Regular Article
pISSN: 2288-9744, eISSN: 2288-9752
Journal of Forest and Environmental Science
Vol. 33, No. 1, pp. 39-48, February, 2017
https://doi.org/10.7747/JFES.2017.33.1.39

JFES
Journal of Forest and Environmental Science

Relationship between Tree Species Diversity and Carbon Stock Density in Moist Deciduous Forest of Western Himalayas, India

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Abstract

With the growing global concern about climate change, relationship between carbon stock density and tree species has become important for international climate change mitigation programmes. In this study, 150 Quadrats were laid down to assess the diversity, biomass and carbon stocks in each of the forest ranges (Barkot Range, Lachchiwala Range and Thano Range) of Dehra Dun Forest Division in Doon Valley, Western Himalaya, India. Community level carbon stock density was analyzed using Two Way Indicator Species Analysis. Species Richness and Shannon Weiner index was correlated with the carbon stocks of Doon Valley. Positive and weak relationship was found between the carbon stock density and Shannon Weiner Index, and between carbon stock density and Species Richness.

Key Words: carbon storage, REDD+, climate change, mitigation, diversity, TWINSPAN

Introduction

Human activities causes the increase in the concentration of the greenhouse gases like carbon dioxide (CO_2), methane (CH_4), etc. 40% Increase in the concentration of CO_2 since pre-industrial times is due to fossil fuel emissions and land use change emissions (IPCC 2013a). The world's forests are able to store carbon and work as natural brake of climate change. Sustainable management of forest, enhancement of carbon stocks through afforestation, assisted natural regeneration can play vital role in sequestering the carbon from the atmosphere. Quantifying the availability of carbon stocks and sequestration potential of forest has become important to assess the role of forests in mitigating climate change (FAO 2010).

Biological diversity encompasses the variety of existing life forms, the ecological roles they perform and the genetic diversity they contain (FAO 1989). Environmental factors like climate, soil, topography, anthropogenic pressure spatially affects the distribution of biomass and biodiversity (Thompson et al. 2012). The relationship of biodiversity and carbon cycle has become important factor for the mitigation of climate change through REDD+ programmes (Midgley et al. 2010).

Forests are considered important for the biodiversity and ecosystem service (Paquette and Messier 2010; Messier et al. 2013). Carbon sequestration service offered by the forests is of prime importance for climate regulation (Rhemtulla et al. 2009; Carlson et al. 2010; McKinley et al. 2011).

In the context of international climate change mitigation and biodiversity conservation programmes, the relationship between tree species diversity and carbon stock density has

Received: July 22, 2016. Revised: September 30, 2016. Accepted: October 3, 2016.

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become more important. Stand structural diversity can be an indicator of overall biodiversity (Staudhammer and LeMay 2001) and is commonly used in the characterization of biophysical parameters (McElhinny et al. 2005).

Several studies are conducted to ascertain the relationship between species diversity and productivity in forest ecosystem (Lei et al. 2009; Paquette and Messier 2011). Negative relationship was reported from Central Europe between aboveground biomass and tree species diversity (Szwagrzyk and Gazda 2007). Jonsson and Wardle (2009) reported that plant diversity has a weak effect on belowground C storage in boreal forest ecosystems. Structural diversity and forest growth has positive relationship in spruce-dominated forests (Lei et al. 2009). Negative correlation exists between stand composition and canopy vertical structure in aspen (*Populus tremuloides* Michx.) forest stands (Edgar and Burk 2001).

Relationship between tree diversity and carbon stocks in the forests of Doon Valley has not been studied. Knowledge about the correlation between tree species and carbon stocks is of very significance on a local and regional level to design the policies for biodiversity conservation, carbon stock enhancement and sustainable management of forests. The research objectives was to assess the carbon stock and biodiversity and to test the hypothesis that whether there exist any relationship between carbon stock and biodiversity in the forests of Doon Valley. The purpose of the study was also to analyze the carbon stock variation with the species specific composition groups. Understanding of the relationship will help in improvement of forest carbon measurement and provide an opportunity to select the species for the afforestation and reforestation under climate change mitigation REDD+ programmes.

Materials and Methods

Study site

The study was conducted in the three ranges (Barkot Range, Lachchiwala Range and Thano Range) of Dehra Dun Forest Division located in Doon Valley in the Southwestern part of the state of Uttarakhand, India. The Doon valley is located in the Western Himalayas, lying between latitudes 29°55'and 30°30' N and longitudes 77°35' and 78°24' E. It is about 20 km wide and 80 km long saucer-shaped valley with a geographical area of ca. 2,100 km^2 (Fig. 1). The area is bounded by the river Ganga in the east and river Yamuna in the West. The northern boundary is formed by Mussoorie hills whereas the Shiwalik Mountains form the southern boundary of the valley. Annual temperature ranges from 1.8°C (in January) to 40.0°C (in June).

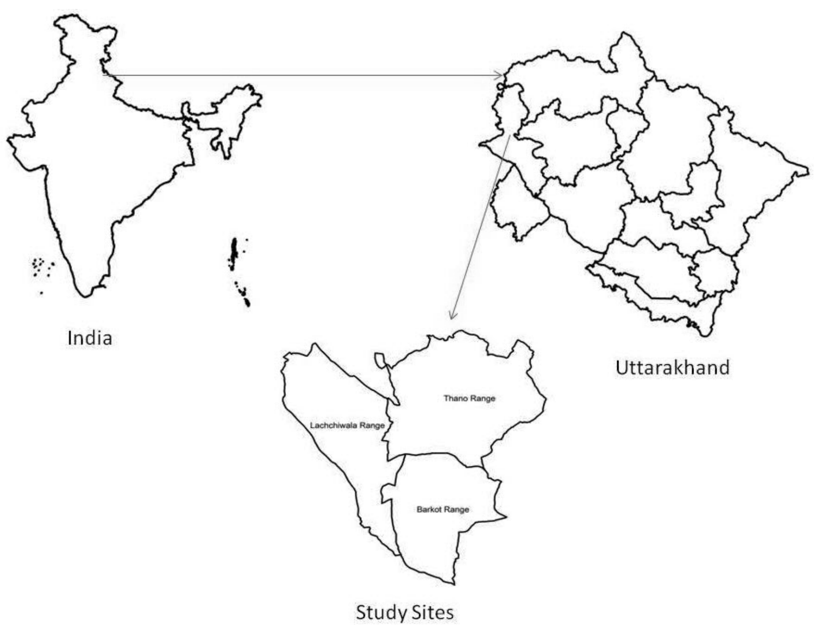

Fig. 1. Location of study sites.

The area received an average annual rainfall of 2,025.43 mm. The region receives most of the annual rainfall during June to September, the maximum rainfall occurring in July and August.

Data collection

A total 150 quadrats of 10×10 m were laid down randomly in all range of the entire study area after thorough survey of the study for its topography, microclimate and biotic stress conditions. Phytosociological studies of the selected sites were conducted during the year 2010-11. The vegetation was analysed by means of random sampling to give most representative composition of vegetation. The height and diameter at breast height (1.37 m above the ground) of all the trees within the sampling quadrat were measured. The volume of the individual trees was estimated using the species specific volume equations (FSI 1996). The estimated volume of each tree was multiplied by its specific gravity (Rajput et al. 1996) to derive the bole biomass. Later, the bole biomass was multiplied by the biomass expansion factor (Haripriya 2000) to derive individual tree aboveground biomass. Aboveground biomass was used to calculate the Belowground biomass by multiplying the value of aboveground biomass with the constant factor 0.26 (IPCC 2006). Aboveground biomass and belowground biomass were added to get the individual tree total biomass. The carbon contents was calculated by the multiplying the individual tree total biomass with the conversion factor 0.5 (IPCC 2006). The individual tree total biomass and carbon contents in a quadrat were summed to obtain total biomass and carbon storage in sampling quadrat. The mean total biomass and carbon were calculated by averaging the total biomass and carbon values in all sampling quadrats.

Diversity indices

The Shannon-Wiener diversity index (H') (Shannon and Wiener 1963) was calculated from the Importance Value Index (IVI) values using the formula as given in Magurran (1988):

where,

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

s = the number of species

p_i = the proportion of individuals or abundance of the ith species expressed as a proportion of total cover

ln = log base n

Importance value index (IVI)

Importance Value Index was evaluated according to Misra (1968) and Curtis and McIntosh (1951).

Two way indicator species analysis (TWINSPAN) species classification

TWINSPAN is a program for classifying species and samples, producing an ordered two-way table of their occurrence. The process of classification is hierarchical; samples are successively divided into categories, and species are then divided into categories on the basis of the sample classification.

The TWINSPAN method is one of the more popular classification programs used in plant community ecology (Hill et al. 1975; Hill 1979b). The results of TWISNPAN analysis were considered community groups and used to estimate the carbon stock availability in different community groups having specific species according to TWINSPAN classification. Windows based version of Twinspan WinTWINS 2.3 was used to perform two way indicator species analysis (Hill and Smilauer 2005).

Species richness

Species richness is a simple and easily interpretable indicator of biological diversity (Peet 1974). Species richness appropriately measured as the number of species in a sample of standard size (Whittaker 1972).

Relationship between carbon and phytodiversity

Relationship between carbon stock density and species richness as well as carbon stock density and Shannon Weiner Index was analyzed using regression analysis.

Results

Dominance (importance value index) of trees species in study area

15 tree species were recorded from the Barkot Range. *Shorea robusta* was the dominant species in the Barkot Range with the IVI value 141.32. The co-dominant species are *Mallotus philippensis* and *Ehretia laevis* with IVI value 33.53 and 31.68 respectively. The minimum IVI value

(3.60) was reported for the *Casearia tomentosa. Shorea robusta* had the 47% share in the forest of the Barkot Range. 14 species are reported from Lachchiwala Range. The maximum IVI (126.36) was for the *Shorea robusta* in Lachchiwala Range. *Mallotus philippensis* and *Syzygium cumini* had the IVI value of 33.28 and 29.84 respectively in Lachchiwala Range. The minimum IVI Value (4.02) was recorded for the *Caseaseria tomentosa*. The *Shorea robusta* had the maximum IVI (187) in the Thano Range. The *Mallotus philippensis* and *Syzygium cumini* had the IVI value 38.97 and 25.36 respectively in Thano Range. A total of six species were recorded in the Thano Range. The minimum IVI Value (15.69) was recorded for the *Terminalia alata* (Table 1).

Diversity measurement

Species Richness was the maximum 15 from the Barkot Range. Lachchiwala Range and Thano had reported the species richness of 14 and 06 respectively. The highest Shannon Weiner index (H') (2.023) was recorded in the Lachchiwala Range while the lowest H' (1.242) was recorded in Thano Range (Table 2).

Table 1. Importance value index of the tree species in study area

Species	IVI		
	BR	LR	TR
Haldina cordifolia (Roxb.) Ridrd.	11.56	9.63	-
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr.	5.35	9.28	-
Bauhinia variegata L.	8.34	6.57	-
Casearia tomentosa Roxb.	3.6	4.02	-
Cassia fistula L.	9.48	6.57	-
Cordia dichotoma Forst.	-	7.67	-
Ehretia laevis Roxb.	31.68	17.18	17.28
Ficus benghalensis L.	4.56	-	-
Flacourtia indica (Burm.f.) Merr.	-	4.42	-
Litsea glutinosa (Lour.) Robins.	4.3	-	-
Mallotus philippensis (Lam.) Muell.- Arg.	33.53	33.28	38.97
Miliusa velutina (Dunal) Hook. f. & Thomson	6.52	9.01	-
Ougeinia oojeinensis (Roxb.) Hochr.	9.04	-	-
Shorea robusta Roxb. ex Gaertn.	141.3	126.4	187
Syzygium cumini (L.) Skeels	10.21	29.84	25.36
Tectona grandis L.f.	-	-	15.71
Terminalia alata Heyne ex Roth	6.1	7.67	15.69
Terminalia bellirica (Gaertn.) Roxb.	14.4	28.51	-

BR, Barkot Range; LR, Lachchiwala Range; TR, Thano Range.

Carbon assessment in barkot, lachchiwala and thano range

Barkot range

A total of 215.59 m^3 ha^{-1} mean volume has been recorded from the Barkot Range. *Shorea robusta* has the maximum contribution of volume (155.17 m^3 ha^{-1}) being the most dominant tree species in the forest. It was followed by *Mallotus philippensis* with the mean volume of 24.37 m^3 ha^{-1}. The minimum volume (0.52 m^3 ha^{-1}) was reported by the *Ougeinia oojeinensis*. A total of 1500 tree ha^{-1} trees were reported from the Moist Deciduous Forest in Barkot Range. The maximum (900 tree ha^{-1}) contribution was by the *Shorea robusta* followed by *Mallotus philippensis* and *Ehretia laevis* with the density of 210 tree ha^{-1} and 180 tree ha^{-1} respectively. A total of 164.94 Mg ha^{-1} carbon stock was recorded in the Moist Deciduous Forest of Barkot Range (Table 3).

Lachchiwala range

A total of 272.17 m^3 ha^{-1} mean volume was recorded in the Moist Deciduous Forest of Lachchiwala Range with the maximum (208.07 m^3 ha^{-1}) contribution by *Shorea robusta*. Total Density of 1170 tree ha^{-1} was recorded in the Moist Deciduous Forest of Lachchiwala Range. *Shorea robusta* had the contribution of 650 tree ha^{-1}. 213.57 Mg ha^{-1} carbon stock was reported from the Moist Deciduous Forest of Lachchiwala Range (Table 3).

Thano range

Mean volume in the Moist Deciduous Forest of Thano Range was 261.44 m^3 ha^{-1}. The mean volume (184.48 m^3 ha^{-1})

Table 2. Diversity index of trees at various study sites

INDICES	Barkot Range	Lachchiwala Range	Thano Range
Richness	15	14	06
Shannon Weiner Index (H')	1.67	2.023	1.242

Table 3. Density, volume, and carbon stock density in various study sites

Tree species	Barkot range			Lachchiwala range			Thano range		
	Density (trees ha^{-1})	Volume (m^3 ha^{-1})	Carbon (Mg ha^{-1})	Density (trees ha^{-1})	Volume (m^3 ha^{-1})	Carbon (Mg ha^{-1})	Density (trees ha^{-1})	Volume (m^3 ha^{-1})	Carbon (Mg ha^{-1})
Haldina cordifolia (Roxb.) Ridrd.	40	2.14	1.38	20	0.64	0.41	-	-	-
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr.	10	5.44	4.72	20	11.29	9.79	-	-	-
Bauhinia variegata L.	20	1.03	0.76	10	2.19	1.63	-	-	-
Casearia tomentosa Roxb.	10	0.55	0.38	10	0.76	0.52	-	-	-
Cassia fistula L.	20	1.04	0.82	10	0.91	0.72		-	-
Cordia dichotoma Forst.	-	-	-	10	0.21	0.17	-	-	-
Ehretia laevis Roxb.	180	10.01	5.68	80	9.17	5.20	40	2.37	1.34
Ficus benghalensis L.	10	5.06	1.80	-	-	-	-	-	-
Flacourtia indica (Burm.f.) Merr.	-	-	-	10	0.74	0.55	-	-	-
Litsea glutinosa (Lour.) Robins.	10	0.59	0.26	-	-	-	-	-	-
Mallotus philippensis (Lam.) Muell.- Arg.	210	24.37	17.34	160	21.74	15.47	140	17.14	12.2
Miliusa velutina (*Dunal*) Hook.f. & Thomson	10	5.14	3.60	20	9.45	6.62	-	-	-
Ougeinia oojeinensis (Roxb.) Hochr.	10	0.52	0.40	-	-	-	-	-	-
Shorea robusta Roxb. ex Gaertn.	900	155.17	124.22	650	208.07	166.57	1070	184.48	147.69
Syzygium cumini (L.) Skeels	40	2.00	1.56	140	3.00	2.72	20	55.12	42.9
Tectona grandis L.f.	-	-	-	-	-	-	20	1.04	0.75
Terminalia alata Heyne ex Roth	10	0.57	0.45	10	1.16	0.92	20	1.29	1.03
Terminalia bellirica (Gaertn.) Roxb.	20	1.96	1.57	20	2.84	2.28	-	-	-

of the *Shorea robusta* was followed by 55.12 m^3 ha^{-1} of *Syzygium cumini*. *Mallotus philippensis* has the contribution of 17.14 m^3 ha^{-1} while the *Ehretia laevis* shared the contribution of 2.37 m^3 ha^{-1}. Total Density of 1,310 tree ha^{-1} was recorded in the Moist Deciduous Forest of Thano Range. The *Shorea robusta* had the density of 1070 tree ha^{-1}. Total Carbon estimated in the Moist Deciduous Forest of Thano Range was 205.91Mg ha^{-1} (Table 3).

Two way indicator species analysis (TWINSPAN) species classification

A total of 18 tree species were analysed with TWINSPAN. Division number 1 classified the 18 species with the Eigen Value 0.364 into 12 species in the Left Hand side and 06 species in the Right Hand Side (RHS). 12 species are further classified with Eigen Value 0.247 into 3 species in the LHS and 09 species in the RHS. Three species forms the group I while 09 species are further clustered into 08 and 01 species. 06 species obtained after the I Division, are classified into 05 species in the LHS and 01 species in the RHS. 01 species at this stage forms the group VIII. 08 species are further classified into 06 and 02 in the LHS and RHS respectively at the Division number 10. 02 species form the group IV and are not further classified. 06 species

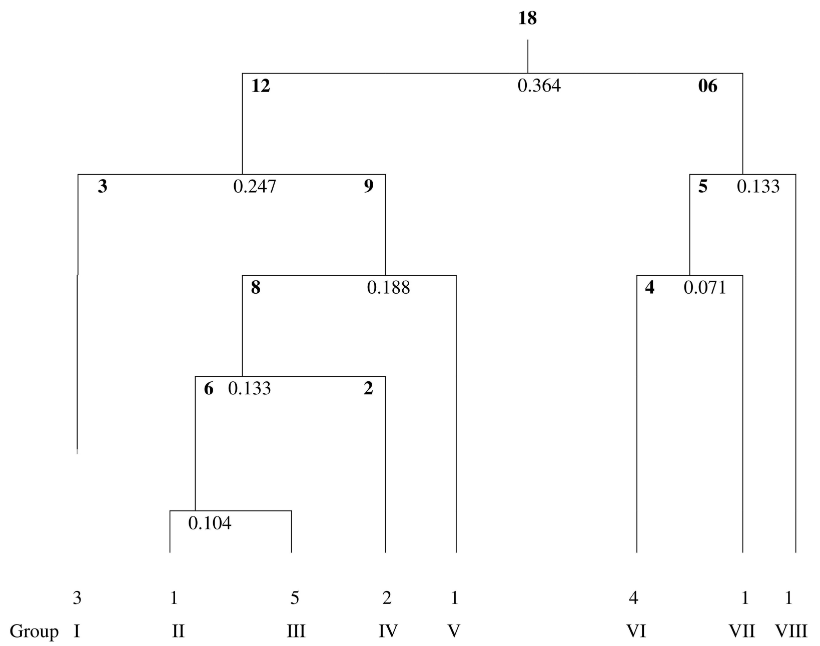

Fig. 2. Classification of Tree Species on the basis of TWINSPAN.

Table 4. Clustering of tree species at various study sites

Group	No. of species	Name of species
I	03	*Ficus benghalensis, Litsea glutinosa, Ougeinia oojeinensis*
II	01	*Haldina cordifolia*
III	05	*Anogeissus latifolia, Bauhinia variegata, Caseaseria tomentosa, Cassia fistula, Miliusa velutina*
IV	02	*Cordia dichotoma, Flacourtia indica*
V	01	*Terminalia alata*
VI	04	*Ehretia laevis, Mallotus philippensis, Shorea robusta, Syzygium cumini*
VII	01	*Terminalia bellirica*
VIII	01	*Tectona grandis*

with Eigen value (0.104) are further classified into 01 and 05 and both forms the groups II and III respectively. 05 species obtained after the Division number 06 are further classified with Eigen Value (0.071) into 04 and 01 species which forms the groups VI and VII respectively (Fig. 2).

A total of eight groups are formed after the classification of tree on the basis of TWINSPAN. Group III was the largest groups with five tree species *Anogeissus latifolia, Bauhinia variegata, Caseaseria tomentosa, Cassia fistula, Miliusa velutina*. One species each was present in the four groups (Group II, V, VII and VIII). Group I have the three species namely *Ficus benghalensis, Litsea glutinosa, Ougeinia oojeinensis. Shorea robusta* alongwith *Ehretia laevis, Mallotus philippensis* and *Syzygium cumini* forms the group VI. Two species *Cordia dichotoma, Flacourtia indica* are present in the Group IV (Table 4).

Relationship between TWINSPAN classified groups and Carbon Stocks

Group VI with the tree species *Ehretia laevis, Mallotus philippensis, Shorea robusta, Syzygium cumini* is the most dominant group with 542.89 Mg ha^{-1} Carbon storage. *Shorea robusta* and *Mallotus philippensis* had the maximum carbon storage (483.49 Mg ha^{-1}) in all the three ranges. *Syzygium cumini* replaced the *Mallotus philippensis* in terms of Carbon storage and become the co-dominant in Thano Range. Group III with largest number of tree species (5) *Anogeissus latifolia, Bauhinia variegata, Caseaseria tomentosa, Cassia fistula, Miliusa velutina* had the contribution of only 21.40 Mg ha^{-1} Carbon in all the studied three ranges.

Relationship between species richness and carbon stock

The results showed that there was positive but weak relationship between species richness and carbon stock in the

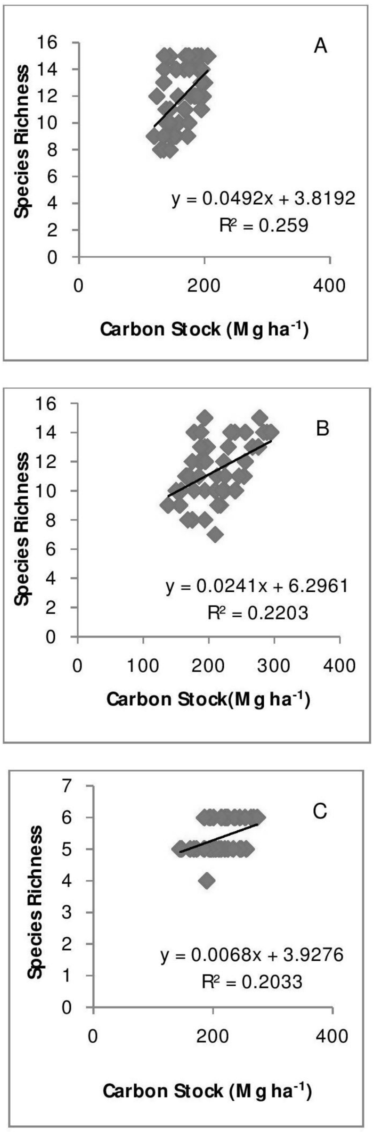

Fig. 3. Relationship between Species Richness and Carbon Stock in different ranges of Doon Valley, India. (A) Barkot, (B) Lachchiwala, (C) Thano.

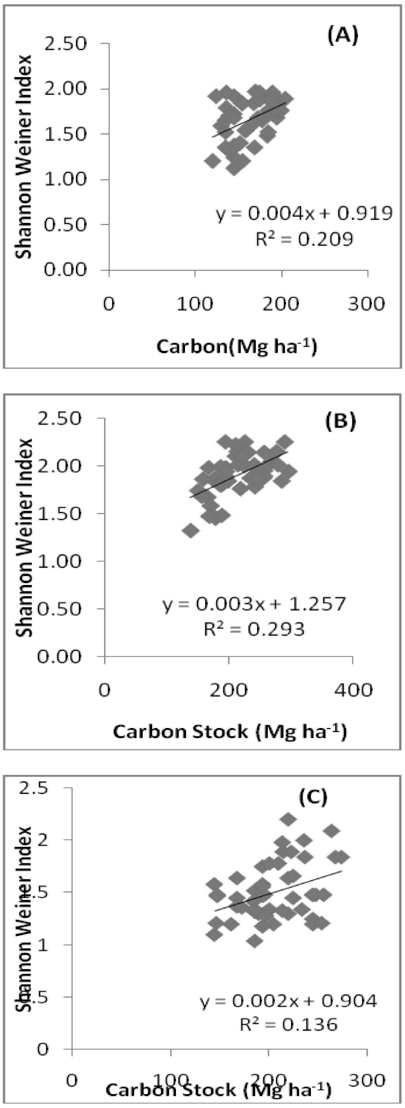

Fig. 4. Relationship between Shannon Weiner Index and Carbon Stock in different ranges of Doon Valley,India. (A) Barkot, (B) Lachchiwala, (C) Thano.

moist deciduous forest of Doon Valley. The value of R^2 of linear regression was 0.259, 0.220 and 0.203 in Barkot, Lachchiwala and Thano Range respectively (Fig. 3). The same findings have been reported by Mandal et al. 2013.

Relationship between shannon weiner index and carbon stock

The positive and weak relationship was obtained between Shannon Weiner Index and carbon stock. The value of R^2 was 0.209, 0.293 and 0.136 in Barkot, Lachchiwala and Thano Range respectively (Fig. 4).

Discussion

Forest ecosystems have structure, composition and function as the important attributes. Variations in these attributes are observed due to climate, topography, soil and anthropogenic factors. These factors along with forest succession causes local and landscape level variations in forest attributes and produce spatial heterogeneity (Timilsina et al.

2007).

Shorea robusta (Sal) Forests of Doon Valley are characteristically homogenous in distribution due to various silvicultural operations carried out in the past (Bisht and Sharma 1987; Rawat and Bhainsora 1999; Pande 1999; Chauhan et al. 2001). The reason for this may be various disturbances prevailing in these forests viz. fuelwood and fodder collection, livestock grazing, illegal timber collection, medicinal plant collection. These anthropogenic pressures have the effected the forest structure.

Importance value of Sal ranged between 123.36 and 187.00, which is well within the limits of earlier studies of Bisht and Sharma (1987); Rawat and Bhainsora (1999); Pande (1999); Agni et al. (2000); Chauhan et al. (2001). Dominance of Sal depends upon the age, available resources, associate species, disturbance regime and successional changes. The Site (Thano Range) in which the IVI exceeds more than 150.00 can be predicted that the Sal Forest is progressing towards the climax stage, where as in other two sites (Barkot Range and Lachchiwala Range), having IVI values are ranging between 100.00 and 150.00 denotes that these sites were under heavy disturbances.

Carbon in Deciduous Forest of Eastern Ghats was 125.826 Mg ha^{-1} while in the Secondary Deciduous Forest was 120.886 Mg ha^{-1} (Ramachandaran et al. 2007). In the present study, 164.94 to 213.57 Mg ha^{-1} Carbon is reported from the Moist Deciduous Forest of Doon Valley. The present study is also comparable with the results of Haripriya (2000) and Sharma et al. (2010). The low value of Carbon in Barkot Range is may be due to the prevailing disturbances like heavy dependence of the local people and being adjacent to National Highway while in Lachchiwala Range and Thano Range, high amount of carbon stock indicates that the disturbance are less as compared to other sites. Studies on diversity and functional relationship have very recently started (Scherer-Lorenzen et al. 2005). Different studies have produced different outputs. Productivity and diversity have positive relationship (Caspersen and Pacala 2001). No relationship was recorded between diversity and productivity (Enquist and Niklas 2001). Frivold and Frank (2002) described that there may be positive or negative relationship between species in a mixed species stand. In the present study, positive and weak relationship was found between Species Richness and Carbon Stock. The positive and weak relationship was also obtained between Shannon Weiner Index and Carbon Stock. A positive relationship between carbon stock density and species diversity is important for the implementation of climate change mitigation programme like reducing emissions from deforestation and forest degradation (REDD+) which can provide multiple benefits for conservation of biodiversity.

Conclusion

Study provides relevant information on the relationship between tree species diversity and carbon stocks. The results are of great significance to understand the heterogeneity of carbon storage in moist deciduous forests and significance of tree species in carbon storage. Results will also help the policy-makers to find the solutions to problems that are threatening the forest ecosystem. Tree Species diversity play very important role in forest resilience and structure. International programme with the objective to protect the biodiversity alongwith the increase in the carbon storage potential of the tree species are effectively implemented after making the observation on relationship between carbon stocks and tree species diversity. It is more necessary to find the accurate and precise biomass estimation for Doon Valley forests to improve understanding of the role played by Doon Valley forests in the global carbon cycle. However, we found that the relationship between carbon stocks and diversity was positive. Further work is required to establish whether biodiversity is important for carbon storage.

Acknowledgements

Authors are thankful to Principal and Head, Department of Botany, DAV (PG) College, Dehradun for providing necessary facilities to conduct the study.

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