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TREE DISTRIBUTION PATTERN, GROWING STOCK CHARACTERISTICS AND BIOMASS CARBON DENSITY OF MONGOLIAN SCOTS PINE (*PINUS SYLVESTRIS* VAR. *MONGOLICA*) PLANTATION OF HORQIN SANDY LAND, CHINA

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Abstract

In the recent scenario of global warming, there is a growing concern of planted forest as a potential option for the mitigation of climate change, combating desertification and land degradation. The amount and monitoring of biomass and carbon in planted forests are necessary for policies formulation and mitigation strategies for global climate change. This study estimates tree distribution, growing stock attributes and biomass allocation in different tree components with respect to different diameter classes (4-14, 15-25, 26-36 cm) in planted Mongolian Scots pine (*Pinus sylvestris* var. *mongolica*) forests, southern-east China. The study also underlines the carbon density in upper and understory vegetation, soil, litter, deadwood and cone of the planted forest ecosystem. The result showed that stem density, basal area, height, volume and biomass varied between 144 to 25, 1.009 to 1.607 (m^2 ha^{-1}), 5.56 to 12.06 (m), 2.77 to 7.71 (m^3 ha-1) and 2.74 to 5.17 (Mg ha^{-1}) in respective diameter classes. The maximum biomass in upper story vegetation was recorded in the stem (62.87 %) followed by branches (17.25 %), roots (17.12 %) and foliage (2.69%). The biomass carbon in upper story vegetation was in the range of 1.37 ± 0.11 to 13.96 ± 0.41 Mg C ha^{-1}. Soil carbon was found in the range of 25.10±11.67 to 6.07±2.26 at the depth 0-20 and 80-100 cm respectively. Similarly the carbon stock of litters, dead wood, fruits and grasses was 0.138 and 0.050 (Mg C ha^{-1}) respectively. Altogether, the estimated carbon density of the plantation was 77. 68 (Mg C ha^{-1}). Out of the total carbon, the soil contributed the highest (75.59%) followed by upper story vegetation biomass carbon (22.17%), litter and dead wood (0.17%) and understory vegetation (0.06%) respectively. The results showed that this forest plantation is an important carbon sink and assisting in mitigating climate change.

Key words: Growing stocks attributes; Carbon pools; Biomass; Biomass carbon density; Mongolian scots pine plantation.

Introduction

Global climate change has been an indisputable environmental problem which has severe ecological, economic and political impacts on a human being (FitzRoy & Papyrakis, 2010; Cowie, 2012). Carbon dioxide, a main greenhouse gas component, play a key role in this unprecedented change (Lieberman *et al*., 2010), which increased from 310 ppm in 1850 to 394 ppm in 2012 (Ahmad *et al*., 2019). It has been observed that 60% of climate change is because of the increase of CO_2 (Grace, 2004).

To control this increase in carbon concentration in the atmosphere and to sequester this increased amount, it has been suggested to increase the forest land under REDD+ activities (Peichl & Arain, 2006; Taylor *et al*., 2007). Being a major carbon source in global ecosystems, forest sequesters more carbon compared to other terrestrial ecosystem (Houghton, 2007), which store about 80% of all upper story global carbon (Waring & Running, 1998) and 40% of soil carbon (Dixon *et al*., 1994; Goodale *et al*., 2002). Because of this active role in mitigating the atmospheric CO_2, the forest is becoming a key source for decreasing the carbon dioxide in research society (Davis *et al*., 2003). The IPCC recognized five carbon pools in the terrestrial forest ecosystem which includes; Upper story, under story biomass, litter, dead woods and soil organic contents (Eggleston *et al*., 2006). Out of these five pools, the above-ground tree biomass has a major contribution in proportion and is the most prominent carbon pool in the terrestrial ecosystem. It has a direct impact on carbon pools if there is deforestation or land degradation. Below-ground biomass, including all the living roots (Eggleston *et al*., 2006), also plays a vital role, while the litter and the debris are not the major carbon pool (Lal, 2005). Soil organic matter also plays an important role in carbon pools (Kumar *et al*., 2006). It has been estimated by Global Forest Resources Assessment that the total amount of carbon stored by world forest is 650 Gt, including 44% biomass, 72 Gt in the litter and dead wood and 45% in soil (Anon., 2010).

In China, the total forest area has now been increased to 311.3 million hectares including 78.98 million hectares planted forests (Anon., & Anon., 2015). The area of planted forest has not been of a huge contribution to the total terrestrial carbon balance but has the capacity to decrease the overall atmospheric increase in CO_2 (Canadell *et al*., 2007). During last two decades in China, carbon sequestration process has been increased (Zhang & Xu, 2003) because of more plantation which contributes about 80% of carbon sink increment to the total forest carbon (Fang *et al*., 2007).

Soil loss and conversion of land into deserts is a big concern, especially in dry areas that lead to the loss of natural resources in the world, particularly in China (Reynolds *et al*., 2007; Ci & Yang, 2010). To control this loss, the Chinese government launched a project in 1978 that comprised of controlling desertification and increasing forest area in

Northern China regions (Ma, 2004). Mongolian Scots Pine (*Pinus sylvestris* var. *mongolica*) had been a leading species in this project and was used to control the desertification and increasing the forest resources in the area. Since in these regions there is a scarcity of water and nutrients, the *Pinus sylvestris* var. *mongolica* was the best candidate to coupe with unlimited water resources and to check the soil loss (Bang *et al.*, 2010).

Despite the fact that the Mongolian Scots Pine Plantation forests in Three-North regions has a great role in the combating of desertification and land degradation, this forest ecosystem is also acting as carbon sinks but very less information about the carbon sequestration rate and potential of this forest is available. Similarly, there is very limited literature about the tree distribution pattern, growing stock characteristics, biomass carbon allocation in different tree components of this important planted forest ecosystem. Thus, we conducted this study with overall objectives; (1) to determine the tree distribution pattern, growing stocks attributes and biomass allocation in different tree components with respect to different diameter classes (2) to estimate the carbon sequestration potentials in different carbon pools of Mongolian Scots Pine and 3) to investigate the role of Scots Pine plantations in mitigating the climate change. Our research will act as a baseline for future studies for the checking and mapping of CO_2 because so far no such study has been conducted in the study area for mitigating the CO_2 along the diameter classes.

Material and Methods

Study area: This study was conducted in Zhanggutai, Zhangwu County, Liaoning Province, China, in the southeastern Horqin Sandy Land (N 42◦ 39.7’, E 122◦ 33.6’, altitude 247.6 m) (Fig. 1). The mean annual temperature was 5.7◦C, and the minimum and maximum air temperatures (1954–2004) are –29.5◦C and 37.2◦C, respectively. Annual precipitation is 450.0 mm (minimum 224.8 mm and maximum 661.3 mm, during 1954–2004) and annual evaporation was about 1700.0 mm. The frost-free period is about 154 days (Xiangyun *et al.*, 2002; Zhu *et al.*, 2003). The current average groundwater table is 5.3 m, but it was 1 m about 50 years ago (Zhu *et al.*, 2003; Zhang *et al.*, 2005).

Pinus sylvestris var. *mongolica* occurs in naturally distributed in Hulun Buir deserts of northern China having strong adaptability to sandy lands with less water, extreme temperature and nutrients. In view of these characteristics, in 1950s Scots pine was first planted in Horqin deserts to check the desertification. In our study, surveyed Mongolian Scots pine plantation is intersected by patches of natural elm, grassland savanna, planted Chinese pine (*Pinus tabulaeformis*) and poplar on the flat fixed sand dunes. Understory vegetation of Mongolian Scots pine includes *Leonurus sibiricus, Setaria viridis, Lespedeza bicolor* and *Ixeris sonchifolia*.

Data collection and biophysical measurement: A random sampling was applied to collect field data in 8 different sites. All the trees were grouped in three diameter classes i.e.: 4-14, 15-25 and 26-35 centimeter respectively. In each site 50 × 50 meter standard plot was taken and then the non-destructive sampling method was applied to determine the upper and understory biomass carbon. This method requires measurement of aboveground variables, like diameter at breast height DBH and height of each tree in sample plots. The DBH (diameter at breast height) of each tree was measured by caliper, while the tree height was measured by a concern indicator (NIKON 550A S, TOKYO, JAPAN).

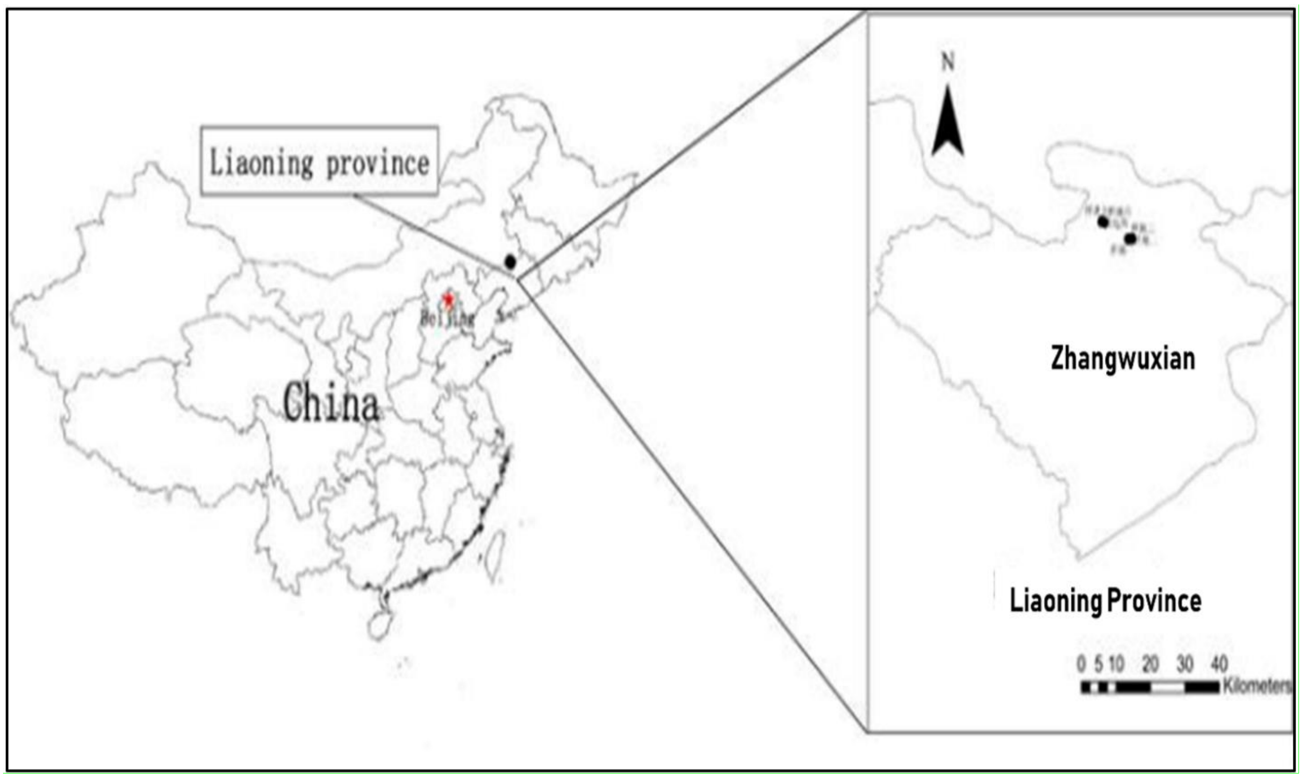

Fig. 1. Map of the study area. Liaoning Province, China.

Grasses, litter, deadwood and cones: A sample plot of 1m×1m was laid for grass, litter, dead woods and cone collection. In each sample plot, the grasses, litter, dead woods and fallen cones were collected and then oven dried for biomass measurement.

Soil sampling: In each 50 × 50 m sample plot, three quadrats of size 1m × 1m were selected across the plantation. Soil samples were collected from the top 100 cm soil profile using soil augur and a soil core of 100 cm^3. Total 24 quadrats were selected at five depth levels: 1-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm. In order to avoid the disturbance of different aspects like wind-thrown, animal holes, etc, the distance from the tree stem was kept 1 meter (Anon., 2003). The collected soil samples were packed in bags and then oven dried for 24 hours at a temperature of 105°C. The soil carbon (%) was measured by following Nelson & Sommers (1982). To determine the soil carbon first, soil bulk density was calculated by the equation (1) (Lal & Shukla, 2004) and then from the value of bulk density, soil layers depth, and percent soil carbon, the soil carbon was estimated.

$$pb = M_s/V_t \qquad (1)$$

where; ρb is the bulk density ($g \cdot cm^{-3}$), M_s is the dry mass total sample (g) and V_t is the core volume (cm^3).

Biomass and carbon estimation of trees: Biomass was calculated using the DBH and tree total height (H) as an explanatory variable. For calculating the above and below ground biomass the experimental models from (Xing *et al.*, 2017) was used for biomass estimation of organs (stem, branch, foliage, and root) of Mongolian Scots pine.

a. Soil carbon analysis: As suggested by Lu (1999) the air-dried soil was passed through a sieve (0.25 mm) to determine the soil carbon concentration. The soil samples were then digested with 8 mL of H_2SO_4 and titrated with dichromate oxidation-ferrous sulfate to determine the organic carbon (Lu, 1999).

b. Calculation of total tree carbon storage: In order to estimate the carbon storage for tree layers, the total CO_2 amount was used to the biomass calculation in the various stand diameter classes, then summed up and scaled on the basis of total area ($t \cdot ha^{-1}$). For the calculation of carbon concentration we used the following equation (2) (Malhi *et al*., 2004; Ahmad *et al*., 2014; Khan *et al*., 2015):

$$Cc = B \times 0.5 \qquad (2)$$

where Cc is carbon concentration (Mg ha^{-1}), B is biomass (Mg ha^{-1}).

Soil organic carbon storage in different profile layers was determined by following Broos & Baldock (2008) as in equation (3);

$$SOCS = SOC \times SBD \times D \qquad (3)$$

where SOCS is soil organic carbon storage (g kg^{-1}), SOC is soil organic carbon (%), SBD is soil bulk density (g cm^{-1}), and D is soil depth (m).

c. Biomass expansion factor (BEF): For calculation of biomass expansion factor, the following equation (4) was used (Abbas *et al*., 2011; Giri *et al*., 2014).

$$BEF = \frac{Total\ biomass}{Stem\ biomass} \qquad (4)$$

d. Statistical analysis: The stand characteristics parameters (basal area, stem biomass, branches biomass, foliage biomass, root biomass, total biomass, biomass expansion factor, stem biomass carbon, branches carbon, foliage biomass carbon, root biomass carbon and total carbon) of Mongolian Scots pine plantations in three diameter classes of 4-14, 15-25 and 26-35 cm were tested with ANOVA, and their relationships with basal area (BA) were fitted as Polynomial Cubic correlation, in the meanwhile, soil organic carbon (Mg C ha^{-1}) in different soil layers and carbon stocks in biomass and soil were also tested with ANOVA. All the statistical analysis were completed by statistical software packages Statistix 8.1 and SigmaPlot 12.5.

Results and Discussion

Details of the growing stocks characteristics and biomass carbon distribution in different tree components are given in Table 1. The results showed that the stem density was found statistically higher in diameter class 15-25 cm. The mean tree height was found higher in the diameter class 26-35 cm. The values of basal area (BA), Volume (V), stem biomass (SBM), foliage biomass (FBM), branches biomass (BBM), root biomass (RBM) and total tree biomass (TBM) were found significantly higher in diameter class 15-25 cm. Regarding the percentage distribution of biomass in different tree components, the maximum biomass was found in the stem then branches, root and foliage in diameter class 4-14 cm. Similarly, in diameter class 15-25 and 26-36 cm, the stem contributes to the larger proportion of total biomass followed by roots, branches and foliage. The biomass expansion factor (BEF) value was recorded higher in diameter class 4-14 cm. A decreasing trend was found in the BEF value with an increasing diameter due to the larger proportion of stem biomass (Table 2). Furthermore, the results depicted that the highest biomass carbon in different tree components (Table 1) was recorded in diameter class 15-25 cm. Overall the results highlighted that the plantation held a mean carbon value of 17.91 ± 0.58 Mg ha^{-1} in the living tree biomass, in which the diameter class 15-25 cm contributed maximum followed by 26-35 cm and 4-14 cm.

The present study also correlated the tree volume, the biomass of the respective tree components (stem, branches, foliage, roots) and total biomass with the basal area in different diameter classes (Fig. 2A, B, C). Similarly, the BEF values and the carbon value of various tree constituents, as well as the total tree biomass carbon, were also correlated with the basal area (Fig. 2A, B, C). Details of the correlation analysis are given in Table 3. The results of the correlation analysis between the basal area and the respective parameters in Table 3 described a positively high correlation with the studied parameters in all diameter classes. This highly positive correlation of basal area with stem volume, different tree biomass carbon components and total trees biomass carbon explained the importance of the basal area in measuring these values.

Table 1. Stand characteristics of mongolian scots pine plantations in three diameter classes of 4-14, 15-25 and 26-35 cm.

Parameters	Diameter classes mongolian scots pine			Total
	4-14 cm	15-25 cm	26-35 cm	
Density	144 ± 8[b]	281 ± 7[a]	25 ± 2.00[c]	420 ± 11.50
Height (m)	5.56 ± 1.90[c]	10.33 ± 0.98[b]	12.06 ± 0.13[a]	9.32 ± 3.04
BA (m^2 ha^{-1})	1.009 ± 0.07[b]	8.76 ± 0.24[a]	1.607 ± 0.10[b]	11.37 ± 0.36
Vol (m^3 ha-1)	2.77 ± 0.22[b]	36.81 ± 1.18[a]	7.71 ± 0.48[b]	47.29 ±1.57
SMB (Mg ha^{-1}))	1.61 ± 0.13[b]	17.84± 0.53[a]	3.41 ± 0.22[b]	22.85 ± 0.75
BBM (Mg ha^{-1})	0.56 ± 0.44[b]	4.64 ± 0.12[a]	0.76 ± 0.05[b]	5.97 ± 0.19
FBM (Mg ha^{-1})	0.12 ± 0.009[b]	0.60 ± 0.014[a]	0.08 ± 0.006[b]	0.80 ± 0.02
RBM (Mg ha^{-1})	0.45 ± 0.04[b]	4.84 ± 0.14[a]	0.91 ± 0.06[c]	6.20 ± 0.20
TBM (Mg ha^{-1})	2.74 ± 0.22[b]	27.92 ± 0.18[a]	5.17 ± 0.34[b]	35.82 ± 1.17
BEF	1.83 ± 0.18[a]	1.57 ± 0.03[b]	1.51 ± 0.01[b]	1.64 ± 0.18
SBMC (Mg C ha^{-1})	0.80 ± 0.06[b]	8.92 ± 0.26[a]	1.71 ± 0.11[b]	11.43 ± 0.38
BBMC (Mg C ha^{-1})	0.28 ± 0.02[b]	2.32 ± 0.06[a]	0.382 ± 0.023[b]	2.98 ± 0.10
FBMC (Mg C ha^{-1})	0.06 ± 0.005[b]	0.30 ± 0.007[a]	0.04 ± 0.003[b]	0.40 ± 0.01
RBMC (Mg C ha^{-1})	0.22 ± 0.02[b]	2.42 ± 0.07[a]	0.46 ± 0.03[b]	3.10 ± 0.10
TBMC (Mg C ha^{-1})	1.37 ± 0.11[b]	13.96 ± 0.41[a]	2.58 ± 0.17[b]	17.91 ± 0.58
% Age	**7.65**	**77.94**	**14.4**	**100**

BA, basal area, SMB, stem biomass, BBM, branches biomass, FBM, foliage biomass, RBM, root biomass, TBM, total biomass, BEF, biomass expansion factor, SBMC, stem biomass carbon, BBMC, branches biomass carbon, FBMC, foliage biomass carbon, RBMC, root biomass carbon and TBMC, total biomass carbon. Different superscripts in each column represent a significant difference (Values are means ± SD, n=8, alpha=0.05)

Soil, understory vegetation and forest floor: The soil organic CO_2 concentration of five (5) layers was determined. The results showed a decreasing trend in organic carbon concentration with the increase in depth. A significant change in soil carbon was found along the depth increment (Table 4). The significantly highest value of organic carbon of 25.10 Mg C ha^{-1} was recorded in layer 0-20 cm and significantly the lowest value of 6.07 Mg C ha^{-1} was in 80-100 cm. It is clear that in total soil carbon, the highest percentage of carbon was found at the depth of 0-20 cm. The layers 20-40 and 40-60 cm shared the nearly same percentage carbon, while the layers 60-80 and 80-100 cm shared the value of 12.88 and 9.69 percent in total carbon respectively. These results revealed that about 77% of the organic CO_2 was stored up to 60 cm in depth (Table 4). Besides the soil carbon, the carbon values of different forest floor components such as litter, deadwood, and cone and understory vegetation were also recorded. The mean carbon density of the different forest floor components and understory vegetation was 0.138 ± 0.084 and 0.050 ± 0.018 Mg C ha^{-1} respectively (Table 5).

Total biomass carbon storage: The total carbon amount of different carbon components of the Mongolian Scots pine planted forest has been summarized in (Table 5). The results clearly explained that among the different carbon pools significance variations in carbon values were found. Among the different carbon components, a significantly higher carbon stock was measured in the soil. Similarly, the upper story vegetation stored statistically higher carbon than forest floor and understory vegetation. However, no significant difference was found in the carbon values of forest floor and understory vegetation though, the mean carbon stock of the forest floor was recorded more than the understory vegetation (Table 5). Altogether, the present results concluded that the Mongolian Scots pine planted ecosystem hold a mean carbon of 77. 68±29.66 Mg C ha^{-1}. Out of the total stored carbon, 75.59% carbon was stored in soil and 22.17% was stored in upper story vegetation.

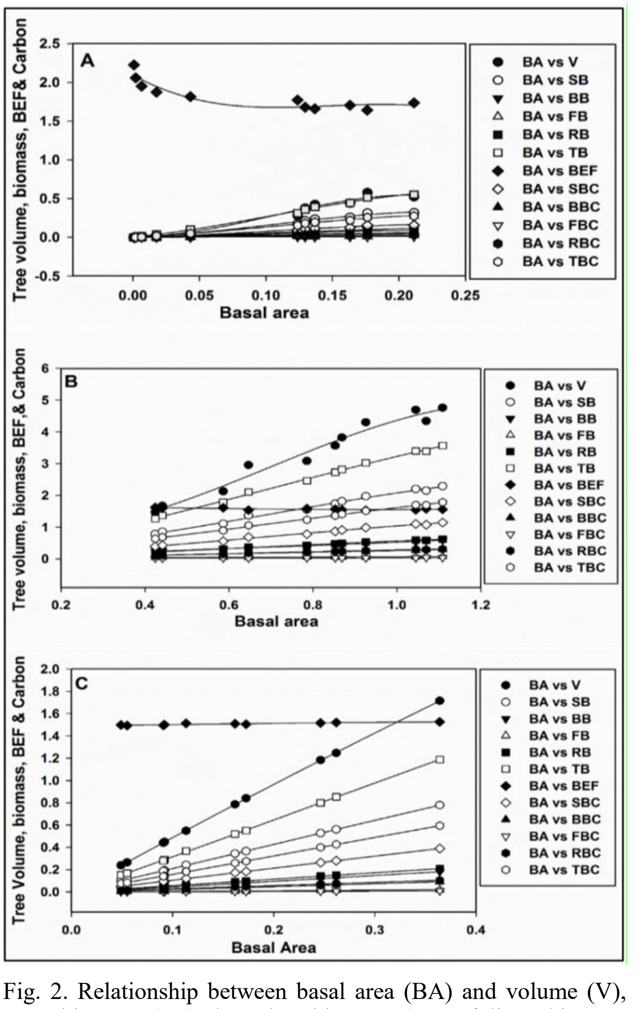

Fig. 2. Relationship between basal area (BA) and volume (V), stem biomass (SB), branches biomass (BB), foliage biomass (FB), root biomass (RB), total biomass (TB), biomass expansion factor (BEF), stem biomass carbon (SBC), branches biomass carbon (BBC), foliage biomass carbon (FBC), root biomass carbon (RBC) and total biomass carbon (TBC) of diameter class 4-14, 15-25 and 26-35 (**A**), (**B**), (**C**).

Table 2. Percentage of biomass accumulation in different components of Mongolian Scots pine categorized by diameter classes.

Parameters	Diameter classes			
	4-14 cm	15-25 cm	26-35 cm	Mean
Stem biomass	58.76	63.90	65.96	62.87
Branches biomass	20.44	16.62	14.70	17.25
Foliage biomass	4.38	2.15	1.55	2.69
Root biomass	16.42	17.33	17.60	17.12

In the recent scenario of climate change, planted forests attached greater value around the globe. Artificial forests, contributing for about 7 % of the total forests area (Anon., 2015), are considered an important carbon mitigation tools (Saeed *et al*., 2016). *Pinus sylvestris* var. *mongolica* is considered one of the major planted species for combating desertification and land degradation (Ma, 2004), and has been widely planted for windbreak and sand stabilization in China. What's more, Mongolian Scots pine plantation also acting an important carbon sink. This study estimates different growing stocks parameters such as stand density, tree height, stand basal area and volume of the Mongolian Scots pine in various diameter classes. The results showed the higher values of stand basal area and stand volume in diameter class 15-25 cm compared to the 4-14 and 26-35 cm classes, which was attributed to the larger proportion of trees in diameter class 15-25 cm (Table 1).

The living trees biomass carbon component is an important and major carbon pool. The living trees store carbon in different biomass constituents such as stem, leaves, branches and roots. Among the different biomass components, the stem is the main portion which stores the highest amount of carbon particularly in conifers (Justine *et al*., 2015; Deng *et al*., 2017). Our results showed a high biomass percentage in the stem in all diameter classes (Table 2). However, an increasing trend was observed in the stem biomass with respect to increasing diameter. In diameter class 4-15 cm the stem contributes 58.76% of the total tree biomass and those in 15-25 cm and 26-35 cm contribute 63.90% and 65.96% in total biomass. This is because at the younger age stem component forms less proportion of a tree as compared to older age and with increasing diameter. The results further showed a decreasing trend in the value of branches and foliage biomass and an increasing trend of root biomass with increasing diameter (Table 2). In the younger age the branched portion of a tree is relatively more as compared to older age trees, as the tree becomes bigger in size, the proportion stem increases and gradual decrease occur in the number of branches because of competition for light and nutrients (Gower *et al*., 1996; Rothstein *et al*., 2004; Nizami, 2012; Alam & Nizami, 2014). The reduction in the number of branches with natural pruning with respect to increasing age and size, the decreasing trend in branches and foliage biomass and an increasing trend in root biomass was observed with respect to increasing diameter.

The BEF is the ratio between the total tree and stem biomass. BEF describes the role of various tree constituents in the total tree biomass. The BEF ratio can be used in assessing the biomass carbon of the whole trees as using the growing stock volume and wood density only gives the stem biomass carbon (Giri *et al*., 2014). The assessed value of BEF in the present study varied between 1.83±0.18 in diameter class 4-14 cm and 1.51±0.01 in 26-35 cm with a mean value of 1.64±0.18 (Table 1). The findings showed a decreasing trend in BEF with respect to the increasing trend in diameter, which is attributed to the increasing stem biomass with increasing diameter. These results are consisted with (Levy *et al*., 2004; Abbas *et al*., 2011).

Basal area of a forest is also an important parameter that can be used in the measurement of stand volume and biomass carbon. Tree basal area has a direct relation with tree volume and biomass carbon and with an increase in its value, the biomass of a tree also increases (Nizami, 2012; Ahmad & Nizami, 2015). Stand basal area can facilitate the measurement of forests carbon as it integrates the diameter and density (Balderas Torres & Lovett, 2012). In this study, we correlated the basal area with stand volume and different biomass components and total tree biomass in respective diameter classes (Fig. 2A, B, C). Table 3 summarized the results of correlations analysis. The regression models clearly explained that basal area is strongly related with stand volume, different biomass components, and total tree biomass as well to BEF (Fig. 2A, B, C; Table 3). These results pinpoint the importance of the basal area in assessing biomass carbon of a forest.

Our findings outline a total mean biomass carbon of 1.37, 13.96 and 2.58 Mg C ha^{-1} in 4-14, 15-25 and 26-35 cm diameter classes respectively (Table 1). This greater value of biomass CO_2 in the diameter class 15-25 cm is due to the number of more trees in the range of 15 to 25 cm. The difference in stand density and nutrients is the major factor of variations in living tree biomass carbon of pine forests (Hooker & Compton, 2003; Noh *et al*., 2010; Baishya & Barik, 2011; Cao *et al*., 2012). This study reveals that stand diameter and density and management history have key roles in influencing the biomass and carbon sequestration and distribution in the whole region of Mongolia Scots Pine.

Soil carbon is an integral part of forests ecosystems. The presents study figured out soil carbon within different depth increment. The findings showed that most of the soil organic carbon is stored in the upper 20 cm soil profile, which is consistent with findings of other studies (Kang *et al*., 2006; Zhou *et al*., 2006). Soil organic carbon reported by others (Cao *et al*., 2012; Justine *et al*., 2015) was higher as compared to this study, this difference might be due to the difference in management history, soil type, soil profile depth, geographic and climatic conditions, environmental and geological factors of the study area. The biomass carbon of grasses and litters, dead wood, fallen cones varied from 0.06% to 0.17% that represent a comparatively lesser amount in the whole biomass carbon (Table 5). Across the whole ecosystem of the study area, most of the carbon quantity was reported in the soil as compared to the forest biomass, which was similar with the studies of that soil was a major pool to sequester ecosystem carbon (Schoenholtz *et al*., 2000).

Table 3. Details of the correlation analysis representing the diameter classes of 4-14 cm, 15-25cm, and 26-35 cm respectively (Polynomial Cubic).

Diameter classes	Parameters	Equation	y0	A	b	C	R^2
4-14 cm	[1]BA vs V t ha^{-1}	V= y0+a*x+b*x^2+c*x^3	0.0097	-0.0451	36.9551	-116.7981	0.97
	BA vs SBM t ha^{-1}	SMB= y0+a*x+b*x^2+c*x^3	0.0033	0.5727	13.5287	-42.6783	0.99
	BA vs BBM t ha^{-1}	BMB= y0+a*x+b*x^2+c*x^3	-7.7244E-005	0.5533	0.0736	-0.2075	1.00
	BA vs FBM t ha^{-1}	FMB= y0+a*x+b*x^2+c*x^3	-0.0003	0.2451	-1.6722	5.2569	0.97
	BA vs RBM t ha^{-1}	RMB= y0+a*x+b*x^2+c*x^3	0.0008	0.1818	3.4619	-10.9177	0.99
	BA vs TBM t ha^{-1}	TBM= y0+a*x+b*x^2+c*x^3	0.0037	1.5528	15.3919	-48.5466	0.99
	BA vs BEF t ha^{-1}	BEF= y0+a*x+b*x^2+c*x^3	2.0946	-9.5741	69.7878	-157.3407	0.86
	BA vs SBMC t ha^{-1}	SBMC= y0+a*x+b*x^2+c*x^3	0.0016	0.2863	6.7643	-21.3392	0.99
	BA vs BBMC t ha^{-1}	BBMC= y0+a*x+b*x^2+c*x^3	-3.8622E-005	0.2767	0.0368	-0.1038	1.00
	BA vs FBMC t ha^{-1}	FBMC= y0+a*x+b*x^2+c*x^3	-0.0002	0.1225	-0.8361	2.6285	0.97
	BA vs RBMC t ha^{-1}	RBMC= y0+a*x+b*x^2+c*x^3	0.0004	0.0909	1.7310	-5.4588	0.99
	BA vs TCS t ha^{-1}	TCS= y0+a*x+b*x^2+c*x^3	0.0018	0.7764	7.6960	-24.2733	0.99
15-25cm	[2]BA vs V t ha^{-1}	V= y0+a*x+b*x^2+c*x^3	1.0924	-3.0722	12.148	-5.8028	0.97
	BA vs SBM t ha^{-1}	SBM= y0+a*x+b*x^2+c*x^3	0.2057	0.5142	2.6152	-1.2574	0.99
	BA vs BBM t ha^{-1}	BBM= y0+a*x+b*x^2+c*x^3	-0.0732	0.9509	-0.671	0.3173	0.99
	BA FBM/ t ha^{-1}	FBM= y0+a*x+b*x^2+c*x^3	-0.0321	0.2828	-0.358	0.1714	0.82
	BA vs RBM t ha^{-1}	RBM= y0+a*x+b*x^2+c*x^3	0.0444	0.2111	0.5920	-0.2852	0.99
	BA vs TBM t ha^{-1}	TBM= y0+a*x+b*x^2+c*x^3	0.1449	1.9590	2.1777	-1.0540	0.99
	BA vs BEF t ha^{-1}	BEF= y0+a*x+b*x^2+c*x^3	1.6785	-0.0847	-0.2415	0.2016	0.55
	BA vs SBC t ha^{-1}	SBC= y0+a*x+b*x^2+c*x^3	0.1029	0.2571	1.3076	-0.6287	0.99
	BA vs BBC t ha^{-1}	BBC= y0+a*x+b*x^2+c*x^3	-0.0366	0.4755	-0.335	0.1587	0.99
	BA vs FBMC t ha^{-1}	FBMC= y0+a*x+b*x^2+c*x^3	-0.0160	0.1414	-0.179	0.0857	0.82
	BA vs RBMC t ha^{-1}	RBMC= y0+a*x+b*x^2+c*x^3	0.0222	0.1055	0.2960	-0.1426	0.99
	BA vs TCS t ha^{-1}	TCS= y0+a*x+b*x^2+c*x^3	0.0725	0.9795	1.0888	-0.5270	0.99
26-35 cm	[3]BA vs Vol t ha^{-1}	V= y0+a*x+b*x^2+c*x^3	-0.0111	5.0956	-1.177	0.5370	1.00
	BA vs SBM t ha^{-1}	SBM= y0+a*x+b*x^2+c*x^3	-0.0031	2.1030	0.3562	-0.6574	0.99
	BA vs BBM t ha^{-1}	BBM= y0+a*x+b*x^2+c*x^3	5.7646E-005	0.4150	0.3928	-0.4534	0.99
	BA vs FBM t ha^{-1}	FBM= y0+a*x+b*x^2+c*x^3	0.0001	0.0325	0.0886	-0.0898	0.99
	BA vs RBM t ha^{-1}	RBM= y0+a*x+b*x^2+c*x^3	-0.0008	0.5582	0.1266	-0.2075	0.99
	BA vs TBM t ha^{-1}	TBM= y0+a*x+b*x^2+c*x^3	-0.0037	3.1086	0.9642	-1.4081	0.99
	BA vs BEF t ha^{-1}	BEF= y0+a*x+b*x^2+c*x^3	1.4895	0.1289	-0.0303	-0.1101	0.86
	BA vs SBC t ha^{-1}	SBC= y0+a*x+b*x^2+c*x^3	-0.0015	1.0515	0.1781	-0.3287	0.99
	BA vs BBC t ha^{-1}	BBC= y0+a*x+b*x^2+c*x^3	2.8823E-005	0.2075	0.1964	-0.2267	0.99
	BA vs FBMC t ha^{-1}	FBMC= y0+a*x+b*x^2+c*x^3	7.3916E-005	0.0163	0.0443	-0.0449	0.99
	BA vs RBMC t ha^{-1}	RBMC= y0+a*x+b*x^2+c*x^3	-0.0004	0.2791	0.0633	-0.1037	0.99
	BA vs TCS t ha^{-1}	TCS= y0+a*x+b*x^2+c*x^3	-0.0018	1.5543	0.4821	-0.7040	0.99

Note: y0, a, b, c are parameters, BA= basal area, V= Volume, SMB, stem biomass, BBM, branches biomass, FBM, foliage biomass, RBM, root biomass, TBM, total biomass, BEF, biomass expansion factor, SBMC, stem biomass carbon, BBMC, branches biomass carbon, FBMC, foliage biomass carbon, RBMC, root biomass carbon and TBMC, total biomass carbon

Table 4. Soil organic carbon (%) and soil organic carbon (Mg C ha^{-1}) in different soil layers of Mongolian Scots pine.

Depth (cm)	SOC (Mg C ha^{-1})	Mean total (%)
0-20	25.10 ± 11.67[a]	40.05
20-40	11.40 ± 4.02[bc]	18.19
40-60	11.77 ± 5.11[b]	18.79
60-80	8.07 ± 5.58[bc]	12.88
80-100	6.07 ± 2.26[c]	9.69
Total	**62.67 ± 7.44**	**100.00**

Different superscripts in each column represent a significant difference (Values are means ± SD, % age, n=8, alpha=0.1)

Table 5. Carbon pools in biomass, soil and total stand of mongolian scots pine.

Parameters	Carbon stock (Mg C ha^{-1})	% Age
Upper story vegetation	17.91 ± 0.58[b]	22.17
Under story vegetation	0.050 ± 0.018[c]	0.06
Litters, dead wood, cones	0.138 ± 0.084[c]	0.17
Soil organic carbon	62.67 ± 9.2[a]	75.59
Total	**77.68 ± 29.66**	**100**

Note: Different superscripts in each column represent a significant difference (Values are means ± SD, %age, n=8, alpha=0.05)

Conclusions

Management and conservation of forests/plantations can lead to the effective achievement of carbon sequestration. Since the study area has a great potential to increase the forested land, hence has more capacity to capture carbon dioxide from the atmosphere. In our study area, the biomass of tree increases with the increase in diameter, which means that biomass is a dependent variable. 62.87 % of the biomass carbon was found in the stem, while the lowest 2.69% was in foliage in term of a forest stand. In whole forest ecosystem of the study area, the highest amount biomass carbon (75.59%) was stored in soil followed by Upper Story Vegetation biomass (22.17%) and the lowest was found in Under Story Vegetation (0.06%). The plantations in the study area sequester 17.91 Mg C ha^{-1}, which shows that Mongolian Scots Pine (*Pinus sylvestris var.* mongolica) plantation plays a key role in mitigating the terrestrial carbon stock. The results show that there is a clear difference in the carbon density value among the different diameter classes of the major carbon pools which proves that considering the diameter classes in assessing the carbon density of a forest using the above experimental models is very significant. Therefore, the authors suggest the use of these experimental models for better understanding of forest carbon dynamics, forest carbon conservation and mapping for effective climate change mitigation regarding the Mongolian Scots Pine (*Pinus sylvestris* var. *mongolica*) Plantation of Horqin Sandy Land, China.

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