Trees, Forests and People 7 (2022) 100172

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.sciencedirect.com/journal/trees-forests-and-people

# A hierarchy of landscape-habitat-plant physiognomic classes in the Indian Trans-Himalaya☆

Amit Kumar [*,1], Bhupendra Singh Adhikari [2], Gopal Singh Rawat [3]

*Wildlife Institute of India, Post Box# 18, Dehradun 248002 Uttarakhand, India*

ARTICLE INFO

*Keywords:*
Cold desert
Conservation planning
Landforms
Protected area
Western himalaya

ABSTRACT

Globally, a number of leading countries have adopted biogeographic based protected area planning to conserve their natural resources. India, a mega-diverse country also has conceded with a massive exercise to prepare a biogeography based conservation planning. Undoubtedly, initiating such conservation planning at national or regional level requires a holistic understanding about the landscapes and its habitat features for their long-term management. In the Indian Trans-Himalaya (ITH), quite a few authors have attempted to identify and name various habitat and vegetation classes. However, several terms have been used on adhoc basis and loosely leading to ambiguity and difficulty in mapping landscape elements and conservation planning. In order to overcome this predicament, the current communication proposes a standardized protocol to identify peculiar landscape-habitat-plant physiognomic classes in ITH. Based on an analysis of habitat characteristics in terms of their geo-morphological and vegetation attributes coupled with an extensive review and examination of existing studies, a total of 20 classes comprising 10 landforms and 10 physiognomic units have been proposed. Salient identifying features of different classes with respect to their physical attributes such as elevation, slope, orientation, stratification, rock exposure, soil type; and vegetation attributes along with dominant and representative species and their management are discussed in detail.

## 1. Introduction

Prioritizing habitats and biotic communities for any conservation program is crucial for their long-term survival and management (Singh and Samant 2010). It provides a first sound basis for the potential assessment of conservation priorities and monitoring schemes (Dhar et al., 2000). In case of plants, an in-depth knowledge of patterns of diversity, level of anthropogenic pressure and population status of species within different habitat types is essential for initiating their conservation prioritization drives. It is evident that the studies on plant community structure and composition reflect the ecosystem properties and ecological conditions of a habitat, 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 across different habitats also form the essential component of the biodiversity of a region, albeit depends on various factors such as elevation, aspect, soil, geology, topography, orography and anthropogenic pressures. Additionally, in order to address the complete linkages between the diversity of plant communities, their key structural determinants and the role of functional factors that have shaped these plant communities, holistic understanding about the entire landscape as well as habitat and its features is needed.

In India, most of the vegetation surveys and habitat assessments have been conducted in zones of biodiversity hotspots including a few well-established protected areas (PAs). However, the current levels of pressure or patterns of biodiversity are under explored or unexplored in the cold arid regions lying in the Indian Trans-Himalaya (hereafter referred as ITH) (Joshi et al., 2006; Kumar 2017). The vegetation in these regions

*Abbreviations:* PA, Protected Area; ITH, Indian Trans-Himalaya.

☆ This article is part of a special issue entitled: "Ecology of forested ecosystems in mountainous regions: patterns, processes, and management implications" published at the journal Trees, Forests and People.

* Corresponding author. Amit Kumar, Scientist, Department of Habitat Ecology, Wildlife Institute of India, Dehradun 248002 Uttarakhand, India.
*E-mail address:* amit@wii.gov.in (A. Kumar).
[1] Research field: Understanding vegetation patterns, plant associations, floristic diversity assessment, plant invasion ecology and ethno-botany & ethno-medicine
[2] Research field: Vegetation ecology; ethno-ecology & medicinal plant conservation; climate change; rangeland ecology
[3] Research field: Alpine plant ecology; grassland ecology; phyto-taxonomy; vegetation science & medicinal plant conservation

https://doi.org/10.1016/j.tfp.2021.100172
Received 21 September 2021; Received in revised form 24 November 2021; Accepted 3 December 2021
Available online 4 December 2021

is strongly influenced by topography, moisture availability, pastoral practices and elevational gradients (Rawat and Adhikari 2005; Dvorsky et al., 2011) and the habitats vary in extent according to geographic conditions (Kumar et al., 2015). Unfortunately, owing to lack of standardized protocol to identify these habitats and their characteristic species, the workers ranging from land use land cover (LULC) mapping to vegetation characterization have used terms loosely. Also, in the absence of well-established hierarchical system of landscape-habitat-physiognomic classification, there is often lack of clarity among conservation agencies. Additionally, in the use of advanced satellite remote sensing techniques and sophisticated tools for the spatial and non-spatial analysis of data, aggravated understanding of habitats characterized by their geo-morphological or physical attributes such as elevation, slope, orientation, stratification, rock exposure and soil type and the habitats characterized and defined by their vegetation attribute is needed. This clearly underlines the need for broad geo-botanical analysis of different landscape-physiognomic units along with their species distribution and patterns. Therefore, keeping aforesaid aspects in view, the principle objectives of the present communication include: (i) an extensive review of plant ecological studies conducted in the entire ITH (ii) a report on comparative account of habitat or vegetation type classifications outlined by various authors in the ITH, and (iii) to propose a standardized protocol to identify various habitats along with their characteristic identifying features and dominant and representative species in the ITH.

## 2. Material and methods

### 2.1. Study area

ITH 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 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. The entire area is characterized by sparse treeless vegetation, often dominated by scrub steppe/alpine dry scrub, alpine dry pastures (desert steppe) or mixed herbaceous formations and low primary productivity with a short growing season. These areas have a unique physical and biological setting that is markedly different from that of the adjoining areas in the Himalaya. Due to harsh climatic conditions and short growing season, these areas support low vegetation cover (<20%) albeit harbor unique assemblages of flora and fauna (Kumar 2017). ITH is spread across four biogeographic provinces, viz. 1A, Ladakh mountains: Kargil, Nubra and Zanskar in Jammu and Kashmir, and Lahaul and Spiti in Himachal Pradesh; 1B, Changthang Plateau in eastern Ladakh which is contiguous with the Tibetan Plateau; 1C, cold arid-regions of eastern Himachal Pradesh (Kinnaur) and Uttarakhand covering Nilang, Niti, Mana, Johar, Darma and Byans valleys and 1D, Sikkim Plateau (Rodgers et al., 2000; Kumar et al., 2017) (Fig. 1).

### 2.2. Methods

Based on an extensive review of existing information on habitat studies in the form of scientific peer reviewed literature, published reports, books, technical notes, dissertations, thesis and scientific research articles using numerous databases, such as google scholar, taylor and francis online, springer-link, the current communication has been divided in three major sections, (i) Eco-floristic studies in ITH, (ii) Habitat or vegetation type classifications in ITH and (iii) Proposed habitat classification. The selection of the proposed habitats in the first place is based on the (i) one or more geo-morphological or physical attributes such as elevation, slope, orientation, stratification, rock exposure and soil type, (ii) vegetation attributes such as habit (herb or shrub or tree), growth form (cushion or prostrate or erect plant) and


**Fig. 1.** Map showing different biogeographic provinces in the Indian Himalaya.

dominance of a species or a group of species and secondarily based on the analysis of the existing ecological information in terms of floristics and habitat or vegetation type classifications outlined by different workers in the ITH coupled with vast field experience (>25 years) of the senior authors. Thus, a standardized protocol to identify the major landscape-habitat-plant physiognomic classes viz., landforms and physiognomic units has been proposed in the current communication. The online search was carried using keywords such as "landforms", "habitats", "vegetation type'', "forest type", "physiognomic unit", "landscape", "trans-Himalaya", "cold-arid region", "cold desert" to mention a few, along with the name of valley or division or district or state or Protected Area in the ITH. Exact phrases of the keywords were used for searching each of the databases. Table 1, 2 and 3 presents the number of studies retrieved from these databases.

## 3. Results and discussion

### 3.1. Eco-floristic studies in ITH

ITH has been extensively explored in terms of eco-floristics by various field explorers (Kumar et al., 2015). The vegetation of this region 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 reveals 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 (Murti 2001; Srivastava 2010). The flora of Tsokar basin in Changthang plateau reflects the dominance of hemi-cryptophytes and chamaephytes (Rawat and Adhikari 2005). As per Srivastava (2010), the cold deserts of Western Himalaya harbor ca. 1405 species of flowering plants belonging to 490 genera under 98 families. Murti (2001) reported about 347 species of monocotyledons belonging to 103 genera under 16 families from the cold arid region of Western Himalaya. Aswal and Mehrotra (1994) recorded 985 species from Lahaul-Spiti, Himachal Pradesh. Further, in recent floristic surveys of the cold arid regions of Himachal Pradesh, Sekar and Srivastava (2009) recorded 513 plant species belonging to 243 genera under 64 families in Pin Valley National Park whereas, Chawla et al. (2012) recorded 911 species of vascular plants in Kinnaur.

Based on extensive floristic studies, several authors have documented the richness of vascular plants from ITH (Kachroo et al., 1977; Klimes 2003; Klimes and Dickore 2005, 2006). Interestingly, most of the published studies on the plant community structure and composition in ITH have been conducted in the Ladakh Union Territory. For example, Dvorsky et al. (2011) identified eight distinct vegetation types in Eastern Ladakh. Of which, scree and alpine grasslands were reported as most species rich habitats. 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 harboring 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. 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 terrain and river beds. 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, Cold Desert Biosphere Reserve, 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) (Singh and Samant 2010). Further, the authors have prioritized 15 habitats and 14 forest communities distributed between 2490 and 4000 m amsl in the Lahaul Valley. 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 the 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* (Chandola et al., 2008; Kumar et al. 2016; Kumar 2017). The unstable scree slopes harbor 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 Biogeographic

**Table 1**
Details of eco-floristic studies carried out in the Indian Trans-Himalaya.

| Eco-floristic region | Area ($km^2$) | Family | Genera | Species | Elevation range (m) | Reference |
|---|---|---|---|---|---|---|
| Western Himalaya | 98,980 | 98 | 490 | 1405 | 4500–6000 | Srivastava (2010) |
| Western Himalaya | 157,671 | – | – | 1810 | 3300–5600 | Rawat (2007) |
| Ladakh | 97,782 | 51 | 190 | 611 | 2900–5900 | Kachroo et al. (1977) |
| Ladakh | 100,000 | – | – | 1180 | 3000–6000 | Klimes and Dickore (2006) |
| Lower Ladakh | 400 | – | – | 355 | 2750–4100 | Klimes and Dickore (2005) |
| Western Ladakh | 6523 | 51 | 159 | 301 | 2700–5300 | Angmo (2013) |
| Eastern Ladakh | 10,227 | – | – | 404 | 4180–6000 | Klimes (2003) |
| Eastern Ladakh | 6912 | 43 | 127 | 272 | 4180–6670 | Dvorsky et al. (2011) |
| Nubra Valley, Ladakh | 22,656 | 56 | 202 | 414 | 2800–5400 | Joshi et al. (2006) |
| Tso Kar, Ladakh | 300 | 38 | 101 | 232 | 4400- 5500 | Rawat and Adhikari (2005) |
| Lahaul and Spiti, Himachal Pradesh | 12,210 | 79 | 353 | 985 | 2000–6600 | Aswal and Mehrotra (1994) |
| Pin Valley, Himachal Pradesh | 1825 | 64 | 243 | 513 | 3300–6600 | Sekar and Srivastava (2009) |
| Kinnaur, Himachal Pradesh | 6400 | 114 | 450 | 911 | – | Chawla et al. (2012) |
| Sangla Valley, Himachal Pradesh | – | 99 | 321 | 639 | 1800–4600 | Devi et al. (2014) |
| Nilang Valley, Uttarakhand | 1360 | 72 | 229 | 441 | 3000->6000 | Chandola (2009) |
| Niti Valley, Uttarakhand | 726 | 73 | 267 | 495 | 3000->6000 | Kumar et al. (2016) |
| Khangchendzonga, Sikkim | 1784 | 67 | 243 | 585 | 4000–5000 | Tambe (2007) |

**Table 2**
A comparative account of habitats studied by various authors in the Indian Trans-Himalaya.

| Habitat and vegetation type class | Ladakh | Himachal Pradesh | Uttarakhand | Western Himalaya | Sikkim | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Agricultural fallow | | | | | | | | | | | √ | | |
| Alpine dry scrub | | | | | | | | √ | | | | √ | |
| Alpine meadow/herbaceous meadow | √ | | √ | | | | √ | | √ | √ | | | √ |
| Alpine mixed community | | | | | | | | √ | | | | | |
| Alpine grassland/grassland/tussock 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 | | | | | | | | | | | √ | | |
| Juniper woodland | | | | | | | | √ | | | | | |
| Marsh meadow/marshy | √ | | √ | √ | | √ | | | | | | | |
| Mesic localities | | | | | | | | | | | | √ | |
| Moist meadows | | | | √ | | | | √ | | | | | |
| Moraine/moraine scrub | √ | | | | √ | | | | √ | √ | √ | | √ |
| Narrow gorges | | | | | √ | | | | | | | | |
| Near settlements | | | | | | √ | | | | | | | |
| Parasitic | | | | | | √ | | | | | | | |
| Plateau/tablelands | √ | | | | √ | | | | | | | | |
| River bed | | | √ | | √ | | | | √ | √ | √ | √ | √ |
| Riverine scrub | | | √ | | | | | √ | | | | √ | |
| 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 | | | | √ | | √ | | | | | √ | | |
| Sub-alpine scrub | | | | | | | | √ | | | | | |
| Sub-nival zone | | √ | | | | | | | | | | | |
| Undulating land areas/undulating land mass | | | | | √ | | | | | | √ | | |
| Water bodies/wetlands | | √ | | | √ | | | | | | √ | | |

Abbreviations: 1: Western Ladakh- Angmo (2013); 2: Eastern Ladakh- Dvorsky et al. (2011); 3: Nubra valley- Joshi et al. (2006); 4: Tso Kar- Rawat and Adhikari (2005); 5: Ladakh- Kala and Mathur (2002); 6: Lahaul valley- Singh and Samant (2010); 7: Pin valley- Sekar and Srivastava (2009); 8: Lahaul and Spiti valley and Kinnaur- Jishtu and Goraya (2008); 9: Niti valley- Kumar (2017); 10: Niti valley- Kumar and Mitra (2015); 11: Nilang valley- Chandola (2009); 12: Western Himalaya (erstwhile J&K, Himachal Pradesh, Uttarakhand)- Rawat (2007); 13: Khangchendzonga- Tambe (2007).

Province (1C) i.e., cold arid-regions of eastern Himachal Pradesh (Kinnaur) and Uttarakhand covering Nilang, Niti, Mana, Johar, Darma and Byans valleys, the table lands or plateau and marshy areas are relatively absent due to comparatively narrow and rugged valleys (Kumar et al., 2015; Kumar 2017). A perusal of existing information on eco-floristics in the ITH has been provided in Table 1.

### 3.2. Habitat or vegetation type classes in ITH

A number of authors have attempted to classify habitat-vegetation classes at a regional scale in ITH, for example Angmo (2013), Dvorsky et al. (2011), Joshi et al. (2006), Rawat (2008), Rawat and Adhikari (2005) and Kala and Mathur (2002) in Ladakh Union Territory; Singh and Samant (2010), Sekar and Srivastava (2009) and Jishtu and Goraya (2008) in Himachal Pradesh; Chandola et al. (2008), Singh and Rai (2008), Chandola (2009), Kumar and Mitra (2015), Kumar (2017) in Uttarakhand; Tambe (2007) and Tambe and Rawat (2008) in Sikkim and Rawat (2007) and Kumar et al. (2015) in ITH (Table 2). These classes vary in extent according to altitude and geographic locations. Further, topographic features viz., degree of slope, terrain and elevational gradients strongly influence the plant communities. For instance, scrub steppe establishes mainly on stable slopes with adequate drainage

**Table 3**
Distinct landform-physiognomic units with their elevational range and characteristic and dominant vegetation in the Indian Trans-Himalaya.

| Elevation range (m) | Landform-physiognomic units | Characteristic and dominant species | Reference |
|---|---|---|---|
| >5000 | Scrub steppe | *Caragana* spp., *Lonicera* spp., *Astragalus* spp., *Acantholimon lycopodioides, Thylacospermum caespitosum* | Rawat and Adhikari (2005), Rawat (2007), Rawat (2008), Dvorsky et al. (2011) |
| | Scree | *Aconogonum tortuosum, Astragalus* spp., *Cousinia thomsonii, Cicer microphyllum* | Kala and Mathur (2002), Dvorsky et al. (2011), Angmo (2013) |
| | Tableland | *Elymus nutans, Stipa* spp., *Oryzopsis munroi, Carex* spp., *Oxytropis* spp., *Potentilla bifurca* | Kala and Mathur (2002), Angmo (2013) |
| | River bed | *Hippophae tibetana, Myricaria* spp., *Salix* spp. | Joshi et al. (2006), Rawat (2007) |
| | Alpine marsh meadow | *Potamogeton pectinatus, Myriophyllum verticillatum, Hippuris vulgaris, Ranunculus natans*, R. *trichophyllus* | Rawat and Adhikari (2005), Joshi et al. (2006), Rawat (2007), Rawat (2008), Angmo (2013) |
| | Sub-nival zone | *Carex nivalis, Christolea* sp., *Saussurea* spp., *Draba altaica, Saxifraga hirculoides, Rhodiola tibetica, Melica* sp., *Leontopodium alpinum* | Dvorsky et al. (2011), Rawat (2008), Dvorsky et al. (2011) |
| 4500–5000 | Scrub steppe | *Caragana versicolor, Krascheninnikovia ceratoides, Lonicera spinosa, Astragalus* spp., *Elymus* spp., *Poa* spp., | Rawat and Adhikari (2005), Tambe (2007), Chandola et al. (2008), Dvorsky et al. (2011), Kumar (2017) |
| | Scree | *Eriophyton rhomboideum, Cicer microphyllum, Aconogonum tortuosum, Cousinia thomsonii* | Kala and Mathur (2002), Dvorsky et al. (2011), Angmo (2013) |
| | Table land | *Agropyron* sp., *Trisetum* sp., *Oryzopsis* sp., *Carex* spp., *Oxytropis* spp., *Potentilla* sp. | Kala and Mathur (2002), Angmo (2013) |
| | River bed | *Hippophae tibetana, Myricaria* spp., *Salix flabellaris*, S. *pycnostachya* | Joshi et al. (2006), Rawat (2007) |
| | Alpine marsh meadow | *Potamogeton pectinatus, Myriophyllum verticillatum, Hippuris vulgaris, Ranunculus natans, Carex* spp., *Kobresia* spp. | Rawat and Adhikari (2005), Joshi et al. (2006), Rawat (2007), Rawat (2008), Angmo (2013) |
| | Sub-nival zone | *Carex* spp., *Saussurea* spp., *Draba altaica, Saxifraga hirculoides, Rhodiola tibetica, Melica* sp., *Stipa* sp. | Dvorsky et al. (2011), Rawat (2008), Dvorsky et al. (2011) |
| 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 (2017) |
| | Scree | *Eriophyton rhomboideum, Aconogonum tortuosum, Astragalus* spp., *Cousinia thomsonii, Cicer microphyllum* | Kala and Mathur (2002), Chandola (2009), Kumar (2017) |
| | Alpine marsh meadow | *Kobresia pygmaea, Carex* spp., *Blysmus compressus, Potentilla anserina, Pedicularis tubiformis* | Joshi et al. (2006), Tambe (2007), Angmo (2013) |
| | Moraine | *Betula utilis, Cassiope fastigiata, Bistorta affinis, Salix* spp. | Kala and Mathur (2002), Tambe (2007), Chandola (2009), Angmo (2013), Kumar (2017) |
| | River bed | *Hippophae tibetana, Myricaria germanica, Salix flabellaris, S. pycnostachya* | Joshi et al. (2006), Tambe (2007), Rawat (2007), Chandola (2009), Kumar (2017) |
| 3500–4000 | Herbaceous meadow | *Kobresia* spp., *Carex* spp., *Trachydium roylei, Potentilla* spp., *Pedicularis* sp. | Joshi et al. (2006), Tambe (2007), Angmo (2013), Kumar (2017) |
| | Moraine | *Betula utilis, Cassiope fastigiata, Bistorta affinis, Salix denticulata* | Kala and Mathur (2002), Tambe (2007), Chandola (2009), Angmo (2013), Kumar (2017) |
| | Remnant woodland | *Betula utilis, Juniperus semiglobosa, Pinus wallichiana, J. indica, J. communis, Rosa* spp., *Berberis* spp. | Rawat (2008), Chandola et al. (2008), Jishtu and Goraya (2008), Chandola (2009), Kumar et al. (2015), Kumar (2017) |
| | River bed | *Hippophae rhamnoides, Myricaria germanica, M. elegans, Salix flabellaris* | Joshi et al. (2006), Tambe (2007), Rawat (2007), Chandola (2009), Kumar (2017) |
| | Tussock grassland | *Danthonia cachemyriana, Deschampsia caespitosa, Bistorta affinis, Androsace sarmentosa, Potentilla* spp., *Thymus linearis, Taraxacum officinale* | Chandola et al. (2008), Dvorsky et al. (2011), Kumar (2017) |
| | Alpine moist meadow | *Carex* spp., *Kobresia, Festuca, Poa, Oryzopsis, Potentilla, Anaphalis, Androsace* | Dar (2008), Rawat (2008), Jishtu and Goraya (2008), Chandola et al. (2008), Tambe and Rawat (2008), Dar (2008) |
| 3000–3500 | Herbaceous meadow | *Trachydium roylei, Potentilla* spp., *Pedicularis* sp., *Bistorta* spp., *Anemone* sp. | Joshi et al. (2006), Tambe (2007), Angmo (2013), Kumar (2017) |
| | River bed | *Hippophae rhamnoides, Myricaria germanica, M. elegans, Salix* spp. | Joshi et al. (2006), Tambe (2007), Rawat (2007), Chandola (2009) |
| | Remnant woodland | *Betula utilis, Juniperus semiglobosa, Pinus wallichiana, J. indica, J. communis, Rosa* spp., *Berberis* spp. | Rawat (2008), Chandola et al. (2008), Jishtu and Goraya (2008), Chandola (2009), Kumar et al. (2015), Kumar (2017) |
| | Tussock grassland | *Danthonia cachemyriana, Bistorta affinis, Androsace sarmentosa, Nepeta laevigata, Potentilla argyrophylla, Taraxacum officinale, Anaphalis* spp. | Chandola et al. (2008), Dvorsky et al. (2011), Kumar (2017) |
| | Alpine moist meadow | *Carex* spp., *Kobresia, Festuca, Poa, Bistorta, Geranium, Rheum* | Tambe and Rawat (2008), Jishtu and Goraya (2008), Chandola et al. (2008), Tambe and Rawat (2008) |

(Rawat and Adhikari 2005). The sub-nival vegetation and alpine arid pastures or grasslands are characteristic features of the ITH at highest elevations (Rawat and Adhikari 2005; Dvorsky et al., 2011).

An analysis of nearly 50 habitat-vegetation classes identified by various authors in ITH revealed that the landforms namely scree, moraine and river bed or valley bottom, and physiognomic units namely scrub steppe, herbaceous meadow, alpine moist or wet meadow, alpine dry scrub and alpine moist scrub are the most studied classes albeit these habitats occupy larger area in the entire ITH range. Whereas, scrub steppe/alpine dry scrub occupies larger area in all the Trans-Himalayan states followed by herbaceous meadow (Kumar et al., 2015). Majority of the Plateaus and gentle slopes in the Trans-Himalaya exhibit Mediterranean type of climate and steppe vegetation i.e., scattered low shrubs with sparse grasses and forbs (Rawat 2007). Interestingly, dry scrub on the Plateau harbor higher species richness compared to riverine scrub. According to Joshi et al. (2006), approximately 78–80% of plant species

are confined to the valley bottoms in Ladakh. The remnant patches of Betula utilis in dry sub-alpine forests, and *Pinus wallichiana* and *Cedrus deodara* in dry temperate forests along the river valleys in the Western Himalaya are relatively absent in Ladakh and Spiti, North-West Himalaya (Kumar et al., 2015; Kumar 2017). Owing to comparatively narrow valleys in Trans-Himalayan region (1C), the table lands or plateau and alpine marsh meadows are reasonably absent (Kumar et al., 2015; Kumar 2017).

While analysing the floristic diversity of different habitat-vegetation classes in the Western and North-West Himalaya, the present authors comprehended that the identified classes in ITH needs validation. Use of terms such as bouldary slope, broken slope, degraded area, dry area, dry meadow, eroded slope, field margin, gentle slope, parasitic, sandy plains, shady moist, smooth slope, stable slope, steep slope, stabilized debris, undulating land area and undulating land mass while identifying the classes has often created ambivalence to the researchers and landscape managers in analysing and comparing data vis-a-vis overall understanding of a landscape (Table 2). Subsequently, owing to use of surrogate terms by various authors such as vegetation type and habitat type, vegetation type and forest type, landform and landform unit, landscape type and landscape unit and physiognomic unit and community type often creates difficulties in analysing information on different landscape and its features. Inevitably, due to climatic variability, phyto-geographic affinities, moisture availability, topographical features and human interference, use of terms for a few unusual habitats at specific biogeographic locations is justifiable, for instance livestock camping site also known as animal resting place resulting due to the transhumant pastoralists have been identified throughout the entire Himalayan range.

### 3.3. Proposed habitat classification

In the Himalaya, habitats hold peculiar ecological settings and harbor unique plant assemblages including several rare, endangered and threatened species (RET). The proposed hierarchical classes provide characteristic identifying features of different habitats along with their dominant and representative species. The most diverse and representative species in a habitat were identified with the following two essential objectives: (i) a good representation of the species in a habitat and (ii) adequate information to scale-up the importance of a species from the habitat to the landscape level. The most diverse and representative plant species were taken into consideration for those species that together make 70–80% of the standing biomass of the habitat. It can be identified by the workers proverbial with the habitat, if no abundance and biomass data is available. In the habitats predominantly of herbaceous vegetation, the species occurrence varies with time during a growing season. As a first step, it is suggested that the species abundance be determined at the time of peak standing biomass of the community.

Based on an analysis of habitat characteristics in terms of their geomorphological and vegetation attributes coupled with an extensive review and examination of existing studies, a standardized protocol to identify peculiar landscape-habitat-plant physiognomic classes have been proposed. A total of 20 classes comprising of 10 landforms namely scree, moraine, river bed or valley bottom, plateau, fell field, water body or wetland or lake, alluvial fan, craggy rock surface, gorge and ridge, and 10 physiognomic units namely scrub steppe/alpine dry scrub, herbaceous meadow, alpine marsh meadow, alpine moist or wet meadow, remnant woodland, riverine scrub, alpine moist scrub, tussock grassland, sub-nival vegetation or sub-nival zone and livestock camping site across the elevational gradients in ITH have been proposed (Fig. 2). Salient identifying features of different classes with respect to their physical attributes such as elevation, slope, orientation, stratification, rock exposure, soil type and vegetation attributes along with dominant and representative species and their management are discussed in detail.

#### 3.3.1. Selection of habitat in a landscape

*3.3.1.1. Landform.* The habitats categorized by their geomorphological or physical attributes such as elevation, slope, orientation, stratification, rock exposure and soil type has been referred as a 'landform'. Scree, moraine, river bed or valley bottom, plateau, fell field, water body or wetland or lake, alluvial fan, craggy rock surface, gorge and ridge are the landforms discernible in ITH (Figs. 3-12; Table 3).

*3.3.1.2. Scree.* Steep slopes typically found above 4000 m amsl are unstable, often sliding substrate accumulation of broken rock fragments comprising of small and angular stones at the base of mountain cliffs or valley shoulders. These barren mountain landforms are usually associated with bouldary slopes (>45°). Landforms associated with these materials are sometimes called as 'Scree slopes'. These areas usually harbor several characteristic species, such as *Eriophyton rhomboideum, Aconogonum tortuosum, Caragana* spp., *Cotoneaster* spp., *Cicer microphyllum, Cousinia thomsonii, Thermopsis inflata, Glechoma nivalis, Colutea nepalensis* and one or more species of *Corydalis, Astragalus, Chesnia, Rheum* and *Silene* in cold arid environments. In semi-arid regions, *Potentilla cuneifolia, Bistorta affinis, Geranium wallichianum, Thymus linearis, Leontopodium brachyactis, Delphinium densiflorum* and *Potentilla argyrophylla* have been reported as the major species in these slopes. Elevation, soil moisture and salinity are the most important environmental factors that influence the species composition in scree slopes. Compared to other landforms, these slopes support less plant species diversity due to steepness and aridity. Kala and Mathur (2002); Rawat (2007); Chandola et al. (2008); Dar (2008); Jishtu and Goraya (2008); Rawat (2008); Rana (2008); Tambe and Rawat (2008); Chandola (2009); Dvorsky et al. (2011); Angmo (2013); Kumar et al. (2015); Kumar and Mitra (2015) and Kumar (2017).

*3.3.1.3. Moraine.* An area characterized by glacially formed accumulation of unconsolidated glacial debris comprising of soil and rock. These landforms consist of weathered rocks with a slope ranging between 25°–50° and high proportion of stones >20 cm in diameter. Moraines being a dynamic landform support higher species richness due to reasonably moist conditions, especially in lateral moraines and 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. The characteristic and dominant taxa include one or more species of *Potentilla, Sibbaldia, Epilobium, Impatiens, Bistorta, Geranium, Cassiope, Gaultheria, Iris, Thymus, Leontopodium, Anaphalis, Polygonum, Acantholimon, Onosma, Stipa, Poa, Danthonia, Urtica, Salix, Rhododendron, Lonicera, Caragana, Cotoneaster, Juniperus* and *Betula*. Elevation ranges between 3500 and 4500 m above mean sea level (AMSL). Kala and Mathur (2002); Gaur et al. (2003); Tambe (2007); Rawat (2007); Tambe and Rawat (2008); Jishtu and Goraya (2008); Dar (2008); Chandola (2009); Angmo (2013); Kumar et al. (2015); Kumar and Mitra (2015) and Kumar (2017).

*3.3.1.4. River bed or valley bottom.* Essentially river banks and valley bottoms characterized by deposition of sand and debris stones. Ecologically characteristic and dominant herbs, graminoids and shrub include different species of *Corydalis, Epilobium, Ranunculus, Potentilla, Sibbaldia,*

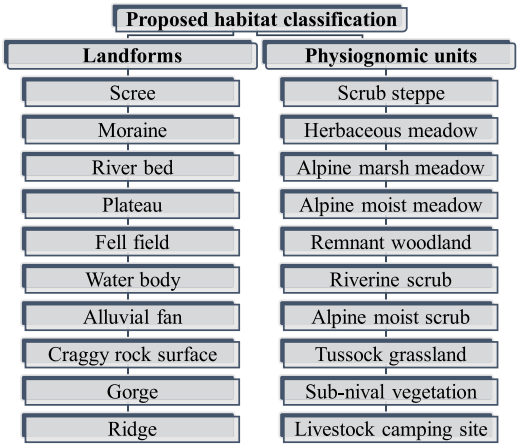


**Fig. 2.** Landscape-habitat-plant physiognomic classes in Indian Trans-Himalaya.

*Carex, Kobresia, Salix, Rosa, Myricaria* and *Hippophae* respectively. Owing to water availability and closeness of grazing grounds of livestock and animal resting places, species such as *Rumex nepalensis* and *Polygonum plebeium* prefers to grow in these areas. These landforms are generally found throughout the ITH. Kala and Mathur (2002); Joshi et al. (2006); Rawat (2007); Tambe (2007); Tambe and Rawat (2008); Chandola et al. (2008); Chandola (2009); Kumar et al. (2015); Kumar and Mitra (2015) and Kumar (2017).

*3.3.1.5. Plateau or tableland.* An area of highland, usually consisting of relatively extensive land area having flat terrain that is raised significantly above the surrounding area, often with one or more sides with steep slopes. Plateaus are found on every continent, with Asia hosting the largest and highest of the world: the Tibetan Plateau. Also called a high plain or tableland, are generally observed at ca. 4500–5500 m above mean sea level harbours comparatively high diversity of species. For example, Eastern Ladakh with many large, brackish water lakes forms an extensive Plateau. *Agropyron-Trisetum-Oryzopsis-Carex community, Elymus nutans, Oryzopsis munroi* and one or more species of *Stipa, Carex, Kobresia, Calamagrostis, Oxytropis* and *Potentilla* are characteristic plants of these landforms. These landforms are typically found above 4000 m amsl. Kala and Mathur (2002); Rawat (2007); Angmo (2013) and Kumar et al. (2015).

*3.3.1.6. Fell field.* The areas generally above 4500 m amsl represent the pioneer environments, including fell-fields dominated by mosses and lichens. Cushion forming communities of *Thylacospermum - Arenaria* and *Androsace* species can often be seen at such heights, especially on stable slopes. The other angiospermic taxa typical of such areas include species of *Rheum, Saxifraga, Sedum, Corydalis* and *Androsace*. Rawat and Adhikari (2005); Joshi et al. (2006); Rawat (2007) and Rawat (2008).

*3.3.1.7. Water body/wetland/lake.* The areas characterized by presence of streams, bogs and high altitude fresh and brackish water lakes. Plant diversity in these landforms varies at different elevations and geographical regions. The Tibetan Plateau comprising of Eastern Ladakh and adjacent parts of Spiti in Trans-Himalayan zone (1B) are characterized by alpine–arid pastures, desert steppe, marsh meadows and brackish water lakes. The stream banks and lakes in Eastern Ladakh exhibit a characteristic sedge-dominated vegetation represented by one or more species of *Carex, Kobresia, Cyperus, Scirpus, Triglochin, Puccinella, Ranunculus*, and *Polygonum*. Rawat (2007); Rawat and Adhikari (2005); Dvorsky et al. (2011) and Kumar et al. (2017).

*3.3.1.8. Alluvial fan.* An alluvial fan is a conical or fan or cone-shaped deposit of sediment crossed and built up by streams. These landforms are developed when a channel emerges from a mountainous catchment to an adjoining valley. Fairly common in Ladakh in ITH, these landforms are one of the most prominent forms of superficial deposits. These deposits are characteristically coarse grained and poorly sorted primarily consist of virgin (first cycle) sediment resulted through erosion and weathering of uplifted bedrock. Depending on flow of debris and extant of water, alluvial fans can be classified as dry fans and wet fans. Vegetation on these landforms varies from phreatophytes and xerophytes (*Ephedra gerardiana*) in excessive arid conditions to dense grasses and shrubs in semi-arid regions. Unlike other landforms, vegetation in these areas also varies with respect to elevation and slope. Rawat (2007); Joshi et al. (2006) and Chandola et al. (2008).

*3.3.1.9. Craggy rock surface.* These land areas are characterized by rough, barren and high-rising crags. These rocky areas exhibit special lithological features consisting of monotonous, phyllitic, olive-coloured shales with fine graded sandstones intermingled with 'exotic' limestone. Geologically, these areas correspond with *Namik La Flysch*. Floristically, these areas are relatively diverse, unique and interesting. The plant species in rocky crags include *Isopyrum anemonoides, Silene viscosa, Minuarta biflora, Valeriana himalayana, Rhodiola fastigiata, Saxifraga* spp., *Androsace* spp., *Campanula* spp., *Biebersteinia odora* and *Festuca kashmiriana*. These landforms are also characterized by *Ephedra-Artemisia* community in Ladakh. Kala and Mathur (2002) and Rawat (2008).

**Fig. 3.** Scree.

**Fig. 4.** Moraine.

**Fig. 5.** River bed/valley bottom.

*3.3.1.10. Gorge.* The area characterized by deep mountain gorges cut through by large rivers. Narrow gorges are areas which are resulted due to the use of small and seasonal rivulets. These landforms are generally devoid of vegetation except the presence of a few lithophytic species such as *Potentilla curviseta, Bergenia stracheyi, Isodon rugosus, Minuartia kashmirica, Oxyria digyna, Rumex hastatus, Dictamnus albus, Paraquilegia anemonoides* and species of *Tragopogon, Tanacetum, Corydalis, Epilobium, Nepeta, Sedum* and *Thalictrum*. Interestingly, Ephedra-Artemisia community has been reported in narrow gorges above 3500 m in Ladakh. These landforms are generally found throughout the ITH range. Kala and Mathur (2002) and Dar (2008).

*3.3.1.11. Ridge.* A mountain ridge is a geological feature consisting of a chain of mountains or hills that form a continuous elevated crest for some distance characterized by rough, barren and high-rising mountain ridges. Landforms associated with these materials are also referred as 'ridge line'. Generally, *Betula utilis* along with one or more species of Juniperus are the major plant associations alongside steep ridges protruding towards hill tops. However, vegetation composition in these landforms varies across different geographical areas, for example *Ephedra-Artemisia* forms a distinct community along with *Androsace* spp. and *Campanula* spp. on the ridges above 3500 m in Ladakh. These landforms are generally found throughout the entire ITH. Kala and Mathur (2002) and Rawat (2007).

*3.3.1.12. Physiognomic units.* The habitats characterized and defined by their vegetation attribute or type of vegetation present are to be referred as a 'physiognomic units. Scrub steppe/alpine dry scrub, herbaceous meadow, alpine marsh meadow, alpine moist or wet meadow, remnant woodland, riverine scrub, alpine moist scrub, tussock grassland and sub-nival vegetation or sub-nival zones are the physiognomic units of vegetation discernible in ITH (Figs. 13-21; Table 3).

*3.3.1.13. Scrub steppe/alpine dry scrub.* Scrub steppes considerably occupy a larger area as well as are one of the dominant physiognomic units in the Indian Trans-Himalaya. Landforms associated with these materials are also referred as 'scrublands'. Species namely, *Caragana versicolor* and *Krascheninnikovia ceratoides* are keystone species of ITH that are distributed in these habitats. The mosaics of *Caragana* scrub on gelifluction lobes give a peculiar appearance to these habitats in Trans-Himalaya. Scrub steppes comprises of pure or associations of scattered scrub vegetation such as *Caragana* spp., *Krascheninnikovia* sp., *Juniperus* spp., *Lonicera* spp., *Ephedra* sp., *Potentilla rigida, Astragalus* spp., *Elymus* spp., and *Thylacospermum caespitosum* that are especially adapted to withstand harsh and dry climatic conditions as well as heavy browsing pressure. Several plant communities such as *Artemisia - Caragana, Ephedra - Juniperus, Salix - Myricaria*, and *Lonicera - Rosa* are the characteristic vegetation in the cold arid regions of Ladakh and Spiti. The typical plant associations in dry scrub of Changthang Plateau include *Artemisia - Kraschenninikovia* and *Caragana - Lonicera*. These habitats are found in comparatively stable slopes along with rich soil nutrients which might contribute to its rich diversity. Alpine dry scrubs are typically found above 4500 m amsl. Beyond 5000 m, the characteristic

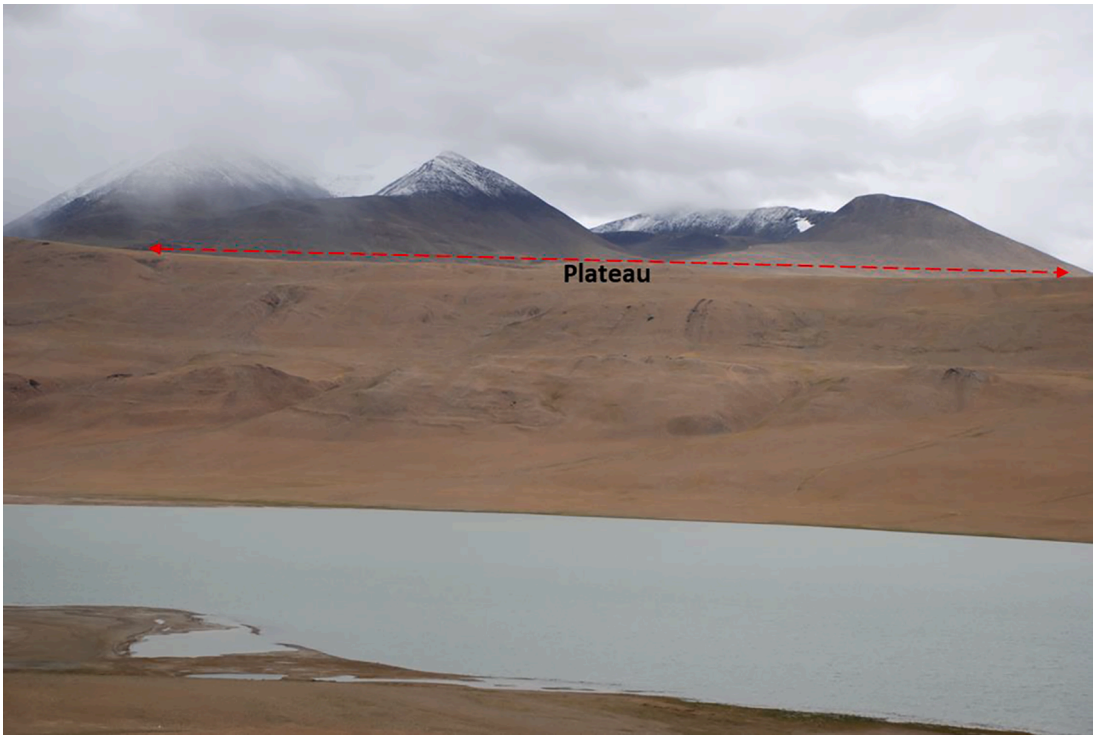


**Fig. 6.** Plateau.

**Fig. 7.** Fell field inhabited by cushioned dwarf herb *Thylacospermum caespitosum*.

**Fig. 8.** Water body/wetland/lake.

**Fig. 9.** Alluvial fan.

**Fig. 10.** Craggy rock surface.

herbaceous plant associations include *Stipa - Oxytropis* and *Acantholimon – Thylacospermum*, and *Caragana – Artemisia, Artemisia – Krascheninnikovia* and *Artemisia – Tanacetum* are the major scrub communities. Rawat and Adhikari (2005); Joshi et al. (2006); Rawat (2007); Tambe (2007); Rawat (2008); Chandola et al. (2008); Jishtu and Goraya (2008); Sekar and Srivastava (2009); Dvorsky et al. (2011); Kumar et al. (2015); Kumar and Mitra (2015) and Kumar (2017).

*3.3.1.14. Herbaceous meadow.* Locally known as `Bugyal' in Garhwal and Kumaon regions of Uttarakahand state, `Dhar' or `Thach' or 'Kanda' in Himachal Pradesh and `Marg' in Jammu and Kashmir, the alpine meadows are the natural herbaceous formations, generally located above the alpine scrub or immediately above the treeline in the absence of later. These alpine meadows comprise a large number of herbaceous communities with varying proportions of grasses and sedges. These areas are characterized by presence of relatively dense herbaceous formations because of high moisture and nutrient availability due to snow or glacial seepage. These formations are favourite grazing grounds for wild as well as domestic animals. The characteristic species of these areas include one or more species of *Kobresia, Trachydium, Euphorbia, Saussurea, Potentilla, Sibbaldia, Carex, Geranium, Pedicularis* and *Anemone*. These physiognomic units are comparatively represented more in transition zones of Greater and Trans-Himalaya between 3000 and 4000 m amsl. Joshi et al. (2006); Tambe (2007); Rawat (2007); Sekar and

**Fig. 11.** Gorge.

Srivastava (2009); Angmo (2013); Kumar et al. (2015); Kumar and Mitra (2015) and Kumar (2017).

*3.3.1.15. Alpine marsh meadow.* These areas are characterized by patchy yet rich lush green meadows comprising of grasses, sedges and several herbaceous species. In Changthang, Eastern Ladakh, several lake basins and seasonally inundated banks have given rise to pools of shallow water that support a number of aquatic plants viz., *Potamogeton pectinatus, Myriophyllum verticillatum, Hippuris vulgaris, Ranunculus natans* and *R. trichophyllus*. Sedges such as *Carex, Blysmus, Kobresia* and *Eleocharis* and a few grasses e.g., *Calamogrostis holciformis, Poa* spp., *Puccinellia* spp. and *Phragmites* spp. are the prominent species in marsh meadows. Representative herbaceous species in these meadows include one or few species of *Ranunculus, Pedicularis, Potentilla, Gentiana, Gentianella* and *Primula*. Some of the characteristic species of saline marshes are *Atriplex tatarica, Pucinellia himalaica, Suaeda olufsenii, Triglochin maritimum* and *Glaux maritima*. Alpine marsh meadows are typically found above 4500 m amsl in Ladakh region. Rawat and Adhikari (2005); Joshi et al. (2006); Rawat (2007); Tambe (2007); Tambe and Rawat (2008); Rawat (2008); Angmo (2013) and Kumar et al. (2015).

*3.3.1.16. Alpine moist meadow.* Areas characterized by relatively high moisture due to high snow deposition resulting in the presence of extensive grasses and herbaceous species. Moist meadows are mostly dominated by sedge species such as *Carex* and *Kobresia*. Due to high precipitation in the form of snow during winters, the moist pockets of Zanskar range support extensive grassy slopes dominated by *Festuca kashmeriana, Poa* spp., *Oryzopsis munroi* and *Melica persica*. The moist meadows harbor a large number of herbaceous including medicinal and aromatic species viz., *Podophyllum hexandrum, Inula rhizocephala, Iris ensata, Swertia speciosa, Arnebia euchroma, Bistorta affinis, Cicer microphyllum, Geranium* spp., *Allium carolinianum* and *Rheum australe*. Few interesting taxa such as *Pulsatilla wallichiana* and *Colchicum luteum* have also been recorded in these meadows. The characteristic plant

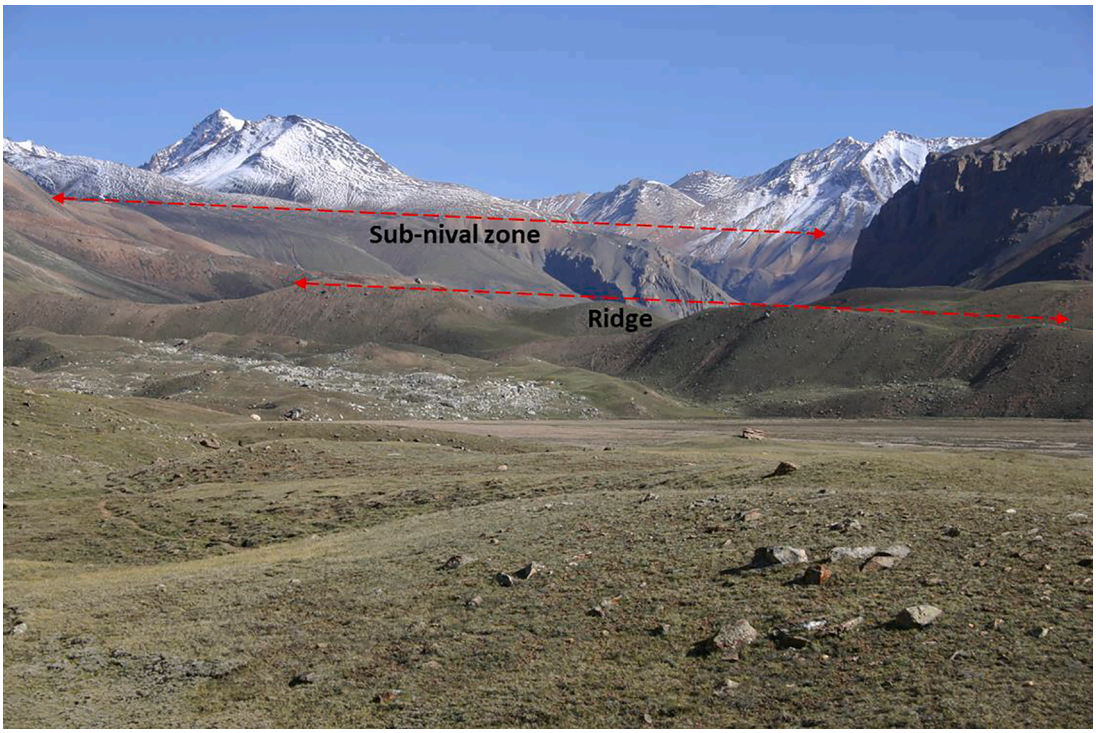


**Fig. 12.** Ridge, and Sub-nival zone near summer snowline.

**Fig. 13.** Scrub steppe/Alpine dry scrub dominated by *Caragana versicolor*.

**Fig. 14.** Herbaceous meadow comprising of short forbs and graminoids.

**Fig. 15.** Alpine marsh meadow.

**Fig. 16.** Alpine moist/wet meadow.

**Fig. 17.** Remnant woodland comprising of *Betula utilis*.

**Fig. 18.** Riverine scrub dominated by *Hipphophae rhamnoides, Myricaria elegans* and *Salix* spp.

**Fig. 19.** Alpine moist scrub dominated by *Rhododendron campanulatum* and *Juniperus* spp.

**Fig. 20.** Tussock grassland dominated by *Danthonia cashmeriana*.

**Fig. 21.** Livestock camping site dominated by *Rumex nepalensis*.

associations include *Kobresia - Carex, Geranium - Potentilla* and *Danthonia cachemyriana* between 3500 and 5000 m amsl. Rawat and Adhikari (2005); Rawat (2007); Rawat (2008); Jishtu and Goraya (2008); Chandola et al. (2008); Tambe and Rawat (2008) and Dar (2008).

*3.3.1.17. Remnant woodland.* Areas characterized by the presence of remnant patches of natural woodland, especially *Betula utilis* (birch), *Juniperus semiglobosa* (juniper), *Ulmus wallichiana* (elm) and some species of poplar such as *Populus euphratica, P. ciliata* and *P. alba* in Western Ladakh and Nubra valley. Plantations of few willows and exotic poplars such as Salix spp., *Populus nigra* and *P. balsamifera* have been replaced by natural woodlands in some of the valleys in Ladakh Mountains. These physiognomic units are relatively present in cold-arid regions of Lahaul and Pangi valley in Himachal Pradesh and Niti, Mana and Nilang valleys in Uttarakhand below 4000 m. *Betula utilis* along with Juniperus spp. in dry sub-alpine forests, and *Pinus wallichiana* and *Cedrus deodara* in dry temperate forests are the major species in these habitats. Unfortunately, so far, no efforts have been made to delineate these natural woodlands for further management planning. Rawat (2008); Chandola et al. (2008); Jishtu and Goraya (2008); Chandola (2009); Kumar et al. (2015); Kumar and Mitra (2015) and Kumar (2017).

*3.3.1.18. Riverine scrub.* The land area characterized by presence of riverside scrub species such as *Hippophae (H. rhamnoides ssp. turkistanica, H. tibetana, Myricaria germanica, M. elegans, M. rosea, Phragmites australis, Tamarix gallica, Rosa webbiana, Salix flabellaris* and *S. pycnostachya*. In riverine scrub above 3300 m amsl, *Hippophae - Myricaria* and *Salix -Myricaria* are the pervasive plant associations along the riverbanks. Joshi et al. (2006); Rawat (2007); Rawat (2008); Chandola et al. (2008); Jishtu and Goraya (2008) and Tambe and Rawat (2008).

*3.3.1.19. Alpine moist scrub.* The area immediately above natural treeline is occupied by various shrubby formations, e.g., Krummholz (stunted forests or crooked wood of *Rhododendron campanulatum* and associated shrub species), shady moist slopes (*Salix - Lonicera*), *Rosa - Lonicera* scrub, and pure patches of *Rhododendron anthopogon, Cassiope fastigiata* and *Salix lindleyana*. The latter forms matted snow-bed community in association with various perennial herbs. These physiognomic units are distributed in the transition zones between Greater and Trans-Himalaya between 3000 and 4200 m amsl. Rawat (2007); Singh and Rai (2008) and Tambe and Rawat (2008).

*3.3.1.20. Tussock grassland.* Tussock grasslands represent the areas comprising of tussock and bunch grasses such as *Danthonia cachemyriana* and *Deschampsia caespitosa* that usually grow as singular plants in clumps, tufts, hummocks or bunch in meadows, grasslands and prairies. Tussocks of *Danthonia cachemyriana* are generally confined to moist conditions and equability in tussock formations remains higher mainly due to contagious distribution of the individuals. The most dominant species include *Bistorta affinis, Androsace sarmentosa, Nepeta laevigata, Potentilla argyrophylla, P. atrosanguinea, Thymus linearis, Taraxacum officinale, Biebersteinia odora, Bergenia stracheyi* and *Anaphalis royleana* in these areas. Like herbaceous meadow, these grasslands are frequently found in transition zones of Greater and Trans-Himalaya between 3000 and 4000 m amsl. Rawat (2007); Chandola et al. (2008); Dvorsky et al. (2011) and Kumar (2017).

*3.3.1.21. Sub-nival vegetation.* Also referred as 'sub-nival zones' usually lies above 5000 m amsl are characterized by extremely harsh climatic conditions with very short growing season (maximum two months).

Owing to snow and avalanche action, these areas are unstable and therefore support very sparse (< 5%) vegetation cover. Some of the characteristic species in these zones are *Carex nivalis, Christolea* sp., *Saussurea gnaphaloides, S. medusa, S. glacialis, S. werneroides, S. nana, Draba altaica, Saxifraga hirculoides, Androsace tapete, Rhodiola tibetica, Melica* sp., and *Leontopodium alpinum*. Moist and stable slopes have cushion-like growth forms that include *Thylacospermum caespitosum, Arenaria bryophylla, Androsace* spp. and scattered mosses and lichens. Rawat (2007); Rawat (2008) and Dvorsky et al. (2011).

*3.3.1.22. Livestock camping site.* The areas which are characterized and defined by the human interference such as livestock grazing and other anthropogenic activities. Livestock camping sites also known as 'animal resting places' are temporary settlements used by the nomadic shepherds or pastoralists. Low plant species richness in these sites is mainly due to high disturbance regime resulting into prevalence of homogenized species. High N, P, K and Na concentration in these sites is attributed due to the livestock dung which adds higher nutrient concentration. Species such as *Rumex nepalensis, Urtica hyperborea, Polygonum plebeium, Chenopodium botrys* and *Impatiens* spp. that are mostly dispersed by livestock prefers to grow in these areas. Other foremost species inhabiting these areas include *Plantago* spp., *Trachydium roylei, Taraxacum officinale, Sibbaldia parviflora* and *Potentilla bifurca*. Rawat (2007); Singh and Samant (2010); Dvorsky et al. (2011); Kumar et al. (2015) and Kumar and Mitra (2015); Kumar (2017).

## 4. Conclusion

Extensive review of literature on landscape, vegetation and habitat characteristics in the ITH underlines the need for developing a standard set of terminologies and units of classification which are essential for preparing inventories, geospatial analysis and detailed conservation planning. Based on a detailed analysis of geo-morphological features and corresponding vegetation, we have proposed landscape-habitat-plant physiognomic classes for the region. A total of 20 classes comprising of 10 landforms namely scree, moraine, river bed or valley bottom, plateau, fell field, water body, wetland; alluvial fan, craggy rock surface, gorge and ridge, and 10 physiognomic units of vegetation namely scrub steppe/alpine dry scrub, herbaceous meadow, alpine marsh meadow, alpine moist or wet meadow, remnant woodland, riverine scrub, alpine moist scrub, tussock grassland, sub-nival vegetation or sub-nival zone and livestock camping site across the elevational gradients in ITH have been proposed. Salient features of these classes with respect to their physical attributes and characteristic plant communities including species of high conservation significance have been presented. Application of a hierarchical classification and geo-spatial analysis would help in identification of rare classes of vegetation and plant communities such as remnant woodlands (*Betula* and *Juniperus* forests), riverine scrub (species of *Hippophae, Myricaria* and *Salix*) and scrub steppe (species of *Caragana, Lonicera, Juniperus* and *Krascheninnikovia*). This would be pre-requisite in developing integrated forest or rangeland management plans for ITH. The proposed classification would also be useful developing a Land Use Land Cover maps at the landscape level. This approach needs to be extended to the alpine regions of the Greater Himalaya.

## CRediT authorship contribution statement

**Amit Kumar:** Writing – review & editing, Data curation, Writing – original draft. **Bhupendra Singh Adhikari:** Writing – review & editing, Methodology. **Gopal Singh Rawat:** Writing – review & editing, Methodology.

## Conflict of interest statement

The authors declare that they have no competing interests.

## Acknowledgments

The authors wish to dedicate this article to Late Dr. Ranbeer Singh Rawal, former Director, GB Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora. We also wish to acknowledge the Director and Dean, Wildlife Institute of India, Dehradun for institutional support.

## References

Angmo, K., 2013. A Study On Ethno-Flora With Special Reference to Traditional Health Care System in Western Ladakh, Jammu and Kashmir. PhD Thesis. Forest Research Institute (Deemed) University, Dehradun, p. 238.
Aswal, B.S., Mehrotra, B.N., 1994. Flora of Lahaul-Spiti. Bishen Singh Mahendra Pal Singh, Dehradun, India, p. 761.
Chandola, S., Naithani, H.B., Rawat, G.S., 2008. Nilang: A little Known Trans-Himalayan valley in Uttarakhand and Its Floral wealth. ENVIS Bulletin: Wildlife and Protected Areas. Wildlife Institute of India, Dehradun, India, pp. 9–15.
Chandola, S., 2009. Vegetational Inventory of Cold Desert Habitat of Nilang area of Jadh Ganga Catchment (Uttarkashi) in Garhwal Himalaya. HNB Garhwal University, Srinagar Garhwal, Uttarakhand, p. 229. PhD thesis.
Chawla, A., Parkash, O., Sharma, V., et al. 2012. Vascular Plants, Kinnaur, Himachal Pradesh, India. Check List 8(3): 321–348.
Dar, G.H., 2008. Special Habitats and Threatened Plants of Kashmir Himalaya. ENVIS Bulletin: Wildlife and Protected Areas, Wildlife Institute of India, Dehradun, India. 29–36.
Dhar, U., Rawal, S., Upreti, J., 2000. Setting priorities for conservation of medicinal plants - a case study in the Indian Himalaya. Biol. Conserv. 95, 57–65. https://doi.org/10.1111/j.1654-109X.2010.01103.x.
Devi, U., Sharma, P., Rana, J.C., et al., 2014. Phytodiversity assessment in Sangla valley, North-West Himalaya, India. Check List 10 (4), 740–760.
Dvorsky, M., Dolezal, J., de Bello, F., et al., 2011. Vegetation types of East Ladakh: species and growth form composition along main environmental gradients. Appl Veg Sci 14, 132–147. https://doi.org/10.1111/j.1654-109X.2010.01103.x.
Gaur, U.N., Raturi, G.P., Bhatt, A.B., 2003. Quantitative response of vegetation in glacial moraine of central himalaya. Environmentalist 23, 237–247.
Jishtu, V., Goraya, G.S., 2008. Cold deserts of Himachal Pradesh: unique habitats and threatened plants. ENVIS Bulletin: Wildlife and Protected Areas, Wildlife Institute of India, Dehradun, India. 17–25.
Joshi, P.K., Rawat, G.S., Padilya, H., et al., 2006. Biodiversity characterization in Nubra Valley, Ladakh with special reference to plant resource conservation and bioprospecting. Biodivers. Conserv. 15, 4253–4270. https://doi.org/10.1007/s10531-005-3578-y.
Kachroo, P., Sapru, B.L., Dhar, U., 1977. Flora of Ladakh: an ecological and taxonomic appraisal. Dehradun, India.Kala, C.P., Mathur, V.B., 2002. Patterns of plant species distribution in the Trans-Himalayan region of Ladakh. India. J. Veg. Sci. 13, 751–754. https://doi.org/10.1111/j.1654-1103.2002.tb02104.x.
Kala, CP., Mathur, V., 2002. Patterns of plant species distribution in the Trans-Himalayan region of Ladakh. India. J. Veg. Sci. 13 (6), 751–754. https://doi.org/10.1111/j.1654-1103.2002.tb02104.x.
Klimes, L., 2003. Life-forms and clonality of vascular plants along an altitudinal gradient in Eastern Ladakh, NW Himalaya. Basic. Appl Ecol. 4(4): 317–328.
Klimes, L., Dickore, W.B., 2005. A contribution to the vascular plant flora of Lower Ladakh, Jammu and Kashmir, India. Willdenowia 35: 125–153.
Klimes, L., Dickore, W.B., 2006. Flora of Ladakh (NW Himalaya) - A preliminary checklist. Accessed at: www.butbn.cas.cz/klimes/desert.html.
Kumar, A., Mitra, M., Adhikari, BS., Rawat, GS., 2016. Flora of Niti Valley: a cold arid region of Nanda Devi Biosphere Reserve, Western Himalaya. India. Check List: The Journal of Biodiversity Data 12 (1), 1824. https://doi.org/10.15560/12.1.1824.
Kumar, A., 2017. A Study On Floristic Diversity and Plant Functional Types Across Various Landforms in Upper Dhauli Valley, Nanda Devi Biosphere Reserve, Western Himalaya. Forest Research Institute (Deemed) University, Dehradun, p. 165. PhD thesis.
Kumar, A., Adhikari, B.S., Rawat, G.S., 2015. Rangeland vegetation of the Indian Trans-Himalaya: an ecological review. In: Rawat GS and Adhikari BS (eds.) Ecology and management of grassland habitats in India, ENVIS Bulletin: Wildlife and Protected Areas, Wildlife Institute of India, Dehradun. pp 28–41.
Kumar, A., Adhikari, B.S., Rawat, G.S., 2017. Biogeographic delineation of the indian trans-himalaya: need for revision. Curr. Sci. 113 (6), 1032–1033.
Kumar, A., Mitra, M., 2015. Landforms, plant diversity and their utilization by ungulates in Upper Dhauli Valley. Nanda Devi Biosphere Reserve, Western Himalaya. WWF-India, New Delhi 53.

Lindenmayer, D.B., Franklin, J.F., 1997. Managing stand structure as a part of ecologically sustainable forest management in australian mountain ash forests. Conserv. Biol. 11 (5), 1053–1068.
Murti, SR (2001). Flora of cold deserts of Western Himalaya. Vol. 1 (Monocotyledons). Dehradun: Botanical Survey of India. 452 pp.
Rana, B.S., 2008. Glechoma Nivalis (Benth.) Press: An interesting Plant of Alpine Scree Slopes from Spiti. ENVIS Bulletin: Wildlife and Protected Areas. Wildlife Institute of India, Dehradun, India, pp 28.
Rawat, G.S., 2007. Alpine Vegetation of the Western Himalaya: Species diversity, Community structure, Dynamics and Aspects of Conservation, DSc thesis, Kumaun University, Nainital. pp 239.
Rawat, G.S., 2008. Special Habitats and Threatened Plants of Ladakh. ENVIS Bulletin: Wildlife and Protected Areas, Wildlife Institute of India, Dehradun, India. pp 1–7.
Rawat, G.S., Adhikari, B.S., 2005. Floristics and distribution of plant communities across moisture and topographic gradients in Tso Kar Basin, Changthang Plateau, Eastern Ladakh. Arct. Antarct. Alp. Res 37 (4), 539–544.
Rodgers, W.A., Panwar, H.S., Mathur, V.B., 2000. Wildlife Protected Area Network in India: A review (executive summary), Wildlife Institute of India, Dehradun. pp 44.
Singh, A., Samant, S.S., 2010. Conservation prioritization of habitats and forest communities in the Lahaul Valley of proposed cold desert biosphere reserve, North Western Himalaya, India. Appl. Ecol. Environ. Res. 8(2): 101–117.
Sekhar, KC, Srivastava, SK, 2009. Flora of the Pin Valley National Park. Botanical Survey of India, Lahul-Spiti, Himachal Pradesh. Kolkata, p. 296.
Singh, G., Rai, I.D., 2008. Threatened Plants of Kedarnath Wildlife Sanctuary, Western Himalaya. ENVIS Bulletin: Wildlife and Protected Areas. Wildlife Institute of India, Dehradun, India, pp. 51–54.
Srivastava, S.K., 2010. Floristic diversity and conservation strategies in cold desert of western himalaya. India. J. Plant Sci 7, 18–25.
Tambe, S., 2007. Ecology and Management of the Alpine Landscape in the Khangchendzonga National Park, Sikkim Himalaya. Forest Research Institute University (Deemed), Dehradun, p. 225. PhD thesis.
Tambe, S., Rawat, G.S., 2008. The Alpine Landscape in Western Sikkim: Special habitats and Threatened plants. ENVIS Bulletin: Wildlife and Protected Areas. Wildlife Institute of India, Dehradun, India, pp. 69–75.