershed (0.52; **Table 4.17; Figure 4.18**).

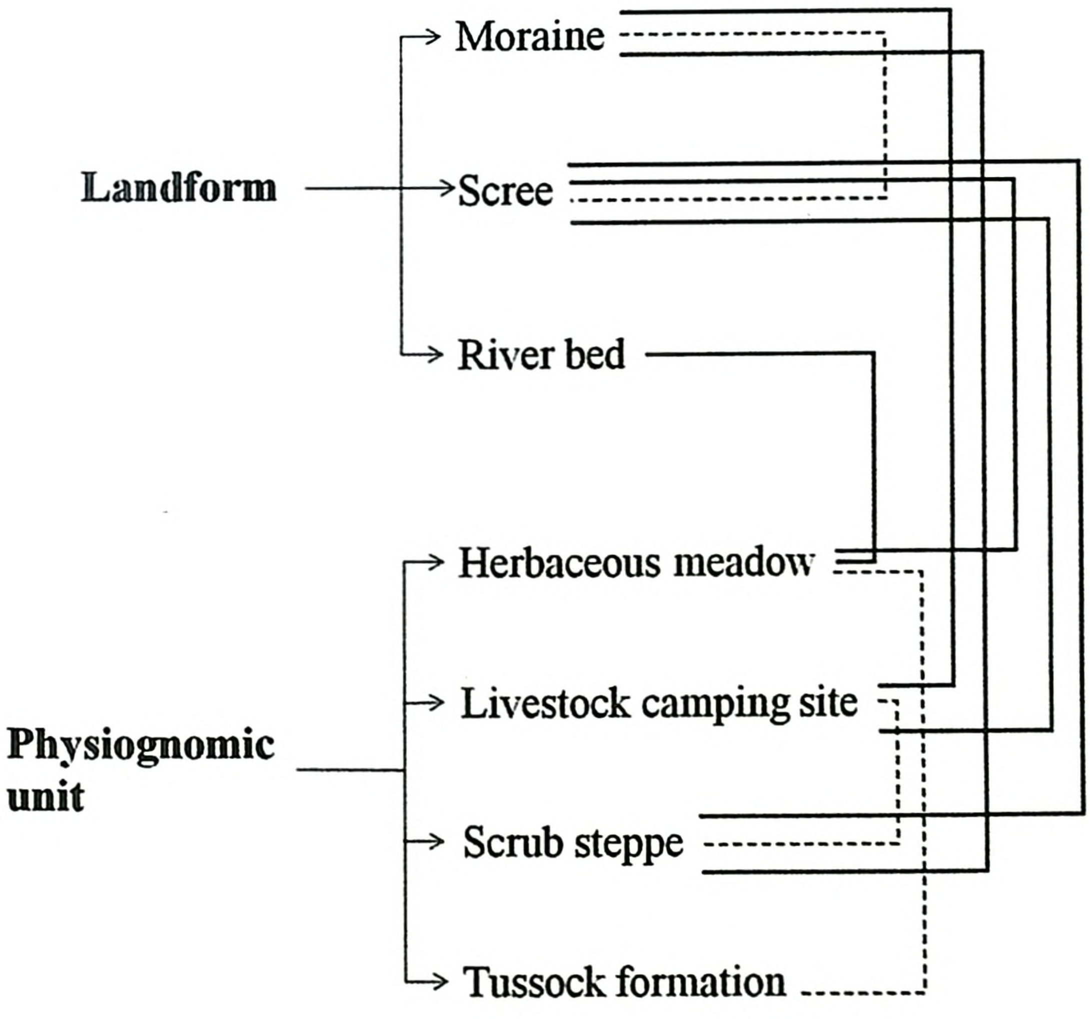

Figure 4.18 Similarity within and between landforms and physiognomic units.

4.4.6.3 Similarity within physiognomic units

Maximum similarity (0.54) was found between livestock camping site of Amrit Ganga and scrub steppe of Satyagad watershed followed by herbaceous meadow and tussock formation of Amrit Ganga (0.52; **Table 4.17; Figure 4.18**).

Table 4.17 Similarity among different landforms and physiognomic units in UDV.

Sites*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00	0.33	0.47	0.31	0.48	0.21	0.37	0.42	0.49	0.29	0.49	0.38	0.36	0.20	0.36	0.54
2		1.00	0.38	0.51	0.34	0.52	0.14	0.29	0.31	0.17	0.23	0.34	0.05	0.32	0.23	0.39
3			1.00	0.38	0.54	0.24	0.21	0.42	0.50	0.23	0.48	0.39	0.16	0.26	0.37	0.47
4				1.00	0.28	0.30	0.17	0.29	0.38	0.25	0.26	0.24	0.09	0.33	0.27	0.30
5					1.00	0.23	0.14	0.35	0.44	0.22	0.46	0.39	0.09	0.19	0.25	0.49
6						1.00	0.13	0.28	0.30	0.26	0.18	0.20	0.00	0.25	0.25	0.33
7							1.00	0.24	0.25	0.17	0.26	0.24	0.43	0.06	0.24	0.24
8								1.00	0.40	0.31	0.50	0.40	0.22	0.30	0.42	0.39
9									1.00	0.40	0.54	0.47	0.18	0.29	0.39	0.52
10										1.00	0.26	0.16	0.20	0.24	0.29	0.29
11											1.00	0.42	0.15	0.23	0.39	0.37
12												1.00	0.15	0.17	0.28	0.36
13													1.00	0.07	0.22	0.22
14														1.00	0.43	0.24
15															1.00	0.35
16																1.00

*Landforms and physiognomic units: 1-livestock camping site, Amrit Ganga (AG); 2-herbaceous meadow (AG); 3-moraine (AG); 4-river bed (AG); 5-scrub steppe (AG); 6-tussock formation (AG); 7-livestock camping site, Ganesh Ganga (GG); 8-herbaceous meadow (GG); 9- moraine (GG); 10- river bed (GG); 11-scree (GG); 12-scrub steppe (GG); 13-livestock camping site, Satyagad (SG); 14-herbaceous meadow (SG); 15-scree (SG); 16-scrub steppe (SG).

4.4.7 Relationship between vegetation and environmental variables

Canonical Correspondence Analysis (CCA) is an ordination technique that correlates the species directly with environmental variables (ter Braak 1986, 1987). This analytical technique allows a quick appraisal of how community composition varies with the environment (ter Braak 1986). This works on two sets of variables, one set of variables (dependent variables: here, abundance of species) are computed in linear combinations of exploratory variables (usually environmental parameters) in a second set. Here, variables such as topographic (slope and aspect), geographic (elevation), soil (pH, temperature and moisture) and rock cover were used as exploratory or environmental variables, as all these have strong influence on the vegetation structure and composition. CCA extracts the major gradient in the data that can be accounted for by the measured explanatory variables. CCA can not be performed, when number of sampling sites is less than the total number of selected environmental variables. Thus, CCA was performed only for moraine of Amrit Ganga watershed, scree and scrub steppe of Ganesh Ganga watershed and scree of Satyagad watershed, which comprise larger area. The details on exploratory or environmental variables (topographic, geographic and soil) used are as follows:

(i) Slope: Inclination of site (degree)
(ii) Aspect: 0°N to 359° orientation (aspect) of the site
(iii) Elevation: Height above mean sea level (m)
(iv) Soil pH: <7-acidic, >7-basic
(v) Soil temperature: Temperature of the soil (°C)
(vi) Soil moisture: (Wet weight-Dry weight)/Dry weight*100
(vii) Rock cover: Total rock/boulders percentage in the site (%)

4.4.7.1 Amrit Ganga watershed: Moraine

4.4.7.1.1 Inter-relationship between exploratory variables

All the aforesaid exploratory variables were treated with Principal Component Analysis to extract the factors of significant contribution to variations, and PCA identified three components. The variables (variance=>1) such as slope, soil moisture and soil temperature were found as principle components which showed the maximum interrelationship among them. **Table 4.18** shows the results of component analysis by PCA.

Table 4.18 Results of component analysis by PCA.

Variable	Component 1	Component 2	Component 3
Slope	0.540	-0.268	0.176
Aspect	0.334	-0.409	0.484
Rock cover	0.328	0.420	0.138
Elevation	0.504	0	-0.374
Soil temperature	0.428	0.127	-0.544
Soil pH	0.227	0.458	0.529
Soil moisture	0	0.595	0
% of Variance	37.07	25.85	16.09
Cumulative proportion	37.07	62.93	79.03

Significant habitat factor of component 1 consist of slope. Component 2 comprised of soil moisture, whereas soil temperature was the main factor of component 3 (**Table 4.18**).

4.4.7.1.2 Relationship between species abundance and exploratory variables

A canonical correspondence analysis was performed for the species with three identified independent variables such as slope, soil moisture and soil temperature. Permutation test revealed the non-significant (p-value=0.54, significance level alpha=0.001) linear relationship between species and different sampling sites with environmental variables. The Eigen values for the 1, 2 and 3 CCA axes were 0.484, 0.348 and 0.152, respectively. Cumulative 84.61 % of total variability is explained by the first two axes. In other words, the accuracy of correspondence between related pair of species and environment was found to be good only for the two axes. Slope and soil temperature formed the major variable of the F1 axes. Biplot depicted the distribution of *Potentilla argyrophylla*, *P. cuneifolia, Arenaria festucoides, Anaphalis royleana, Oxyria digyna* and *Nepeta laevigata* that are influenced by soil temperature. Soil moisture formed the major variable of the F3 axes and ordination diagram revealed that abundance of *Potentilla argyrophylla*, *P. cuneifolia, Euphrasia himalaica* and *Arenaria festucoides. Bistorta affinis*, *Euphrasia himalaica, Pedicularis bicornuta*, *Rheum webbianum* were mostly influenced by slope. *Pedicularis porrecta, Plantago himalaica, Bupleurum lanceolatum, Lotus corniculatus, Geranium wallichianum, Trigonella emodi, Turritis glabra, Sibbaldia parviflora, Cynanchum vincetoxicum* and *Aconogonum tortuosum* had the negative relationshiop with soil moisture and soil temperature. *Primula denticulata, Arisaema jacquemontii, Leontopodium brachyactis, Gaultheria trichophylla, Rumex nepalensis* and *Androsace sarmentosa* had the negative relationship with slope. A graphical representation of the contribution of exploratory variable to the distribution of plant species and sites are given in **Figure 4.19 and 4.20** respectively.

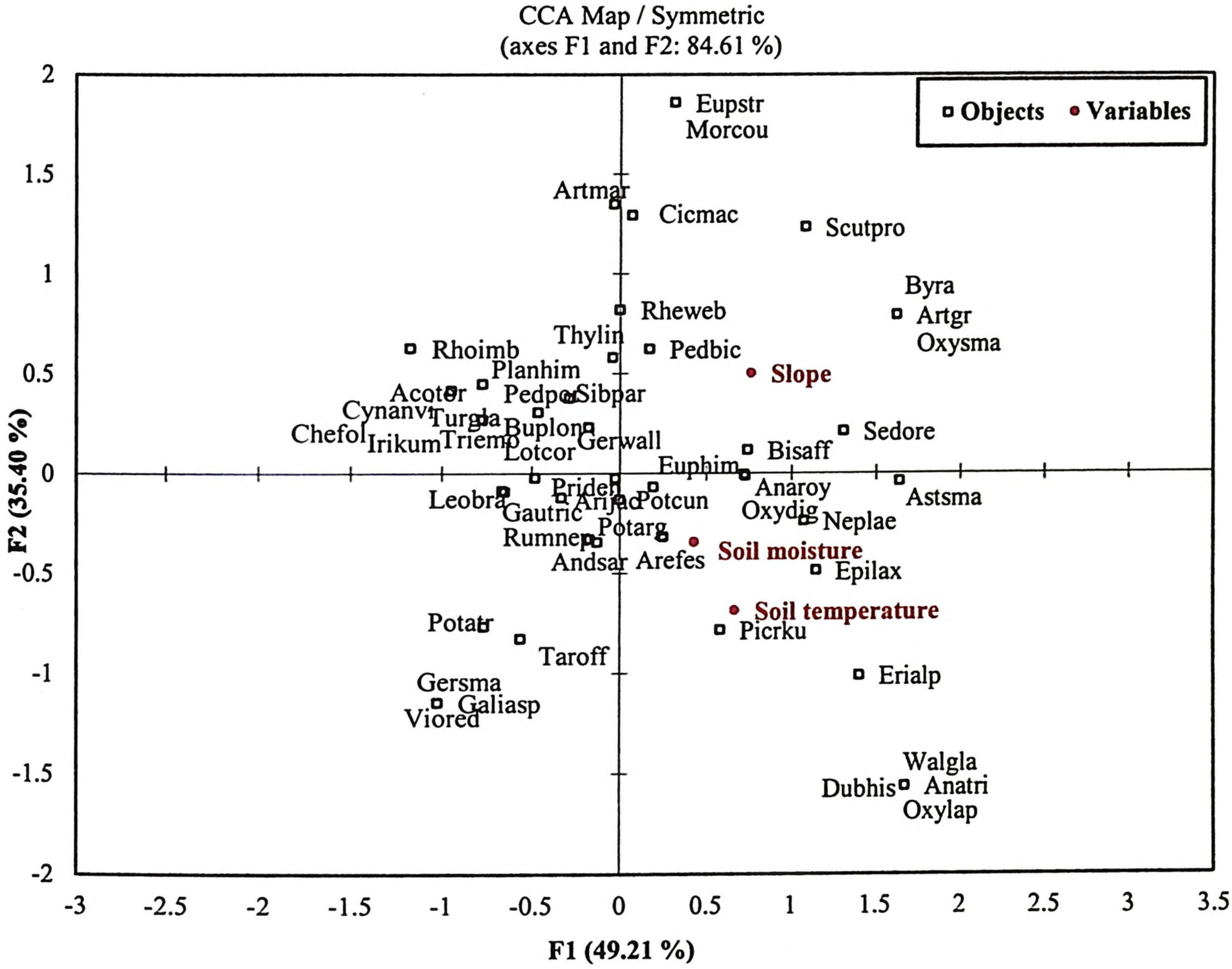

Figure 4.19 CCA map depicting relationship between species and exploratory variables in moraine, Amrit Ganga watershed. [Codes of plant species used in CCA: Acotor-*Aconogonum tortuosum*, Anaroy-*Anaphalis royleana*, Anatr-*Anaphalis triplinervis*, Andsar-*Androsace sarmentosa*, Arefes-*Arenaria festucoides*, Arijac-*Arisaema jacquemontii*, Artgr-*Artemisia* sp., Artmar-*Artemisia maritima*, Astsma-*Astragalus candolleanus*, Bisaff-*Bistorta affinis*, Byra-*Brachyactis menthodora*, Buplon-*Bupleurum lanceolatum*, Chefol-*Chenopodium foliosum*, Cicmac-*Cicerbita macrorhiza*, Cynanvi-*Cynanchum vincetoxicum*, Dubhis-*Dubyaea hispida*, Epilax-*Epilobium laxum*, Erialp-*Erigeron acris*, Eupstr-*Euphorbia stracheyi*, Euphim-*Euphorbia* sp., Galiasp-*Galium asperuloides*, Gautric-*Gaultheria trichophylla*, Gersma-*Gerbera gossypina*, Gerwall-*Geranium wallichianum*, Irikum-*Iris kemaonensis*, Leobra-*Leontopodium brachyactis*, Lotcor-*Lotus corniculatus*, Morcou-*Morina coultriana*, Neplae-*Nepeta laevigata*, Oxydig-*Oxyria digyna*, Oxylap-*Oxytropis lapponica*, Oxysma-*Oxytropis* sp., Pedbic-*Pedicularis bicornuta*, Pedpor-*Pedicularis porrecta*, Picrku-*Picrorhiza scrophulariiflora*, Planhim-*Plantago himalaica*, Potarg-*Potentilla argyrophylla*, Potatr-*Potentilla atrosanguinea*, Potcun-*Potentilla cuneifolia*, Priden-*Primula denticulata*, Rheweb-*Rheum webbianum*, Rhoimb-*Rhodiola imbricata*, Rumnep-*Rumex nepalensis*, Scutpro-*Scuttelaria prostrata*, Sedore-*Rosularia alpestris*, Sibpar-*Sibbaldia parviflora*, Taroff-*Taraxacum officinale*, Thylin-*Thymus linearis*, Triemo-*Trigonella emodi*, Turgla-*Turritis glabra*, Viored- *Viola biflora*, Walgla-*Waldheimia glabra*].

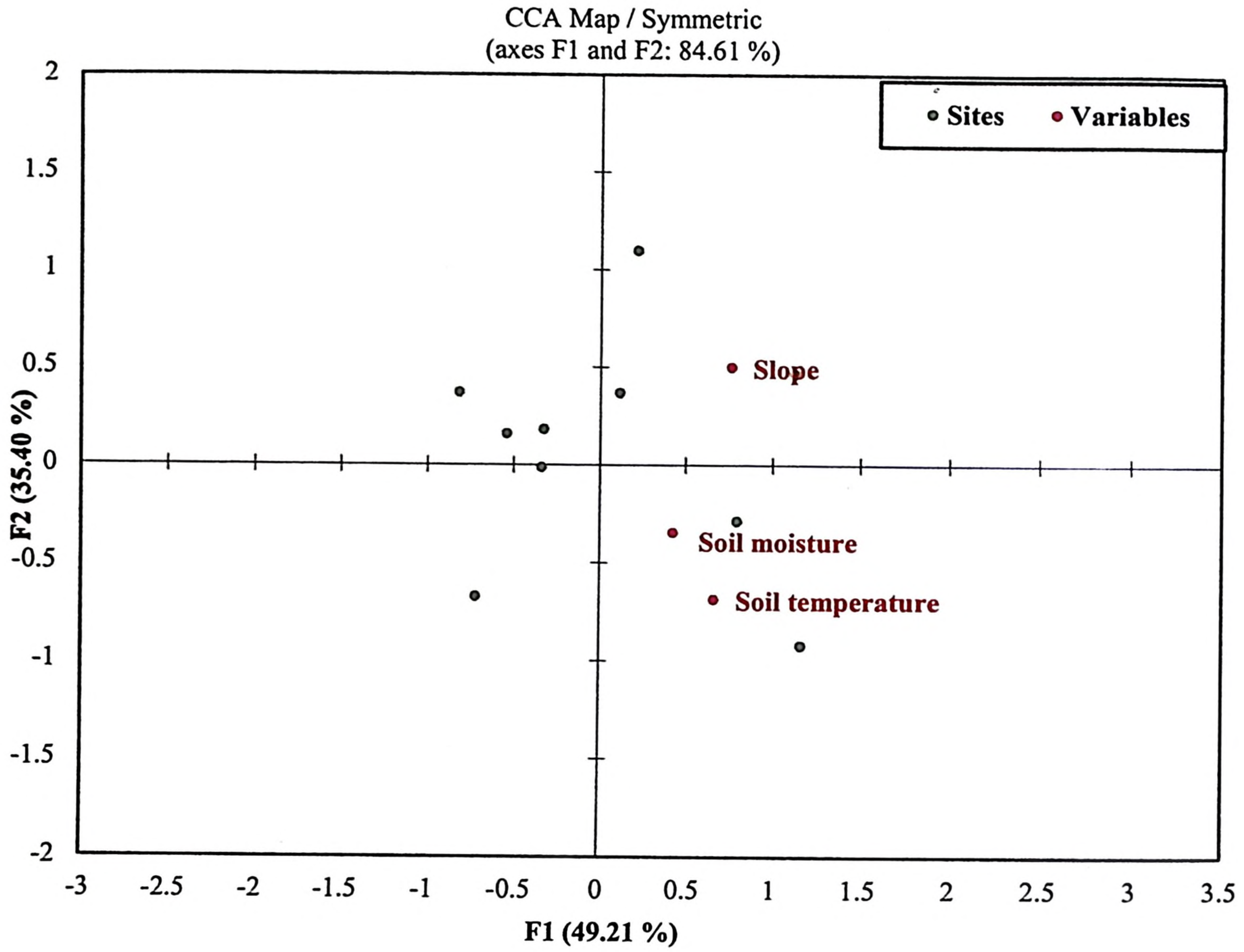

Figure 4.20 CCA map depicting relationship between sites and exploratory variables in moraine, Amrit Ganga watershed.

4.4.7.2 Ganesh Ganga: Scrub steppe

4.4.7.2.1 Inter-relationship between exploratory variables

All the aforesaid exploratory variables were treated with Principal Component Analysis to extract the factors of significant contribution to variations, and PCA identified three components (variance=>1). The variables such as elevation, slope, soil moisture, soil temperature and soil pH were found as principle components which showed maximum interrelationship among them. **Table 4.19** shows the results of component analysis by PCA.

Table 4.19 Results of component analysis by PCA.

Variable	Component 1	Component 2	Component 3
Elevation	0.551	-0.294	-0.111
Aspect	-0.389	-0.499	0
Rock cover	0	-0.261	-0.694
Slope	0.440	0	0.310
Soil moisture	0.324	0.475	0
Soil temperature	-0.490	0.383	0
Soil pH	0	-0.470	0.631
% of Variance	30.99	24.34	15.92
Cumulative proportion	30.99	55.34	71.26

Significant habitat variable of component 1 consist of elevation, slope and soil moisture. Component 2 comprised of soil moisture and soil temperature, whereas soil pH and slope were the main variables of component 3 (**Table 4.19**).

4.4.7.2.2 Relationship between species abundance and exploratory variables

A canonical correspondence analysis was performed for the species with five identified independent variables such as elevation, slope, soil moisture, soil temperature and soil pH. Permutation test revealed the significant (p-value=<0.002, significance level alpha=0.050) linear relationship between species and different sampling sites with environmental variables. The Eigen values for the 1, 2 and 3 CCA axes were 0.604, 0.548 and 0.239, respectively. Cumulative 68.87% of total variability is explained by the first two axes. In other words, the accuracy of correspondence between related pair of species and environment was found to be good only for the first two axes. Elevation and slope formed the major variable of the F1 axes. Biplot depicted the distribution of *Potentilla cuneifolia, P.argyrophylla, Silene* sp., *Aconogonum tortuosum, Thymus linearis Arenaria festucoides, Rhodiola wallichiana* and *Astragalus* sp. were mostly influenced by elevation. *Polygonum plebeium, Bistorta affinis, Euphorbia stracheyi, Sibbaldia parviflora, Anaphalis xylorhiza* and *Androsace sarmentosa* are influenced by slope and soil moisture. Soil pH and soil temperature formed the major variable of the F2 axes and ordination diagram revealed that abundance of *Trigonella emodi, Galium asperuloides, Iris kemaonensis, Morina coultriana, Artemisia maritime, Thalictrum platycarpum, Rosularia alpestris and Astragalus* sp. are influenced by soil temperature and soil pH. A graphical representation of the contribution of exploratory variable to the distribution of plant species and sites are given in **Figure 4.21 and 4.22** respectively.

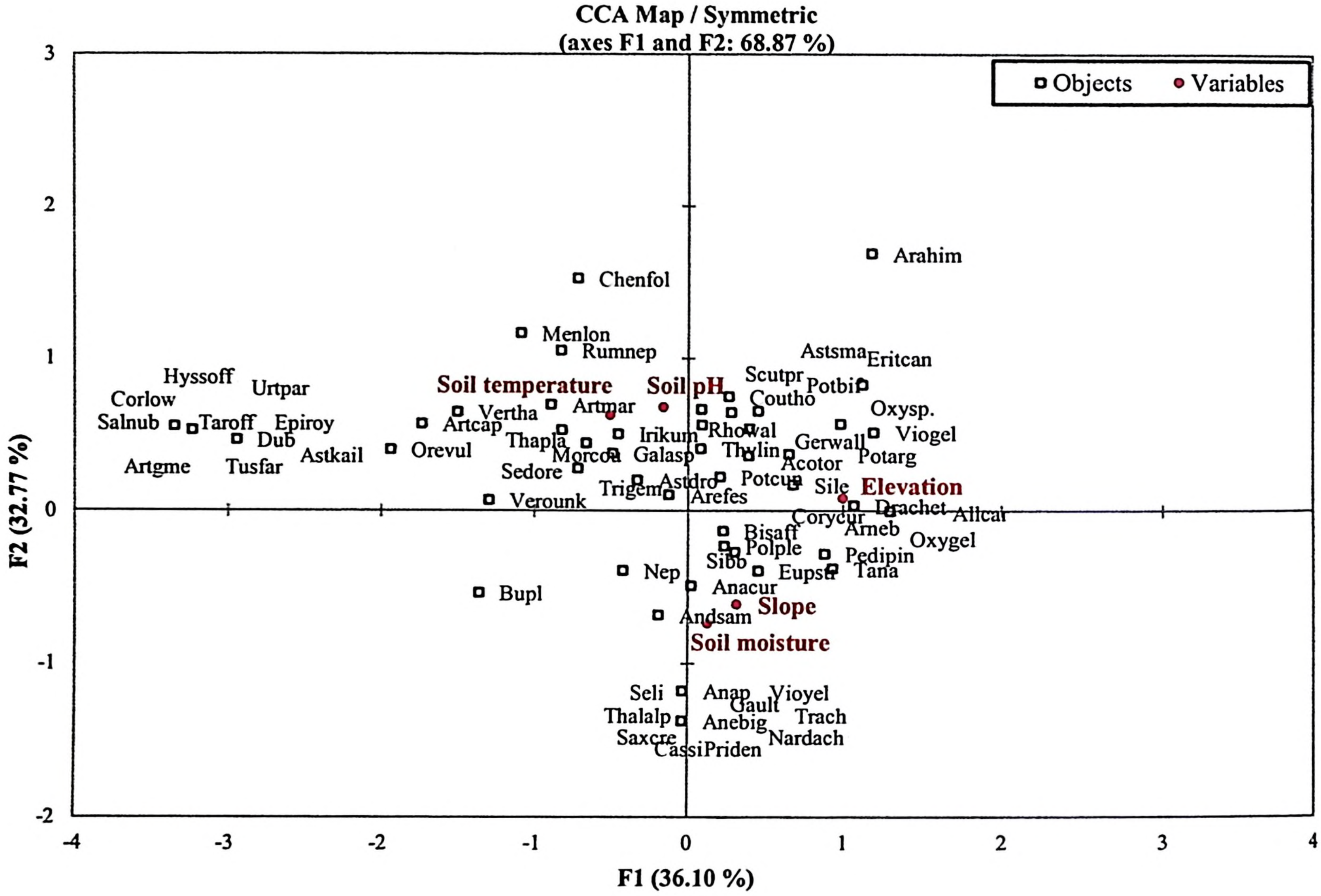

Figure 4.21 CCA map depicting relationship between species and exploratory variables in scrub steppe of Ganesh Ganga watershed. [Codes of plant species used in CCA:Acotor-*Aconogonum tortuosum*, Allicar-*Allium carolinianum*, Anap-*Anaphalis royleana*, Anapcur-*Anaphalis xylorhiza*, Andsam-*Androsace sarmentosa*, Anebig-*Anemone rupicola*, Arefes-*Arenaria festucoides*, Arneb-*Arnebia benthamii*, Artcap-*Artemisia capillaris*, Artgme-*Artemisia gmelinii*, Artemar-*Artemisia maritima*, Astdro-*Astragalus rhizanthus,* Astkail-*Astragalus densiflorus*, Astsma-*Astragalus candolleanus*, Bisaff-*Bistorta affinis*, Bupl-*Bupleurum* sp., Cassi-*Cassiope fastigiata*, Chenofol-*Chenopodium foliosum*, Corycur-*Corydalis cornuta*, Corlow-*Corydalis nana*, Coutho-*Cousinia thomsonii*, Drachet-*Dracocephalum heterophyllum*, Dub-*Dubyaea hispida*, Epiroy-*Epipectis royleana*, Eritcan-*Eritrichum canum,* Eupstr-*Euphorbia stracheyi*, Galasp-*Galium asperuloides*, Gault-*Gaultheria trichophylla*, Gerwall-*Geranium wallichianum*, Hyssoff-*Hyssopus officinale*, Irikum-*Iris kemaonensis*, Menlon-*Mentha longifolia*, Morcou-*Morina coultriana*, Nardach-*Valeriana hardwickii*, Nep-*Nepeta laevigata*, Orevul-*Oreganum vulgare*, Oxygel-*Oxytropis microphylla*, Oxysp.-*Oxytropis* sp., Pedipin-*Pedicularis* sp., Polple-*Polygonum plebeium*, Potarg-*Potentilla argyrophylla*, Potbif-*Potentilla bifurca*, Potcun-*Potentilla cuneifolia*, Priden-*Primula denticulata*, Rhowa-*Rhodiola wallichianum*, Rumnep-*Rumex nepalensis*, Salnub-*Salvia nubigena*, Saxcre-*Saxifraga flabellaris*, Scutpr-*Scuttelaria prostrata*, Sedore-*Rosularia alpestris*, Seli-*Selinum wallichianum*, Sibb-*Sibbaldia parviflora*, Sile-*Silene* sp., Tana-*Ajania tibetica*, Taroff-*Taraxacum*

officinale, Thalalp-*Thalictrum alpinum*, Thapla-*Thalictrum platycarpum*, Thylin-*Thymus linearis*, Trach-*Trachydium roylei*, Trigem-*Trigonella emodi*, Tusfar-*Tussilago farfara*, Urtpar-*Urtica parviflora*, Vertha-*Verbascum thapsus*, Verounk-*Veronica* sp., Viogel-*Viola kunawurensis*, Vioyel-*Viola biflora*].

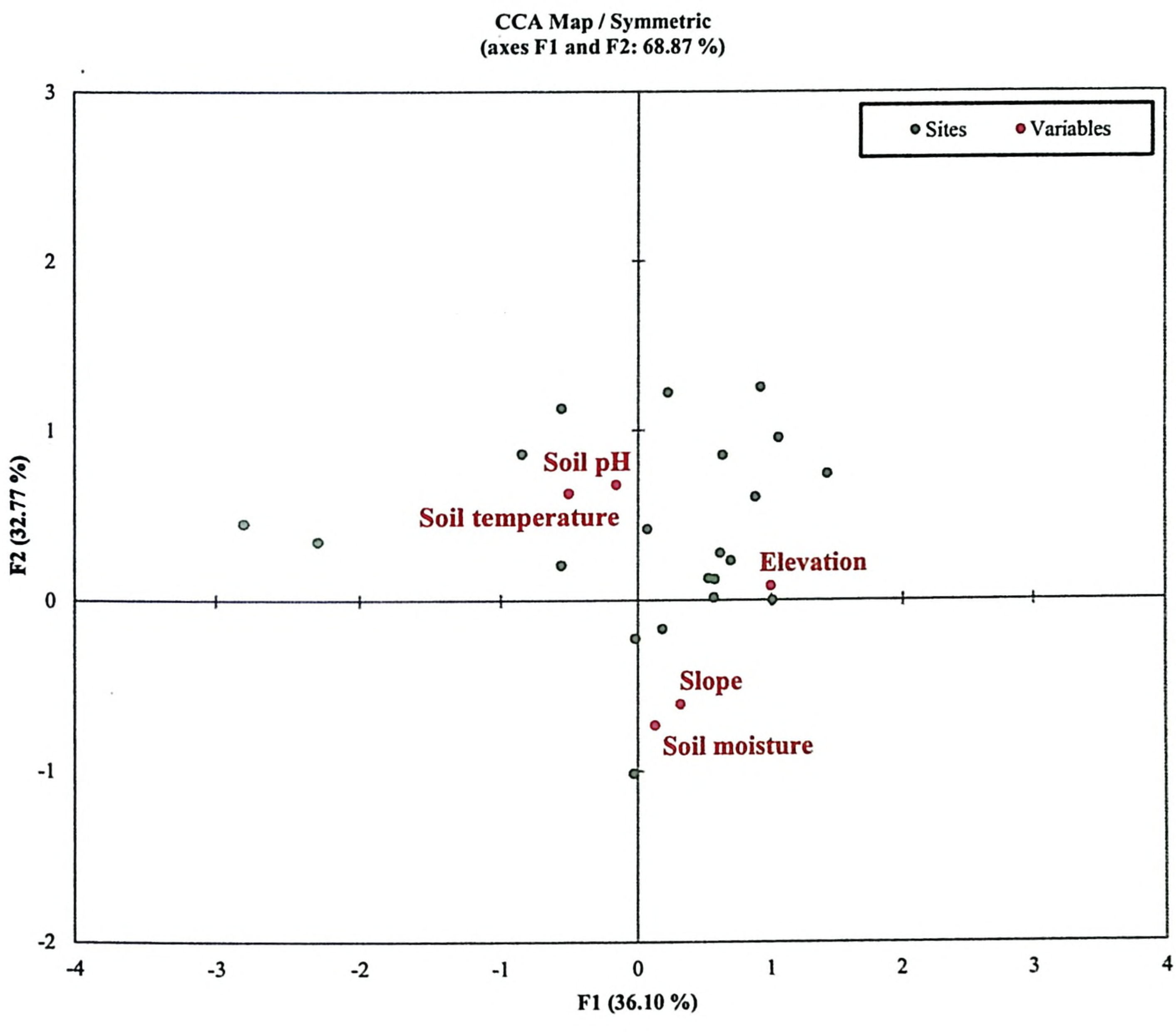

Figure 4.22 CCA map depicting relationship between sites and exploratory variables in scrub steppe of Ganesh Ganga watershed.

4.4.7.3 Ganesh Ganga: Scree

4.4.7.3.1 Inter-relationship between exploratory variables

All the aforesaid exploratory variables were treated with Principal Component Analysis to extract the factors of significant contribution to variations, and PCA identified three components (variance=>1). The variables such as rock cover, slope and soil temperature were found as principle components which showed the maximum interrelationship among them.**Table 4.20** shows the results of component analysis by PCA.

Table 4.20 Results of component analysis by PCA.

Variable	Component 1	Component 2	Component 3
Elevation	-0.509	-0.172	0.273
Aspect	0	-0.564	-0.474
Rock cover	-0.573	0	0
Slope	-0.182	-0.598	-0.108
Soil moisture	-0.450	0.152	-0.309
Soil temperature	0	0.292	-0.770
Soil pH	-0.420	0.422	0
% of Variance	37.89	31.59	17.29
Cumulative proportion	37.89	69.48	86.78

Significant habitat factors of component 1 consist of all variables with negative relationship. Component 2 comprised of soil pH, where as elevation was the main component of component 3 (**Table 4.20**).

4.4.7.3.2 Relationship between species abundance and exploratory variables

A canonical correspondence analysis was performed for the species with independent variables. Permutation test revealed the non-significant (p-value=0.425, significance level alpha=0.001) linear relationship between species and different sampling sites with environmental variables. The Eigen values for the 1, 2 and 3 CCA axes were 0.579, 0.428 and 0.267, respectively. Cumulative 73% of total variability is explained by the first two axes. In other words, the accuracy of correspondence between related pair of species and environment was found to be good only for the first two axes. Rock cover formed the major variable of the F2 axes and slope formed the major variable of F3 axes. Biplot depicted the distribution of *Potentilla cuneifolia, Geranium wallichianum, Oxytropis* sp., *Viola biflora, Allium carolinianum, Polygonum plebeium, Delphinium denudatum, Potentilla bifurca, Physochlaina praealta* due to influence of rock cover. *Delphinium cashimirianum, Dracocephallum heterophyllum, Potentilla argyrophylla* and *Bistorta affinis* were mostly influenced by slope and soil temperature. *Iris kemaonensis, Bupleurum candollei, Aconogonum tortuosum, Verbascum thapsus, Scrophularia edgeworthii, Nepeta laevigata, Mentha longifolia, Rumex nepalensis* showed negative relation with slope and soil temperature. *Astragalus candolleanus, Thymus linearis, Morina coultriana, Cousinia thomsonii, Arenaria festucoides, Lappula barbata, Potentilla atrosanguinea Rosularia* *alpestris, Thermopsis barbata* and *Heracleum pinnatum* showed negative relation with rock cover. A graphical representation of the contribution of exploratory variable to the distribution of plant species and sites are given in **Figure 4.23-4.24** respectively.

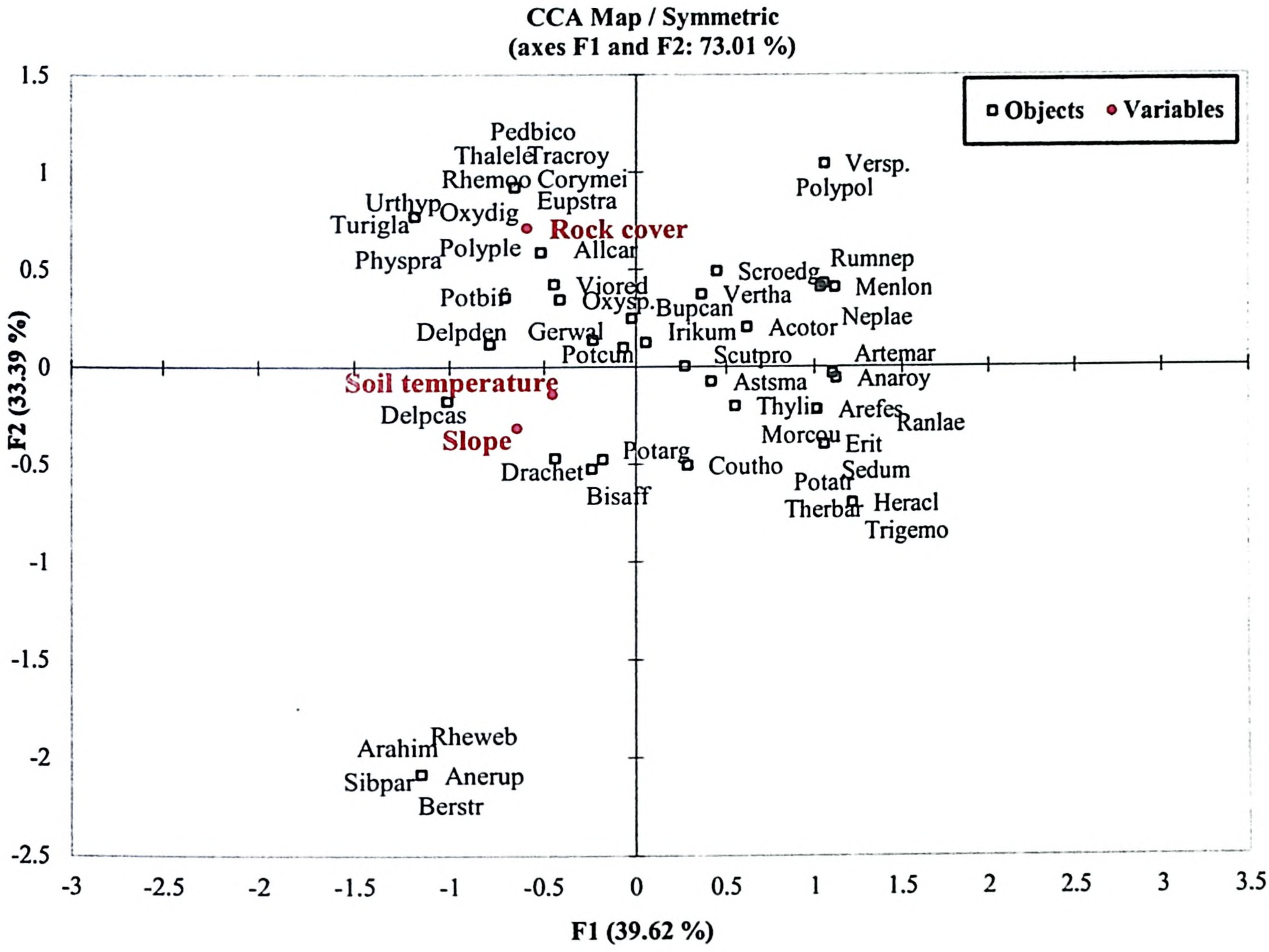

Figure 4.23 CCA diagram depicting relationship between species and exploratory variablesin scree of Ganesh Ganga watershed. [Codes of plant species used in CCA: Acotor-*Aconogonum tortuosum*, Allcar-*Allium carolinianum*, Anaroy-*Anaphalis royleana*, Anerup-*Anemone rupicola*, Arahim-*Crucihimalaya himalaica*, Arefes-*Arenaria festucoides*, Artemar-*Artemisia maritima*, Astsma-*Astragalus candolleanus*, Berstr-*Bergenia stracheyi*, Bisaff-*Bistorta affinis*, Bupcan-*Bupleurum candollei*, Coutho-Cousinia thomsonii, Corymei-*Corydalis meifolia*, Delpcas-*Delphinium cashimirianum*, Delpden-*Delphinium denudatum*, Drachet-*Dracocephalum heterophyllum*, Erit-*Lappula barbata*, Eupstra-*Euphorbia stracheyi*, Gerwal-*Geranium wallichianum*, Heracl-*Heracleum pinnatum*, Irikum-*Iris kemaonensis*, Menlon-*Mentha longifolia*, Morcou-*Morina coultriana*, Neplae-*Nepeta laevigata*, Oxydig-*Oxyria digyna*, Oxysp.-*Oxytropis* sp., Pedibico-*Pedicularis bicornuta*, Physopr-*Physochlaina praealta*, Polyple-*Polygonum plebeium*, Polypol-*Rubrivena polystachya*, Potatr-*Potentilla atrosanguinea*, Potbif-*Potentilla bifurca*, Potcun-*Potentilla cuneifolia*, Potarg-*Potentilla argyrophylla*, Ranlae-*Ranunculus laetus*, Rhemoo-*Rheum moorcraftianum*, Rheweb-*Rheum webbianum*, Rumnep-*Rumex nepalensis*, Scroedg-*Scrophularia edgeworthii*, Scutpro-*Scutellaria prostrata*, Sedum-*Rosularia alpestris*, Sibpar-*Sibbaldia parviflora*, Thalele-*Thalictrum elegens*, Therbar-*Thermopsis barbata*, Thylin-*Thymus linearis*, Trigemo-*Trigonella emodi*, Turigla-*Turritis*

glabra, Urthyp-*Urtica hyperborea*, Vertha-*Verbascum thapsus*, Verosp.-*Veronica* sp., Tracroy-*Trachydium roylei*, Viored-*Viola biflora*].

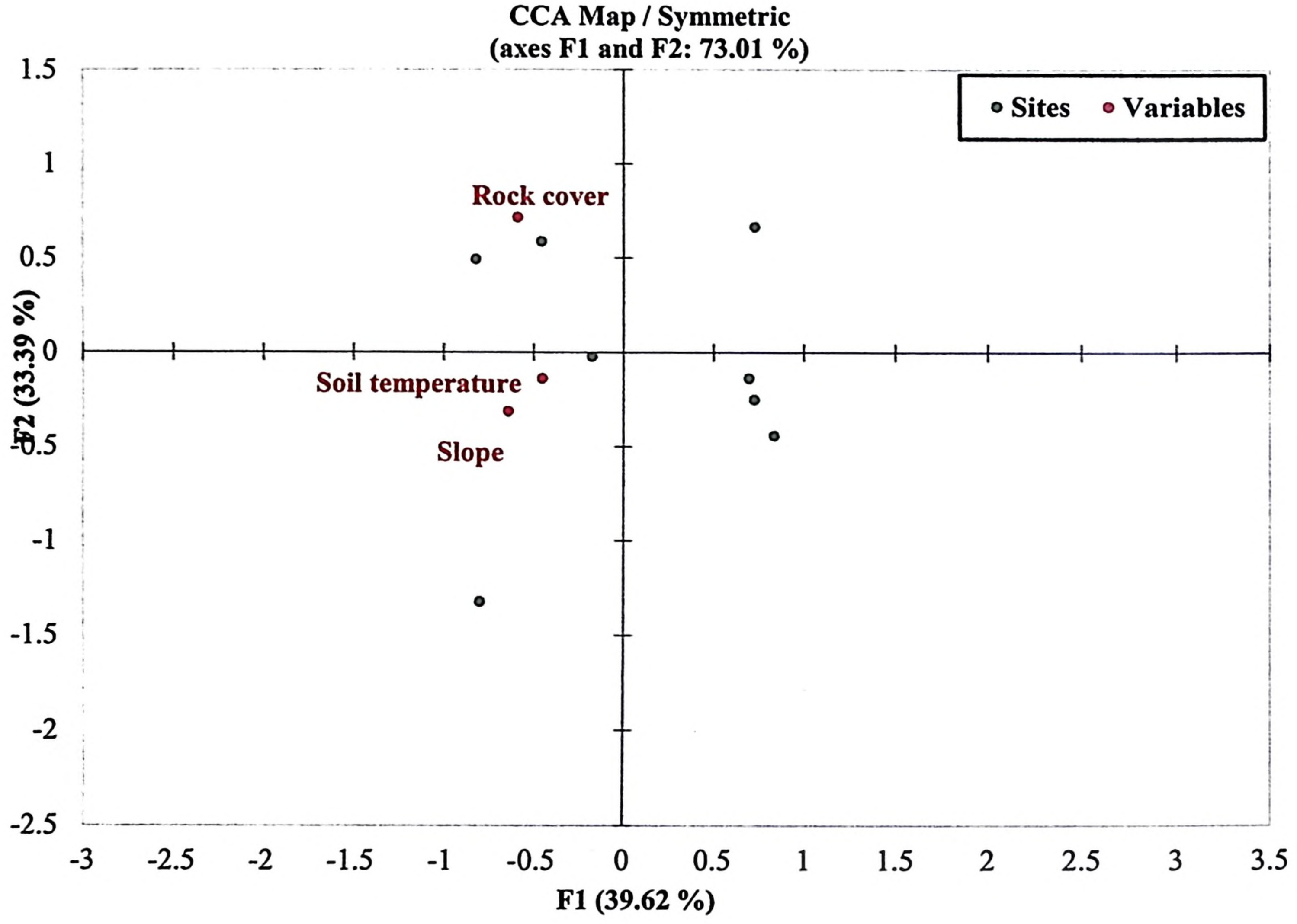

Figure 4.24 CCA diagram depicting relationship between sites and exploratory variables in scree of Ganesh Ganga watershed.

4.4.7.4 Satyagad watershed: Scree

4.4.7.4.1 Inter-relationship between exploratory variables

All the aforesaid exploratory variables were treated with Principal Component Analysis to extract the factors of significant contribution to variations, and PCA identified three components (variance=>1). The variables such as slope, soil moisture and elevation were found as principle components which showed the maximum interrelationship among them. **Table 4.21** shows the results of component analysis by PCA.

Table 4.21 Results of component analysis by PCA.

Variable	Component 1	Component 2	Component 3
Slope	0.440	0.306	-0.456
Aspect	-0.393	0.292	0
Rock cover	-0.557	0.179	-0.242
Soil temperature	-0.191	-0.409	-0.476
Soil pH	-0.431	0.239	-0.338
Soil moisture	0.332	0.488	-0.404
Elevation	0	0.572	0.478
% of Variance	38.12	23.69	19.41
Cumulative proportion	38.12	61.81	81.23

Significant habitat factors of component 1 consist of slope. Component 2 comprised of elevation and soil moisture, whereas elevation was the main component of component 3 (**Table 4.21**).

4.4.7.4.2 Relationship between species abundance and exploratory variables

A canonical correspondence analysis was performed for the species with three identified independent variables such as slope, soil moisture and elevation. Permutation test revealed the non-significant (p-value=0.698, significance level alpha=0.050) linear relationship between species and different sampling sites with environmental variables. The Eigen values for the 1, 2 and 3 CCA axes were 0.459, 0.385 and 0.114, respectively. Cumulative 88% of total variability is explained by the first two axes. In other words, the accuracy of correspondence between related pair of species and environment was found to be good only for the first two axes. Slope formed the major variable of the F1 axes. Biplot depicted the distribution of *Potentilla* sp., *Androsace globifera* and *Spongiocarpella nubigena* due to influence of slope. Soil moisture formed the major variable of F2 axes. *Potentilla* sp., *Androsace globifera Spongiocarpella nubigena* and *Potentilla bifurca* were mostly influenced by soil moisture. *Oxytropis* sp., *Potentilla argyrophylla* and *Bistorta affinis* showed negative relation to slope and soil moisture. *Potentilla cuneifolia, Geranium wallichianum* and *Nepeta laevigata* showed negative relation to elevation. A graphical representation of the contribution of exploratory variable to the distribution of plant species and sites are given in **Figure 4.25-4.26,** respectively.

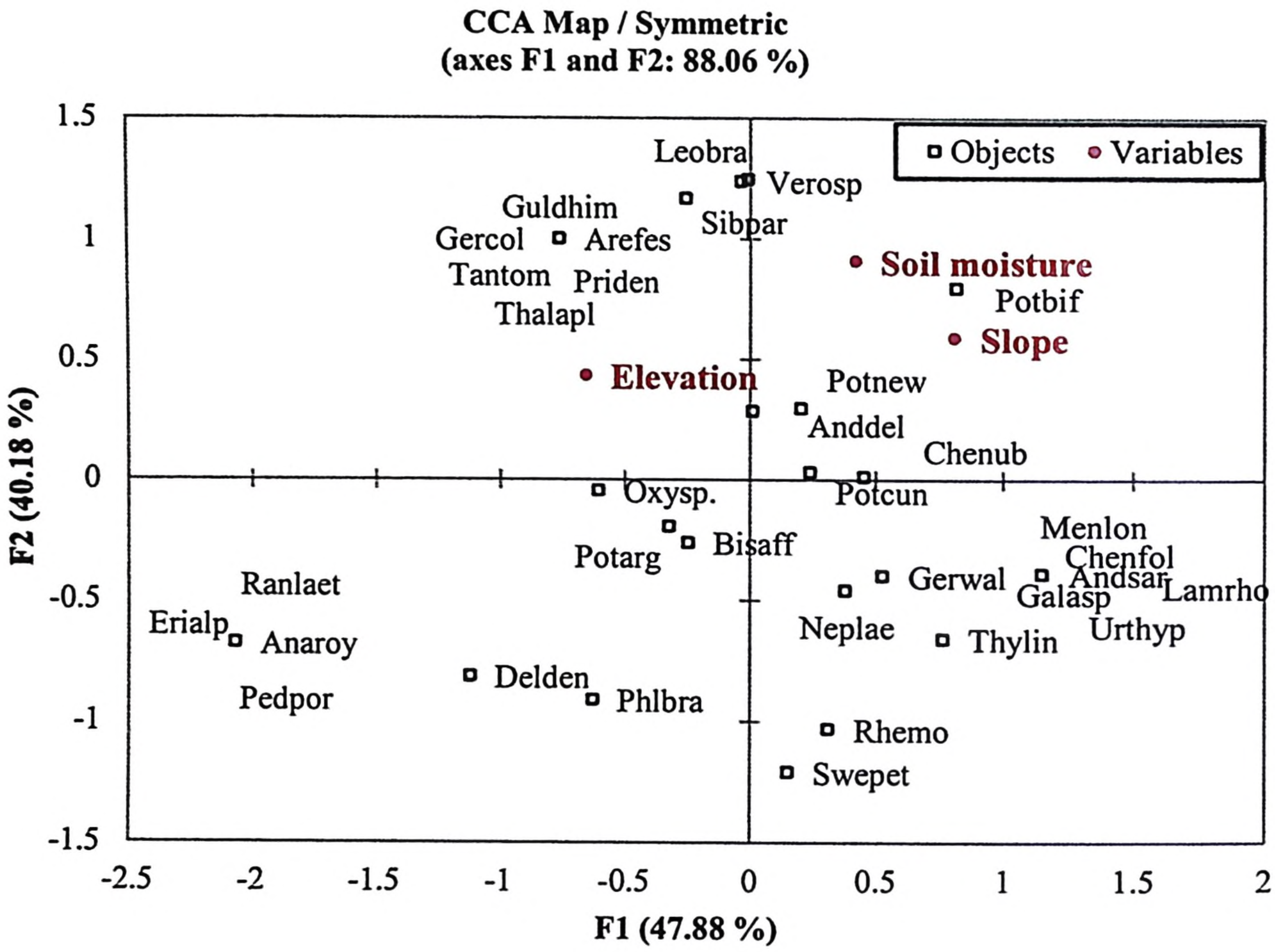

Figure 4.25 CCA diagram depicting relationship between species and exploratory variables in scree, Satyagad watershed. [Codes of plant species used in CCA:Anaroy-*Anaphalis royleana*, Anddel-*Androsace globifera*, Andsar-*Androsace sarmentosa*, Arefes-*Arenaria festucoides*, Bisaff-*Bistorta affinis*, Chenfol-*Chenopodium foliosum*, Chenub-*Spongiocarpella nubigena*, Thalalp-*Thalictrim alpinum*, Delden-*Delphinium denudatum*, Erialp-*Erigeron acris*, Galasp-*Galium asperuloides*, Gercol-*Geranium collinum*, Gerwal-*Geranium wallichianum*, Guldhim-*Tibetia himalaica*, Lamrho-*Eriophyton rhomboideum*, Leobra-*Leontopodium brachyactis*, Menlon-*Mentha longifolia*, Neplae-*Nepeta laevigata*, Oxysp.-*Oxytropis* sp., Pedpor-*Pedicularis porrecta*, Phlbra-*Phlomis bracteata*, Potarg-*Potentilla argyrophylla*, Potbif-*Potentilla bifurca*, Potcun-*Potentilla cuneifolia*, Potnew-*Potentilla* sp., Priden-*Primula denticulata*, Ranlaet-*Rananculus laetus*, Rhemo-*Rheum moorcraftianum*, Sibpar-*Sibbaldia parviflora*, Swepet-*Swertia petiolata*, Tantom-*Ajania tibetica*, Thylin-*Thymus linearis*, Urthyp-*Urtica hyperborea*, Verosp-*Veronica* sp.]

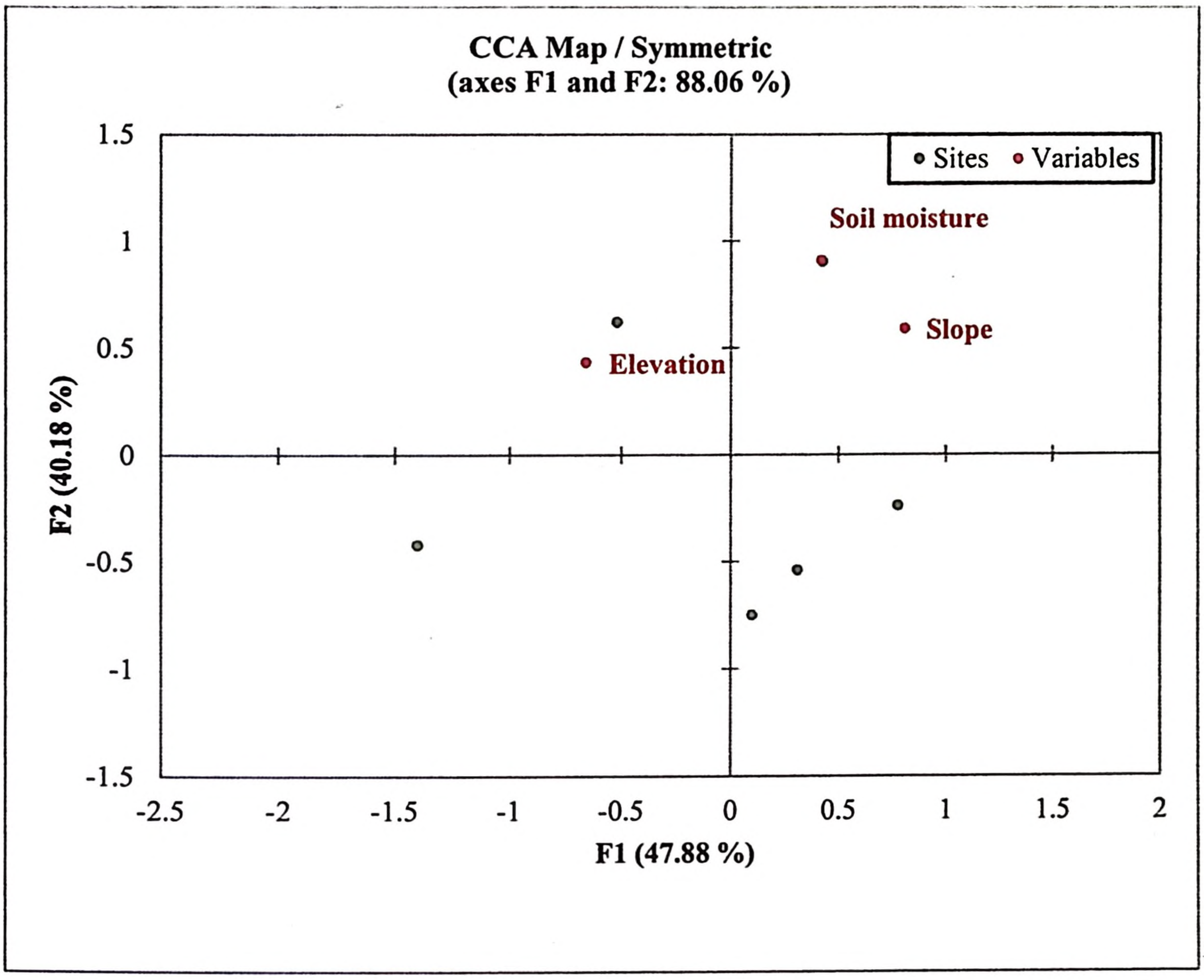

Figure 4.26 CCA diagram depicting relationship between sites and exploratory variables in scree, Satyagad watershed.

4.4.8 Soil chemical properties

The physico-chemical properties of soil play a significant role to provide conducive environment for plant growth. Soil nutrients storage has vital role to overcome from various stress conditions in the harsh climatic condition in the high altitude region. The chemical and biological properties are also regulated by physical make-up of the soil. The soil chemical properties are related to supply of nutrients to plant. However, many physical and biological properties of soil are controlled by the chemical nature of the soil.

4.4.8.1 Nutrient concentration

4.4.8.1.1 Nutrient concentration across different landforms in the valley

Nutrient concentration in the identified landforms such as moraine, river bed and scree was analyzed. Of six soil parameters recorded among different landforms, the concentration (%) for N, P, K and Na along with soil pH was recorded highest in scree. Compared to moraine, concentration of P, OC and Na along with soil pH was recorded higher in river bed where concentrations of N and K were lower. Higher nutrient percentage in scree could be attributed due to accumulation of soil and rock debris resulted due to weathering at the scree slopes. Lower nutrient percentage in moraine could be due to leaching of nutrients. The concentration of N was recorded highest in scree (0.19%) followed by moraine (0.10%) and river bed (0.07%). P was recorded highest in scree (0.17%) followed by river bed (0.12%) and moraine (0.11%). K was recorded highest in scree (0.63%) followed by moraine (0.49%) and river bed (0.20%). OC was recorded highest in river bed (2.28%) followed by scree (1.92%) and moraine (1.71%). Na was recorded highest in scree (0.43%) followed by river bed (0.40%) and moraine (0.35%). Soil pH was recorded highest in scree (6.94) followed by river bed (6.15) and moraine (5.82). The chemical attributes of the soil across different landforms are givenin **Table 4.22.**

Table 4.22 Nutrient concentrations (%±SD) across different landforms.

Nutrients	Landform		
	Moraine	River bed	Scree
Nitrogen (N)	0.10±0.03	0.07±0.05	0.19±0.19
Phosphorus (P)	0.11±0.05	0.12±0.03	0.17±0.07
Potassium (K)	0.49±0.10	0.20±0.02	0.63±0.40
Organic Carbon (OC)	1.71±0.69	2.28±1.08	1.92±1.12
Sodium (Na)	0.35±0.10	0.40±0.12	0.43±0.35
Soil pH*	5.82±0.92	6.15±1.07	6.94±1.12

*= value not in %.

4.4.8.1.2 Nutrient concentration across landforms in different watersheds of the valley

The concentration of N ranged from 0.05 (river bed in GG) to 0.27% (scree in SG), P from 0.09 (river bed in GG) to 0.17% (scree in SG and GG), K from 0.19 (river bed in AG) to 0.79% (scree in SG), OC from 1.60 (river bed in GG) to 2.97% (River bed in AG), Na from 0.25 (moraine in GG) to 0.60% (scree in GG) and soil pH from 5.32 (moraine in AG) to 7.28 (scree in GG). The chemical attributes of the soil across landformsin different watersheds are given in **Table 4.23.**

Table 4.23 Nutrient concentrations (%±SD) across landforms in different watersheds.

Nutrients	Landform					
	Moraine		River bed		Scree	
	AG	GG	AG	GG	SG	GG
Nitrogen (N)	0.10±0.04	0.11±0.02	0.09±0.02	0.05±0.07	0.27±0.23	0.12±0.11
Phosphorus (P)	0.12±0.06	0.13±0.06	0.14±0.03	0.09±0.01	0.17±0.09	0.17±0.06
Potassium (K)	0.52±0.09	0.40±0.09	0.19±0.02	0.21±0.02	0.79±0.52	0.46±0.15
Organic Carbon (OC)	1.75±0.84	1.63±0.17	2.97±1.22	1.60±0.35	2.16±1.17	1.67±1.17
Sodium (Na)	0.39±0.08	0.25±0.07	0.39±0.10	0.40±0.17	0.26±0.08	0.60±0.45
Soil pH*	5.32±0.32	7.07±0.59	5.66±0.51	6.65±1.48	6.61±1.35	7.28±0.91

Abbreviations: AG=Amrit Ganga watershed; GG=Ganesh Ganga watershed; SG=Satyagad watershed. *= value not in %.

4.4.8.1.3 Nutrient concentrations across different physiognomic units in the valley

Nutrient concentration in the identified physiognomic units such as herbaceous meadow, livestock camping site and scrub steppe was analyzed. Of six soil parameters recorded among different physiognomic units, the nutrient concentration for N, P, K and Na was recorded highest in livestock camping site. This could be attributed due to the livestock dung which adds higher nutrient concentration. The concentration of N was recorded highest in livestock camping site (0.35%) followed by herbaceous meadow (0.30%) and scrub steppe (0.25%). P was recorded highest in livestock camping site (0.25%) followed by herbaceous meadow (0.22%) and scrub steppe (0.16%). K was recorded highest in livestock camping site (0.72 %) followed by herbaceous meadow (0. 62%) and scrub steppe (0.60%). OC was recorded highest in herbaceous meadow (4.25%) followed by livestock camping site (4.19%) and scrub steppe (2.29%). Na was recorded highest in livestock camping site (0.62%) followed by scrub steppe (0.44%) and herbaceous meadow (0.42%). Soil pH was recorded highest in scrub steppe (6.94) followed by livestock camping site (5.99) and herbaceous meadow (5.58). The chemical attributes of the soil across different physiognomic units are given in **Table 4.24.**

Table 4.24 Nutrient concentrations (%±SD) across physiognomic units in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

Nutrients	Physiognomic unit		
	Herbaceous meadow	Livestock camping site	Scrub steppe
Nitrogen (N)	0.30±0.19	0.35±0.19	0.25±0.26
Phosphorus (P)	0.22±0.12	0.25±0.16	0.16±0.06
Potassium (K)	0.62±0.23	0.72±0.31	0.60±0.33
Organic Carbon (OC)	4.25±1.37	4.19±2.06	2.29±0.77
Sodium (Na)	0.42±0.11	0.62±0.33	0.44±0.16
Soil pH*	5.58±0.73	5.99±1.20	6.94±0.97

*= value not in %.

4.4.8.1.4 Nutrient concentrations across physiognomic units in different watersheds of the valley

The concentration of N ranged from 0.13 (herbaceous meadow in AG) to 0.55% (herbaceous meadow in SG), P from 0.08 (herbaceous meadow in AG) to 0.45% (livestock camping site in GG), K from 0.36 (scrub steppe in AG) to 1.08% (livestock camping site in SG), OC from 2.06 (scrub steppe in GG) to 6.43% (livestock camping site in SG), Na from 0.37 (herbaceous meadow in GG) to 0.85% (livestock camping site in GG) and soil pH from 4.96 (livestock camping site in AG) to 7.37 (scrub steppe in SG). The chemical attributes of the soil across physiognomic units in different watersheds are given in **Table 4.25.**

Table 4.25 Nutrient concentrations (%±SD) across physiognomic units in different watersheds of Upper Dhauli Valley, Nanda Devi Biosphere Reserve (±SD, *= value not in %).

Nutrients	Physiognomic unit								
	Herbaceous meadow			Livestock camping site			Scrub steppe		
	AG	SG	GG	AG	SG	GG	AG	SG	GG
Nitrogen (N)	0.13± 0.14	0.55± 0.19	0.26± 0.04	0.26± 0.05	0.44± 0.37	0.40± 0.15	0.22± 0.03	0.30± 0.12	0.24± 0.32
Phosphorus (P)	0.08± 0.00	0.36± 0.09	0.21± 0.06	0.15± 0.02	0.17± 0.07	0.45± 0.11	0.21± 0.14	0.17± 0.04	0.14± 0.02
Potassium (K)	0.44± 0.20	0.94± 0.07	0.55± 0.09	0.63± 0.19	1.08± 0.25	0.50± 0.22	0.36± 0.31	0.84± 0.59	0.59± 0.21
Organic Carbon (OC)	4.08± 0.61	5.70± 2.27	3.59± 0.74	3.33± 1.99	6.43± 1.60	3.2±0. 96	2.73± 0.34	2.68± 0.94	2.06± 0.77
Sodium (Na)	0.40± 0.06	0.52± 0.16	0.37± 0.09	0.65± 0.27	0.45± 0.16	0.85± 0.53	0.39± 0.05	0.47± 0.23	0.44± 0.16
Soil pH*	5.50± 0.32	6.09± 0.40	5.37± 0.96	4.96± 0.43	7.06± 0.34	6.45± 1.52	5.32± 0.01	7.37± 0.61	7.26± 0.69

Abbreviations: AG=Amrit Ganga watershed, GG=Ganesh Ganga watershed; Sg=Satyagad watershed.
*= value not in %.

4.5 Special Habitats

4.5.1 Cushioned vegetation

In alpine, sub-alpine, arctic or subarctic ecosystems around the world, the habitats predominately of cushioned vegetation are characterized by compact, low growing, and mat forming plant species. In the cold-arid ecosystems (above 4400 m), semi-globose to nearly mat-forming dwarf herb, *Thylacospermum caespitosum* is one of the most prominent alpine cushion plants. It occupies the highest vegetation belts at the upper vegetation limits in the region. The mosaics of *Thylacospermum* give a peculiar appearance to the landscape and represent the characteristic species as well as special habitat of the Trans-Himalayan regions. The species is chiefly found in open dry and stable slopes forming pure patches and also major association with *Caragana versicolor* (Kumar et al. 2016a). In cold-arid environments, it is chiefly the only species with a sufficiently large canopy.

In general, cushion plants are commonly considered as keystone nurse species that ameliorate the harsh conditions they inhabit in alpine ecosystems, thus facilitating other species and increasing alpine plant biodiversity. However, according to de Bello (2011b), no nursing effects of *T. caespitosum* on other alpine plants were detected. This species is phylogenetically related to another cushion species, *Arenaria polytrichoides*, having a nursing effect on the other plants, due to improved soil resources (Yang et al., 2010).

In the present study area, the presence of contiguous distribution of *Thylacospermum caespitosum* in east and south-east slopes on way to Geldung Lake (>5000 m) in Ganesh Ganga watershed and *Androsace globifera* in southern slopes of Kalazowar (>4000 m) in Satyagad watershed represent the characteristic species as well as habitats of the cold deserts **(Plate 4.1)**. These species are one of the little known, rare and spectacular cushion species in the Trans-Himalaya.

4.5.2 Caragana steppe

Amongst reported species of *Caragana*, *Caragana versicolor* Benth. is the dominant shrub species in alpine arid rangelands of the Tibetan plateau and the Trans-Himalayan Grasslands (Rawat 2008; Chandola et al. 2008; Jishtu and Goraya 2008; Dvorsky 2014). This thorny shrub and legume species is confined to West and North-West Himalaya, China, Nepal, Afghanistan and Pakistan. The dense bushy nature, thick root stock and stunted growth with cushion like habit are its adaptation to the cold arid conditions. Locally known as *'Trama'* (Western Ladakh) and *'Dam'* or *'Dama'* (Uttarakhand), *C. versicolor* is among most important and highly preferred fodder and fuel wood above 4000 m in the Trans-Himalayan regions (Rawat 2007; Rawat 2008; Jishtu and Goraya 2008; Chandola 2009). It usually occurs in well drained and loose sandy soils and can be found growing between 3800-5400 m altitudes. The mosaics of *Caragana* scrub alone and amidst *Kraschenninikovia ceratoides*, *Devendraea spinosa* and *Potentilla rigida* add a peculiar appearance to the landscape in the Geldung region of Niti Valley (Kumar et al. 2016a,c; **Plate 4.1**). Due to its adaptability to withstand harsh conditions, the growing period of this species is believed to be long as compared to other shrub species. *C. versicolor* along with few graminoids species (*Elymus*, *Carex* and *Kobresia*) is one of the few and important species grazed by wild ungulates as well as livestock during onset and outward passage of the growing seasons and especially during winter season when the resources are scarce. Owing to short growing period of graminoids and other herbaceous species, this legume species along with *Devendraea spinosa* and *Kraschenninikovia ceratoides* are the alternatives left as fodder species. Moreover, it also provides the chief source of food during the peak growing season *viz.* snow free period (June-September) every year (Rawat 2008; Chandola 2009). Keeping its unique and crucial significance to the wild and domestic ungulates in view, an attempt to highlight *C. versicolor* as a keystone species in Changthang, Ladakh has been done (Rawat 2008). Apart from animal fodder and its role in soil stabilization, whole plant is extracted by local inhabitants (Chandola 2008) and transhumant pastoralists for fuel primarily because of the lack of other source of energy in the region. In present scenario, its wide and common distribution may not be a cause of concern. *C. versicolor* is under tremendous pressure due to grazing or browsing of aboveground parts (leaves and tender shoots by sheep and goats and extraction for fuel by the herders. The depletion in its growth, population and regeneration might be crucial for sustenance of the wild as well as domestic ungulates and for local inhabitants and pastoral communities.

4.6 Discussion

4.6.1 Identification and naming of landforms and physiognomic units

Determined by climatic variability, phytogeographic affinities, moisture availability, topographical features and human interferences, the representation of habitats and their diverse plant communities at some specific biogeographic locations is justifiable. Notably, several authors have attempted to study various landscape or habitat features with their plant associations in the Indian Trans-Himalaya (ITH). Based on the review of the studies been conducted on various landscape or habitat features in ITH, the present study conclude that due to lack of general protocol to identify various landforms or physiognomic units or landscape units and their characteristic species, the workers have used such terms loosely, such as dry, degraded, undulating land areas, shady moist, eroded land. Markedly, instead of referring a particular habitat to a physiognomic unit, it has been described or defined under a landform category. Therefore, the present study provides a general protocol to identify various habitats. It suggests that the habitats which are categorized by their geo-morphological or physical attributes such as elevation, slope, orientation, stratification, rock exposure, and soil type must be referred as a '*landform*', for example moraine, scree, river bed, table land, plateau, gorge and ridge. And the habitats that are defined by their vegetation attribute or type of vegetation present such as herbaceous meadow, scrub steppe, scrublands, alpine grassland, alpine dry scrub, alpine meadow and riverine scrub are required to be referred as a '*physiognomic* or *landscape unit*'.

4.6.2 Affinity of floral characteristics

Presence of typical Trans-Himalayan floral elements (as discussed in the third chapter) and the plant communities (18) such as *Caragana-Krascheninnikovia, Potentilla rigida-Devendraea spinosa-Caragana versicolor, Potentilla rigida-Devendraea spinosa, Hippophae tibetana-Myricaria rosea, Potentilla rigida-Devendraea spinosa-Caragana versicolor, Myricaria rosea-Juniperus indica, Thymus linearis-Cousinia thomsonii-Morina coultriana, Thymus linearis-Aconogonum tortuosum-Potentilla cuneifolia, Thymus linearis-Cousinia thomsonii-Potentilla argyrophylla, Thymus linearis-Scuttelaria prostrata, Juniperus communis-Devendraea spinosa-J. indica, Potentilla rigida-Myricaria rosea, Devendraea spinosa-Lonicera obovata, Devendraea spinosa-Lonicera obovata-Juniperus indica, Caragana gerardiana-Juniperus indica, Cousinia thomsonii-Scuttelaria prostrata, Thylacospermum caespitosum-Caragana versicolor* and *Androsace globifera-Potentilla cuneifolia-P. argyrophylla* and rest of other communities from Greater Himalayan region revealed that the Upper Dhauli Valley has affinity of floral characteristics from both the regions and hence the valley forms a transition zone. In future, the information generated from the study might aid to revision of biotic province of the Himalaya, if needed.

4.6.3 Species diversity and richness across landforms and physiognomic units in three watersheds

The average number of herb species across various landform or physiognomic units was highest in herbaceous meadow (5.4±1.6) of Ganesh Ganga, tussock formation (5.4±1.7) of Amrit Ganga and herbaceous meadow (5.1±2.0) of Satyagad, whereas it was lowest (2.5±0.9 and 2.8±0.5, respectively) in livestock camping site and river bed of Ganesh Ganga. Among shrubs, average number of species was highest (3.6±1.1) in river bed of Ganesh Ganga and scrub steppe (2.9±1.1) of Amrit Ganga. Generally, the species richness decreases with increase in elevation, however, it also varies with the site conditions, for instance, the species richness was more or less similar to moraine (3400-4000 m) of Amrit Ganga and scree (>4000 m) of Satyagad and Ganesh Ganga (**Table 4.26**). Compared to adjoining areas such as Valley of Flowers National Park, the numbers of species in various landscape units are 2.5-3 times lesser in the present study area due to increasing aridity along the elevational gradients. Kala et al. (1998) recorded 10±2 and 9±3 species, respectively in river bed and moraine of VoFNP.

Table 4.26 Number of species (Mean±SD) across various landform or physiognomic units.

Landform	Watershed	No. of herb species ± SD	No. of shrub species± SD
Moraine	Amrit Ganga	3.9±1.2	2.6±1.5
	Ganesh Ganga	4.6±1.6	1.9±0.9
River bed	Amrit Ganga	4.7±1.3	1.7±0.9
	Ganesh Ganga	2.8±0.5	3.6±1.1
Scree	Satyagad	3.8±1.4	0.6±0.6
	Ganesh Ganga	3.7±1.8	1.8±0.8
Herbaceous meadow	Amrit Ganga	4.4±1.5	-
	Satyagad	5.1±2.0	-
	Ganesh Ganga	5.4±1.6	-
Physiognomic unit	**Watershed**	**No. of herb species ± SD**	**No. of shrub species± SD**
Livestock camping site	Amrit Ganga	3.9±1.2	-
	Satyagad	3.2±1.0	-
	Ganesh Ganga	2.5±0.9	-
Scrub steppe	Amrit Ganga	4.8±1.8	2.9±1.1
	Satyagad	4.0±1.2	2.8±1.3
	Ganesh Ganga	3.3±1.8	2.4±1.0
Tussock formation	Amrit Ganga	5.4±1.7	-

4.6.4 Plant communities across different landforms in three watersheds

A total of 39 plant communities in three landforms were identified using TWINSPAN computer package in three landforms across different watersheds. Highest number of communities (18) was recorded in scree while 11 in moraine and 10 in river bed (**Table 4.27**). All the landforms had different plant communities, except *Hippophae tibetana-Myricaria rosea* which was found common in riverbed of Amrit Ganga and Ganesh Ganga. Based on the stability of landscape, two courses of succession (forest and meadow succession) can be seen in the study area. Past disturbances, glacial and avalanche actions, snow deposits and geomorphological features have resulted into a mosaic of vegetation communities. Tall herbaceous plants such as *Rumex nepalensis, Impatiens sulcata* and *Epilobium* spp. seem to form a seral stage in disturbed areas. Of total, highest communities (18; 10 herb and 08 shrub) were recorded in Ganesh Ganga, followed by Amrit Ganga (12; 08 herb and 04 shrub) and Satyagad watershed (09; 06 herb and 03 shrub). The diverse flora vis a vis large number of communities in Ganesh Ganga is attributed due to larger area and varying elevational gradients.

Of total herb communities recorded, *Potentilla cuneifolia* and *Thymus linearis* represented in 11 and 10 communities, respectively. In Amrit Ganga, Satyagad and Ganesh Ganga, *Potentilla cuneifolia* dominated in three, one and two communities, respectively, while overall it represented in four, four and three communities, respectively. In Amrit Ganga and Ganesh Ganga, *Thymus linearis* dominated in one and two communities, respectively, while overall it represented in three and five communities, respectively. In Satyagad, it represented in one community. Among shrub communities, *Juniperus indica* represented in six communities albeit dominated in two communities followed by *Devendraea spinosa* in four and three (each) by *Myricaria rosea* and *Potentilla rigida*. *Hippophae tibetana-Myricaria rosea* community was found common in river bed of Amrit Ganga and Ganesh Ganga. Compared to Amrit Ganga and Satyagad watersheds, the composition of species vis a vis communities and habitats are diverse in Ganesh Ganga. Towards interior areas such as, Goting and Geldung in Ganesh Ganga affinities of most of the floral species are from Trans-Himalaya due to increasing aridity. Satyagad watershed, which is relatively small and narrow, *Juniperus indica* in southern slopes and *Rhododendron lepidotum* in north-west slopes were the principle species forming homogenous communities. In Amrit Ganga, affinities of most of the floral species are from Great Himalaya. The plant community composition was represented by species of *Potentilla, Bistorta, Anaphalis, Thymus,* *Sibbaldia, Cassiope, Gaultheria* and *Rhododendron,* which resembles to the adjoining areas such as Valley of Flowers National Park and Nanda Devi National Park. Long term monitoring and aut-ecological studies of these species will be essential for conservation of the habitats.

Table 4.27 Plant communities across different landforms in three watersheds of Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

Landform	Amrit Ganga	Satyagad	Ganesh Ganga
Moraine	*Thymus linearis-Bistorta affinis-Sibbaldia parviflora*	-	*Potentilla cuneifolia-Thymus linearis-Scuttelaria prostrata*
	Potentilla cuneifolia-Thymus linearis-Rosularia alpestris	-	*Thymus linearis-Cousinia thomsonii-Morina coultriana*
	Potentilla cuneifolia-Thymus linearis-Androsace sarmentosa	-	*Aconogonum tortuosum-Potentilla argyrophylla-Geranium wallichianum*
	Gaultheria trichophylla-Leontopodium brachyactis-Sibbaldia parviflora	-	*Juniperus communis-Devendraea spinosa-J. indica*
	Rhododendron campanulatum-Cassiope fastigiata	-	*Potentilla rigida-Devendraea spinosa*
	Devendraea myrtillus-Juniperus indica	-	-
River bed	*Potentilla cuneifolia-Thymus linearis-Taraxacum officinale*	-	*Potentilla cuneifolia-Cousinia thomsonii-Thymus linearis*
	Sibbaldia parviflora-Gerbera gossypina-Potentilla cuneifolia	-	*Bistorta affinis-Rosularia alpestris*
	Rumex nepalensis-Anaphalis royleana-Primula involucrata	-	*Potentilla rigida-Myricaria rosea*
	Equisetum diffusum-Epilobium laxum	-	*Hippophae tibetana-Myricaria rosea*
	Myricaria rosea-Juniperus indica	-	-

	Hippophae tibetana-Myricaria rosea	-	-
Scree	-	*Bistorta affinis-Potentilla argyrophylla*	*Thalictrum elegans-Trachydium roylei*
	-	*Delphinium denudatum-Anaphalis royleana*	*Dracocephalum heterophyllum-Oxytropis* sp.
	-	*Geranium wallichianum-Potentilla biflora-P.cuneifolia*	*Bistorta affinis-Anemone rupicola-Thymus linearis*
	-	*Geranium wallichianum-Potentilla cuneifolia-Thymus linearis*	*Thymus linearis-Aconogonum tortuosum-Potentilla cuneifolia*
	-	*Potentilla cuneifolia-Bistorta affinis-Geranium wallichianum*	*Cousinia thomsonii-Scuttelaria prostrata- Iris kemaonensis*
	-	*Androsace globifera-Potentilla cuneifolia-P. argyrophylla*	*Devendraea spinosa-L. obovata*
	-	*Rhodendron lepidotum*	*Potentilla rigida-Devendraea spinosa*
	-	*Juniperus indica*	*Juniperus indica-Rosa sericea*
	-	*Caragana gerardiana-Juniperus indica*	*Berberis pseudumbellata-Juniperus communis*

4.6.5 Plant communities across different physiognomic units in three watersheds

A total of 52 plant communities in four physiognomic units were segregated. Scrub steppe supported higher (28) communities followed by herbaceous meadow (12) and livestock camping site (10), tussock formation (02; **Table 4.28**). Of total, highest communities (23; 18 herb and 05 shrub) were recorded in Ganesh Ganga, followed by Amrit Ganga (16; 13 herb and 03 shrub) and Satyagad watershed (13; 10 herb and 03 shrub).

Of total herb communities recorded, *Thymus linearis* and *Potentilla argyrophylla* represented in 13 and 10 communities, respectively. In Amrit Ganga, Satyagad and Ganesh Ganga, *Thymus linearis* dominated and represented in five, three and five communities, respectively. *Potentilla argyrophylla* represented in Amrit Ganga, Satyagad and Ganesh Ganga with three and two and five communities, respectively. *Caragana versicolor-Krascheninnikovia ceratoides* and *Potentilla rigida-Devendraea spinosa-Caragana versicolor* are one of the most prominent and peculiar alpine scrub communities above 4000 m in Ganesh Ganga. The mosaics of *Caragana* give a peculiar appearance to the landscape and represent the characteristic species as well as special habitat of the Trans-Himalayan regions. The species is chiefly found in open dry and stable slopes forming pure patches and also major association with *Krascheninnikovia* alone and with *Devendraea spinosa* (Kumar et al. 2016a). In cold-arid environments, it is chiefly the only species with a sufficiently large canopy. Similarly, in Satyagad watershed, *Caragana gerardiana* admist *Devendraea spinosa* forms one of the prominent communities in southern slopes above 3800 and *Astragalus candolleanus-Rosa sericea* below 3800 m. In Amrit Ganga, the major scrub communities recorded were *Juniperus indica-Cotoneaster microphyllus*, *Ephedra gerardiana-Devendraea myrtillus* and *Rosa sericea-R. webbiana* and tussock formations comprised of *Danthonia cachemyriana* were mostly confined in this watershed.

Table 4.28 Plant communities across different physiognomic units in three watersheds of Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

Physiognomic unit	Amrit Ganga	Satyagad	Ganesh Ganga
Herbaceous meadow	*Trachydium roylei-Sibbaldia parviflora-Taraxacum officinale*	*Trachydium roylei-Potentilla cuneifolia-Sibbaldia parviflora*	*Bistorta affinis-Thymus linearis-Spongiocarpella nubigena*
	Gaultheria tichophylla-Euphorbia stracheyi-Sibbaldia parviflora	*Potentilla argyrophylla-Oxytropis* sp.-*Bistorta affinis*	*Potentilla argyrophylla-Bistorta affinis-Crucihimalaya himalaica*
	Thymus linearis-Potentilla bifurca	*Bistorta affinis-Potentilla argyrophylla-Bistorta tenuifolia*	*Geranium wallichianum-Potentilla cuneifolia*
	-	*Anaphalis royleana-Leontopodium brachyactis*	*Polemonium caeruleum-Aconitum balfourii*
	-	-	*Cassiope fastigiata-Rhododendron lepidotum*
Scrub steppe	*Potentilla cuneifolia-Sibbaldia parviflora*	*Thymus linearis-Scuttelaria prostrata*	*Thymus linearis-Scuttelaria prostrata*
	Thymus linearis-Sibbaldia parviflora-Thalictrum alpinum	*Thymus linearis-Potentilla bifurca-Geranium wallichianum*	*Oxytropis-Scuttelaria prostrata*
	Thymus linearis-Lotus corniculatus-Thesium himalense	*Thymus linearis-Galium asperuloides*	*Eritrichum canum-Potentilla argyrophylla*
	Scuttelaria prostrata-Morina coultriana	*Bistorta affinis-Iris kemaonensis*	*Thymus linearis-Viola kunawurensis-Tanacetum tomentosum*
	Rosa sericea-R. webbiana	*Astragalus candolleanus-Rosa sericea*	*Thymus linearis-Cousinia thomsonii-Potentilla argyrophylla*
	Juniperus indica-Cotoneaster microphyllus	*Juniperus communis-Devendraea spinosa*	*Potentilla argyrophylla-Anaphalis* sp.-*Aconogonum tortuosum*
	Ephedra gerardiana-Devendraea myrtillus	*Caragana gerardiana-Devendraea spinosa*	*Thymus linearis-Bistorta affinis-Potentilla argyrophylla*
	-	-	*Scuttelaria prostrata-Potentilla bifurca-P. cuneifolia*
	-	-	*Artemisia gmelinii-A. capillaris-Oreganum*

			vulgare
	-	-	*Caragana versicolor-Krascheninnikovia ceratoides*
	-	-	*Potentilla rigida-Devendraea spinosa-Caragana versicolor*
	-	-	*Devendraea spinosa-Lonicera obovata-Juniperus indica*
	-	-	*Juniperus indica-Astragalus candolleanus-Berberis pseudumbellata*
	-	-	*Rhododendron anthopogon-Devendraea myrtillus*
Tussock formation	*Danthonia cachemyriana-Potentilla argyrophylla-Bistorta affinis*	-	-
	Danthonia cachemyriana-Androsace sarmentosa-Potentilla argyrophylla	-	-
Livestock camping site	*Rumex nepalensis-Sibbaldia parviflora-Taraxacum officinale*	*Urtica parviflora-Potentilla bifurca*	*Rumex nepalensis-Chenopodium opulifolium*
	Plantago himalaica- Trachydium roylei-Taraxacum officinale	*Geranium wallichianum-Rumex nepalesis-Urtica parviflora*	*Potentilla bifurca-Malva verticillata*
	Thymus linearis-Rumex nepalensis-Potentilla cuneifolia	-	*Potentilla bifurca-Geranium wallichianum*
	Thymus linearis-Potentilla argyrophylla	-	*Chenopodium opulifolium-Polygonum plebeium*

4.6.6 High conservation concern to *Caragana versicolor,* a keystone species

Considering role of *Caragana versicolor* in ecological stability of fragile trans-Himalayan ecosystem, it would be prudent to map its distribution and area of occurrence within alpine arid rangelands of the Himalaya. Conservation awareness about the species, providing alternate fuelwood and non-conventional sources energy such as solar cookers and fuel efficient portable ovens to the pastoral communities at subsidized rates could reduce the pressure on the species. Additionally, restoration of heavily degraded sites reseeding *Caragana* and participatory monitoring with the help of herders would be the most practical way forward (Kumar et al. 2016c).

Caragana versicolor Benth. (Fabaceae), a keystone species in the Hindu Kush Himalaya.

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PLATE 4.1 LANDFORMS IN THE STUDY AREA

Moraine

Scree

PLATE 4.2 LANDFORMS IN THE STUDY AREA

River bed

PLATE 4.3 PHYSIOGNOMIC UNITS IN THE STUDY AREA

Scrub steppe

Herbaceous meadow

PLATE 4.4 PHYSIOGNOMIC UNITS IN THE STUDY AREA

Livestock camping site

Tussock grassland

CHAPTER 5

PLANT FUNCTIONAL TYPES

5.1 Introduction

The concept of classifying vascular plants was first developed by von Humboldt (1806), originally for a non-taxonomical comparison of vegetation types in different regions of the Earth. This approach is particularly useful in environments with pronounced climatic seasonality, especially where winter frost and summer drought strongly affect seasonal plant growth and development (Raunkiaer 1910). The concept of Plant functional types (PFTs), although introduced long ago (Raunkiaer 1934, Grime 1977, Noble and Slatyer 1980, Box 1981, 1996), has received new attention as one possible framework for predicting ecosystem response to human-induced changes at a global scale.

Plant Functional Types (PFTs) can be defined as groups of plants, which shows similar responses to environmental conditions with similar effects on the dominant ecosystem processes (Walker 1992; Noble and Gitay 1996; Diaz and Cabido 1997). Plants are grouped on the basis of their functional traits in the ecosystem and their utilization of various resources such as water, soil nutrients and substrate (Smith et al. 1997). There is a growing recognition of classifying terrestrial plant species on the basis of their 'functional types' rather than their higher taxonomic identity (Cornelissen et al. 2003).

Plant 'life form' classification is a simple but still useful way of functionally classifying plants designed by Raunkaier (1934). Robert Whittaker described life form classification as follows (Whittaker 1975) "*instead of the mixture of characteristics by which growth forms are defined, a single principal characteristic is used: the relation of the plant's perennating tissue to the ground surface. Perennating tissue is what enables the plant to survive harsh, unfavorable (cold or dry) seasons. For perennial plants (as contrasted with annuals), its location relative to the ground surface is an essential feature of a plant's adaptation to climate. The harsher the climate, the fewer plant species are likely to have perennating buds far above the ground surface, fully exposed to the cold or the drying power of the atmosphere*". Locating the perennating buds below the surface provides added protection from harsh-season conditions. For species that may be subject to disturbances, such as grazing and fire, the position of buds or bud-forming tissues allows us to understand the likelihood of their survival (Cornelissen et al. 2003; Harguindeguy et al. 2013).

The plant species have frequently been grouped according to the basic morphological features of their aboveground parts, i.e. growth form (Barkman 1988; Mitchley 1988). The growth form composition of communities may greatly affect the processes which are responsible for the vertical structuring in canopies (Givnish 1982; Kohyama 1992). The degree of canopy stratification, which obviously depends on community productivity, light availability and canopy density, may also be related to community growth-form structure, variability of species traits, and species diversity (Givnish 1987; Zobel and Liira 1997; Zobel et al. 1997). Plant 'growth form' is mainly determined by the direction and extent of growth, and any branching of the main-shoot axis or axes. These affect canopy structure, including its height, and both the vertical and horizontal distribution of leaves. Growth form may be associated with eco-physiological adaptation in many ways, including maximizing photosynthetic production, sheltering from severe climatic conditions, or optimizing the height and positioning of the foliage to avoid or resist grazing by particular herbivores, with rosettes and prostrate growth forms being associated with high grazing pressure by mammals (Cornelissen et al. 2003; Harguindeguy et al. 2013).

Clonality is the ability of a plant species to reproduce or regenerate itself vegetatively, thereby producing new 'ramets' (aboveground units) and expanding horizontally. Clonality can give plants competitive vigour and the ability to exploit patches rich in key resources (nutrients, water and light). Clonal behaviour may be an effective mean of short-distance migration under circumstances of poor seed dispersal or seedling recruitment. Clonality also gives a plant the ability to form a bud bank, which can be a very important determinant of recovery and persistence after environmental disturbances (Cornelissen et al. 2003; Harguindeguy et al. 2013). Clonality is considered to be important especially in stressful environments, such as cold regions of high mountains and the Arctic (Bliss 1971, Billings 1974, Jonsdottir et al. 1996, Korner 1999).

5.2 Review of Literature

5.2.1 Studies on Plant Functional Types in the Trans-Himalaya

The biological spectra of the flora of different Trans-Himalayan regions have been determined by several workers such as Klimes (2003), Rawat and Adhikari (2005), Dvorsky et al. (2011, and Shaheen et al. (2011). However, most of the studies are confined to the North West Himalaya only, especially Eastern Ladakh. Klimes (2003) reported that of total 404 vascular plants species recorded, hemicryptophytes prevailed strongly (62%) followed by therophytes (22.3%), chamaephytes (5.4%), geophytes (4.2%), phanerophytes (3.5%) and hydrophytes (1.7%) indicating desert-steppe and steppe vegetation in Eastern Ladakh. Rawat and Adhikari (2005) revealed that hemicryptophytes (57%) and chamaephytes (24%) dominate in the Tso Kar basin of Changthang Plateau. Dvorsky et al. (2011) concluded that the life-form spectrum in Eastern Ladakh is closer to desert-steppes and steppes, due to high proportion of hemicryptophytes, high number of turf grasses and low proportion of therophytes. Shaheen et al. (2011) revealed the dominance of hemicryptophytic life form (40%) followed by Chamaephytes (22%), therophytes (19%), geophytes (16%) and nanophanerophytes (3%) in the Pir Panjal subrange of Himalaya, at line of control between India and Pakistan. The rich and varied flora of NDBR has not been studied so far from this perspective.

In Eastern Ladakh, Klimes (2003) reported 26.7% of 404 plant species as clonal. Klimes (2008) recorded *ca.* 50% of 540 plants as non-clonal, which contributed more than the proportion of integrators (25–30%) and splitters (19–22%) in Ladakh. In a study conducted in Eastern Ladakh, Klimesova et al. (2011) found that non-clonal perennial species with a pleiocorm having short branches were the most abundant growth forms in steppes, *Caragana* shrubs and screes. Further, de Bello et al. (2011a) found that the proportion of non-clonal species with a perennial main root ranged from 27 to 42% across the different types of vegetation in Eastern Ladakh.

5.2.2 Studies on Plant Functional Types in the Greater Himalaya

Ram and Arya (1991) recorded a total of 142 species from Rudranath in Western Himalaya, out of which, short forbs contributed 36%, cushion and spreading forbs contributed 27%, grasses and sedges and tall forbs accounted for 17% species each, while shrubs and under shrubs contributed only 3% of the flora. Life form analysis revealed 2.8% nanophanerophytes, 12.7% therophytes, 24.6% hemigeophytes and 31% chamaephytes. Negi et al. (1992) studied phenology of 50 plant species in Baideni-Ali alpine meadow and recorded 40% species as cushion forming and sprawling forbs while rest included short forbs (24%), tall forbs (16%), grasses and sedges (14%) and shrubs and under shrubs (6%). In the Valley of Flowers National Park, Kala (1999) studied growth forms of 95 angiosperms and recorded 84% species as forbs (33% tall forbs, 22% short forbs and 29% cushion and spreading forbs), 14% evergreen shrubs and under shrubs and the remaining 2% as grasses and sedges. Vashistha et al. (2011a) reported maximum values for density and Importance

Value Index (IVI; 452.10 plants m^{-2} and 157.8, respectively) in tussock graminoids in Tungnath. Vashistha et al. (2011b) based to plant habit and height classified 68 plants of Tungnath as forbs, shrubs, grasses and sedges and under-shrubs and life form spectra revealed hemicryptophytes as dominant plant forms followed by cryptophytes, chamaephytes, phanerophytes and therophytes at grazed as well as non-grazed sites. Nautiyal et al. (2001a) reported 171 species from Tungnath, of which 9% species were grasses, sedges, other monocots, and under shrubs and 78% were forbs, of which 18% were tall forbs, 22% medium forbs, and 38% short forbs. Life form analysis revealed that phanerophytes, chamaephytes, hemicryptophytes, geophytes and therophytes were represented by 11, 18, 82, 50, and 10 species, respectively.

This chapter deals with the third objective, 'to assess the plant functional types in various landforms' and provides an elaborative account on the growth forms, life forms and clonality (clonal and non-clonal forms) across landforms and physiognomic units in Upper Dhauli Valley, a part of Nanda Devi Biosphere Reserve.

5.3 Methodology

5.3.1 Data collection and analysis

Based on direct field observations as well as descriptions or figures or photographs in the literature, each species (in the sampled sites) across landforms (moraine, scree and riverbed) and physiognomic units (herbaceous meadow, scrub steppe, tussock formation and livestock camping site) was critically analyzed and classified in one of the life form, growth form and clonality categories following Cornelissen et al. (2003) and Harguindeguy et al. (2013). The plants were assessed separately for the entire study area as well as across landforms and physiognomic units in the Upper Dhauli Valley.

5.3.1.1 Life form

The life form categories were classified based on Raunkiaer's system as modified by Ellenberg and Mueller-Dombois (1974), Cornelissen et al. (2003) and Harguindeguy et al. (2013). A biological spectrum was drawn for Upper Dhauli Valley to determine the phytoclimate of the area and was compared with Raunkiaer's normal spectrum. The definitions given below refer to the highest perennating buds for any particular plant.

i) *Phanerophytes*: plants that grow taller than 0.50 m and whose shoots do not die back periodically to that height limit.

ii) *Chamaephytes*: plants whose mature branch or shoot system remains below 0.50 m, or plants that grow taller than 0.50 m, but whose shoots die back periodically to that height limit.

iii) *Hemicryptophytes*: periodic shoot reductions to a remnant shoot system, such that the buds that produce new growth following the annual harsh season are located about at ground level.

iv) *Geophytes*: annual reduction of the shoot (and often also of the root) system to perennating organs located below the soil surface.

v) *Hydrophytes*: plants that grow in aquatic habitats, and whose perennating organs remain, during the harsh season, either in the water or (much more often) in the mud or soil at the bottom of that body of water. Aquatic plants that perennate from a bottom-dwelling organ such as a rhizome or tuber but whose shoots emerge, and display their leaves, above the water surface during the growing season, are termed *emergent hydrophytes* or *helophytes* (Greek *helos*, marsh).

vi) *Helophytes*: plants that perennate under water from a bottom-dwelling organ such as a rhizome or tuber but whose shoots emerge, and display their leaves, above the water surface during the growing season.

vii) *Therophytes*: plants whose entire shoot and root system dies after seed production, so perennate only through their seeds.

Bulb, corm and tuber-bearing plants, and those that perennate via subsurface rhizomes, are geophytes. Prostrate sub-shrubs, perennial cushion and rosette forms and plants perennating by rhizomes that grow on the ground surface, are all hemicryptophytes. Dwarf shrubs are chamaephytes. Climbers and epiphytes, along with shrubs and trees, are phanerophytes since they normally extend, or occur, more than 0.5 m above the ground surface. Therophytes include not only annuals, but also monocarpic perennials which, however, for the seasons prior to their seed reproduction, must fall into one of the other life-form categories.

5.3.1.2 Growth form

The growth forms were classified in one of the following categories:

i) *Short basal*: leaves less than 0.5 m long very close to the ground surface; rosette plants or prostrate growth forms.

ii) *Long basal*: large leaves (petiole) greater than 0.5 m long emerging from the soil surface but not forming tussocks.

iii) *Semi-basal*: significant leaf area deployed both close to the soil surface and higher up the plant.

iv) *Erect leafy*: plant essentially erect, leaves concentrated in the middle and/or top parts.

v) *Cushions* (pulvinate): tightly packed foliage held close to the soil surface, with relatively even and rounded canopy boundary.

vi) *Tussock*: many leaves from basal meristem forming prominent tufts.

vii) *Short succulent* (plant height less than 0.5 m): green globular or prostrate 'stems' with minor or no leaves.

viii) *Tall succulent* (greater than 0.5 m): green columnar 'stems' with minor or no leaves.

ix) *Climber*: plants that root in the soil and use external support for growth and leaf positioning.

x) *Dwarf shrub*: woody plants up to 0.8 m tall.

xi) *Shrub*: woody plants taller than 0.8 m with main canopy deployed relatively close to the soil surface on one or more relatively short trunks.

xii) *Tree*: woody plants with main canopy elevated on a substantial trunk.

5.4.1.3 Clonality (clonal and non-clonal forms)

For above ground clonal structures, a minimum of three plants that are far enough apart unlikely to be interconnected, and that are well developed were observed and photographed. For below ground structures, a minimum of three healthy looking plants were dig up, observed and photographed. In some cases (large and heavy root systems), partial excavation gave sufficient evidence for classification especially along trails, roadside, rocks, boulders, small streams and river. Clonality was assessed near the end of growing season. The species were considered clonal, if at least one plant clearly has one of the following clonal organs:

(A) Clonal: above ground and below ground

(I) Clonal (above ground) - clonal organs present above ground, such as,

i) *Stolon*: specialized, often hyper-elongated horizontal stems whose axillary bud growth and nodal rooting yields ultimately independent plants (*Fragaria nubicola* and *Saxifraga flagellaris*).

ii) *Bulbil*: deciduous, rooting bulblets produced from axillary or what would otherwise be flower buds, or by adventitious bud growth on leaves.

iii) Simple fragmentation of the vegetative plant body (mostly aquatic plants and bryophytes).

(II) Clonal (below ground) - clonal organs present below ground, such as,

i) *Rhizome*: more or less horizontal, below-ground stems, usually bearing non-photosynthetic scale leaves (many grasses and sedges), and sometimes instead bearing photosynthetic leaves that emerge above ground (*Iris* spp.).

ii) *Tuber*: conspicuously thickened, belowground stems or rhizomes that function as carbohydrate storage organs and bearing axillary buds that can propagate the plant (*Aconitum* spp.).

iii) *Bulb*: relatively short, below-ground stems that bear concentrically nested, fleshy scale-leaves that act as storage organs; the whole globose structure serves to perennate the plant vegetatively, through growth of axillary buds within the bulb into daughter bulbs or 'offsets'(*Allium* spp.).

(B) Non-clonal: Clonal organs absent.

5.4 Results and Discussion

5.4.1 Distribution of Life forms

5.4.1.1 Life form in Upper Dhauli Valley

The biological spectrum of the flora (495 species) revealed the dominance of hemicryptophytes (61%) followed by phanerophytes (12%), therophytes and geophytes (11% each) and chamaephytes (5%; **Figure 5.1**).

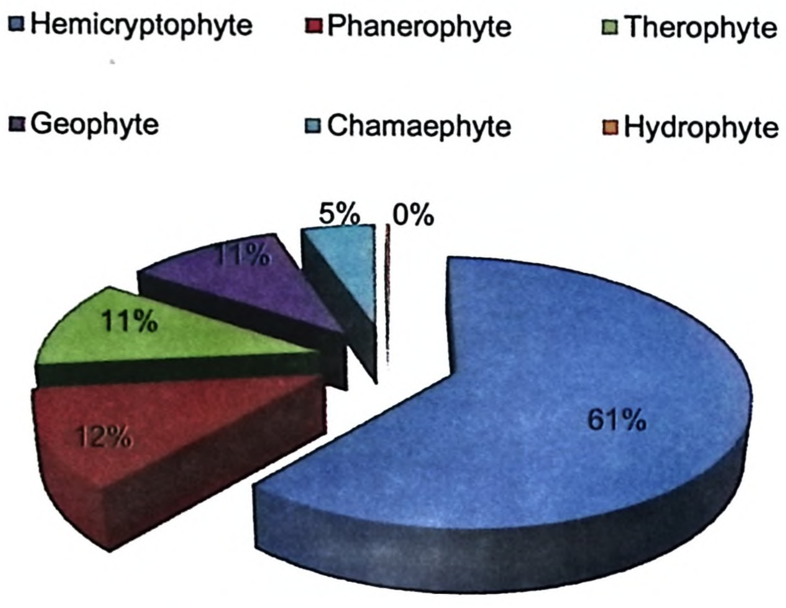

Figure 5.1 Life form categories in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

Due to high proportion of hemicryptophytes (graminoids) and low proportion of other life form categories, the biological spectrum **indicated 'hemicryptophytic' phytoclimate of the** Upper Dhauli Valley. The presence of chamaephytes (5.1%) such as *Caragana* spp., *Krascheninnikovia* sp., *Devendraea* spp., *Lonicera* spp., *Juniperus* spp., and high proportion of hemicryptophytes (61.4%) and geophytes (10.5%) indicates the flora of the region above 3800 m similar to desert steppe and steppe. Due to the presence of dry temperate forests in the lower reaches and dry sub-alpine forests predominately of *Betula utilis* (remnant patches) alongside steep ridges protruding towards hill tops, phanerophytes are comparatively higher, **albeit lower than the Raunkiaer's normal spectrum. Therophytes, which are characteristics of** desert, constitute 11.1% in the area. The therophytes (11.1%), hydrophytes (0.2%) and chamaephytes (5.1%) have comparatively smaller percentage than the normal spectrum. It clearly indicates that anthropogenic (especially over grazing) and natural factors (glaciations, landslides) are operating together. The results in present study are comparable to the similar investigations in different Trans-Himalayan regions (Klimes 2003; Rawat and Adhikari 2005; Dvorsky et al. 2011); Shaheen et al. 2011). **Tables 5.1** and **5.2** show life form studies conducted in Trans-Himalayan and Greater Himalayan regions, respectively.

Table 5.1 Comparison of major life form studies in the Trans-Himalaya.

Study area and reference	Total species	Elevation (m)	Life form (%)					
			Phanerophytes	Chamaephytes	Hemicryptophytes	Hydrophytes	Geophytes	Therophytes
Normal (Raunkaier 1934)	–	–	28	9	26	2	4	13
Ladakh (Kachroo et al. 1977)	611	2600-6000	2.6	26.8	9.6	0.6	21.3	33.2
Eastern Ladakh (Klimes 2003)	404	4180-6000	3.5	5.4	62.1	1.7	4.2	22.3
Changthang (Rawat and Adhikari 2005)	232	4400-5800	–	23.5	56.5	2.2	4.8	11.7
Pir Panjal subrange (Shaheen et al. 2011)	69	2600-3500	3	22	40	–	16	19
Present study	**495**	**3200->5000**	**11.9**	**5.1**	**61.4**	**0.2**	**10.5**	**11.1**

Table 5.2 Comparison of major life form studies in the Greater Himalaya.

Study area and reference	Total species	Elevation (m)	Life form (%)					
			Phanerophytes	Chamaephytes	Hemicryptophytes	Hydrophytes	Geophytes	Therophytes
Normal (Raunkaier 1934)	-	-	28	9	26	2	4	13
Central Himalaya (Rawat and Pangtey 1987)	-	4700-5600	-	46.6	30	-	18.3	5
Rudranath (Ram and Arya 1991)	142	3250–4200	2.8	31	24.6	-	28.9	12.7
Tungnath (Nautiyal et al. 2001a)	171	3400–4400	6.43	10.53	47.95	-	29.23	12
Tons Valley (Rana et al. 2002)	761	-	29.06	22.19	2.11	8.58	2.64	17.83
Kashmir (Dad and Khan 2010)	-	3500	5.7	13.8	48.3	-	13.8	18.4
Present study	**495**	**3200-5000**	**11.9**	**5.1**	**61.4**	**0.2**	**10.5**	**11.1**

5.4.1.2 Life form across different landforms in Upper Dhauli Valley

In all the landforms (moraine, scree and river bed), hemicryptophytes dominated strongly followed by chamaephytes, geophytes, phanerophytes and therophytes (**Figure 5.2**). Of 99 species recorded in moraine, 56% were represented by hemicryptophytes followed by chamaephytes (17%), geophytes and phanerophytes (10% each) and therophytes (6%). In scree, 65% of 88 species were represented by hemicryptophytes followed by chamaephytes (14%), geophytes (8%), phanerophytes (7%) and therophytes (6%). Of 44 species recorded in river bed, 61 % species were represented by hemicryptophytes followed by chamaephytes (18%), geophytes (11%), phanerophytes (4.5%) and therophytes (4.5%). The similar life form spectra in the landforms could be primarily due to the similarity between species of moraine and scree (54%) in Ganesh Ganga watershed. Also, species in moraine of Amrit Ganga watershed had similarity with moraine (50%) and scree (48%) of Ganga Ganga watershed (refer to section 4.5.6).

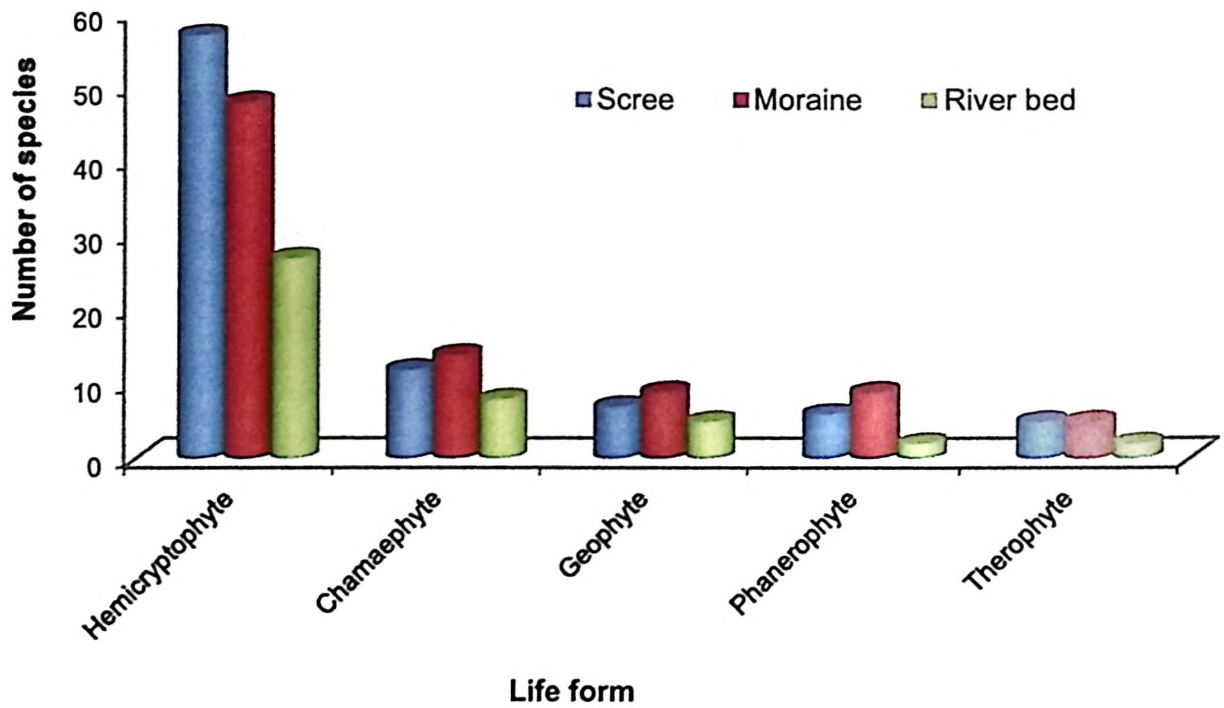

Figure 5.2 Life form categories across landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

5.4.1.3 Life form across different physiognomic units in Upper Dhauli Valley

Owing to the predominance of perennial species along with short and tall forbs in herbaceous meadow, tussock formations and livestock camping sites, the percentage of hemicryptophytes was >70%, however phanerophytes, chamaephytes and hydrophytes were relatively absent. Compared to rest of the physiognomic units, the higher percentage of phanerophytes in scrub steppe was primarily due to the prevalence of scrub vegetation. **Figure 5.3** shows the distribution of life form categories across physiognomic units in Upper Dhauli Valley. Of total 97 species recorded in scrub steppe, 60% species were represented by hemicryptophytes followed by phanerophytes (17.6%), chamaephytes (9.2%), therophytes (7.6%) and geophytes (5.3%). In herbaceous meadows, 75% of 76 species recorded were represented by hemicryptophytes followed by geophytes (13%), chamaephytes (7%) and therophytes (4.2%). In livestock camping sites, 70% of 52 species recorded were represented by hemicryptophytes followed by phanerophytes (10%), chamaephytes and therophytes (7.8% each) and geophytes (4%). Of 20 species recorded in tussock formations, 73% species were represented by hemicryptophytes followed by therophytes and geophytes (13.3% each).

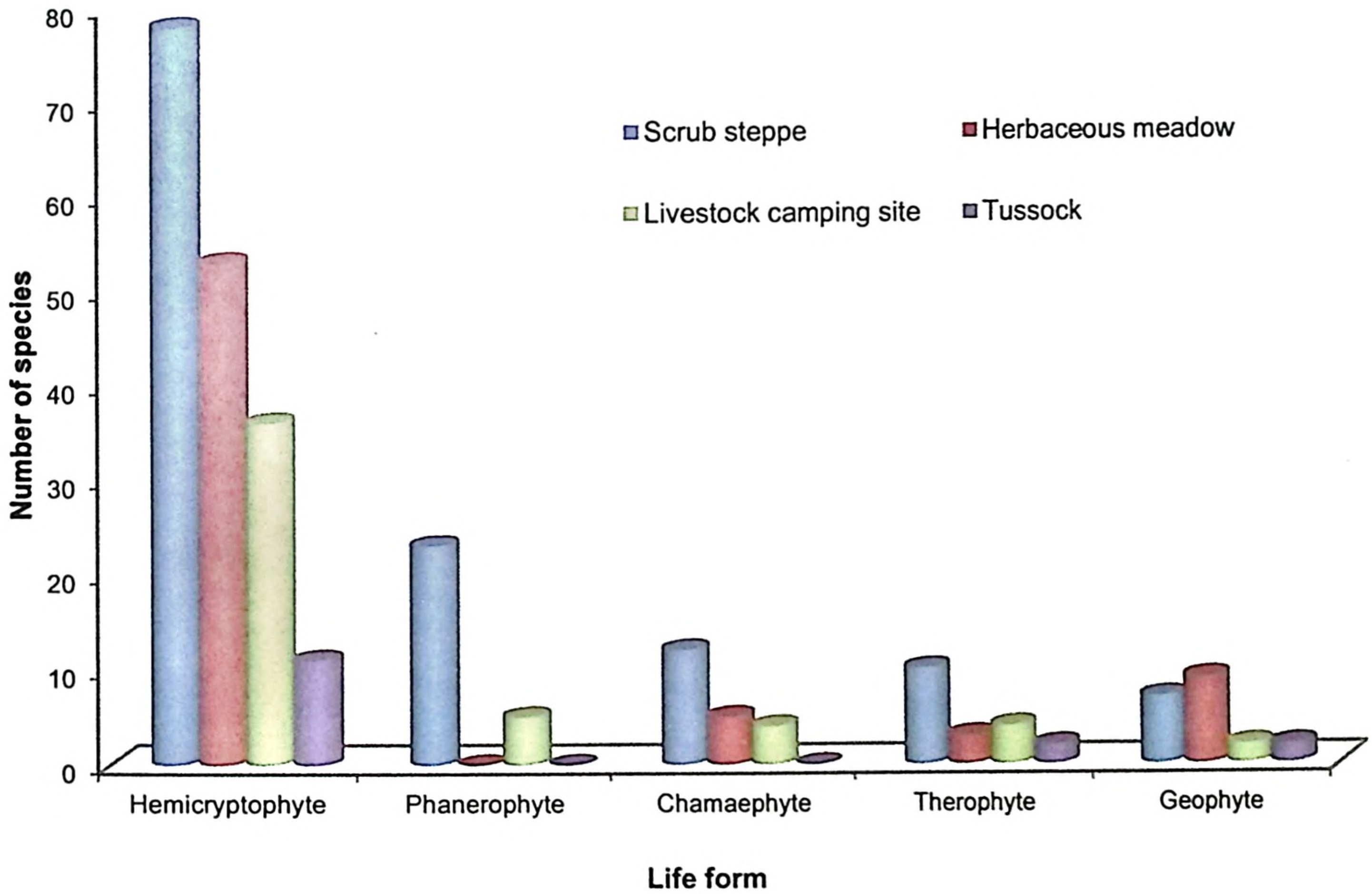

Figure 5.3 Life form categories across physiognomic units in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

5.4.2 Distribution of Growth forms

5.4.2.1 Growth form in Upper Dhauli Valley

Of 495 species recorded, semi basal and erect leafy growth forms showed dominance representing 30% and 29% species, respectively, followed by short basal (22%), shrub (7%), dwarf shrub and tree (4% each) and climber (2%; **Figure 5.4**).

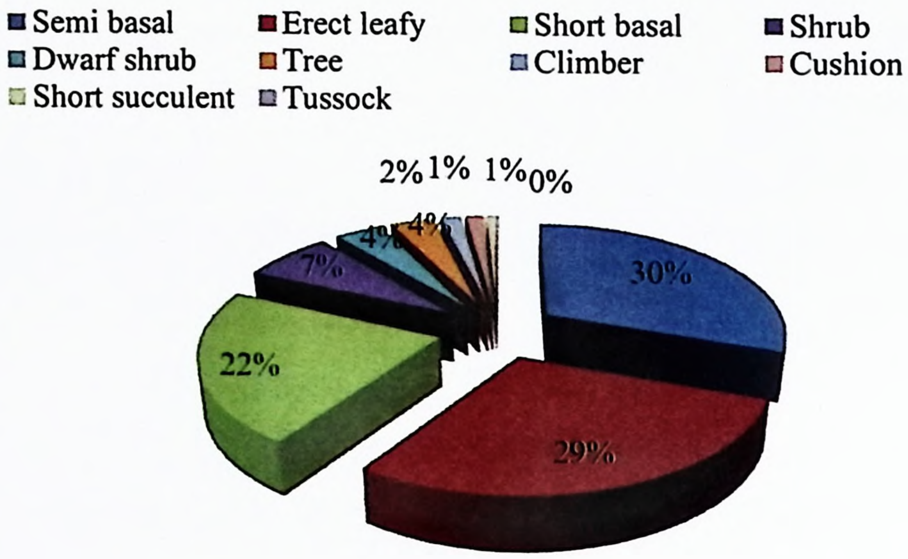

Figure 5.4 Growth form analysis of vascular plants in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

5.4.2.2 Growth form across different landforms in Upper Dhauli Valley

In moraine (99 species) and scree (88 species), short basal growth form was dominant (33% and 30% species, respectively) followed by semi basal (20% and 29% species respectively), erect leafy (17% species each), dwarf shrub (16.4% and 12.6% species) and shrub (8% and 7% species). Compared to other growth forms, short basal (rosette or prostrate plants), which is one of the characteristics of alpine arid regions represented higher percentage. The similar growth form pattern in the landforms could be primarily due to the similarity between species of moraine and scree (54%) in Ganesh Ganga watershed. Also, species in moraine of Amrit Ganga watershed had similarity with moraine (50%) and scree (48%) of Ganga Ganga watershed (refer to section 4.5.6). **Figure 5.5** shows growth form categories across different landforms in the valley. The growth forms such as tree and climber were relatively absent in scree. In river bed (44), short basal growth form was dominant (38.6% species) followed by semi basal and dwarf shrub (18% species each), erect leafy (16% species) and shrub and cushion (4.5% species each). Tree, climber and short succulent were absent in river bed.

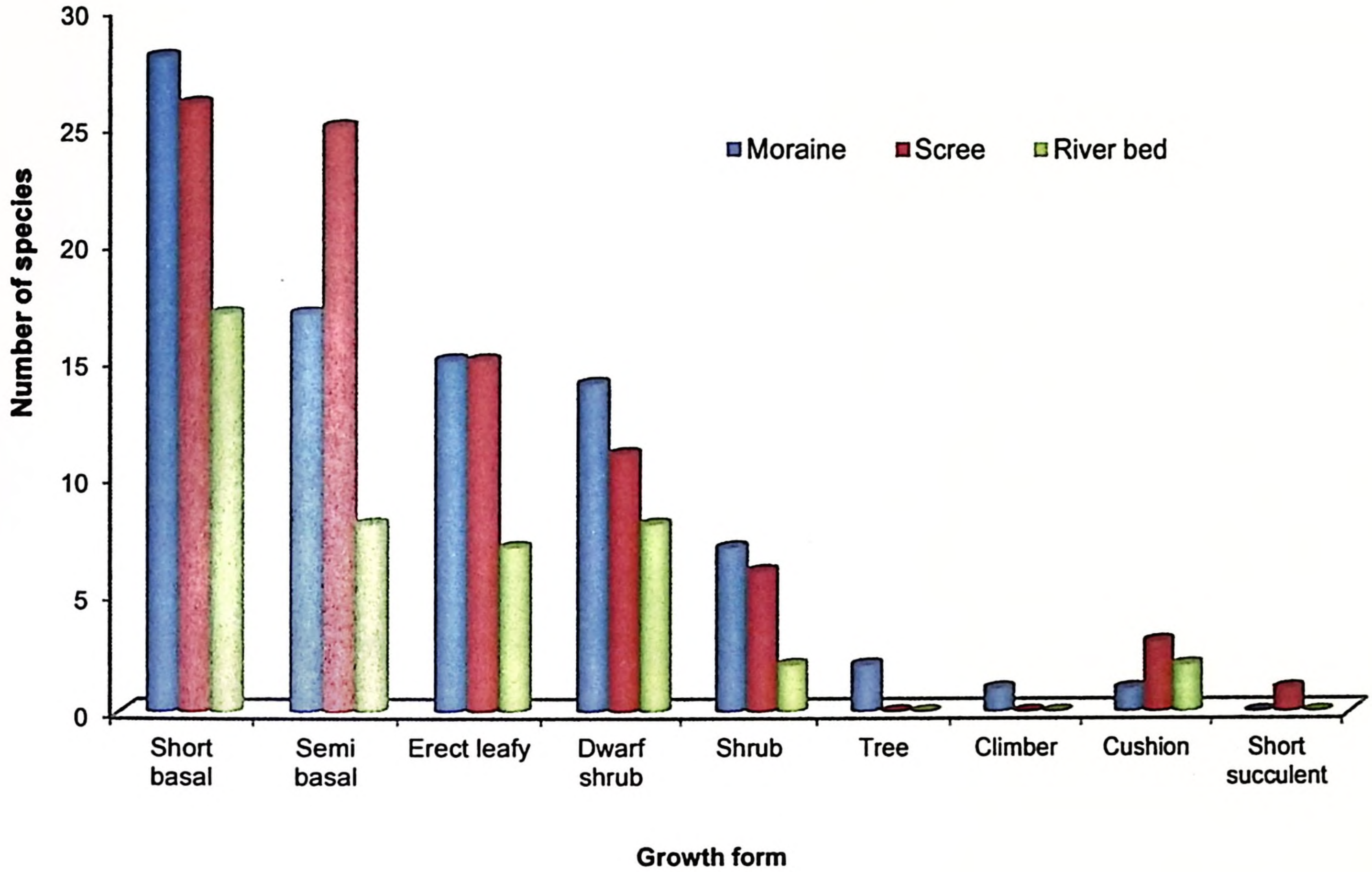

Figure 5.5 Growth form categories across landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

5.4.2.3 Growth form across different physiognomic units in Upper Dhauli Valley

In scrub steppe (97 species), erect leafy and short basal growth form dominated (25.3% and 24.6% species respectively) followed by semi basal (20.7%), shrub (13%), dwarf shrub (9.2%), tree (3%) and climber (2.3%). In herbaceous meadow (76 species), short basal were dominant (42% species) followed by semi basal (23.6%), erect leafy (18.4%), dwarf shrub (5.2%) and cushion (2.6%). In livestock camping sites (52 species), short basal were dominant (33.3% species) followed by erect leafy (29.4%), semi basal (19.6%), shrub (9.8%) and dwarf shrub (7.8%). In tussock formations (20 species), short basal represented with 60% species, semi basal (26.6%) and erect leafy and tussock (6.6% species each). **Figure 5.6** shows growth form categories across different physiognomic units in the valley.

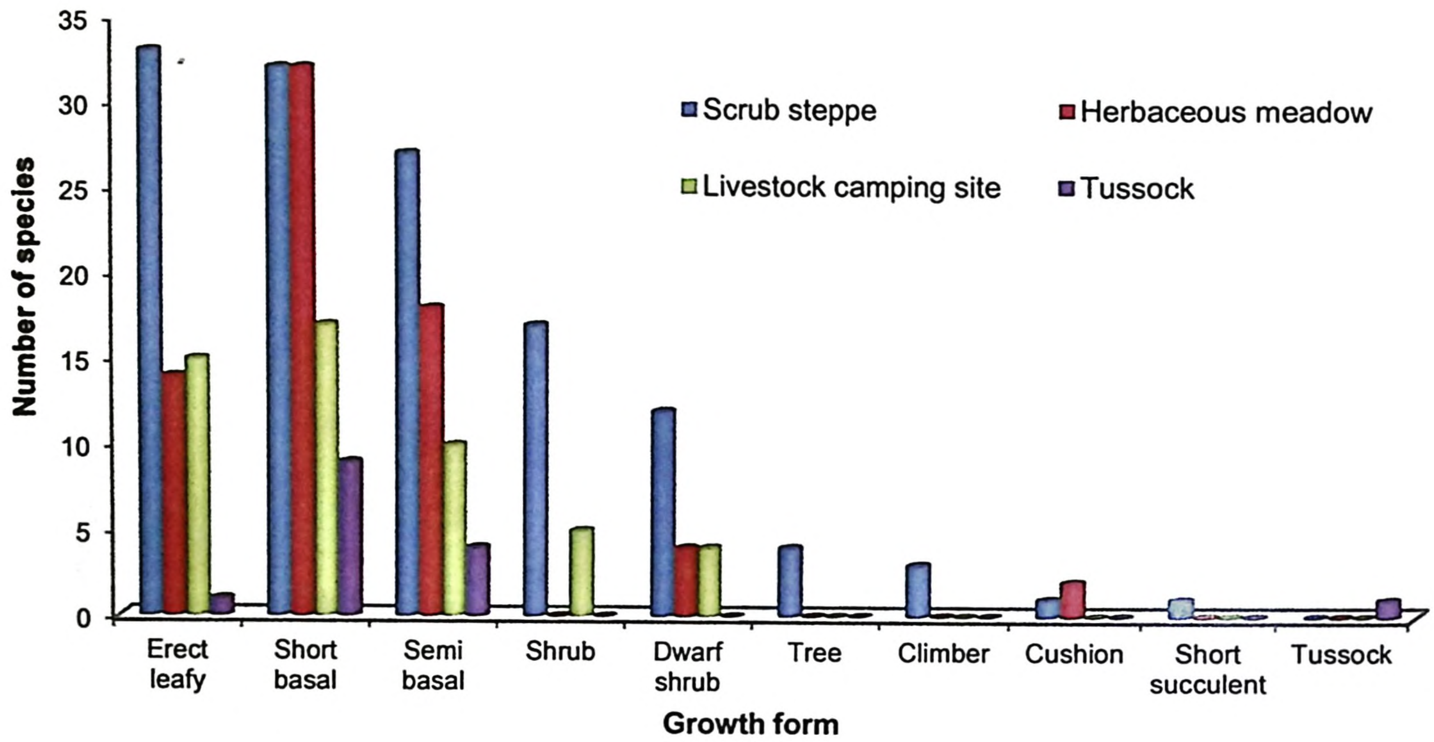

Figure 5.6 Growth form categories across physiognomic units in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

5.4.3 Clonality

5.5.3.1 Clonality in Upper Dhauli Valley

Of total 495 species recorded, non-clonal forms prevailed strongly represented by 387 species (78%). The results of present study are comparable to the similar investigations in different Trans-Himalayan regions (Klimesova et al. 2011 and de Bello et al. 2011a). Interestingly, compared to other Trans-Himalayan regions, higher proportion of non-clonal species and low proportion of clonal plants in Upper Dhauli Valley could be chiefly due to the transition zone and the affinity of floral characteristics from Greater and Trans-Himalayan region.

Among 108 clonal species (22% of total species), maximum dominance was of clonal with other mode of multiplication (49%) followed by clonal- rhizome (32.4%), clonal- bulb and clonal- tuber (6.5% each) and clonal- stolon (5.6%; **Figure 5.7**).

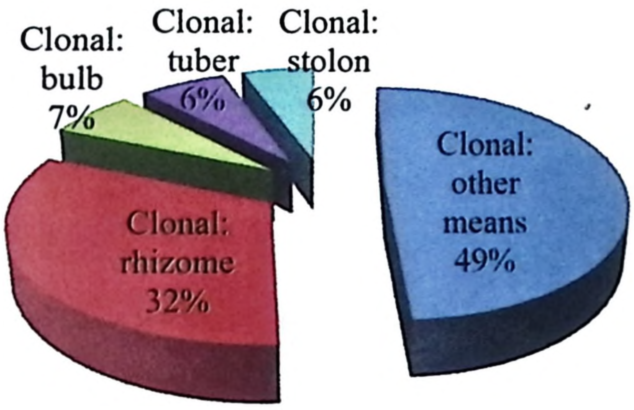

Figure 5.7 Clonality of vascular plants in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

5.4.3.2 Clonality across different landforms in Upper Dhauli Valley

Non-clonal forms were higher in scree (78 species; 20.2% of total non-clonal species) and moraine (75 species; 19.4%) followed by river bed (40 species; 10.3%). **Figure 5.8** shows clonality across different landforms in the valley. Among clonal forms, rhizome form was represented by seven species (20% of total clonal species) in moraine, six species (17%) in scree and 4 species (11.4%) in river bed. Bulb form was represented by two species namely, *Arisaema jacquemontii* and *Allium carolinianum* in moraine and one species (*Allium carolinianum*) in scree. Stolon form was represented by two species, *Androsace sarmentosa* and *Saxifraga flagellaris* in scree and one species (*Androsace sarmentosa*) in moraine.

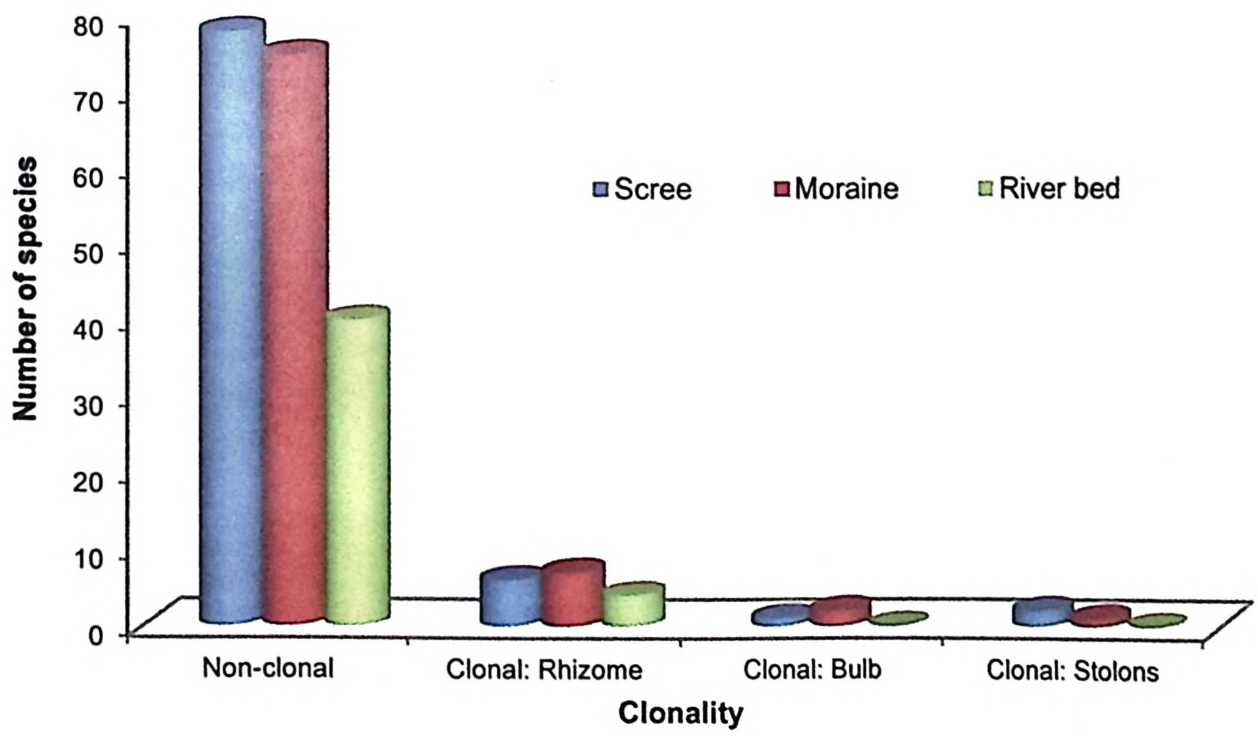

Figure 5.8 Clonality across landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

5.4.3.3 Clonality across different physiognomic units in Upper Dhauli Valley

Non-clonal forms were higher in scrub steppe (87 species; 22.4% of total non-clonal species) followed by herbaceous meadow (60 species; 15.5%), river bed (49; 12.6% of total) and tussock (11 species; 2.8%). **Figure 5.9** shows clonality across different physiognomic units in the valley. Among clonal forms, rhizome was represented by six species (5.5% of total clonal species) in herbaceous meadow, five species (4.6%) in scrub steppe and two species (2%) each in livestock camping site and tussock formation. Stolon form was represented by three species (2.7%) in scrub steppe and two species (2%) each in herbaceous meadow and tussock formation. Bulb form, represented by *Arisaema jacquemontii* and *Allium carolinianum*, was found in scrub steppe. Tuber form was represented by *Aconitum violaceum* and *Parnassia nubicola* in herbaceous meadow.

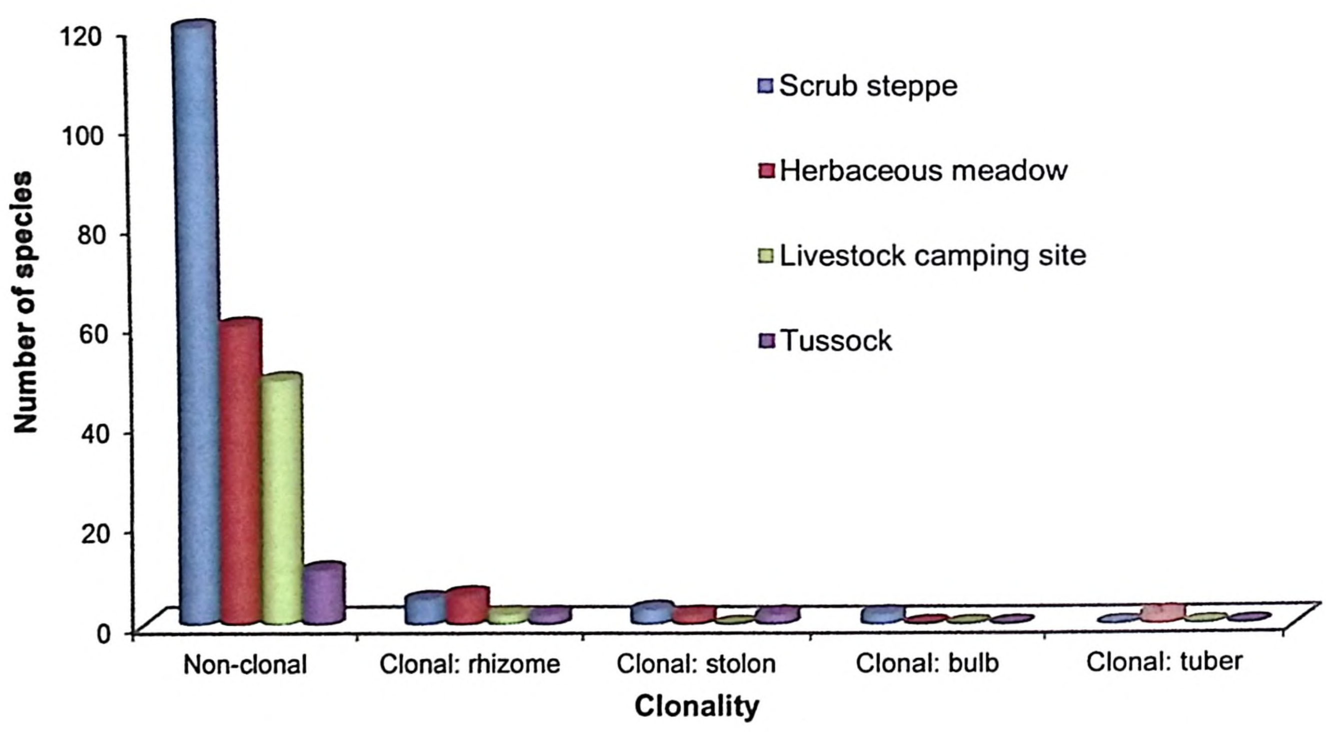

Figure 5.9 Clonality in vascular plants across physiognomic units in Upper Dhauli Valley, Nanda Devi Biosphere Reserve.

5.5 Discussion

The description and classification of vegetation is necessary to show the inter-relationship between flora and the general ecological distribution of the species with topography and climate. In Himalaya, most of the workers have focused to work on floristics and habitat ecology of plants, however, aspects such as plant architecture and phenology are poorly understood, especially in alpine habitats. Further, due to lack of standardized worldwide protocol in recent past, workers have used different categories or terms to classify the plant species. The discrepancy between results reported by individual authors was possibly partly caused by the definition of various plant forms.

In general, vegetation of the Upper Dhauli Valley is predominately of dry temperate to dry alpine type. The present study revealed five major life forms which were distinguished among the total vascular flora. All life forms were recorded between elevational ranges of 3200 to 5030 m. The dominance of hemicryptophytic life form (61%) followed by phanerophytes (12%), therophytes and geophytes (11% each) and chamaephytes (5%) indicates alpine flora equivalent to desert steppe and steppe. In the landforms such as moraine, scree and river bed, hemicryptophytes dominated strongly followed by chamaephytes, geophytes, phanerophytes and therophytes. Diversity of life forms in the study area decreased gradually above 4500 m. The life form that ceased at the lowest elevation was the phanerophytes, which reached up to 4400 m. *Betula utilis* represented as highest growing tree species. Therophytes decline gradually after 4000 m. Chamaephytes and geophytes keep a low but constant share up to 4800 m. Hemicryptophytes reach absolute dominance at the highest elevations, between 4000-5000 m and above this elevation their number gradually declined. Due to comparatively narrow valleys in cold-arid regions of Uttarakhand, marshy areas are reasonably absent; therefore hydrophytes were absent, except *Ranunculus radicans*. Similar life form patterns such as prevalence of hemicryptophytes at the highest elevations have been reported from other mountains in Central Asia, such as Hindu Kush (Agakhanyantz and Breckle 1995) and Nanga Parbat (Dickoré and Nüsser 2000). However, in the study area particular similarities with respect to the life form spectra of other Trans-Himalayan regions take place at high elevations (above 4000m).

Among the growth forms, semi basal and erect leafy showed dominance representing 30% and 29% species respectively, followed by short basal (22%), shrub (7%), dwarf shrub and tree (4% each) and climber (2%). Subsequently, in the landforms such as moraine and scree, short basal growth form was dominant (33% and 30% species, respectively) followed by semi basal (20% and 29% species, respectively), erect leafy (17% species each), dwarf shrub (16.4% and 12.6% species) and shrub (8% and 7% species). In river bed, short basal growth form dominated (38.6% species) followed by semi basal and dwarf shrub (18% species each), erect leafy (16% species) and shrub and cushion (4.5% species each).

Out of 495 species of vascular plants recorded in the study area, clonal plants comprised 21.8% of species and non-clonal forms prevailed strongly represented by 387 species (78.2%). Among clonal species, maximum dominance was of clonal (49%) followed by clonal- rhizome (32.4%), clonal- bulb and clonal- tuber (6.5% each) and clonal- stolon (5.6%). Subsequently, across different landforms, non-clonal forms were higher in scree (78 species) and moraine (75) followed by river bed (40). Among clonal forms, rhizome represented with seven species in moraine, six species in scree and 4 species in river bed. Plants with bulb, stolon and tuber are very few in the studied area, and almost confined to drier areas along steep slopes. Bulb form represented with two species in moraine and one species in scree. Stolon form represented with two species in scree and one species in moraine. As per Klimes (2003), among clonal plants of Ladakh, tuft grasses with limited clonal spreading prevail (12.1% of species), followed by plants with hypogeogenous (initiated below-ground) rhizomes (7.4%). The results in present study are comparable to the similar investigations in different Trans-Himalayan regions such as Eastern Ladakh, where the non-clonal perennial species prevailing in steppes, *Caragana* shrubs and screes are the most abundant species. Similar trends of decreasing clonality in vascular plants were also observed at extreme latitudes of the Arctic (Aleksandrova 1983).

Compared to Ladakh Mountains and Tibetan Plateau, rock mass and slope instability is relatively more towards adjacent parts of Kinnaur such as Sangla Valley and Uttarakhand along northern frontiers. Substrate or slope instability due to periglacial phenomena such as solifluction, which disturbs whole plants and ramet connections and tough soil texture preventing horizontal growth in the below ground are probably main factors responsible for the relatively low participation of clonal plants in the study area.

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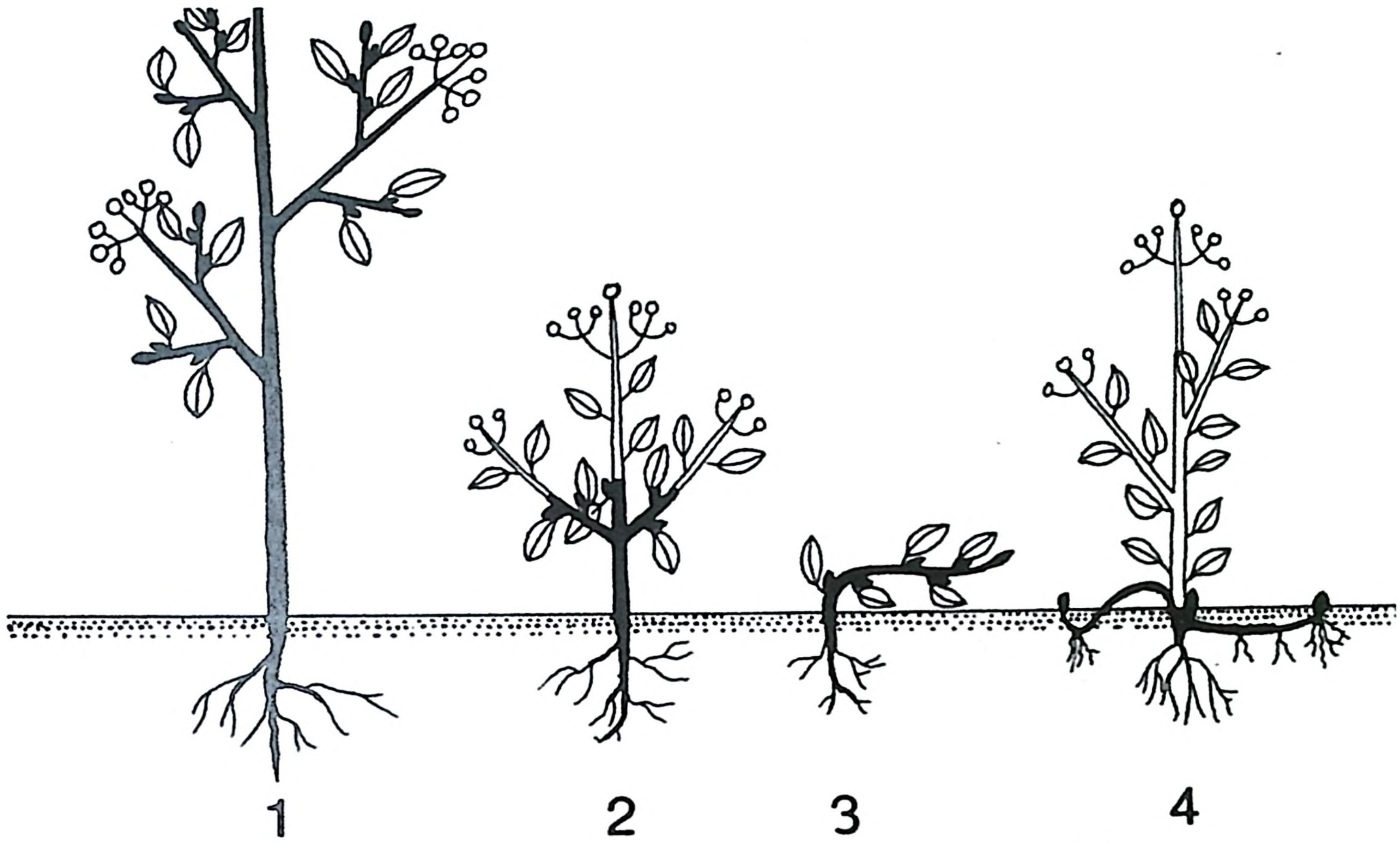
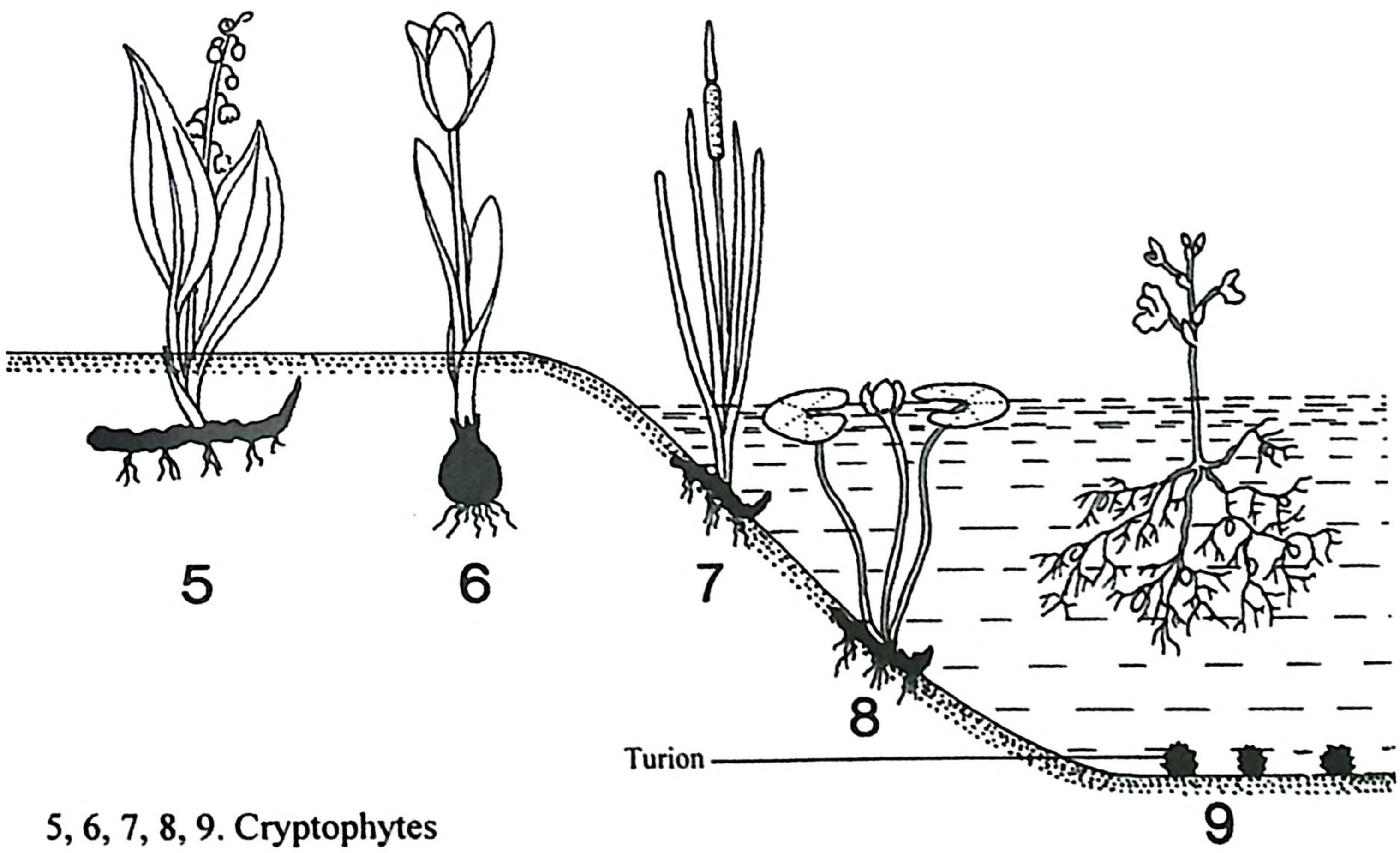
PLATE 5.1 LIFE FORMS



1.Phanerophyte 2,3.Chamaephytes 4.Hemicryptophyte



5, 6, 7, 8, 9. Cryptophytes

Source: Raunkiaer (1934)

PLATE 5.2 SPECIES REPRESENTING VARIOUS GROWTH FORMS


Short basal (*Taraxcum officinale*)


Semi-basal (*Morina coulteriana*)


Erect leafy (*Chamerion angustifolium*)


Tussock (*Danthonia cachemyriana*)


Cushion (*Thylacospermum caespitosum*)


Short succulent (*Sedum* sp.)

PLATE 5.3 SPECIES REPRESENTING CLONAL AND NON-CLONAL FORMS

Saxifraga flagellaris (Stolon)

Gymnadenia orchidis (Tuber)

Picrorhiza scrophulariiflora (Rhizome)

Bistorta vivipara (Bulbils)

Allium stracheyi (Bulb)

Dontostemon glandulosus (Non-clonal)

CHAPTER 6

GENERAL DISCUSSION AND CONSERVATION IMPLICATIONS

The Himalaya is home to diverse floral components across topo-climatic gradient from sub-tropical moist forests to alpine zone and from broad leaved and coniferous forests to alpine arid rangelands. Despite a long history of botanical explorations, vast area of Himalaya remains unexplored or under explored. The interior valleys of Great and Trans-Himalayan regions need to be studied for its rich biodiversity and to endow with potential assessment of conservation priorities.

1. The current study with an aim to understand the floristic diversity, richness and ecological setting of the cold-arid landscape of the Upper Dhauli Valley reports a total of 495 species of vascular plants (angiosperms, gymnosperms and pteridophytes) belonging to 267 genera and 73 families. It updates the flora of the Nanda Devi Biosphere Reserve, a fairly explored region, with 183 species indicating need of such detailed inventorization in other interior areas of Himalaya. During recent floristic surveys, new species or distributional record of *Anemone demissa* (Ranunculaceae) and *Anthoxanthum flexuosum* (Poaceae) which are hitherto undescribed from the Western Himalaya and *Potentilla pamirica* (Rosaceae), *Carex sagaensis* (Cyperaceae) and *Dontostemon glandulosus* (Brassicaceae) from the state of Uttarakhand could be attributed to their extended distributional range or restrained botanical excursions in these interior valleys. However, presence of only few individuals of these species indicates their rarity in the region. Further, floristic surveys would be required to assess the population status of these species in near future.

2. The flora of Himalaya, Tibet and west China had a common origin and they radiated into distinct eco-floristic zones gradually as the Himalaya and Tibetan Plateau rose from sea level to become the highest region in the world (Kashyap 1932). A large number of Western Himalayan alpine floras of the Garhwal and Kumaon region seem to have come from Tibet, west China and adjoining north-east Asia (Rau 1975). In Upper Dhauli Valley, presence of typical floral elements and plant communities of Trans and Greater Himalayan region revealed that the valley has affinity of floral characteristics from both the regions and hence the valley represents a transition zone. Towards interior areas of the valley i.e., in Satyagad Ganesh Ganga watersheds, the flora shows affinities to Trans-Himalayan region where diversity is relatively low due to increasing aridity. The xeric species such as *Caragana versicolor, Kraschenninikovia ceratoides, Hippophae tibetana, Lonicera spinosa* and

Potentilla rigida which prefer dry conditions were recorded as major shrub species in these areas. On the other hand, Amrit Ganga watershed has higher floral diversity due to comparatively moist conditions. The affinities of floral characters were of Greater Himalayan region, especially in lateral moraines and mixed herbaceous formations. The current classification of Indian bio-geographic zones does not consider this region's geo-botanical affinity to the Trans-Himalaya. In future, the information generated from the study might aid to revision of biotic province of the Himalaya, if needed.

3. The present work also throws light on the population and threat status of plant species of the region as it harbours several focal species of immense conservation importance. Keeping their current population status in view, preparation of micro-plans, sustainable management and utilization of dwindling populations of threatened medicinal species such as *Aconitum lethale, Aconitum violaceum, Allium carolinianum, Allium stracheyi, Angelica glauca, Arnebia benthamii, Dioscorea deltoidea, Ephedra gerardiana, Juniperus semiglobosa, Pleurospermum densiflorum, Saussurea costus, Saussurea nana, Rheum moorcroftianum, Rheum webbianum, Thermopsis barbata, Thylacospermum caespitosum* and *Viola kunawurensis* is recommended. These species were mostly encountered on peculiar microhabitats. Detailed geo-botanical study will be needed in order to document the ecological requirements of species which are of high conservation value in this region.

4. A number of authors have attempted to classify landforms or habitats in the Trans-Himalayan region. These landforms vary in extent according to elevation and geographic locations. Unfortunately, due to lack of general protocol to identify various landforms or physiognomic units or landscape units and their characteristic species, several workers have used such terms loosely, for example, dry, degraded, undulating land areas, shady moist, bouldary and eroded land. Noticeably, instead of referring a particular habitat to a 'physiognomic unit', it has been described or defined under a 'landform' category. Therefore, based on the review of the studies conducted on various landscape or habitat features in Indian Trans-Himalaya, the current study provides a general protocol to identify the habitats. It suggest that the habitats that are characterized by their geo-morphological attributes or physical attributes such as elevation, slope, orientation, stratification, rock exposure, and soil type must be referred as a 'landform', for example, moraine, scree, river bed, table land, plateau, gorge and ridge. The habitats which are characterized and defined by their vegetation such as herbaceous meadow, scrub steppe, scrublands, alpine grassland, alpine dry scrub,

alpine meadow and riverine scrub are required to be referred as a 'physiognomic or landscape unit'.

5. In cold arid regions, vegetation types with respect to plant cover largely follow moisture and elevational gradients. The presence of typical plant formations along the river beds comprising of the species of *Myricaria, Salix* and *Hippophae* in the study area and rest of the Trans-Himalayan regions corroborates this. However, the vegetation in and around livestock camping sites or animal resting places is scattered along the elevation gradient quite haphazardly because its distribution is partly of human origin. Species such as *Rumex nepalensis, Polygonum* sp., *Urtica hyperborea* and *Chenopodium* sp. in the present study area is mostly dispersed by livestock which prefer growing in animal resting places. It could be due to nitrogen enrichment of soil by their dung. Poor species richness in such areas compared to other landforms or physiognomic units is mainly due to limited extent of these habitats and high disturbance regime which possibly reduce diversity by increasing plant mortality. In Upper Dhauli Valley, the dry and undulating slopes towards Geldung (4500-5500 m), exhibit characteristic scrub steppe vegetation dominated by *Caragana versicolor, Lonicera spinosa* and *Potentilla rigida* and at places by *Krascheninnikovia ceratoides*. The unstable scree slopes harbour a distinct community characterized by *Aconogonum tortuosum, Eriophyton rhomboideum, Cicer microphyllum,* and *Cousinia thomsonii.* Scrub steppe and moraine, respectively are the most frequent landform and physiognomic unit in the valley. Higher species diversity and richness in scrub steppe and moraine could also be relative to land area, the larger an area is, the more species and larger populations it can support. Moraine being a dynamic landform support higher species richness due to presence of multiple micro-habitats. The micro habitats are resultant of continuous process of glaciation and stabilization of the debris over the period. In Amrit Ganga, approximately 70% of the area is comprised of moraine. Scrub steppe harbours both the growth forms *viz.,* herbs amidst shrub species which contributed to its rich diversity. In Satyagad watershed, due to comparatively narrow and dry and rugged terrain, the moraine and river bed were reasonably absent. Scree slopes alone contributed approximately 60% of the total area of this watershed. *Caragana gerardiana, Astragalus candolleanus, Juniperus* spp., *Devendraea spinosa* towards Sailsala (3800 m), *Arenaria festucoides, Corydalis nana* and *Androsace globifera* in Kalajowar (4200-4500 m) represented some of the characteristic Trans-Himalayan floral elements.

6. *Caragana* steppe, cushioned habitat, tussock formation and alpine arid pastures are the special habitats for rare species such as *Allium stracheyi*, *Thylacospermum caespitosum, Thermopsis barbata, Rheum tibeticum, Ephedra gerardiana, Saussurea nana, Arnebia benthamii* and *Viola kunawurensis* in the region. Elevation and micro-climatic conditions at specific locations are the dominant environmental gradients underlying the species composition in these specific habitats. Distinct plant assemblages can be identified in the alpine meadows, aided by elevational variations resulting in the presence of unique zones within the alpine flora. This puts such species under threat of local extinction if the habitat is degraded due to anthropogenic disturbances such as overgrazing and trampling by livestock and extraction of species for trade. Thus, it is imperative to monitor the impacts of exploitation of the species and habitat degradation for long term conservation of rare and threatened taxa of the region. Conservation in such areas cannot be achieved without the involvement of local communities, who are directly dependent on these resources for their sustenance and livelihood generation. These communities could be encouraged to set aside some habitats for in-situ conservation of rare and high value medicinal plants. Efforts are needed to establish cold desert conservatorium and medicinal plant gardens in the region.

7. Like in other parts of the state, people in the cold arid region of Nanda Devi Biosphere Reserve too are engaged in animal husbandry, agriculture and horticulture albeit at small scale. However, the cattle and sheep population is almost four times the humans, coupled with hordes of additional sheep and goats of the transhumant pastoralists coming to the alpine regions every summer. Grazing is completely banned in the adjoining areas such as Valley of Flowers National Park and Nanda Devi National Park; therefore, there is a great pressure on the alpine pastures of the Upper Dhauli and Girthi valleys. Indiscriminate use of the grazing areas has therefore resulted in critically low plant biomass along with the emergence of weeds, such as *Rumex nepalensis*, *Polygonum* spp., *Urtica* spp., *Impatiens* spp. and *Malva* spp. that threaten the native species. Hence, like other severely grazed alpines of Western Himalaya, overgrazing has caused loss of habitat (for wildlife or native flora) and vegetation degradation in many parts of this region causing threats to biodiversity.

8. The community attributes, including species richness, evenness and diversity responded significantly to environmental as well as anthropogenic stimuli. Anthropogenic and biotic disturbances such as uncontrolled and heavy seasonal grazing and trampling were identified as the potential threats causing degradation and retrogression of arid pastures and affecting the native plant diversity and community structure of this fragile alpine biome. There is a

need to control the degradation and disturbance processes which pose threat to the biodiversity. Development and implementation of regional conservation strategies are necessary to protect the rare and little known alpine habitats such as cushioned habitat predominantly of *Thylacospermum caespitosum,* a keystone nurse species that ameliorates the harsh conditions and facilitates other species to grow, thus increasing alpine plant biodiversity. For this, a detailed socio-economic study and geospatial analysis of the area is needed, which was beyond the scope of the present study.

9. Though a few attempts have been made to map the rangeland vegetation and land use and land cover of some pockets, a consolidated and comprehensive vegetation map for the entire Trans-Himalaya would be needed for better management and conservation planning. Geospatial analysis of rangelands showing the distribution of certain keystone species such as *Caragana versicolor* and *Kraschenninikovia ceratoides* should be done on priority basis which is crucial for predicting the dynamics of rangeland vegetation. For the restoration of degraded rangelands, these species along with other leguminous forbs and grasses need to be focused up on for conservation of the fragile ecosystem of the region. Awareness generation about the species of conservation significance, providing alternate fuelwood and non-conventional sources energy such as solar cookers and fuel efficient portable ovens to the pastoral communities at subsidized rates could reduce the pressure on the species such as *Caragana* scrub. Additionally, restoration of heavily degraded sites by reseeding *Caragana* and participatory monitoring with the help of herders would be the most practical way forward to restore degraded sites. In order to conserve the herbaceous meadows, the most grazed feeding grounds of livestock and critical and most preferred wild ungulates habitats, it would be necessary to develop integrated rangeland management plans based on participatory processes. Self regulated and good herding practices traditionally followed by the herders in many pockets of region would go a long way in the conservation of alpine rangelands.

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SCIENTIFIC RESEARCH PUBLICATIONS

1. **Kumar, A.,** M. Mitra, B.S. Adhikari and G.S. Rawat. 2016a. Flora of Niti Valley: a cold arid region of Nanda Devi Biosphere Reserve, Western Himalaya, India. Check List 12(1): 1824. DOI: http://dx.doi.org/10.15560/12.1.1824.

2. **Kumar, A.,** B.S. Adhikari and G.S. Rawat. 2016b. New phytogeographically noteworthy plant records from Uttarakhand, Western Himalaya. Journal of Threatened Taxa 8(6): 8943–8947. DOI: http://dx.dofi.org/10.11609/jott.2416.8.6.8943-8947.

3. **Kumar, A.,** B.S. Adhikari and G.S. Rawat. 2016c. *Caragana versicolor* Benth. (Fabaceae), a keystone species of high conservation concern in the Hindu Kush Himalayan region. Current Science 111(6): 985–987.

4. **Kumar, A.,** B.S. Adhikari and G.S. Rawat. 2015a. Rangeland vegetation of the Indian Trans-Himalaya: An ecological review; pp. 28–41, In G.S. Rawat and B.S. Adhikari (Eds.) Ecology and Management of Grassland Habitats in India, ENVIS Bulletin: Wildlife & Protected Areas. Dehradun: Wildlife Institute of India. Vol. 17: 240 pp.

5. **Kumar, A.,** M. Mitra, B.S. Adhikari and G.S. Rawat. 2015b. Depleting indigenous knowledge of medicinal plants in cold-arid region of Nanda Devi Biosphere Reserve, Western Himalaya. Medicinal & Aromatic Plants 4(3): 195. DOI:10.4172/2167-0412.1000195.

6. **Kumar, A.** and M, Mitra. 2015. Landforms, plant diversity and their utilization by ungulates in Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya. WWF-India, New Delhi.

7. **Kumar, A.,** M. Mitra, B.S. Adhikari and G.S. Rawat. 2013a. Additions to plant wealth of Nanda Devi Biosphere Reserve, Western Himalaya. The Indian Forester 139(10): 959–961.

8. **Kumar, A.,** M. Mitra, B.S. Adhikari and G.S. Rawat. 2013b. Archetype conservation in Trans-Himalayan region of Nanda Devi Biosphere Reserve, Western Himalaya. e Journal of Applied Forest Ecology 1(1): 84–86.

9. Mitra M, **A. Kumar,** B.S. Adhikari and G.S. Rawat. 2013. A note on transhumant pastoralism in Niti Valley, Western Himalaya, India. Pastoralism: Research, Policy and Practice, Springer, 3: 29. DOI: 10.1186/2041-7136-3-29.

Check List the journal of biodiversity data

LISTS OF SPECIES

Check List 12(1): 1824, 6 January 2016 doi: http://dx.doi.org/10.15560/12.1.1824
ISSN 1809-127X

Flora of Niti Valley: a cold arid region of Nanda Devi Biosphere Reserve, Western Himalaya, India

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Abstract: Located in the extended buffer zone of Nanda Devi Biosphere Reserve in Western Himalaya, Niti valley represents a cold arid region. The reserve has been extensively surveyed in terms of floral diversity by various workers, albeit highly confined to the core zones. The current survey recorded 495 species belonging to 267 genera and 73 families of vascular plants through systematic collection in the years 2011, 2012 and 2014. Of the recorded species, 383 were dicots, 93 monocots, 9 pteridophytes and 10 gymnosperms. Asteraceae was most diverse family (32 genera with 58 species), followed by Poaceae (22 genera with 41 species), Lamiaceae (15 genera with 19 species) Fabaceae (14 genera with 22 species), Brassicaceae (12 genera with 12 species) and Rosaceae (11 genera with 36 species). The present survey also updates the existing flora of Nanda Devi Biosphere Reserve (801 species) with addition of 167 species. This study reveals that the Niti valley forms a transition zone, as the floral elements have affinity with Trans as well as Greater Himalaya.

Key words: floristic diversity; Indian Trans-Himalaya; Nanda Devi National Park; southern Asia; Valley of Flowers National Park

INTRODUCTION

Mountainous regions of the world are fascinating as they cover an ample range of biological diversity over smaller areas (Dash and Saxena 2012). In Himalayan region, the alpine zone occupies nearly 33% of the total geographical area, of which about 25.98% area is vegetated and remaining 7.1% area falls under perpetual snow (Lal et al. 1991). The arid tracts lying extreme north and parallel to the Greater Himalayan range, constituting the sediments of Tethyan sea bed, are referred as Trans-Himalaya (Chandola 2009). These areas are not affected by the Indian monsoon as they are positioned in the rain shadow of the main Himalayan region and characterized by extreme climatic conditions, such as diurnal fluctuations in temperatures, scanty and erratic rainfall, heavy winds and snowfall.

The Indian Trans-Himalaya (ITH) usually described as 'High Altitude Cold Desert Zone' (Zone 1) spreads into three biogeographic provinces: 1A, Ladakh mountains: Kargil, Nubra and Zanskar in Jammu and Kashmir and Lahul and Spiti in Himachal Pradesh); 1B, Tibetan plateau: Changthang region of Ladakh and northern parts of the states of Uttarakhand; and 1C, Sikkim Plateau (Rodgers et al. 2000; WII 2015, unpublished). The vegetation of ITH has been described as *Caragana-Lonicera-Artemisia* formation (Osmaston 1922), alpine steppe (Schweinfurth 1957), dry alpine scrub (Champion and Seth 1968) and alpine stony deserts (Puri et al. 1989). The extreme north of the state of Uttarakhand contributes approximately 1% (ca. >1,000 km²) of the total Trans-Himalayan region of India (ca. 98,660 km²) covering Nilang, Niti and Mana valleys (Nanda Devi Biosphere Reserve) and Johar valley in Uttarkashi, Chamoli and Pitthoragarh districts, respectively.

The Nanda Devi Biosphere Reserve (NDBR) located in the state of Uttarakhand, India has been extensively surveyed in terms of flora by Hajra and Balodi (1995) and recorded 801 species of vascular plants covering the then area of reserve ca. 2000 km². The core zones, Nanda Devi National Park (NDNP) and Valley of Flowers National Park (VoFNP), were surveyed by Samant (1993; 656 species of vascular plants) and Kala et al. (1998; 521 species of vascular plants). Joshi and Samant (2004) reported 76 woody species and 13 forest communities from buffer zone of NDBR, Samant and Joshi (2005) recorded 490 plant species from NDNP, Murthy (2011) prepared a pictorial field guide for VoFNP covering 287 species belonging to 190 genera under 63 families and Kumar et al. (2013a) added 16 species of vascular plants to the plant wealth of NDBR. It is noteworthy that although the Great Himalayan range has been thoroughly explored by the botanists, very few

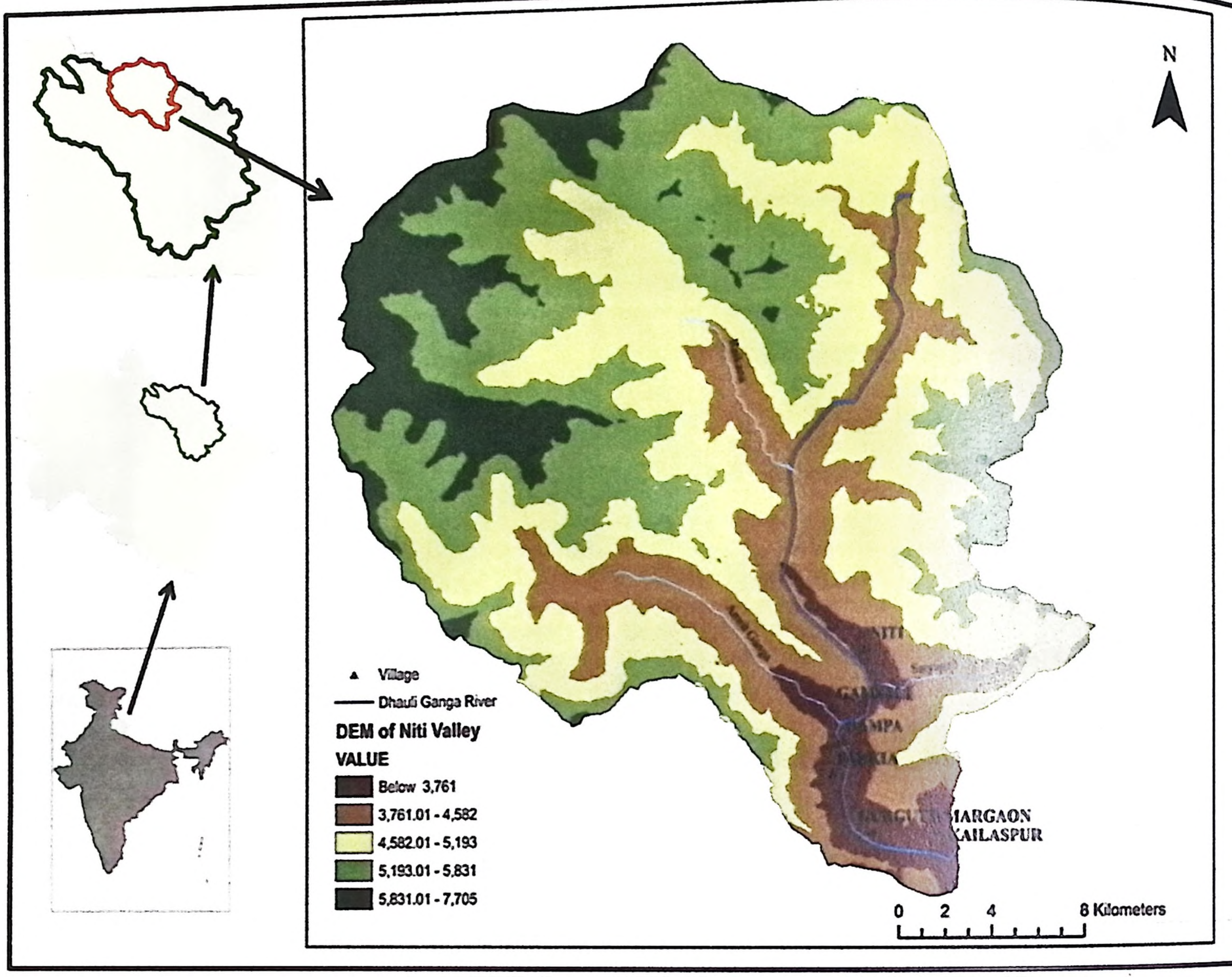

Figure 1. Map showing the location of Niti valley in Nanda Devi Biosphere Reserve, Western Himalaya, India.

floristic surveys in the equally important areas, such as the Trans-Himalayan region, have been conducted, especially in the state of Uttarakhand, except Chandola (2009). Additionally, flora of NDBR has been extensively surveyed by various workers albeit highly confined to the core zones. Therefore, the present study was conducted to assess the diversity of vascular plants in the Niti valley, an extended buffer zone of the Biosphere Reserve which represents the cold arid landscape.

MATERIALS AND METHODS

Study area

Located in the state of Uttarakhand in India, Nanda Devi Biosphere Reserve (ca. 6,407 km², 30°08′ to 31°02′ N, 079°12′ to 080°19′ E) has two core zones, Nanda Devi National Park (NDNP; 630 km²) and the Valley of Flowers National Park (VoFNP; 87.5 km²), which are together listed as a world natural heritage site (http://www.whc.unesco.org). This study was conducted in the Niti valley, a buffer zone of NDBR, Western Himalaya (Figure 1). The valley with an average elevation ranging from 3,500–5,000 m above mean sea level is spread over ca. 727.7 km² area. The valley also known as Upper Dhauli valley, is named after the river *Dhauli Ganga* that forms one of the major catchments of river Alaknanda (a sub-catchment of the river Ganga). The picturesque landscape of valley comes under Trans-Himalayan region of the Uttarakhand state in the Western Himalaya. *Bhotiya*, an ethnic community of Indo-Mongoloid origin inhabited in the valley has own perspective on conservation of natural resources for example, *Allium stracheyi* Baker, through local archetypes (Kumar et al. 2013b). The valley has three sub-watersheds: Amrit Ganga, Ganesh Ganga and Satyagad. The important alpine pastures are Dhaman, Bamplas, Kalazowar, Rekhana (base of Mount Kamet), Gothing and Geldung and the area continues to be used for transhumant pastoralism (Mitra et al. 2013). This area is situated in the rain-shadow zone of NDBR and dryness increase towards upper reaches of the valley and Girthi valleys, which remain snow bound for more than 6 months in a year. Summer is very short and generally lasts from June to August. The region receives low amount of precipitation and remains dry and dusty above 3,200 m above mean sea level.

The vegetation of the study area is broadly divisible into following classes: (i) dry temperate forests dominated by blue pine (*Pinus wallichiana* A.B.Jacks.), deodar (*Cedrus deodara* (Roxb. ex D.Don) G.Don) and spruce (*Picea smithiana* Boiss.) in the lower reaches of the valley, (ii) sub-alpine forests dominated by birch (*Betula utilis* D.Don), fir (*Abies pindrow* Spach) and juniper (*Juniperus* spp.), (iii) riverine scrub dominated by species of *Hippophae* L., *Salix* L. and *Myricaria* Desv., (iv) alpine dry scrub (*Caragana* sp., *Juniperus* sp., *Krascheninnikovia ceratoides* (L.) Gueldenst., *Potentilla rigida* Wall. ex Lehm., *Devendraea spinosa* (Decne.) Pusalkar and *Lonicera* spp. and (v) alpine mixed herbaceous formations (*Kobresia* sp., *Trachydium roylei* Lindl., *Danthonia* sp. and *Potentilla* sp.). Most of the area (>70%) falls under alpine dry scrub and alpine mixed herbaceous formations, which is further divisible into several communities depending upon topographic features (elevation, aspect and slope).

Field survey and data collection

Systematic survey of vascular plants was done during the growing season from May to October in 2011, 2012 and 2014. The entire valley was traversed on foot to cover all the landscape features, which included alpine arid tracts, *nallahs*, ridges, exposed and unexposed sites, riverside tracts, valley bottoms, grasslands, agricultural fields, near human habitations and various habitats in and around forests and in the inaccessible areas wherever possible. To facilitate the process of correct identification and the information on parameters such as elevation, aspect, important taxonomic characters including habit and habitat of the species were also gathered. The identification of plant specimens was cross-checked with authentic specimens housed in herbaria (BSD, DD and WII) and based on field characters with the aid of existing florulas and literature (Naithani 1984a, 1984b; Hajra and Balodi 1995; Chandola 2009; Pusalkar and Singh (2012). The currently accepted botanical names and authorities were updated following http://www.ipni.org and the families were updated following APG III (2009). The voucher specimens were dried, pressed and mounted on herbarium sheets following Jain and Rao (1976) and deposited in the herbarium of Wildlife Institute of India, Dehradun (WII) for future reference and records. The plant species including threatened or common, which were easily identified in the field were only photographed. The threat status of species was also determined with the aid of existing literature (Nayar and Sastry 1987–90; Walter and Gillett 1998; Ved et al. 2003; Hedge et al. 2003 and Srivastava 2010). Species richness was determined as the total number of the species in an area.

Table 1. Detailed analysis of floristic diversity under various taxonomic groups (values in parentheses are percent contribution of the total).

Plant Groups	Family	Genera	Species
Dicotyledons	52 (71.2)	208 (78)	383 (77.3)
Monocotyledons	10 (13.6)	43 (16)	93 (18.7)
Pteridophytes	8 (10.9)	9 (3.3)	9 (1.8)
Gymnosperms	3 (4.1)	7 (2.6)	10 (2)
Total	73	267	495

RESULTS

Floristic diversity and richness

The systematic floristic survey and detailed inventory of the entire area revealed presence of 495 species of vascular plants (angiosperms, gymnosperms and pteridophytes) belonging to 267 genera and 73 families (Table 1). Of the recorded species, 383 were dicots, 93 monocots, 9 pteridophytes and 10 gymnosperms. The valley comprises 62% of the vascular plants of NDBR and 35% of the flora of cold deserts of Western Himalaya. The current documentation also updates the flora of NDBR with new distributional records of 167 species (Table 2, asterisked). The ratio of monocots to dicots in respect of families, genera and species is 1:5.6, 1:4.7 and 1:4, respectively. The dominant families in terms of high

Table 2. List of vascular plants recorded in Niti Valley, Nanda Devi Biosphere Reserve, Western Himalaya, India. Abbreviations: H=Herb, S=Shrub, T=Tree, C=Climber, F=Fern, O=Orchids, G=Grass and Sd=Sedge. *=new distributional records for Nanda Devi Biosphere Reserve, India.

Plant group	Family	Growth form	Source	Voucher number
Angiosperms				
**Acroglochin persicarioides* Moq.	Amaranthaceae	H	Pusalkar and Singh (2012)	WII0100P
Axyris hybrida L.	Amaranthaceae	H	Pusalkar and Singh (2012)	WII0101P
Chenopodium botrys L.	Amaranthaceae	H	Pusalkar and Singh (2012)	WII0102P
Chenopodium foliosum Asch.	Amaranthaceae	H	Pusalkar and Singh (2012)	WII0103P
Chenopodium hybridum L.	Amaranthaceae	H	Pusalkar and Singh (2012)	WII0104P
Chenopodium opulifolium Schrad. ex W.D.J.Koch & Ziz	Amaranthaceae	H	Pusalkar and Singh (2012)	WII0105P
**Krascheninnikovia ceratoides* (L.) Gueldenst.	Amaranthaceae	S	Pusalkar and Singh (2012)	WII20851
**Allium carolinianum* DC.	Amaryllidaceae	H	Murti (2001)	WII20601
Allium stracheyi Baker	Amaryllidaceae	H	Murti (2001)	WII20866
Allium wallichii Kunth	Amaryllidaceae	H	Murti (2001)	WII0012P

Continued

Table 2. *Continued.*

Plant group	Family	Growth form	Source	Voucher number
**Angelica archangelica* L.	Apiaceae	H	Hajra and Balodi (1995)	WII0174P
**Angelica glauca* Edgew.	Apiaceae	H	Pusalkar and Singh (2012)	WII00217701320
Bupleurum candollei Wall. ex DC.	Apiaceae	H	Pusalkar and Singh (2012)	WII20683
Bupleurum falcatum L.	Apiaceae	H	Pusalkar and Singh (2012)	WII0175P
Bupleurum lanceolatum Wall. ex DC.	Apiaceae	H	Pusalkar and Singh (2012)	WII0176P
**Bupleurum longicaule* Wall. ex DC.	Apiaceae	H	Pusalkar and Singh (2012)	WII20644
**Carum carvi* L.	Apiaceae	H	Pusalkar and Singh (2012)	WII0177P
Chaerophyllum reflexum Lindl.	Apiaceae	H	Pusalkar and Singh (2012)	WII20635
Eriocycla caespitosa H.Wolff	Apiaceae	H	Pusalkar and Singh (2012)	WII20670
**Heracleum candicans* Wall. ex DC.	Apiaceae	H	Pusalkar and Singh (2012)	WII0178P
**Heracleum pinnatum* C.B.Clarke	Apiaceae	H	Pusalkar and Singh (2012)	WII0179P
**Pleurospermum brunonis* Benth. ex C.B.Clarke	Apiaceae	H	Pusalkar and Singh (2012)	WII0180P
**Pleurospermum candollei* (DC.) Benth. ex C.B.Clarke	Apiaceae	H	Pusalkar and Singh (2012)	WII00000001356
***Pleurospermum stellatum* Benth. ex C.B.Clarke**	Apiaceae	H	Pusalkar and Singh (2012)	WII20689
Selinum candollei Edgew.	Apiaceae	H	Pusalkar and Singh (2012)	WII0181P
Selinum wallichianum (DC.) Raizada & Saxena	Apiaceae	H	Pusalkar and Singh (2012)	WII0182P
Trachydium roylei Lindl.	Apiaceae	H	Pusalkar and Singh (2012)	WII20805
Vicatia coniifolia DC.	Apiaceae	H	Pusalkar and Singh (2012)	WII00000001364
**Cynanchum auriculatum* Royle ex Wight	Apocynaceae	C	Pusalkar and Singh (2012)	WII0119P
**Cynanchum vincetoxicum* Pers.	Apocynaceae	H	Pusalkar and Singh (2012)	WII00401502082
Arisaema flavum Schott.	Araceae	H	Pusalkar and Singh (2012)	WII0001P
Arisaema jacquemontii Blume	Araceae	H	Murti (2001)	WII0002P
Asparagus filicinus Buch.-Ham. ex D.Don	Asparagaceae	H	Hajra and Balodi (1995)	WII0012P
Polygonatum cirrhifolium Royle	Asparagaceae	H	Pusalkar and Singh (2012)	WII00632903303
Polygonatum graminifolium Hook.	Asparagaceae	H	Pusalkar and Singh (2012)	WII20898
Polygonatum verticillatum All.	Asparagaceae	H	Pusalkar and Singh (2012)	WII20624
Ajania tibetica (Hook.f. & Thomson) Tzvelev	Asteraceae	H	www.efloras.org	WII20832
Anaphalis nepalensis (Spreng.) Hand.-Mazz.	Asteraceae	H	Pusalkar and Singh (2012)	WII0142P
**Anaphalis nubigena* DC.	Asteraceae	H	Pusalkar and Singh (2012)	WII20700
Anaphalis royleana DC.	Asteraceae	H	Pusalkar and Singh (2012)	WII20876
Anaphalis triplinervis Sims ex C.B.Clarke	Asteraceae	H	Pusalkar and Singh (2012)	WII00248601590
**Anaphalis xylorhiza* Sch.-Bip. ex Hook.f.	Asteraceae	H	Pusalkar and Singh (2012)	WII0143P
Arctium lappa L.	Asteraceae	H	Pusalkar and Singh (2012)	WII0144P
Artemisia capillaris Thunb.	Asteraceae	H	Hajra and Balodi (1995)	WII00293501609
***Artemisia edgeworthii* N.P.Balakr.**	Asteraceae	H	Pusalkar and Singh (2012)	WII20880
Artemisia gmelinii Weber ex Steckm. var. *gmelinii*	Asteraceae	H	Pusalkar and Singh (2012)	WII20871
Artemisia macrocephala* **Jacquem. ex Besser	Asteraceae	H	Pusalkar and Singh (2012)	WII00286501598
Artemisia maritima L.	Asteraceae	H	Hajra and Balodi (1995)	WII0146P
**Artemisia salsoloides* Willd.	Asteraceae	H	Pusalkar and Singh (2012)	WII0147P
Artemisia sp.	Asteraceae	H	Pusalkar and Singh (2012)	WII20641
**Artemisia vestita* Wall.	Asteraceae	H	Pusalkar and Singh (2012)	WII0145P
Aster albescens (DC.) Wall. ex Hand.-Mazz.	Asteraceae	H	Pusalkar and Singh (2012)	WII0148P
Aster flaccidus Bunge	Asteraceae	H	Pusalkar and Singh (2012)	WII20844
**Brachyactis menthodora* Benth.	Asteraceae	H	Pusalkar and Singh (2012)	WII0198P
**Brachyactis pubescens* Aitch. & Clarke	Asteraceae	H	Pusalkar and Singh (2012)	WII0149P
Brachyactis roylei (DC.) Wendelbo	Asteraceae	H	Pusalkar and Singh (2012)	WII00256101644
Carduus edelbergii Rech.f.	Asteraceae	H	Pusalkar and Singh (2012)	WII0150P
Cicerbita macrorhiza Beauverd	Asteraceae	H	Pusalkar and Singh (2012)	WII00344301665
**Cicerbita violifolia* Beauverd	Asteraceae	H	www.efloras.org	WII0151P
Cirsium wallichii DC.	Asteraceae	H	Pusalkar and Singh (2012)	WII0152P
Cousinia thomsonii C.B.Clarke	Asteraceae	H	Pusalkar and Singh (2012)	WII0153P
Cremanthodium arnicoides R.D.Good	Asteraceae	H	Pusalkar and Singh (2012)	WII0154P
Crepis flexuosa (Ledeb.) Benth. ex C.B.Clarke	Asteraceae	H	Pusalkar and Singh (2012)	WII20663
Dolomiaea macrocephala DC.	Asteraceae	H	Pusalkar and Singh (2012)	WII20892
Dubyaea hispida DC.	Asteraceae	H	Pusalkar and Singh (2012)	WII0155P
Echinops cornigerus DC.	Asteraceae	H	Pusalkar and Singh (2012)	WII00366801687
Erigeron acris L.	Asteraceae	H	Pusalkar and Singh (2012)	WII20877
Erigeron multiradiatus (Lindl. ex DC.) Benth. ex C.B.Clarke	Asteraceae	H	Pusalkar and Singh (2012)	WII00249401721
Gerbera gossypina Beauverd	Asteraceae	H	Hajra and Balodi (1995)	WII00422001732
**Hippolytia senecionis* Poljakov ex Tzvelev	Asteraceae	H	Pusalkar and Singh (2012)	WII0156P
**Inula grandiflora* Willd.	Asteraceae	H	Pusalkar and Singh (2012)	WII0157P

Cont'

Table 2. *Continued.*

Plant group	Family	Growth form	Source	Voucher number
Lactuca dolichophylla Kitam.	Asteraceae	H	Pusalkar and Singh (2012)	WII0158P
Leontopodium brachyactis Gand.	Asteraceae	H	Pusalkar and Singh (2012)	WII20887
**Leontopodium nanum* (Hook.f. & Thomson ex C.B.Clarke) Hand.-Mazz.	Asteraceae	H	Pusalkar and Singh (2012)	WII20680
Myriactis javanica DC.	Asteraceae	H	Hajra and Balodi (1995)	WII0159P
**Petasites tricholobus* Franch.	Asteraceae	H	Pusalkar and Singh (2012)	WII0207P
Picris hieracioides L.	Asteraceae	H	Pusalkar and Singh (2012)	WII0160P
Prenanthes brunoniana Wall. ex DC.	Asteraceae	H	Pusalkar and Singh (2012)	WII00526201725
Prenanthes violifolia Decne.	Asteraceae	H	Hajra and Balodi (1995)	WII0161P
**Saussurea abnormis* Lipsch.	Asteraceae	H	www.efloras.org	WII0162P
Saussurea albescens (DC.) Sch.Bip.	Asteraceae	H	Pusalkar and Singh (2012)	WII20882
Saussurea costus (Falc.) Lipsch.	Asteraceae	H	Pusalkar and Singh (2012)	WII0211P
**Saussurea nana* (Pamp.) Pamp.	Asteraceae	H	www.efloras.org	WII20860
Saussurea obvallata Wall.	Asteraceae	H	Pusalkar and Singh (2012)	WII20874
**Senecio dubitabilis* C.Jeffrey & Y.L.Chen	Asteraceae	H	Pusalkar and Singh (2012)	WII0163P
Senecio krascheninnikovii Schischk.	Asteraceae	H	Pusalkar and Singh (2012)	WII0164P
**Senecio kunthianus* Wall.	Asteraceae	H	Pusalkar and Singh (2012)	WII0165P
Senecio laetus Edgew.	Asteraceae	H	Pusalkar and Singh (2012)	WII0166P
Solidago virga-aurea Auct.	Asteraceae	H	Pusalkar and Singh (2012)	WII00338101799
Sonchus oleraceus L.	Asteraceae	H	Pusalkar and Singh (2012)	WII0167P
Taraxacum officinale F.H.Wigg.	Asteraceae	H	Pusalkar and Singh (2012)	WII00640601811
Tussilago farfara L.	Asteraceae	H	Pusalkar and Singh (2012)	WII0168P
Waldheimia glabra Regel	Asteraceae	H	Pusalkar and Singh (2012)	WII0169P
Waldheimia tomentosa Regel	Asteraceae	H	Pusalkar and Singh (2012)	WII20864
**Impatiens badrinathii* Pusalkar & D.K.Singh	Balsaminaceae	H	Pusalkar and Singh (2012)	WII0203P
**Impatiens brachycentra* Kar. & Kir.	Balsaminaceae	H	Pusalkar and Singh (2012)	WII0204P
Impatiens scabrida DC.	Balsaminaceae	H	Pusalkar and Singh (2012)	WII20652
Impatiens sp.	Balsaminaceae	H	Pusalkar and Singh (2012)	WII0106P
Impatiens sulcata Wall.	Balsaminaceae	H	Pusalkar and Singh (2012)	WII0107P
Berberis pseudumbellata R.Parker	Berberidaceae	S	Pusalkar and Singh (2012)	WII20821
Berberis jaeschkeana Schneider	Berberidaceae	S	Pusalkar and Singh (2012)	WII20820
Sinopodophyllum hexandrum (Royle) T.S.Ying	Berberidaceae	H	Pusalkar and Singh (2012)	WII00005000099
Betula utilis D.Don	Betulaceae	T	Pusalkar and Singh (2012)	WII00297803129
Incarvillea arguta Royle	Bignoniaceae	H	Hajra and Balodi (1995)	WII0139P
Arnebia benthamii (Wall. ex G.Don) I.M.Johnst.	Boraginaceae	H	Pusalkar and Singh (2012)	WII20886
Arnebia euchroma (Royle ex Benth.) I.M.Johnst.	Boraginaceae	H	Pusalkar and Singh (2012)	WII20686
Cynoglossum glochidiatum Benth.	Boraginaceae	H	Pusalkar and Singh (2012)	WII0120P
Eritrichium canum (Benth.) Kitam.	Boraginaceae	H	Pusalkar and Singh (2012)	WII20681
Hackelia uncinata (Royle ex Benth.) C.E.C.Fisch.	Boraginaceae	H	Pusalkar and Singh (2012)	WII0121P
**Lappula barbata* Gürke	Boraginaceae	H	Pusalkar and Singh (2012)	WII20863
**Lindelofia stylosa* (Kar. & Kir.) Brand	Boraginaceae	H	Pusalkar and Singh (2012)	WII00000002194
**Arabis amplexicaulis* Edgew.	Brassicaceae	H	Pusalkar and Singh (2012)	WII0078P
**Brassica campestris* L.	Brassicaceae	H	Pusalkar and Singh (2012)	WII0079P
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	H	Pusalkar and Singh (2012)	WII0214P
**Chorispora sabulosa* Cambess.	Brassicaceae	H	www.efloras.org	WII20833
Crucihimalaya himalaica (Edgew.) Al-Shehbaz, O'Kane & R.A.Price	Brassicaceae	H	Pusalkar and Singh (2012)	WII20605
**Descurainia sophia* (L.) Webb ex Prantl	Brassicaceae	H	Pusalkar and Singh (2012)	WII0080P
**Dontostemon glandulosus* (Kar. & Kir.) O.E.Schulz	Brassicaceae	H	www.efloras.org	WII0202P
Draba altaica Bunge	Brassicaceae	H	Pusalkar and Singh (2012)	WII20848
Erysimum hieraciifolium L.	Brassicaceae	H	Pusalkar and Singh (2012)	WII20849
Lepidium apetalum Willd.	Brassicaceae	H	Pusalkar and Singh (2012)	WII0215P
**Parrya nudicaulis* (L.) Regel	Brassicaceae	H	Pusalkar and Singh (2012)	WII20603
Turritis glabra L.	Brassicaceae	H	Pusalkar and Singh (2012)	WII20602
**Campanula argyrotricha* Wall. & DC.	Campanulaceae	H	Pusalkar and Singh (2012)	WII0140P
**Campanula aristata* Wall.	Campanulaceae	H	Pusalkar and Singh (2012)	WII20654
Campanula pallida Wall.	Campanulaceae	H	Pusalkar and Singh (2012)	WII0199P
Codonopsis rotundifolia Royle	Campanulaceae	C	Pusalkar and Singh (2012)	WII21971
**Cyananthus linifolius* Wall. ex Hook.f. & Thomson	Campanulaceae	H	Pusalkar and Singh (2012)	WII0141P
Cannabis sativa L.	Cannabaceae	H	Pusalkar and Singh (2012)	WII0067P
Abelia triflora R.Br.	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII00403301389
Devendraea myrtillus (Hook.f. & Thomson) Pusalkar	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII20629
Devendraea spinosa (Decne.) Pusalkar	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII20630

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Table 2. *Continued.*

Plant group	Family	Growth form	Source	Voucher number
Lonicera hypoleuca Decne.	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII0170P
Lonicera obovata Royle ex Hook.f. & Thomson	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII0171P
**Lonicera quinquelocularis* Hardw.	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII20643
Lonicera webbiana Wall.	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII20873
***Lonicera asperifolia* Hook.f. & Thomson**	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII20628
Morina coulteriana Royle	Caprifoliaceae	H	Pusalkar and Singh (2012)	WII0172P
Morina longifolia Wall. ex DC.	Caprifoliaceae	H	Pusalkar and Singh (2012)	WII0173P
Valeriana hardwickii Wall.	Caprifoliaceae	H	Pusalkar and Singh (2012)	WII20660
Viburnum cotinifolium D.Don	Caprifoliaceae	S	Pusalkar and Singh (2012)	WII00479501412
Arenaria serpyllifolia L.	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII0197P
Arenaria festucoides Benth.	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII20865
Arenaria perlevis Hand.-Mazz.	Caryophyllaceae	H	Hajra and Balodi (1995)	WII0093P
**Cerastium* sp.	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII0200P
Gypsophila cerastioides D.Don	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII20870
Silene edgeworthii Bocquet	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII0094P
***Silene gonosperma* (Rupr.) Bocquet**	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII20878
Silene indica Roxb. ex Otth	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII20637
***Silene moorcroftiana* Wall.**	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII20684
**Silene setaesperma* Majumdar	Caryophyllaceae	H	www.efloras.org	WII0095P
Silene viscosa Pers.	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII0096P
Silene vulgaris (Moench) Garcke	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII0097P
Stellaria decumbens Edgew.	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII0098P
Stellaria monosperma Buch.-Ham. ex D.Don	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII00852600239
Stellera chamaejasme L.	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII0099P
Thylacospermum caespitosum (Cambess.) Schischk.	Caryophyllaceae	H	Pusalkar and Singh (2012)	WII20894
Parnassia nubicola Wall.	Celastraceae	H	Pusalkar and Singh (2012)	WII00522901160
Convolvulus arvensis L.	Convolvulaceae	C	Pusalkar and Singh (2012)	WII00553302208
Cuscuta europaea L. var. *indica* Engelm.	Convolvulaceae	C	Pusalkar and Singh (2012)	WII00285402237
***Cuscuta reflexa* Roxb.**	Convolvulaceae	C	Pusalkar and Singh (2012)	WII0122P
**Hylotelephium ewersii* (Ledeb.) H.Ohba	Crassulaceae	H	Pusalkar and Singh (2012)	WII20868
Rhodiola heterodonta (Hook.f. & Thomson) Boriss.	Crassulaceae	H	Pusalkar and Singh (2012)	WII20693
Rhodiola imbricata Edgew.	Crassulaceae	H	Pusalkar and Singh (2012)	WII0036P
***Rhodiola quadrifida* Fisch. & C.A.Mey.**	Crassulaceae	H	Pusalkar and Singh (2012)	WII20692
Rhodiola wallichiana (Hook.) Fu	Crassulaceae	H	Pusalkar and Singh (2012)	WII0038P
**Rosularia alpestris* (Kar. & Kir.) Boriss.	Crassulaceae	H	Pusalkar and Singh (2012)	WII0039P
Sedum multicaule Wall. ex Lindl.	Crassulaceae	H	Pusalkar and Singh (2012)	WII00527501173
Sedum trullipetalum Hook.f. & Thomson	Crassulaceae	H	Pusalkar and Singh (2012)	WII0040P
**Tillaea pharnaceoides* Hochst. ex Steud.	Crassulaceae	H	www.efloras.org	WII0041P
***Blysmus compressus* (L.) Panz. ex Link**	Cyperaceae	Sd	Murti (2001)	WII21996
**Carex cruenta* Nees	Cyperaceae	Sd	Murti (2001)	WII0014P
***Carex gracilenta* Boott ex Boeckeler**	Cyperaceae	Sd	Murti (2001)	WII21999
***Carex lehmannii* Drejer**	Cyperaceae	Sd	Murti (2001)	WII20620
Carex nivalis Boott	Cyperaceae	Sd	Murti (2001)	WII20621
Carex nubigena D.Don	Cyperaceae	Sd	Pusalkar and Singh (2012)	WII21989
**Carex orbicularis* Boott	Cyperaceae	Sd	Murti (2001)	WII20807
**Carex sagaensis* Y.C.Yang	Cyperaceae	Sd	www.efloras.org	WII20818
Carex sp.	Cyperaceae	Sd	Murti (2001)	WII22004
Carex sp.	Cyperaceae	Sd	Murti (2001)	WII22011
Kobresia capillifolia (Decne.) C.B.Clarke	Cyperaceae	Sd	Murti (2001)	WII0015P
Kobresia laxa Nees	Cyperaceae	Sd	Murti (2001)	WII0016P
Kobresia nepalensis (Nees) Kuk.	Cyperaceae	Sd	Murti (2001)	WII0017P
**Kobresia nitens* C.B.Clarke	Cyperaceae	Sd	Murti (2001)	WII20836
**Kobresia pygmaea* (C.B.Clarke) C.B.Clarke	Cyperaceae	Sd	Murti (2001)	WII20815
Kobresia royleana (Nees) Nees ex Boeckeler	Cyperaceae	Sd	Murti (2001)	WII21994
Kobresia sp.	Cyperaceae	Sd	Murti (2001)	WII22003
Kobresia sp.	Cyperaceae	Sd	Murti (2001)	WII22009
Kobresia sp.	Cyperaceae	Sd	Murti (2001)	WII22009
Dioscorea deltoidea Wall.	Dioscoreaceae	C	Murti (2001)	WII00850503272
Hippophae salicifolia D.Don	Elaeagnaceae	S	Pusalkar and Singh (2012)	WII00338002902
Hippophae tibetana Schltdl.	Elaeagnaceae	S	Pusalkar and Singh (2012)	WII0065P
Cassiope fastigiata D.Don	Ericaceae	S	Pusalkar and Singh (2012)	WII0110P

Table 2. *Continued.*

Plant group	Family	Growth form	Source	Voucher number
Gaultheria trichophylla Royle	Ericaceae	S	Pusalkar and Singh (2012)	WII00645501874
Monotropa hypopitys L.	Ericaceae	H	Pusalkar and Singh (2012)	WII0111P
Rhododendron anthopogon D.Don	Ericaceae	S	Pusalkar and Singh (2012)	WII20884
Rhododendron campanulatum D.Don	Ericaceae	S	Pusalkar and Singh (2012)	WII00594601889
Rhododendron lepidotum Wall. ex G.Don	Ericaceae	S	Pusalkar and Singh (2012)	WII00343001891
Euphorbia sp.	Euphorbiaceae	H	Pusalkar and Singh (2012)	WII20804
Euphorbia stracheyi Boiss.	Euphorbiaceae	H	Pusalkar and Singh (2012)	WII20801
Astragalus candolleanus Boiss.	Fabaceae	S	Pusalkar and Singh (2012)	WII0042P
Astragalus chlorostachys Lindl.	Fabaceae	H	Hajra and Balodi (1995)	WII00850900696
***Astragalus densiflorus* Kar. & Kir.**	Fabaceae	H	Chandola (2009)	WII20685
Astragalus himalayanus Klotzsch	Fabaceae	H	Pusalkar and Singh (2012)	WII20646
**Astragalus lessertioides* Benth. ex Bunge	Fabaceae	H	Pusalkar and Singh (2012)	WII20668
**Astragalus rhizanthus* Royle ex Benth.	Fabaceae	H	Pusalkar and Singh (2012)	WII20855
**Caragana gerardiana* Benth.	Fabaceae	S	Pusalkar and Singh (2012)	WII0043P
Caragana versicolor Benth.	Fabaceae	S	Pusalkar and Singh (2012)	WII20697
Cicer microphyllum Royle	Fabaceae	H	Pusalkar and Singh (2012)	WII20899
**Lespedeza juncea* (L.f.) Pers.	Fabaceae	H	Pusalkar and Singh (2012)	WII00528000841
**Medicago edgeworthii* Sirj.	Fabaceae	H	Pusalkar and Singh (2012)	WII0206P
Oxytropis lapponica Gaudin.	Fabaceae	H	Pusalkar and Singh (2012)	WII00000000862
**Oxytropis microphylla* DC.	Fabaceae	H	Pusalkar and Singh (2012)	WII00000000863
**Oxytropis* sp.	Fabaceae	H	Pusalkar and Singh (2012)	WII20664
Parochetus communis Buch.-Ham. ex D.Don	Fabaceae	H	Pusalkar and Singh (2012)	WII00335300866
**Phaseolus vulgaris* L.	Fabaceae	H	Naithani (1984)	WII0044P
**Pisum sativum* L.	Fabaceae	H	Naithani (1984)	WII0045P
**Spongiocarpella nubigena* (D.Don) Yakovlev	Fabaceae	H	Pusalkar and Singh (2012)	WII20667
Thermopsis barbata Benth.	Fabaceae	H	Pusalkar and Singh (2012)	WII0046P
Tibetia himalaica (Baker) H.P.Tsui	Fabaceae	H	Pusalkar and Singh (2012)	WII20824
**Trifolium repens* L.	Fabaceae	H	Pusalkar and Singh (2012)	WII00478800901
Trigonella emodi Benth.	Fabaceae	H	Pusalkar and Singh (2012)	WII20632
Gentiana aprica Decne.	Gentianaceae	H	Hajra and Balodi (1995)	WII00131902119
Gentiana argentea Royle ex D.Don	Gentianaceae	H	Pusalkar and Singh (2012)	WII00646602123
Gentiana stipitata Edgew.	Gentianaceae	H	Pusalkar and Singh (2012)	WII00252202131
Gentiana venusta Wall.	Gentianaceae	H	Pusalkar and Singh (2012)	WII0115P
***Gentiana tianschanica* Rupr.**	Gentianaceae	H	Pusalkar and Singh (2012)	WII0116P
***Gentianella tenella* (Rottb.) Harry Sm.**	Gentianaceae	H	Pusalkar and Singh (2012)	WII20893
Halenia elliptica D.Don	Gentianaceae	H	Pusalkar and Singh (2012)	WII0117P
Lomatogonium carinthiacum (Wulfen) Rchb.	Gentianaceae	H	Pusalkar and Singh (2012)	WII0118P
Swertia ciliata (G.Don) B.L.Burtt	Gentianaceae	H	Pusalkar and Singh (2012)	WII00251802135
**Swertia petiolata* Royle	Gentianaceae	H	Pusalkar and Singh (2012)	WII00342602143
**Geranium collinum* Stephan ex Willd.	Geraniaceae	H	Pusalkar and Singh (2012)	WII0071P
**Geranium himalayense* Klotzsch	Geraniaceae	H	Pusalkar and Singh (2012)	WII0072P
Geranium nepalense Sweet	Geraniaceae	H	Pusalkar and Singh (2012)	WII00400100428
Geranium wallichianum D.Don	Geraniaceae	H	Pusalkar and Singh (2012)	WII00344000437
Ribes alpestre Wall. ex Decne.	Grossulariaceae	S	Pusalkar and Singh (2012)	WII0030P
Ribes orientale Desf.	Grossulariaceae	S	Pusalkar and Singh (2012)	WII0031P
Deutzia compacta Craib	Hydrangeaceae	S	Pusalkar and Singh (2012)	WII20647
**Hypericum japonicum* Thunb.	Hypericaceae	H	Pusalkar and Singh (2012)	WII0070P
Iris kemaonensis D.Don	Iridaceae	H	Murti (2001)	WII0011P
Juglans regia L.	Juglandaceae	T	Hajra and Balodi (1995)	WII00331403123
Juncus himalensis Klotzsch	Juncaceae	Sd	Pusalkar and Singh (2012)	WII00250503321
Juncus sp.	Juncaceae	Sd	Murti (2001)	WII22007
Juncus sp.	Juncaceae	Sd	Murti (2001)	WII20816
Juncus thomsonii Buchenau	Juncaceae	Sd	Murti (2001)	WII20858
**Juncus triglumis* L.	Juncaceae	Sd	Murti (2001)	WII22006
Luzula spicata (L.) DC.	Juncaceae	Sd	Murti (2001)	WII20810
Clinopodium umbrosum (M.Bieb.) Kuntze	Lamiaceae	H	Pusalkar and Singh (2012)	WII20634
**Clinopodium vulgare* L.	Lamiaceae	H	Pusalkar and Singh (2012)	WII00508002567
Dracocephalum heterophyllum Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII20837
Elsholtzia eriostachya Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII00260702580
Elsholtzia strobilifera Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII00595302585
**Eriophyton rhomboideum* (Benth.) Ryding	Lamiaceae	H	Pusalkar and Singh (2012)	WII20682

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Table 2. *Continued.*

Plant group	Family	Growth form	Source	Voucher number
Hyssopus officinalis L.	Lamiaceae	H	Pusalkar and Singh (2012)	WII0133P
**Leonurus cardiaca* L.	Lamiaceae	H	Pusalkar and Singh (2012)	WII20651
Mentha longifolia (L.) Huds.	Lamiaceae	H	Pusalkar and Singh (2012)	WII0134P
Nepeta discolor Royle ex Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII00287702622
Nepeta laevigata (D.Don) Hand.-Mazz.	Lamiaceae	H	Pusalkar and Singh (2012)	WII0135P
Nepeta leucophylla Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII20608
Origanum vulgare L.	Lamiaceae	H	Pusalkar and Singh (2012)	WII00509902634
Phlomis bracteosa Royle ex Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII00000002647
Prunella vulgaris L.	Lamiaceae	H	Pusalkar and Singh (2012)	WII00597202663
Salvia nubicola Wall. ex Sweet	Lamiaceae	H	Pusalkar and Singh (2012)	WII0136P
Scutellaria prostrata Jacquem. ex Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII0137P
**Stachys melissifolia* Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII20675
Thymus linearis Benth.	Lamiaceae	H	Pusalkar and Singh (2012)	WII20872
**Gagea lutea* Ker Gawl.	Liliaceae	H	Pusalkar and Singh (2012)	WII0003P
Lloydia serotina (L.) Sweet	Liliaceae	H	Pusalkar and Singh (2012)	WII20689
**Nomocharis oxypetala* E.H.Wilson	Liliaceae	H	Pusalkar and Singh (2012)	WII0004P
Malva verticillata L.	Malvaceae	H	Pusalkar and Singh (2012)	WII0076P
**Malva verticillata* L. var. *crispa* L.	Malvaceae	H	Pusalkar and Singh (2012)	WII0077P
Aletris pauciflora (Klotzsch) Hand.-Mazz.	Nartheciaceae	H	Hajra and Balodi (1995)	WII0013P
Boerhavia diffusa L.	Nyctaginaceae	H	Pusalkar and Singh (2012)	WII00507504543
Fraxinus xanthoxyloides Wall.	Oleaceae	T	Hajra and Balodi (1995)	WII0125P
**Chamerion angustifolium* (L.) Holub	Onagraceae	H	Pusalkar and Singh (2012)	WII0073P
Chamerion speciosum (Decne.) Holub	Onagraceae	H	Pusalkar and Singh (2012)	WII0074P
Epilobium cylindricum D.Don	Onagraceae	H	Pusalkar and Singh (2012)	WII20633
**Epilobium laxum* Royle	Onagraceae	H	Pusalkar and Singh (2012)	WII0075P
**Epilobium royleanum* Hausskn.	Onagraceae	H	Pusalkar and Singh (2012)	WII20666
Epipactis helleborine (L.) Crantz	Orchidaceae	O	Murti (2001)	WII00000003200
**Epipactis royleana* Lindl.	Orchidaceae	O	Pusalkar and Singh (2012)	WII00000003204
**Goodyera repens* (L.) R.Br.	Orchidaceae	O	Murti (2001)	WII0005P
Gymnadenia orchidis Lindl.	Orchidaceae	O	Pusalkar and Singh (2012)	WII0006P
Herminium monorchis R.Br.	Orchidaceae	O	Murti (2001)	WII20850
Liparis rostrata Rchb.f.	Orchidaceae	O	Pusalkar and Singh (2012)	WII0008P
Malaxis muscifera (Lindl.) Kuntze	Orchidaceae	O	Murti (2001)	WII0009P
**Neottianthe cucullata* Schltr.	Orchidaceae	O	www.efloras.org	WII20891
**Peristylus duthiei* (Hook.f.) Deva & H.B.Naithani	Orchidaceae	O	Naithani (1984)	WII0007P
**Platanthera latilabris* Lindl.	Orchidaceae	O	Naithani (1984)	WII0010P
**Euphrasia himalayica* Wettst.	Orobanchaceae	H	Pusalkar and Singh (2012)	WII0127P
**Leptorhabdos parviflora* Benth.	Orobanchaceae	H	Pusalkar and Singh (2012)	WII0128P
Orobanche alba Stephan ex Willd.	Orobanchaceae	H	Pusalkar and Singh (2012)	WII0138P
**Pedicularis bicornuta* Klotzsch	Orobanchaceae	H	Pusalkar and Singh (2012)	WII20606
Pedicularis longiflora var. *tubiformis* (Klotzsch) P.C.Tsoong	Orobanchaceae	H	Pusalkar and Singh (2012)	WII0129P
**Pedicularis oederi* Vahl	Orobanchaceae	H	Pusalkar and Singh (2012)	WII00000002310
Pedicularis pectinata Wall.	Orobanchaceae	H	Pusalkar and Singh (2012)	WII20638
Pedicularis porrecta Wall.	Orobanchaceae	H	Pusalkar and Singh (2012)	WII0130P
Meconopsis aculeata Royle	Papaveraceae	H	Pusalkar and Singh (2012)	WII00216700103
**Corydalis adiantifolia* Hook.f. & Thomson	Papaveraceae	H	www.efloras.org	WII0201P
Corydalis cornuta Royle	Papaveraceae	H	Pusalkar and Singh (2012)	WII20653
Corydalis govaniana Wall.	Papaveraceae	H	Pusalkar and Singh (2012)	WII20897
Corydalis meifolia Wall.	Papaveraceae	H	Chandola (2009)	WII0022P
**Corydalis nana* Royle	Papaveraceae	H	Pusalkar and Singh (2012)	WII20610
Corydalis casimiriana Duthie & Prain	Papaveraceae	H	Pusalkar and Singh (2012)	WII0023P
Corydalis sp.	Papaveraceae	H	Pusalkar and Singh (2012)	WII20631
Phytolacca acinosa Roxb.	Phytolaccaceae	H	Pusalkar and Singh (2012)	WII00857202776
**Lagotis kunawurensis* Rupr.	Plantaginaceae	H	Pusalkar and Singh (2012)	WII20694
**Picrorhiza scrophulariiflora* Pennell	Plantaginaceae	H	Pusalkar and Singh (2012)	WII20885
**Plantago depressa* Willd.	Plantaginaceae	H	Pusalkar and Singh (2012)	WII0126P
Plantago himalaica Pilg.	Plantaginaceae	H	Pusalkar and Singh (2012)	WII20862
**Veronica biloba* L.	Plantaginaceae	H	Pusalkar and Singh (2012)	WII20881
**Veronica capitata* Royle ex Benth.	Plantaginaceae	H	Pusalkar and Singh (2012)	WII21969
**Veronica ciliata* Fisch. subsp. *cephaloides* (Pennell) D.Y.Hong	Plantaginaceae	H	Pusalkar and Singh (2012)	WII20665
**Veronica lanosa* Royle ex Benth.	Plantaginaceae	H	Pusalkar and Singh (2012)	WII0132P

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Table 2. *Continued.*

Plant group	Family	Growth form	Source	Voucher number
**Agrostis gigantea* Roth	Poaceae	G	Murti (2001)	WII20648
**Agrostis munroana* Aitch. & Hemsl.	Poaceae	G	Murti (2001)	WII21985
Agrostis pilosula Trin.	Poaceae	G	Murti (2001)	WII21991
Agrostis sp.	Poaceae	G	Murti (2001)	WII21987
Andropogon munroi C.B.Clarke	Poaceae	G	Hajra and Balodi (1995)	WII0018P
**Bromus inermis* Leyss.	Poaceae	G	Murti (2001)	WII20858
Bromus pectinatus Thunb.	Poaceae	G	Murti (2001)	WII00253603649
**Calamagrostis holciformis* Jaub. & Spach	Poaceae	G	Murti (2001)	WII21998
**Calamagrostis pseudophragmites* (Haller f.) Koeler	Poaceae	G	Murti (2001)	WII21997
Calamogrostis sp.	Poaceae	G	Murti (2001)	WII20859
Chrysopogon gryllus (L.) Trin. subsp. *echinulatus* (Nees) Cope	Poaceae	G	Murti (2001)	WII20615
Dactylis glomerata L.	Poaceae	G	Murti (2001)	WII21992
Danthonia cachemyriana Jaub. & Spach	Poaceae	G	Murti (2001)	WII00335103746
Elymus nutans Griseb.	Poaceae	G	Murti (2001)	WII20831
Elymus longiaristatus subsp. *canaliculatus* (Nevski) Tzvelev	Poaceae	G	Murti (2001)	WII21993
**Festuca kashmiriana* Stapf	Poaceae	G	Murti (2001)	WII20622
**Festuca tibetica* (Stapf) E.B.Alexeev	Poaceae	G	Murti (2001)	WII20819
Festuca valesiaca Schleich. ex Gaudin	Poaceae	G	Murti (2001)	WII20838
**Hierochloe flexuosa* Hook.f.	Poaceae	G	www.efloras.org	WII21967
**Hierochloe laxa* R.Br.	Poaceae	G	Murti (2001)	WII0019P
**Hordeum vulgare* L.	Poaceae	G	Chandola (2009)	WII0020P
**Koeleria macrantha* (Ledeb.) Schult.	Poaceae	G	Murti (2001)	WII20613
Melica persica Kunth	Poaceae	G	Murti (2001)	WII20623
**Melica scaberrima* Hook.f.	Poaceae	G	Chandola (2009)	WII20803
**Oryzopsis gracilis* (Mez) Pilg.	Poaceae	G	Pusalkar and Singh (2012)	WII21988
**Oryzopsis munroi* Stapf ex Hook.f.	Poaceae	G	Murti (2001)	WII20813
**Pennisetum flaccidum* Griseb.	Poaceae	G	Murti (2001)	WII20673
**Phleum alpinum* L.	Poaceae	G	Murti (2001)	WII20609, WII20618
Poa alpina L.	Poaceae	G	Murti (2001)	WII22002
**Poa pratensis* L.	Poaceae	G	Murti (2001)	WII21965
Poa sp.	Poaceae	G	Murti (2001)	WII22000
Poa sp.	Poaceae	G	Murti (2001)	WII22005
Poa sp.	Poaceae	G	Murti (2001)	WII22008
Poa sp.	Poaceae	G	Murti (2001)	WII22012
**Polypogon fugax* Nees ex Steud.	Poaceae	G	Murti (2001)	WII00853504036
**Puccinellia* sp.	Poaceae	G	Murti (2001)	WII22001
**Setaria pumila* (Poir.) Roem. & Schult.	Poaceae	G	Murti (2001)	WII21986
Stipa sp.	Poaceae	G	Murti (2001)	WII0021P
Trisetum sp.	Poaceae	G	Murti (2001)	WII22012
Trisetum sp.	Poaceae	G	Murti (2001)	WII22015
**Trisetum spicatum* (L.) K.Richt.	Poaceae	G	Murti (2001)	WII22010
**Polemonium caeruleum* L.	Polemoniaceae	H	Pusalkar and Singh (2012)	WII21968
Bistorta affinis Greene	Polygonaceae	H	Pusalkar and Singh (2012)	WII20834
Bistorta vacciniifolia Greene	Polygonaceae	H	Pusalkar and Singh (2012)	WII0085P
Bistorta vivipara (L.) Gray	Polygonaceae	H	Pusalkar and Singh (2012)	WII20636
**Bistorta tenuifolia* (H.W.Kung) Miyam. & H.Ohba var. *gidarensis* I.D.Rai, Singh & Rawat	Polygonaceae	H	Rai et al. (2013)	WII20678
Fagopyrum dibotrys (D.Don) Hara	Polygonaceae	H	Pusalkar and Singh (2012)	WII0086P
Fagopyrum esculentum Moench	Polygonaceae	H	Pusalkar and Singh (2012)	WII0087P
**Knorringia sibirica* (Laxm.) Tzvelev	Polygonaceae	H	Pusalkar and Singh (2012)	WII20856
**Koenigia nepalensis* D.Don	Polygonaceae	H	Pusalkar and Singh (2012)	WII0088P
Koenigia delicatula (Meisn.) Hara	Polygonaceae	H	Pusalkar and Singh (2012)	WII0089P
Oxyria digyna Hill	Polygonaceae	H	Pusalkar and Singh (2012)	WII00320302778
Persicaria nepalensis (Meisn.) Miyabe	Polygonaceae	H	Pusalkar and Singh (2012)	WII0090P
Pleuropteropyrum rumicifolium (Royle ex Bab.) Munshi & Javeid	Polygonaceae	H	Pusalkar and Singh (2012)	WII0083P
**Polygonum plebeium* R.Br.	Polygonaceae	H	Pusalkar and Singh (2012)	WII20867
**Polygonum tortuosum* D.Don	Polygonaceae	H	Pusalkar and Singh (2012)	WII0084P
Rheum australe D.Don	Polygonaceae	H	Pusalkar and Singh (2012)	WII0196P
Rheum moorcroftianum Royle	Polygonaceae	H	Pusalkar and Singh (2012)	WII0091P
**Rheum tibeticum* Maxim. ex Hook.f.	Polygonaceae	H	Chandola (2009)	WII20696
Rheum webbianum Royle	Polygonaceae	H	Pusalkar and Singh (2012)	WII0092P

Continued

Table 2. *Continued.*

Plant group	Family	Growth form	Source	Voucher number
Rubrivena polystachya (Wall. ex Meisn.) M.Kral	Polygonaceae	H	Pusalkar and Singh (2012)	WII00329702809
Rumex acetosa L.	Polygonaceae	H	Pusalkar and Singh (2012)	WII20645
Rumex nepalensis Spreng.	Polygonaceae	H	Pusalkar and Singh (2012)	WII00396302825
Androsace delavayi Franch.	Primulaceae	H	Pusalkar and Singh (2012)	WII0108P
Androsace globifera Duby	Primulaceae	H	Pusalkar and Singh (2012)	WII20677
Androsace rotundifolia Hardw.	Primulaceae	H	Pusalkar and Singh (2012)	WII0109P
Androsace sarmentosa Wall.	Primulaceae	H	Pusalkar and Singh (2012)	WII20625
Primula denticulata Sm.	Primulaceae	H	Pusalkar and Singh (2012)	WII20808
Primula involucrata Wall. ex Duby	Primulaceae	H	Pusalkar and Singh (2012)	WII20626
Aconitum lethale Griff.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII0024P
Aconitum violaceum Jacquem. ex Stapf	Ranunculaceae	H	Pusalkar and Singh (2012)	WII0025P
Actaea acuminata Royle	Ranunculaceae	H	Pusalkar and Singh (2012)	WII0026P
Anemone rivularis Buch.-Ham. ex DC.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20650
Anemone rupicola Cambess.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20607
Anemone tetrasepala Royle	Ranunculaceae	H	Pusalkar and Singh (2012)	WII00000100006
**Aquilegia fragrans* Benth.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20695
Clematis orientalis L.	Ranunculaceae	C	Pusalkar and Singh (2012)	WII00287600024
Delphinium brunonianum Royle	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20669
Delphinium cashmerianum Royle	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20658
**Delphinium densiflorum* Duthie ex Huth	Ranunculaceae	H	Pusalkar and Singh (2012)	WII0027P
**Delphinium caeruleum* Jacquem. ex Cambess.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20678
**Paraquilegia anemonoides* Ulbr.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20830
Ranunculus hirtellus Royle	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20655
Ranunculus pulchellus C.A.Mey.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII0028P
**Ranunculus radicans* C.A.Mey.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20604
Thalictrum alpinum L.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20802
Thalictrum cultratum Wall.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20889
Thalictrum foliolosum DC.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII00000700051
**Thalictrum platycarpum* Greene	Ranunculaceae	H	Pusalkar and Singh (2012)	WII0029P
Thalictrum sp.	Ranunculaceae	H	Pusalkar and Singh (2012)	WII20687
Berchemia edgeworthii Lawson	Rhamnaceae	S	Pusalkar and Singh (2012)	WII0066P
Rhamnus prostrata Jacquem.	Rhamnaceae	S	Pusalkar and Singh (2012)	WII00261900551
**Aruncus dioicus* (Walter) Fernald	Rosaceae	H	Pusalkar and Singh (2012)	WII0047P
**Cotoneaster bacillaris* Wall. ex Lindl.	Rosaceae	S	Naithani (1984)	WII00000001017
**Cotoneaster duthieanus* (C.K.Schneid.) G.Klotz	Rosaceae	S	Pusalkar and Singh (2012)	WII0048P
Cotoneaster garhwalensis G.Klotz	Rosaceae	S	Hajra and Balodi (1995)	WII0049P
Cotoneaster integrifolius (Roxb.) G.Klotz	Rosaceae	S	Hajra and Balodi (1995)	WII20671
**Cotoneaster marginatus* (Loudon) Schltdl.	Rosaceae	S	Pusalkar and Singh (2012)	WII0050P
Cotoneaster microphyllus Wall. ex Lindl.	Rosaceae	S	Pusalkar and Singh (2012)	WII0051P
**Cotoneaster roseus* Edgew.	Rosaceae	S	Pusalkar and Singh (2012)	WII0052P
Fragaria nubicola Lindl. ex Lacaita	Rosaceae	H	Pusalkar and Singh (2012)	WII0053P
**Malus domestica* Borkh.	Rosaceae	T	Pusalkar and Singh (2012)	WII0054P
**Potentilla anserina* L.	Rosaceae	H	www.efloras.org	WII0055P
Potentilla argyrophylla Wall. ex Lehm.	Rosaceae	H	Pusalkar and Singh (2012)	WII20842
Potentilla atrosanguinea Lodd., G.Lodd. & W.Lodd.	Rosaceae	H	Pusalkar and Singh (2012)	WII00648301036
Potentilla biflora D.F.K.Schltdl.	Rosaceae	H	Pusalkar and Singh (2012)	WII20896
Potentilla bifurca L.	Rosaceae	H	Pusalkar and Singh (2012)	WII20861
**Potentilla cuneifolia* Bertol.	Rosaceae	H	Pusalkar and Singh (2012)	WII0056P
**Potentilla curviseta* Hook.f.	Rosaceae	H	www.efloras.org	WII0057P
Potentilla gelida C.A.Mey.	Rosaceae	H	Pusalkar and Singh (2012)	WII0208P
Potentilla microphylla D.Don	Rosaceae	H	Pusalkar and Singh (2012)	WII20674
Potentilla multifida L.	Rosaceae	H	Pusalkar and Singh (2012)	WII20879
**Potentilla pamirica* Th.Wolf	Rosaceae	H	www.efloras.org	WII20661
Potentilla rigida Wall. ex Lehm.	Rosaceae	S	Pusalkar and Singh (2012)	WII21967
**Prunus armeniaca* L.	Rosaceae	T	Pusalkar and Singh (2012)	WII00000001053
Prunus cornuta (Wall. ex Royle) Steud.	Rosaceae	T	Pusalkar and Singh (2012)	WII00594401062
Prunus persica (L.) Batsch	Rosaceae	T	Pusalkar and Singh (2012)	WII0205P
Prunus jacquemontii Hook.f.	Rosaceae	T	Hajra and Balodi (1995)	WII0058P
Rosa beggeriana Schrenk	Rosaceae	S	Pusalkar and Singh (2012)	WII0060P
Rosa macrophylla Lindl. var. *minor* Lindl.	Rosaceae	S	Pusalkar and Singh (2012)	WII0061P
Rosa sericea Lindl.	Rosaceae	S	Pusalkar and Singh (2012)	WII0059421096

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Table 2. *Continued.*

Plant group	Family	Growth form	Source	Voucher number
Rosa webbiana Wall. ex Royle	Rosaceae	S	Pusalkar and Singh (2012)	WII0029081097
Sibbaldia parviflora Willd.	Rosaceae	H	Pusalkar and Singh (2012)	WII20833
Sorbaria tomentosa (Lindl.) Rehder	Rosaceae	S	Pusalkar and Singh (2012)	WII0000001135
**Sorbus aucuparia* L.	Rosaceae	S	Pusalkar and Singh (2012)	WII0062P
Sorbus microphylla Wenz.	Rosaceae	S	Pusalkar and Singh (2012)	WII0062P
**Spiraea arcuata* Hook.f.	Rosaceae	S	Pusalkar and Singh (2012)	WII0063P
Spiraea canescens D.Don.	Rosaceae	S	Pusalkar and Singh (2012)	WII0064P
Galium aparine L.	Rubiaceae	H	Pusalkar and Singh (2012)	WII00602504598
**Galium asperuloides* Edgew.	Rubiaceae	H	Pusalkar and Singh (2012)	WII0112P
**Galium rotundifolium* L.	Rubiaceae	H	Pusalkar and Singh (2012)	WII0113P
Leptodermis lanceolata Wall.	Rubiaceae	S	Pusalkar and Singh (2012)	WII00466101491
Rubia cordifolia L.	Rubiaceae	C	Pusalkar and Singh (2012)	WII00289401532
Populus ciliata Wall. ex Royle	Salicaceae	T	Pusalkar and Singh (2012)	WII00856103161
**Salix daphnoides* Vill.	Salicaceae	S	Pusalkar and Singh (2012)	WII0209P
Salix denticulata Andersson	Salicaceae	S	Pusalkar and Singh (2012)	WII0068P
Salix karelinii Turcz. ex Stschegl.	Salicaceae	S	Pusalkar and Singh (2012)	WII0210P
Salix lindleyana Wall. ex Andersson	Salicaceae	S	Pusalkar and Singh (2012)	WII00593803168
Salix sp.	Salicaceae	S	Pusalkar and Singh (2012)	WII20672
Thesium himalense Royle	Santalaceae	H	Pusalkar and Singh (2012)	WII0081P
Acer acuminatum Wall. ex D.Don	Sapindaceae	T	Pusalkar and Singh (2012)	WII0212P
***Bergenia ciliata* (Haw.) Sternb.**	Saxifragaceae	H	Pusalkar and Singh (2012)	WII0213P
Bergenia stracheyi (Hook.f. & Thomson) Engl.	Saxifragaceae	H	Pusalkar and Singh (2012)	WII20841
Saxifraga brunonis Ser.	Saxifragaceae	H	Pusalkar and Singh (2012)	WII0033P
**Saxifraga crenua* L.	Saxifragaceae	H	Pusalkar and Singh (2012)	WII0034P
Saxifraga flagellaris Willd.	Saxifragaceae	H	Pusalkar and Singh (2012)	WII20679
Saxifraga sibirica L.	Saxifragaceae	H	Pusalkar and Singh (2012)	WII0035P
Saxifraga wallichiana Sternb.	Saxifragaceae	H	Pusalkar and Singh (2012)	WII0032P
**Scrophularia dentata* Royle ex Benth.	Scrophulariaceae	H	Pusalkar and Singh (2012)	WII20853
Scrophularia edgeworthii Benth.	Scrophulariaceae	H	Pusalkar and Singh (2012)	WII0131P
Verbascum thapsus L.	Scrophulariaceae	H	Pusalkar and Singh (2012)	WII00432102234
Hyoscyamus niger L.	Solanaceae	H	Pusalkar and Singh (2012)	WII0123P
Physochlaina praealta Miers	Solanaceae	H	Pusalkar and Singh (2012)	WII20825
**Solanum tuberosum* L.	Solanaceae	H	Pusalkar and Singh (2012)	WII0124P
Myricaria elegans Royle	Tamaricaceae	S	Pusalkar and Singh (2012)	WII0082P
Myricaria rosea W.W.Sm.	Tamaricaceae	S	Pusalkar and Singh (2012)	WII20888
Urtica dioica L.	Urticaceae	H	Pusalkar and Singh (2012)	WII00632003116
**Urtica hyperborea* Jacquem. ex Wedd.	Urticaceae	H	Pusalkar and Singh (2012)	WII00286703117
Viola betonicifolia Sm.	Violaceae	H	Pusalkar and Singh (2012)	WII00604804662
Viola biflora L.	Violaceae	H	Pusalkar and Singh (2012)	WII0069P
**Viola kunawurensis* Royle	Violaceae	H	Chandola (2009)	WII20676
Gymnosperms				
Cupressus torulosa D.Don	Cupressaceae	T	Pusalkar and Singh (2012)	WII00000003185
Juniperus communis L.	Cupressaceae	S	Pusalkar and Singh (2012)	WII00000003174
Juniperus indica Bertol.	Cupressaceae	S	Pusalkar and Singh (2012)	WII0187P
Juniperus semiglobosa Regel	Cupressaceae	T	Pusalkar and Singh (2012)	WII20883
Ephedra gerardiana Wall. ex Stapf	Ephedraceae	S	Pusalkar and Singh (2012)	WII0183P
Abies pindrow Spach	Pinaceae	T	Pusalkar and Singh (2012)	WII20875
Abies spectabilis Spach	Pinaceae	T	Pusalkar and Singh (2012)	WII0184P
Cedrus deodara (Roxb. ex D.Don) G.Don	Pinaceae	T	Pusalkar and Singh (2012)	WII0185P
Picea smithiana Boiss.	Pinaceae	T	Pusalkar and Singh (2012)	WII20869
Pinus wallichiana A.B.Jacks.	Pinaceae	T	Pusalkar and Singh (2012)	WII0186P
Pteridophytes				
Adiantum venustum D.Don	Adiantaceae	F	Khullar (2000)	WII00333704147
Asplenium septentrionale (L.) Hoffm.	Aspleniaceae	F	Khullar (2000)	WII0190P
**Athyrium foliolosum* (Wall.) Moore	Athyriaceae	F	Khullar (2000)	WII0192P
**Deparia allantodioides* (Bedd.) M.Kato	Athyriaceae	F	Khullar (2000)	WII0193P
**Dryopteris barbigera* (Moore) Kuntze	Dryopteridaceae	F	Khullar (2000)	WII00340404149
Equisetum diffusum D.Don	Equisetaceae	F	Pusalkar and Singh (2012)	WII0188P
Lepisorus sp.	Polypodiaceae	F	Khullar (2000)	WII0194P
Onychium sp.	Pteridaceae	F	Khullar (2000)	WII0189P
**Thelypteris levingei* (C.B.Clarke) Ching	Thelypteridaceae	F	Khullar (2000)	WII0191P

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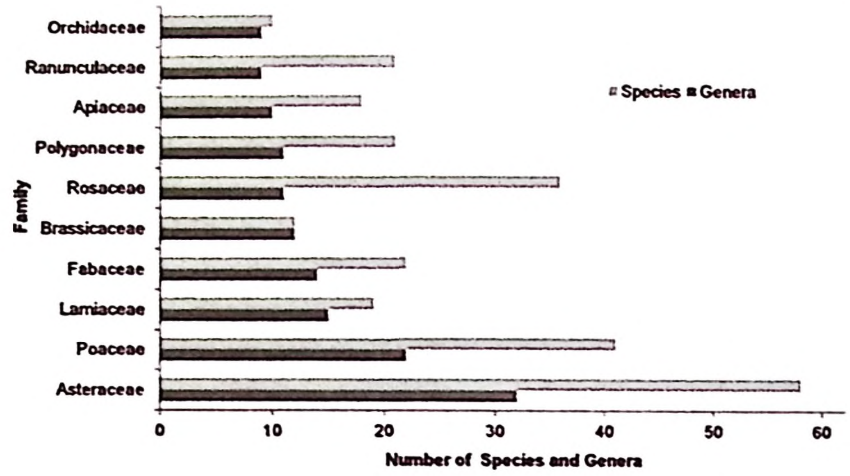

Figure 2. Dominant families with number of genera and species in Niti valley, Nanda Devi Biosphere Reserve, India.

species richness in the valley were Asteraceae (32 genera with 58 species) followed by Poaceae (22 genera with 41 species) and Lamiaceae (15 genera with 19 species; Figure 2). Analysis of data indicates that 52% of total species found in the present flora belongs to these ten dominating families (Figure 2). The presence of families such as Asteraceae, Poaceae, Lamiaceae, Fabaceae, Brassicaceae, Rosaceae, Polygonaceae, Apiaceae, Ranunculaceae and Orchidaceae could be attributed to the mesic conditions in the valley. Among gymnosperms, three major families (Pinaceae, Ephedraceae and Cupressaceae) were recorded, of which Pinaceae had five species, Cupressaceae had four species and Ephedraceae had only one species. A total of nine species (eight families with nine genera) of pteridophytes were recorded from the valley, with the family Athyriaceae having two species. Altogether, 24 families (Adiantaceae, Aspleniaceae, Betulaceae, Bignoniaceae, Cannabaceae, Celastraceae, Dioscoreaceae, Dryopteridaceae, Ephedraceae, Equisetaceae, Hydrangeaceae, Hypericaceae, Iridaceae, Juglandaceae, Nartheciaceae, Nyctaginaceae, Oleaceae, Phytolaccaceae, Polemoniaceae, Polypodiaceae, Pteridaceae, Santalaceae, Sapindaceae and Thelypteridaceae) were represented by single species in Niti valley. Among the different growth forms, herbs contributed 70.7% followed by shrubs (11.3%), grasses (7.2%), sedges (4.3%) trees (2.6%), climbers and ferns (1.8% each). The currently accepted name of the plant, author citation, family, habit and voucher specimen's number for each species is given in Table 2.

Potentilla L. was the dominant genus with 12 species, including one shrub species (*Potentilla rigida* Wall. ex Lehm.), followed by the monocotyledons (*Carex* L. and *Kobresia* Willd.) with nine species each, and dicotyledons such as *Artemisia* L., *Corydalis* DC. and *Silene* L. (seven species each) and *Astragalus* L. and *Poa* L. (six species each). The other common herbaceous vegetation were *Anaphalis* DC., *Oxytropis* DC., *Danthonia* DC., *Pedicularis* L., *Androsace* L., *Saxifraga* L. and *Rhodiola* L. Among the shrubs, *Cotoneaster* with seven species followed by *Lonicera* L. (five) dominated the valley, while *Juniperus indica* Bertol., *Juniperus communis* L., *Caragana versicolor* Benth., *Krascheninnikovia ceratoides* (L.) Gueldenst., *Potentilla rigida* Wall. ex Lehm., *Devendraea* sp., *Rosa* sp., *Ephedra gerardiana* Wall. ex Stapf, *Rhododendron anthopogon* D.Don, *R. lepidotum* Wall. ex G.Don, *Hippophae* sp. and *Salix* sp., were common. The major trees found in the valley were *Pinus wallichiana* A.B.Jacks., *Cedrus deodara* (Roxb. ex D.Don) G.Don, *Picea smithiana* Boiss., *Betula utilis* D.Don, *Fraxinus xanthoxyloides* Wall. and *Juniperus semiglobosa* Regel. *Pinus wallichiana* A.B.Jacks., *Pinus-Cedrus*, and *Pinus-Cedrus-Picea* were the major forest communities in the lower reaches of the valley. Additionally, *Betula utilis* D.Don was the major community alongside steep ridges protruding towards hill tops. *Rumex nepalensis* Spreng., locally known as *khoksya*, was found growing excessively in open riverine and alpine tracts of Amrit Ganga (Dhaman payar), animal resting places, near human habitations and agricultural fields throughout the valley. An overview of the study area with some specific habitats, rare and important medicinal plants in the region are shown in Figures 3–6.

Threatened taxa

Saussurea costus (Falc.) Lipsch. (locally known as *kuth*; cultivated) and *Juniperus semiglobosa* Regel were recorded from the region, which are listed as Critically Endangered and Least Concern, respectively (IUCN 2015). *Aconitum lethale* Griff. and *Allium stracheyi* Baker (wild as well as cultivated) were reported as Indeterminate and Vulnerable, respectively, as per Walter and Gillett (1998). *Allium carolinianum* DC. (Vulnerable), *Thermopsis barbata* Benth. (Vulnerable), *Thylacospermum caespitosum* (Cambess.) Schischk. (Endangered) and *Viola kunawurensis* Royle (Critically Endangered) are threatened species of cold-arid regions as per Srivastava (2010); *Allium stracheyi* Baker (Vulnerable) as per Nayar and Sastry (1987–90) and *Dioscorea deltoidea* Wall. in the Appendix II of CITES (2003). Additionally, the valley also harbours 23 threatened plants, which falls under various threat categories as per Conservation Assessment and Management Prioritization of selected medicinal plants in Western Himalaya (Ved et al. 2003; Table 3). Of these, 35%, 35%, 22% and 8% plants were Endangered, Vulnerable, Near Threatened and Critically Endangered, respectively. Moreover, despite the presence of suitable habitats in Amrit Ganga watershed, the authors did not find any individuals of *Dactylorhiza hatagirea* (D.Don) Soo from the valley. However, local inhabitants of the valley mentioned its presence in the valley, though the identity of this plant is mostly confused among locals with *Gymnadenia orchidis* Lindl.

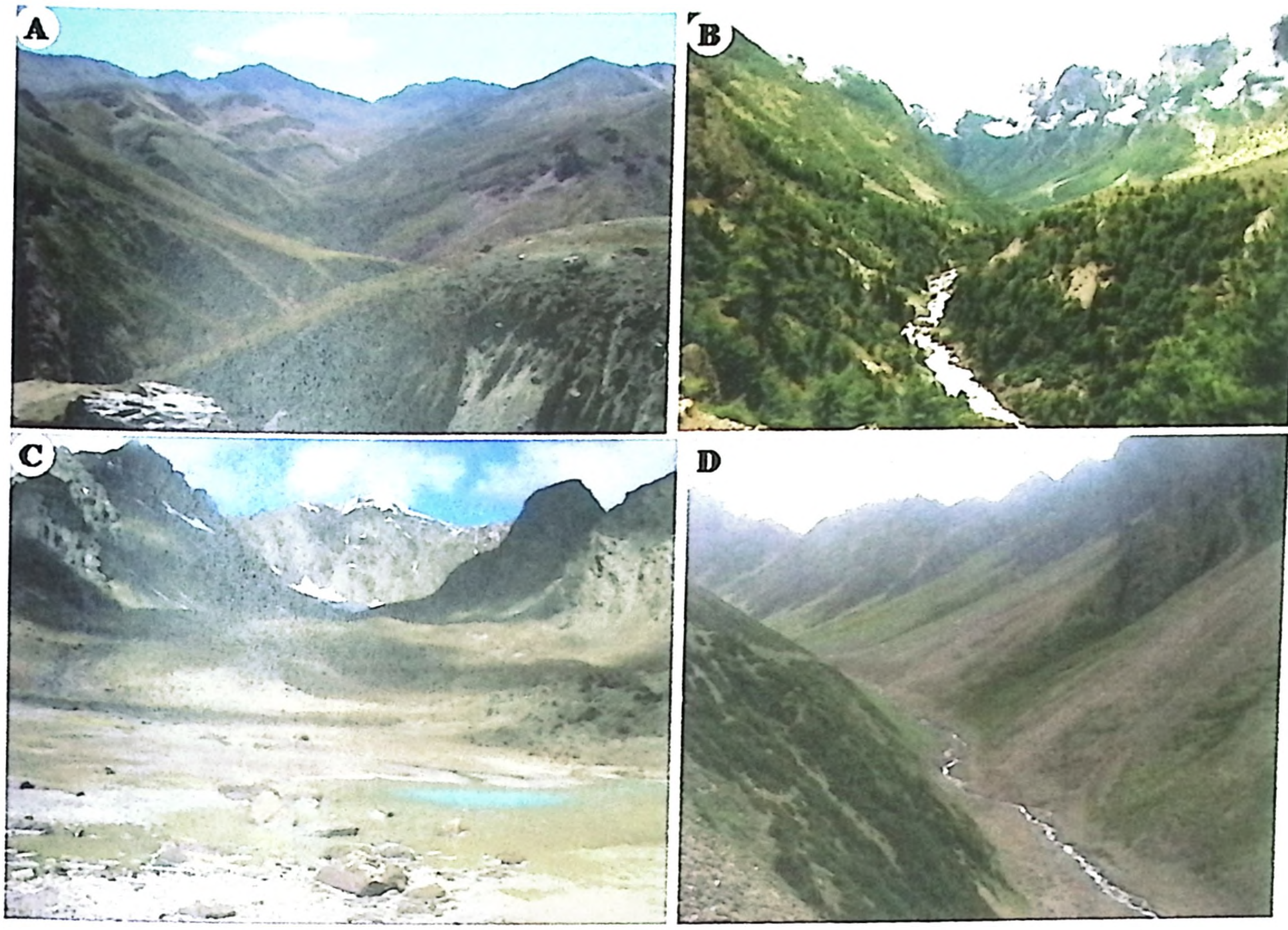

Figure 3. An overview of the valley at different locations. (A) Dry alpine pastures towards Geldung (4,500–5,500 m); **(B)** *Pinus-Cedrus* forests (3,200–3,600 m) along the river *Dhauli Ganga*; **(C)** Glacial lake at Geldung (5,030 m); **(D)** Scree slopes on left bank and *Caragana* scrub on right bank of Satyagad watershed (>4,000 m). Photos: Amit Kumar.

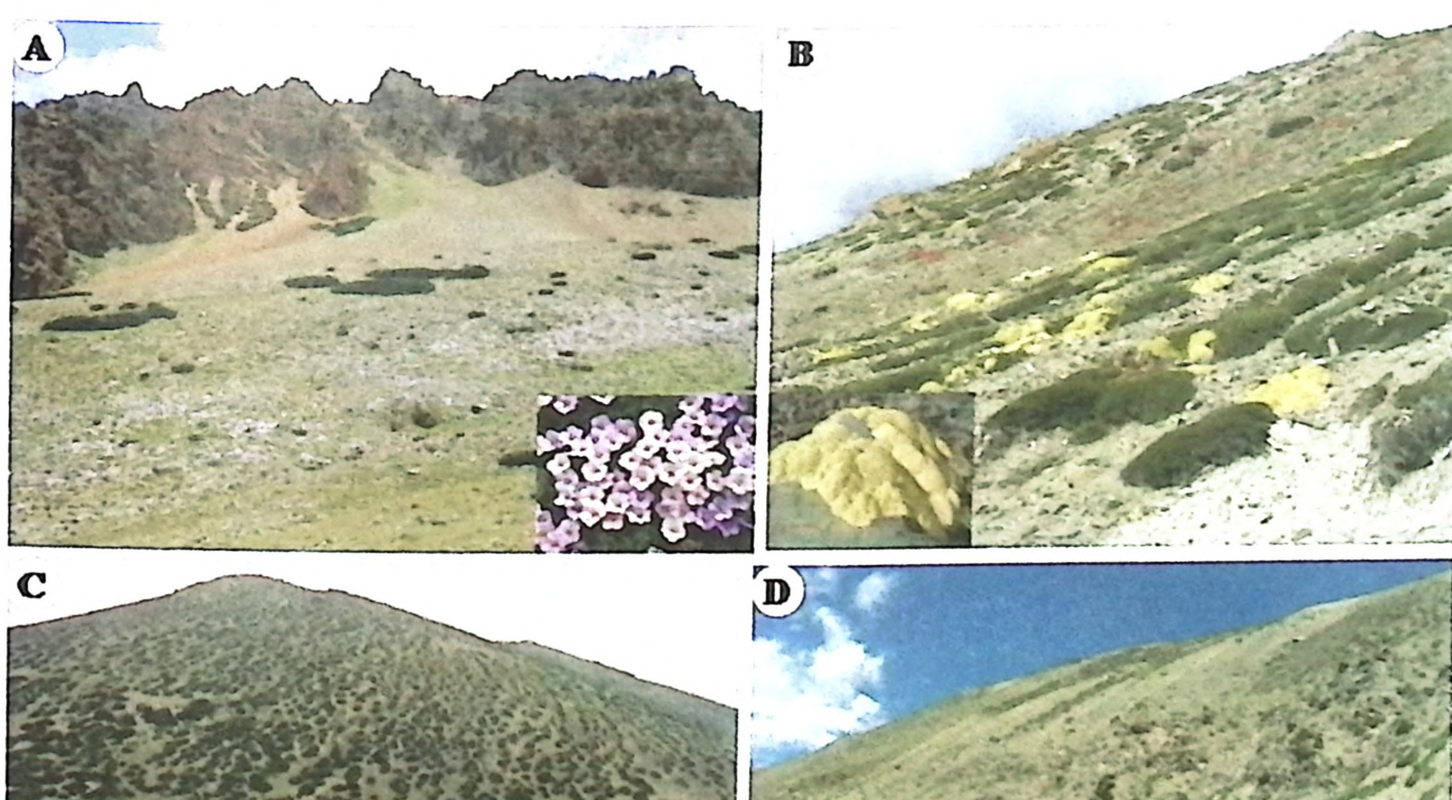

Figure 4. Specific habitats of different species (above 4,500 m). **(A)** Open dry slope covered by *Androsace globifera*; **(B)** *Thylacospermum caespitosum* amidst *Caragana versicolor* on gentle slopes; **(C)** *Caragana* steppe; **(D)** *Cicer microphyllum* on dry steep slopes along the *Dhauli Ganga* River. Photos: Amit Kumar.

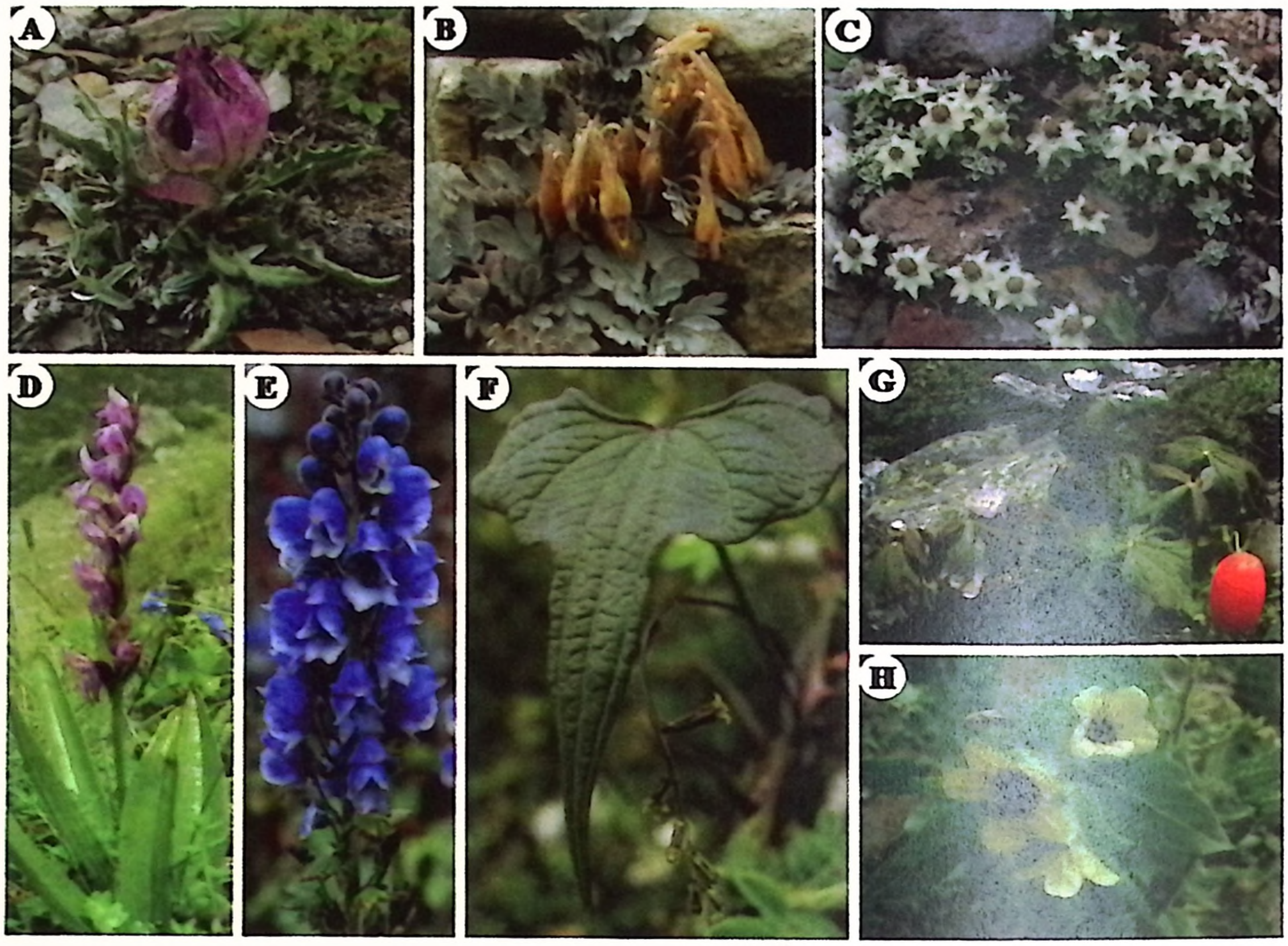

Figure 5. Few rare species of the valley. **(A)** *Saussurea nana*; **(B)** *Corydalis nana*; **(C)** *Leontopodium nanum*; **(D)** *Neottianthe cucullata*; **(E)** ***Aconitum lethale***; **(F)** *Dioscorea deltoidea*; **(G)** ***Sinopodophyllum hexandrum***; **(H)** *Hyoscyamus niger*. Photos: Amit Kumar.

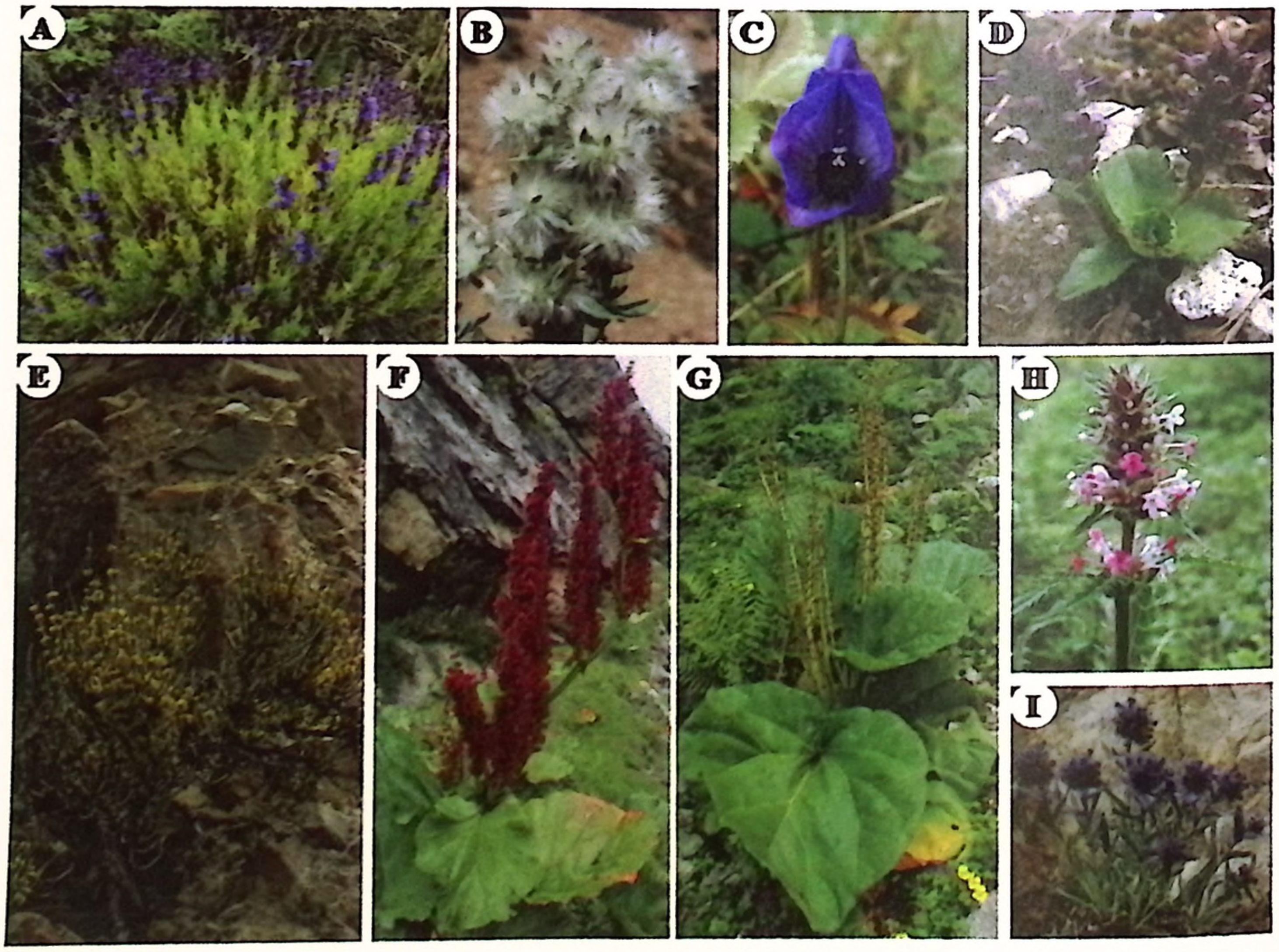

Figure 6. Few important medicinal plants in the valley. **(A)** ***Hyssopus officinalis***; **(B)** *Krascheninnikovia ceratoides*; **(C)** *Aconitum violaceum*; **(D)** *Picrorhiza scrophulariiflora*; **(E)** *Ephedra gerardiana*; **(F)** *Rheum australe*; **(G)** *Rheum moorcroftianum*; **(H)** *Morina longifolia*; **(I)** *Arnebia euchroma*. Photos: Amit Kumar.

Table 3. List of taxa in each threat category in Niti valley, Nanda Devi Biosphere Reserve, Western Himalaya, India. Abbreviations used: CR=Critically Endangered, EN=Endangered, VU=Vulnerable, NT=Near Threatened, I=Indeterminate, AG= Amrit Ganga, GG= Ganesh Ganga, SG= Satyagad. Ved et al. (2003).

Species	Vernacular name	Potential localities	Conservation Assessment and Management Prioritization Report
Aconitum lethale Griff.	Meetha	AG	VU
Aconitum violaceum Jacquem. ex Stapf	Atis	SG	VU
Allium stracheyi Baker	Jambu Faran	AG, SG, GG	VU
Angelica glauca Edgew.	Choru	AG	EN
Arnebia benthamii (Wall. ex G.Don) I.M.Johnst.	Balchadi, Laljari	GG	CR
Arnebia euchroma I.M.Johnst.	Balchadi, Laljari	GG	EN
Artemisia maritima L.	Purchu	AG, GG	NT
Bergenia stracheyi (Hook.f. & Thomson) Engl.	Silfore	GG	NT
Betula utilis D.Don	Bhuj	AG, SG, GG	NT
Dioscorea deltoidea Wall.	—	AG	EN
Dolomiaea macrocephala DC.	—	AG	EN
Ephedra gerardiana Wall. ex Stapf	Somlata	AG, GG	EN
Hippophae salicifolia D.Don	Ames	AG	NT
Hyoscyamus niger L.	Phagun	AG	VU
Meconopsis aculeata Royle	—	AG	EN
Polygonatum cirrhifolium Royle	—	AG	VU
Polygonatum verticillatum All.	Salammisri	AG	VU
Rheum moorcroftianum Royle	Dholu	GG	NT
Rheum webbianum Royle	Tatar, Tatri	AG	VU
Rhodiola heterodonta (Hook.f. & Thomson) Boriss.	—	AG, GG	VU
Saussurea costus (Falc.) Lipsch.	Kuth	cultivated	EN
Saussurea obvallata Wall.	Brahma Kamal	SG	EN
Sinopodophyllum hexandrum (Royle) T.S.Ying	Ban kakri	AG	EN

DISCUSSION

The presence of 495 species of vascular plants in an area of ca. 726 km² indicates rich floral diversity and it can be said that this area has high species richness as compared to Nilang valley (1,360 km²), an adjacent Trans-Himalayan valley (441 species) in the state. In the Satyagad (Kalazowar) and Ganesh Ganga watersheds, towards inner side of the valley, species such as *Caragana versicolor* Benth., *Cousinia thomsonii* C.B.Clarke, *Ephedra gerardiana* Wall. ex Stapf, *Festuca tibetica* (Stapf) E.B.Alexeev, *Hippophae tibetana* Schltdl., *Juniperus semiglobosa* Regel, *Kraschenninikovia ceratoides* (L.) Gueldenst., *Melica persica* Kunth and *Rheum tibeticum* Maxim. ex Hook.f. show affinities with the Trans-Himalayan region due to increasing aridity. The mosaics of *Caragana* scrub alone and amidst *Kraschenninikovia ceratoides* (L.) Gueldenst., *Devendraea spinosa* (Decne.) Pusalkar and *Potentilla rigida* Wall. ex Lehm. add a peculiar appearance to the landscape in the Geldung and Kalazowar regions. Moreover, the presence of cushioned dwarf herbs such as *Thylacospermum caespitosum* (Cambess.) Schischk. on east and south-east slopes near Geldung Lake (above 5,000 m) and *Arenaria festucoides* Benth. and *Androsace globifera* Duby in Kalajowar (above 4,000 m) were among the typical Trans-Himalayan floral elements. However, the Amrit Ganga watershed (Dhaman payar) is comparatively rich in flora due to reasonably moist conditions and affinities of floral characteristics with the Greater Himalayan region, especially in lateral moraines, open riverine tracts and mixed herbaceous formations with species of *Rhododendron campanulatum* D.Don, *R. lepidotum* Wall. ex G.Don, *Cassiope fastigiata* D.Don, *Trachydium roylei* Lindl., *Potentilla* L., *Anaphalis* DC., *Gentiana* L., *Rosa* L., *Sorbus* L., *Primula* L. and *Pedicularis* L. Therefore, based on the existence of phyto-elements from both the Trans and Greater Himalayan regions, it can be concluded that the Niti valley forms a transition zone.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Ministry of Environment, Forests and Climate Change, New Delhi; WWF-INDIA (AK and MM) and University Grant Commission under Rajiv Gandhi National Fellowship scheme, New Delhi (AK) for funding support. The authors are also grateful to Director, Wildlife Institute of India for institutional support, Uttarakhand State Forest Department and Sub-divisional Magistrate, Joshimath for granting permission and help. The authors thank Drs. Pankaj Kumar, U.L. Tiwari and I.D. Rai for identification of plants, Mr. Sachin Sharma, Ms. Upma Manral for valuable suggestions and Dinesh, Prakash, Amar and Amit for assisting in the field.

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Author contributions: AK contributed to the collection of plant species, field data collection, photography, review of literature, data analysis and manuscript writing; MM helped in field data collection; BSA guided the field work and GSR helped in identification of plants and interpretation of data.

Received: 11 August 2015
Accepted: 26 December 2015
Academic editor: Gustavo Hassemer

Journal of Threatened Taxa

The international journal of conservation and taxonomy

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

NOTE

NEW PHYTOGEOGRAPHICALLY NOTEWORTHY PLANT RECORDS FROM UTTARAKHAND, WESTERN HIMALAYA, INDIA

Amit Kumar, Bhupendra Singh Adhikari & Gopal Singh Rawat

26 June 2016 | Vol. 8 | No. 6 | Pp. 8943–8947
10.11609/jott.2416.8.6.8943-8947

ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

OPEN ACCESS

New phytogeographically noteworthy plant records from Uttarakhand, western Himalaya, India

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The Indian Himalayan Region (IHR), covering wide physiographic zones from the Shivalik ranges along the foothills in the south to the Tibetan Plateau in the north, is known for its biological, geo-hydrological, aesthetic and cultural values. It comprises two biotic zones and six biogeographic provinces viz., Ladakh Mountains (1A), Tibetan Plateau (1B), northwestern Himalaya (2A), western Himalaya (2B), central Himalaya (2C) and eastern Himalaya (2D) (Rodgers et al. 2000). The western Himalaya (WH) between Satluj and Sharada rivers in the states of Himachal Pradesh and Uttarakhand (2B) represents a highly complex and diverse system both in terms of biological and physical attributes. A few authors describe this region in northwestern Himalaya as well (Deva & Naithani 1986; Gaur 1999).

Compared to other Himalayan states of India, Uttarakhand has been most extensively explored. Plant collections in the region started in 1796 when Thomas Hardwicke collected plants from the Alaknanda Valley of Garhwal Himalaya. Since then, various plant collectors such as Osmaston (1927), Gupta (1928, 1968), Babu (1977), Raizada & Saxena (1977), Naithani (1984), Gaur (1999), Rawat (2005, 2007) have worked in the state and have deposited their collections in the three national herbaria located in Dehradun, viz.: Botanical Survey of India (BSD), Forest Research Institute (DD) and Wildlife Institute of India (WII). The most comprehensive collections in terms of flora were made by R. Strachey and J.E. Winterbottom between the years 1846–1849. Their collections, comprising of ca. 2000 species were submitted mainly to the Kew Herbarium (K; in the years 1852–1853), the British Museum Natural History (BM) and the Linnaean Society (LNS). Additionally, discovery of new plant species is still going on from the state (Rai & Adhikari 2012; Rawat 2014; Tiwari et al. 2014; Rai et al. 2015). Recently, Uniyal et al. (2007) have brought out a comprehensive list of flowering plants from Uttarakhand which reveals that the state harbours ca. 4,700 species under 1,503 genera and 213 families, thus accounting for about 27% of India's total angiospermic flora.

Although the entire state has been extensively explored by botanists, the patterns of biodiversity are under explored or unexplored even from well demarcated remote areas such as the trans-Himalaya. These areas with an average elevation ranging from 3,500–5,000 m are situated in the rain-shadow zone of Himalaya. These areas under cold deserts constitute a unique ecosystem, which are characterized by extreme climatic conditions, such as diurnal fluctuations in temperatures, scanty and erratic rainfall, heavy winds and snowfall. Most of the area (>70%) in these regions fall under the alpine dry scrub (scrub steppe) and alpine

DOI: http://dx.doi.org/10.11609/jott.2416.8.6.8943-8947

Editor: Pankaj Kumar, Kadoorie Farm and Botanic Garden (KFBG) Corporation, Tai Po, Hong Kong. **Date of publication:** 26 June 2016 (online & print)

Manuscript details: Ms # 2416 | Received 18 November 2015 | Final received 23 March 2016 | Finally accepted 26 May 2016

Citation: Kumar, A., B.S. Adhikari & G.S. Rawat (2016). New phytogeographically noteworthy plant records from Uttarakhand, western Himalaya, India. *Journal of Threatened Taxa* 8(6): 8943–8947; http://dx.doi.org/10.11609/jott.2416.8.6.8943-8947

Funding: University Grant Commission (UGC), New Delhi; World Wide Fund for Nature-India.

Conflict of Interest: The authors declare no competing interests.

WWF
भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Acknowledgements: The authors are grateful to Director, Wildlife Institute of India, Dehradun for institutional support. The first author wishes to acknowledge University Grant Commission (UGC), New Delhi for Rajiv Gandhi National Fellowship; WWF-India's small grants programme and Dr. I.D. Rai and Ms. Upma Manral for their valuable suggestions.

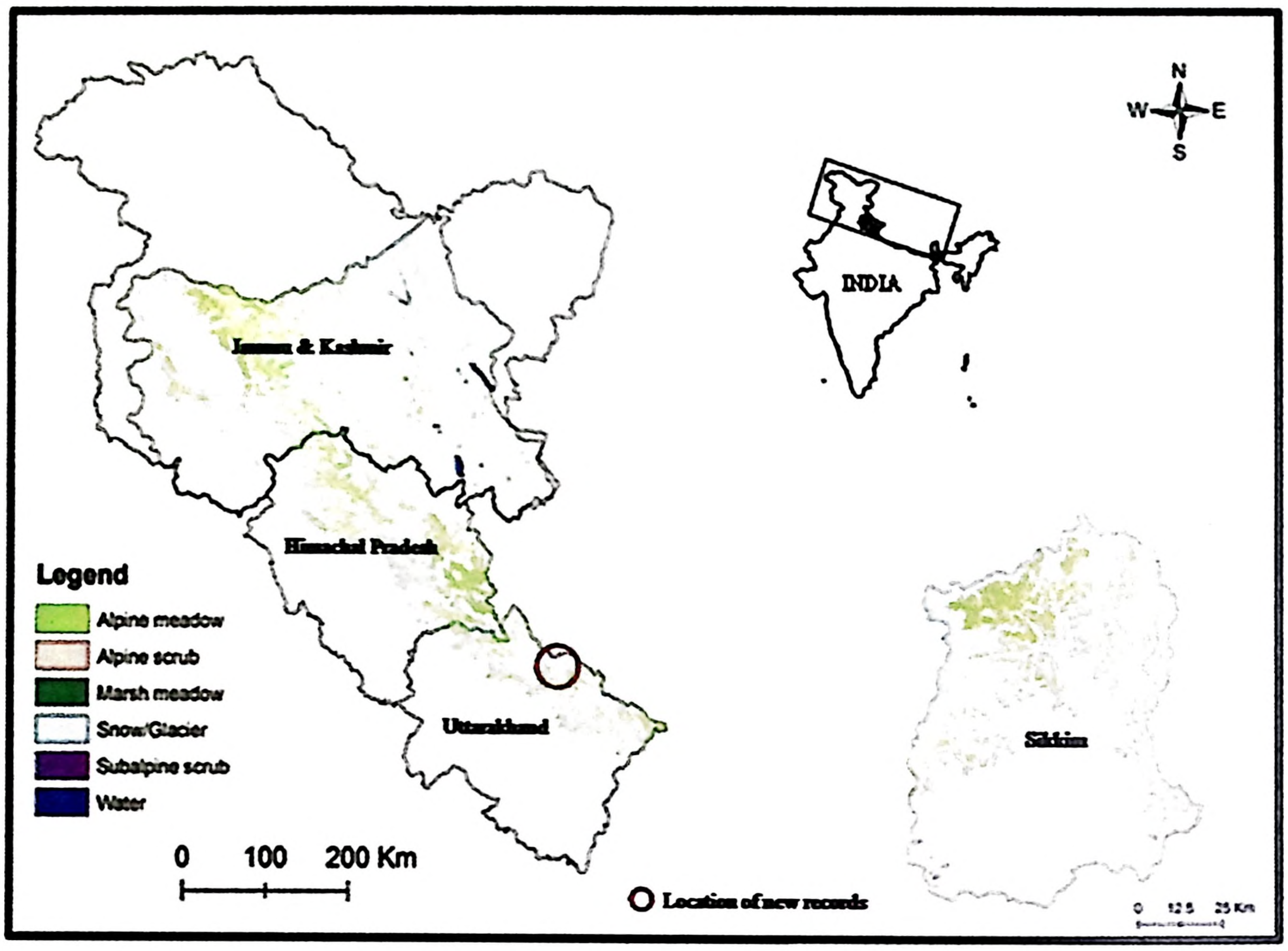

Figure 1. Map showing the location of new plant records in the cold-arid region of Uttarakhand, western Himalaya.

dry pastures (desert steppe) type.

During recent floristic surveys in the Upper Dhauli Valley (also known as the Nīti Valley), a trans-Himalayan region of Nanda Devi Biosphere Reserve (ca. 6,407km^2; 30^{0}08'–31^{0}02'N & 79^{0}12'–80^{0}19'E; Fig. 1) in Uttarakhand, a few interesting plant species were collected. A detailed scrutiny of the characters observed in the field, the literature and the authentic herbarium specimens (BSD, DD & WII) revealed that the species were new records to the state of Uttarakhand, western Himalaya. The plant specimens were processed and prepared following standard herbarium methods and deposited at WII. The botanical names were updated following www.theplantlist.org and other recent published literature. The description, phenology, distribution and habitat of these species are provided along with photographs of live or herbarium specimens.

Taxonomic treatment and description

1. ***Dontostemon glandulosus*** (Kar. & Kir.) O.E. Schulz, Notizbl. Bot. Gart. Berlin-Dahlem. 10: 554. 1930.

Arabis glandulosa Kar. & Kir., Bull. Soc. Imp. Naturalistes Moscou. 15: 146. 1842.

Alaida glandulosa (Kar. & Kir.) Dvorak, Feddes Repert. 82(6): 431. 1971.

Dimorphostemon glandulosus (Kar. & Kir.) Golubk., Bot. Zhurn. (Moscow & Leningrad) 59(10): 1454. 1974.

D. sergievskianus (Polozhij) S.V. Ovchinnikova, Fl. Sibir. (Berberidac.-Grossulariac.) 7: 100. 1994.

Erysimum karelinianum Kuntze, Revis. Gen. Pl. 2: 933. 1891.

Neotorularia sergievskiana (Polozhij) Czerep., Vasc. Pl. Russia & Adj. States (former USSR) 145. 1995.

Sisymbrium glandulosum (Kar. & Kir.) Maxim., Fl. Tangut. 61. 1889.

Stenophragma glandulosum (Kar. & Kir.) B. Fedtsch., Rastit. Turkest. 457. 1915.

Torularia glandulosa (Kar.& Kir.) Vassilcz. Fl. URSS. 8: 69. 1939.

T. sergievskiana Polozhij., Novosti Sist. Vyssh. Rast. 11: 210. 1974.

Annual or biennial herbs, 4–20 cm long, glandular, stems erect to spreading or suberect, sparsely hairy with simple and glandular hairs. Basal and lower cauline leaves pubescent, rosulate, narrowly spathulate or linear, glandular, 8–28 x 3–5 mm, petiole 3–12 mm, entire or sinuate-toothed, leaf blade lanceolate or oblong, apex acute. Racemes 10–25–flowered, up to 6cm long in fruit. Flowers 3–5 mm across, white or pinkish; pedicels up to 8mm long in fruit, ascending, glandular. Sepals

Image 1. *Dontostemon glandulosus* (Kar. & Kir.) O.E. Schulz

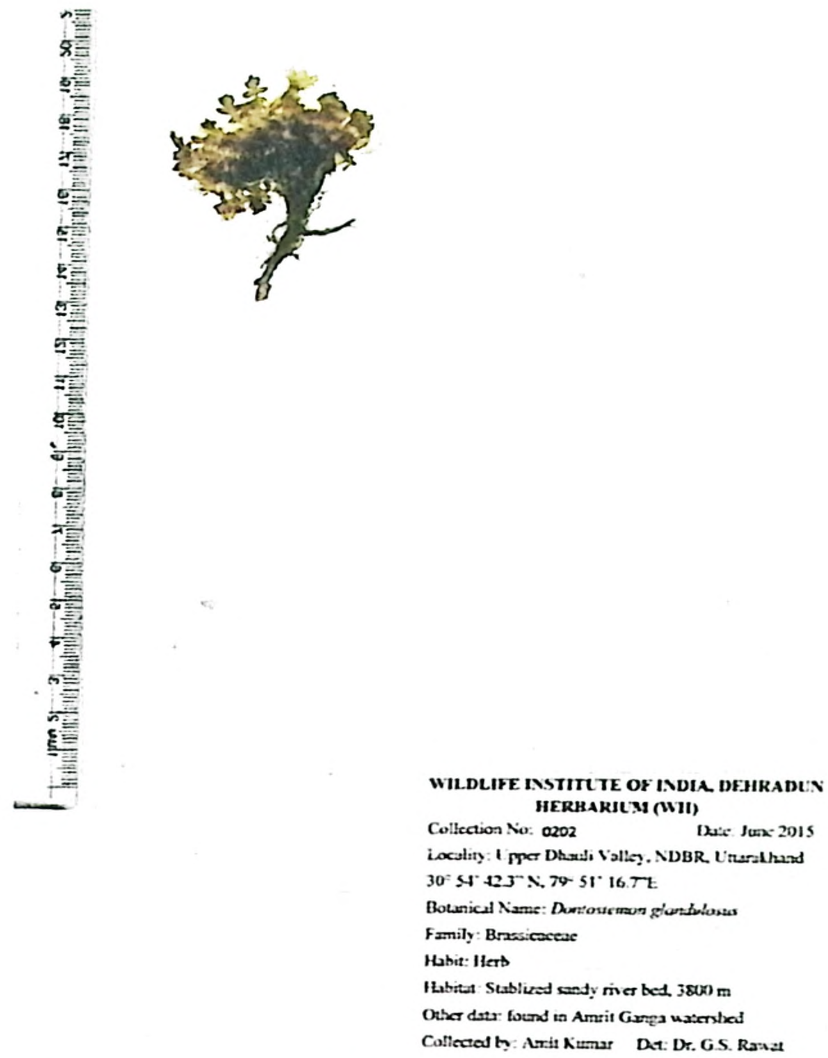

Image 2. Herbarium image of *Dontostemon glandulosus*

oblong, 2–3 mm long, sparsely pubescent apically or glabrous. Petals white with pale lavender or pink tinge, spatulate, 3–5 x 1.5–2 mm, sub–marginate or obtuse at apex, subrounded. Stamens ca. 2–3 mm long; anthers ca. 0.5mm long, broadly ovate. Style minute with short depressed stigma; seeds brown, 10–15 in each locule, ovate or oblong, oblong-ellipsoid, cotyledons obliquely accumbent or obliquely incumbent, Ovules 14–70 per ovary.

Specimen examined: WII0202 (WII), 22.vi.2015, Amrit Ganga watershed, Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Uttarakhand, India, 3,800m, 30°47'1.69"N & 79°46'59.1E, coll. Amit Kumar (Images 1 & 2).

Flowering and Fruiting: June–August.

Habitat: Grows on open habitats especially on stabilized sandy river bed at 3,800m altitude, sparsely distributed in association with *Thymus linearis* Benth., *Sibbaldia parviflora* Willd., *Potentilla cuneifolia* Bertol., *P. argyrophylla* Wall., *Kobresia* sp., *Carex* sp., and *Bistorta affinis* Greene.

Phytogeographic notes: In India, *Dontostemon glandulosus* was reported only from Jammu & Kashmir and Sikkim (www.efloras.org). Other reports of the species are from China (Gansu, Nei Mongol, Ningxia, Qinghai, Sichuan, Xinjiang, Xizang and Yunnan), Tibet (now Ziziang province of China), Kazakhstan, Nepal, Russia and Tajikistan.

2. ***Potentilla pamirica*** Th. Wolf, Trudy Imp. Bot. Sada Petra Velikago 31(3): 489. 1915.

Potentilla thomsonii Hand.–Mazz., Acta Horti. Gothob. 13: 307. 1939.

Potentilla thomsonii var. *trijuga* Sojak, Bot. Jahrb. Syst. 106(2): 208. 1986.

Perennial, caespitose herb with much divided root stock. Flowering stems many, tufted together, 5–18 cm long, slender with thin silky hairs. Basal leaves mostly adpressed together at the base, 3–4 pinnate, petiole 8–12 mm. long, adpressed pilose. Indumentum on the petioles <2mm long. Leaflets 5–15 x 3–6 mm, upper surface sparsely to densely silky hairy, lower surface of leaflets with greyish tomentose hairs, lobes 4–8, approximate, 2–3 mm. broad, obovate obtuse. Basal stipules membranous, dark-brown, auricles ovate-lanceolate, stem stipules are leafy, entire or 2–3 divided. Bright yellow flowers 1–1.5 cm across, Sepals are densly hairy. Petals 5–7 mm long. Stamens 20–25. Carpels numerous, styles uniformly thickened about 1–1.5 mm long, sub-terminal.

Specimen examined: WII20661, WII20890, 12.vii.2012, India, Uttarakhand, Nanda Devi Biosphere Reserve, Upper Dhauli Valley, Amrit Ganga watershed, 3828m, 30°46.273'N & 79°47.554'E, coll. Amit Kumar (Images 3 & 4).

Flowering and Fruiting: June–September.

Habitat: The species inhabits the slopes left bare by melting snow, sandy and stony grounds, lateral moraine and sandy plains at elevations ranging from 4000–5000

Image 3. *Potentilla pamirica* Th. Wolf

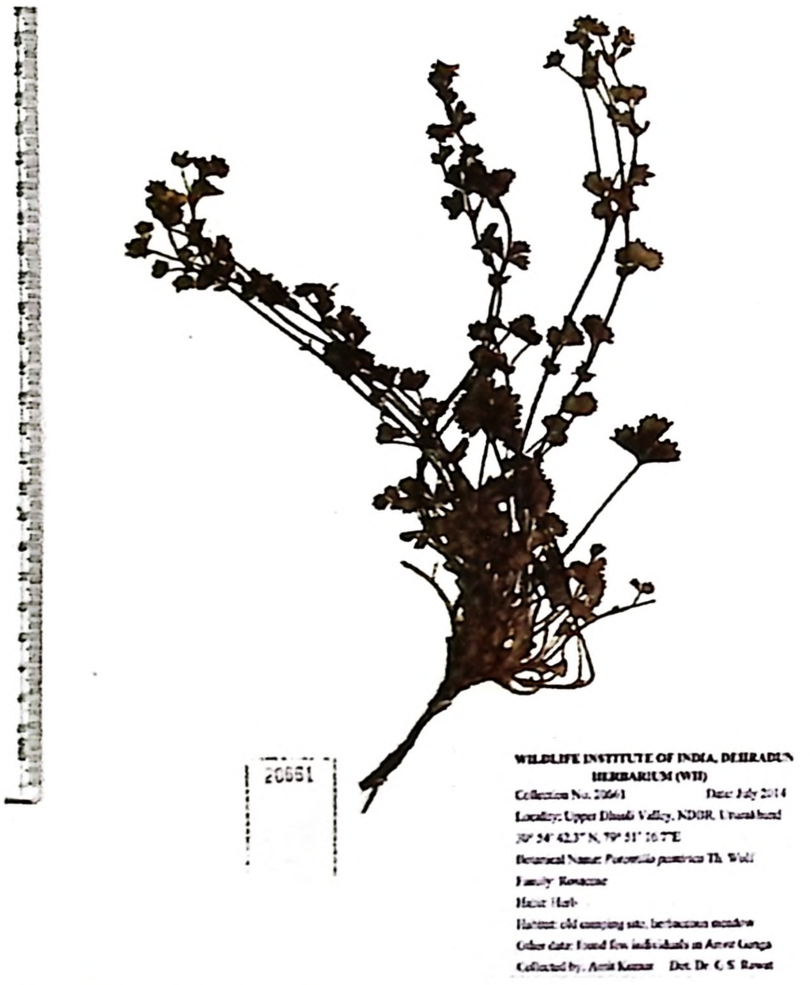

Image 4. Herbarium image of *Potentilla pamirica*

m (www.efloras.org). In Amrit Ganga watershed, NDBR, it was reported at old camping or animal resting sites. It grows in association with *Rumex nepalensis* Spreng., *Polygonum plebeium* R. Br., *Geranium wallichianum* D.Don ex Sweet, *Potentilla bifurca* L., *P. atrosanguinea* G.Lodd., *P. argyrophylla* Wall. ex Lehm. and *Fragaria nubicola* (Lindl. ex Hook. f.) Lacaita.

Phytogeographic notes: In India, *Potentilla pamirica* is reported from B-9 Kashmir, Depsang Plains, F. Ludlow 457 (BM); Mashoo Nullah, Leh (Ladakh) F. Ludlow & G. Sherrif 8447 (E); Khyung Tso, Rupshu, W. Koelz 2255 (K,W), (www.efloras.org). Other reports of this species are A-8 Gilgit, Khunjrab Top ca. 5,000m, Shah & Jamshed 189 B (ABD); Gharesa Glacier 4,816m, O. Polunin 6184 (BM); China (Zizang & Shan); Tajikistan (Pamir Alai); southwestern Mongolia; Afghanistan; Iran and Pakistan.

3. ***Carex sagaensis*** Y.C. Yang, Fl. Xizang. 5: 439. 1987.

Perennial rhizomatous herbs, densely tufted culms, 4–8 cm tall, trigonous, smooth. Leaves longer or shorter than culm, blades needle–like, less than 1mm wide, hairy. Involucral bracts glumelike, broadly obovate, sheathless, awned at apex. Inflorescence capitate, broadly elliptic or ovate, 6–8 mm; spikes 2 or 3, androgynous, elliptic, 5–6 mm. Stigmas 2. Female glumes pale brown, lanceolate, 4.5 mm, membranous, 1–veined. Utricles subequaling glume, lanceolate, membranous, base cuneate, apex gradually attenuate into a slightly scabrous beak, orifice 2–toothed. Nutlets broadly oblong, compressed trigonous, 2 mm, base shortly stipitate.

Specimen examined: WII20818, 24.vii.2014, Geldung Lake, Ganesh Ganga watershed, Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Uttarakhand, India, 5,030m, coll. Amit Kumar (Images 5 & 6).

Flowering and Fruiting: July–August.

Habitat: The species inhabits moist habitats along glacial streams and lateral moraines above 4,500m. In Ganesh Ganga, NDBR, *Carex sagaensis* grows along the small glacial streams near Geldung Lake at ca. 5,000m elevation.

Image 5. *Carex sagaensis* Y.C. Yang

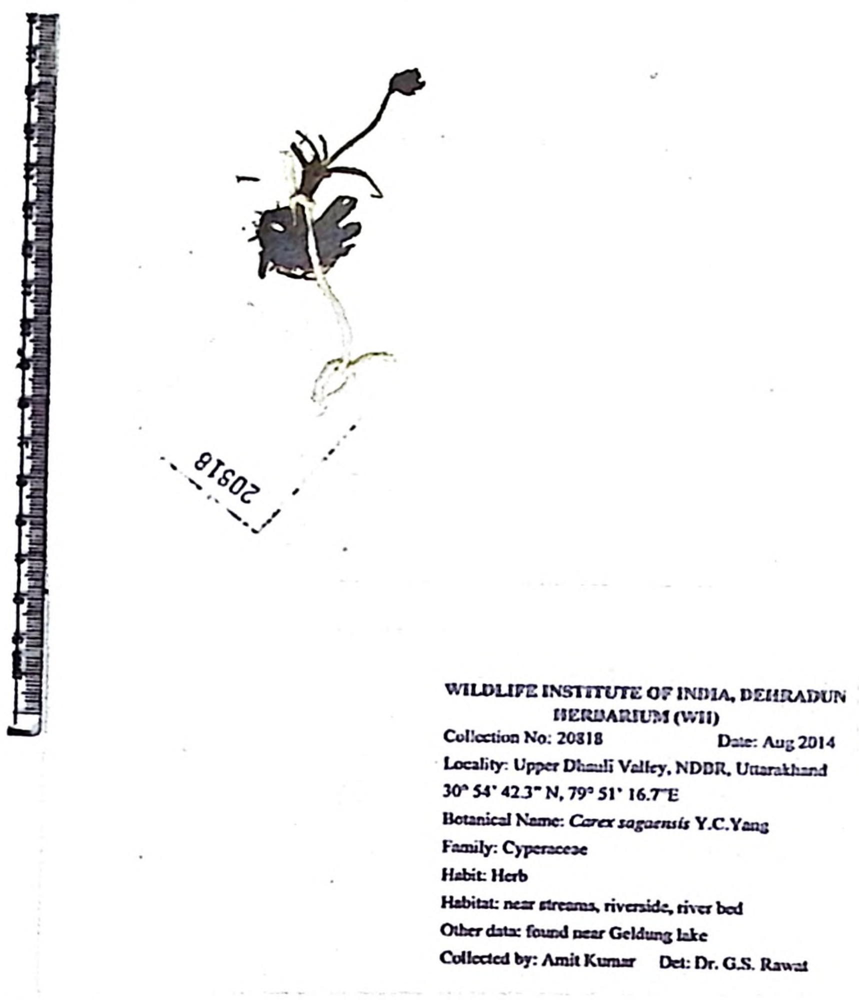

Image 6. Herbarium image of *Carex sagaensis*

Phytogeographic notes: The Xizang (Saga) in China was the type locality of this species (www.efloras.org). In India, this species was reported recently from Eastern Ladakh at about 5,000m in northwestern Himalaya (Dvorsky 2014).

Discussion

In the Indian Himalayan region, the three species discussed above are previously known to occur in the Trans-Himalaya—the Ladakh Mountains (1A) and the Tibetan Plateau (1B). However, the current reports from the Trans-Himalayan region of NDBR in western Himalaya make them bio-geographically noteworthy by means of their distribution in similar phytogeographic regions. The new species record of *Potentilla pamirica* and *Carex sagaensis* in 1A, 1B and 2A and *Dontostemon glandulosus* (1B) could be attributed to its extended distributional range and restrained botanical explorations in the state of Uttarakhand in western Himalaya. There are no records on the distribution of these species hence are additions to the state flora of Uttarakhand. During the present floristic exploration we found only a few individuals of *Dontostemon glandulosus* (two), *Potentilla pamirica* (five) in the UDV, NDBR indicating their rarity in the region.

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Journal of Threatened Taxa

OPEN ACCESS

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

June 2016 | Vol. 8 | No. 6 | Pages: 8849–8952
Date of Publication: 26 June 2016 (Online & Print)
DOI: 10.11609/jott.2016.8.6.8849-8952
www.threatenedtaxa.org

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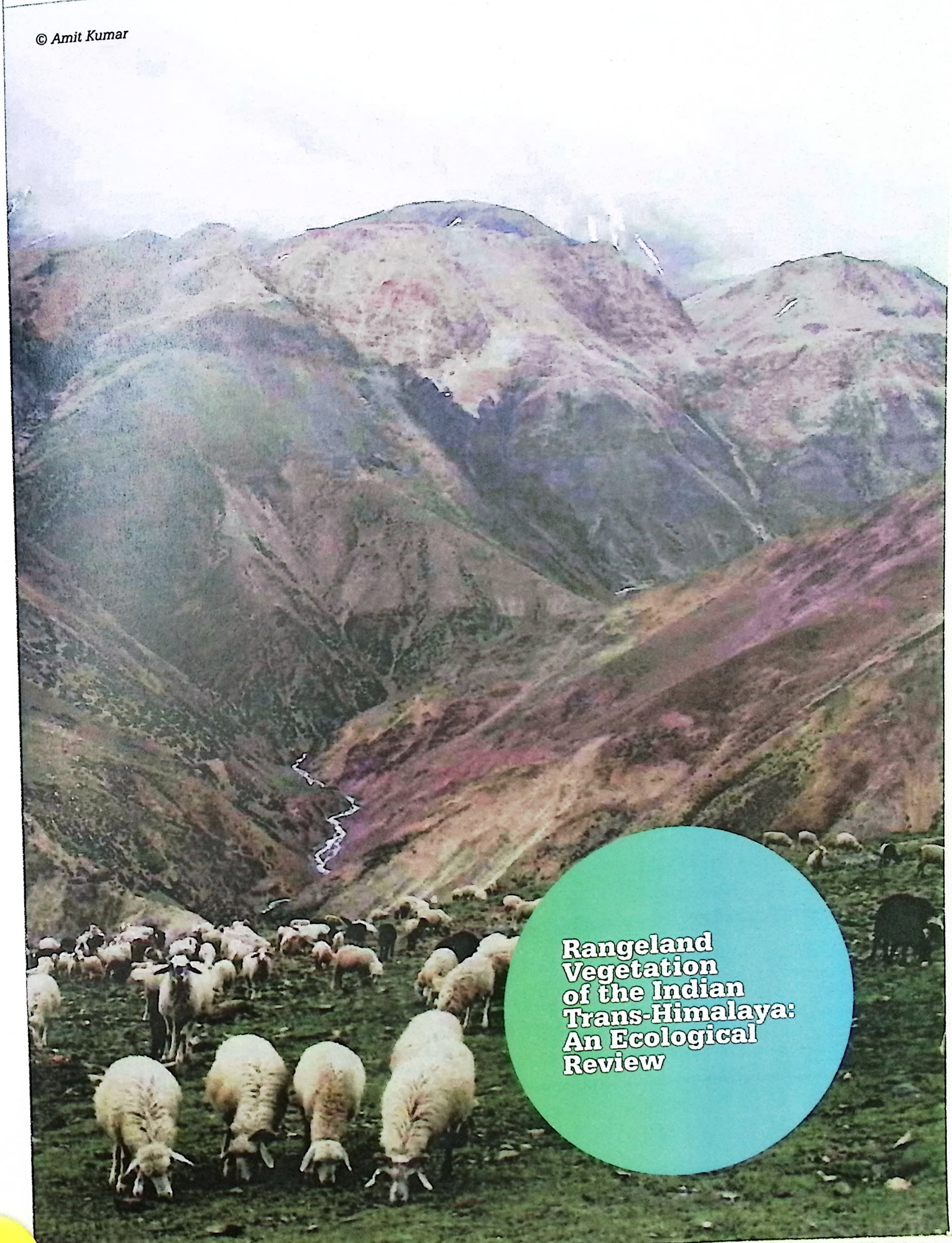

Rangeland Vegetation of the Indian Trans-Himalaya: An Ecological Review

Abstract

The Indian Trans-Himalaya (ITH) is characterized by sparse vegetation cover, low primary productivity and short growing season. Much of the area is unsuitable for cultivation but a large number of local and migratory pastoral communities use these areas for livestock grazing. Despite a high density of domestic livestock and low productivity, these rangelands support a rich assemblage of wild ungulates and other faunal groups. Though, several eco-floristic studies have been conducted in different parts of ITH, a comprehensive account on the distribution of major landform units or habitat types, and factors influencing the distribution of major vegetation communities across the larger landscape are needed. This paper gives an overview of vegetation structure and composition in the ITH across major landforms namely scrub steppe, scree slope, plateau/table land, marsh meadow, herbaceous meadow, moraine, dry sub-alpine & temperate forests and riverbed across the elevational gradients in ITH with their predominant species. We then provide an overview of vegetation structure and composition including patterns of species richness and diversity across various sub-regions, community composition, habitat use by wild ungulates and livestock, factors influencing the rangeland vegetation including topography and anthropogenic pressures. Major conservation issues such as degradation of pastures, need for eco-restoration and long term monitoring of rangeland vegetation are discussed.

Key words: Grazing, Ladakh, Landforms, North-West Himalaya, Wild ungulates

Introduction

Rangelands include natural grasslands, savannas, scrublands, steppes and wetlands dominated by grasses and grass-like plants predominantly used for livestock grazing. Spread over more than one third of the global land surface (Everitt et al. 1992), rangelands provide diverse ecosystem services and functions (Busby and Cox, 1994). They serve as main feed resource for traditional pastoral production system in many parts of the world and include about 70 percent of the feed for domestic ruminants. Other key ecosystem services from the rangelands include atmospheric carbon storage, watershed functions and critical habitat for a variety of flora and fauna.

The Indian Trans-Himalaya (ITH), located in the rain shadow zone beyond Greater Himalaya, has been used by a large number of local and migratory pastoral communities for livestock grazing since several centuries. This region is characterized by sparse treeless vegetation, often dominated by scrub, desert steppe or mixed herbaceous vegetation. Owing to extensive use of these areas for livestock grazing, they are often referred as rangelands. This region is also home to a large number of threatened species of flora and fauna. It is spread across three biogeographic provinces viz., 1A i.e., Ladakh Mountains in the north-west; 1B i.e., Tibetan plateau comprising of Eastern Ladakh, adjacent parts of Spiti, small pockets of Uttarakhand along northern frontiers and 1C i.e., Sikkim Plateau (Rodgers et al., 2000; WII, 2015; unpublished). These provinces are usually located above 4000 m above mean sea level and represent characteristic ecology and biogeography. The Trans-Himalayan rangelands are least influenced by summer monsoon and characterized by low productivity, extreme climatic conditions, high diurnal fluctuation in temperatures, scanty and erratic rainfall (<50mm), heavy winds and snowfall during winter. The region is generally considered floristically impoverished as compared to adjacent high altitude areas of Greater Himalaya (Mani, 1978; Schweinfurth, 1984). The vegetation of this region has been described by various authors as *Caragana-Lonicera-Artemisia* formation (Osmaston, 1922), Alpine steppe (Schweinfurth, 1959), Dry alpine scrub (Champion and Seth, 1968) and Alpine stony deserts (Puri et al., 1989).

The ITH has a unique physical, biological, hydrological and anthropological setting that is markedly different from that of the adjoining areas in the Greater Himalaya. This area is of considerable ecological and conservation significance which is crucial for pastoral production for the local herders as well as other ecosystem functions. The area forms upper catchment of several rivers such as Indus, Chenab, Satluj, Jahnavi or Jad Ganga, Alaknanda, Gori Ganga, Lasser Yangti, Kutti Yangti, and Teesta. These areas are quite distinct from the moist meadows of the Greater Himalaya in terms of

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physiognomy, plant community composition, primary productivity and patterns of seasonal use by the wild as well as domestic ungulates. This paper gives an overview of the rangeland vegetation in ITH including major landform units or habitat types across the elevational gradients, their ability to support populations of wild ungulates and domestic livestock and the factors determining the vegetation structure and composition.

Vegetation Structure and Composition

Phyto-diversity and Species Richness

The Indian Trans-Himalaya has been extensively surveyed in terms of eco-floristics by several workers. According to Srivastava (2010), the cold deserts of Western Himalaya are represented by ca. 1405 species, 490 genera under 98 families of flowering plants. Murti (2001) has reported about 347 species, belonging to 103 genera under 16 families of monocotyledons from the same region (Murti, 2001). Other workers, based on extensive floristic studies conducted in different areas have documented the richness of vascular plants e.g., Kachroo et al. (1977), Klimes (2003) and Klimes and Dickore (2005, 2006). Rawat and Adhikari (2005) recorded 232 species of vascular plants in ca. 300 sq. km area and identified several plant communities such as *Caragana-Artemisia, Artemisia- Kraschenennikovia* and *Artemisia-Tanacetum* in Changthang area of Ladakh. Rawat (2007a) estimated that a total of over 1800 species of flowering plants occur within the alpine region of Western Himalaya in an area of ca. 157,671 sq. km. Joshi et al. (2006) recorded 414 species of vascular plants from Nubra Valley, Ladakh. The patterns of plant species distribution in eight landscape types in Ladakh has been studied by Kala and Mathur (2002). In Trans-Himalayan region of Himachal Pradesh, Aswal and Mehrotra (1994) recorded 985 species from the Lahaul-Spiti. In recent floristic surveys of the cold arid regions of the state, Sekhar (2009) recorded 513 plant species belonging to 243 genera under 64 families from Pin Valley National Park while Chawla et al. (2012) reported 911 species of vascular plants in Kinnaur, Himachal Pradesh. The cold arid regions of Uttarakhand include Nilang, Mana and Niti valleys in Garhwal and Johar, inner Darma and Byans valleys in Kumaun. Very few studies have been done on the eco-floristics of these valleys. Naithani (1988) reported ca. 170 species of flowering plants from Nilang valley. However, Chandola (2009) recorded 441 species of vascular plants distributed under 229 genera and 72 families from the same valley. Efforts on ecological assessments of habitat types or landscape units in the alpine arid areas have not been carried out, except in Niti valley, which forms the buffer zone and cold arid region of Nanda Devi Biosphere Reserve. Kumar and Mitra (2015) recorded a total of 469 species belonging to 75 genera under 261 families of vascular plants. A perusal of literature on floristics of the ITH by various workers has been provided in **Table 2.1.**

Table 2.1. Details of floristic studies carried out in the Indian Trans-Himalaya.

Eco-floristic region & State	Area (sq. km)	Family	Genera	Species	Elevation range (m)	Author (s)
Cold deserts, Western Himalaya; J&K, H.P., UK	98,980	98	490	1405	4500-6000	Srivastava (2010)
Western Himalaya; J&K, H.P., UK	157,671	--	--	1810	3300-5600	Rawat (2007a)
Ladakh, J&K	97,782	51	190	611	2900-5900	Kachroo et al. (1977)
Ladakh, J&K	100,000	--	--	1180	3000-6000	Klimes and Dickore (2006)
Lower Ladakh, J&K	400	--	--	355	2750-4100	Klimes and Dickore (2005)
Western Ladakh, J&K	6523	51	159	301	2700-5300	Angmo (2013)
Eastern Ladakh, J&K	10,227	--	--	404	4180-6000	Klimes (2003)
Eastern Ladakh, J&K	6,912	43	127	272	4180-6670	Dvorsky et al. (2011)
Nubra Valley, J&K	22,656	56	202	414	2800-5400	Joshi et al. (2006)
Tso Kar Basin, Changthang, J&K	300	38	101	232	4400- 5500	Rawat and Adhikari (2005)
Lahaul and Spiti, H.P.	12,210	79	353	985	2000-6600	Aswal and Mehrotra (1994)
Pin Valley National Park, H.P.	1825	64	243	513	3300-6600	Sekhar (2009)
Kinnaur, H.P.	6400	114	450	911	--	Chawla et al. (2012)
Sangla Valley, H.P.	--	99	321	639	1800-4600	Devi et al. (2014)
Nilang Valley, UK	1,360	72	229	441	3000->6000	Chandola (2009)
Niti Valley, UK	726	75	261	469	3000->6000	Kumar and Mitra (2015)
Khangchendzonga National Park, SK	1784	67	243	585	4000-5000	Tambe (2007)

Abbreviations: J &K: Jammu and Kashmir, H.P: Himachal Pradesh, UK: Uttarakhand, SK: Sikkim

Plant community structure and composition

Most of the published studies on the plant community structure and composition pertaining to the ITH are from the Ladakh Mountains of the North-West Himalaya. For example, Dvorsky et al. (2011) identified eight distinct vegetation types and found scree as well as alpine grasslands as the most species-rich and reported altitude, soil moisture and salinity as the most important environmental factors influencing the species composition in Eastern Ladakh. In Ladakh, Rawat (2008) identified eight special habitats, viz., moist meadows, marsh meadows, craggy rock surfaces, scree bases, scrub steppe and sub-nival zones and remnant woodlands which harbours unique plant assemblages including some rare and threatened plants viz. *Colchicum luteum, Inula rhizocephala, Saussurea medusa, Allium przewalskianum*, and *Arnebia euchroma*. In a comprehensive effort covering Trans-Himalayan region of North-West and Western Himalaya, Rawat (2007a) identified eleven major vegetation communities, of which *Lonicera spinosa-Caragana versicolor-Oryzopsis lateralis* and *Thalictrum alpinum-Saussurea gnaphaloides-Trisetum aenium* showed highest diversity (2.27 and 2.37 respectively) and lowest (1.12) by *Phragmites australis-Lycium ruthenicum* community. Among the 16 plant communities observed in Tso-Kar Basin of Changthang Plateau, Eastern Ladakh, Rawat and Adhikari (2005) reported *Stipa-Alyssum-Oxytropis* and *Caragana-Poa* as the most extensive communities with respect to the aerial coverage. Kala and Mathur (2002) identified six communities in western Ladakh, viz., *Ephedra-Artemisia, Poa annua-Ranunculus hirtellus-Pedicularis oederi, Caragana brevifolia-Cotoneaster, Hippophae rahmnoides-Myricaria germanica, Artemisia-Salsola collina-Kraschenennikovia ceratoides* and *Agropyron-Trisetum-Oryzopsis-Carex*. In Nubra valley of Ladakh, Joshi et al. (2006) reported that herbaceous meadows on the gentle slopes had higher species diversity (1.2-2.29) and richness (14-21) followed by fell fields with species diversity (2.08-2.23) and richness (13-18) and least diversity was observed on scree slopes and on lower eroded slopes. The study also revealed that nearly 78-80% of plant species are restricted to the valley bottoms.

Of the 14 forest communities recorded from Lahaul valley by Singh and Samant (2010), tree density was found maximum for *Hippophae salicifolia* community (1850 individuals ha^{-1}), followed by *Fraxinus xanthoxyloides* (1000 individuals ha^{-1}), *Juglans regia-Ulmus wallichiana-Acer acuminatum* mixed (760 individuals ha^{-1}), *Abies pindrow-Pinus wallichiana* mixed (640 individuals ha^{-1}), *Juniperus polycarpos-Cedrus deodara* mixed (600 individuals ha^{-1}) while *Cedrus deodara-Acer cappadocicum* mixed community had lowest density (171 individuals ha^{-1}). Further, these authors have prioritized 15 habitats and 14 forest communities distributed between 2490-4000 m in the Lahaul Valley, Cold Desert Biosphere Reserve for conservation. Jisthu and Goraya (2008) identified six unique habitats such as moist meadows, riverine scrub, Juniper woodland and sub-alpine scrub, alpine dry scrub, alpine mixed communities and riverine scrub with respect to taxa of high conservation significance in cold deserts of Lahaul and Spiti valley and part of Pooh sub-division in Kinnaur, Himachal Pradesh.

In Niti and Nilang valleys of Uttarakhand state, the dry and undulating slopes in interior areas exhibit characteristic scrub steppe vegetation dominated by *Caragana versicolor, Lonicera spinosa* and *Potentilla rigida* and at places by *Krascheninnikovia ceratoides*. The unstable scree slopes harbour a distinct community characterized by *Aconogonum tortuosum, Eriophyton rhomboideum, Cicer microphyllum*, and *Cousinia thomsonii* (Chandola et al. 2008; Kumar and Mitra 2015).

In alpine meadows of north Sikkim, Tambe and Rawat (2008) reported the dominance of sedges namely *Kobresia nepalensis* on smooth slopes, *Kobresia duthiei* on broken slopes and *Kobresia pygmaea* and *Kobresia schoenoides* in dry meadows. The study also identified 11 vegetation types in the alpine landscape namely, 'krummholz' thicket, Juniper scrub, *Rhododendron* scrub, morainic scrub, *Salix sikkimensis* riverine thicket, *Myricaria rosea* riverine scrub, *Kobresia nepalensis* moist meadow, *Kobresia duthiei* moist meadow, *Kobresia pygmaea* moist meadow, *Deschampsia caespitosa* marsh meadow and *Anaphalis xylorhiza* dry meadow based on numerical classification.

Habitat use by wild ungulates and livestock in Indian Trans-Himalaya

Several workers have studied habitat use by wild ungulates and their interaction with domestic livestock in the ITH (e.g., Johnsingh et al., 1999; Mishra, 2001; Bagchi et al., 2002; Raghavan, 2003; Namgail et al., 2007; Rawat, 2007b; Chanchani et al., 2008; Hussain, 2009; Kumar and Mitra, 2015). Johnsingh et al. (1999) studied the ecology of the Ibex (*Capra sibirica*) in Pin Valley NP and its interaction with livestock. Mishra (2001) studied pastoralism, human-animal conflict and livestock competition with Blue sheep (*Pseudois nayaur*) in the Spiti valley, Himachal Pradesh and concluded the co-existence between pastoralism and wildlife is far from harmonious and suggested that majority of the rangelands of the valley are overstocked, as they are grazed at intensities much higher than what is biologically optimal. In Spiti, Himachal Pradesh, Bagchi et al. (2002) found that domestic goat and sheep imposed resource limitation on ibex and excluded them spatially. Ibex remained relatively unaffected by other livestock such as yaks, donkeys and cattle. Raghavan (2003) investigated the interaction between Ladakh urial (*Ovis orientalis vignei*) and livestock and opined that Urial may have been pushed to areas with sub-optimal resources, by livestock that used relatively resource rich areas. Namgail et al. (2007) reported a shift in the habitat use by the Tibetan Argali (*Ovis ammon hodgsoni*) in the presence of livestock in the

Gya-Miru Wildlife Sanctuary, Ladakh. Rawat (2007b) based on a landscape survey in Western Himalaya reported higher densities of livestock in the alpine areas of Uttarakhand compared to those of Himachal Pradesh and Jammu & Kashmir. Chanchani et al. (2010) studied seasonal distribution of four ungulates viz., Tibetan argali, Tibetan gazelle (*Procapra picticaudata*), Southern kiang (*Equus kiang polyodon)* and blue sheep (*Pseudois nayaur*) in Trans-Himalayan region of Sikkim. These authors found that argali was associated with sparsely-vegetated scree hills, gazelles frequently used valleys, basins and plateaus, kiang predominately used plateaus and gentle slopes and blue sheep were mainly seen on rocky or grassy slopes in the transition zone. According to these authors persistence of these ungulates in the small area of Sikkim plateau may be due to non-hunting practices of the local herders and absence of livestock grazing by domestic livestock during summer season. According to Hussain (2009) kiang showed complete separation with livestock (sheep, goat and horse) with respect to habitat preferences in Hanley valley of Changthang Wildlife Sanctuary, Ladakh. However, Kumar and Mitra (2015) in Niti valley of Nanda Devi Biosphere Reserve, Uttarakhand found that scrub steppe is used in high percentage by blue sheep and livestock and suggested that the area is avoided by blue sheep in the presence of domestic livestock.

Factors affecting rangeland vegetation in the Indian Trans-Himalaya

The Indian Trans-Himalaya is characterized by low productivity, high intensity of solar radiation and high degree of seasonality. The plant species in these altitudes exhibit several features such as reduced leaves, stunted growth, deep tap root system, xerophytic nature. Several factors such as climatic, topographical, bio-geographical and anthropogenic play important role in determining the vegetation structure and plant community composition in these areas. The key factors determining the vegetation of the Trans-Himalayan rangelands are summarized below:

Topography and altitude: Topographic features such as terrain, degree of slope and elevational gradients strongly influence the vegetation communities. For example, scrub steppe, one of the dominant physiognomic units in Trans-Himalayan region of Ladakh is found mostly on gentle slopes with adequate drainage (Rawat and Adhikari, 2005). Alpine grasslands and the sub-nival vegetation are common vegetation features of the landscape at the highest elevations (Dvorsky et al., 2011; Rawat and Adhikari, 2005). Table lands and undulating terrain harbour highest diversity of species in Ladakh (Kala and Mathur, 2002). Kumar and Mitra (2015) found that the species richness among various landforms was highest in morainic deposits (99 species) and scrub steppe (97 species) followed by scree slopes in Niti valley, Uttarakhand.

Moisture availability: In cold arid regions, vegetation types with respect to plant cover largely follow moisture and altitudinal gradients (Rawat and Adhikari, 2005; Dvorsky et al., 2011). The presence of typical plant formations along the river beds comprising of the species of *Myricaria*, *Salix* and *Hippophae* in entire ITH range corroborates the previous statement. Moist meadows having greatest species richness are mostly dominated by sedge such as species of *Carex* and *Kobresia* and moist areas above 5000m are usually dominated by *Thylacospermum-Arenaria* community (Rawat and Adhikari, 2005).

Anthropogenic factors: Alpine rangelands in the ITH have been used by local and migratory pastoral communities for seasonal livestock grazing since several centuries. Despite a harsh climate, poor vegetation cover and relatively low standing biomass, this area sustains a high livestock population (Rawat, 2007b). Alpine grasslands very likely experience the greatest grazing pressure compared to other areas and the prevalence and dominance of a specific group of plants is determined by grazing history of the region. The vegetation in and around animal resting places or camping sites is scattered along the elevation gradient quite haphazardly because its distribution is partly of human origin. Species such as *Rumex nepalensis, Urtica hyperborea*, *Chenopodium botrys*, mostly dispersed by livestock prefer growing in animal resting places which could be due to nitrogen enrichment of soil by their dung. Poor species richness compared to other habitats is mainly due to limited extent of these habitats and high disturbance regime which possibly reduce diversity by increasing plant mortality.

Phytogeographic affinities of Rangelands: Western Ladakh and adjacent mountain ranges, Eastern Ladakh, Lahaul and Spiti, Cold arid regions of Uttarakhand and Sikkim plateau represent different biogeographic sub-divisions and provinces. Accordingly, there is a gradual transition of species assemblage across the region from west to east. For example, *Haloxylon-Statice; Acantholimon-Thylacospermum* and riverine scrub vegetation especially *Tamarix-Hippophae rhamnoides* are confined to 1A. In the Sikkim plateau the lower fringes of rangelands have moist alpine scrub dominated by *Rhododendron setosum*, *Juniperus indica*, *Salix calyculata* and *Myricaria prostrata*. It is noteworthy that grassy meadows of *Danthonia cachemyriana* and tall forb communities in deep soil are more characteristic of the western Himalaya and are virtually absent in Khangchendzonga National Park, Sikkim (Rawat, 2005). Such differences in the vegetation are largely influenced by phytogeographic affinities with the surrounding regions. The sole presence of *Pinus gerardiana* in dry temperate forests of Kinnaur region compliments the above statement.

Distribution of species across major landforms or habitats:

A number of authors have attempted to classify landforms or habitats in the Trans-Himalayan region. These landforms vary in extent according to altitude and geographic locations. The present ecological review suggests eight major landforms or habitats namely herbaceous meadow, dry sub-alpine and temperate forests, moraine, scree slope, tableland, marsh meadow, riverbed and scrub steppe (**Plate 2.1 - 2.12**) across the elevational gradients in ITH with their predominant species (**Table 2.2**). Among various landforms,scrub steppe occupies larger area in all the Trans-Himalayan states followed by herbaceous meadow. The dry sub-alpine forests predominately of *Betula utilis* (remnant patches) and dry temperate forests (*Pinus wallichiana* and *Cedrus deodara*) in lower reaches of the interior valleys in Western Himalaya are relatively absent in North West Himalaya (Ladakh and Lahaul and Spiti). Due to comparatively narrow valleys in cold-arid regions of Uttarakhand and Kinnaur, Himachal Pradesh, the table lands and marshy areas are reasonably absent.

Plate 2.1: Herbaceous meadow

Plate 2.2: Dry Sub-alpine forests

Plate 2.3: Dry temperate forests

Plate 2.4 : Moraine

Plate 2.5 : Scree slope

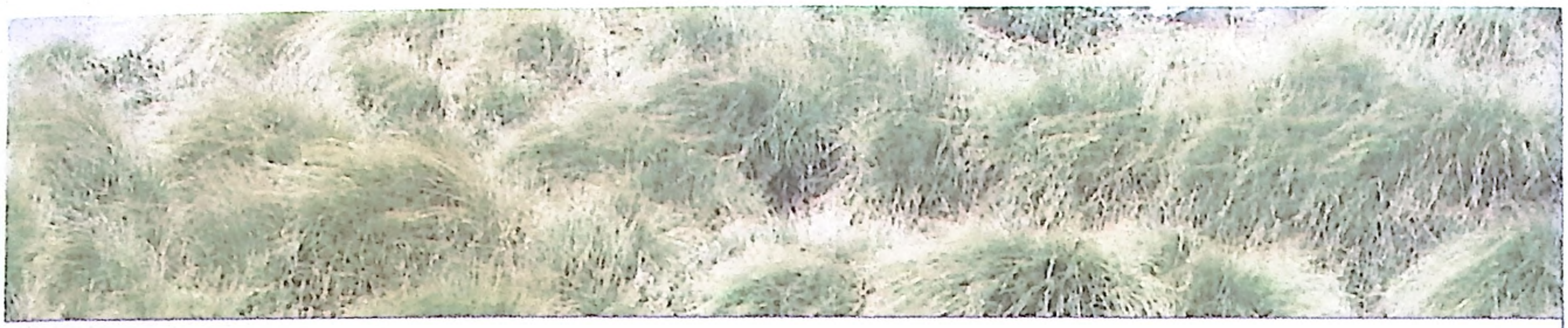

Plate 2.6 : Table land

Plate 2.7 : Marshy area

Plate 2.8 : Riverbed

Plate 2.9: Scrub steppe vegetation comprising *Caragana-Krascheninnikovia* community in Niti valley, Uttarakhand

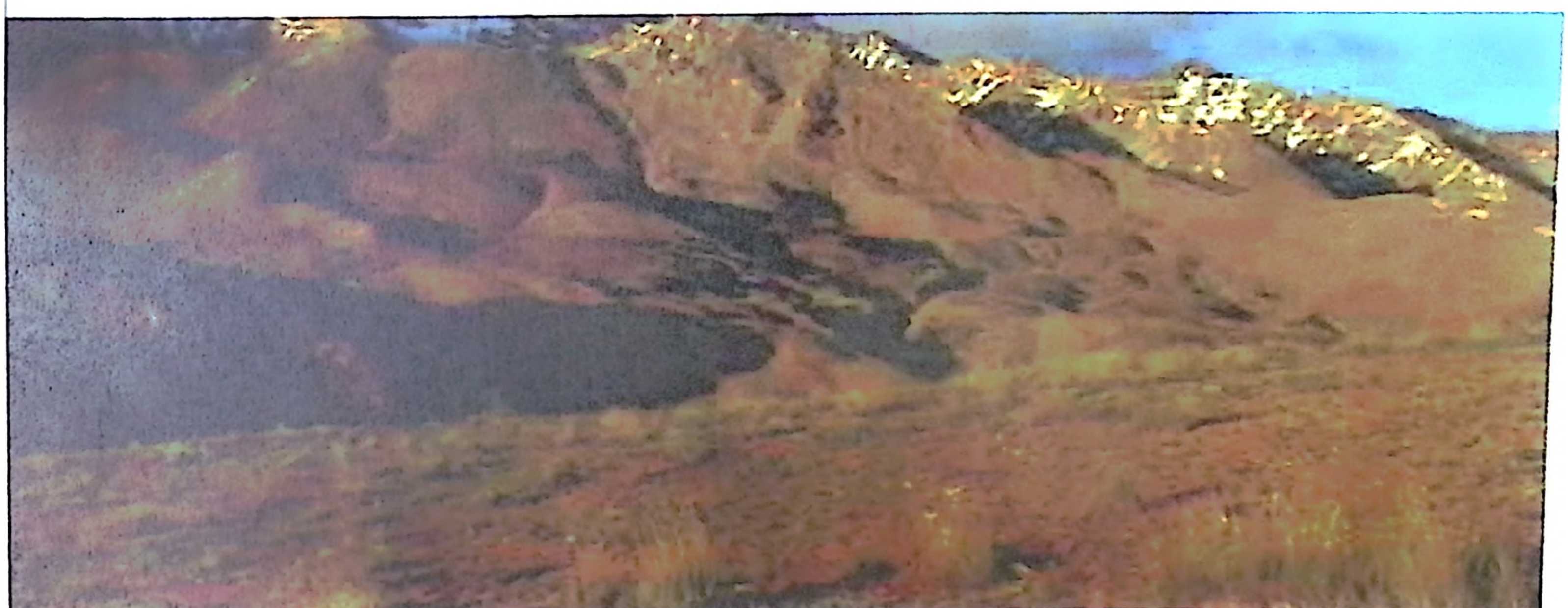

Plate 2.10: Overview of an alpine arid pasture in Spiti valley, Himachal Pradesh. ©*Yashveer Bhatnagar*

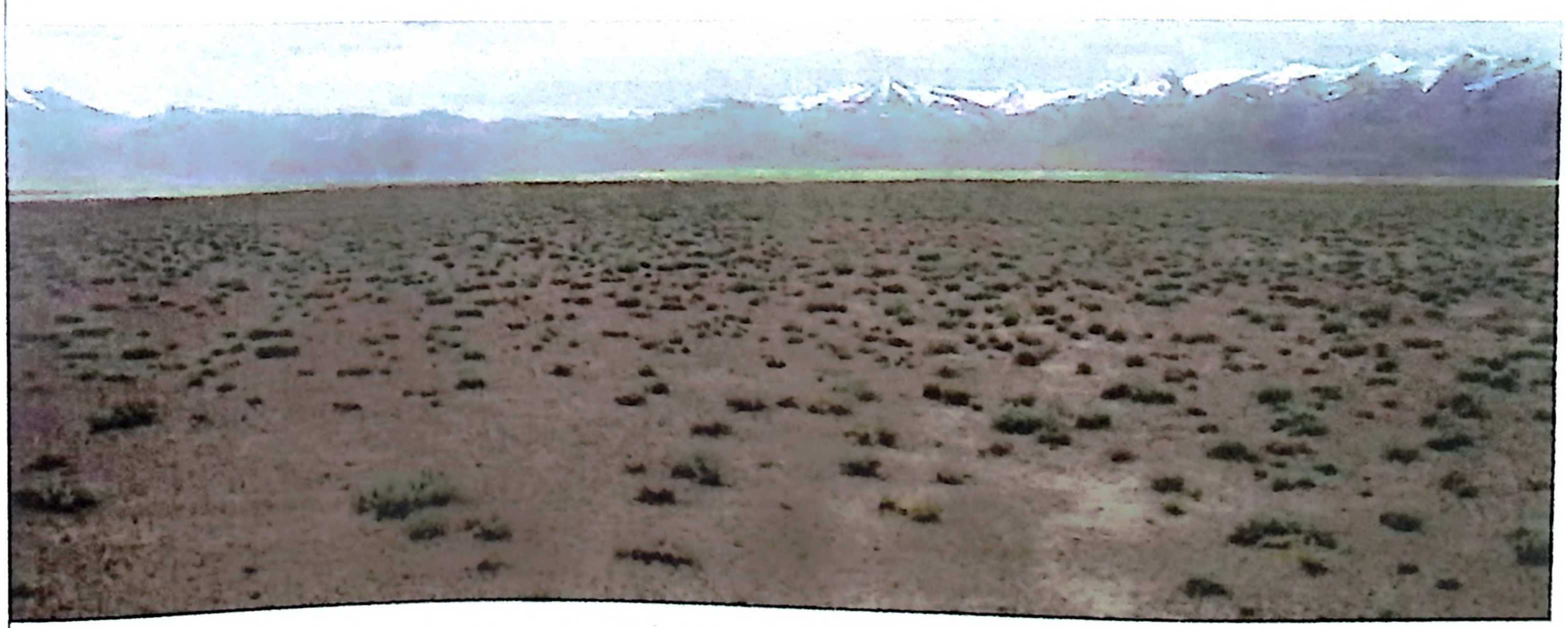

Plate 2.11: Alpine dry scrub (Scrub steppe) dominated by *Krascheninnikovia ceratoides*, a key stone species in Eastern Ladakh.

Table 2.2 Major landforms/habitats with respect to elevational range, characteristic and dominant vegetation in the Indian Trans-Himalaya.

Elevation range (m)	Landforms/ Habitats	Characteristic species	Reference
>5000	Scrub steppe	*Astragalus* spp., *Acantholimon lycopodioides*, *Thylacospermum caespitosum*	Rawat and Adhikari (2005), Rawat (2007a), Dvorsky et al. (2011)
	Scree slope	*Aconogonum tortuosum*, *Astragalus* spp., *Cousinia thomsonii*, *Cicer microphyllum*	Kala and Mathur (2002), Dvorsky et al. (2011), Angmo (2013)
	Plateau/Tableland	*Elymus nutans*, *Stipa* spp., *Oryzopsis munroi*, *Carex moorcroftiana*, *Oxytropis* spp., *Potentilla bifurca*	Kala and Mathur (2002), Angmo (2013)
	River bed	*Hippophae tibetana*, *Myricaria germanica*, *Salix flabellaris*	Joshi et al. (2006), Rawat (2007a)
4500-5000	Scrub steppe	*Caragana versicolor*, *Krascheninnikovia ceratoides*, *Lonicera spinosa*, *Astragalus* spp., *Elymus* spp., *Poa* spp.,	Rawat and Adhikari (2005), Tambe (2007), Dvorsky et al. (2011), Kumar and Mitra (2015)
	Scree slope	*Eriophyton rhomboideum*, *Cicer microphyllum*, *Aconogonum tortuosum*, *Cousinia thomsonii*	Kala and Mathur (2002), Dvorsky et al. (2011), Angmo (2013)
	Plateau/Tableland	*Agropyron* sp., *Trisetum* sp., *Oryzopsis* sp., *Carex* sp., *Oxytropis* sp., *Potentilla* sp.	Kala and Mathur (2002), Angmo (2013)
	River bed	*Hippophae tibetana*, *Myricaria germanica*, *Salix flabellaris*, *S. pycnostachya*	Joshi et al. (2006), Rawat (2007a)
4000-4500	Scrub steppe	*Caragana versicolor*, *Krascheninnikovia ceratoides*, *Juniperus* sp., *Lonicera spinosa*, *Astragalus* sp., *Ephedra gerardiana*, *Elymus* spp., *Poa* spp.,	Rawat and Adhikari (2005), Tambe (2007), Dvorsky et al. (2011), Kumar and Mitra (2015)
	Scree slope	*Eriophyton rhomboideum*, *Aconogonum tortuosum*, *Astragalus* spp., *Cousinia thomsonii*, *Cicer microphyllum*	Kala and Mathur (2002), Chandola (2009), Kumar and Mitra (2015)
	Marsh meadow	*Kobresia pygmaea*, *Carex* spp., *Blysmus compressus*, *Potentilla anserina*, *Pedicularis tubiformis*	Joshi et al. (2006), Tambe (2007), Angmo (2013), Kumar and Mitra (2015)
	Moraine	*Betula utilis*, *Cassiope fastigiata*, *Bistorta affinis*, *Salix denticulata*	Kala and Mathur (2002), Tambe (2007), Chandola (2009), Angmo (2013), Kumar and Mitra (2015)
	River bed	*Hippophae tibetana*, *Myricaria germanica*, *Salix flabellaris*, *S. pycnostachya*	Joshi et al. (2006), Tambe (2007), Rawat (2007a), Chandola (2009), Kumar and Mitra (2015)
3500-4000	Herbaceous meadow	*Kobresia* spp., *Carex* spp., *Trachydium roylei*, *Potentilla* spp., *Pedicularis* sp.	Joshi et al. (2006), Tambe (2007), Angmo (2013), Kumar and Mitra (2015)
	Moraine	*Betula utilis*, *Cassiope fastigiata*, *Bistorta affinis*, *Salix denticulata*	Kala and Mathur (2002), Tambe (2007), Chandola (2009), Angmo (2013), Kumar and Mitra (2015)
	Dry sub-alpine & temperate Forests	*Betula utilis* (remnant patches), *Juniperus semiglobosa*, *Pinus* spp., *J. indica*, *J. communis*, *Rosa* spp., *Berberis* spp.	Chandola (2009), Kumar and Mitra (2015)

Elevation range (m)	Landforms/ Habitats	Characteristic species	Reference
	River bed	*Hippophae rhamnoides, Myricaria germanica, M. elegans, Salix flabellaris*	Joshi et al. (2006), Tambe (2007), Rawat (2007a), Chandola (2009), Kumar and Mitra (2015)
3000-3500	Herbaceous meadow	*Trachydium roylei, Potentilla* sp., *Pedicularis* sp., *Bistorta* sp., *Anemone* sp.	Joshi et al. (2006), Tambe (2007), Angmo (2013), Kumar and Mitra (2015)
	River bed	*Hippophae rhamnoides, Myricaria germanica, M. elegans, Salix flabellaris*	Joshi et al. (2006), Tambe (2007), Rawat (2007a), Chandola (2009)
	Dry sub-alpine & temperate Forests	*Betula utilis* (remnant patches), *Juniperus semiglobosa, Pinus* spp., *J. indica, J. communis, Rosa* spp., *Berberis* spp.	Chandola (2009), Kumar and Mitra (2015)

Conclusion

Rangeland vegetation of the ITH is strongly influenced by topography, altitude, moisture availability and pastoral practices. Distribution and abundance of several plant communities can be predicted based on the land forms. There is an urgent need to carry out geospatial analysis of these rangelands and establish baselines for long term monitoring in a coordinated manner. A cadre of trained rangeland managers within Forest and Wildlife Departments would be needed to work closely with the pastoral communities (who have inherited rich knowledge on the management of livestock and optimum utilization of rangelands) so as to evolve strategies for better management. Some of the important parameters for monitoring rangeland vegetation and ecosystem health include: Land use and Land cover classes using Remote Sensing (RS) and Geographic Information System (GIS); Primary productivity and proportion of quality forage which determine the carrying capacity of rangelands and livestock production; Vegetation dynamics; Livestock composition; and Dependence of fuel wood for cooking and heating. Though a few attempts have been made to map the rangeland vegetation, land use and land cover for some pockets, a consolidated and comprehensive vegetation map for the entire trans-Himalaya would be needed for better conservation planning. Similarly geospatial analysis of rangelands showing the distribution of certain keystone species such as *Caragana versicolor* and *Kraschenninikovia ceratoides* would be crucial for predicting the dynamics of rangeland vegetation. For the restoration of degraded rangelands these species along with other leguminous forbs and grasses need to be taken up. Alpine marsh meadows dominated by *Kobresia pygmaea* are the crucial winter season grazing areas for livestock in Changthang, Ladakh. In order to conserve these critical winter feeding grounds of livestock and important wildlife habitats, e.g., nesting areas of threatened birds, it would be necessary to develop integrated rangeland management plans based on participatory processes. Self regulated and good herding practices traditionally followed by the herders in many pockets of ITH would go a long way in maintenance of alpine rangelands (Bhatnagar, 1997; Rawat, 1998; Mitra et al., 2013).

Acknowledgements

The authors are grateful to the Director, Wildlife Institute of India, Dehradun for institutional support. The first author wishes to acknowledge University Grant Commission (UGC), New Delhi for fellowship under Rajiv Gandhi National Fellowship scheme. Thanks are also due to Ms. Upma Manral for her valuable suggestions.

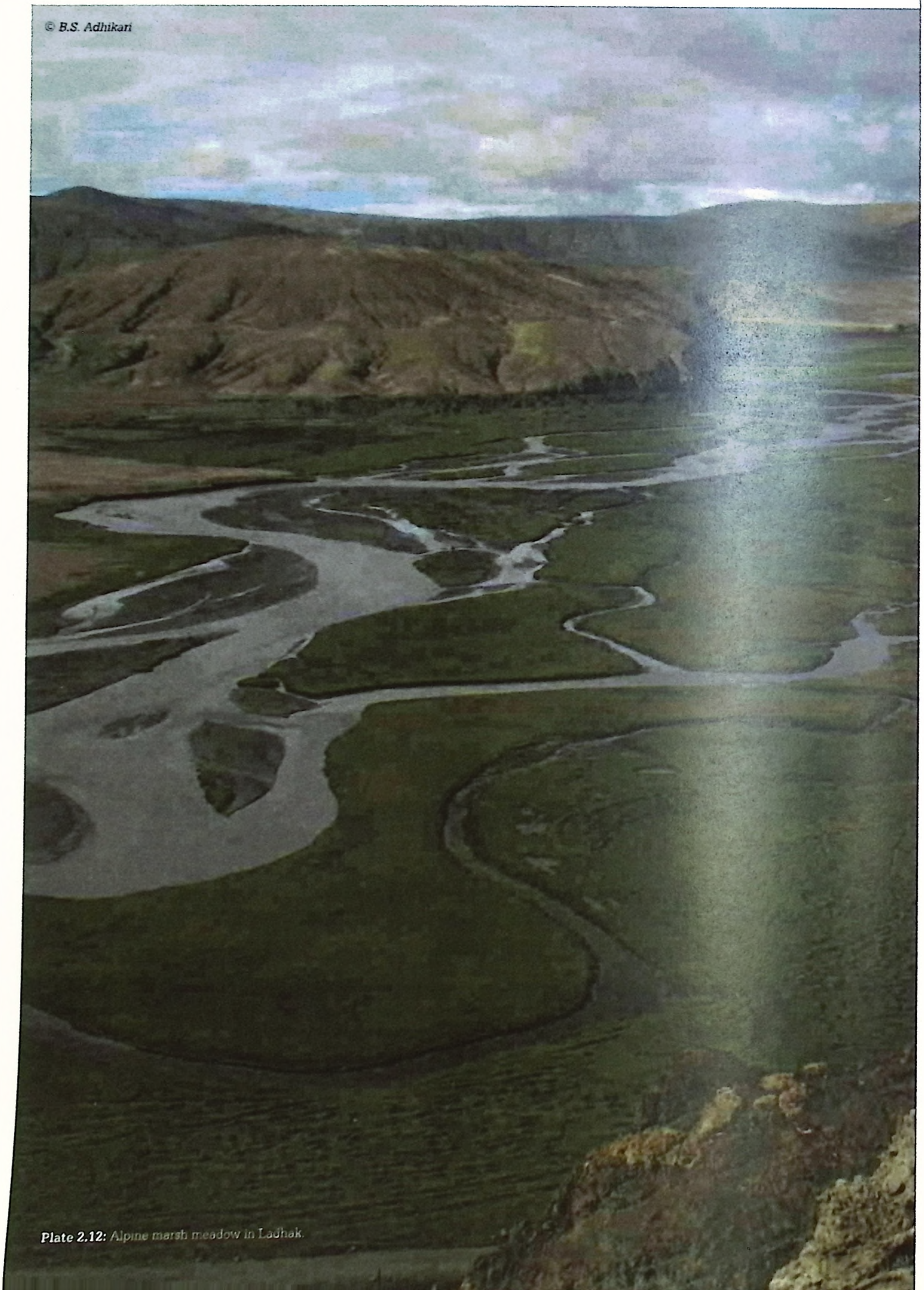

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Plate 2.12: Alpine marsh meadow in Ladhak.

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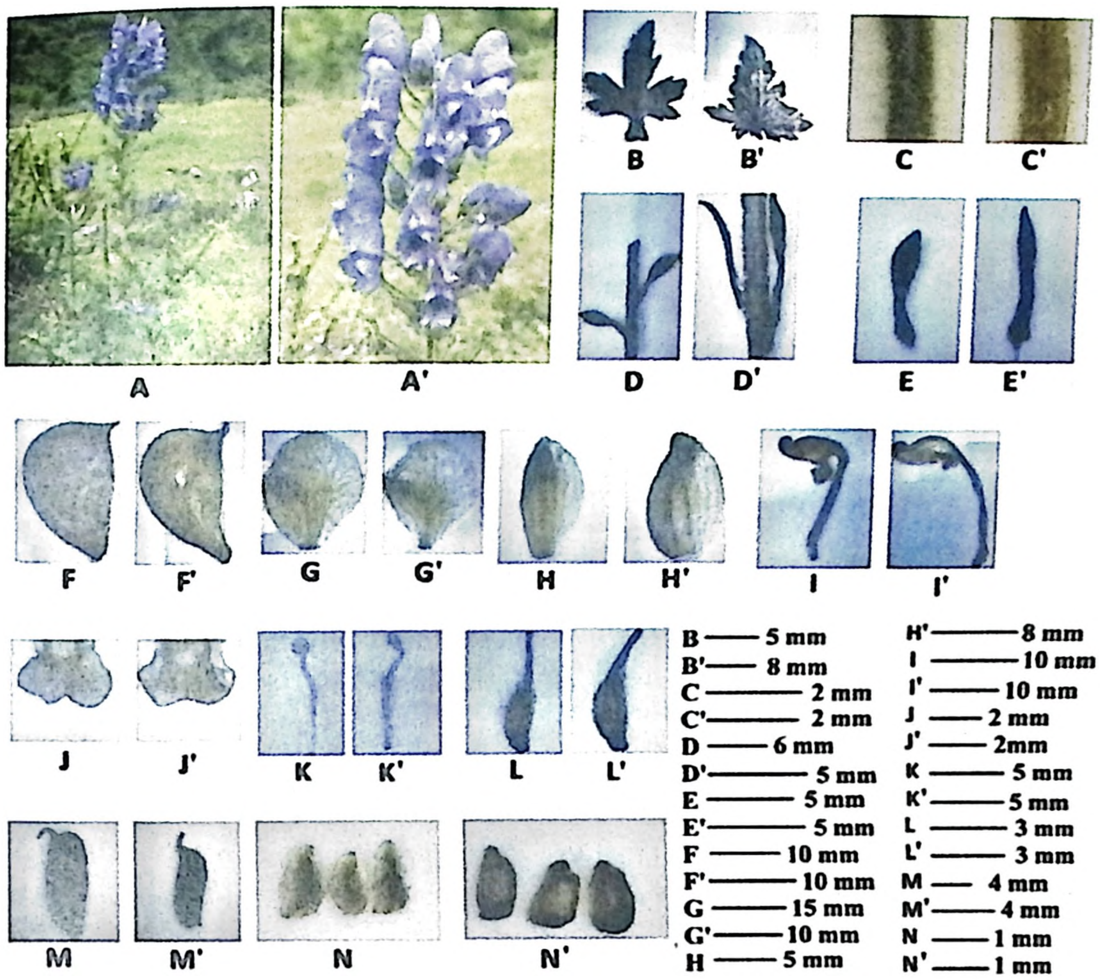

Figure 1. *Aconitum arunii*. (A) Habit and (A') inflorescence. (B–N) *A. spicatum* from T. Husain & P. Agnihotri 257631 LWG. (B'–N'), *A. arunii* from T. Husain & P. Agnihotri 257637 LWG. **B** and **B'**, Bract; **C**, **C'**, Pedicel; **D** and **D'**, Attachment of bracteoles on pedicel. **E**, **E'**, Bracteole; **F**, **F'**, Upper sepal; **G**, **G'**, Lateral sepal; **H**, **H'**, Lower sepal; **I**, **I'**, Petal; **J**, **J'**, Lobes of petal lip; **K**, **K'**, Stamen; **L**, **L'**, Carpel; **M**, **M'**, Fruit and **N**, **N'**, Seed.

half of pedicel, linear ca. 7 mm, hairy. Sepals five, upper sepal helmet-shaped, 2.5 cm long, 2.2 cm high, 14–15 mm wide, erect, indistinctly clawed, helmet obliquely semiorbicular, shallowly depressed near beak; beak minute, directed upward; lateral sepal orbicular, 15.8–16.2 × 20 cm, not clawed, yellow tinged on one side, turning dark when dry, pubescent; lower sepal broadly elliptic 7–7.5 × 12–13 mm, densely so at apex on outer surface. Petals two, pubescent; claw 2.1–2.2 cm long, leaning forward, hood oblique to almost horizontal, gibbous at apex on the back, ca. 1.2 mm diameter, black when dry; lip ca. 3 mm long from a broad base, scarcely bilobed. Stamens numerous, ca. 9 mm long; filaments ca. 8 mm long, upper part hairy, distally membranous, staminal teeth prominent; anthers ca. 0.8 × 1 mm, glabrous. Carpels five, 5–5.8 mm long; ovary 3–3.6 mm long, densely hairy on one side, hairs on anterior side curled or twisted; style ca. 2 mm, lower part hairy; stigma indistinct. Follicles five, obliquely oblong, truncate at base, 6–7.2 × 1.8–2 mm, densely hairy; seeds ovate, 0.6–0.7 × 1.2–1.3 mm.

Flowering and fruiting: September–October.

Distribution and habitat: Grows on moist soils in Kupup, East Sikkim at 3943 m altitude.

ACKNOWLEDGEMENTS. We thank the Director, CSIR-NBRI, Lucknow, for providing the necessary facilities and DST, New Delhi for financial assistance under SERB. We also thank the Principal Director of Forest, Government of Sikkim for granting us permission for field work.

Received 27 August 2015; revised accepted 26 July 2016

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Caragana versicolor Benth. (Fabaceae), a keystone species of high conservation concern in the Hindu Kush Himalayan region

Situated in the highly elevated areas well above 3000 m, where alpine shrubs and grasses are the dominant vegetation, rangelands provide diverse ecosystem services[1] to local and downstream communities. Spread over more than a third of the globe[2] and about 54% of the Hindu Kush Himalayan (HKH) region[3], these serve as the main feed resource for traditional livestock rearing systems in many parts of the world and include about 70% of the feed for domestic ruminants[1]. The HKH region is one of the largest and most assorted mountain settings in the world inhabited by more than 210 million people representing diverse ethnic and socio-cultural groups[4]. The alpine arid rangelands (AAR) in HKH are usually located at elevations above 4000 m with a unique characteristic ecology and biogeography. In Himalaya, these rangelands are positioned in the rain shadow zone and north of the Greater Himalaya. It is estimated that as many as ten million people currently reside in and depend on mountain rangelands in the Himalaya[5]. In the Trans-Himalayan region of India, the AAR are spread across two biogeographic provinces, viz. Ladakh mountains in the north-west and Tibetan Plateau that includes Eastern Ladakh, adjacent parts of Spiti, small pockets of Uttarakhand along northern frontiers and Sikkim Plateau[6]. Wild mammals such as Snow leopard (*Panthera uncia*), Himalayan marmot (*Marmota himalayana*), Tibetan woolly hare (*Lepus oiostolus*) and Himalayan wild ungulates, viz. blue sheep (*Pseudois nayaur*), Himalayan musk deer (*Moschus chrysogaster*), Tibetan argali (*Ovis ammon hodgsoni*), Tibetan gazelle (*Procapra picticaudata*), kiang (*Equus kiang polyodon*) and ibex (*Capra ibex*) inhabit and utilize AAR for food and shelter. Dominated by alpine dry scrub (scrub steppe) vegetation comprising major shrub species such as *Caragana*, *Devendraea*, *Kraschenninikovia*, *Juniperus*, *Ephedra*, *Hippophae*, *Lonicera* and *Potentilla* and alpine dry pastures (desert steppe), the AAR in HKH have been used by a large number of indigenous communities and local and migratory pastoralists for livestock grazing (domestic sheep, goat, cow, yak, horse and mule) as well as for their social and cultural causes. Thus, human dependence is a characteristic feature as nomadic and semi-nomadic pastoral communities such as *Changpas* (nomadic community that rears famous Pashmina goat) of Changthang, Ladakh, *Gaddis*, *Gujjars*, *Bakarwals*, *Kinnauras*, *Kaulis* and *Kanets* of the north-west Indian Himalaya, *Bhotias* of Garhwal and Kumaon Himalaya, *Bhotias* and *Sherpas* of Khumbu valley of Nepal, *Kirats* of eastern Nepal, *Monpa* yak breeders of Arunachal Pradesh and *Bhutias* of Lachen and Lachung in Sikkim make efficient use of the seasonally abundant natural resources in these regions[7].

One such phyto-resource, viz. *Caragana* derived from the Mongolian name *Charachana*, for ornamental shrub, are drought-resistant leguminous species distributed widely in Eurasia. It is endemic to temperate Asia, with most species distributed on the Qinghai-Tibetan Plateau and in north-western China[8]. In China, it is mainly found in the arid and semi-arid regions of the northern part of the Yellow River catchment, and the Tibetan Plateau. There are more than 100 species in the genus of which 66 are recorded from China. Their global distribution range is from the Caucasus and Central Asia going east towards Russian Siberia, Korea and Japan, southwards to Nepal, Bhutan, Sikkim and northern India. They are mostly deciduous xerophytic shrubs and a dominant life form of cold arid regions[9]. Some of the common species found in the HKH region include *Caragana brevispina* Benth., *C. conferta* Baker, *C. crassicaulis* Benth. (now *Spongiocarpella nubigena* (D. Don) Yakovlev), *C. cuneata* (Benth.) Baker (now *Chesneya cuneata* (Benth.) Ali), *C. gerardiana* Benth., *C. nubigena* (D. Don) Bunge (now *Spongiocarpella nubigena* (D.Don) Yakovlev), *C. versicolor* Benth. and *C. polyacantha* Royle[10]. This legume is chiefly found in open dry slopes forming pure patches and also majorly associates with other xeric species, viz. *Devendraea*, *Artemisia*, *Juniperus*, *Potentilla* and at places with *Kraschenninikovia ceratoides*[11–16]. The mosaics of *Caragana* scrub on gelifluction lobes give a peculiar appearance to the Trans-Himalayan landscape[13]. Interestingly, *Caragana nubigena* (syn. *Chesneya nubigena* (D. Don) Ali), *Spongiocarpella nubigena* (D. Don) Yakovlev), have been reported to moderate the physical environment by forming soil, increasing organic matter composition and by raising soil temperatures, thus providing a micro-habitat suitable for colonization by grasses and forbs[17].

Amongst reported species of *Caragana*, *Caragana versicolor* Benth. is the dominant shrub species in AAR of the Tibetan plateau and the Trans-Himalayan Grasslands[13,15,18,19] (Figure 1). This thorny shrub species is confined to West and North-West Himalaya, China, Nepal, Afghanistan and Pakistan. The dense bushy nature, thick root stock and stunted growth with cushion-like appearance are its adaptations to the cold arid conditions. Locally known as *Trama* (Western Ladakh) and *Dam* or *Dama* (Uttarakhand), *C. versicolor* is among most important and highly preferred fodder and fuel wood above 4000 m in the Trans-Himalayan regions[13,14,19,20]. Additionally, this species has been reported to cure food poisoning, fever and throat infection in Western Ladakh[21]. It usually occurs in well drained and loose sandy soils and can be found growing between 3800 and 5400 m altitudes. Due to its adaptability to withstand harsh conditions, the growing period of this species is believed to be long when compared to other shrub species. *C. versicolor* along with few graminoids species (*Elymus*, *Carex* and *Kobresia*) is one of the few important species grazed by wild ungulates as well as livestock during onset and outward passage of the growing seasons and especially during winter season when the resources are scarce. Owing to short growing period of graminoids and other herbaceous species, this legume species along with *Devendraea spinosa* and *Kraschenninikovia ceratoides* are the alternatives left as fodder species.

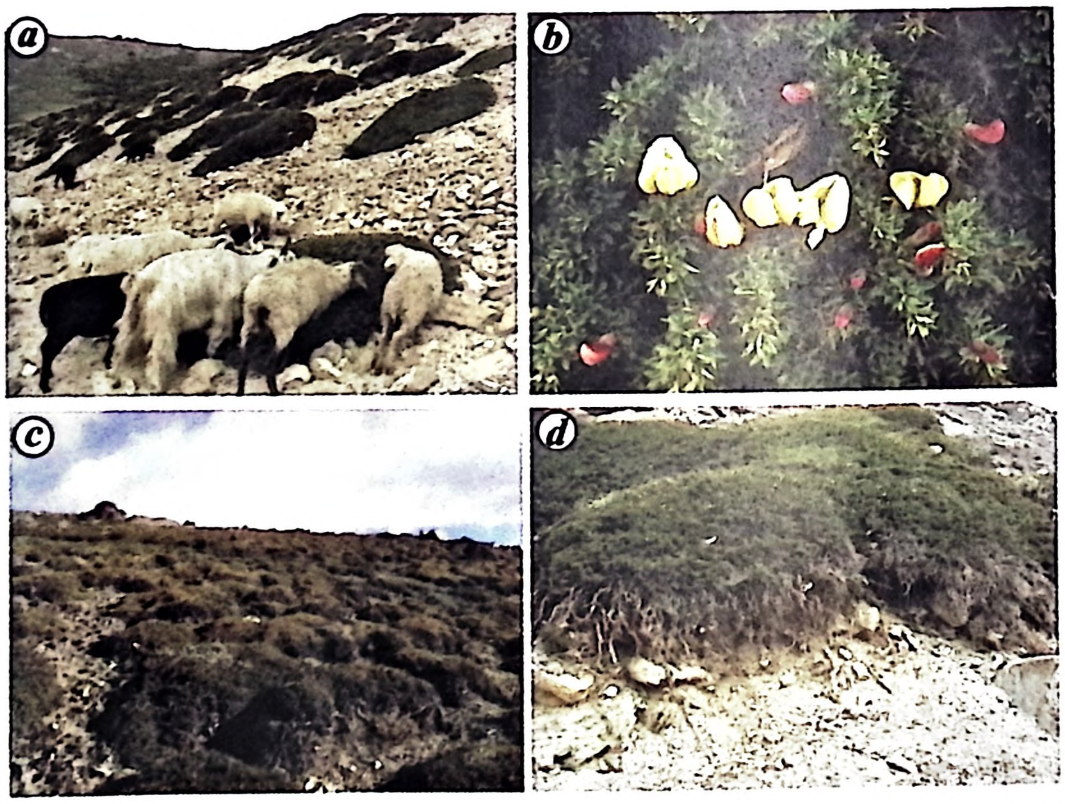

Figure 1. *Caragana versicolor*: *a*, browsing by domestic livestock; *b*, in flowering; *c*, mosaics of *Caragana* scrub; *d*, dry and thick root system usually used as fuel wood.

Moreover, it also provides the chief source of food during the peak growing season, viz. snow free period (June–September) every year[13,14]. Keeping its unique and crucial significance to the wild and domestic ungulates in view, an attempt to highlight *C. versicolor* as a key-stone species in Changthang, Ladakh has been done[13]. Apart from animal fodder and its role in soil stabilization, the whole plant is extracted by local inhabitants[18] and transhumant pastoralists for fuel primarily because of the lack of other energy sources in the region. In the present scenario, its wide and common distribution may not be a cause of concern. *C. versicolor* is under tremendous pressure due to loss of parts aboveground owing to grazing of leaves and tender shoots by sheep, goats and extraction for fuel by the herders. The depletion in its growth, population and regeneration might be crucial for sustenance of the wild as well as domestic ungulates and for local inhabitants and pastoral communities. Considering the role of *Caragana versicolor* in maintaining ecological stability of the fragile trans-Himalayan ecosystem, it would be prudent to map its distribution and area of occurrence within Hindu Kush Himalaya. Conservation awareness about the species and taking steps to provide alternate fuelwood and non-conventional energy sources such as solar cookers and fuel efficient portable ovens to the pastoral communities at subsidized rates could reduce the pressure on the species. Additionally, restoration of heavily degraded sites reseeding *Caragana* and participatory monitoring with the help of herders would be the most practical way forward.

Conflict of interest statement: The authors declare that they have no competing interests.

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ACKNOWLEDGEMENTS. We thank the Director, Wildlife Institute of India, Dehradun for support. The first author wishes to acknowledge University Grant Commission (UGC), New Delhi for Rajiv Gandhi National Fellowship; WWF-India's small grants programme and Ms Upma Manral for her valuable suggestions.

Received 9 November 2015; revised accepted 18 May 2016

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