INNOVARE JOURNAL OF LIFE SCIENCE

Vol 6, Issue 1, 2018 ISSN - 2321-550X

Review Article

ECOLOGICAL STUDY OF AN IMPORTANT MEDICINAL PLANT OF KASHMIR VALLEY, *CAPSELLA BURSA-PASTORIS*

QURATUL-AIN[1]*, WASEEM MUSHTAQ[1], SIDDIQUI MB[1], SHAMEEM SA[2]

[1]Department of Botany, Allelopathy Laboratory, Aligarh Muslim University, Aligarh - 202 002, Uttar Pradesh, India. [2]SKUAST-K Campus, Shalimar, Srinagar - 190 025, Jammu and Kashmir, India. Email: quratpandith76@gmail.com

Received: 21 July 2018, Revised and Accepted: 24 August 2018

ABSTRACT

The vegetation of a geographical landscape relies heavily on the local environment. Altitude is a major factor in shaping the phytodiversity and biomass. The biomass study is essential for estimating the productivity of natural ecosystems. The demand for medicinal plants has been increased and it has become a trend to utilize forests and its products according to their productivities. The present study was aimed to investigate the attitudinal and other ecological variations in biomass of an important medicinal plant of Kashmir, *Capsella bursa-pastoris.* The method, we used to estimate the biomass of selected medicinal plant at different ecological sites, was the harvest method. We compared the biomass (fresh and dry matter) of two protected sites having altitudinal and other ecological variations. The maximum biomass was recorded at the Site I with lower altitude and the minimum value was recorded at Site II with higher altitude. The minimum above ground biomass was recorded at Site II. However, at Bijbehara, biomass variation was observed at two different sites. Maximum biomass was found at the Site II (Dara Shikoh garden Bijbehara). The below-ground biomass showed a considerable increase on decreasing altitude. Roots react instantly to better soil moisture conditions. The maximum biomass in underground parts at the Site I may be because of translocation of the main materials from the above-ground parts to the below-ground parts as the above-ground biomass was greater at same altitude. The minimum biomass at higher altitude and the ecologically disturbed site may be because of unfavorable microclimatic conditions and degradation of medicinal plants by grazing activity, respectively.

Keywords: Altitudinal variation, Biomass, Medicinal plant, Phytodiversity.

INTRODUCTION

Himalayan region is famous for its rich biodiversity and has always been a botanist's pride. It's diversified landforms, topography and environmental conditions sustain many forest types. Vegetation within the forest types is greatly affected by differences in the microclimate, slope aspect, and altitude [1]. Microclimate is the climatic conditions measured in localized areas near the earth's surface [2]. These include the abiotic environmental components such as temperature, light, wind speed, and moisture. Shirley [3] in seminal studies, emphasized microclimate as a determinant of ecological patterns in both flora and fauna communities and is the driver of such phenomena as growth and death rates of organisms. The importance of microclimate is in affecting ecological processes such as plant growth and regeneration, biomass, nutrient cycling, and soil respiration.

Altitude is one of the major factors in shaping the phytodiversity, because it powerfully affects the seasonal length associated with temperature, particularly in the temperate regions, and the availability of soil moisture and nutrients [4]. There is limited information from the high altitude regions which in fact are ideal for studying biodiversity patterns along altitudinal gradients as the environmental conditions in these systems can change within short distances [5]. Moreover, it is critical to examine the relationship at different spatial scales, as different geophysical factors can become essential at different spatial scales.

Ecologically each species assumes importance and possess its definite relationship with its abiotic and biotic surroundings. There is a specific effect of anthropogenic activities on the growth and biomass of medicinal plants of the Himalayan region especially Kashmir which was taken for the detailed study. Phenological events are influenced by climatic variables such as atmosphere, wind, humidity, temperature, soil temperature, precipitation, sunlight, and snow cover and topographical factors such as altitude, slope, *and* exposure. Biomass difference in medicinal plant, Capsella burs-pastoris has *been observed* because of some varied environmental conditions and anthropogenic activities such as grazing and physical stress. Each species, in addition of bearing its ecological amplitude, possesses its specific relationship with its biotic and abiotic environment. Community structure, forest composition, *and* diversity patterns are important ecological attributes that significantly correlates with prevailing environmental and anthropogenic variables as well.

Grasslands signify the most diverse and largest land resources in the world. High altitude grasslands are habitat to a sole collection of plants and animals [6]. It is a storehouse of medicinal plants and supplier of ecosystem resources and service to local people. It is also a home of world's most threatened and endemic species. Livestock grazing is one of the major distressing agents in grassland ecosystems. Almost half of the world's land surface is grazed. Its environmental and ecological impacts have been recognized such as effects on plant biodiversity, productivity, and species richness [7-9]. Grazing can affect plant species richness and grassland biodiversity [10-14]. These effects can be negative or positive depending on grazing intensities and ecosystem properties.

Biomass depicts the ecosystem competence during a definite time span in accumulating organic matter, *so* it *is regarded* as the depiction of an ecosystem. At the landscape level, the composition of vegetation in a microclimate is influenced by various abiotic and biotic factors. Among the biotic factors, livestock grazing *is* having a severe effect that influences the flora at a local scale. Even though many plants are not resilient to grazing, there are numerous reports of plant species which respond to herbivory with improved growth in contrast with that of un-grazed plants. On the other hand, as grazing intensity increases, losses of biomass will reach the levels that can never be maintained by productivity and re-growth, leading to a decline in biodiversity of the region. In this study, an attempt was made for estimation of the altitudinal drift in biomass of C. bursa-pastoris from protected and grazing sites in Kashmir valley.

We believe variations in vegetation biomass in response to climatic factors from three aspects: Changes in the allocation ratio of above- and below-ground biomass, changes in an allocation ratio of above-ground organs (stem, branches, leaves, and reproductive tissue) and dominant species, and changes of below-ground biomass allocation in different soil layers. A very few studies have *been involved* in the *thorough* assessment of changes of biomass allocation along sequences of *climate associated* variables or vegetation types, most have *concerned* forest, *and* a very few have concerned grasslands [15], and most have not integrated at one time all the aspects of biomass. As examples, Schulze *et al*. [16] studied the change of root density and root biomass with soil depth and distribution of above- and below-ground biomass in relation *to* an aridity gradient.

For the present study, the medicinal plant, C. bursa-pastoris has been taken for the detailed study for the investigation and ecological variations were assessed to study the influence of altitude and grazing pressure on biomass and morpho-physical characters of the selected plant. The objective of the present investigation has been to evaluate the biomass and morpho-physical characters of C. burs-pastoris at three different ecological sites (at Bijbehara Anantnag and SKUAST-K campus Shalimar) of Kashmir valley.

Many of the plants have *been traditionally used* as medicines for centuries such as *Aconitum heterophyllum, Adiantum capillus, Allium victoratis, Urtica dioica, C. bursa-pastoris, Datura stramonium, Taraxacum Officinale*, and *Plantago* major. These species are confined to many altitudinal sites of Kashmir valley and have got many physiological variations, variations in biomass due to altitude, and other related ecological variations. Not much work related to the ecological variations in some medicinal plants had been so for carried out with particular reference to the study area. In this way, a preliminary investigation has been carried out at different selected sites in the Kashmir valley. The present study *was carried* at three different localities of Kashmir valley. The selected sites for the present study *are elaborated* as under.

Site I (protected) SKUAST-K campus

The site is located in the northeast of Dal lake about 16 km away from the main city Srinagar, the summer capital of Jammu and Kashmir. It lies at an elevation of 1585 m with latitudinal and longitudinal extensions of 34° 5'N and 74° 47'E. The soil is protected, and sampling was done while surveying the whole campus and at different selected locations. The campus is completely fenced and devoid of any grazing activity.

Site II (Protected) dara shikoh garden bijbehara

The town of Bijbehera of district Anantnag is located in the north of district headquarters on the banks of river Jhelum, commonly known as "Veth." The major portion of the area is under agriculture as irrigation facilities are available from the river Jehlum. The site is about 50 km away from the main city of Srinagar. It lies at an elevation of 1591 m (5223ft) with latitudinal and longitudinal extensions of 33° 48` N and 75° 06`E/33.80° N and 75.10° E. The town is crammed with Chinar trees (*Platanus orientalis. L*), and hence it is also called "the Town of Chinars." The Chinar trees were imported from Iran by the Mughal Emperors. The selection of this site was based on its importance of medicinal plants under protected conditions in comparison to the other site (grazing site). The study area (Site II) is completely fenced and is being protected from any disturbance from the past few years. The site is a sun-drenched open place and is well drained and plane.

Site III (grazing field), an open field of bijbehara

The site is also 50 km away from the main city of Srinagar, the summer capital of Jammu and Kashmir. Human habitations and agricultural fields are near to the site and are under stress from both anthropogenic as well as livestock grazing. Microclimates and topographic features make the site favorable for the growth of plants mainly medicinal.

DESCRIPTION OF SELECTED PLANT

C. bursa-pastoris

Vernacular name	Kraal Mounj
Common name	Shepherd's purse
Family	Cruciferae

C. bursa-pastoris of family Cruciferae grows from a rosette of lobed leaves at the base. The stem emerges from the base, which is about 0.2–0.5 m tall and bears a few pointed leaves that partly grasp the stem. The flowers are in loose racemes and are small and white producing heart-shaped seed pods.

Habitat of the herb: Distribution

It is a common weed of cultivated soil and is mainly found in grasslands, gardens, waste places, etc.

Edible parts of Shepherd's purse

Leaves-raw or cooked: The young leaves make a fine addition to salads before the plant comes to the flowering stage. The leaves are used as a substitute to cress and cabbages and become peppery with age. These contain about 2.9% protein, 0.2% fat, 3.4% carbohydrate, and 1% ash. The leaves are rich in essential nutrients such as iron, calcium, and vitamin C. The juvenile blossoming shoots can be eaten uncooked or cooked. They are somewhat thin and fussy, but the taste is somewhat satisfactory. They can be accessible nearly all times of the year.

Seeds raw or cooked: These can be grinded into a powdery form and used as a meal and in soups, etc. It is very difficult to collect and utilize the seeds, as the seeds are very small. The seeds contain 35% of fat.

Medicinal use of Shepherd's purse

Shepherd's purse is commonly used as a domestic remedy, being mainly effective in the treatment of internal as well as external bleeding, diarrhea, etc. An extract obtained from boiling of the whole plant in the water, is antiscorbutic, astringent, diuretic, hemostatic, hypotensive, oxytocic, stimulant, vasoconstrictor, vasodilator, and vulnerary. A tea prepared from the dehydrated herb is well thought - out to be a supreme medication against all kinds of hemorrhages - the stomach, lungs, uterus, and particularly kidney. Medical trials on the usefulness of this plant as a wound herb have been uncertain. It seems that either it varies significantly in its efficiency from batch to batch, or possibly a white fungus that is often found on the plant contains the medically dynamic properties. The plant has been ranked 7th among 250 potential anti-fertility plants in China. It has verified uterine-contracting properties and is by tradition used during childbirth. The plant is a good remedy for cancer - it contains fumaric acid which has noticeably reduced development and feasibility of Ehrlich tumor in mice. A homeopathic preparation made from the fresh plant is used in the healing of nose bleeding and urinary calculus.

MATERIALS AND METHODS

Biomass estimation and sampling

After months of acclimatization of plants during January–June, randomly selected plants of *C. bursa-pastoris* were uprooted from each of the experimental sites. The harvest method was used for the estimation the biomass of the chosen medicinal plant. The biomass (above ground biomass) was calculated by collecting the plants from the quadrats of 1 m × 1 m size. The pits of size 25 cm × 25 cm × 30 cm were dug out in the quadrat area for the estimation of underground biomass. The uprooted plants were washed carefully in tap water followed by distilled water to remove any dirt and blotted off moisture with the help of blotting paper. The plants were separated into roots and shoots. Then, all the divided components were cleaned, and the fresh matter weight of the collected plants was instantly calculated at the field by a portable electronic balance. The samples were kept in labeled and sealed polythene bags and taken to the laboratory and oven dried at 80°C for 48 h. Then, the samples were weighed, and the oven dry weight was estimated and presented as the dry matter (DM) present in the sample.

Data analysis

The growth parameters were calculated on the basis of formulae described by Evans (1972). Absolute leaf water content (ALWC) was calculated with the help of formulae given by Hughes *et al.* (1970). The detailed formulations are given below.

Calculations

$$\text{Leaf weight ratio } (\text{LWR})\ g-1 = \frac{\text{Leaf dry weight}}{\text{whole plant dry weight}}$$

$$\text{Root shoot ratio } (\text{R.S ratio})\ g-1 = \frac{\text{Root dry weight}}{\text{Shoot dry weight}}$$

Absolute leaf water content (ALWC) g=Fresh weight - dry weight

$$\text{Specific leaf water content } (\text{SLWC})\ g-1 = \frac{\text{Leaf water content}}{\text{Leaf dry weight}}$$

$$\text{Percent dry matter content } (\text{PDMC}) = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

MEASUREMENT OF GROWTH PARAMETERS

Since this investigation was aimed at finding out the extent of stability and flexibility in character during acclimatization or adaptation of the species under two different altitudes, it was considered essential to have an idea of the general behavior of species in its natural habitat. Hence, the plants were experimented at 1585 m in its natural habitat as well as at 1591 m altitude. Plant samples were randomly uprooted at two selected sites (Site I and Site II). The uprooted plants were washed carefully in tap water followed by distilled water to remove any dirt and blotted off moisture with the help of blotting paper. Then, some morphological characters were recorded.

RESULTS

Results obtained throughout the study period for altitudinal variation in biomass estimates of the selected plant are given in Tables 1-4. At first, we compared the biomass of two protected sites (Site I and Site II) having altitudinal variation and other ecological variations.

The ecological difference (difference in morpho-physical characters and biomass) was revealed in case of *C. bursa-pastoris* in the same altitude of 1591 m but at different sites (Site II-protected and Site III-grazing site) at Bijbehara. The general differences are described in Table 2.

The maximum biomass, fresh weight (142.7 g/m^2) was found in the Site II, and minimum fresh weight (101.7 g/m^2) was found in Site III, where grazing activities are allowed. It was recorded that the maximum dry weight (22.9 g/m^2) of plant samples at the Site II and minimum dry weight (16.3 g/m^2) at the Site III.

Since this investigation was also aimed at finding out the extent of stability and flexibility in character during acclimatization or adaptation of the species under different altitudes; it was considered essential to have an idea of the general behavior of species in its natural habitat. Hence, the plants were experimented at 1585 m (Site I) in its natural habitat as well as comparatively higher altitudes 1591 m (Site II). Morpho-physical parameters of plant species *C. bursa-pastoris* were recorded at two different altitudes, and after the

Table 1: Altitudinal variations in biomass of *C. bursa-pastoris*

Sites	FM (g/m^2)		Total fresh weight	DM (g/m^2)		Total DM
Site I (1585 m)	Root	Shoot		Root	Shoot	
	13.0	126	139	4.67	29.4	34.07
Site II (1591 m)	33.3	109.4	142.7	4.2	18.7	22.9

C. bursa-pastoris: Capsella bursa-pastoris, DM: Dry matter, FM: Fresh matter

Table 2: Biomass variation in *C. bursa-pastoris* at different sites of same altitude

Sites (AT 1591 altitude) bijbehara	FM (g/m^2)			DM (g/m^2)		
	Root	Shoot	Total	Root	Shoot	Total
Site II (protected)	33.3	109.4	142.7	4.2	18.7	22.9
Site III (open)	26.4	75.3	101.7	4.5	11.8	16.3

C. bursa-pastoris: Capsella bursa-pastoris, DM: Dry matter, FM: Fresh matter

Table 3: The morpho-physical variations in *C. bursa-pastoris*

Sites	Plant height (cm)	Root length (cm)	Number of leaves	LL (cm)	LW (cm)	Petiole lenth (cm)
Site I (1585 m)	9.00	3.50	25	6.00	1.50	3.00
Site II (1591 m)	10.00	10.00	19	9.00	1.50	4.00
Site III (1591 m)	5.00	11.00	24	6.00	1.00	4.00

C. bursa-pastoris: Capsella bursa-pastoris, LW: Leaf width, LL: Leaf length

Table 4: Growth analysis of *C. bursa-pastoris* at different sites

Sites	LWR (g)	R/S ratio (g)	Percent DM (%)	Absolute leaf water content (g)	SLWC (g)
Site I (1585 m)	0.86	0.15	24.46	96.60	3.28
Site II (1591 m)	0.81	0.22	16.00	90.70	4.85
Site III (1591 m)	0.72	0.38	16.06	63.46	5.35

C. bursa-pastoris: Capsella bursa-pastoris, DM: Dry matter, LWR: Leaf width ratio, R/S: Root shoot, SLWC: Specific leaf water content

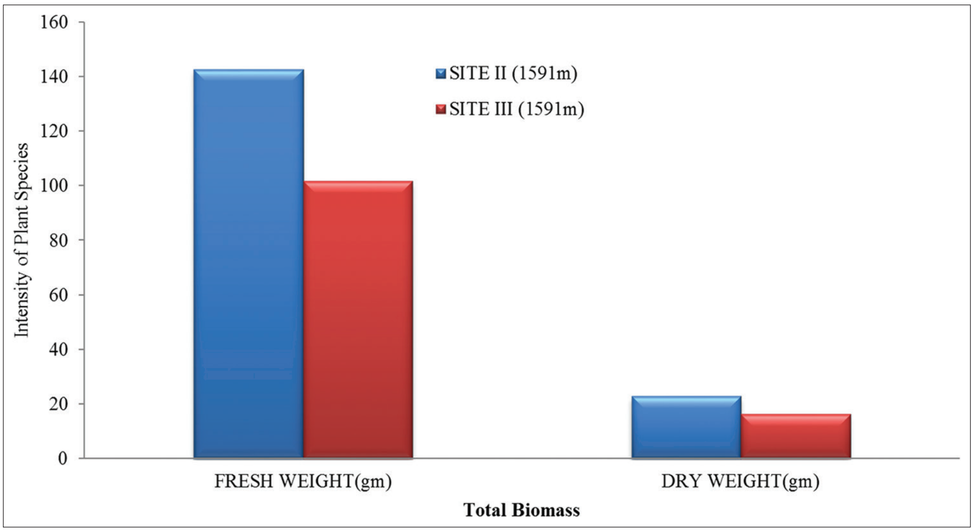

Figure 1: Altitudinal variation in *Capsella bursa-pastoris*

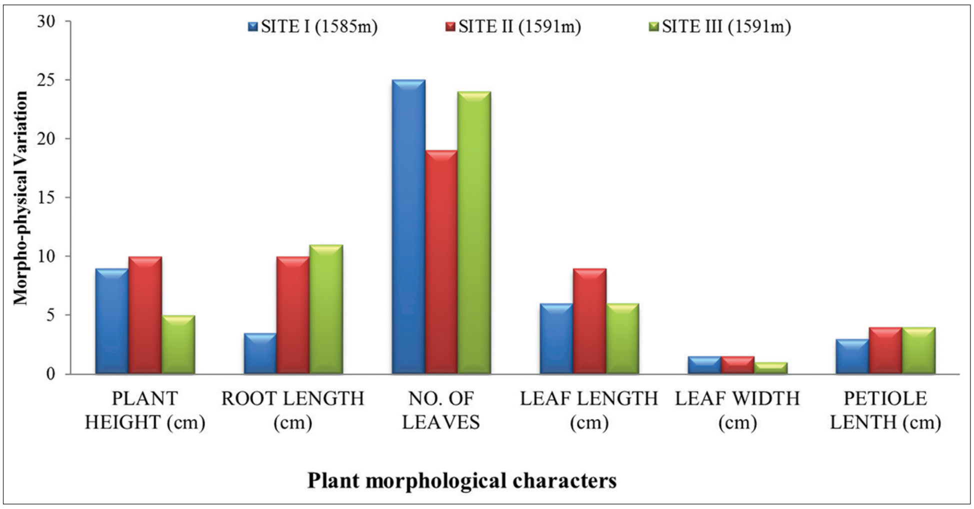

Figure 2: Histogram showing morphophysical variation of different plant parts of *Capsella bursa-pastoris*

months of acclimatization of plants at all the experimental sites, some morphological and biomass attributes were studied. The general trends are depicted in Tables 1-4 and are described as under:

GROWTH ANALYSIS

Variations in morphological characters of plant samples are summarized in Tables 1-4.

Plant height: Plant height was recorded maximum (10.00 cm) at Site II (1591 m) and minimum (9.00 cm) at Site I (1585 m).

Root length: Root length was recorded maximum (10.0cm) and minimum (3.50 cm) at Site II and Site I, respectively.

Leaf number: Number of leaves was highest (25.00) at Site I and lowest (19.00) at Site II.

Leaf length (LL): And leaf width (LW): LL was maximum (9.00 cm) at Site II and minimum (6.00 cm) at Site I, and LW found same (1.50 cm) at both the selected.

Petiole length: The petiole length was recorded maximum at Site I (1585 m) and minimum at Site II (1591 m).

Leaf weight ratio (LWR): The LWR was recorded maximum at Site I and minimum LWR was recorded at Site II.

Root-shoot ratio (R/S): R/S Ratio was recorded maximum at Site II and minimum at Site I.

Percent DM (%): The percent DM shown in Tables 1-4 indicated that percent DM was maximum at Site I and minimum at Site II.

ALWC and specific leaf water content (SLWC): ALWC was recorded maximum at Site I and minimum at Site II, while SLWC was recorded maximum at Site II and minimum at Site I.

Histograms showing variations

DISCUSSION

Biomass is the dry weight of organic matter, including preserved food present in a species population and presented in terms of a given area or volume of the habitat. It is the mass of living organisms in a given area or ecosystem at a given time. Biomass of any area is affected by a number of factors such as community structure, species composition, slope, soil type, precipitation, altitude, road construction, biotic interference, grazing activities, and population density. Temperature

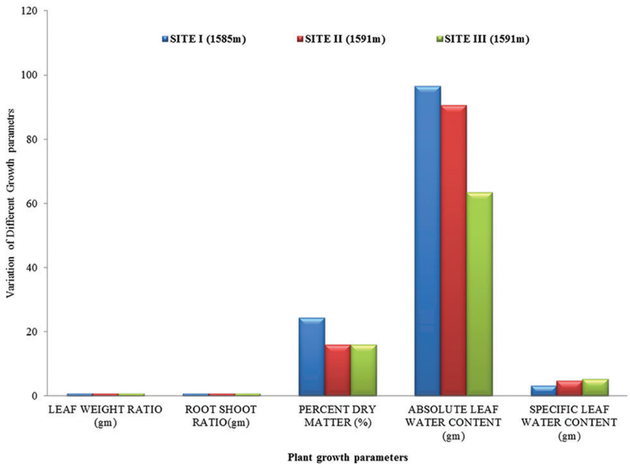

Figure 3: Histogram showing variation of different growth parameters of *Capsella bursa pastoris*

and rainfall are the major factors which affect the biomass of any area. It is governed by climatic and soil characteristics to which phenology and floristic diversity are strongly related. The existence of a species in a particular habitat depends on its ecological adaptations as well as on the related species and the abiotic environment. Inside a given biotic community, many plant species are taken as forage by herbivores, while others are avoided by the same. In the current study, the *C. bursa-pastoris* was selected for the study of ecological variations in Kashmir valley.

The maximum biomass was recorded at the Site I. This could be due to less biotic intervention, favorable environmental conditions, and low altitude. Both above- and below-ground biomass depicted substantial variations. The minimum above-ground biomass was recorded at Site II. However, at Bijbhera, biomass variation was observed at two different sites. Maximum biomass was found at the Site II (DaraShikoh garden Bijbehara) which is a protected site. This may be due to less grazing pressure and less biotic interference, and minimum biomass was found in the Site III (open field) where grazing activities were frequently allowed. The below-ground biomass showed a considerable increase in decreasing altitude. Roots react instantly to superior soil moisture conditions, and hence the biomass values are greater for roots at altitude 1585 m where the soil moisture was favorable. One more reason for the maximum biomass of underground parts at Site I possibly will be due to translocation of the primary materials from the above-ground parts to the underground parts as the above ground biomass was greater at the same altitude. Hence, result in an increase in root biomass of the plant species.

Livestock disturbances led to variations in biomass across a fine scale. The example pertaining to the current study was reported at the grazing site (degraded site). By continuous grazing the majority of leaves of the different species were grazed by the grazing animals, consequently, the overall above-ground biomass decreased. Likewise, at the same time as comparing standing total and green biomass on the grazed and non-grazed site, the biomass at both sites varied considerably due to livestock grazing. Combined with the human disturbance, the livestock grazing in the area leads to the decrease in biomass in the study area.

Altitudinal variations in growth parameters were noticed during acclimatization under two selected altitudes. Remarkable altitudinal variation was observed in morphological parameters, namely plant height, LW, *LL* and, petiole length in *C. bursa-pastoris.* At Site I, the highest range of these parameters showed a direct and adaptive response to the climate associated with changing altitude. Reduced growth noticed at Site II must be due to the stressful climatic conditions which showed incompatibility of the species in respect of commercial cultivation at this altitude. Stressful factors are known to influence growth and development of plant species, but only limited information is available regarding the behavior of plants to these factors under natural conditions. Environmental factors affect plant growth through their effects on assimilatory apparatus, and the resulting effect is expressed in the magnitude of changes in the relative growth rate.

The other attributes, which control the growth behavior of plants along an altitudinal gradient are *R*/S ratio and LWR. The LWR in C. bursa-pastoris decreases with increasing altitude indicate advanced growth of underground parts due to faster translocation toward it which is a characteristic of high altitude species to overcome the effect of stresses, especially in the winter season when the area was covered with snow. The overall studies revealed that altitudinal variation differentially influenced morphological and growth responses of C. bursa-pastoris. Altitudinal variations in growth performance of *the species indicate their* adaptive potential and suitability of climatic and environmental conditions *at* a *lower* altitude of Site I (Shalimar, 1585 *m*) in comparison to the higher altitude of Site II (Bijbehara Anantnag 1591 *m*). Conclusions also support the fact that the plants will change their morphology and physiology with changing environmental conditions.

CONCLUSION

The variation in biomass is controlled by the altitude and grazing pressure during the growing season. *This study reflects that overgrazing, overexploitation and soil erosion were strongly suffering the range, which must be cared for*. It is obvious from the results that on the whole, ecological studies of the selected medicinal plant (C. bursa-pastoris) in three different localities vary significantly. *Except* Site III, other two sites are completely fenced and *does not* reveal disturbances due to anthropogenic disturbances and grazing. The investigation on ecological studies reflects that the maximum yield of medicinal plants can *be harvested* in the areas of lower altitude. Moreover, there is an immediate need for conservation and management followed by regular monitoring because of the degradation of ground flora due to anthropogenic and animal activities. To protect degraded environment and fragile ground flora ecosystem, it may be suggested that the intense grazing activities should *be* stopped in the areas where the medicinal plants prevail and the practice of gardening, agroforestry or social forestry by local people could result in the sustainable production of medicinal plants.

REFERENCES

1. Pande *et al*. Plant species diversity and vegetation analysis in temperate Himalyan forest. New Delhi: First Indian Ecological Congress; 1996. p. 51.
2. Geiger R. The Climate Near the Ground. Cambridge: Harvard University Press; 1965.
3. Shirley HL. The influence of light intensity and light quality upon the growth and survival of plants. Am J Bot 929;16:354-39.
4. Soethe N, Lehmann J, Engels C. Nutrient availability at different altitudes in a tropical montane forest in Ecuador. J Trop Ecol 2008;24:397-406.
5. Dufour A, Gadallah F, Wagner HH, Guisan A, Buttler A. Plant species richness and environmental heterogeneity in a mountain landscape: Effects of variability and spatial configuration. Ecography 2006;29:573-84.
6. Yonzon PB, Heinen JT, editors. Nepal's biodiversity and protected areas. Kathmandu: The 1997 Protected Areas Management Workshop of the National Biodiversity Action Plan; 1997.
7. Milchunas DG, Sala OE, Lauenroth WK. A generalized-model of effects of grazing by large herbivores on grassland community structure. Am Nat 1988;132:87-106.
8. Fleischner TL. Ecological costs of livestock grazing in western north-America. Conser Biol 1994;8:629-44.
9. Jones A. Effects of cattle grazing on North American arid ecosystems: A quantative review. Western N Am Nat 2000;60:155-64.
10. White JG, Cosgrove GP. Lucerne grazing management 2. Effect of grazing duration on defoliation pattern by ewes. N Z J Agric Res 1990;33 621-5.

11. O'Connor TG. Composition and population responses of an African savanna grassland to rainfall and grazing. J Appl Ecol 1994;31:155-71.
12. Kazmaier RT, Hellgren EC, Ruthven DC, Synatzske DR. Effects of grazing on the demography and growth of the Texas tortoise. Conser Biol 2001;15:1091-101.
13. Critchley CN, Burke MJ, Stevens DP. Conservation of lowland semi-natural grasslands in the UK: A review of botanical monitoring results from agri-environment schemes. Biol Conser 2004;115:263-78.
14. Gillen RL, Sims PL. Stocking rate, precipitation, and herbage production on sand sagebrush-grassland. J Range Manage 2004;57:148-52.
15. Mokany K, Raison RJ, Prokushkin AS. Critical analysis of root: Shoot ratios in terrestrial biomes. Global Change Biol 2006;12:84-96.
16. Schulze ED, Mooney HA, Sala OE, Jobbagy E, Buchman N, Bauer G, *et al*. Rooting depth, water availability, and vegetation cover along an aridity gradient in Patagonia. Oecologia 1996;108:503-11.