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Estimation of Carbon Stock in the Chir Pine (*Pinus roxburghii* Sarg.) Plantation Forest of Kathmandu Valley, Central Nepal

Krishna Prasad Sharma[1], Suresh Prashad Bhatta[2,*], Ganga Bahadur Khatri[1], Avinash Pajiyar[1] and Daya Krishna Joshi[1]

[1]*Department of Botany, Amrit Campus, Tribhuvan University, Kathmandu 44600, Nepal*
[2]*Central Department of Botany, Tribhuvan University, Kathmandu 44600, Nepal*

Abstract

Vegetation carbon sequestration and regeneration are the two major parameters of forest research. In this study, we analyzed the vegetation carbon stock and regeneration of community-managed pine plantation of Kathmandu, central Nepal. Vegetation data were collected from 40 circular plots of 10 m radius (for the tree) and 1m radius (for seedling) applying a stratified random sampling and nested quadrat method. The carbon stock was estimated by Chave allometric model and estimated carbon stock was converted into CO_2 equivalents. Density-diameter (d-d) curve was also prepared to check the regeneration status and stability of the plantation. A d-d curve indicates the good regeneration status of the forest with a stable population in each size class. Diversity of trees was very low, only two tree species *Pinus roxburghii* and *Eucalyptus citriodora* occurred in the sample plots. Pine was the dominant tree in terms of density, basal area, biomass, carbon stock and CO_2 stock than the *eucalyptus*. The basal area, carbon stock and CO_2 stock of forest was 33±1.0 m^2 ha^{-1}, 108±5.0 Mg ha^{-1} and 394±18 Mg ha^{-1}, respectively. Seedling and tree density of the plantation was 4,965 ha^{-1} and 339 ha^{-1} respectively. The forest carbon stock showed a positive relationship with biomass, tree diameter, height and basal area but no relationship with tree density. Canopy cover and tree diameter have a negative effect on seedling density and regeneration. In conclusion, the community forest has a stable population in each size class, sequestering a significant amount of carbon and CO_2 emitted from densely populated Kathmandu metro city as the forest biomass hence have a potentiality to mitigate the global climate change.

Key Words: climate change, CO_2 stock, community forest, d-d curve, regeneration

Introduction

Global warming has emerged as the major environmental challenge which was resulted due to anthropogenic activities (Korkanc 2014; Aryal et al. 2017). Increasing carbon (C) sequestration by increasing forested land area has been suggested as an effective means to mitigate increased atmospheric carbon dioxide (CO_2) concentrations which would contribute towards the prevention of global warming (Watson et al. 2000). The forested land area can be maintained or either increased by reducing the deforestation and forest degradation rates, increasing reforestation or plantation activities or creating new forests which would mitigate increased atmospheric CO_2 concentration by storing atmospheric C in their ecosystems. The role of forest in mitigation of global climate change has been already recognized

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Corresponding author: Suresh Prashad Bhatta

Central Department of Botany, Tribhuvan University, Kathmandu 44600, Nepal
Tel: 977-9849156470, Fax: 977-1-333722, E-mail: sureshbhatta2@gmail.com

and various studies have suggested forests as a high potential of storing terrestrial C (Zhong et al. 2017). In a forest, terrestrial C is stored in different pools but tree and soil are the main pools that store more C than the other pools (Amir et al. 2018). Thus, the estimation of C storage in tree biomass and soil is important to understand the potential of forest in climate change mitigation. In Nepal, the forest covers about 44.74% of the total land area of the country and estimation of C stock from these forests is important in terms of mitigation of global climate change (Ghimire et al. 2018).

The C stock of the forest and potential of forest to sequester C depends on the various factors such as forest type, the age of the forest, the size of trees, the density of trees, biomass decomposition, climate, topography, stand condition, degree and history of disturbance and land management (Dixon et al. 1994; Zhang et al. 2011; Vayreda et al. 2012). Estimation of biomass contained within the forests is critical aspects of determination of the C loss associated with the wide range of land use and land cover change processes (Food and Agriculture Organization of the United Nations [FAO] 2005). In order to assess the impact of deforestation and re-growth rates on the global C cycle, it is necessary to know the C stocks as biomass per unit area for different forest types (Ghimire et al. 2018). The productive and well-managed forests have the potential to sequestrate a good quantity of C (Pokharel et al. 2007). Thus, the forest should be managed well to increase the C storage capacity of the forest.

The mechanism of forming a new plant by the different reproductive process for maintaining and expanding the population in the community with time and space is known as plant regeneration (Bharali et al. 2012). The regenerative status illustrates a development pattern of the community, species composition and stability of the forests in the future (Napit 2016). Regeneration status of a forest specifies its health and vitality and healthy and sustainable forest must have good regeneration, proper age class, normal increment and normal growing stock (Awasthi et al. 2015). Age class analysis of different tree species is the most commonly used method for reproductive and regeneration analysis of forest (Tripathi and Khan 2007). Species having sufficient number of seedlings, saplings and young trees is considered to have satisfactory regeneration, while the inadequate number of seedlings and saplings of the species in a forest is considered to a have poor regeneration and complete absence of seedlings and saplings of tree species in a forest has no regeneration (Khumbongmayum et al. 2006; Tripathi and Khan 2007).

The regeneration of plant depends mainly upon the ability to initiate new seedlings and ability of its seedlings and saplings to survive, grow and the establishment and also on the average seed output, the viability of seeds, seed dormancy, seed dispersal, vegetative growth and reproductive growth (Tripathi and Khan 2007; Napit 2016). Regeneration of tree species and the survival and growth of their seedlings is affected directly or indirectly by various abiotic and biotic factors of the forest environment (Borja 2014). Similarly, several types of disturbances like logging, landslides, gap formation, litterfall, herbivory, etc. can affect the potential regenerative status of species composing the forest stand spatially and temporally (Khumbongmayum et al. 2006).

Carbon stock estimation reflects the potentiality of forest in climate change mitigation (Ghimire et al. 2018) while reliable data on regeneration patterns are required for successful management and conservation of natural forests (Eilu and Obua 2005). Thus, C stock estimation and regeneration assessment are important in terms of mitigation of climate change and management and conservation of forest wisely and sustainably. In addition, chir pine (*Pinus roxburghii* Sarg.; hereafter referred to as pine) forest covers 8.45% of the total area of the country (proportionally the fifth-highest total area in the country) (Forest Resource Assessment Nepal 2015) but C stock estimation and regeneration assessment data is limited for this species from the forests of Nepal. Similarly, there is also a lack of C stock estimation as well as regeneration assessment data for pine plantation forests in Kathmandu district of Nepal. Thus, to overcome these research gaps, it is necessary to estimate the C stock and regeneration status in order to understand the potential role of pine forests in C storage that results in mitigation of global climate change and sustainability of forest in future. Hence, the present study was undertaken in the community managed pine plantation forest of Kathmandu district of central Nepal with the following objectives: (i) to estimate the vegetation carbon stock and to assess the regeneration status in the community managed pine plantation forest of Kathmandu district of central Nepal, and (ii) to know the variation of vegetation carbon stock with tree variables i.e. density, diameter, height, basal area and biomass.

Materials and Methods

Study area

The study was carried out in the Adinath community forest of Kirtipur municipality-06, Chobhar of Kathmandu district of central Nepal. It is located between 85°17'18" E to 85°17'45" E and 27°39'56" N to 27°40'16" N with an altitude ranging from 1,283-1,379 m asl (meter above sea level) (Fig. 1). The forest area is about 11.5 ha and is managed as CF only after 1998 A.D when the plantation was done for the last time. Before it, the plantation was done for the first time in 1962 and later on the subsequent plantation was done from 1970-1972 A.D for the second, third and fourth time, respectively. The planted species were mainly pine with the association of *Eucalyptus citriodora* Hook. (hereafter referred as eucalyptus), *Grevillea robusta* A. Cunn. ex R. Br., *Alnus nepalensis* D. Don and *Choerospondias axillaris* (Roxb.) B. L. Burtt & A. W. Hill. The invasive species like *Lantana camara* L., *Ageratina adenophora* (Spreng.) R. M. King & H. Rob., *Bidens pilosa* L., *Oxalis latifolia* Humb., *Ageratum conyzoides* L., *A. houstonianum* Mill. and *Parthenium hysterophorus* L. were also present as ground vegetation. Out of these invasive species, *A. adenophora* and *L. camara* were the most dominant species. The slope of the study site ranged from 5-25° while canopy cover ranged from 60-75%.

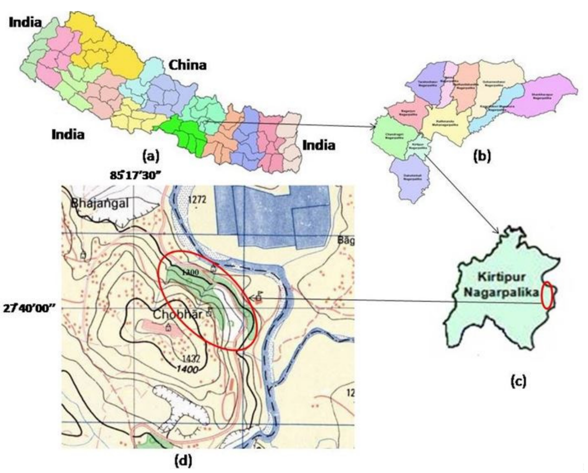

Fig. 1. The geographical location of the study area; map of Nepal with districts (a), the political division of Kathmandu district (b), Kirtipur municipality (c), a contour map of the study forest, red circled (d). The vertical distance between the contours is 20 m.

Phyto-geographically, the study area is located in the subtropical monsoonal climatic zone. The average annual temperature becomes maximum (31.9°C) during June and minimum during the month of December (2°C). The average annual rainfall is 1,480.4 millimetres (mm) (Department of hydrology and meteorology [DHM] 2013).

Sampling and measurements

Vegetation sampling data were collected from 40 circular plots of 10 m radius (Aryal et al. 2017) from September 23 to October 9, 2018. The sampling plots were located applying a stratified random sampling method. The forest is divided by Balkhu-Dakshinkali road into two divisions and these two forest divisions were considered as strata. The sample plots were located randomly in these two forest divisions. About 1.3 ha (10.9%) of the total forest area was sampled. The geographic location of each plot was recorded from the centre of the plot using the Global Positioning System (GPS) while slope and aspect of each plot were recorded from a centre of a plot by clinometer. Canopy cover (%) was estimated visually from the centre of the plot. Tree height (H > 137 cm) and diameter at breast height (DBH, 137 cm) of all individuals of tree species (only trees with DBH ≥ 10 cm were measured) enrooted inside the plots were measured using a clinometer and DBH tape, respectively (Ekoungoulou et al. 2018).

The nested quadrat method was applied to assess the regeneration status of the forest at two life stages, i.e., seedlings and trees. The number of seedlings (< 137 cm height) were counted in 1 m radius circular plot constructed inside each main plot of 10 m radius (Subedi et al. 2010). The number of trees (≥ 10 cm DBH) were counted in the main plot of 10 m radius. Total 40 circular plots were studied for regeneration assessment.

The plant specimens were identified during vegetation sampling. Annotated checklist of the flowering plants of Nepal was used for the nomenclature of specimens (Press et al. 2000).

Estimation of biomass and carbon stock

The allometric model developed for the tropical "moist forest" (annual precipitation 1,500–3,500 mm) by Chave et al. (2005) was applied for the estimation of above-ground biomass (AGB) of the tree layer as annual precipitation of present study area is 1,480 mm.

$$AGB\ (kg) = 0.0509 \times \rho D^2 H \cdots\cdots\cdots\cdots \quad (1)$$

where ρ is wood density (g cm^{-3}), D is diameter at breast height of the tree (cm), and H is the height of the tree (m). The global database of Zanne et al. (2009) was used for the dry wood density for pine and Eucalyptus which was 0.327 and 0.804, respectively.

The below-ground biomass (the root of tree layers) was estimated by assuming that it constitutes 20% of the above-ground biomass (MacDicken 1997; Karki et al. 2016).

The total dry biomass (only living) was obtained as the sum of the above & below-ground biomass of the trees. The living C stock was calculated by multiplying the sum of the dry living biomass with the default C fraction of 0.5 (Aryal et al. 2013; Amir et al. 2018; Ekoungoulou et al. 2018; Luintel et al. 2018).

Biomass and C stock of individual tree species in a forest were determined by the following equation (2) as described by Bhatta et al. (2018).

Carbon stock (%)=(Carbon stock of particular tree species)/(the sum of carbon stock of all tree species)×100 ······ (2)

Estimated C stocks were converted into CO_2 equivalents (quantity of C×44/12) for calculating CO_2 stock by biomass of trees (Aryal et al. 2013; Bhatta et al. 2018).

Carbon stock in all the plots was calculated based on DBH of 5 cm intervals. Then, size class diagram (d-d curve) of C stock was prepared to analyze the distribution pattern of C stock in DBH classes.

Analysis of community structure

The field data were used to calculate density and basal area following the method described by Yadav et al. (1987).

A total number of plants of all species recorded in all the plots were divided into different size classes based on DBH of 5 cm intervals. Then, the d-d curve of plants was prepared to analyze the distribution pattern of individuals in DBH classes. Total count of plants was obtained by summation of the number of plants from all sampling plots.

Data analysis

Descriptive statistics were applied to generate means, range, total and standard error. Correlation analysis was performed to access the variation of C stock with stand density, tree height, tree DBH, biomass, basal area, canopy cover and seedling density. Similarly, a correlation among stand characteristics was also performed. A significant correlation was obtained if a confidence interval was less than 0.05 ($p < 0.05$). Prior to the correlation analysis, the data were tested for the normality (Shapiro-Wilk test, $p > 0.05$). Diameter, height and basal area meet the assumption of normality while density, biomass and C stock were log-transformed to meet the assumption of normality ($p > 0.05$). So, they were correlated by parametric test i.e. Pearson correlation. Canopy cover and seedling density didn't meet the assumption of normality ($p < 0.05$) even after transformation, so they were correlated by Spearman correlation, a non-parametric test. All these analyses were done using Microsoft Excel 2007 (Microsoft Corp., Redmond, WA, USA) and Statistical Package for Social Sciences (SPSS) version 20 (IBM Corp., Armonk, NY, USA).

Table 1. Mean density (plants ha^{-1}) and basal area (BA, m^2 ha^{-1}) of the two plant species and mean density (plants ha^{-1}), basal area (BA, m^2 ha^{-1}), plant DBH (cm) and height (m) of the study area

Eucalyptus citriodora		*Pinus roxburghii*		Study area			
Density±SE	BA±SE	Density±SE	BA±SE	Density±SE	BA±SE	DBH±SE	Height±SE
4.0±1.7	0.6±0.3	335.0±15.3	32.1±1.0	339.0±15.0	32.7±1.1	34.9±0.7 (range: 12.6-72)	24.4±0.4 (range: 15-61.3)

DBH, diameter at breast height; SE, standard error.

Results and Discussion

Forest properties

The study encountered only two tree species, namely, *Eucalyptus citriodora* (eucalyptus) and *Pinus roxburghii* (pine) (Table 1). This is because the studied CF is plantation forest where mainly pine with few other species including eucalyptus was planted at the time of plantation. Pine has 335.0±15.3 plants ha^{-1} density and 32.1±1.0 m^2 ha^{-1} basal area (Table 1). Similarly, density and basal area of eucalyptus are 4.0±1.7 plants ha^{-1} and 0.6±0.3 m^2 ha^{-1}, respectively. This showed that density and basal area of the pine were higher than the eucalyptus which is due to the plantation of the high number of pine than the eucalyptus and also the pine has faster growth rate than the broad-leaved eucalyptus (Aryal et al. 2013).

The forest has a density and basal area of 339.0±15.0 plants ha^{-1} and 32.7±1.1 m^2 ha^{-1}, respectively (Table 1). The density and basal area of the present study was within the range of the density (107-878 plants ha^{-1}) and basal area (18.1-32.3 m^2 ha^{-1}) of the previous studies from Nepal and abroad (Nizami et al. 2009; Sharma et al. 2010; Sheikh and Kumar 2010; Nizami 2012; Kumar et al. 2013; Shaheen et al. 2016; Amir et al. 2018; Ghimire et al. 2018) (For detail see Table 2). Similarly, the forest has trees with mean DBH and height of 34.9±0.7 cm (range: 12.6-72) and 24.4±0.4 m (range: 15-61.3), respectively (Table 1). This showed that the trees were of big size indicating the mature nature of the forest. The mean DBH of the present study was within the range of mean DBH (16.8-40.7 cm) of the previous studies while mean tree height was slightly higher than the mean tree height (15.3-20.6 m) of the previous studies (Baral et al. 2009; Kumar et al. 2013; Kaur and Kaur 2016; Amir et al. 2018; Ghimire et al. 2018) (For detail see Table 3). This difference may be due to site differences that may have altered the growth rate of pine and resulted in the overall variation of mean height (Ekoungoulou et al. 2018).

Diameter class-wise distribution is considered an important feature of forest dynamics, structural heterogeneity and functioning of numerous forest ecosystems (Lutz et al. 2013). This study revealed that total stem density (trees with diameter ≥10 cm) increases with an increasing diameter up to certain limit i.e. up to intermediate diameter class (30-34.9) and then total stem density decreases with further increasing diameter thus the d-d curve appeared almost bell-shaped (Fig. 2). It explained the mature nature of the forest (Dar et al. 2017). This situation may be due to disturbances in the past which may have reduced the regeneration potential of the forest and also the removal of big sized trees (Nizami 2012). But, after the community management, these activities were stopped which may have facilitated the growth of trees. Similar pattern was also observed by Dar et al. (2017) in the coniferous and broad-leaved forests of India.

Biomass and carbon stock

The aboveground (AG), belowground (BG) and total biomass of pine were 167.7±6.6 Mg ha^{-1}, 33.5±1.3 Mg ha^{-1} and 201.2±7.9 Mg ha^{-1}, respectively (Table 4). Similarly,

Table 2. Correlation analysis between the carbon stock (Mg ha^{-1}), biomass (Mg ha^{-1}), tree density (trees ha^{-1}), tree DBH (cm), tree height (m), basal area (m^2 ha^{-1}), seedling density (seedlings ha^{-1}) and canopy cover (%) of the present study

Variables	Carbon stock	Biomass	Density	DBH	Height	Basal area	Canopy cover	Seedling density
Carbon stock	1	1*	0.26	0.45*	0.67*	0.88*	0.22	-0.30
Biomass	1*	1	0.26	0.45*	0.67*	0.88*	0.22	-0.30
Density	0.26	0.26	1	-0.69*	-0.30	0.53*	-0.32*	0.29
DBH	0.45*	0.45*	-0.69*	1	0.67*	0.22	0.32*	-0.33*
Height	0.67*	0.67*	-0.30	0.67*	1	0.33*	0.27	-0.31
Basal area	0.88*	0.88*	0.53*	0.22	0.33*	1	0.12	-0.18
Canopy cover	0.22	0.22	-0.32*	0.32*	0.27	0.12	1	-0.65*
Seedling density	-0.30	-0.30	0.29	-0.33*	-0.31	-0.18	-0.65*	1

No. of plots. N=40.

*Represents the significant difference, $p < 0.05$.

Table 3. Comparison of forest characteristics of the presently studied chir pine (*Pinus roxburghii*) forest with chir pine forests of Nepal and other parts of the world

Locality	DBH (cm)	Height (m)	Density (ha^{-1})		Basal area (m^2 ha^{-1})	Biomass (Mg ha^{-1})	Vegetation C density (Mg ha^{-1})	References
			Trees	Seedlings				
Kathmandu, Nepal	34.9	24.4	339	4,965	32.7	214.9	107.5	Present study
Lalitpur, Nepal	-	-	-	-	-	-	173.3	Aryal et al. (2013)
Langtang National Park, Nepal	-	-	-	-	-	-	454.4-706	Aryal et al. (2017)
Sirmaur, Himachal Pradesh, India	-	-	690	2,611-7,778	-	-	-	Attri et al. (2017)
Garhwal Himalaya, India	-	-	380	450	-	-	-	Ballabha et al. (2014)
Lalitpur, Nepal	31.2	18.1	-	-	-	-	38.7	Baral et al. (2009)
Makawanpur, Nepal	30.8	17.9	107	-	-	307.5	144.96	Ghimire et al. (2018)
Myagdi & Sindhupalchowk, Nepal	-	-	-	-	-	-	41.5-101.9	Mandal et al. (2017)
Gorkha & Dolakha, Nepal	-	-	-	-	-	-	91.4	Pandey et al. (2014)
Salyan, Nepal	-	-	-	-	-	-	24.6	Shrestha and Devkota (2016)
Murree hill, Pakistan	40.7	16	350.4	-	32.3	338.3	158.6	Amir et al. (2018)
Almora (Uttarakhand), India	-	-	-	-	-	-	62	Jina et al. (2008)
Solan (Himachal Pradesh), India	20.3	20.6	-	-	-	144.9	65.2	Kaur and Kaur (2016)
Tehri Garhwal (Uttarakhand), India	16.8	15.3	590-640	-	-	105.8-132.7	52.9-66.3	Kumar et al. (2013)
Murree hill, Pakistan	-	-	776 & 878	-	26.1 & 30.4	186 & 237	92 & 119	Nizami (2012)
Murree hill, Pakistan	-	-	878	-	28.5	186 & 237	93 & 119	Nizami et al. (2009)
Solan (Himachal Pradesh), India	-	-	-	-	-	-	47.3	Shah et al. (2014)
Kashmir Himalayas, Pakistan	-	-	275 & 320	50-110	-	369.6 & 589	184.8 & 294.7	Shaheen et al. (2016)
Pauri Garhwal (Uttarakhand), India	-	-	525	-	-	159.4 & 298	73.3 & 137.1	Sharma et al. (2010)
Tehri Garhwal (Uttarakhand), India	-	-	860	-	18.1	133	59.8	Sheikh and Kumar (2010)
Nainital, Kumaun Himalaya, India	-	-	540 & 935	405 & 465	-	-	-	Singh et al. (2014)

DBH, diameter at breast height; C, carbon; cm, centimetre; m, meter; ha, hectare; Mg, megagram.

eucalyptus has AG, BG and total biomass of 8.9±3.9 Mg ha^{-1}, 1.8±0.8 Mg ha^{-1} and 10.7±4.7 Mg ha^{-1}, respectively. The AG, BG and total C stock of pine was 85.1±3.4 Mg ha^{-1}, 17.0±0.7 Mg ha^{-1} and 102.1±4.1 Mg ha^{-1}, respectively (Table 4). The AG, BG and total C stock of eucalyptus was 4.5±2.0 Mg ha^{-1}, 0.9±0.4 Mg ha^{-1} and 5.4±2.4 Mg ha^{-1}, respectively. The CO_2 stock of pine and eucalyptus was 374.7±14.9 Mg CO_2 ha^{-1} and 19.7±8.7 Mg CO_2 ha^{-1}, respectively (Table 2). This indicated that pine has higher biomass, C stock and CO_2 stock than the eucalyptus. This is due to higher density (Ghimire et al. 2018) and basal area (Amir et al. 2018) of pine than the eucalyptus.

The forest has 214.9±9.8 Mg ha^{-1} biomass with 179.1±8.1 Mg ha^{-1} aboveground and 35.8±1.6 Mg ha^{-1} belowground (Table 4). Similarly, aboveground, belowground and total C stock of the forest was 89.57±4.1 Mg ha^{-1}, 17.9±0.8 Mg ha^{-1} and 107.5±4.9 Mg ha^{-1}, respectively (Table 4). The biomass and C stock of the forest are in accordance with the range of biomass (105.8-589 Mg ha^{-1}) and C stock (24.6-706 Mg ha^{-1}) reported from the similar type of forest from Nepal and abroad (Jina et al. 2008; Baral et al. 2009; Nizami et al. 2009; Sharma et al. 2010; Sheikh and Kumar 2010; Nizami 2012; Aryal et al. 2013; Kumar et al. 2013; Pandey et al. 2014; Shah et al. 2014; Kaur and Kaur 2016; Shaheen et al. 2016; Shrestha and Devkota 2016; Aryal et al. 2017; Mandal et al. 2017; Amir et al. 2018; Ghimire et al. 2018) (For detail see Table 3).

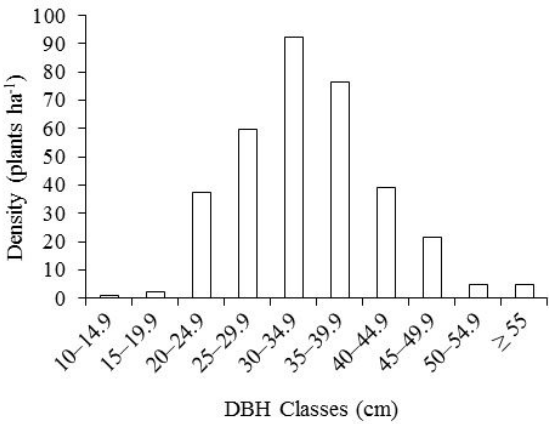

Fig. 2. DBH size class distribution diagram (d-d curve) of the plants of the present study area.

The forest stored 394.4±17.9 Mg CO_2 ha^{-1} (Table 4). This value is lower than the value reported by Aryal et al. (2017) in the pine forests of Langtang National Park of Nepal (3,346.3-2,038 Mg ha^{-1}) which is due to differences in site conditions, disturbance between the forests (Rossi et al. 2007) and management type.

The d-d curve for the C stock attained the J-shaped pattern (Fig. 3) which is due to larger diameter trees with increasing diameter classes (Sharma et al. 2010; Dar et al. 2017; Nath et al. 2017) as diameter have important role in altering the C stock of the forest (Aryal et al. 2013; Nath et al. 2017; Amir et al. 2018; Bhatta et al. 2018; Ghimire et al. 2018). This showed that higher diameter plants are important members of the forest in terms of C storage which stored a high proportion of forest C and removal of these individuals from the forest would release a high amount of C from the forest.

Regeneration status

The seedling and tree density in the forest was 4,965 seedlings ha^{-1} and 339 trees ha^{-1}, respectively (Fig. 4). This shows the good regeneration status of the forest as seedling density was greater than tree density (Khumbongmayum et al. 2006; Tripathi and Khan 2007). The tree density was lower than the previous studies (Ballabha et al. 2014; Singh et al. 2014; Attri et al. 2017) while seedling density was higher than Ballabha et al. (2014), Shaheen et al. (2016) and Singh et al. (2014). But, seedling density was within the range of value reported by Attri et al. (2017) (For detail see Table 3). The regeneration differences between the present study and previously mentioned studies are mainly

Table 4. Biomass and carbon stock in the two plant species and study area of present study

Species & study area	Mean biomass (Mg ha^{-1})			Mean carbon stock (Mg ha^{-1})			COS±SE (Mg ha^{-1})
	AGB±SE	BGB±SE	TB±SE	AGC±SE	BGC±SE	TC±SE	
Eucalyptus	8.9±3.9	1.8±0.8	10.7±4.7	4.5±2.0	0.9±0.4	5.4±2.4	19.7±8.7
Pine	167.7±6.6	33.5±1.3	201.2±7.9	85.1±3.4	17.0±0.7	102.1±4.1	374.7±14.9
Study area	179.1±8.1	35.8±1.6	214.9±9.8	89.6±4.1	17.9±0.8	107.5±4.9	394.4±17.9

AGB, aboveground biomass; BGB, belowground biomass; TB, total biomass; AGC, aboveground carbon stock; BGC, belowground carbon stock; TC, total carbon stock; COS, CO_2 stock; SE, standard error.

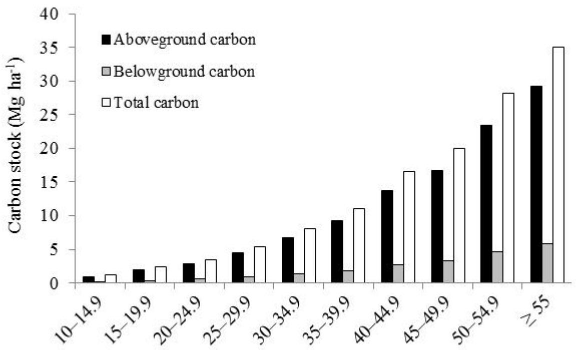

Fig. 3. DBH class wise carbon stock in the forest of the present study.

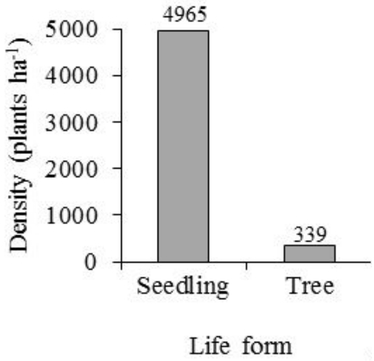

Fig. 4. Seedling and tree density in the forest of the present study.

due to the differences in the forest species composition, edaphic factors, climatic condition, disturbance intensity and also the criteria applied for categorisation of regeneration class i.e. life forms (Ballabha et al. 2014; Khaine et al. 2018).

Correlation analysis

The correlation analysis (Table 2) showed that the forest C stock was positively correlated with plant DBH, height, basal area (BA) and biomass. A similar finding was also observed by Thapa-Magar and Shrestha (2015) and Shaheen et al. (2016). Thus, tree diameter, height, BA and biomass are the determinant variable for forest C. Similarly, biomass was positively correlated with DBH, height, BA and C stock. Density and DBH were negatively correlated which is in accordance with Nizami et al. (2009), Nizami (2012) and Amir et al. (2018). This may be not only due to the natural thinning process but due to selective removal of big sized trees (Nizami 2012). Likewise, DBH and height were positively correlated which is similar to findings of Nizami et al. (2009). This is because plants of the study site experienced similar environmental condition and their growth rate is affected in the same way (Ekoungoulou et al. 2018). Similarly, DBH was positively correlated with canopy cover. Density and seedling density was negatively correlated with canopy cover and DBH. This may be due to a reduction in light penetration with increasing canopy cover as pine is a strong light demander which requires sufficient light for proper growth (Jackson 1994). Density and plant height was positively correlated with a BA (Table 2).

Conclusion

Only two tree species were recorded in the study area, namely, *Eucalyptus citriodora* (eucalyptus) and *Pinus roxburghii* (pine). Among these two species, pine has higher density, basal area, biomass, C stock and CO_2 stock than the Eucalyptus. The forest has a density and basal area of 339.0±15.0 plants ha^{-1} and 32.7±1.1 m^2 ha^{-1}, respectively. The forest stored 107.5±4.9 Mg ha^{-1} carbon and 394.4±17.9 Mg ha^{-1} CO_2. The result indicated the mature nature of the forest with big sized trees where most of the C of the forest was stored by the large-sized trees. The regeneration was good with 4,965 seedlings ha^{-1} and 339 trees ha^{-1}. The result showed that the tree DBH, height, basal area and biomass were the determinant variable for forest C which positively affected the forest C stock while tree density has no effect on forest C stock. Similarly, seedling density was negatively affected by DBH and canopy cover. To conclude, the forest has good regeneration status, stored a significant amount of carbon and carbon dioxide into the forest biomass and have a potentiality to mitigate the global climate change.

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