



Biomass and Carbon Stock at Various Habitats of Alpine Meadows in the Kumaun Himalaya, India

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Abstract: This study investigates biomass and carbon stock across six alpine habitats (Moist Habitat, Gentle Slope Habitat, Upland Mountain Habitat, Open Grassy Habitat, Stream Bank Habitat, Dry Rocky Habitat) in the Kumaun Himalaya, examining species richness, aboveground biomass, belowground biomass, total biomass, and associated carbon stocks. Species richness varied from 22 to 35. Among all habitats the species richness was highest in Stream Bank Habitat with 35 and lowest in Dry Rocky Habitat with 22. Aboveground biomass was highest in Moist Habitat 89.16 g/m², while the lowest was observed in Gentle Slope Habitat 64.1 g/m². Belowground biomass was highest in Stream Bank Habitat 97.55 g/m², while the lowest was observed in Dry Rocky Habitat 78.94 g/m². Total biomass was highest in Moist Habitat (183.4 g/m²) and lowest in Dry Rocky Habitat (149.7 g/m²). Significant differences were observed for Above Ground Biomass, Total Biomass, Above Ground Carbon, Total Carbon, and species richness across habitats. Below Ground Biomass and Below Ground Carbon did not vary significantly.

Keywords: Alpine, Meadows, Biomass, Carbon, Biodiversity

Alpine grasslands play a crucial role in supporting the livelihoods of over one billion people worldwide while providing significant ecological benefits (Buisson et al., 2022, Lopez et al., 2022). The typical mosaics of alpine microhabitats, which show a significant deal of heterogeneity among the plant communities and survival strategies among individual species, are more pronounced on steeper mountain slopes and terrain with different topographic structure (Liang et al., 2016). Alpine environments are distinguished by their nutrient-poor soils, chilling winds, winter precipitation in the form of snow, and abrupt seasonality pattern. Above ground biomass also provides key information for understanding the responses of vegetation to climate change and resilience (Liang et al., 2016) and can be used to directly estimate grassland productivity (Lopez et al., 2022). Overgrazing, poor management of natural grasslands and biodiversity loss have all been linked to changes in plant community structure and declining productivity in some grasslands (WenJun et al., 2014).

Biomass serves as a fundamental ecological parameter, influencing species diversity, productivity, and carrying capacity in rangelands and pasturelands (Rawat et al., 2012). Grassland biomass is influenced by various topographical factors, including altitude, slope characteristics, as well as biodiversity, all of which contribute to ecosystem stability and productivity (Bhandari and Zhang 2019, Yang et al., 2021, Liu et al., 2022). The grasslands are a vital component of global vegetation, storing approximately one-third of the terrestrial carbon pool (Liang et al., 2016). Alpine and subalpine grasslands primarily occur at high elevations where extreme environmental conditions prevent

tree growth, typically forming low stature vegetation (Padalia et al., 2019). Furthermore, plant biomass allocation patterns, particularly between above- and belowground components, reflect species adaptation to environmental constraints such as low temperatures and nutrient availability (Ma et al., 2010). Accurate estimation of aboveground biomass and belowground biomass is critical for understanding the role of alpine grasslands in the global carbon cycle and for informing sustainable management strategies (Yang et al., 2010).

Plant habitats are the specific environmental conditions in which species grow, survive, and reproduce. These conditions include both abiotic factors (such as soil type, moisture, temperature, elevation, and light availability) and biotic interactions (such as competition, herbivory, and mutualism), all of which influence plant distribution and community composition (Sandel et al., 2011). The diversity of plant habitats ranging from tropical forests and grasslands to alpine meadows and arid deserts reflects the variety of ecological niches occupied by different species (Scheiter et al., 2013). In the face of global environmental change, understanding plant habitat preferences is critical for predicting shifts in species distributions, conserving biodiversity, and managing ecosystems sustainably (Rumpf et al., 2019).

Alpine plants exhibit specialized traits such as dwarfism, deep-root systems, and physiological resilience to cope with extreme conditions (Choler 2015). Although limited in spatial extent, these ecosystems support a high proportion of endemic species and serve as sensitive indicators of climate change impacts (Rumpf et al., 2019). Understanding plant adaptation and community dynamics in alpine habitats is

essential for biodiversity conservation and ecosystem management under ongoing environmental change. Habitat degradation, fragmentation, the invasion of alien species, over-exploitation, and an ever-increasing human population are among the critical factors contributing to species loss across the globe (Barnosky et al., 2012), placing approximately one-fifth of plant species at risk of extinction. Species habitat recovery is recognized as one of the most effective ecological engineering strategies for species rehabilitation and habitat conservation (Polak & Saltz 2011 and Rawat et al., 2021).

The several studies have been made on the Himalayan alpine grasslands among these are (Rawat et al., 2012, Namgail et al., 2012, Padalia et al., 2019, Joshi et al., 2020, Chandra et al., 2021, Barman et al., 2021, Rawat et al., 2021 and Kumar 2024). The alpine climate formed a diverse habitat for the growth and development of plants. The habitat may be different in species composition and community structure as well as biomass. The conservation and management of different habitat condition would be of paramount importance. There is little or no information is available on the biomass and carbon stock in the Byans valley of Kumaun Himalaya. Thus, the present study aims to measure the biomass in different habitats of the Byans valley in central Himalayan region.

MATERIAL AND METHODS

Study area: The Study area is located between $30^{\circ}10'$ and $30^{\circ}20'$ N latitude and $80^{\circ}20'$ and $80^{\circ}50'$ E longitude between 3000-3500m elevation in high elevation area of Byans valley Kumaun Himalaya, India. The Byans valley is the last valley of the Indian Himalayan region before the bordering with Tibet. It runs along a North West to South East axis, formed by the Kuti yankti river, which is one of the headwaters of the Kali River that forms the boundary between India and Nepal in this region. The study area was selected considering

various geographical attributes along with environmental coordinates such as latitude, longitude, altitude, and slope using a global positioning system (Garmin model 2000).

Climate: The area covered with snow during early winter season to late spring (November-April). The climatic data were collected from tehsil Dharchula, nearest climatic station in 2023, the mean maximum temperature was 13.9°C and mean minimum temperature was -2.3°C . The rainy season (summer monsoon) extends from mid-June to September, and maximum rainfall (about one third of the annual) occurs during this period (1520mm) (Fig. 2). The snowfall, begins from October and continue until the first week of April. Snow melt begins around mid-April which provide sufficient moisture to the growth of herbaceous vegetation. Geologically the study area situated in greater Himalayan region. The soil in the study area has diverse nature and showed close relationship with vegetation pattern. Texture of soil is sandy loam and clay loam varies in depth across the altitudinal gradients and slightly reddish in colour.

The area is situated at high elevation where climatic conditions do not favour the growth of tree vegetation and shows the presence of small-structured woody vegetation,

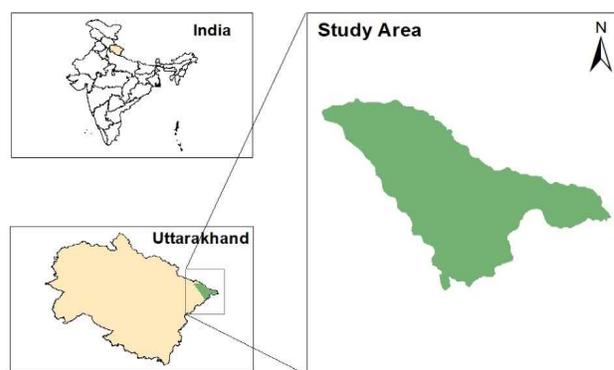


Fig. 1. Map of study area

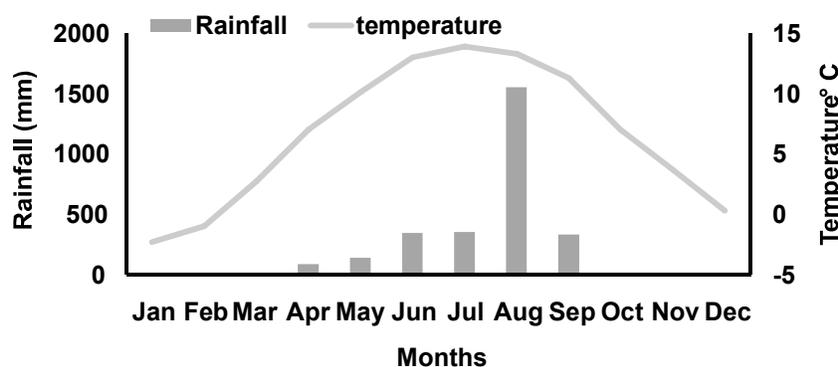


Fig. 2. Monthly variation in rainfall (mm) and temperature (°C)

grasses, and herbs. The plant communities exhibit a diverse distribution, because of their extremely modest spatial extents, many of these communities can be seen in small patches (<1 to 2 m²) at a single place.

Methods: The study was conducted during 2023-2024 at an elevation of 3000-3500m above sea level in Byans valley of Kumaun Himalaya. After through survey six different habitats were identified based on topography, moisture, and vegetation types (Table 1). In each habitat, three plots of 1 × 1 m were randomly selected and used to harvest for the aboveground biomass. The fresh weight of the aboveground material was measured in the field. All harvested aboveground plant material was packed in polyethylene bags, and brought to the laboratory. Then oven dried at 60° C until the constant weight and weighed. Similarly, the belowground plant material was collected using a monolith (25 × 25 × 30 cm) from each harvest plot. The roots were washed and free from soil particles using a thin jet of water

and fresh weight was taken in the field, then brought to the laboratory, oven-dried at 60°C until a constant weight and weighed. The biomass carbon stocks for herbs were determined following the IPCC guidelines, assuming a carbon content of 47.5% of the aboveground and belowground biomass (IPCC 2006; Joshi et al., 2021).

$$C = Y \times 0.475$$

Where, C = carbon stocks, Y = Biomass

The habitat was identified based on the field conditions like soil moisture, slope, and landscape and the habitat characteristics are given in (Table 1).

Statistical analysis: The statistical data were analysed, using MS Excel 2019, IBM-SPSS 16.0 version.

RESULTS AND DISCUSSION

Among all six habitats, the number of species ranged between 22 to 35. It was minimum in Dry Rocky Habitat and maximum in Stream Bank Habitat. Biomass are also varied

Table 1. Habitat types and its characteristics in high altitude alpine meadow

Habitat	Site	Slope	Elevation (m)	Soil moisture	Site characteristics
Moist Habitat (MH)	Budi	7.5%	3005	65.7	Slopes that are shaded and mostly covered with herbaceous plants, moderate slope, a fair amount of moisture, and an open canopy of blue pine and silver fir trees.
Gentle Slope Habitat (GSH)	Challekh 01	10.2%	3155	56.3	Gentle, slopes are undulating landscape. Exposed and dominated by a variety of herbaceous species.
Dry Rocky Habitat (DRH)	Challekh 02	33%	3267	23.7	Dry mountain slopes are well-exposed but generally less solid, with many small loose rocks and dominated by sparsely growing <i>Juniperous communis</i> with few patches of grasses on and around it.
Stream Banks Habitat (SBH)	Champhunala	13.4%	3378	78.6	A seasonal stream flows through this narrow, shaded mountain ravine and several small rocky outcrops along the sides.
Open Grassy Habitat (OGH)	Champhunala	44.3%	3428	53.8	Steep slopes with few small scattered boulders and dominated mainly by grasses herbaceous plants.
Upland Mountain Habitat (UMH)	Challekh 03	8.7%	3502	37.6	Elevated mountain tops an exposed, tableland with sporadic tiny rocks scattered throughout. It contains a flat vegetation mat and dominated by <i>potentilla argyrophylla</i> , <i>bistorta affinis</i> , <i>Sibbaldia parviflora</i> , <i>Primula denticulata</i> , <i>Geranium wallichianum</i> , and <i>Trachydium roylei</i> .

Statistical analysis: The statistical data were analysed, using MS Excel 2019, IBM-SPSS 16.0 version

Table 2. Biomass, and carbon stock in different habitats

Parameters	OGH	GSH	SBH	MH	UMH	DRH	F	P value
No. of species	30	24	35	33	32	22	6.8	0.003
AGB (g/m ²)	87.2	64.1	80	89.16	79.18	70.75	41.2	0.00
BGB (g/m ²)	86.9	89.23	97.55	94.23	85.81	78.94	0.99	NS
TB (g/m ²)	174.1	153.3	178.3	183.4	165	149.7	3.94	0.02
AGC (g/m ²)	41.41	30.46	38.3	42.35	37.6	33.6	41.1	0.00
BGC (g/m ²)	41.27	42.38	46.3	44.7	40.7	37.4	0.99	NS
TC (g/m ²)	82.69	72.84	84.7	87.11	78.3	71.1	3.9	0.02

AGB; Above ground biomass, BGB; Belowground biomass, TB; Total biomass, AGC; Above ground carbon, BGC; Belowground carbon, TC; Total carbon

across the habitat and support the findings of earlier studies (Padalia et al., 2019, Aziz et al., 2019, Wan et al., 2024). The Aboveground biomass ranged between 70.75 - 89.16 g/m² in present study, maximum in Moist Habitat (89.16 g/m²) followed by Open Grassy Habitat (87.2 g/m²), and minimum in Gentle Slope Habitat (70.75 g/m²). The belowground biomass ranged between 78.94 - 97.55 g/m² in present study, maximum in Strem Bank Habitat (97.55 g/m²) followed by Moist Habitat (94.23 g/m²), and minimum in Dry Rocky Habitat (78.94 g/m²). The total biomass ranged between 149.7 - 183.4 g/m² in present study, maximum in Moist Habitat (183.4 g/m²) followed by Strem Bank Habitat (178.3 g/m²) and minimum in Dry Rocky Habitat (149.7 g/m²) (Table 2). The ANOVA indicates that the species richness (F = 6.8, P < 0.005), Aboveground biomass (g/m²) (F = 41.2, P = < 0.0001), Total biomass (F = 3.94, P = < 0.05) showed significant variation among habitats (Table 2). The LSD test revealed that biomass in Moist Habitat was significantly higher than in Gentle Slope Habitat, Open Grassy Habitat, Stream Bank Habitat, Dry Rocky Habitat, and Upland Mountain Habitat. A similar trend of carbon stock was also observed in each habitat (Table 2). Wan et al. (2024) reported

70.1 - 122.8 g/m² aboveground biomass and 666.3 - 1385.4 g/m² for belowground biomass. The total biomass was 745.2 - 1493.5 g/m² in Tibetan Plateau. Similarly, Aziz et al., (2019) reported 1.03 – 92.12 t/ha aboveground biomass, and 0.2 – 18.42 t/ha belowground biomass. The total biomass 1.23 – 110.6 t/ha in Kashmir western Himalaya.

The alpine zone of the Himalaya experiences a short growing season (May to September), and many plant species are completed their growth cycle within three to five months. Consequently, peak community biomass tends to be lower than peak species biomass, as different species reached their peak biomass in different periods of growing season (Wan et al., 2024). The availability of abundant sunlight and moisture throughout the growing season makes it possible to grow and survive greater number of species in the Stream Bank Habitat and Moist Habitat. Thus, the habitats will be one of the important aspects to regulate the community structure and composition. The Himalayan alpine vegetation formed a mosaic in different ecological and topographical conditions. The moisture is never a limiting factor for the growth and development of plant species. The relationship between soil moisture and aboveground

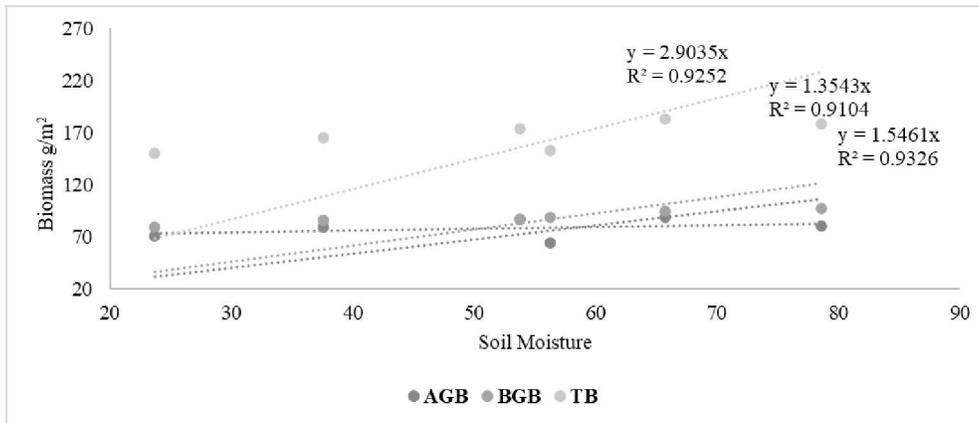


Fig. 3. Relation between soil moisture and biomass

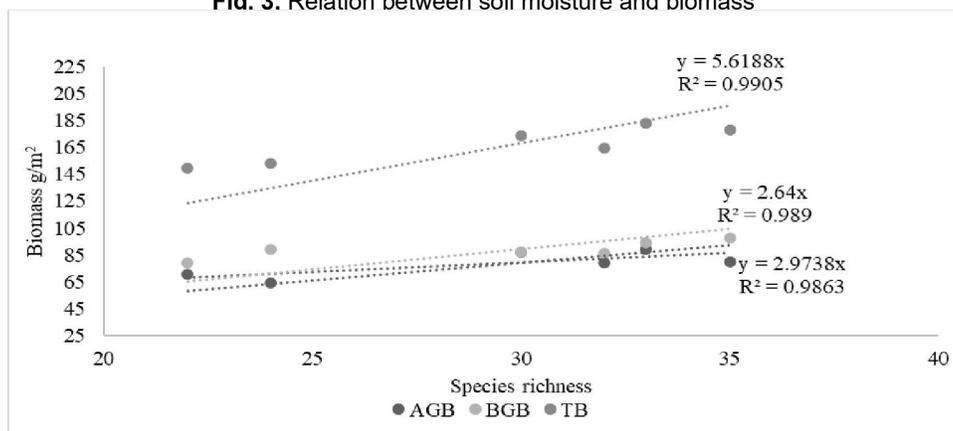


Fig. 4. Relation between species richness and biomass

biomass, belowground biomass and total biomass showed positive relationship (Fig. 3).

Among all the studied habitats, Moist Habitat exhibited the highest belowground biomass, may be due to more consistent soil moisture, deeper rooting zones, and prolonged growing seasons compared to drier sites. The saturated conditions in Moist Habitat supports a dense growth of graminoids and forbs, which are efficient in biomass accumulation under favourable moisture regimes. This result aligns with previous studies in alpine and subalpine systems which report higher productivity in hydrologically stable sites (Zhang et al., 2022). The species richness, and biomass were low as compare to other studies reported for similar vegetation type (Padalia et al., 2019, Wan et al., 2024) because this can be attributed to a combination of ecological constraints such as steeper slopes, shallow or poorly developed soil, and potentially less favourable microclimatic conditions. The dominance of unpalatable species such as *Anaphilis*, *Primula*, *Rumex*, *Iris* and *Potentilla* indicates the presence of high grazing pressure in this area. These factors significantly limit plant growth, leading to lower aboveground and belowground biomass, species richness, and carbon stock values. Moreover, anthropogenic pressures such as grazing, tourism may further stress these fragile alpine ecosystems, inhibiting vegetation development and biomass accumulation. Despite these limitations, the study area still supports considerable species richness and diversity, indicating the ecological resilience of alpine plant communities under harsh environmental conditions. The relationship between species richness and aboveground biomass, belowground biomass and total biomass showed strong positive relationship (Fig. 4).

CONCLUSION

To conclude this study indicated that aboveground biomass and total biomass varied significantly along the habitat. The belowground biomass was comparatively high in all habitats except Open Grassy Habitat. This may be due to the growth ceased earlier for aboveground vegetation and food material translocated too belowground. The belowground biomass was not significantly varied among the habitats, because the moisture and other factor regulate the belowground biomass. Thus, the variations in habitat conditions govern the accumulation of above and belowground biomass. Therefore, the conservation of habitats will be important for the species diversity as well as for biomass and production of these alpine meadows.

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