International Journal of Ecology and Environmental Sciences 44 (1): 17-25, 2018
ISSN: 2320-5199 (Online)

Tree Species Richness, Diversity and Biomass in Farmland and Forest of Kosi-watershed, Kumaun Himalaya, India

Manmohan Singh Kanwal[1,2]*. Vijay Arya[1]. A.K.Yadava[2] and S.C.R.Vishvakarma[1]

[1] *G.B.Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal (Almora) 263643, Uttarakhand, India*
[2] *Department of Forestry and Environmental Science, Kumaun University, S.S.J. Campus, Almora 263601, Uttarakhand, India*

Email IDs: MSK: *Kanwal.manmohan3@gmail.com; VA: vijayarya429@gmail.com;
AKY: akyadava09@gmail.com; SCRV: scrvishvakarma@hotmail.com
* corresponding author

ABSTRACT

We studied tree species richness, diversity, community composition and biomass densities on farmland and forest sites of Kosi watershed, Kumaun Himalaya. For phytosociological analysis, sampling quadrats (n=60) of 10 x10 m size were randomly placed in three farmlands and three forest sites of the watershed. On farmlands, *Quercus leucotrichophora* was the dominant tree species with the highest IVI of 83.13 followed by *Grewia optiva* (76.09). On the forest sites, IVI ranged from 11.89 (*Cupressus torulosa*) to 145.36 (*Pinus roxburghii*). Tree density (N ha^{-1}) ranged from 460 ± 25 to 510 ± 23 and 720 ± 34 to 860 ± 56 under farmlands and forest sites, respectively. Species richness varied from 13-14 and 06-10 in farmlands and forests, respectively. Tree species diversity (Shannon diversity index) ranged between 2.10 to 2.40 and 1.51 to 1.95 under farmland and forest sites, respectively. Biomass densities (Mg ha^{-1}) of tree species varied from 156.79 to 161.14 in farmlands while 208.93 to 639.29 in forest sites. Practicing agroforestry i.e. growing trees in farmlands can be a useful strategy for biodiversity conservation as the species diversity was comparatively higher under farmlands.

Keywords: Biodiversity Conservation; Farmland; Biomass; Altitudinal Gradient; Watershed; Vegetation Analysis

INTRODUCTION

Biodiversity conservation has been established as an important and urgent environmental goal in recent decades as diverse species ensures natural sustainability for all life forms. During recent period, mountains are receiving priority for biodiversity conservation due to their exclusive and inimitable diversity of flora and fauna. There is a great diversity in the floristic pattern of Himalayan region due to altitudinal variation and rainfall (Arora 1995, Zhang et al. 2006). The mountain ecosystem is very fragile with biodiversity and vegetative cover threatened by various drivers such as increase in anthropogenic activities, habitat loss, overexploitation of natural resources, invasive alien species, pollution, agricultural expansion into forest lands and climate change (Kumar and Ram 2005, Xu et al. 2009, Tse-ring et al. 2010, Rashid and Romshoo 2013). Further, vegetation diversity of Himalaya is influenced by topography, soil, climate and geographical location of the region. To achieve the goal of sustainable development in Himalayan region, conservation of biodiversity is prerequisite as it offers food, shelter and other ecosystem services for humanity. Apart from *ex-situ* and *In-situ* biodiversity conservation strategies involvement of local communities in such programmes can be beneficial on account of their traditional knowledge and rich experience about local culture and environment.

In the Kumaun Himalya, traditionally farmers maintain naturally regenerating tree species (e.g., *Bauhinia variegata, Grewia optiva, Mangifera indica, Quercus* spp.) on the edges of crop fields to meet their requirements of firewood, fodder and fruits. This system is well known as indigenous agroforestry system (Ram and Singh 1996). Agroforestry, as practiced in the Kumaun Himalaya, is a typical example of land sharing. This type of landscape is globally common and covers more than half of the global agricultural land (Nair 1993, Zomer et al. 2009). Agroforestry practices have wide and promising potential to enhance soil fertility, reduce erosion, improve water quality, sequester carbon, enhance biodiversity and increase aesthetics (Garrett and McGraw 2000, Garrity 2004, Acharya 2006, Williams-Guille´n et al. 2008, Nair et al. 2009, Yadava 2010).

Inspite of significant impact of agroforestry on Indian economy, natural resources and environment, it has not become as popular among farmers as it should have been. Various experiments and trials are being conducted all over the country to evolve suitable agroforestry models for specific site condition of right species for specific locality, their socio-economic feasibility and adaption by farmers. Adoption of a system or a variant combination system will depend on the resource base of the farmer, given agro-climatic conditions and returns from the system as compared to other options. Traditional agroforestry plays a fundamental role in livelihood support for the farmers of Kumaun Himalaya. Therefore, agroforestry system could have a favoured place among other rural development programmes. The present study makes a quantitative analysis of variations in species richness, diversity, Importance Value Index (IVI) and biomass production of agroforestry and forest tree species in different elevation (800-1750 m) of Kumaun Himalaya.

STUDY AREA

The study was conducted during 2015 in the three representative farmlands and forest stands viz. Dabra-Saonral (Site 1), Dhaniyakot (Site 2) and Kantli (Site 3) of Kosi watershed, Kumaun Himalaya located between elevations of 800-1800 m (Figure 1). Total area of the watershed was 1868 km^2 and characteristic features of the study sites are given in Table 1. Climatically, the watershed fall under sub-tropical zone following the Koppen (1900) classification. The watershed has three main seasons; summer (April-June), rainy (July-September) and winter (November-February). During the study period annual air temperature ranged from a maximum of 32.1 $^{\circ}$C (June) to minimum -0.8 $^{\circ}$C (January) and the mean annual temperature was approxi-

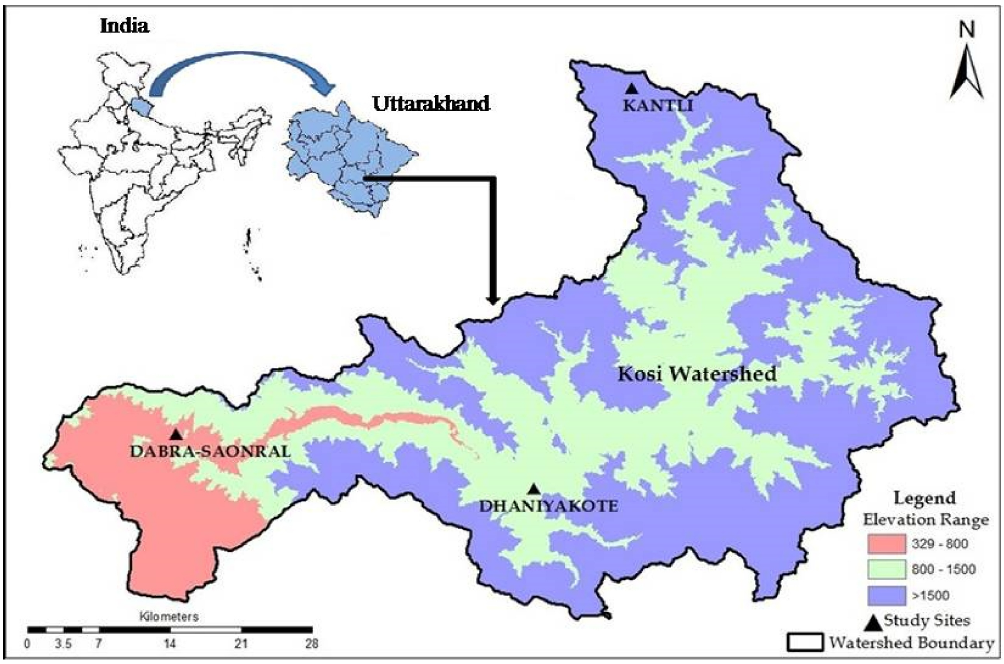

Figure 1. Location map of the study sites

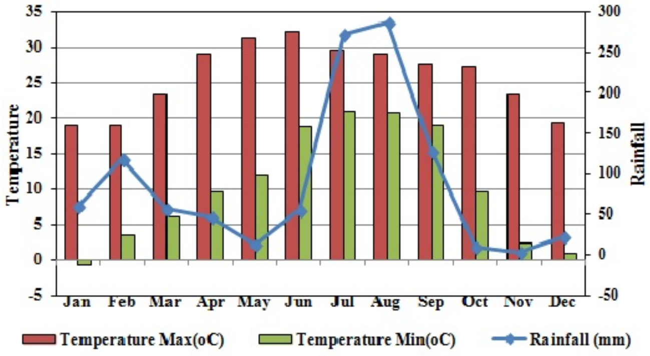

Figure 2. Precipitation and temperature conditions in Kosi watershed

Table 1. Characteristics of the study sites

Parameters	Site 1	Site 2	Site 3
Latitude (N)	29°32′36″	29°29′31″	29°50′55″
Longitude (E)	79°13′31″	79°26′57″	79°33′57″
Altitude (m)	839	1064	1750
Agricultural land area (ha)	44.8	63.1	38.7
Distance from nearest forest (km)	06	04	03
Total household (HH)	100	212	117
Agroforestry practicing HH (%)	51	57	54
Livestock population	223	370	136

Figure 3. A view of a farmland (Site 2) with trees, settlement and agricultural fields

Figure 4. A view of a forest (Site 2) dominated with *Pinus roxburghii*

mately 18 °C. Rainfall varies from 3 mm (November) to 287 mm (August) across the year (Figure 2). The farmland of the study sites consists of settlements, crop fields, and trees on private land (Figure 3). The forest sites of the study area have mixed vegetation with dominance of different species; for instance, site-1 was dominated with *Shorea robusta* whereas site 2 and site 3 were dominated with *P. roxburghii* (Figure 4). Agriculture is the prime occupation of majority of the population residing in the study area. More than 50 % households have maintained tree species in their farmlands like *G. optiva*, *Ficus glomerata*, *Phoenix sylvestris*, *Mangifera indica*, *Q. leucotrichophora*, *Q. glauca*, etc., to meet their needs such as fodder, fuelwood, fruits, etc.

METHODS

Sixty 10 x 10 m size quadrats were placed randomly in the farmland and forest of the study sites. Within each sampling quadrat, tree cbh (circumference at breast height, 1.37 m above ground level) was measured and species number was recorded. The individuals were categorized into trees (cbh > 31.5 cm), saplings (10.5 - 31.5 cm cbh) and seedlings (< 10.5 cm cbh) following Knight 1963. The importance value index (IVI) of tree species was calculated following Curtis and McIntosh (1950). Shannon diversity index (H) was calculated using formula given by Shannon and Wiener (1963).

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$

where S = number of species; P_i = Proportion of individuals or abundance of the i^{th} species expressed as a proportion of total cover; and ln = log base n.

Concentration of dominance (Cd) was calculated following Simpson (1949). Evenness (E) was calculated using formula given by Pielou (1966).

$$E = H/\ln S$$

where, H= Shannon-wiener index, S= species richness

Biomass of the tree species was estimated using allometric equation in the form of

$$Y = a + b \ln X$$

where, Y= dry weight of component (kg); X= mean cbh (cm); a= intercept and b= slope and Ln is natural log.

`Regression equations for each species were used following Singh and Singh (1992). The biomass of the tree species includes bole, branch, twig, leaf, stump root, lateral root and fine root. Regeneration pattern was assessed following Shankar (2001).

RESULTS AND DISCUSSION

Density, Species Richness and Diversity

Tree density (N ha^{-1}) ranged from 460 ± 25 to 510 ± 23 and 720 ± 34 to 860 ± 56 in studied farmlands and forest sites of the watershed respectively. Sapling density ranged between 120 to 260 saplings ha^{-1} in farmlands and 440 to 600 saplings ha^{-1} in forests while seedling density ranged between 11 to 20 seedlings ha^{-1} in farmlands and 520-690 seedlings ha^{-1} in forests. Total basal area (m^2 ha^{-1}) of the tree species varied from 31.55 to 140.54 under farmland while it was 19.21 to 91.32 across the forest sites, respectively. Species richness varied from 13-14 and 06-10 in farmlands and forest sites, respectively. Species evenness was found to be ranging from 0.91-1.05 and 0.65-0.85 in farmlands and forest sites, respectively. The value of Shannon- Wiener diversity index ranged 2.10 to 2. 43 and 1.51 to 1.95 in farmland and forest sites, respectively. Concentration of dominance (Cd) ranged between 0.10 and 0.16 under farmlands while Cd varied from 0.19 to 0.29 in forest sites. The regeneration status was poor under all the farmlands while it was fair in various studied forest sites (Table 2).

Dominance of Tree Species (IVI)

Under studied farmlands, IVI ranged from 6.46 (*Ficus palmata*) to 76.09 (*Grewia optiva*), 9.27 (*Celtis australis*) to 47.67 (*Mangifera indica*) and 9.51 (*Prunus persica*) to 83.13 (*Q. leucotrichophora*) at site-1, site-2 and site-3, respectively (Figure 5). Across the studied forest sites, *Shorea robusta* was the dominant tree species with highest IVI of 106.04 followed by *Mangifera indica* (46.88) at site-1, while at site-2 and site-3 *P. roxburghii* was recorded as the dominant tree species with the highest IVI of 125.79 and 145.36, respectively (Figure 6).

Biomass of Tree Species

Under the studied farmlands, total biomass densities (Mg ha^{-1}) of tree species varied from 156.79 to 161.14. At site-1, maximum biomass (Mg ha^{-1}) was estimated for *Boehmeria rugulosa* (69.12) followed by *Ficus glomerata* (31.14) and minimum for *Ficus palmata* (0.45). At site-2 and site-3, maximum biomass (Mg ha^{-1}) was estimated for *Mangifera indica* (38.95) and *Quercus leucotrichophora* (79.51), respectively. In the forest sites, total biomass densities ranged from 208.93 to 639.29 Mg ha^{-1}. At forest site-1, maximum biomass was estimated for *Shorea robusta* 559.34 Mg ha^{-1} followed by *Mangifera indica* (20.02 Mg ha^{-1}) and minimum for *Melia azedarach* (5.48 Mg ha^{-1}). At forest site-2 *Pinus roxburghii* had the maximum biomass (135.64 Mg ha^{-1}) followed by *Pyrus pashia* (17.24 Mg ha^{-1}) and minimum biomass was estimated for *Eucalyptus tereticornis* (2.01 Mg ha^{-1}). At forest site-3 tree species biomass (Mg ha^{-1}) ranged from 3.24 (*Myrica esculenta*) to 153.55 (*Pinus roxburghii*) (Table 3).

Growing naturally regenerating tree species along the edges of agricultural field is an age-old practice in the Indian Himalayan region. Like other parts of the Himalaya, in Kosi watershed of Kumaun Himalaya, farmers have maintained tree species on edges and boundaries of terraced agricultural fields under lower density. Agroforestry is one of the sustainable approaches to land-use management where both agriculture and forestry combine into an integrated production system to get maximum benefits (Kidd and Pimentel 1992, Nair 1998, Bammanahalli et al. 2016). There are a variety of multipurpose tree species grown and managed for subsistence requirement of local communities (Vishvakarma et al. 1998, Maikhuri et al. 2000) such as fuelwood, fodder, timber, fiber, fruits etc.

Table 2.Population structure and diversity indices in farmland and forest sites of Kosi watershed

Parameters	Farmland			Forest		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Tree density (N ha^{-1})	460 ± 25	470 ± 33	510 ± 23	860 ± 56	720 ± 34	810 ± 44
Sapling density (N ha^{-1})	120 ± 23	200 ± 38	260 ± 26	440 ± 42	570 ± 28	600 ± 32
Seedling density (N ha^{-1})	20 ± 02	15 ± 05	11 ± 03	690 ± 30	540 ± 12	520 ± 40
Total basal area (cover m^2 ha^{-1})	140.54	40.16	31.55	91.32	30.11	19.21
Species richness	13	13	14	09	10	06
Species evenness (E)	0.91	1.05	1.04	0.85	0.84	0.65
Shannon (H)	2.10	2.43	2.40	1.95	1.94	1.51
Dominance (Cd)	0.16	0.10	0.12	0.19	0.21	0.29
Regeneration status	Poor	Poor	Poor	Fair	Fair	Fair

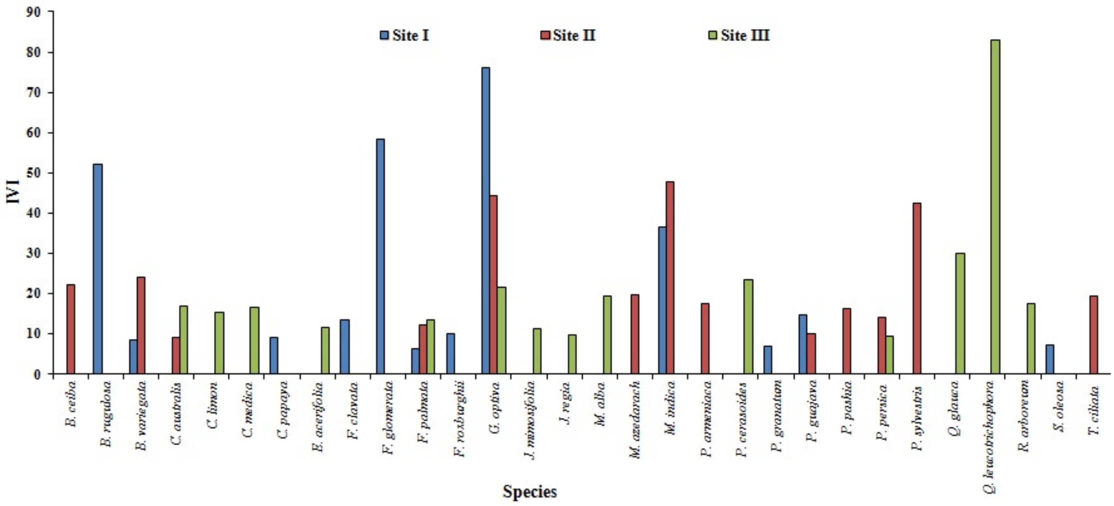

Figure 5. Importance value index of tree species under farmlands of Kosi watershed

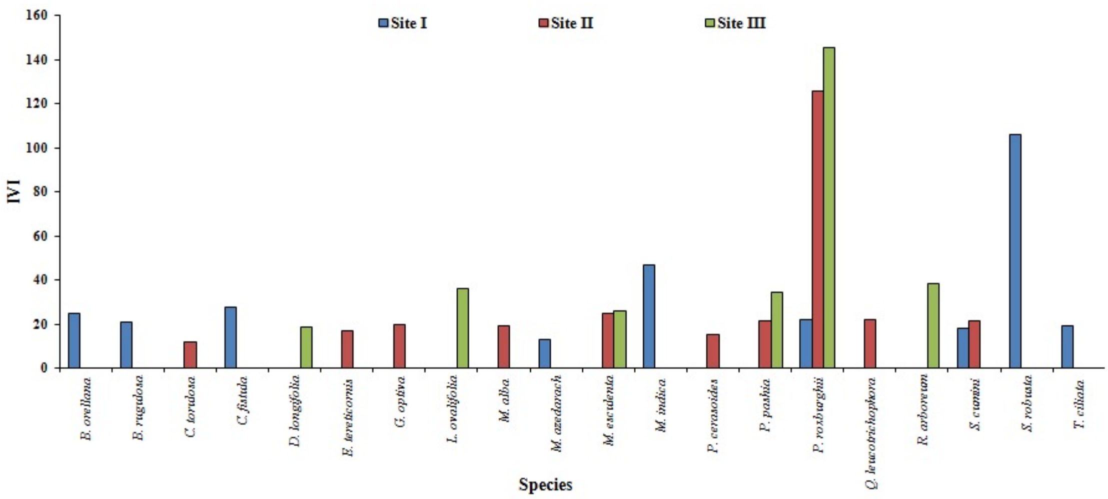

Figure 6. Importance value index of tree species in forests of Kosi watershed

Table 3. Biomass densities (Mg ha^{-1}) of tree species in various studied farmlands and forest sites

Species	Family	Farmland			Forest		
		Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Bauhinia variegata L.	Caesalpiniaceae	01.42	11.71	–	–	–	–
Bixa orellana L.	Bixaceae	–	–	–	5.89	–	–
Boehmeria rugulosa Wedd.	Urticaceae	69.12	–	–	12.60	–	–
Bombax ceiba L.	Bombacaceae	–	5.99	–	–	–	–
Carica papaya L.	Caricaceae	1.74	–	–	–	–	–
Cassia fistula L.	Fabaceae	–	–	–	7.88	–	–
Celtis australis L.	Cannabaceae	–	2.32	7.07	–	–	–
Citrus limon L.	Rutaceae	–	–	5.36	–	–	–
C. medica L.	Rutaceae	–	–	6.70	–	–	–
Cupressus torulosa D.Don	Cupressaceae	–	–	–	–	15.37	–
Debregeasia longifolia Wedd.	Urticaceae	–	–	–	–	–	7.06
Eucalyptus tereticornis Sm.	Myrtaceae	–	–	–	–	2.01	–
Excoecaria acerifolia Didr.	Euphorbiaceae	–	–	4.73	–	–	–
Ficus clavata Will. ex Miq.	Moraceae	2.50	–	–	–	–	–
F. glomerata Roxb.	Moraceae	31.14	–	–	–	–	–
F. palmata Forssk.	Moraceae	0.45	3.39	3.44	–	–	–
F. roxburghii Wall.	Moraceae	2.38	–	–	–	–	–
Grewia optiva J.R.Drumm. ex Burret	Tiliaceae	30.40	30.57	8.63	–	8.31	–
Jacaranda mimosifolia D.Don	Bignoniaceae	–	–	2.85	–	–	–
Juglans regia L.	Juglandaceae	–	–	2.32	–	–	–
Lyonia ovalifolia (Wall.) Drude	Ericaceae	–	–	–	–	–	30.14
Mangifera indica L.	Anacardiaceae	12.46	38.95	–	20.02	–	–
Melia azedarach L.	Meliaceae	–	9.79	–	5.48	–	–
Morus alba L.	Moraceae	–	–	8.89	–	4.35	–
Myrica esculenta D. Don	Myricaceae	–	–	–	–	5.91	3.24
Phoenix sylvestris (L.) Roxb.	Arecaceae	–	27.64	–	–	–	–
Pinus roxburghii Sarg.	Pinaceae	–	–	–	6.83	135.64	153.55
Prunus armeniaca L.	Rosaceae	–	6.65	–	–	–	–
P.cerasoides D.Don	Rosaceae	–	–	10.80	–	6.33	–
P. persica (L.) Batsch	Rosaceae	–	6.60	2.28	–	–	–
Psidium guajava L.	Myrtaceae	3.75	2.65	–	–	–	–
Punica granatum L.	Punicaceae	0.63	–	–	–	–	–
Pyrus pashia L.	Rosaceae	–	4.55	–	–	17.24	12.39
Quercus glauca Thunb.	Fagaceae	–	–	16.79	–	–	–
Q. leucotrichophora A. Camus	Fagaceae	–	–	79.51	–	9.04	–
Rhododendron arboreum Sm.	Ericaceae	–	–	1.76	–	–	9.32
Schleichera oleosa (Lour.) Merr.	Sapindaceae	0.79	–	–	–	–	–
Shorea robusta Roth	Dipterocarpaceae	–	–	–	559.34	–	–
Syzygium cumini (L.) Skeels.	Myrtaceae	–	–	–	6.20	4.75	–
Toona ciliata M. Roem.	Meliaceae	–	7.73	–	15.05	–	–
Total		156.79	158.54	161.14	639.29	208.93	215.70

Studies indicate one important attribute of indigenous AF system is to reduce pressure from the natural forest (Vishvakarma et al. 1998, Singh and Lodhiyal 2009). The vegetation characteristic shows dominance of one or more species in the forests. At higher and middle altitude zone of Kosi watershed, forests were dominated by *Pinus roxburghii* while at lower altitude *Shorea robusta* was the dominant tree species. Sharma and Tiwari (2014) recorded *Pinus roxburghii* was the dominant tree species in the forest of central Himalaya between an altitude of 800-2000 m and below 1000 m *Shorea robusta* was limited in patches over the Sivalik hills. Total tree density varied from 460-510 trees ha^{-1} on farmlands and 720-860 trees ha^{-1} in forests of Kosi watershed. Reported tree density of central Himalayan region by several researchers (Singh et al. 1994, Semwal 2006, Singh et al. 2014) varied from 250 tree ha^{-1} to 2070 trees ha^{-1}. In the present study, the value of total basal area of different species under farmlands and forests were lies between 31.55–140.54 m^2 ha^{-1} and 19.21–91.32 m^2 ha^{-1}, respectively. It was little higher than reported TBA for this region. The tree basal area for several Central Himalayan forest was reported in the ranged of 16.6–69.5 m^2 ha^{-1} (Saxana and Singh 1982, Tewari 1982).

Different studies on the temperate forests revealed that the tree richness ranged from 3–43 species (Baduni and Sharma 1996, Rikhari et al. 1997, Ghildiyal et al. 1998) which is comparable to the present study. Rawat et al. (2010) in Lahaul velly of Himanchal Pradesh recorded species richness were higher under agroforestry system as compare to forest that support the present study. Samant (2007) reported that high richness may be due to diverse habitats and suitable edaphic and climatic factors supporting growth and survival of the species. Lower values of Cd were recorded under AF system as compare to forest by Rawat et al. (2010). Whittaker (1965) and Risser and Rice (1971) reported concentration of dominance for tree layer in the range of 0.10–0.99 for temperate forests. Saxena and Singh (1982) and Tiwari and Singh (1985) reported the value of 0.11 to 1.00 for different forest in the Kumaun Himalaya. Species diversity under farmlands and forest system are comparable with values reported for most of the low elevation Central Himalayan forest (0.33 – 2.95) by Saxena and Singh (1982), Upreti et al. (1985), Bargali et al. (1987), Tripathi et al. (1987) and Rikhari et al. (1989). Monk (1967) and Risser and Rice (1971) obtained 2–3 as the highest values for species diversity of temperate forest. Species diversity was higher in farmlands and low in forests of all the study sites. Rawat et al. (2010) and Sharma and Vetaas (2015) also observed more species diversity under AF system than forest at Lahaul valley of HP and mid-hills of central Nepal, respectively. For forests, the value of evenness was 0.65 to 0.85. These values were more or less similar to the values (0.73–0.85) reported by Holmes (2008) for riparian areas of North-eastern Ohio. Evenness value was recorded 0.69–0.81 by Burton et al. (2005) for riparian woody plant diversity and forest structure along an urban rural gradient. In the present study, evenness under farmlands ranged from 0.91 to 1.04 which is higher than the forest.

Higher biomass in all the forest sites can be attributed to greater density of tree species in forests as compared to farmlands. However, total basal area of trees was higher in farmlands. Biomass distribution pattern might be dependent on species richness, diversity and age of the stands (Singh and Ramakrishnan 1982, Mishra and Ramakrishnan 1983). In general, biomass production in agroforestry or forest ecosystems is species specific as well as growth performance (Gairola et al. 1990). The value of forest biomass has been noted to remain high (500-600 mg ha^{-1}) upto 2600 m altitude, with gradual decline with increasing altitude (Singh et al. 1994, Garkoti and Singh 1995, Gairola et al. 2011, Sharma et al. 2016). Some species may produce better biomass in wide growth ranges while some may be site specific for better biomass production (Maikhuri et al. 2000). Moreover, biomass production in early successional species has been noted to be greater than that of late successional tree species (Shukla and Ramakrishnan 1984). In agroforestry, potentially higher basal area could be due to capture of more growth resources *i. e.* light, water and nutrients applied to improved soil fertility. Several studies (Srivastava and pant 1979, Shekhawat et al. 1988, Tokey 1997) conducted in different parts of India suggested that agroforestry is more profitable to farmers than agriculture or forestry for a particular area of land.

CONCLUSION

The study reflects that practicing agroforestry i.e. growing trees in farmlands can be a useful strategy for biodiversity conservation in the central Himalayan region as the species diversity was comparatively higher under farmlands. *Grewia optiva* was the most successful tree species under AF system of this region. However, selection of tree species is site specific and higher biomass can be obtained if grown in suitable climatic zones.

ACKNOWLEDGEMENTS

We thank the Director, G.B. Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal for providing necessary facilities. This work was funded by the Ministry of Environment and Forest, Government of India.

REFERENCES

Acharya, K.P. 2006. Linking trees on farms with biodiversity conservation in subsistence farming systems in Nepal. Biodiversity Conservation 15: 631-646.

Arora, R.K. 1995. Himalayan Resources, Diversity and Conservation. Pages 39-55, In: Dhar, U. (Editor), Himalayan Biodiversity. Gyanodaya Prakashan, Nainital: India.

Baduni, N.P. and Sharma, G.M. 1997. Effect of aspect on the structure of some natural stands of *Cupressustorulosa* in Himalayan Moist temperate forests. Proceeding of Indian National Science Academy B62: 345-352.

Bammanahalli, S.; Swamy, K.; Sankanur, M. and Yewale, A. 2016. Fruit-based agroforestry systems for food security and higher profitability. International Journal of Farm Sciences 6: 302-311.

Bargali, S.S.; Tewari, J.C.; Rawat, Y.S. and Singh, S.P. 1987. Woody vegetation in blue pine-mixed oak forest of Kumaun Himalaya, India. Pages 121-135, In: Pangtey, Y.P.S. and Joshi, S.C. (Editors), Western Himalaya: Environmental Problems and Development. Gyanodaya Prakashan, Nainital, India.

Burton, M.L.; Samuelson, L.J. and Pan, S. 2005. Riparian woody plant diversity and forest structure along an urban-rural gradient. Urban Ecosystems 8(1): 93-106.

Curtis, J.T. and McIntosh, R.P. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31(3): 434-455.

Gairola, M.; Rana, U. and Nautiyal, A.R. 1990. Biomass production potential of some mountain tree species under high density plantations. Journal of Tree Science 9(2): 75-77.

Gairola, S.; Sharma, C.M.; Suyal, S. and Ghildiyal, S.K. 2011. Composition and diversity of five major forest types in moist temperate climate of the western Himalayas. Forestry Studies in China, 13(2): 139-153.

Garkoti, S.C. and Singh, S.P. 1995. Variation in net primary productivity and biomass of forests in the high mountain of Central Himalaya. Journal of Vegetation Science 6: 23-28.

Garrett, H.E. and McGraw, R.L. 2000. Alley cropping practices. Pages 149-188, In: Garrett , H.E.; Rietveld, W.J. and Fisher, R.F. (Editors) North American Agroforestry: An Integrated Science and Practice. American Society of Agronomy, Madison, WI, USA.

Garrity, D.P. 2004. Agroforestry and the achievement of the millennium development goals. Agroforestry Systems 61: 5-17.

Ghildiyal, S.; Baduni, N.P.; Khandari, V.P. and Sharma, C.M. 1998. Community structure and composition of oak forest along altitudinal gradients in Garhwal Himalaya. Indian Journal of Forestry 21(3): 242-247.

Holmes, K.L. 2008. The ecology and management of headwater riparian areas in the Erie Gorges Ecoregion of northeastern Ohio (Doctoral dissertation, The Ohio State University).

Kidd, C.V. and Pimentel, D. (Editors). 1992. Integrated Resource Management: Agroforestry for Development. Academic Press, San Diego, CA. 223 pages.

Knight, D.H. 1963. A distance method for constructing forest profile diagrams and obtaining structural data. Tropical Ecology 4: 89-94.

Köppen, W. 1900. Versuch einer Klassifikation der Klimate, Vorzugsweise nach ihren Beziehungen zur Pflanzenwelt Geographische Zeitschrift 6 (12): 657-679.

Kumar, A. and Ram, J. 2005. Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, central Himalaya. Biodiversity and Conservation 14(2): 309-331.

Maikhuri, R.K.; Semwal, R.L.; Rao, K.S.; Singh, K. and Saxena, K.G. 2000. Growth and ecological impacts of traditional agroforestry tree species in Central Himalaya, India. Agroforestry Systems 48(3): 257-271.

Mishra, B.K.; Ramakrishnan PS. 1983. Secondary succession subsequent to slash and burn agriculture at higher elevations of north-east India. Acta Oecologica-Oecologica Applicata 4(2): 95-107.

Monk, C.D. 1967. Tree species diversity in the eastern deciduous forest with particular reference to north central Florida. American Naturalist, 10:173-187.

Nair, P.K.R. 1993. An Introduction to Agroforestry. Kluwer Academic Publishers (in cooperation with the International Centre for Research in Agroforestry), Dordrecht, The Netherlands. 499 pages.

Nair, P.K.R. 1998. Directions in tropical agroforestry research: past, present, and future. Pages 223-245, In: Directions in Tropical Agroforestry Research, Netherlands: Springer.

Nair, P.K.R.; Kumar, B.M. and Nair, V.D. 2009. Agroforestry as a strategy for carbon sequestration. Journal of plant nutrition and soil science, 172(1): 10-23.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. Journal of theoretical biology, 13: 131-144.

Ram, S.C. and Singh, G.S. 1996. *Grewia oppositifolia*- time for revival in Himalayas. Agroforestry Today, 9: 14-15.

Rashid, I. and Romshoo, S.A. 2013. Impact of anthropogenic activities on water quality of Lidder River in Kashmir Himalayas. Environmental monitoring and assessment, 185(6): 4705-4719.

Rawat, Y.S.; Vishvakarma, S.C.R.; Oinam, S.S. and Kuniyal, J.C. 2010. Diversity, distribution and vegetation assessment in the Jahlmanal watershed in cold desert of the Lahaul valley, north-western Himalaya, India. iForest-Biogeosciences and Forestry, 3(3): 65-71.

Rikhari, H.C.; Adhikari, B.S. and Rawat, Y.S. 1997. Woody species composition of temperate forests along an elevational gradient in Indian Central Himalaya. Journal of Tropical Forest Science 10(2): 197-211.

Rikhari, H.C.; Chandra, R. and Singh, S.P. 1989. Patterns of species distribution and community along a moisture gradient within and Oak Zone of Kumaun Himalaya. Proceedings of the Indian National Science Academy B55(5&6): 431-438.

Risser, P.G. and Rice, E.L. 1971. Diversity in tree species in Oklahoma upland forests. Ecology, 52(5): 876-880.

Samant, S.S. 2007. Assessment of plant diversity and prioritization of communities for conservation in Mornaula Reserve Forest. Applied Ecology and Environmental Research, 5(2): 123-138.

Saxena, A.K. and Singh, J.S. 1982. A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. Vegetatio 50(1): 3-22.

Semwal, S. 2006. Studies on phytosociology, Diversity patterns and competition along an altitudinal gradient in a part of lesser Himalaya, Garhwal, Uttarakhand, Ph. D. thesis, H.N.B. Garhwal University, Srihagar, Garhwal, Uttarakhand, India.

Shankar, U. 2001. A case of high tree diversity in a sal (*Shorea robusta*)-dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation. Current Science 81(7): 776-786.

Shannon, C.E. and Wiener, W. 1963. The mathematical theory of communication. Urbana Illinois Press, USA 117 pages.

Sharma, C.M.; Mishra, A.K.; Krishan, R.; Tiwari, O.P. and Rana, Y.S. 2016. Variation in vegetation composition, biomass production, and carbon storage in ridge top forests of high mountains of Garhwal Himalaya. Journal of Sustainable Forestry 35(2): 119-132.

Sharma, L.N. and Vetaas, O.R. 2015. Does agroforestry conserve trees? A comparison of treespecies diversity between farmland and forest in mid-hillsof central Himalaya. Biodiversity Conservation 24 (8): 2047-2061.

Sharma, N.K. and Tiwari, A.K. 2014. Vegetation Analysis in Kumaun Himalaya using Remote Sensing. Research & Reviews: Journal of Space Science & Technology 3(1): 9-16.

Shekhawat, J.S.; Sen, N.L. and Somani, L.L. 1988. Evaluation of agroforestry systems under semi-arid conditions of Rajastan. Indian Forester 114(2): 98-101.

Shukla, R.P. and Ramakrishnan, P.S. 1984. Biomass allocation strategies and productivity of tropical trees related to successional status. Forest Ecology and Management 9: 315-324.

Simpson, E.H. 1949. Measurement of diversity. Nature 163L 668.

Singh, J. and Ramakrishnan, P.S. 1982. Structure and function of a sub-tropical humid forest of Meghalaya I. vegetation, biomass and its nutrients. Proceedings of the Indian National Science Academy 91(3): 241-253.

Singh, J.S. and Singh, S.P. 1992. Forests of Himalaya: Structure, Functioning and Impact of Man. Gyanodaya Prakashan, Nainital India, 90 pages.

Singh, N.; Tamta, K.; Tewari, A. and Ram, J. 2014. Studies on vegetational analysis and regeneration status of *Pinus roxburghii* Roxb. and *Quercus leucotrichophora* forests of Nainital Forest Division. Global Journal of Science Frontier Research 14(3): 41-47.

Singh, P. and Lodhiyal, L.S. 2009. Biomass and Carbon Allocation in 8 year old Poplar (*Populus deltoides* Marsh) Plantation in Tarai Agroforestry Systems of Central Himalaya, India. New York Science Journal 2(6): 49-53.

Singh, S.P.; Adhikari, B.S. and Zobel, D.B. 1994. Biomass, productivity, leaf longevity, and forest structure in the central Himalaya. Ecological Monographs 64(4): 401-421.

Srivastava, B.P. and Pant, M.M. 1979. Social forestry on a cost benefit analysis framework. Indian Forester 105(1): 2-35.

Tewari, J.C. 1982. Vegetational Analysis Along Altitudinal Gradient Around Nainital, Ph.D. Thesis, Kumaun University, Nainital. 570 pages.

Tiwari, J.C. and Singh, S.P. 1985. Analysis of woody vegetation in a mixed oak forest of Kumaun Himalaya. Proceedings of Indian National Science Academy, 51(3): 332-347.

Toky, O.P. 1997. Poplar an economy booster and eco-friendly agroforestry tree. Agroforestry Newsletter, NRC for Agroforestry, Jhansi 9: 2-3.

Tripathi, B.S.; Rikhari, H.C. and Singh, R.P. 1987. Dominance and diversity distribution in certain forest of Kumaun Himalayas. In: IX International Symposium on Tropical Ecology, Banaras Hindu University, Varanasi, India.

Tsering, K.; Sharma, E.; Chettri, N. and Shrestha, A.B. (Editors). 2010. Climate Change Vulnerability of Mountain Ecosystems in the Eastern Himalayas: Climate Change Impact and Vulnerability in the Eastern Himalayas - Synthesis Report. International Centre for Integrated Mountain Development (ICIMOD), Kathmandu. 103 pages.

Upreti, N.; Tewari, J.C. and Singh, S.P. 1985. The oak forests of the Kumaun Himalaya (India): composition, diversity, and regeneration. Mountain Research and Development 5(2): 163-174.

Vishvakarma, S.C.R.; Kuniyal, J.C. and Singh, G.S. 1998. Indigenous Agroforestry System of North Western Himalaya. Pages 99-118, In: Agrawal, D.K.; Nandi, S.K. and Farooquee, N.A. (Editors) Research for Mountain Development. Some Initiatives and Accomplishments. Himavikas Publication 12. Gyanodaya Prakashan, Nainital, India.

Williams-Guillén, K.; Perfecto, I. and Vandermeer, J. 2008. Bats limit insects in a neotropical agroforestry system. Science, 320(5872): 70.

Whittaker, R.H. 1965. Dominance and diversity in land plant communities. Science 147(3655): 250-260.

Xu, J.; Grumbine, R.E.; Shrestha, A.; Eriksson, M.; Yang, X.; Wang, Y.U.N. and Wilkes, A. 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. Conservation Biology 23(3): 520-530.

Yadava, A.K. 2010. Biomass production and carbon sequestration in different agroforestry systems in Tarai region of central Himalaya. Indian Forester 136(2): 234-244.

Zhang, J.T.; Ru, W. and Li, B. 2006. Relationships between vegetation and climate on the Loess Plateau in China. Folia Geobotanica 41(2): 151-163.

Received 22 June 2017
Accepted 23 December 2017