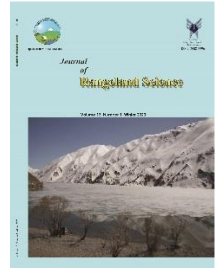
Contents available at ISC and SID
Journal homepage: www.rangeland.ir



Research and Full Length Article:

Effects of Plant Diversity and Soil Properties on Aboveground Biomass along Altitudinal Gradient: A Case Study from Grassland of Mustang District, Nepal

Sumit Kumar Rauniyar[A], Rajeev Joshi[B]*, Dhruba Bijaya G.C.[A], Jyoti Bhandari[A], Dinesh Bhandari[A]
[A]Tribhuvan University, Institute of Forestry, Pokhara Campus, Pokhara-33700, Nepal
[B]Faculty of Forestry, Agriculture and Forestry University, Hetauda-44107, Nepal; Amity Global Education, CTEVT, Tokha-11, Kathmandu-44600, Nepal. *(Corresponding author), E-mail: joshi.rajeev20@gmail.com

Received on: 06/06/2021
Accepted on: 24/12/2021
DOI: 10.30495/RS.2023.687344

Abstract. This research was conducted in the Mustang district of Nepal to see the effect of plant diversity and soil properties on Above Ground Biomass (AGB) in altitudinal gradient. For determining AGB and soil properties, altogether 57 sample quadrats were laid out. Species richness and Shannon-Wiener's diversity indices were used to study species diversity. The AGB production was measured using harvesting method. The samples for AGB were collected at peak biomass production in late summer 2020 in two sites of Kunjo and Kowang in the Gandaki province, northern Nepal. At each site of 100 m^2 area, three $1m^2$ independent plots (quadrats) were laid out at the interval of 30m along a 100m transect. The result showed that AGB decreased with increase in altitude, whereas species richness increased with increase in altitude. Kunjo site had high dominance of species than that of Kowang site accounting 23 and 12, respectively. *Kobresia spp*. had high Importance Value Index (IVI) (91.13) followed by *Carex spp*. (52.17) in Kowang. Moreover, AGB decreased with increasig in soil pH. Hence, to increase the AGB of grasslands and to protect the diversity of Mustang district, it is necessary to conserve mountain grassland, especially in higher altitude zones, by protecting soil from erosion and landslides, and rotational grazing of livestock's for increasing soil organic matter.

Key words: Above ground biomass, Altitude, Species diversity, Species richness

Introduction

Nepal has an extreme altitudinal range from 60-8848 m above sea level with heterogeneous topography and distinct climatic zones. The country is considered a biodiversity hotspot, with nearly a quarter of the land area located in protected areas (Bhattacharjee *et al.*, 2017). The Himalayas are one of the most representative mountain ranges possessing vast alpine vegetation and great varieties of alpine plants. The biodiversity of this ranges are represented by grasslands and rangelands areas which covers about 12% of the country's total land area (GoN/MoFSC, 2014). In addition, grasslands and rangeland comprise an area of 3.326 m ha, 22.60% of the total land area of Nepal (Acharya and Baral, 2017.) out of which 60% lies within the Himalayan landscape (ICIMOD, 2017). Grasslands are any extensive areas of land that are occupied by native herbaceous or shrub by vegetation which are grazed by domestic or wild herbivores. They are geographical regions dominated by grass and grass-like species with or without scattered woody plants (Getabalew and Alemneh, 2019).

Grasslands are important resources that cover 41% of the earth's land surface, and support livelihoods for nearly 800 m people, provide forage for livestock, regulate ecosystem services, and serve as locations for recreation and tourism (Lu *et al.*, 2017).

Grasslands of upper Mustang are major source to sustain livestock as well as people's livelihood as they are rich in medicinal and aromatic plants and trans-Himalayan biodiversity. They are also sources of other natural resources, tourism, carbon sink, valuable cultural landscape, place for recreation and aesthetic value, and beautiful scenery. Much of the Mustang landscape is dominated by pastures but the prevailing harsh climatic condition does not permit to grow sufficient grasses in these lands (Kunwar, 2003). The keeping of livestock has been practiced for millennia in many parts of the world, and it is an important biotic factor that influences grassland ecosystems (Mayer *et al.*, 2006).

IPCC (2006) defines aboveground biomass (AGB) as "All living biomass above the soil including stem, stump, branches, bark, seeds and foliage". The estimation of aboveground biomass in grassland is critical for carbon cycle modeling and climate change mitigation program (Laurin *et al.*, 2014). Estimation and measurements of vegetation biomass not only plays an important role in the study of production, carbon cycles, and allocation of nutrients in terrestrial ecosystems but also supports natural resource management (Bhandari *et al.*, 2015).

Mostly aboveground biomass and species diversity (i.e., species richness) are primarily determined by altitude, climate, and soil fertility (Ma *et al.*, 2010). Species richness is an easily interpretable indicator of biological diversity and ecological condition of the area (Peet, 1974). Eilu and Obua (2005) have pointed out that different altitudes and slopes influence the species richness and dispersion behavior of plant species. Most alpine and subalpine grasslands are characterized by steep slopes, and altitude influences soil properties and plant species composition (Roukos *et al*., 2011). Altitude has been recognized as the most important factor that influences the abiotic environment by changing climatic variables and topography (Roukos *et al*., 2017).

Human activity, particularly the grazing of animals, is very common throughout the alpine zone of the Himalayas, grasslands have been the major sources of animal products such as meat, milk, wool and pelts, and are home to the majority of the ethnic people and accordingly, alpine vegetation is as important as that in low altitudes as a natural resource. There are different factors affecting the productivity and the biodiversity of the grasslands. In recent years, researches have shown that overgrazing and cultivation activities have reduced the vegetation cover which was critically affected by wind erosion (Cheng *et al.*, 2008).

In global scenario numerous studies of grassland ecosystems have found that plant biomass depends on the availability of limiting resources in temperate region (Tilman *et al.*, 2012). Terrain and its topography are paramount in ecological studies for their influence on numerous physical processes associated with the distribution of plant growth and vegetation structure (Coops *et al.*, 1998). Mountain grasslands with unique and sensitive climatic and topographical properties are the most vulnerable natural resources on which indigenous communities rely for their subsistence. The mountainous area of Nepal has experienced changes in socio-economy mostly driven by globalization (such as labour migration has offered additional income opportunities and diversified household income, but on the other hand, it has created labour shortage, increased land abandonment and decreased production from traditional farming systems (Khanal *et al.*, 2015), policy changes (that has affected in tourism promotion, biodiversity conservation and land tenure system) and climate change.

Only few studies have been done in grasslands of the Himalayan Range on the effects of environmental factors on diversity and biomass production of grassland (Bhandari and Zang, 2019). Previous studies on effects of livestock grazing in grassland of Manaslu (Thapa *et al.*, 2016), Sagarmatha (Mt. Everest) National Park, Gaurishankar Conservation Area and Khaptad National Park (Aryal *et al.,* 2015) have been conducted however studies on estimation of biomass and analyzing the relationship with environment factors were lacking. Different natural causes and anthropogenic activities determine the productivity of the grasslands but the extent of the impact of each cause has remained unclear. This research will eventually help to identify and evaluate the effect of plant diversity and soil properties on aboveground biomass of the grassland of Mustang district and its variance along with the altitude gradient.

Materials and methods

Study area

Our studied area was conducted on grasslands of the Mustang district of Nepal with the coordinates of 28º24′ to 29º20′ N latitude and 83º30′ to 84º10′ E longitude. The study area consists of two sites, located in the Kunjo and Kowang villages of lower Mustang (Thasang rural municipality ward No. 2 and 5) in the Gandaki Province of Northern Nepal that covers about 61 ha. of sea buckthorn forest/thicket, the majority of which is located along the Kali Gandaki River (Rajchal, 2007) (Fig. 1). The terrain of Mustang district is rugged and ranges from 1372 to 8167 m above sea level, thus representing sub-tropical to alpine types of climate, which is a part of the Annapurna Conservation Area that covers most of the Annapurna Himal complex and the Kali Gandaki Valley. Mustang experiences a trans-Himalayan climatic condition which is cool and semi-arid. The average annual temperature of the region is about 10.9°C during the daytime with a mean annual precipitation of 307 mm. The district is characterized by a very large biodiversity, unique landscapes and rich cultural heritage, and has, therefore, become one of the most important tourist destinations in the nation.

The habitat composition of the study area mainly includes patches of forests (mainly of *Juniperus* spp., *Betula* spp. and *Populus ciliata*), dry alpine scrubland, alpine meadows and Tibetan desert steppe. Plantations are carried out exclusively by *Salix* spp. and *Populus ciliata*. In addition, *Juniperus indica*, *Hippophae tibetana*, *Rhododendron lepidotum, Lonicera obovata, Ephedra gerardiana*, *Spiraea arcuata, Cotoneaster* spp., *Caragana* spp., *Berbaris* spp., *Artemisia* spp. are dominant plant species of the dry alpine scrubland habitat, which lie between (2900-4000) m throughout the area. The study area of high altitude pastures above 4000 m consist of alpine meadows.

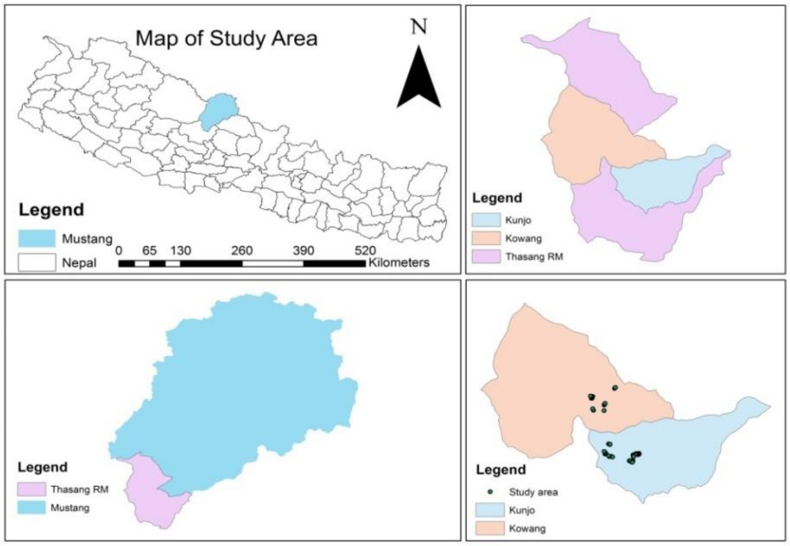


Fig. 1. Map of the study area

Data collection

Sampling design

The field survey was conducted during the peak growing season (February-March) of 2020 on the both sites. Twelve sites on the Lete-Kunjo village and 7 sites on the Kowang village were selected for the sampling (Fig. 2). The study sites were classified into three altitudinal zones based on altitude. In both sites, the lower zone represents the altitude from 2400 to 2599 m, the middle zone represents the altitude from 2600 to 2799 m, and the upper zone represents the altitude from 2800 to 2999 m.

The aboveground biomass production was measured by the harvesting method with the help of herbal and woody species sampled. The samples for aboveground biomass were collected at peak biomass production in late summer. At each site of 100 m^2 area, three 1m^2 independent plots (quadrats) were laid out at the interval of 30m along a 100m transect (Bhandari *et al.*, 2015. This gave 36 (12×3) sampled quadrats in Kunjo village and 21 (7×3) sampled quadrats in Kowang village. Plants were harvested from five plots of 1 m^2 to measure above-ground biomass for each site.

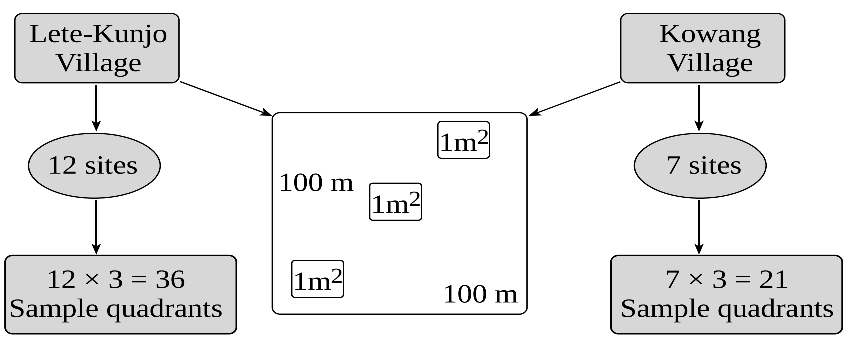


Fig. 2. The flowchart for aboveground biomass sample collection

Sampling Method

For aboveground biomass (AGB) measurement, plant materials were clipped at ground surface, and litter was collected by hand. Samples were immediately placed into individual zip bags and then transported to the laboratory. To estimate the dry weight in each plant group, the samples were placed in a drying oven at 65°C for 48 hours and weighted until they reached a constant weight.

Soil samples were collected from the different surface layer of soil. Soil samples were taken from 12 different sites on the Kunjo village and 7 sites in the Kowang village (Fig. 3). At each sampling site, one pit of 30 cm was excavated and undisturbed soil samples were taken at three layer depths (0-10 cm, 10-20 cm and 20-30 cm) to characterize physical and chemical properties of the soils. Altogether 57 soil samples were collected from each sample plot (12×3 in Kunjo village and 7×3 in Kowang village) with different soil depths using soil auger. Bagged samples were transferred to the pre-weighed sampling bags. Prior to the analyses of the soil physical and chemical properties, each soil samples were air-dried at room temperature, grind into small particles, and passed through 2 mm soil sieve. Various standard protocols were used for the analysis of physiochemical properties of the soil. The soil pH (1:2.5 w/vol) was determined using a glass Calomel pH meter and soil organic matter was determined by the colorimetric method (Anderson and Ingram, 1993). Total nitrogen content in soil (% N) was determined using dry-block digester method called as Kjeldahl method (Bremner, 1960).

Available content of phosphorus (ppm P) was determined using Bray-Kurtz P1 method (Bray and Kurtz, 1945). Soil texture was estimated using feel method (Thien, 1979) and bulk density was determined using core sampling method (Blake and Hartge, 1986). Soil samples were analyzed under the facilitation of Anmol Biu Pvt. Ltd. Bharatpur, Chitwan to assess the status of major physio-chemical properties.

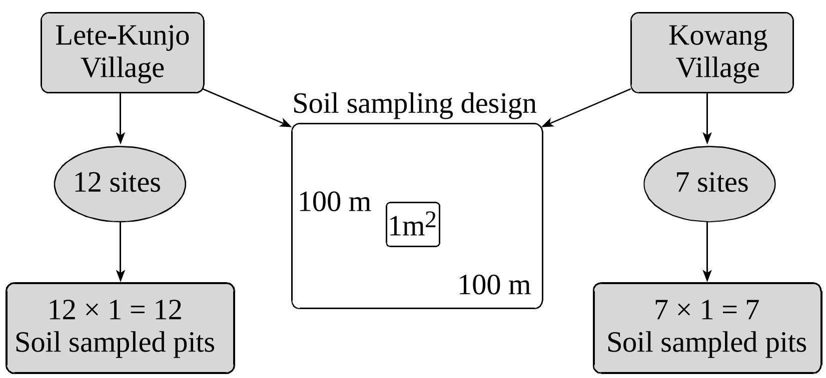


Fig. 3. The flowchart for soil sample collection

Data Analysis

Bulk density

To determine bulk density, a metal core ring sampler of 125.6 g cm^{-3} (4 cm dia. and 10 cm length) was used to extract soil samples at 0-10 cm, 10-20 cm and 20-30 cm depths.

The soil samples extracted were oven-dried at 105℃ (temperature) until a constant weight was recorded. Then the oven-dried soil samples were sieved through a 2 mm sieve to differentiate stones which helps to determine moisture correction (Joshi *et al.*, 2020; Joshi *et al.*, 2021). Finally, the total amount of coarse fragments was estimated from each soil sample collected from different sample sites and subtracted from the soil weight to get a precise soil weight. The following formula was used to calculate the bulk density (Pearson *et al.*, 2007).

$$\text{Bulk density (g/cm}^3) = \frac{\text{Oven dry weight of soil (g)}}{\text{Volume of the soil (cc)}},$$

Where:

Volume of the soil = Volume of core – Volume of the stone.

Vegetation indices

Species richness was calculated using Menhinik's index as given by (Whittaker *et al.*, 2001). Generally, species richness is a measure of the number of species found in the sample and may it increase by increasing the sample size, because the larger sample may contain the more species. Species richness was calculated using Menhinik's index as fallow

$$\text{Species richness} = \frac{S}{\sqrt{n}},$$

where: S= the number of species and n= total number of individuals of all species.

The following quantitative characteristics of the vegetation were determined using the following formula given by Zobel et al. (1987).

- $\text{Frequency} = \frac{\text{No.of plots with the individual species}}{\text{Total no.of plots studies}} \times 100$
- $\text{Relative Frequency (RF)} = \frac{\text{Frequency of any one species}}{\text{Total frequency of all species}} \times 100$
- $\text{Density} = \frac{\text{Total no.of individual species in all plots}}{\text{Total no of plots} \times \text{area of plots}}$
- $\text{Relative Density (RD)} = \frac{\text{Density of a species}}{\text{Total density of all species}} \times 100$
- $\text{Relative Coverage (RC)} = \frac{\text{Coverage of a species}}{\text{Total coverage}} \times 100$
- Importance value index (IVI) = RF+RD+RC

Shannon-Wiener's diversity index (H′)

Species diversity was determined using Shannon-Wiener's diversity index as described by Krebs (1989). The value of Shannon index generally ranges from 1.5 to 3.5, higher value indicating higher diversity.

$$H = -\sum\left[\left(\frac{ni}{N}\right) \times \ln\left(\frac{ni}{N}\right)\right],$$

Where:

ni is the number of individuals of each species,

N is the total number of individuals (or amount) for the site, and

ln is the natural log of the number.

Statistical Analysis

Statistical analyses were carried out using SPSS version 10.0. Means comparisons for treatments were carried out using $LSD_{0.05}$.

Results and Discussion

Effect of altitude on aboveground biomass (AGB)

The aboveground biomass was found higher in Kunjo village with average 72.32 g m^{-2} than those fund in the Kowang village with average aboveground biomass production of 62.43 g m^{-2}. The result shows that the highest AGB was found in lower altitude (2400-2599 m) range (93.54 g m^{-2}). Results showed that AGB of higher altitude (2800-2999 m) range (47.06 g m^{-2}) was significantly lower than the lower altitude (2400-2599 m) range. However, the mean AGB of mid altitude (2600-2799 m) range (61.25 g m^{-2}) was not significantly differ in lower altitude range and higher altitude range (Table 1). Similarly, there was negative linear relationship between AGB and altitude (r=-0.39) $p<0.05$.

A number of studies in alpine ecosystems show that at high altitudes, plant growth is mainly associated with temperature rather than precipitation (Ganjurjav *et al.,* 2018). In both study sites, AGB were founded to gradually decrease with increase in altitude. Our findings of decreased AGB with rising altitude were consistent with those of (Bhandari and Zhang, 2019; Roukos *et al.,* 2011). This might be due to two reasons; firstly, air temperature at the higher altitude zone is lower due to lower radiation input than at other sites (Feßel *et al.,* 2016).

Secondly, altitude exerts greater effects on snowpack accumulation and hence growing season length, soil water availability, and the distribution of plants at the highest altitude sites than the lowest sites. From these findings, we can understand that there is a negative influence of altitude on aboveground biomass.

Effect of altitude on plant biodiversity

The species richness with value of 6.26 was found highest in higher altitude (2800 to 2999 m) and Shannon diversity index with value of 3.01 was found highest in middle altitude (2600 to 2799 m. However there was no significant difference in Shannon diversity index among the three different altitude gradients (Table 1). The species richness was positively correlated with AGB and (r=0.41) $p<0.05$. From the study species richness was found to be high in altitude ranging from 2800 m to 2999 m, while the case was quite abnormal in the study of Limbu *et al.,* (2017). Similarly, the study conducted by Bhattarai and Upadhyay, (2013) in Sagarmatha National Park, Nepal, has also shown that the species richness is negatively correlated with the altitude.

Species richness is estimated by interpolation of presences between the extreme recorded altitudinal ranges. The number of species in 100-m altitudinal bands increases steeply with altitude until 1,500 m above sea level. Between 1,500 and 2,500 m, little change in the number of species is observed, but above this altitude, a decrease in species richness is evident' (Grytnes and Vetaas, 2012). High-altitude areas have lower temperature, which limits plant growth, while low-altitude areas lack adequate rainfall and cannot meet moisture requirements for plant growth (Zhang *et al.,* 2016). An optimal range of temperature and precipitation occurred in the middle elevations (Kludge *et al.,* 2006).

As elevation increases, total area decreases; thus, there are more species present at middle elevations than high elevations (Pauchard *et al.,* 2009). The relationship between species richness and elevation depended on the life form studied (Cirimwami *et al.,* 2019). Species richness decreases with increasing elevation for woody lifeforms (tree and shrub lifeform) (Bhattarai and Vetaas, 2003). Conversely, species richness in the herbaceous lifeform increases with elevation (Cirimwami *et al.,* 2019) which is the outcome of our study sites.

Different plant species utilize resources at different times (Gulmon *et al*. 1983) and places, and contain different chemical properties in nutrients (von Felten *et al.,* 2009). Due to the high altitude and the low temperatures of the alpine region, growth and survival of plant species are limited (Shaver and Jonasson, 1999). Under this stressful condition, high species richness plays significant role in adsorbing productivity. Many researchers had experimented relationship between ecosystem biomass and species richness and their result varied in different regions establishing a hump-shaped relation (Chalcraft *et al.,* 2004, Pärtel *et al.,* 2007) rather than positive linear relationship.

Chalcraft *et al.* (2004) reported that the linear and hump-shaped patterns of the species richness and biomass depend largely on spatial scale. Therefore, our study does not have evidence of hump-shaped as it is done only in local level which might be important in competitive exclusion among plant species.

Table 1. Effect of altitude on above-ground biomass (AGB) and biodiversity indices

Altitude range	No. of plots	Aboveground biomass (gm^{-2})	Range of AGB (gm^{-2})	Species richness	Shannon diversity index
L (2400 to 2599m)	18	93.54±8.14 [a]	25.5-130.7	4.11±0.68 [a]	2.67±0.17 [a]
M (2600 to 2799m)	24	61.25±7.51[ab]	6.8-116.4	4.66±0.57 [a]	3.01±0.32 [a]
H (2800 to 2999m)	15	47.06±7.03 [b]	10.2-107.0	6.26±0.49 [b]	2.66±0.18[a]

Means with the same letter are not significantly different based on LSD ($p<0.05$).

Assessment of plant communities between two sites

Comparing the results between two different sites, Kunjo has high dominance of species than that of Kowang accounting 23 and 12 respectively (Table 2). *Kobresia* spp. has high IVI (91.13) followed by *Carex* spp. (52.17) in Kowang. Similarly, *Kobresia* spp. (82.79) has the high IVI followed by *Potentilla plurijuga* (45.71) in Lete-Kunjo.

This means *Kobresia* spp. is highly dominant in lower Mustang in grazed area. This Plant communities' assessment conducted by Pokharel (2005) also reveals that *Kobresia* spp. (89.22) a highly palatable species was dominating both ungrazed and grazed plots. A number of plant species found in the Himalaya exhibit varying patterns of distribution. This study revealed that species diversity decreased with increasing elevation Kowang being at lower elevation than that of Kunjo. Pausas and Austin (2001) suggested that over any large region, the distribution of species richness is likely to be governed by two or more environmental factors and not by a single factor. High Himalayan regions have a thin soil layer, a low precipitation and low temperature resulting in a very harsh climate. These environmental factors are not good for plant growth. Temperature decreases with increasing altitude (Barry, 2008). If temperature were the main determinant for species richness with altitude, the pattern predicted decreasing diversity with increasing altitude (McCain, 2007).

Table 2. Species wise Relative frequency (RF), Relative dominance (RD), Relative coverage (RC) and Importance Value Index (IVI) in the study area

S.N.	Species	Lete-Kunjo Site				Kowang Site			
		RF	RD	RC	IVI	RF	RD	RC	IVI
1	*Agrostis capilleries*	12.16	0.18	4.4	28.9	0	0	0	0
2	*Anaphalis* spp.	1.13	0.02	4.9	7.14	8.29	0.18	4.86	21.3
3	*Androace* spp.	1.66	0.02	1.9	5.21	0	0	0	0
4	*Caragana gerardiana*	1.42	0.02	1	3.87	0.2	0	9.14	9.54
5	*Caragana jubata*	1.46	0.02	3.7	6.61	0.82	0.02	1.51	3.14
6	*Carex* spp.	6.16	0.09	3.9	16.3	24.36	0.52	3.85	52.2
7	*Cortia depressa*	0.85	0.01	1	2.67	0	0	0	0
8	*Ephendra* spp.	2.31	0.03	1.4	6.09	0	0	0	0
9	*Gentiana ornata*	1.78	0.03	0.5	4.1	8.39	0.18	7.51	24.2
10	*Juniperus squamata*	0.89	0.01	3.2	5.04	0.2	0.004	4.14	4.55
11	*Kobresia* spp.	17.43	0.26	47.7	82.8	21.9	0.46	47.68	91.1
12	*Lancena tibetica*	8.51	0.13	3.6	20.8	0	0	0	0
13	*Pediculais* spp.	1.5	0.02	0.2	3.26	0	0	0	0
14	*Peristeum* spp.	1.86	0.03	1	4.8	0	0	0	0
15	*Poaceae* spp.	4.7	0.07	1.2	10.7	0	0	0	0
16	*Potentilia biflora*	1.13	0.02	2.7	4.96	0	0	0	0
17	*Potentilla plurijuga*	21.89	0.32	1.6	45.7	0	0	0	0
18	*Potentilla* spp.	4.82	0.07	2.2	11.9	0	0	0	0
19	*Rosa sericea*	0.77	0.01	2.9	4.44	0	0	0	0
20	*Saussurea nepalensis*	2.8	0.04	1	6.68	0	0	0	0
21	*Saxifragceae* spp.	2.76	0.04	3.4	8.98	0	0	0	0
22	*Saxifrage* spp.	0.28	0	3.4	4	0	0	0	0
23	Unidentified spp. I	0	0	0	0	16.89	0.36	0.72	34.2
24	Unidentified spp. II	0	0	0	0	6.65	0.14	0.24	13.4
25	Unidentified spp. III	0	0	0	0	10.44	0.22	1.43	22.1
26	Unidentified spp. IV	0	0	0	0	1.84	0.04	2.43	6.09
27	Unidentified spp. V	0	0	0	0	1.64	0.03	16.5	19.8
28	Unidentified spp. VI	1.7	0.03	3.2	6.6	0	0	0	0

Effect of altitude, on soil properties

There was no significant difference between three levels of altitude for soil pH, soil organic matter and Bulk density (Table 3).

Soil moisture content was significantly lower in low altitude (9.78%), than middle and higher altitude range (14.36 and 11.67%), respectively. For nitrogen and phosphorous there was significant difference between all the altitude ranges. The lower values of N% (0.12%) and p (1.88 ppm) were obtained in lower altitude range than higher altitude range whereas there were no significant differences between middle and high altitude for both traits (Table 3).

The concentrations of Soil organic carbon (SOC) were found highest in top layer (0- 10 cm) in all grassland and decreased gradually in down layers where high accumulation of organic matter is found (Joshi *et al.*, 2021). Higher amount of humus present in the top layer of soil increase the carbon content in soil. Another factor that affects SOC in the soil is the soil profile. The soil texture and clay size fraction largely affect the organic matter content in soil (Trujillo *et al.*, 2018).

Vegetation cover in the soil layer also affects in vertical distribution of carbon. Research suggests that in average 42% of SOC is accumulated in the top layer (Jobbágy *et al.*, 2000).

Total nitrogen (N) in the soil is solicited because the nitrogen in the soils occurs in several forms and it takes into account all the nitrogen in organic and inorganic forms.

Some scientists argue that total N does not give good indication of soil fertility because only a small portion of total N is available to plants. About 2 to 3% of total N is in the inorganic form, mostly ammonium

(NH_4^+) and Nitrate (NO_3^-) which is only available to the plants (Bandel and Meisinger, 2000). Others present a different view that organic and inorganic forms of nitrogen are always interchangeable and it would be better to consider the total nitrogen to investigate soil quality. Determination of Nitrate (NO_3^-) and Ammonium (NH_4^+) would not give an overall picture of the fertility, but give a snapshot of the N availability not only for plants but also, for micro-organisms in the soil (Truelsen, 2001). This all indication gives that increase in nitrogen content in the soil leads to increase in aboveground biomass productivity (Dimitrakopoulos and Schmid, 2004).

The soil pH was negatively correlated with AGB and (r=-0.38) $p<0.05$. Previous studies have also shown a negative relationship between species richness and soil pH (Diamond and Smeins, 1985; Palpurina *et al.,* 2017). On acidic soils, the number of species could be constrained by high phytotoxicity and nutrient limitation (Abedi *et al.,* 2013). The lower soil pH and higher soil organic matter may be due to differences in parent soil material. In our study AGB significantly decreased with increase in soil pH. This result in the increase in aboveground biomass is directly related with species richness which is finally influenced by soil pH.

Table 3: Effect of altitude soil properties

Altitude range	Soil pH	Bulk density (g cm^{-3})	Soil moisture content (%)	Soil organic matter (%)	Nitrogen (%)	Soil available P (ppm)
L (2400 to 2599)	7.70±0.18[a]	1.30±0.05[a]	9.78±0.91[a]	2.05±0.28[a]	0.12±0.06[b]	1.88±0.98[b]
M (2600 to 2799)	7.85±0.08[a]	1.21±0.06[a]	14.36±1.10[a]	3.35±0.20[a]	0.49±0.02[a]	3.51±0.25[a]
H (2800 to 2999)	7.97±0.03[a]	1.31±0.07[a]	11.67±0.87[a]	2.52±0.35[a]	0.31±0.06[a]	5.54±1.62[a]

Means with the same letter are not significantly different based on LSD ($p<0.05$).

Conclusion

The AGB was gradually decreased by increasing in the altitude in both of the study sites. Species richness was found highest in the higher altitude range, whereas Shannon diversity index was found highest in middle altitude range. Despite the fact that soil nutrients are highly important for plant biomass, we found their influences on AGB and plant species richness to be weak and insignificant. To protect the diversity and increase the AGB of grasslands of Mustang district, it is necessary to conserve mountain grassland, especially in higher altitude zones, by protecting soil from erosion and landslides, and rotational grazing of livestock's for increasing soil organic matter.

Acknowledgment

We are grateful to University Grants Commission, Nepal for providing Small R & D grants to conduct this research as well as Tribhuwan University, Institute of Forestry, Office of Dean, Pokhara/Norhed-Sunrem Himalaya project for providing Faculty Strategic Research Grant scheme. Similarly, the author(s) are thankful to Mr. Abilal Magar, Mr. Chandra Prasad Magar, Mr. Kapil Dungana, Mr. Ajay Bhandari and Mr. Prasiddha Khadka and some field experienced local people of Kunjo and Kowang villages, Mustang district for their generous support and help during the field work.

References

Abedi, M., Bartelheimer, M. and Poschlod, P., 2013. Aluminium toxic effects on seedling root survival affect plant composition along soil reaction gradients–a case study in dry sandy grasslands. Journal of Vegetation Science, 24(6): 1074-1085. DOI: https://doi.org/10.1111/jvs.12016

Acharya, D. and Baral, N. R., 2017. Neglected high altitude rangelands of Nepal: Need for reform. Journal of Forest and Livelihood, 15(1): 103-119. DOI: https://doi.org/10.3126/jfl.v15i1.23093

Anderson, J. M. and Ingram, J. S. I., 1993. Tropical Soil Biology and Fertility: A Handbook of Methods, Wallingford: CAB International.

Aryal, S., Cockfield, G. and Maraseni, T. N., 2015. Effect of summer livestock grazing on plant species richness and composition in the Himalayan rangelands. The Rangeland Journal, 37(3): 309-321. DOI: https://doi.org/10.1071/RJ14088

Bandel, A. B. R. and Meisinger, J. J., 2000. Basic Principles of Soil Fertility I: plant nutrients. Maryland cooperative extension. University of Maryland, Maryland, USA.

Barry, R. G., 2008. Mountain Weather and Climate, Cambridge, UK: Cambridge University Press.

Bhandari, J. and Zhang, Y., 2019. Effect of altitude and soil properties on biomass and plant richness in the grasslands of Tibet, China, and Manang District, Nepal. Ecosphere, 10(11): e02915. DOI: https://doi.org/10.1002/ecs2.2915

Bhandari, J., Pan, X., Zhang, L., Wei, P., Shao, C., GC, D. B., Li, Q.Y., Mehmood, I., 2015. Diversity and productivity of semi-arid grassland of Inner Mongolia: influence of plant functional type and precipitation. Pakistan Journal of Agricultural Sciences, 52(2): 259-264.

Bhattacharjee, A., Anadón, J. D., Lohman, D. J., Doleck, T., Lakhankar, T., Shrestha, B. B., Thapa, P., Devkota, D., Tiwari, S., Jha, A., Siwakoti, M., Devkota, N.R., Jha, P.K., Krakauer, N.Y., 2017. The impact of climate change on biodiversity in Nepal: Current knowledge, lacunae, and opportunities. Climate, 5(4): 80. DOI: https://doi.org/10.3390/cli5040080

Bhattarai, K. R. and Vetaas, O. R., 2003. Variation in plant species richness of different life forms along a subtropical elevation gradient in the Himalayas, east Nepal. Global Ecology and Biogeography, 12(4), 327-340. DOI: https://doi.org/10.1046/j.1466-822X.2003.00044.x

Bhattarai, K. R. and Upadhyay, T. P., 2013. Rangeland management in Sagarmatha (Mount Everest) national park and buffer zone, Nepal: An ecological perspective. Mountain Research and Development, 33(1): 19-28. DOI: https://doi.org/10.1659/mrd-journal-D-11-00077.1

Blake, G. R. and Hartge., K. H., 1986. Bulk density. Pages 363-375 in A. Klute, editor. Methods of soil analysis. Part 1. Second edition. Agronomy Monographs 9. ASA and SSSA, Madison, Wisconsin, USA.

Bray, R. H. and Kurtz, L. T., 1945. Determination of Total Organic and Available Forms of Phosphorus in Soils. Soil Science, 59(1): 39-46.

Bremner, J. M., 1960. Determination of nitrogen in soil by the Kjeldahl method. Journal of Agricultural Science, 55: 11-33.

Chalcraft, D. R., Williams, J. W., Smith, M. D., Willig, M. R., 2004. Scale dependence in the species‐ richness–productivity relationship: the role of species turnover. Ecology, 85(10): 2701-2708. DOI: https://doi.org/10.1890/03-0561

Cheng, Y., Tsendeekhuu, T., Narantuya, N., Nakamura, T., 2008. Phytosociological study of steppe vegetation in Mongolia. Grassland science, 54(3): 107-116. DOI: https://doi.org/10.1111/j.1744-697X.2008.00112.x

Cirimwami, L., Doumenge, C., Kahindo, J. M., Amani, C., 2019. The effect of elevation on species richness in tropical forests depends on the considered lifeform: results from an East African mountain forest. Tropical Ecology, 60(4): 473-484. DOI: https://doi.org/10.1007/s42965-019-00050-z

Coops, N. C., Waring, R. H. and Landsberg, J. J., 1998. Assessing forest productivity in Australia and New Zealand using a physiologically-based model driven with averaged monthly weather data and satellite-derived estimates of canopy photosynthetic capacity. Forest Ecology and Management, 104 (1-3): 113-127. DOI: https://doi.org/10.1016/S0378-1127(97)00248-X

Diamond, D. and Smeins, F., 1985. Composition, Classification and Species Response Patterns of Remnant Tallgrass Prairies in Texas. The American Midland Naturalist, 113(2): 294-308. DOI:10.2307/2425575

Dimitrakopoulos, P. G. and Schmid, B., 2004. Biodiversity effects increase linearly with biotope space. Ecology Letters, 7(7): 574-583. DOI: https://doi.org/10.1111/j.1461-0248.2004.00607.x

Eilu, G. and Obua, J., 2005. Tree condition and natural regeneration in disturbed sites of Bwindi Impenetrable Forest National Park, southwestern Uganda. Tropical Ecology, 46(1): 99-112.

Feßel, C., Meier, I. C. and Leuschner, C., 2016. Relationship between species diversity, biomass and light transmittance in temperate semi‐ natural grasslands: is productivity enhanced by complementary light capture? Journal of Vegetation Science, 27(1): 144-155. DOI: https://doi.org/10.1111/jvs.12326

Ganjurjav, H., Gornish, E. S., Hu, G., Wan, Y., Li, Y., Danjiu, L., Gao, Q., 2018. Temperature leads to annual changes of plant community composition in alpine grasslands on the Qinghai-Tibetan Plateau. Environmental monitoring and assessment, 190(10): 1-12. DOI: https://doi.org/10.1007/s10661-018-6964-0

Getabalew, M. and Alemneh, T., 2019. Factors Affecting the Productivity of Rangelands. Journal of Plant Sciences and Agricultural Research, 3(1): 19.

GoN/MoFSC, 2014. Nepal Biodiversity Strategy and Action Plan 2014-2020. Government of Nepal, Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Grytnes, J. A. and Vetaas, O. R., 2002. Species richness and altitude: a comparison between null models and interpolated plant species richness along the Himalayan altitudinal gradient, Nepal. The American Naturalist, 159(3): 294-304.

Gulmon, S. L., Chiariello, N. R., Mooney, H. A., Chu, C. C., 1983. Phenology and resource use in three co-occurring grassland annuals. Oecologia, 58(1): 33-42. DOI: https://doi.org/10.1007/BF00384539

ICIMOD, 2017. Management of Invasive Alien Species in the Hindu Kush Himalaya. ICIMOD, Kathmandu, Nepal

IPCC, 2006. Revised Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas Inventories. Intergovernmental Panel on Climate Change Publication, Cambridge University Press, Cambridge.

Jobbágy, E. G. and Sala, O. E., 2000. Controls of grass and shrub aboveground production in the Patagonian steppe. Ecological Applications, 10(2): 541-549. DOI: https://doi.org/10.1890/1051-0761(2000)010[0541:COGASA]2.0.CO;2

Joshi, R., Singh, H., Chhetri, R., Yadav, K., 2020. Assessment of carbon sequestration potential in degraded and non-degraded community forests in Terai Region of Nepal. Journal of forest and environmental science, 36(2): 113-121. DOI: https://doi.org/10.7747/JFES.2020.36.2.113

Joshi, R., Singh, H., Chhetri, R., Poudel, S., Rijal, S., 2021., Carbon sequestration potential of community forests: A comparative analysis of soil organic carbon stock in community managed forests of Far-Western Nepal. Eurasian Journal of Soil Science, 10(2): 96-04. DOI: 10.18393/ejss.825066

Khanal, U., Alam, K., Khanal, R.C., Regmi, P. P. 2015. Implications of out-migration in rural agriculture: a case study of Manapang village, Tanahun, Nepal. The Journal of Developing Areas, 49(1): 331-352. Retrieved May 28, 2021, from http://www.jstor.org/stable/24241301

Krebs, C.J., 1989. Ecological methodology. Harper Collins. New York, New York, USA.

Kunwar, P. B., 2003. People wildlife conflict in the Upper Mustang of Annapurna Conservation Area (M.Sc. Dissertation), Tribhuvan University, Institute of Forestry, Pokhara Nepal.

Laurin, G. V., Chen, Q., Lindsell, J. A., Coomes, D. A., Del Frate, F., Guerriero, L., Valentini, R., 2014. Above-ground biomass estimation in an African tropical forest with lidar and hyperspectral data. ISPRS Journal of Photogrammetry and Remote Sensing, 89: 49-58. DOI: https://doi.org/10.1016/j.isprsjprs.2014.01.001

Limbu, D., Koirala, M. and Shang, Z., 2017. Does Altitude Effect on Species Composition and Diversity on Himalayan Rangeland. Himalayan Journal of Science and Technology, 1(1): 26-30.

Lu, X., Kelsey, K. C., Yan, Y., Sun, J., Wang, X., Cheng, G., Neff, J. C., 2017. Effects of grazing on ecosystem structure and function of alpine grasslands in Qinghai-Tibetan Plateau: a synthesis. Ecosphere, 8(1): e01656. DOI: https://doi.org/10.1002/ecs2.1656

Ma, W., Yang, Y., He, J., Zeng, H., Fang, J., 2008. Above and belowground biomass in relation to environmental factors in temperate grasslands, Inner Mongolia. Science in China Series C: Life Sciences, 5: 263-270.

Mayer, A. C., Stöckli, V., Konold, W., Kreuzer, M., 2006. Influence of cattle stocking rate on browsing of Norway spruce in subalpine wood pastures. Agroforestry systems, 66(2): 143-149. DOI: https://doi.org/10.1007/s10457-005-5460-z

McCain, C. M., 2007. Could temperature and water availability drive elevation species richness patterns? A global case study for bats. Global Ecology and biogeography, 16(1): 1-13. DOI: https://doi.org/10.1111/j.1466-8238.2006.00263.x

Palpurina, S., Wagner, V., von Wehrden, H., Hájek, M., Horsák, M., Brinkert, A., Chytrý, M., 2017. The relationship between plant species richness and soil pH vanishes with increasing aridity across Eurasian dry grasslands. Global Ecology and Biogeography, 26(4): 425-434. DOI: https://doi.org/10.1111/geb.12549

Pärtel, M., Laanisto, L. and Zobel, M., 2007. Contrasting plant productivity–diversity relationships across latitude: the role of evolutionary history. Ecology, 88(5): 1091-1097. DOI: https://doi.org/10.1890/06-0997

Pauchard, A., Kueffer, C., Dietz, H., Daehler, C. C., Alexander, J., Edwards, P. J., Seipel, T., 2009. Ain't no mountain high enough: plant invasions reaching new elevations. Frontiers in Ecology and the Environment, 7(9): 479-486. DOI: https://doi.org/10.1890/080072

Pausas, J. G. and Austin, M. P., 2001. Patterns of plant species richness in relation to different environments: an appraisal. Journal of Vegetation Science, 12(2): 153-166. DOI: https://doi.org/10.2307/3236601

Pearson, T. R. H., Brown, S.L. and Birdsey, R. A., 2007. Measurement guidelines for the sequestration of forest carbon. United States Department of Agriculture, Forest Service, Northern Research Station, General Technical Report NRS-18. USA. 42p. Available at [Access date: 30.04.2021]: https://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs18.pdf

Peet, R., 1974. The Measurement of Species Diversity. Annual Review of Ecology and Systematics, 5, 285-307. Retrieved May 28, 2021, from http://www.jstor.org/stable/2096890

Pokharel, B. K., Stadtmüller, T. and Pfund, J. L., 2005. From degradation to restoration: An assessment of the enabling conditions for community forestry in Nepal. Intercooperation, Swiss Foundation for Development and International Cooperation, Switzerland, 273, 13.

Rajchal, R., 2007. Biomass Production of Seabuckthorn (*Hippophae salicifolia*) and its Role in Income Generation (M.Sc. Thesis, Tribhuvan University, Institute of Forestry, Pokhara, Nepal).

Roukos, C., Koutsoukis, C., Akrida-Demertzi, K., Karatassiou, M., Demertzis, G. P., Kandrelis, S., 2017. The effect of altitudinal zone on soil properties, species composition and forage production in a subalpine grassland in northwest Greece. Applied Ecology and Environmental Research, 15(1): 609-626. DOI: http://dx.doi.org/10.15666/aeer/1501_609626

Roukos, C., Papanikolaou, C., Mountousis, I., Kandrelis, S., Chatzitheodoridis, F., 2011. Soil property variations in relation to plant community and altitudinal zone in the rangelands of Epirus, Greece. Bulgarian Journal of Agricultural Science, 17: 806–815.

Shaver, G. R. and Jonasson, S., 1999. Response of Arctic ecosystems to climate change: results of long- term field experiments in Sweden and Alaska. Polar Research, 18(2): 245-252. DOI: https://doi.org/10.1111/j.1751-8369.1999.tb00300.x

Thapa, S., All, J. and Yadav, R. K. P., 2016. Effects of livestock grazing in pastures in the Manaslu Conservation Area, Nepalese Himalaya. Mountain Researchqce007A and Development, 36(3): 311-319. DOI: https://doi.org/10.1659/mrd-Journal-D-13-00066.1

Thien, S. J., 1979. A flow diagram for teaching texture- by- feel analysis. Journal of Agronomic Education, 8(1): 54-55.

Tilman, D., Reich, P. B. and Isbell, F., 2012. Biodiversity impacts ecosystem productivity as much as resources, disturbance, or herbivory. Proceedings of the National Academy of Sciences, 109(26): 10394-10397. DOI: https://doi.org/10.1073/pnas.1208240109

Truelsen, O. M., 2001. Application of the Nutrient Balance Concept to the Traditional Subsistence Farming System in the Middle Hills of Nepal: A Case Study from Dhola VDC, Dhading District (Doctoral dissertation, Royal Veterinary and Agricultural University, Department of Agricultural Sciences, Laboratory for Agrohydrology and Bioclimatology).

Trujillo, W., Amezquita, E., Fisher, M. J., Lal, R., 2018. Soil organic carbon dynamics and land use in the Colombian savannas I. Aggregate size distribution. In Soil processes and the carbon cycle (pp. 267-280). CRC Press.

Von Felten, S., Hector, A., Buchmann, N., Niklaus, P. A., Schmid, B., Scherer-Lorenzen, M., 2009. Belowground nitrogen partitioning in experimental grassland plant communities of varying species richness. Ecology, 90(5): 1389-1399. DOI: https://doi.org/10.1890/08-0802.1

Whittaker, R. J., Willis, K. J. and Field, R., 2001. Scale and species richness: towards a general, hierarchical theory of species diversity. Journal of biogeography, 28(4): 453-470. DOI.org/10.1046/j.1365-2699.2001.00563.x

Zhang, W., Huang, D., Wang, R., Liu, J., Du, N., 2016. Altitudinal patterns of species diversity and phylogenetic diversity across temperate mountain forests of northern China. PloS one, 11(7): e0159995. DOI: https://doi.org/10.1371/journal.pone.0159995

Zobel, D. B., Jha, P. K., Behan, M. J., Yadav, U. K. R., 1987. A practical manual for ecology. Ratna Book Distributors, Kathmandu, Nepal, 149.