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BIOMASS AND SOIL CARBON STOCKS ASSESSMENT IN WESTERN HIMALAYAN ALPINE AND SUBALPINE VEGETATION ZONES OF KASHMIR

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Abstract

United Nations Framework Convention on Climate Change (UNFCCC) greatly emphasizes on the accurate estimation of carbon stocks at local and regional levels. The Western Himalayan alpine and subalpine highlands are a good choice to analyze carbon sequestration dynamics because of having unique and fragile ecosystems. Present study was conducted in the alpine and subalpine regions of Kashmir to estimate the biomass and soil carbon stocks. The carbon stocks in the trees, herbs and soil were estimated by using allometric equations, destructive sampling and Walkley-Black method respectively. The average carbon stocks in the alpine region were estimated to be 372.5 t/ha with biomass carbon share of 2.27 tons per hectare while the soil organic carbon stocks share was recorded as 370.6 t/ha. The total carbon stock value of subalpine zone was found to be 340.9 t/ha with biomass carbon reserves as 81.1 t/ha whereas the soil organic carbon as 261 t/ha. Soil carbon contents showed an increasing trend with increasing altitude with alpine zone having higher values as compared to subalpine region. Whereas biomass carbon values showed a negative correlation with altitude with maximum values in sub alpine region as compared to minimum in alpines. Principal Component Analysis revealed altitude as the major factor affecting the carbon stocks. Current study provides the very 1st scientific information about carbon stocks of western Himalayan highlands with diverse future implications. Carbon sequestration potential was found to be negatively affected by fuel wood extraction, over grazing and soil degradation. Sustainable management of these alpine forest is recommended to enhance the carbon stocks as well as to conserve the floristic wealth of the area.

Key words: Carbon sequestration, Subalpine, Alpine, Biomass carbon, Soil organic carbon.

Introduction

Carbon sequestration is defined as the capture and long term storage of atmospheric carbon in different carbon sinks (Anon., 2005). Carbon sequestration involves both natural and developed methods which can either eliminate carbon dioxide from atmosphere or can store it in to different carbon sinks, like soil and vegetation by its diversion from emission sources (Anon., 2006). Carbon sequestration methodologies are among the prime preferences as mitigation options due to exponential increase in CO_2 concentrations in atmosphere and consequent climate change impacts (Canadell & Rapauch, 2008).

Forest ecosystem is considered as an important terrestrial carbon sink with 283 Gt of carbon sequestered in biomass (Hagedorn *et al*., 2002). It is estimated that forests can annually accumulate about 60 Gt of carbon during photosynthesis, growth and development (Schipper *et al*., 2007). Every single ton of carbon stored in tree biomass removes 3.67 tomes of CO2 from atmosphere (Hunt, 2009). Soils are another important carbon pool with the ability to store three times higher carbon as compared to vegetation and two times higher as compared to atmosphere (Sheikh *et al*., 2009). Soil ecosystem stores about 2500 Gt of carbons, out of which 1550 Gt is stored as organic carbon (Oelkers & Cole, 2008). Any alteration in the carbon stocks in the vegetation or soils has prominent impacts on carbon stocks in the atmosphere (Schuman *et al.,* 2001). The important natural variables affecting the Carbon stocks include altitude, temperature, topography and climate. Altitude is among the key environmental factors controlling the Carbon stocks of any carbon pool (Zhang *et al*., 2012).

United Nations frame work convention on Climate change (UNFCCC) has greatly emphasizes on the accurate estimation of carbon stocks at local and regional levels. The Himalayan region is a good choice to analyze the dynamics of carbon sequestration because of having many unique and special fragile ecosystems (Upadhyay *et al*., 2005). Himalayas are facing immense changes in carbon flux due to rapid forest loss and increased emissions (Ali *et al*., 2016). The studies for the quantification of carbon stocks in subtropics and temperate areas are available but due to remoteness of the alpines and harsh environmental conditions, very few studies have been conducted in the alpine ansd subalpine areas. Carbon stocks in subalpine and alpine vegetation types of western Himalayas have immense ecological significance, vital for the regional and global carbon reserves. The carbon storage capacity of western Himalayan highlands has not been quantified properly so far (Kurz & Apps, 1999). Keeping in view this information gap, current study was designed with the aim to estimate the biomass and soil carbon stocks in the alpine and sub alpine vegetation types of Azad Jammu and Kashmir. The objectives also included to investigate the environmental and anthropogenic variables affecting the dynamics of the carbon stocks in these fragile ecosystems.

Materials and Method

The study area lies in Pir-Panjal sub range of western Himalayan Mountains situated in sub alpine and alpine zones of the Shounther valley, Neelum District of Kashmir. The area is located at 34·57.14 North Latitude and 74 31.20 East longitude having an altitudinal range of 3200 to 4200m having high mountains and deep valleys (Fig. 1). The area represents high glaciated peaks and sub alpine and alpine grasslands experiencing long harsh winter season which starts from mid of November and ends at last of April with temperature below freezing point; whereas short summers from June to August with temperatures in 10-15°C (Pak-Met, 2014; Ishtiaq *et al*., 2013).

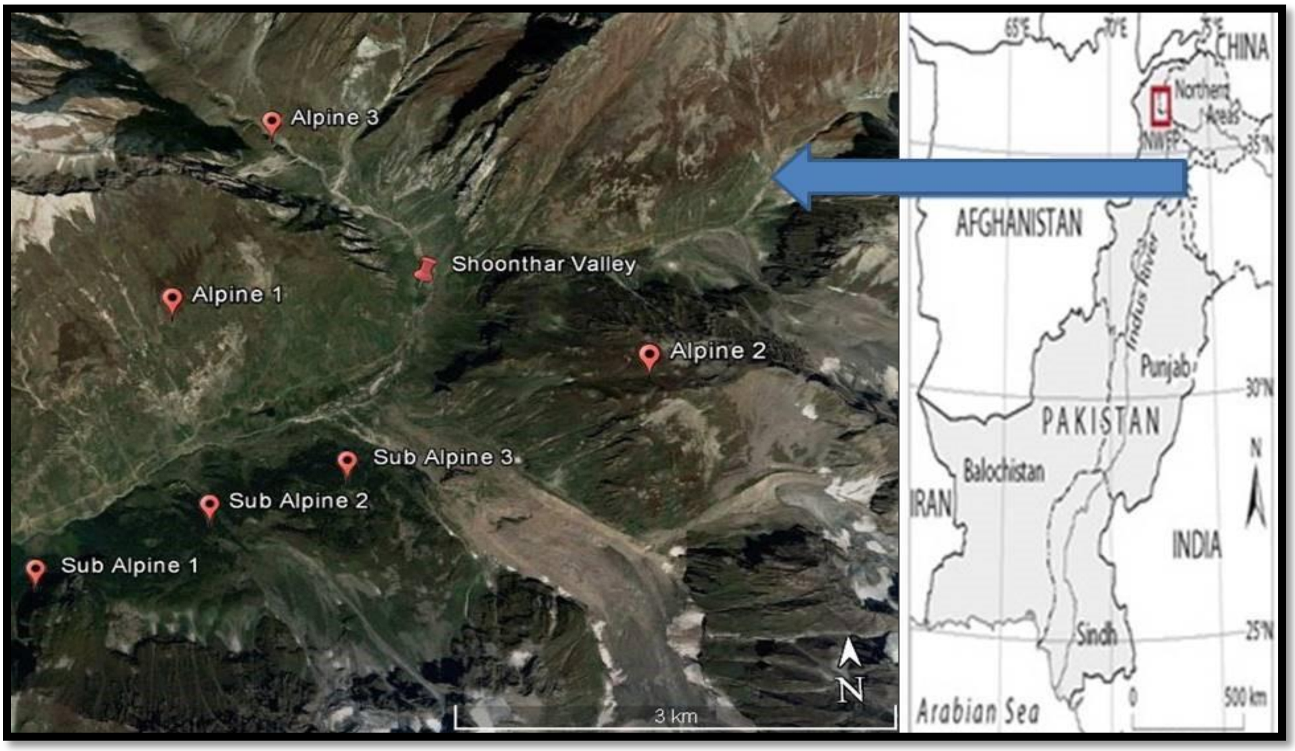

Fig. 1. Location of the study area and satellite imagery of the study sites in Himalayas.

Six sites including 3 sites in subalpine *Betula utilis* forest stands and 3 in alpine pastures were selected for the investigations of carbon stocks of the area. Geographical characteristics of the sites were recorded by using GPS. A total of 180 quadrates (30/site) were laid with a quadrate size of 10 m x 10 m for trees at subalpine forest sites whereas 1m x 1m for herbs. The vegetation parameters including Diameter of trees at breast height (DBH), Tree height, Density, frequency and Cover were recorded following standard protocols (Waran, 2001). Destructive method was used for the calculation of biomass of herbs in alpine zone as well as in sub alpine forest following MacDicken (1997). Above ground biomass of *Betulla utilis* was measured by using the following expression: Above ground biomass = d ×v where $V = \pi r^2 h$; r=D/2 and D= DBH (Nizami, 2010). The biomass stock of the plots sampled was converted to biomass carbon stock after multiplication with the default value of carbon fraction 0.5 (Anon., 2006). Below ground biomass (BGB) was calculated based on 1:5 for root-to-shoot value indicating that BGB was considered as 20% of AGTB (MacDicken 1997). Soil sampling was carried out at all the studied sites taking 5 samples from each quadrat up to the depth of 0- 15cm and 15-30cm, and then mixed to get a composite from each quadrat. These samples were then analyzed to determine the carbon concentration following Walkley-Black method (Allison *et al.*, 1965). Bulk density of the soil was obtained by following formula: Soil bulk density= Oven dried weight of soil ÷ Volume of cylinder (Nizami, 2010). Soil organic carbon stock inventory was expressed as Mg ha-1 as SOC (t/ha) = OC (g/kg) × bulk density (g/cm^3) × depth (cm) (Carlos *et al.*, 2001). The effect of anthropogenic disturbances was recorded at all the sites. Deforestation rate at Sub alpine *Betula* forest was recorded by counting the number of stumps/ha whereas grazing intensity was assessed by using visual indicators like browsed vegetation, trampling, droppings and hoof marks following Kapalanga (2008). The regeneration of *Betula* stands was recorded by counting seedlings/ha. Erosion intensity was categorized as low, moderate and severe based on observations. The data was statistically analyzed using Principal Component Analysis, which is an effective multivariate ordination technique (ter-Braak & Smilauer, 1988).

Results

The average carbon stocks determined for the study area was 356.73 t/ha. Highest carbon stock was recorded as 395.04 t/ha at the alpine site 3 at 3800m altitude whereas lowest was calculated as 326.86 t/ha at the subalpine site 3 at an altitude of 3400m. The alpine zone at higher elevation (>3400) revealed higher average carbon stock value of 372.6 t/ha as compared to 340.9 t/ha in relatively lower elevetional subalpine range (3000-3400m).

Sub-alpine carbon stock values: The subalpine zone was dominated by *Betula utilis* pure stands with herbaceous understory. Betula utilis was the only tree species recorded at the subalpine forest sites making pure stands. The average carbon stocks in the subalpine region were recorded to be 340.9 t/ha with the highest as 352.46 t/ha and lowest estimated as 326.86 t/ha. The average biomass carbon stocks were 81.1 t/ha with tree biomass carbon as 80.3 t/ha whereas herbaceous biomass carbon as 0.8 t/ha. Average above ground carbon stock value and below ground carbon stocks value were recorded to be 67.9 t/ha and 13.2 t/ha respectively. Highest carbon stocks were recorded at site 1 as 352.16 t/ha while the lowest were at site 3 estimated as 326.86 t/ha. The subalpine SOC were measured to be 260.9 t/ha (Table 2).

Table 1. Geographic characteristics, disturbances and regeneration recorded from the study sites.

Site	Altitude (m)	Grazing class	Erosion Class	Slope class	Regeneration (/hectare)	Stumps (/hectare)
Alpine site 1	3550	2	2	3	-	-
Alpine site 2	3650	3	2	2	-	-
Alpine site 3	3800	2	3	2	-	-
Sub alpine site 1	3050	1	2	3	77	101
Sub alpine site 2	3300	1	2	2	165	87
Sub alpine site 3	3400	2	3	3	211	96

(Grazing Intensity/ ErosionIntensity: High: Class 1, Moderate: Class 2, Low: Class 3 Slope Class: 0-30^0: 1, 31-60^0: 2, 61-90^0:3)

Table 2. Carbon stock Values (t/ha) recorded at different alpine and subalpine sites of the study area.

Sites	Altitude	AGC (Trees)	BGC (Trees)	Total carbon (Trees)	AGC (herbs)	BGC (herbs)	Total C (herbs)	AGB	BGB	TBC	SOC	Total C stock
Sub alpine site 1	3050	91.5	18.3	109.8	0.62	0.12	0.74	92.12	18.42	110.54	241.92	352.46
Sub alpine site 2	3300	66.2	12.24	78.44	0.7	0.14	0.84	66.9	12.38	79.28	268	343.28
Sub alpine site 3	3400	44	8.8	52.8	0.89	0.17	1.06	44.89	8.97	53.86	273	326.86
Average sub alpine region	3250	67.2	13.1	80.3	0.7	0.1	0.8	67.9	13.2	81.1	261	340.9
Alpine site 1	3550	0	0	0	2.12	0.42	2.54	2.12	0.42	2.54	341	343.54
Alpine site 2	3650	0	0	0	1.03	0.2	1.23	1.03	0.2	1.23	378	379.23
Alpine site 3	3800	0	0	0	2.54	0.5	3.04	2.54	0.5	3.04	392	395.04
Average alpine region	3666.7	0	0	0	1.89	0.38	2.27	1.89	0.38	2.27	370.3	372.6
Average total					0.36	0.07	0.43	33.97	6.63	40.6	315.65	356.73

Alpine carbon stock values: The alpine zone showed an average carbon stock value of 372.5 t/ha with the lowest of 343.5 t/ha whereas the highest vale was 395.04 t/ha. The biomass carbon stocks were estimated to be 2.27 t/ha with above ground biomass value of 1.89 t/ha and below ground biomass values of 0.38 t/ha. The alpine SOC was calculated as 370.3 t/ha (Table 2).

Anthropogenic disturbances: The alpine sites were characterized by high soil erosion along with the high grazing pressure. The subalpine sites showed relatively lower/moderate grazing and erosion intensity. The deforestation intensity in the subalpine *Betula utilis* stands was reflected by a stump density of 94/ha whereas the regeneration capacity was calculated to be 151/ha (Table 1).

Principal Component Analysis was applied on the primary data matrix to extract the significant correlations explaining >95% variance in the data. PCA biplot clearly separated the alpine and subalpine sites into distinguishable groups on X and Y axis respectively. Altitude was identified as the major factor affecting the carbon stocks showing a liner relationship with Carbon contents. PCA revealed close affinity of subalpine sites with biomass carbon values that may be attributed to the *Betula utilis* forest stands having maximum Biomass content. On the other hand, all of the alpine sites were closely associated with soil Organic carbon showing maximum values (Fig. 3). It appeared that the dominance of *Betula utilis* biomass at lower elevetional subalpine sites was overcome by the high soil organic carbon values at the high altitude alpine sites.

Discussion

Forest ecosystems have a key role in the recycling of carbon at local and global level by storing large amount of carbon, having the capacity to act as a carbon sink (Anon., 2005). The main objective of current study was the quantification of the above and below ground biomass carbon stocks and the organic carbon stocks in soils of the subalpine and alpine regions of Neelum valley in Pir Panjal sub range of Western Himalayan Mountains. The biomass and carbon stocks in subalpine forest were estimated by analyzing the growing stocks in the *Betula utilis* forest stands.

The average biomass carbon reserves in subalpine forest were estimated to be 81.56 t/ ha. These results are lower than those reported as 120-195.5 tons/ha in the subalpine regions of western China (Zhang *et al.*, 2012); 135-150 t/ha in Qinghai Plateau of China (Liu *et al.*, 2008); 109 t/ha in German subalpines (Prietzel & Christophel, 2014); and 116 t/ha in Swiss alpines (Bolliger *et al.*, 2008). The lower values can be attributed to the lower DBH classes, poor species composition along with soil degradation (Chhabara *et al.*, 2002). *Betula utilis* stands are reported to have lower carbon sequestration as compared to coniferous species due to lower DBH and lesser tree heights (Luyssaert *et al.*, 2008; Zhou *et al.*, 2006). Fitted line regression plot revealed that the Biomass carbon stocks decreased along the altitudinal gradient (Fig. 2). The sub-alpine vegetation sequesters relatively higher level of carbon due to presence of *Betula utilis* trees which are having higher biomass as compared to the herbaceous vegetation in alpine zone (Liu *et al.*, 2008). Also the broad leaved forbs in subalpines have high rate of photosynthesis as compared to small leaved alpine grasses (Trumbore *et al.*, 1996). Average soil carbon stocks in subalpine zone was 260.66 t/ha which was in line with the findings of Bolliger *et al.*, (2008) and Zhang *et al.*, (2006).

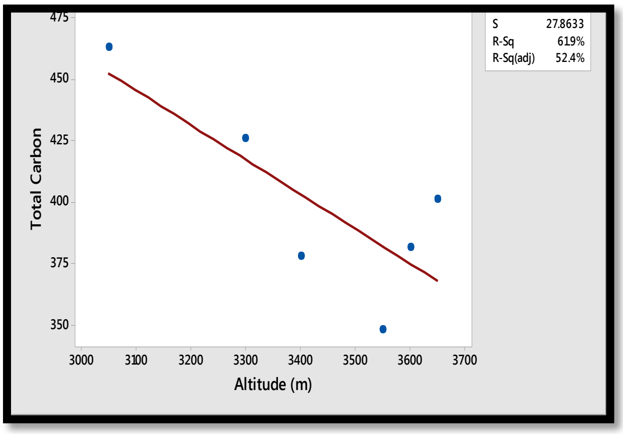

Fig. 2. Fitted line regression plot of total carbon vs altitude.

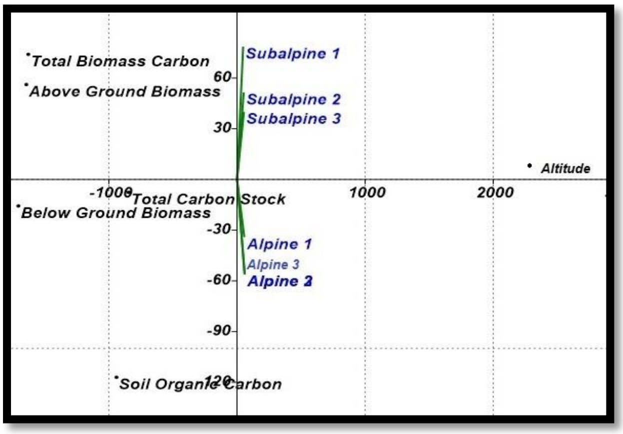

Fig. 3. Principal component analysis biplot of study sites.

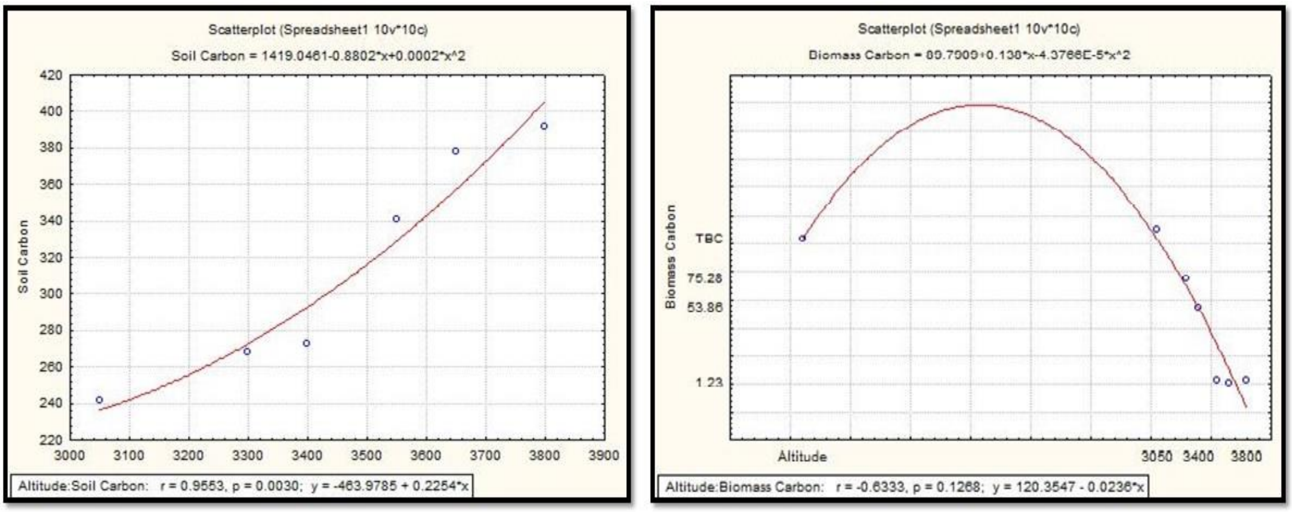

Fig. 4. Scatterplot showing relationship of soil carbon (left) and biomass (right) with altitude.

Carbon dynamics are highly affected by the composition and diversity of species (Fornara & Tilman, 2008). It was found that the soil organic carbon stocks showed an increasing trend with the increase in the altitude (Fig. 4). The positive correlation of carbon stocks with altitude in high elevated cold deserts is a widely accepted fact (Shedayi *et al*., 2016). This may be because of the decrease in average annual temperature, increasing mean annual pressure; slow decomposition rate of litter, longer accumulation time for soil organic matter (Yang *et al.,* 2009); higher ratio of root to shoot in plants ratio and shallow root system at higher elevations as compared to lower altitude (Groffman *et al.,* 2009). Soils of the *Betula utilis* forest are reported to have higher concentrations of carbon and nitrogen making efficient carbon sinks (Chang *et al*., 2014).

The alpine zone showed an average carbon stock value of 372 t/ha which is significantly higher than 97 t/ha in Chinese alpines (Liu *et al*., 2016); 52 t/ha in Tibetan plateau (Mu *et al*., 2015); and 263 t/ha in Indian Himalayan Alpines (Jha *et al*., 2003). The disturbances, both natural and anthropogenic, affect the soil carbon storage capacity in alpine regions. The unsustainable and intense extraction of alpine medicinal herbs in the area is resulting into severe soil degradation and increased erosion, becoming a significant threat to the local carbon stocks (Dai *et al.,* 2011). Controlled grazing activity with minimum disturbance was observed at the subalpine forests resulting in high carbon stocks (Table 1). Intermediate level of grazing is thought to be beneficial for the alpine pastures as it enhances nutrient cycling, promotes species diversity and increases carbon accumulation (Derner & Schuman, 2007). In contrast, the increased forage consumption rate and low productivity in grasslands at lower altitudes has heavy grazing pressure which negatively affect soil carbon stocks (Hafner *et al*., 2012). Our results are in agreement with the recent investigations in alpine grasslands revealing the negative impacts of overgrazing on soil organic carbon (Sun *et al.,* 2011).

It is suggested to monitor and reduce the rates of soil degradation and erosion along with regulating the grazing pressure and medicinal plants extraction in the area to enhance the soil organic carbon. Integrated land use management practices have to be employed including slope stabilization, rotational grazing and contouring at the steep alpine slopes to minimize the impact of runoff water and avalanches during the snow melt. Similarly, the intense fuelwood extraction pressure on the *Betula utilis* subalpine forest stands should be addressed to enhance above ground tree biomass by providing alternate energy resources to the local populations.

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