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Research article

Floristic composition and phytosociology of various forage-based land-use systems in the Himalayas over an altitudinal gradient

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Abstract

Systematic sampling method was used to study ground vegetation diversity and phytosociology of chir pine silvipasture (SPCP), mixed-trees silvipasture (SPM), ban oak silvipasture (SPBO) and grasslands (Gr) in the western Himalaya, India along an altitudinal gradient *viz*., E_1 (< 850 m), E_2 (851–1150 m), E_3 (1151–1450 m), E_4 (1451–1750 m) and E_5 (>1751 m). Ground vegetation belonging to 36 families, 106 genera, and 122 species were recorded, of which 68.85% of species belong to herbs and 31.15% belong to shrubs. Shannon-Wiener and Shannon evenness indices varied from 1.51 (Gr at E_2) to 2.86 (SPM at E_5), 0.46 (Gr at E_2) to 0.80 (SPM at E_4), for herbs; 1.91 (Gr at E_1) to 2.78 (SPM at E_5), 0.79 (SPCP at E_1) to 0.92 (SPM at E_3), for shrubs, respectively. The density and basal area of herbs were higher in grassland as compared to silvipasture systems, while it was *vice-versa* in the case of shrubs. These phytosociological characteristics of herbs and shrubs typically declined with elevation in all the land-use systems. Thus, silvipasture systems showed higher ground species diversity than grasslands. The phytosociological parameters of herbs were better in grasslands as compared to silvipastures. However, shrubs showed better growth parameters under silvipasture systems as compared to grasslands.

Keywords: Basal area, Diversity index, Floristic composition, Grassland, Silvipasture

Introduction

The Himalayas, one of the most biologically diverse regions in the world, is a treasure house for botanists. The presence of varied landforms, relief and environmental conditions makes this region suitable to support large numbers of land uses and vegetation. The structure of an ecosystem is largely determined by vegetation (Yadav *et al.,* 2020). Various factors determine the composition and structure of the community, as well as the diversity of associated species of mountain vegetation (Kunwar *et al.*, 2019). One of these factors is elevation, which influences the floral spectrum and soil properties of different land use (Bhutia *et al*., 2021). Conversely, the temperature, humidity, soil composition and solar radiations are key variables in defining altitudinal zones, which support specific microclimates and, consequently distinct land uses with particular vegetation patterns and soil properties. Many studies have documented attitudinal variation in vegetation type as a function of altitude shift (Adhikari *et al*., 1992) and linked it to climate, habitat heterogeneity, biotic interaction, and history (Currie and Francis, 2004). Variations in species diversity along an elevation gradient have been studied multiple times. Maximum studies showed a hump-shaped distribution of species, reporting the higher species diversity near the mid of the elevation gradient (Kidane, 2019). However, several exceptions have been reported against the humped pattern (Da Silva Mota *et al.,* 2018). In general, increase or decrease in species diversity along an elevation gradient depends largely on interactions among plant communities, environmental factors and management (Körner, 2007; Boscutti *et al*., 2018).

Accurate assessment and understanding of vegetation and species diversity patterns in different land-use systems along elevations are vital for their sustainable management and utilization. It also assists in identifying the threats to biodiversity from advancing anthropogenic and climatic change, allowing strategies to be developed and implemented in the right perspective. In the Himalayas, semi-arid or arid regions, forage-based land use systems (LUS) are the foundation of rural subsistence, supplying critical fodder for their cattle, fuelwood for cooking in their homes, small timber for house construction and agriculture equipment, soil conservation and so on (Ram *et al*., 2023). However, there was a lack of data/information on the structure and diversity of these LUS in this region. Hence, the current study focused on the ground floristic composition and phytosociological attributes of silvipastures (SP) and grassland (Gr) along an elevation gradient in India's north-western Himalayas.

Materials and Methods

Study area: The study was conducted in Solan district, north-western Himalaya, India (latitude 30°40′–31°21′N and longitude 76.35′–77°15′E). The region has altitudes ranging from 360 to 2300 m above MSL. The soil is mainly neutral, ranging from sandy to clay loams, with shallow depth except in areas with vegetative cover. Solan district experiences a subtropical climate at lower elevations and wet temperate at higher reaches, receiving approximately 1420 mm of annual rainfall, mostly during the rainy season. Winter temperatures drop below 0°C in higer reaches, while summer temperatures reach around 38°C in lower areas. Vegetation distribution is influenced by temperature and moisture. Lower areas are characterized by dry mixed deciduous forests, mainly Acacia catechu and Shorea robusta. Chir pine forests (Pinus roxburghii) extend from lower to higher elevations, while Ban oak forests are found in specific areas. Higher altitudes feature oak mixed with conifers like Deodar. Natural grasslands and silvipastures exist throughout the district, differing in tree species composition along the altitudinal gradient.

Site selection: To conduct the study, the whole district was delineated into five elevation zones, *i.e.*, E_1: <850 m; E_2: 851-1150 m; E_3: 1151-1450 m; E_4: 1451-1750 m; E_5: >1751 m. Six experimental sites (approx. 1-km^2 area each) were randomly selected at each elevation zone. Forage-based land-use system *viz*., chir pine silvipasure (SPCP), mixed-trees silvipasture (SPM) and ban oak silvipasture (SPBO) and grasslands (Gr) were selected to study the ground vegetation characteristics. SPCP, SPM and Gr were present in all the elevation zones whereas SPBO was present only in the upper three elevation zones.

Floristic composition and phytosociology: In each selected land-use system, six quadrats of 100 m^2 size were laid out to study shrubs during the year 2017-18 growing season. Several shrub species in each plot were counted, and their density was determined. Based on visual appearance, each shrubs species was differentiated into different groups and in each, the number of plants was counted. A proportionate sampling method was used to sample shrubs from each group to determine the stem basal area of different species. Similarly, to study herbaceous vegetation 6 quadrats of 50 × 50 cm size (standardized through species-area curve method) were randomly laid out to uproot herbage from each of them at the time of peak growth of herbage. The number of herbage species in each quadrat was counted and segregated into grass, sedge, legume, and forb. The tillers of each grass species were counted, and their basal area was determined at ground level. The number of individual plants in each species was counted for herb species other than grasses to determine their density. The individual species density, frequency, basal area and importance value index (IVI) of both shrubs and herbaceous vegetation were determined (Mishra, 1969). The field survey included 648 plots of 10 x 10 m and 50 cm x 50 cm size quadrats to study shrubs and herbs, respectively. All specimens of plants were identified at the University Herbarium, Department of Forest Products, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan and Systematic Botany Division in Forest Research Institute, Dehradun.

Vegetation indices: The Shannon-Wiener, Shannon evenness and Species richness indices were computed.

Statistical analysis: The data obtained were analyzed using JMP 10-SAS software. Data on density and basal area of ground vegetation were analyzed by analysis of variance (ANOVA), and least square (LS) means were compared by Tukey HSD test ($p < 0.05$).

Results and Discussion

Floristic composition: The ground plant richness in SP and Gr swathes 36 families, 106 genera and 122 species, of which 68.85% belonged to herbaceous vegetation and 31.15% species belonged to shrubs. Among different LUS, the ground floral spectrum of SPCP comprised of 32 plant families, 93 genera and 105 species (28 grasses, six sedges, 29 forbs, seven legumes, 35 shrubs). In SPM, ground flora belonging to 33 families, 93 genera and 104 species (27 grasses, seven sedges, 30 forbs, five legumes, 35 shrubs) were recorded, while in SPBO, it was comprised of 33 families, 85 genera, and 92 species (19 grasses, six sedges, 32 forbs, seven legumes, 28 shrubs). However, grassland vegetation comprised of 30 plant families, 86 genera and 97 species (25 grasses, six sedges, 30 forbs, four legumes and 32 shrubs). The findings demonstrated that the ground floristic composition in SP and Gr of Solan district is diversified, with numerous species exhibiting broad ecological amplitude and occupying a variety of ecological niches. These vegetation systems are stable communities with consistent change because they have developed through time under specific climatic circumstances and are a function of time, height, slope, latitude, aspect, rainfall, and humidity in a given location. Despite this, these systems are not indestructible and are vulnerable to biotic perturbations as well as global climate change.

The number of plants recorded in the present investigation was similar to the results of vegetation of the Himalayas reported earlier (Srivastav et al., 2015; Hussain et al., 2019). Few reports have indicated the presence of more plant genera, species, and families in Himalayan vegetation (Chandra et al., 2010; Dar and Sundarapandian, 2016). These workers might have investigated large areas and studied all types of land uses, including forests, non-agricultural land, barren and unculturable lands, which were excluded in our study. Prevailing management inputs also govern differences in floral diversity and habitat condition of any area (Hailu, 2017).

It was inferred that most of the species were represented by a few plant families like Poaceae, Asteraceae, Lamiaceae, Fabaceae and Cyperaceae, comparable to the results of Srivastav *et al*. (2015) and Gupta *et al*. (2015) in the Himalayas (Table 1). More species from only a few families in any area is a manifestation of existing germplasm and the successful adaptation of its species to the environment. Due to the number of species from only a few families, the herbaceous population exhibited the following four main plant categories: grasses, sedges, legumes and forbs. The ground plant categories were the same in silvipasture systems and grasslands, but the number of plant genera or species varied. The number of species in herbaceous plant categories followed the decreasing precedence: forbs > grasses > legumes > sedges.

***Vegetation indices*:** Shannon Wiener Index for herbaceous vegetation in different LUS of Solan district varied from 1.51 in Gr at E_2 to 2.86 in SPM at E_5, whereas for shrubs, it varied from 1.91 in Gr at E_1 to 2.78 in SPM at E_5. Shannon Evenness Index for herbaceous vegetation and shrubs at different elevations also showed a similar trend, with the value ranged from 0.46 in Gr at E_2 to 0.80 in SPM at E_4 and 0.79 in SPCP at E_1 and 0.92 in SPM at E_3, respectively (Table 1).

The results showed that all the vegetation indices were higher in mixed-tree silvipastures (SPM), indicating that SPM had a greater number of species present and individuals distributed more equitably among these species, implying a stable site with many different niches. Diverse tree species in mixed-tree silvipastures created conditions for better regeneration and establishment of more ground vegetation. Low vegetation index values

Table 1. Vegetation Indices of herbs and shrubs in silvipasture systems and grasslands

Vegetation indices	Plant category	Systems (S)	E_1	E_2	E_3	E_4	E_5	Vegetation indices
Shannon Weiner Index	Herbs	SPCP	2.09	2.58	2.57	2.47	2.59	2.88
		SPM	2.43	2.46	2.51	2.79	2.86	3.03
		SPBO			2.63	2.76	2.64	2.94
		Gr	1.83	1.51	2.37	2.45	2.60	2.53
	Shrubs	SPCP	2.01	2.69	2.51	2.75	2.74	2.97
		SPM	2.02	2.72	2.55	2.72	2.78	3.01
		SPBO	-	-	2.52	2.67	2.65	2.78
		Gr	1.91	2.36	2.50	2.54	2.63	2.88
Shannon Evenness Index	Herbs	SPCP	0.66	0.74	0.70	0.67	0.70	0.68
		SPM	0.70	0.74	0.66	0.80	0.79	0.71
		SPBO	-	-	0.69	0.77	0.71	0.71
		Gr	0.60	0.46	0.68	0.71	0.71	0.61
	Shrubs	SPCP	0.79	0.87	0.89	0.85	0.89	0.84
		SPM	0.84	0.89	0.92	0.88	0.89	0.85
		SPBO	-	-	0.91	0.86	0.89	0.83
		Gr	0.83	0.80	0.90	0.86	0.85	0.83

'-' = Not present; E_1 (<850 m), E_2 (851–1150 m), E_3 (1151–1450 m), E_4 (1451–1750 m) and E_5 (>1751 m); SPCP = Chir pine silvipasture, SPM = Mixed-trees silvipasture, SPBO = Ban oak silvipasture and Gr = Grassland in grasslands suggest the presence of few potential niches where only a few species could establish and grow. Altitude is considered one of the most important determinants of vegetation distribution in mountain ecosystems due to its direct impact on the microclimate of the habitat. In the present investigation, the average value of different vegetation indices showed irregular patterns along elevational zones over the range of elevation covered in this study, which was contradictory with the results reported earlier. Many studies have shown a hump-shaped species distribution, reporting maximum species diversity near the middle of the elevational gradient (Kidane, 2019). In Western Himalayas, Dar and Sundarapandian (2016) reported maximum species diversity at middle elevations (2300–2800 m), while Zhang *et al.* (2013) reported a humped pattern (1500–1600 m) along elevational gradients in Baihua mountain reserve in China. However, Da Silva Mota *et al.* (2018) reported maximum species diversity at low elevations and the lowest at high elevations in Rupestrian grasslands in South-Eastern Brazil. The variation in species diversity with elevation might be due to the creation of varied climatic conditions along elevation (Rahbek, 2005; Fenetahun *et al.*, 2020) and soil differentiation (Korner, 2007; Bhutia *et al.*, 2021). These two together promoted the diversification of plant species (Wang *et al.*, 2007; Karami *et al.*, 2015; Lee and Chun, 2016).

Phytosociology of vegetation: The density of herbage in different Solan district land use systems ranged from 465.18 to 947.28 tillers m^{-2} (Table 2). The average density of herbage in SP differed significantly along the elevations ($p < 0.001$). Maximum density as 715.14 tillers m^{-2} was recorded at E_1 which decreased to 561.36 tillers m^{-2} at elevation E_5. Whereas in Gr the density of herbage differed significantly ($p < 0.0001$) and followed the decreasing order as $E_2 > E_3 > E_4 > E_5 > E_1$. It was observed that the mean density of herbage was significantly ($p < 0.0001$) high in Gr followed by SPCP, SPM and SPBO. The interaction of vegetation systems and elevation significantly affected herbage density ($p < 0.0001$).

The basal area of herbage in different LUS of the district ranged from 21.38 to 58.04 cm^2 m^{-2} (Table 3). A thorough examination of data indicates that mean basal area of herbage (cm^2/m^2) in silvipasture systems was significantly high as 51.70 cm^2 m^{-2} at elevation E_1 that gradually reduced to 28.77 cm^2 m^{-2} at E_5 ($p < 0.0001$) Whereas in Gr, it was 58.04 cm^2 m^{-2} at E_1 that reduced along the elevations to 39.29 cm^2 m^{-2} at E_5 ($p < 0.0001$). The mean basal area of herbage was significantly higher in Gr followed by SPCP, SPM and SPBO ($p < 0.0001$). The interaction effect of vegetation systems and elevations on the basal area of herbage was significant ($p < 0.0001$). In this study, it was observed that the density of chir pine silvipasture (SPCP), mixed-tree silvipasture (SPM), and ban oak silvipasture (SPBO) was reduced by 21.98, 25.79, and 42.88%, respectively as compared to grassland (Gr), while the basal area of herbage was reduced by 15.58, 19.35, and 51.74%, respectively, as compared to grasslands. The decrease in these phytosociological parameters of herbage in silvipastures as compared to grasslands might be due to shade effect of trees, enhanced inter-specific or intra-specific competition for resource utilization, site type and inhibition of seed germination on account of tree exudates (Anderson *et al.*, 1969; Gupta and Sharma, 2015). In addition, the amount of litter deposited on the soil surface might also contribute to the decline (Ellsworth *et al.*, 2004) which might be influenced by litter deposition and litter decomposition rate, the density of overstorey vegetation, site and environmental conditions. Further, a higher value of density and basal area of herbage in chir pine silvipasture as compared to other silvipastures could be ascribed to a sparse crown cover of dominant trees owing to its needle-shaped leaves accompanied by regular burning of litter before the commencement of rains by the local inhabitants creating optimal conditions for herbaceous growth. The low values of these parameters of herbage at higher elevations could be ascribed to adverse environmental variables like lower pressure of atmospheric gases which influence gas exchange (Terashima *et al.*, 1995), decrease in atmospheric temperature (Korner and Paulsen, 2004), increase in radiation (Korner *et al.*, 1983) and reduced

Table 2. Density (tillers/m^2) of herbage in silvipasture systems and grasslands at different elevations

Systems (S)	Density of herbage at different elevations (E)					Mean (S)
	E_1	E_2	E_3	E_4	E_5	
SPCP	712.78	694.21	667.02	652.02	641.66	673.54 b
SPM	717.50	684.87	641.79	581.61	577.25	640.61 b
SPBO	-	-	537.22	476.88	465.18	493.10 c
Mean (E)	715.14 a	689.54 a	615.34 b	570.17b	561.36b	619.23
Gr	797.33 c	947.28 a	911.87 ab	840.69 bc	819.11 c	863.26a

'-' = Not present; E_1 (<850 m), E_2 (851–1150 m), E_3 (1151–1450 m), E_4 (1451–1750 m) and E_5 (>1751 m); SPCP = Chir pine silvipasture, SPM = Mixed-trees silvipasture, SPBO = Ban oak silvipasture and Gr = Grassland; Different successive letters suffixing the numbers in the columns for 'Mean (S)' and rows for Mean (E), Gr' denote significant difference, SxE = Significant

Table 3. Basal area (cm^2/m^2) of herbage in silvipasture systems and grasslands at different elevations

Systems (S)	Basal area of herbage at different elevations (E)					Mean (S)
	E_1	E_2	E_3	E_4	E_5	
SPCP	50.20	45.51	41.40	37.95	35.19	42.05 b
SPM	53.20	46.05	39.70	32.15	29.74	40.17 b
SPBO	-	-	27.02	23.73	21.38	24.04 c
Mean (E)	51.70 a	45.78 a	36.04 b	31.28 bc	28.77 c	37.17 b
Gr	58.04 a	54.93 ab	51.63b	45.18 c	39.29 d	49.81 a

'-' = Not present; E_1 (<850 m), E_2 (851-1150 m), E_3 (1151-1450 m), E_4 (1451-1750 m) and E_5 (>1751 m); SPCP = Chir pine silvipasture, SPM = Mixed-trees silvipasture, SPBO = Ban oak silvipasture and Gr = Grassland; Different successive letters suffixing the numbers in the columns for 'Mean (S)' and rows for Mean (E), Gr' denote significant difference, SxE = Significant

growing season (Wang *et al.*, 2007). Similarly, Gupta and Sharma (2015) and Yadav *et al.* (2020) found that the density and basal area of the herbage decreased with elevation in grasslands and tree-based systems in the Himalayas.

In the present study, IVI values of constituent species of the herbage revealed that only a few species displayed high values of IVI compared to all other species in different land-use systems with no particular trend along the elevation. The dominant species in the herbage community of SPCP was *Chrysopogon fulvus* (IVI = 58.16) and *Themeda anathera* (IVI = 50.73) was the co-dominant species. In SPM systems, *C. fulvus* (IVI = 46.65) and *Apluda mutica* (IVI value = 36.36) were dominant and co-dominant species, respectively. However, the dominant and co-dominant species in SPBO were *T. anathera* (IVI = 52.73) and *A. mutica*. (IVI = 34.88) respectively and in Gr, the dominant species was *C. fulvus* (IVI = 79.29) and co-dominant species was *Heteropogon contortus* (IVI = 51.90) (Table 4).

Given the dominant and co-dominant species of different silvipastures and grasslands of the district, it was clearly observed that only a few grass species dominate these land-use systems. The common herbaceous species in silvipastures and grasslands were *A. mutica*, *Arundinella nepalensis*, *C. fulvus*, *H. contortus*, *Panicum maximum*, *Themeda anathera*. The presence of species in any area is determined by the prevailing environmental conditions and their tolerance and adaptation to it. These species exhibited wide ecological amplitude, confirming their

Table 4. Importance value index (IVI) of herbage species in silvipasture systems and grasslands

Species/categories	SPCP	SPM	SPBO	Gr
Grasses				
A. mutica Linn.	23.61	36.36	34.88	13.68
Arundinella nepalensis Trin.	17.36	23.37	20.39	12.60
Avena fatua Linn.	3.66	13.42	24.16	0.86
Bothriochloa pertusa (L.) A. Camus	-	-	8.26	-
Brachiaria reptans (L.) Gard. & C. E. Hubbard	0.54	1.45	-	-
Capillipedium huegelii (Hack.) A. Camus	4.44	1.44	2.04	4.03
Chloris dolichostachya Lag.	0.42	-	-	-
Chloris gayana Kunth	-	-	-	0.29
Chrysopogon gryllus (L.) Trin.	3.018	0.68	1.44	2.83
Chrysopogon montanus Trin.	58.16	46.65	12.99	79.29
Cymbopogon martinii (Roxb.) Wats.	2.63	1.52	-	5.15
Dichanthium annulatum (Forssk.) Stapf	2.57	1.16	0.72	1.34
Digitaria stricta Roth ex Roem. & Schult.	4.79	4.61	2.05	3.67
Echinochloa colona (Linn.) Link	0.17	2.79	-	0.28
Eragrostis nigra Nees ex Steud.	0.79	-	0.61	-
Eulaliopsis binata (Retz.) C.E. Hubb.	3.62	5.94	-	-

Species/categories	SPCP	SPM	SPBO	Gr
Grasses				
Hemarthria protensa Steud.	0.46	0.66	-	5.50
Heteropogon contortus (Linn) P. Beauv.ex Roem. & Schult.	24.50	17.81	2.57	51.90
Imperata cylindrica (Linn.) P. Beauv.	8.68	4.85	1.04	3.94
Panicum coloratum Linn.	2.48	1.99	-	2.19
Panicum maximum Jacq.	7.49	3.80	7.78	15.94
Panicum sanguinale Linn.	1.05	4.73	-	5.30
Paspalidium flavidum (Retz.) A. Camus	-	0.64	-	-
Paspalum notatum Flugge	0.17	0.33	0.35	0.43
Pennisetum flaccidum Griseb.	0.796	1.84	2.79	1.71
Pennisetum orientale L. C. Rich.	3.67	1.92	0.23	4.44
Setaria glauca (Linn.) P. Beauv.	2.27	1.65	-	0.42
Setaria verticillata (Linn.) P. Beauv.	0.94	0.43	-	1.76
Sorghum bicolor (Linn.) Moench	-	1.44	-	0.68
Themeda anathera (Nees ex Steud.) Hack	50.73	26.72	52.73	22.20
Urochloa panicoides P. Beauv.	8.43	10.04	19.95	6.97
Vetiveria zizanioides (Linn.) Nash	0.70	-	1.13	-
Sedges				
Carex cruciata Wahlenb.	-	1.24	7.69	0.21
Carex wallichiana Spreng.	1.43	0.35	1.37	-
Cyperus esculantus Linn.	1.21	1.16	0.55	1.34
Cyperus rotundus Linn.	1.66	2.18	9.17	0.43
Eriophorum comosum (Wall.) Nees	2.69	2.93	-	1.77
Fimbristylis pierotii Miquel	3.11	2.92	2.32	4.20
Fimbristylis rigidula Nees	0.196	2.33	4.37	0.57
Forbs				
Achyranthes aspera Linn.	0.45	-	-	-
Adiantum incisum Forssk.	2.09	3.91	0.94	-
Ageratum conyzoides Linn.	4.62	6.36	1.48	2.03
Anaphalis busua (Buch.-Ham.) DC.	0.76	0.22	-	0.10
Artemisia roxburghiana Wall. Ex Besser	1.79	3.93	2.67	5.73
Barleria strigosa Willd.	-	-	-	0.71
Bidens pilosa Linn.	8.54	9.25	4.15	6.29
Bidens tripartita Linn.	0.89	2.18	2.92	0.96
Bupleurum flacutum Linn.	-	-	1.30	0.29
Centella asiatica (Linn.) Urban.	0.24	0.57	1.45	0.19
Cheilathes farinosa (Forssk.) Kaulf.	0.24	1.74	0.68	0.12
Cissampelos pareira Linn.	0.59	0.35	0.83	0.91
Commelina benghalensis Linn.	1.61	3.95	6.47	0.53
Dicliptera bupleuroides Nees	1.72	1.92	3.54	2.19

Species/categories	SPCP	SPM	SPBO	Gr
Grasses				
Dioscorea esculenta (Lour.) Burkill	0.25	0.25	1.28	-
Erigeron annuus (Linn.) Pers.	2.68	5.48	7.46	2.27
Euphorbia heterophylla Linn.	0.79	1.08	1.58	1.75
Galinsoga parviflora Cav.	-	-	0.59	0.1
Galium aparine Linn.	0.21	1.01	-	-
Gerbera gossypina (Royle) Beauv.	0.42	1.10	0.7	0.120
Gnaphalium luteo-album Linn.	0.11	0.33	1.26	0.60
Justicia simplex D. Don.	0.43	0.67	0.52	0.80
Lamium album Linn.	-	0.89	0.96	0.12
Leucas lanata Benth.	1.25	0.43	0.36	0.34
Malaxis acuminata D.Don	0.26	1.00	0.92	-
Micromeria biflora (Buch.-Ham. ex D.Don) Benth.	4.67	2.45	0.89	4.52
Origanum vulgare Linn.	1.75	2.26	6.08	0.94
Pimpinella diversifolia DC.	0.40	1.03	1.15	0.30
Polygala persicariaefolia sensu Eyles non DC.	0.11	-	0.26	0.24
Reinwardtia indica Dumort.	2.82	1.91	4.67	0.52
Rumex nepalensis Spreng.	-	0.29	5.98	-
Scutellaria scandens D.Don.	-	1.28	-	-
Sonchus oleraceus Linn.	2.36	1.54	1.96	0.39
Teucrium quadrifarium Buch.-Ham.	0.28	-	0.15	0.10
Thalictrum foliosum DC.	3.35	5.10	2.28	0.52
Tricholepis elongata DC.	0.50	-	0.24	1.94
Viola serpens Wall. Ex Ging.	-	2.22	0.47	0.17
Herbaceous legumes				
Argyrolobium flaccidum (Royle) Jaub. & Spach	1.10	-	1.79	0.53
Cassia absus Linn.	0.87	0.58	2.59	1.67
Cassia mimosoides Linn.	0.98	1.00	1.82	2.13
Desmodium laxiflorum DC.	-	0.22	0.87	-
Desmodium pulchellum Backer	0.39	0.60	-	-
Flemingia vestita Benth. ex Baker.	0.31	0.73	3.65	-
Lespedeza gerardiana Maxim.	1.71	0.81	1.07	4.89
Rhynchosia himalensis Benth. Ex Baker	0.89	-	0.45	-

'-' = Not present; SPCP = Chir pine silvipasture, SPM = Mixed-trees silvipasture, SPBO = Ban oak silvipasture and Gr = Grassland

ability to survive successfully in subtropical through mesic to a temperate climate and revealing their long biotic range.

The total density of shrubs in different land-use systems of the district varied from 1516.67 to 3015.00 plants ha^{-1} (Table 5). The density of shrubs (plants ha^{-1}) in silvipasture systems changed significantly ($p < 0.0001$) along the elevation. The maximum total density of shrubs was recorded at E_2 and lowest at E_5. In Gr, the density of shrubs decreased significantly along elevation with maximum value at E_1 and minimum at E_5. The mean density of shrubs was significantly high in SPM (2673.11 plants ha^{-1}) as compared to SPBO (2277.78 plants ha^{-1}), SPCP (2129.00 plants ha^{-1}) and Gr (1973.41 plants ha^{-1}) ($p < 0.0001$). The interaction effect of vegetation systems and elevations on the density of shrubs was insignificant. The total basal area of shrubs in different land use systems of the district varied from 0.32 m^2 ha^{-1} in SPBO

Table 5. Density (plants ha^{-1}) of shrubs in silvipasture systems and grasslands at different elevations

Systems (S)	Density of shrubs at different elevations (E)					Mean (S)
	E_1	E_2	E_3	E_4	E_5	
SPCP	2316.67	2583.33	2238.89	1880.00	1626.11	2129.00 b
SPM	2933.33	3015.00	2726.11	2580.00	2111.11	2673.11 a
SPBO	-	-	2633.33	2255.56	1944.44	2277.78 b
Mean (E)	2625.00 a	2799.17 a	2532.78 ab	2238.52 b	1893.89 c	2372.61
Gr	2411.11 a	2172.11 ab	2027.78abc	1739.39 bc	1516.67c	1973.41 b

'-' = Not present; E_1 (< 850 m), E_2 (851–1150 m), E_3 (1151–1450 m), E_4 (1451–1750 m) and E_5 (> 1751 m); SPCP = Chir pine silvipasture, SPM = Mixed-trees silvipasture, SPBO = Ban oak silvipasture and Gr = Grassland; Different successive letters suffixing the numbers in the columns for 'Mean (S)' and rows for Mean (E), Gr' denote significant difference , SxE = Non-significant

Table 6. Basal area (m^2/ha) of shrubs in silvipasture systems and grasslands at different elevations

Systems (S)	Basal area of shrubs at different elevations (E)					Mean (S)
	E_1	E_2	E_3	E_4	E_5	
SPCP	0.48	0.55	0.46	0.40	0.34	0.44 a
SPM	0.53	0.58	0.50	0.45	0.39	0.49 a
SPBO	-	-	0.45	0.37	0.32	0.38 b
Mean (E)	0.50 ab	0.57 a	0.47 b	0.41 c	0.35 d	0.45
Gr	0.51 a	0.47 ab	0.44 ab	0.42 bc	0.37 c	0.44a

'-' = Not present; E_1 (< 850 m), E_2 (851–1150 m), E_3 (1151–1450 m), E_4 (1451–1750 m) and E_5 (>1751 m); SPCP = Chir pine silvipasture, SPM = Mixed-trees silvipasture, SPBO = Ban oak silvipasture and Gr = Grassland; Different successive letters suffixing the numbers in the columns for 'Mean (S)' and rows for Mean (E), Gr' denote significant difference, SxE = Non-significant

at E_5 to 0.58 m^2ha^{-1} in SPM at E_2 (Table 6). In silvipasture systems mean basal area of shrubs differed significantly ($p < 0.0001$) among different elevations. The mean basal area of shrubs in silvipasture systems decreased in order: $E_2 > E_1 > E_3 > E_4 > E_5$. Likewise, in Gr it significantly decreased ($p < 0.0001$) with an increase in elevation. SPM produced the highest mean basal area of shrubs followed by SPCP, Gr and SPBO ($p = 0.0001$). The interaction effect of vegetation systems and elevations on basal area of shrubs was insignificant. However, the highest basal area of shrubs of soil was recorded in SPM at E_2 and lowest in SPBO at E_5 ($p = 0.2635$).

Comparing density and basal area of shrubs in individual silvipasture with grasslands, it was recorded that density of shrubs increased by 7.31, 26.18 and 13.36% in chir pine silvipasture, mixed-trees silvipasture and ban oak silvipasture, respectively as compared to grassland while, basal area of shrubs in chir pine silvipasture was almost equal to their basal area in grassland but, increased by 10.20% in mixed-trees silvipasture and decreased by 13.64% in ban oak silvipasture as compared to basal area of shrubs in grasslands. These results suggested that changes in microclimate conditions under tree-based systems like soil moisture, organic matter, light conditions, soil composition, pH and drainage patterns etc. favoured shrub growth. The differences in shrub population and their growth among sivlipastures resulted from differences in microclimatic parameters described above and the shade effect. The higher population of shrubs in SPM and SPBO indicated that shade-tolerant shrubs were dominant in ground vegetation. The dominance of shade-tolerant shrubs in vegetation was reported earlier by Ou *et al.* (2011). Anthropogenic activities in silvipastures could not be denied for such differences. These silvipastures are important fodder resources for rearing domestic animals and people often destroy unwanted species, thereby the open spaces were available for shrubs appearance. Furthermore, chir pine silvipasture are regularly burnt to enhance fodder availability which might have encouraged shrub diversity.

Analysis of the IVI value of shrub species (Table 7) revealed that *Lantana camara* (IVI = 31.07) was a dominant species and *Woodfordia fruticosa* (IVI = 27.93) and *Berberis lyceum* (IVI = 27.75) were considered as co-dominant species in SPCP. In SPM, shrub species like *W. fruticosa* (IVI = 33.08) and *L. camara* (IVI = 29.54) were dominant and co-dominant species, respectively. *Berberis lycium* (IVI = 55.26) and *Rubus ellipticus* (IVI = 38.70) were dominant and co-dominant species, respectively in SPBO and in Gr, the dominant and co-dominant species were *Carissa carandas* (IVI = 34.35) and *W. fruticosa* (IVI = 28.74).

Constituent shrubs' importance value index (IVI) varied with elevation in all land use systems barring ban oak sivlipasture (SPBO). *W. fruticosa, L. camara, C. carandas, R. ellipticus, B. lycium, M. africana* and *M. koenigii* species of shrubs maintained higher IVI in all the communities.

Table 7. Importance value index (IVI) of shrub species in silvipasture systems and grasslands

Species/categories	SPCP	SPM	SPBO	Gr
Adhatoda vasica (Linn.) Nees	7.08	6.94	-	9.66
Aechmanthera gossypina (Nees) Nees	0.29	-	0.56	-
Asparagus adscendens Roxb.	5.49	6.96	5.43	5.85
B. lycium Royle	27.75	28.57	55.26	24.98
Buddleja paniculata Wall.	7.74	5.11	-	8.37
Carissa carandas Linn.	26.51	21.10	5.69	34.35
Caryopteris wallichiana Schauer	0.44	1.02	-	-
Colebrookea oppositifolia Smith	0.82	0.54	-	0.22
Dodonaea viscosa (L.) Jacq.	2.65	2.72	-	4.37
Elaeagnus umbellata Thunb.	-	-	2.97	-
Hamiltonia suaveolens (Roxb.) Roxb.	13.13	13.38	2.02	13.59
Hypericum oblongifolium Choisy	0.40	1.09	2.84	1.01
Indigofera pulchella Roxb.	13.03	9.90	13.69	20.47
Inula cappa (Buch.-Ham. ex D.Don) DC.	0.31	0.50	0.74	-
Inula cuspidata (Wall. ex DC.) C.B. Clarke	1.97	0.80	-	1.60
Jasminum humile Linn.	1.81	2.91	2.76	0.47
Jasminum pubescens (Retz.) Willd.	1.42	0.86	-	0.44
L. camara Linn.	31.07	29.54	2.19	25.94
Leptodermis lanceolata Wall.	6.97	7.23	15.53	4.72
Leptopus cordifolius Decne.	0.33	1.43	1.41	0.48
Lespedeza stenocarpa (Klotzsch) Maxim.	1.95	0.98	-	1.86
Meriandra strobilifera Benth.	4.21	3.19	-	3.49
Mimosa rubicaulis Lamarck	6.99	6.45	1.37	6.51
Murraya koenigii (L.) Spreng.	24.54	21.08	-	27.12
Myrsine africana Linn.	26.41	24.87	28.49	23.60
Osyris arborea Wall. ex A. DC.	3.60	3.38	2.48	5.37
Plectranthus rugosus Wall. ex Benth	5.64	5.06	7.23	5.69
Prinsepia utilis Royle	4.80	4.98	14.89	3.67
Randia tetrasperma (Wall. ex Roxb.) Benth. & Hook.f. ex Brandis	5.78	10.06	29.19	3.88
Rhamnus virgatus Roxb.	1.39	0.84	2.76	1.33
Rosa brunonii Lindl.	5.58	6.89	12.07	8.37
R. ellipticus Smith	24.16	27.12	38.70	19.20
Rubus niveus Thunb.	2.24	4.32	14.32	1.05
Salvia coccinea Juss. ex Murray	3.19	2.86	1.75	1.72
Sarcococca saligna (D.Don) Muell.-Arg.	-	-	4.16	-
Strobilanthes atropurpureus Nees.	-	1.81	20.70	-
W. fruticosa (Linn) Kurtz	27.93	33.08	5.96	28.74
Zanthoxylum armatum DC.	2.35	2.47	4.85	1.88

'-' = Not present; SPCP = Chir pine silvipasture, SPM = Mixed-trees silvipasture, SPBO = Ban oak silvipasture and Gr = Grassland

Higher IVI of these species was an indicator of their better growth in prevailing environment due to their harmonious ecological adaptation, good power of regeneration and greater ecological amplitude in comparison to other species. The dominance of *L. camara*, an invasive exotic species in the lower to mid-elevations indicated that the open ecosystem of these forage-based land-use systems along with the suitable climatic conditions of the region provides ideal conditions for the regeneration and establishment of this species, which may be a major threat to biodiversity and productivity of these land-use systems soon.

Conclusion

The floral spectrum in various silvipasture systems and grasslands of Solan district, Himachal Pradesh, was broad. Silvipasture systems had more diversity of herbs and shrub species than grasslands, suggesting a stable site conducive to regeneration and establishing more ground vegetation species. However, phytosociological parameters like density and basal area of herbaceous vegetation were better in grasslands than in silvipasture systems, revealing the adverse effect of trees on the growth of herbage. Among silvipastures, the growth of herbage was most affected in ban oak silvipastures. Shrubs showed better growth parameters under silvpasture systems than grasslands. However, these parameters of vegetation decreased along the elevation.

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