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Original Article

Tree species composition, growing stock and biomass carbon dynamics of the major timber species in Hindu Kush regions of Pakistan

Composição de espécies de árvores, estoque em crescimento e dinâmica de biomassa de carbono das principais espécies madeireiras nas regiões de Indocuche no Paquistão

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Abstract

Using inventory data, this study evaluates the species composition, growing stock volume (GSV), and biomass carbon (BMC) of the five major timber species in the sub-tropical, and temperate/sub-alpine regions of Pakistan. It was found that the stem density varies between 50 and 221 trees ha $^{-1}$, with a mean of 142 trees ha^{-1} (13.68 million trees for entire forest area). Among the species, *Pinus wallichiana* showed a high species composition (27.80%) followed by *Picea smithiana* (24.64%). The GSV was found in the range of 67.81 to 425.94 m^3 ha^{-1}, with a total GSV value of 20.68 million m^3 for the entire region. Similarly, The BMC ranged from 27.04 to 169.86 Mg ha^{-1}, with a mean BMC value of 86.80 Mg ha^{-1}. The total amount of stored carbon was found at 8.69 million tons for a total of 95842 ha of commercially managed forest. Furthermore, the correlation analysis between the basal area (BA) and GSV and BMC showed that BA is the best predictor of GSV and BMC. The findings provide insights to the policy makers and forest managers regarding the sustainable commercial forest management as well as forest carbon management in the recent global carbon management for climate change mitigation.

Keywords: managed forest, biomass, carbon stock, carbon management, policy makers.

Resumo

Usando dados de inventário, este estudo avaliou a composição de espécies, volume de estoque crescente (GSV) e carbono de biomassa (BMC) das cinco principais espécies madeireiras nas regiões subtropicais e temperadas/subalpinas do Paquistão. Constatou-se que a densidade do caule variou entre 50 e 221 árvores ha^{-1}, com média de 142 árvores ha^{-1} (13,68 milhões de árvores para toda a área florestal). Entre as espécies, *Pinus wallichiana* apresentou alta composição de espécies (27,80%), seguida de *Picea smithiana* (24,64%). O GSV foi encontrado na faixa de 67,81 a 425,94 m^3 ha^{-1}, com um valor total de 20,68 milhões de m^3 para toda a região. Da mesma forma, o BMC variou de 27,04 a 169,86 mg ha^{-1}, com valor médio de 86,80 mg ha^{-1}. A quantidade total de carbono armazenado foi de 8,69 milhões de toneladas para um total de 95.842 ha de floresta manejada comercialmente. Além disso, a análise de correlação entre área basal (BA), GSV e BMC mostrou que BA é o melhor preditor de GSV e BMC. As descobertas fornecem insights para os formuladores de políticas e gestores florestais sobre o manejo florestal comercial sustentável, bem como o manejo florestal de carbono no recente gerenciamento global de carbono para a mitigação das mudanças climáticas.

Palavras-chave: floresta manejada, biomassa, estoque de carbono, gestão de carbono, formuladores de políticas.

1. Introduction

Carbon dioxide (CO_2) one of the major greenhouse gasses plays an important role in climate change (Vashum and Jayakumar, 2012). Forest, a major carbon sink among the terrestrial ecosystems, is extremely important in the global carbon cycle. The better understanding of the global carbon cycle requires an accurate estimate of the sinks and sources, both for the emissions and removal of carbon between the natural reseriveros (Le Quéré et al., 2009). Forest stored 45%

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of the total terrestrial carbon and sequestering approximately 33% of the total land emitted carbon (Houghton et al., 2012). Forest vegetation sequester CO_2 through the process of photosynthesis and store it in their biomass. The amount of biomass in a forest determines the quantity of carbon sequestered from the atmosphere or added (Brown et al., 1999). Due to the woody nature, forest trees can accumulate a larger amount of carbon over their lifetime. Recent estimates have shown that the world's forests contained 861 Pg carbon with 450 to 650 Pg in vegetation biomass (Pan et al., 2011; Wani et al., 2015). The forest growing stock volume (GSV) is a key component in managing forest for wood harvest as well carbon in the current global climate change issues (Santoro et al., 2011). The GSV represent the stem volume per unit area, which is a major predictor for the tree biomass estimation, and a fundamental parameter for the measurement of net carbon exchange between the land and atmosphere (Jenkins et al., 2003; Somogyi et al., 2008; Santoro et al., 2011). For carbon inventory, the GSV is first converted into biomass using different methods like biomass expansion factors (BEF) and biomass expansion and conversion factors (Tolunay, 2011).

The anthropogenic land-use change, forest fragmentation, changing management objectives, and forest degradation affected the global forests. These factors affect not only the traditional services of timber production and water catchments protection, but also the role of forests in sinking emitted carbon (Birdsey and Pan, 2015). Managed forest generally refers to forests directly impacted by human activities and their management related to the attainments of specified goals under defined objectives by the management entity (Foley et al., 2005; Birdsey and Pan, 2015). The area of managed forests under a documented management plan is gradually increasing around the world (FAO, 2015). Forests under a management plan are not only managed for timber production, but also for multiple purposes such as wildlife and watershed protection, environmental and climatic rehabilitation (FAO, 2010, 2015). The carbon stocks in a forest may be significantly affected by the management intensity, though having more timber production and carbon removal ability, but may have fewer carbon stocks compared to primary forests (McKinley et al., 2011). The increasing concerns for global climate change at the national and international level attached greater importance regarding forest carbon management (FAO, 2015; Wani et al., 2015). In the present climatic change scenarios forests, carbon management is considered an important activity for the stabilization of GHGs and climate change mitigation (Ravindranath and Ostwald, 2008). Hence, it becomes important to produce regional and national estimates of forest carbon dynamics (Fang et al., 2006).

The role of forests in climate change mitigation has been recognized by different international bodies such as the IPCC, UNFCC, KP, and REDD+ (Wani et al., 2012, 2015; Ahmad et al., 2018) . Pakistan is a member of the above mentions bodies and the measurement of carbon fluxes is their obligation. Pakistan has a diver's ecology and forests types particularly the mountains ranges of Hindu Kush, Karakoram and Himalaya are the hubs to forests resources. Most of the forests in these regions are declared as protected forests that are further classified as commercially managed forest, protection forests and community managed forests. The commercially managed forests are at large scale, while the protection and community managed forests are partly managed under selection working system for timber production for commercial and domestic purposes. In Pakistan, some of the researchers focused their attention on the species composition and stand structure of these forests (Ahmed et al., 2009; Ahmed et al., 2011). Regarding the GSV, these forests are managed under documented plans in the respective forest divisions. The growing stocks of these forests are regulated under regular inventories in the shape of forests working plans by the respective department (Ahmad et al., 2014). Similarly, some of the local studies are available regarding the carbon sock (Ahmad et al., 2015; Ahmad and Nizami, 2015; Ahmad et al., 2018). However, under the existing management system, a particular species may face greater selection preferences for harvesting upon their worth and value. Due to more harvesting intensity, the composition of a particular species may change. Under the existing scenario, the forests might be at risk of conversion to a monospecific community. Furthermore, the GSV of the forests is managed under the traditional volume tables that are based on height and diameter. Additionally, the available carbon stock data is not reflecting the whole carbon dynamics potential of the region. Similarly, up till now, no biomass carbon tables have been constructed for the region. Therefore, a detailed study is needed to document the species composition, growing stock characteristics and biomass carbon density of the region as well to construct GSV and BMC tables based on the basal area.

This study for the first time in Pakistan documented the species composition, GSV and biomass carbon stock of the managed forests in the sub-tropical and temperate/sub-alpine forests of Pakistan. Furthermore, we developed regression models for GSV and biomass carbon based on basal area and proves that the basal area is the best predictor of GSV and biomass carbon. Similarly, we also develop GSV and biomass carbon tables for effective future management and stand evaluation. The current study broadly address the following questions (1) What is the species composition of the commercial timber trees and how it is effected under the existing management system? (2) How the GSV is distributed, species-wise as well region wise? (3) How vegetation carbon is distributed among the different species as well region? (4) Does the basal area is the best predictor of GSV and BMC? (5) Does GSV and BMC tables, based on the basal area have the potential to replace the traditional volume tables that are based on tree height and diameter? The finding of this research is expected to be helpful for policymakers and forest managers regarding the sustainable GSV regulation, balancing the species composition and forest carbon conservation and management.

2. Materials and Methods

2.1. Study area, and description of forests

The study was carried out in the 8 forest divisions (Table 1) of Malakand civil division (MKD) of the Khyber Pakhtunkhwa, Pakistan (Figure 1). The MKD with a

Table 1. Geographic Location, Climate and area statistics of the area.

Division	Latitude (N)	Longitude (E)	Elevation (m)	MAT (°C)	MAR (mm)	TMFA (ha)	TCMFA (ha)	%
DKFD	35°9'-35°47'	71°52'-72°22'	1200-5750	0.7-30	1000-1600	62053	29554	48
WFD	34°37'-35°16'	71°47' -72°20'	760-4462	-2-32	700-1431	60501	8139	13
DFD	34°37'-35°21'	71°30'-72°21'	761-3300	-2-36	685-1431	42179	928	2
MFD	34°40'-35°12'	72°5'-72°30'	700-4000	-1-40	700-1400	31779	11831	37
SFD	34°34'-35°07'	72°36'	750-3500	10-36	700-1200	28038	3060	11
BFD	34°9' -35°43'	72°10'-72°7'	366-3000	-1-40	700-1200	41001	2113	5
AFD	34°31'-35°8'	72°35'-73°1'	450-4464	11-37	700-1000	44408	19755	44
CFD	35°15'-36°55'	71°12'-73°55'	1000-7782	-6-36	500-1000	72820	20462	28
Total						**382779**	**95842**	**25**

DKFD= Dir Kohistan forest division; WFD= Warrai forest division; DRD= Dir forest division; MFD= Matta forest division; SFD= Swat forest division; BFD= Buneer forest division; AFD= Alpuri forest division; CFD= Chitral forest division; MAT= Mean annual temperature; MRA= Mean annual rainfall; TMFA= Total managed forest area; TCMFA= Total commercial managed forest area.

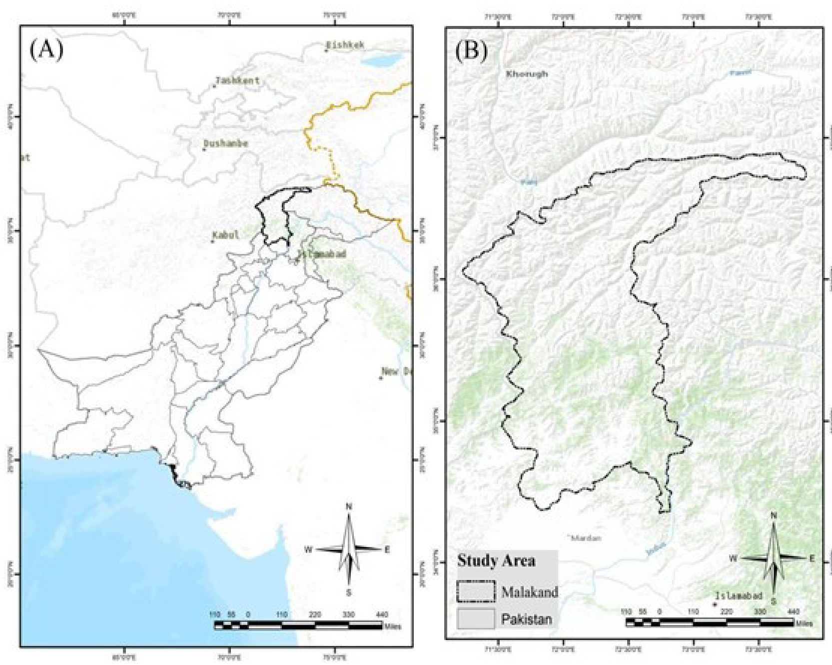

Figure 1. Location map of the study area. (A) geographical location of Pakistan, (B) geographical location of MKD.

total land area of 2987100 ha, extends between 34°9' and 36°55' in latitude, and 72°10' and 73°55' longitude. The elevation ranges from 450 m to 7782 m. The climate is subtropical to temperate. The average annual temperature varies from -6 °C to 40 °C. The mean annual precipitation varies between 500 mm to 1600 mm. The forests extend on an area of 812637 ha (27%). The managed forest land amounts 382779 ha, out of which 95842 (25%) ha land is declared commercially managed forests (CMF) and the rest is protection and community managed forest (Table 1). The major conifer trees species of the area includes *Cedrus deodara* (CD), *Pinus wallichian* (PW), *Pinus gerardiana, Pinus roxburghii* (PR), *Abies pindrow* (AP), *Picea smithiana (*PS), *Taxux baccata*, and the major broadleaved species including, *Quercus incana*, *Olea ferrugenia*, *Juglans regia*, *Morus alba*, *Betula utilis*, *Populus ciliata*, *Acacia modesta*. Among the major trees species, 5 trees including CD, PW, AP, PS, and PR are the commercially exploited trees.

2.2. Description of forests management

The managed forests of the area are legally declared as protected forests and the local people are entitled to different rights and concessions such as; out of commercial sale proceeds, 60 to 80% share, to local people as "Royalty", right of cutting dry branches and trees for firewood, right of getting timber for domestic construction, right of grazing, right of collection the non-timber forest products and right of collection a fee from the nomadic communities. Regarding forest management, the managed forests are subdivided into small units called compartments. The compartments are allotted to three different working circles, the selection working circle or commercial working circle (CMF), Protection working circle or non-commercial working circle (PWC) and Community working circle (CWC). The CWC consisting of fully stocked forests and are largely managed for commercial timber harvesting. The PWC comprised of poorly stocked forests and water catchments area and are managed under improvement felling system to meet local timber requirements. The CWC comprised of forests area near to local communities on which the dependency of local people for construction timber, fuel wood, fodder, and grazing is high. The growing stock volume (GSV) in the CMF is assessed through field inventory at 10 to 15-year cycle. The annual yield is regulated using Von Mantel yield regulation method under the selection Silviculture system (Ahmad et al., 2018). For annual yield regulation, the respective forest officials known as DFO (Divisional forest officer) carried out the marking operation (selection of trees for harvesting) according to the fixed exploitation principals in each forest division. Felling is carried out according to a sequenced design. During felling operation, preference is given to over mature, wind fallen, dead and dying trees.

2.3. Specie composition and growing stock assessment

The data for the species composition and GSV has been taken from the respective management plans of the selected divisions (Table 1). For this purposes, concern department known as "Working plan section" carrying regular ground inventories at 10-20 year cycle. The GSV is calculated through point sampling techniques. At least 10 to 14 points in each compartment are selected. Tree height and diameter are recorded and a local volume table is developed based on height and diameter. Similarly, based on the inventory data the stand and stock tables for the whole forest division are prepared. From the stand tables in each forest division, the stem density of the five major timber species was measured and the species composition was assessed using Equation 1. The GSV was assessed from the stock tables of the respective divisions.

$$\text{SC}(\%) = \text{Density of a specie / Density of all species}*(100) \quad (1)$$

2.4. Biomass carbon assessment

We first estimated the stem biomass from the GSV. The assessed stem volume was converted to stem biomass using Equation 2.

$$\text{Stem biomass}\left(\text{t ha}^{-1}\right) = \text{GSV*WD} \quad (2)$$

where, GSV= growing stock volume (m^3 ha^{-1}), WD= wood density (Kg/m^3) species.

The values of wood densities were sourced from the available literature (Haripriya, 2000, Nizami, 2012, Ahmad et al., 2018). As stem biomass only accounted for stem and does not consider other tree components like branches, leaves, twigs, cones. In order to estimate the total tree biomass or above ground biomass we used a fixed ratio of 1.51, which is the biomass expansion factor (BEF). The BEF was sourced from (Haripriya, 2000; Nizami, 2012; Ahmad et al., 2014, 2018). The following equation was used to estimate the above-ground biomass

$$\text{Above ground biomass}\left(\text{t ha}^{-1}\right) = \text{Stem biomass}\left(\text{t ha}^{-1}\right) * BEF \quad (3)$$

The below ground biomass was assessed using root to shoot ration (R) following (Rana et al., 1989; Adhikari et al., 1995; Amir et al., 2018). Equation 3 was used to calculate the below ground biomass. The total above and below ground biomass was calculated using Equation 4, and total tree biomass was calculated using Equation 5.

$$\text{BGBM}\left(\text{t ha}^{-1}\right) = \text{AGBM}\left(\text{t ha}^{-1}\right) * \text{R} \quad (4)$$

where, BGBM= Below ground biomass, AGBM= Above ground biomass.

$$\text{Total tree biomass}\left(\text{t ha}^{-1}\right) = \text{AGBM}\left(\text{t ha}^{-1}\right) + \text{BGBM}\left(\text{t ha}^{-1}\right) \quad (5)$$

The carbon values were measured from the biomass. The biomass was converted into carbon using a conversion factor of 0.5 (Equation 6) (Ahmad et al., 2014; Nizami, 2012; Ahmad and Nizami, 2015; Mannan et al., 2019; Saeed et al., 2019; Mannan et al., 2018).

$$\text{Carbon stock}\left(\text{t ha}^{-1}\right) = \text{Total tree biomass}\left(\text{t ha}^{-1}\right) * 0.5 \quad (6)$$

2.5. Development of GSV and BMC tables based on basal area

The traditional volume table based on diameter and height is a laborious process that needs individual tree dendrometry like diameter and height measurement. The relationship of the basal area with GSV and BMC could be used to facilitate the measurement of GSV and BMC as the basal area can be rapidly assessed on the ground using different methods such as Bitterlich stick, prism sweep method, relascopes (Burrows et al., 2000; Balderas Torres and Lovett, 2012). In order to develop the GSV and BMC table based on basal area we first measured the basal area of the respective trees in respective diameter using Equation 7, then we developed regression models for basal area and growing stock and basal area and biomass carbon for each species using sigma plot version 12. Based on the regression models, we developed growing stock and biomass carbon tables based on basal area.

$$\text{Basal area} = \pi r^2 * \text{Density t ha}^{-1} \quad (7)$$

Where, πr^2= cross sectional area and D= number of trees

3. Results

3.1. Stem density and species composition

Details of the stem density, species composition and growing stock volume of the respective commercially harvested species are presented in Table 2. The results in the table reveal a variation of stem numbers in the respective divisions. The results showed that stem density ranges from 50 trees ha^{-1} in swat forest division (SFD) to 221 trees ha^{-1} in Alpuri forest division (AFD) with a mean value of 142 trees ha^{-1}. The stem density distribution exhibited that the highest stems of *Cedrus deodara* (CD) were recorded in Chitral forest division (CFD) whereas *Pinus wallichaian* (PW), *Abies pindrow* (AP), *Picea smithiana* (PS) and *Pinus roxburghii* were found higher in AFD, and Buner forest division (BFD) respectively. Overall, the stem density for CD was recorded at 33 trees ha^{-1}, while for PW, AP, PS, and PR it was 39, 34, 35 and 1 trees ha^{-1} respectively. The results of the species composition demonstrate that CD is found in highest percentage in CFD, while PW, AP, PS, and PR are found in AFD, SFD, WFD (Wari forest division and BFD respectively. In the entire commercially managed forest in term of species composition the highest percentage was recorded for PW followed by PS, AP, CD, and PR. Altogether, the results showed that among the species PW is distributed throughout the whole range while PR only occurred BFD and AFD. Similarly, AP and PS distributed over the entire region except BFD and CD are distributed over DKFD (Dir Kohistan forest division) WFD, DFD (Dir forest division) and CFD.

3.2. Growing stock volume and biomass carbon

The results of the GSV in Table 3 shows that among the different divisions, the larger GSV values for CD, PW, AP, and PS were recorded in DKFD, while for PR it was in BFD. Species-wise the maximum GSV value was recorded for CD

Table 2. Stem density and species composition.

Division	CD Dha^{-1}	PW Dha^{-1}	AP Dha^{-1}	PS Dha^{-1}	PR Dha^{-1}	GT Dha^{-1}	CDC%	PWC%	APC%	PSC%	PRC%
DKFD	57	33	42	44	0	176	32.10	18.74	23.97	25.19	0.00
WFD	3	15	21	42	0	80	3.26	18.48	26.09	52.17	0.00
DFD	4	22	23	36	0	85	4.42	26.36	26.85	42.38	0.00
MFD	0	21	22	32	0	75	0.00	28.05	28.83	43.12	0.00
SFD	0	8	28	14	0	50	0.00	15.08	56.38	28.54	0.00
BFD	0	4	0	0	55	59	0.00	6.33	0.00	0.00	93.67
AFD	2	102	65	52	1	221	0.87	46.10	29.33	23.68	0.45
CFD	69	18	9	8	0	105	66.24	17.50	8.94	7.31	0.00
Total	**33**	**39**	**34**	**35**	**1**	**142**	**23.19**	**27.80**	**23.90**	**24.64**	**0.70**

DKFD= Dir Kohistan forest division; WFD= Warrai forest division; DFD= Dir forest division; MFD= Matta forest division; SFD= Swat forest division; BFD= Buneer forest division; AFD=Alpuri forest division; CFD= Chitral forest division; CD= *Cedrus deodara*; PW= *Pinus wallichiana*; AP= *Abies pindrow*; PS= *Picea smithiana*; PR= *Pinus roxburghii*; GT= *Grand total*; CDC= Cedrus deodara composition; PWC= Pinus wallichiana composition; APC= Abies pindrow composition; PSC= Picea smithiana composition; PRC= Pinus roxburghii composition.

Table 3. Total Growing stock of the area.

Division	CD GSV ha^{-1}	PW GSV ha^{-1}	AP GSV ha^{-1}	PS GSV ha^{-1}	PR GSV ha^{-1}	GT GSV ha^{-1}
DKFD	122.60	88.12	101.13	114.10	0.00	425.94
WFD	1.77	23.01	51.34	97.37	0.00	173.49
DFD	3.34	36.87	38.39	65.22	0.00	143.81
MFD	0.00	25.98	52.67	71.63	0.00	150.29
SFD	0.00	15.80	59.72	35.76	0.00	111.29
BFD	0.00	4.86	0.00	0.00	62.95	67.81
AFD	0.62	69.26	5.50	4.44	0.02	79.83
CFD	93.55	24.71	12.62	10.33	0.00	141.21
Total	58.09	52.86	48.15	57.19	1.39	217.67

DKFD= Dir Kohistan forest division; WFD= Warrai forest division; DRD= Dir forest division; MFD= Matta forest division; SFD= Swat forest division; BFD = Buneer forest division; AFD= Alpuri forest division; CFD= Chitral forest division; CD= *Cedrus deodara*; PW= *Pinus wallichiana*; AP= *Abies pindrow*; PS= *Picea smithiana*; PR= *Pinus roxburghii*; GT= *Grand total*.

followed by PS, AP, PW, and PR respectively. Division wise the GSV values ranged from 67.81 in BFD to 425.94 m^3 ha^{-1} in DKF. Over the entire region the GSV fluctuated between 1.39 m^3 ha^{-1} in PR and 58.09 m^3 ha^{-1} in CD. Overall the mean GSV value was recorded at 217.67 m^3 ha^{-1}. The results of the BMC underline that the species-wise the maximum BMC was recorded for CD (DKFD) and the minimum was recorded for PR (AFD). Division wise DKFD had the highest carbon stock while BFD had the lowest biomass carbon stock. Over the entire region, the BMC varied between 23.70 (PW) and 24. 21 (CD) t ha^{-1}, with an overall average of 86.80 t ha^{-1} (Table 4).

3.3. Growing stock and Biomass carbon tables based on basal area

Basal area is the cross-sectional area of trees on a hectare basis. It integrates both the tree diameter and stem density. The basal area can be used to measure the GSV and BMC directly without individual trees measurement. In this study, we developed regression models between basal area and GSV and basal area and BMC for all tree species (Table 5; Figure 2A-E). The results of the correlation analysis underline a strong positive relationship between basal area and GSV and basal area and BMC with R^2 value ranges from 0.76 to 0.99 (α=0.05, p=<0.0001). We also developed GSV and BMC tables on the base of the basal area. Details of the basal area of all species with the respective GSV and BMC information is given in Appendix 1-3. The results clearly explained that the values of GSV and BMC increase with an increasing basal area. Overall the results of the regression analysis (Table 5; Figure 2A-E) and GSV and BMC tables depicted that basal area can be directly used for assessing the GSV and BMC.

4. Discussion

4.1. Stem density and specie composition

A significant trend has been found in the management status of the global forest over the last two decades. The area of managed forest (under a documented management plan) increased by 18%, with a total area of 161 million ha (FAO, 2015; Birdsey and Pan, 2015). This study documented the species composition, growing stock volume (GSV) and biomass carbon stock potential (BMC) of the commercially

Table 4. Total biomass carbon stock of the area.

Division	BMCCD t ha^{-1}	BMCPW t ha^{-1}	BMCAP t ha^{-1}	BMCPS t ha^{-1}	BMCPR t ha^{-1}	GTBMC t ha^{-1}
DKFD	51.09	39.51	34.08	39.49	0.00	169.86
WFD	0.74	10.32	17.30	33.70	0.00	69.19
DFD	1.39	16.53	12.94	22.57	0.00	57.35
MFD	0.00	11.65	17.75	24.79	0.00	59.93
SFD	0.00	7.09	20.13	12.38	0.00	44.38
BFD	0.00	2.18	0.00	0.00	28.35	27.04
AFD	0.26	31.05	1.85	1.54	0.01	31.84
CFD	38.99	11.08	4.25	3.57	0.00	56.31
Total	24.21	23.70	16.23	19.79	0.63	86.80

BMCCD= Biomass carbon *Cedrus deodara*; BMCPW= Biomass carbon *Pinus wallichiana*; BMCAP= Biomass carbon *Abies pindrow*; BMCPS= Biomass carbon *Picea smithiana*; BMCPR= Biomass carbon *Pinus roxburghii*; GTBMC= Grand total biomass carbon.

Table 5. Regression analysis between basal area (m^2 ha^{-1}) and growing stock (m^3 ha^{-1}), basal area (m^2 ha^{-1}) and biomass carbon (t ha^{-1}).

Species	Relationship	Equation	R^2	y0	A	P
Cedrus deodara (CD)	BA Vs GSV (Linear)	GSV = y0+a*BA	0.87	-0.3303	11.45	0.1991
	BA Vs BMC (Linear)	BMC= y0+a*BA	0.87	-0.1377	4.82	<0.0001
Pinus wallichiana (PW)	BA Vs GSV (Linear)	GSV = y0+a*BA	0.80	0.0583	11.39	0.8051
	BA Vs BMC (Linear)	BMC= y0+a*BA	0.80	0.0264	5.15	<0.0001
Abies pindrow (AP)	BA Vs GSV (Linear)	GSV = y0+a*BA	0.76	-0.1599	11.69	0.5981
	BA Vs BMC (Linear)	BMC= y0+a*BA	0.76	-0.0539	3.94	<0.0001
Picea smithiana (PS)	BA Vs GSV (Linear)	GSV = y0+a*BA	0.90	-0.2551	12.23	0.2078
	BA Vs BMC (Linear)	BMC= y0+a*BA	0.90	-0.0883	4.23	<0.0001
Pinus roxberghi (PR)	BA Vs GSV (Linear)	GSV = y0+a*BA	0.99	-0.0352	7.73	0.7456
	BA Vs BMC (Linear)	BMC= y0+a*BA	0.99	-0.0158	3.48	<0.0001

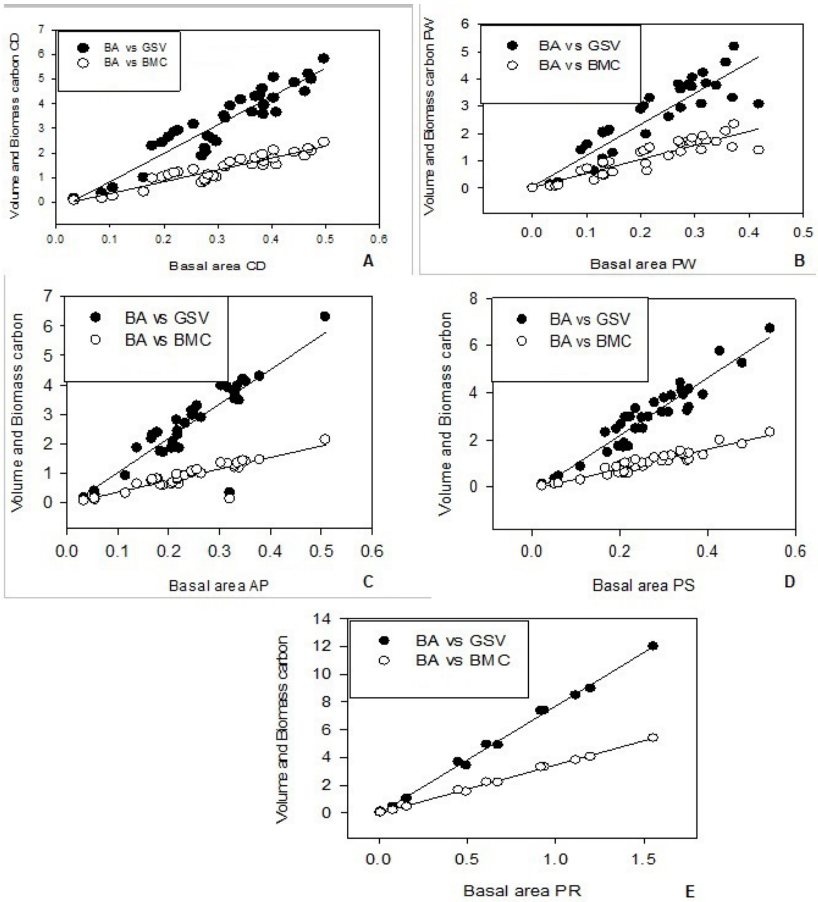

Figure 2. Relationship between Basal area and growing stock volume and biomass carbon.

Table 6. Total and percent stand density stand growing stock and total biomass carbon of the area.

	Stand density (million)	%	Growing stock (million m³)	%	Biomass carbon (million tons)	%
Cedrus deodara	3.16	23.20	5.57	26.69	2.41	29.35
Pinus wallichiana	3.78	27.80	5.07	24.29	2.29	27.86
Abies pindrow	3.25	23.91	4.61	22.12	1.56	18.92
Picea smithiana	3.30	24.26	5.48	26.27	1.90	23.08
Pinus roxburghii	0.12	0.85	0.13	0.64	0.06	0.73
Total	13.61	100.03	20.86	100	8.22	100

managed forest in sub-tropical, and temperate/subalpine regions of Malakand civil division in Pakistan. The results of stem density and species composition in different regions showed an uneven distribution over the area (Table 2). Overall, the stem density statistics in Table 6 revealed that a total of 13.61million trees were found in the area, out of this the lowest number of trees were recorded for CD 3.16 million, and highest for PW (3.78 million). This uneven distribution of trees is the results of the current management system. As earlier discussed that these forests are declared as protected forest and the local people are entitled to multiple rights such as grazing, fuel wood collection, and domestic timber requirements for construction. The local people have the right to obtain the timber for domestic construction on an issued permit by the respective forest department. Mostly, local community preferred CD due to their durability and strength as compared to other species. Similarly, during commercial harvesting, a slightly high amount of timber of CD is harvested due to their high market price. Furthermore, due to weak law enforcement and partial protection policies of the concern government department (forest department), the CD is the common victim of timber mafia and wood smugglers (Hasan, 2007; Qamer et al., 2016; Ahmad et al., 2018).

4.2. Growing stock Volume and Biomass carbon

The growing stock is a key parameter for forest management as well in assessing the forest biomass and carbon stock (Somogyi et al., 2008, Santoro et al., 2011). Globally, national forest inventories data are used in calculating forest dynamics such as growth, and harvest. Global Statistics regarding the GSV, biomass carbon and other forest attributes are based on national forest inventories (FAO, 2010). This study used the available inventory data for estimating the GSV and BMC. The results indicated that overall the commercially managed forest has 13.61 million m^3 GSV (Table 6). Among the different species (Table 3 and 6) CD have the highest GSV. Similarly region wise the DKFD have the maximum GSV value. This higher GSV value can be linked to the presence of larger diameter in CD, trees up to 150 to 180 cm of CD m were recorded in some area of the region (Ahmad et al., 2014, Ahmad et al., 2018). Region wise the higher GSV in DKFD can be attributed to the presences of larger diameter trees as reported by (Ahmad et al., 2018). In comparison, the current GSV values are consistent with (Haripriya, 2000) form the Himalaya regions of India.

The total assessed BMC for the commercially managed forest was estimated at 8.22 million tons (Table 6). Species-wise CD holds the maximum carbon stock due to presences of more mature and over mature trees. Region wise DKFD holds maximum carbon stock that is attributed to the presence of old age forests. Old growth forest holds more carbon values because of more biomass accumulation, which is a time-dependent process (Zhang et al., 2013). It can be seen from the Table 3 that PS has more GSV value than PS, but the results in the Table 3 and 6 indicated a higher BMC value for PW than PS. This higher value of carbon in PW reflecting the higher wood density of the species. In comparison, the current carbon stock value (86.80 t ha-1) is comparable with (Haripriya, 2000; Wani et al., 2015) in India.

4.3. Growing stock and Biomass carbon tables based on basal area

Basal area is the sum of cross-sectional area of trees at dbh (diameter at breast height) and it is expressed as m^2 ha^{-1}. Basal area is the best predictor of forest growing stock and biomass and widely used for biomass estimation in tropical moist and dry forests (Balderas Torres and Lovett, 2012). In the present study, we developed regression models between basal area and GSV and basal area and BMC. The correlation analysis presented in Table 5 and Figures 2A to 2E highlighted a strong correlation with R^2 value of 76 to 99. The correlation analysis demonstrated that with an increasing basal area the GSV and BMC increases. This study for the first time in Pakistan develops GSV and BMC carbon tables (Appendix 1-3) that can be used effectively for the direct measurement of GSV and BMC. As the relationship of the basal area between GSV and BMC could be used to facilitate the measurement of biomass rapidly because the basal area can be rapidly be assessed through different methods such as Bitterlich stick, prism sweep, and relascopes (Balderas Torres and Lovett, 2012). The uses of basal area do not require individual tree base measurement, thus speeding up the measurement process (Balderas Torres and Lovett, 2012). The relationship of basal area and GSV and BMC and the GSV and BMC table based on the basal area can also be used in combination with GIS and remote sensing for biomass carbon mapping in Pakistan.

5. Conclusion

This study estimated the species composition, growing stock and biomass carbon of the commercially managed forests in the Malakand civil division of Khyber Pakhtunkhwa, Pakistan. The area lies in Hindu Kush, Himalaya ranges in Pakistan, rich in forest resources. The local people are highly dependent on forest resources for their livelihood, particularly for fuel and timber. The forests are legally declared as protected forests and local people have multiple rights in forests such as grazing, fuel wood collection, and share in commercial proceeds. For commercial harvesting about 95842 ha has been assigned as commercially managed forests. However, the current management system affected the species composition and created an uneven distribution of trees. The high market price and durability of some species like CD prone it to high harvesting. This study briefly underlines the species composition of the major timber species among the different regions as well the growing stock volume. These results provide clear directions and guidelines that how the yield can be regulated taking into account species composition. Furthermore, the study highlighted the BMC potential of the major timber species over the region. These results can be used in calculating the carbon dynamics and to illustrate the annual flow and accumulation rate. Additionally, this study also developed GSV and BMC carbon tables that prove that the basal area is the best predictor of GSV and BMC. As a field, inventory is required for GSV and BMC, but most of the natural forests in Pakistan are located in high mountains of Hindu Kush, Karakoram and Himalaya and the lack of research facilities and finance, accessibility and unavailability of data are the major limitations. In this regard, the GSV and BMC tables based on the basal area will be particularly important in reducing both the physical and financial efforts.

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References

ADHIKARI, B., RAWAT, Y. and SINGH, S., 1995. Structure and function of high altitude forests of central Himalaya I. Dry matter dynamics. *Annals of Botany*, vol. 75, no. 3, pp. 237-248. http://dx.doi.org/10.1006/anbo.1995.1017.

AHMAD, A. and NIZAMI, S.M., 2015. Carbon stocks of different land uses in the Kumrat valley, Hindu Kush Region of Pakistan. *Journal of Forestry Research*, vol. 26, no. 1, pp. 57-64. http://dx.doi.org/10.1007/s11676-014-0008-6.

AHMAD, A., LIU, Q.I.J., NIZAMI, S.M., MANNAN, A. and SAEED, S., 2018. Carbon emission from deforestation, forest degradation and wood harvest in the temperate region of Hindukush Himalaya, Pakistan between 1994 and 2016. *Land Use Policy*, vol. 78, pp. 781-790. http://dx.doi.org/10.1016/j.landusepol.2018.07.009.

AHMAD, A., MIRZA, S.N. and NIZAMI, S., 2014. Assessment of biomass and carbon stocks in coniferous forest of Dir Kohistan, KPK. *Pakistan Journal of Agricultural Sciences*, vol. 51, pp. 35-350.

AHMAD, A., NIZAMI, S., MARWAT, K. and MUHAMMAD, J., 2015. Annual accumulation of carbon in the coniferous forest of Dir Kohistan: an inventory based estimate. *Pakistan Journal of Botany*, vol. 47, pp. 115-118.

AHMED, M., SHAUKAT, S.S. and SIDDIQUI, M.F., 2011. A multivariate analysis of the vegetation of Cedrus deodara forests in Hindu Kush and Himalayan ranges of Pakistan: evaluating the structure and dynamics. *Turkish Journal of Botany*, vol. 35, pp. 419-438.

AHMED, M., WAHAB, M., KHAN, N., SIDDIQUI, M.F., KHAN, M.U. and HUSSAIN, S., 2009. Age and growth rates of some gymnosperms of Pakistan: a dendrochronological approach. *Pakistan Journal of Botany*, vol. 41, pp. 849-860.

AMIR, M., LIU, X., AHMAD, A., SAEED, S., MANNAN, A. and MUNEER, M.A., 2018. Patterns of biomass and carbon allocation across chronosequence of chir pine (*Pinus roxburghii*) forest in Pakistan: inventory-based estimate. *Advances in Meteorology*, vol. 2018, pp. 2018. http://dx.doi.org/10.1155/2018/3095891.

BALDERAS TORRES, A. and LOVETT, J.C., 2012. Using basal area to estimate aboveground carbon stocks in forests: La Primavera Biosphere's Reserve, Mexico. *Forestry: An International Journal of Forest Research*, vol. 86, no. 2, pp. 267-281. http://dx.doi.org/10.1093/forestry/cps084.

BIRDSEY, R. and PAN, Y., 2015. Trends in management of the world's forests and impacts on carbon stocks. *Forest Ecology and Management*, vol. 355, pp. 83-90. http://dx.doi.org/10.1016/j.foreco.2015.04.031.

BROWN, S.L., SCHROEDER, P. and KERN, J.S., 1999. Spatial distribution of biomass in forests of the eastern USA. *Forest Ecology and Management*, vol. 123, no. 1, pp. 81-90. http://dx.doi.org/10.1016/S0378-1127(99)00017-1.

BURROWS, W., HOFFMANN, M., COMPTON, J., BACK, P. and TAIT, L., 2000. Allometric relationships and community biomass estimates for some dominant eucalypts in Central Queensland woodlands. *Australian Journal of Botany*, vol. 48, no. 6, pp. 707-714. http://dx.doi.org/10.1071/BT99066.

FANG, J., BROWN, S., TANG, Y., NABUURS, G.-J., WANG, X. and SHEN, H., 2006. Overestimated biomass carbon pools of the northern mid-and high latitude forests. *Climatic Change*, vol. 74, no. 1-3, pp. 355-368. http://dx.doi.org/10.1007/s10584-005-9028-8.

FOLEY, J.A., DEFRIES, R., ASNER, G.P., BARFORD, C., BONAN, G., CARPENTER, S.R., CHAPIN, F.S., COE, M.T., DAILY, G.C., GIBBS, H.K., HELKOWSKI, J.H., HOLLOWAY, T., HOWARD, E.A., KUCHARIK, C.J., MONFREDA, C., PATZ, J.A., PRENTICE, I.C., RAMANKUTTY, N. and SNYDER, P.K., 2005. Global consequences of land use. *Science*, vol. 309, no. 5734, pp. 570-574. http://dx.doi.org/10.1126/science.1111772. PMid:16040698.

FOOD AND AGRICULTURE ORGANIZATION – FAO, 2010. *Global forest resources assessment 2000.* Rome.

FOOD AND AGRICULTURE ORGANIZATION – FAO, 2015. *Global forest resources assessment*. Rome.

HARIPRIYA, G.S., 2000. Estimates of biomass in Indian forests. *Biomass and Bioenergy*, vol. 19, no. 4, pp. 245-258. http://dx.doi.org/10.1016/S0961-9534(00)00040-4.

HASAN, L., 2007. An anatomy of state failures in forest management in Pakistan. *Pakistan Development Review*, vol. 46, no. 4II, pp. 1189-1203. http://dx.doi.org/10.30541/v46i4IIpp.1189-1203.

HOUGHTON, R., VAN DER WERF, G., DEFRIES, R., HANSEN, M., HOUSE, J., LE QUÉRÉ, C., PONGRATZ, J. and RAMANKUTTY, N., 2012. Carbon emissions from land use and land-cover change. *Biogeosciences Discussions*, vol. 9, pp. 5125-5142.

JENKINS, J.C., CHOJNACKY, D.C., HEATH, L.S. and BIRDSEY, R.A., 2003. National-scale biomass estimators for United States tree species. *Forest Science*, vol. 49, pp. 12-35.

LE QUÉRÉ, C., RAUPACH, M.R., CANADELL, J.G., MARLAND, G., BOPP, L., CIAIS, P., CONWAY, T.J., DONEY, S.C., FEELY, R.A., FOSTER, P., FRIEDLINGSTEIN, P., GURNEY, K., HOUGHTON, R.A., HOUSE, J.I., HUNTINGFORD, C., LEVY, P.E., LOMAS, M.R., MAJKUT, J., METZL, N., OMETTO, J.P., PETERS, G.P., PRENTICE, I.C., RANDERSON, J.T., RUNNING, S.W., SARMIENTO, J.L., SCHUSTER, U., SITCH, S., TAKAHASHI, T., VIOVY, N., VAN DER WERF, G.R. and WOODWARD, F.I., 2009. Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, vol. 2, no. 12, pp. 831-836. http://dx.doi.org/10.1038/ngeo689.

MANNAN, A., FENG, Z., AHMAD, A., LIU, J., SAEED, S. and MUKETE, B., 2018. Carbon dynamic shifts with land use change in Margallah Hills National Park, Islamabad (Pakistan) from 1990 to 2017. *Applied Ecology and Environmental Research*, vol. 16, no. 3, pp. 3197-3214. http://dx.doi.org/10.15666/aeer/1603_31973214.

MANNAN, A., LIU, J., ZHONGKE, F., KHAN, T.U., SAEED, S., MUKETE, B., CHAOYONG, S., YONGXIANG, F., AHMAD, A., AMIR, M., AHMAD, S. and SHAH, S., 2019. Application of land-use/land cover changes in monitoring and projecting forest biomass carbon loss in Pakistan. *Global Ecology and Conservation*, vol. 17, pp. e00535. http://dx.doi.org/10.1016/j.gecco.2019.e00535.

MCKINLEY, D.C., RYAN, M.G., BIRDSEY, R.A., GIARDINA, C.P., HARMON, M.E., HEATH, L.S., HOUGHTON, R.A., JACKSON, R.B., MORRISON, J.F., MURRAY, B.C., PATAKL, D.E. and SKOG, K.E., 2011. A synthesis of current knowledge on forests and carbon storage in the United States. *Ecological Applications*, vol. 21, no. 6, pp. 1902-1924. http://dx.doi.org/10.1890/10-0697.1. PMid:21939033.

NIZAMI, S.M., 2012. The inventory of the carbon stocks in sub tropical forests of Pakistan for reporting under Kyoto Protocol. *Journal of Forestry Research*, vol. 23, no. 3, pp. 377-384. http://dx.doi.org/10.1007/s11676-012-0273-1.

PAN, Y., BIRDSEY, R.A., FANG, J., HOUGHTON, R., KAUPPI, P.E., KURZ, W.A., PHILLIPS, O.L., SHVIDENKO, A., LEWIS, S.L., CANADELL, J.G., CIAIS, P., JACKSON, R.B., PACALA, S.W., MCGUIRE, A.D., PIAO, S., RAUTIAINEN, A., SITCH, S. and HAYES, D., 2011. A large and persistent carbon sink in the world's forests. *Science*, vol. 333, no. 6045, pp. 988-993. http://dx.doi.org/10.1126/science.1201609. PMid:21764754.

QAMER, F.M., SHEHZAD, K., ABBAS, S., MURTHY, M., XI, C., GILANI, H. and BAJRACHARYA, B., 2016. Mapping Deforestation and forest degradation patterns in Western Himalaya, Pakistan. *Remote Sensing*, vol. 8, no. 5, pp. 385. http://dx.doi.org/10.3390/rs8050385.

RANA, B., SINGH, S. and SINGH, R., 1989. Biomass and net primary productivity in Central Himalayan forests along an altitudinal gradient. *Forest Ecology and Management*, vol. 27, no. 3-4, pp. 199-218. http://dx.doi.org/10.1016/0378-1127(89)90107-2.

RAVINDRANATH, N.H. and OSTWALD, M., 2008. *Carbon inventory methods handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects.* Dordrecht: Springer. http://dx.doi.org/10.1007/978-1-4020-6547-7.

SAEED, S., YUJUN, S., BECKLINE, M., CHEN, L., ZHANG, B., AHMAD, A., MANNAN, A., KHAN, A. and IQBAL, A., 2019. Forest edge effect on biomass carbon along altitudinal gradients in Chinese Fir (*Cunninghamia lanceolata*): a study from Southeastern China. *Carbon Management*, vol. 10, no. 1, pp. 1-12. http://dx.doi.org/10.1080/17583004.2018.1537517.

SANTORO, M., BEER, C., CARTUS, O., SCHMULLIUS, C., SHVIDENKO, A., MCCALLUM, I., WEGMÜLLER, U. and WIESMANN, A., 2011. Retrieval of growing stock volume in boreal forest using hyper-temporal series of Envisat ASAR ScanSAR backscatter measurements. *Remote Sensing of Environment*, vol. 115, no. 2, pp. 490-507. http://dx.doi.org/10.1016/j.rse.2010.09.018.

SOMOGYI, Z., TEOBALDELLI, M., FEDERICI, S., MATTEUCCI, G., PAGLIARI, V., GRASSI, G. and SEUFERT, G., 2008. Allometric biomass and carbon factors database. *Iforest - Biogeosciences and Forestry*, vol. 1, no. 3, pp. 107-113. http://dx.doi.org/10.3832/ifor0463-0010107.

TOLUNAY, D., 2011. Total carbon stocks and carbon accumulation in living tree biomass in forest ecosystems of Turkey. *Turkish Journal of Agriculture and Forestry*, vol. 35, pp. 265-279.

VASHUM, K.T. and JAYAKUMAR, S., 2012. Methods to estimate above-ground biomass and carbon stock in natural forests: a review. *J. Ecosyst. Ecogr*, vol. 2, no. 4, pp. 1-7. http://dx.doi.org/10.4172/2157-7625.1000116.

WANI, A.A., JOSHI, P., SINGH, O. and PANDEY, R., 2012. Carbon sequestration potential of Indian forestry land use systems: a review. *Wetlands*, vol. 354, pp. 182.

WANI, A.A., JOSHI, P.K. and SINGH, O., 2015. Estimating biomass and carbon mitigation of temperate coniferous forests using spectral modeling and field inventory data. *Ecological Informatics*, vol. 25, pp. 63-70. http://dx.doi.org/10.1016/j.ecoinf.2014.12.003.

ZHANG, Y., GU, F., LIU, S., LIU, Y. and LI, C., 2013. Variations of carbon stock with forest types in subalpine region of southwestern China. *Forest Ecology and Management*, vol. 300, pp. 88-95. http://dx.doi.org/10.1016/j.foreco.2012.06.010.

Appendix 1. Growing stock ($m^3\ ha^{-1}$) and Biomass carbon ($t\ ha^{-1}$) table of *Cedrus deodara* and *Pinus wallichiana* based on basal area ($m^2\ ha^{-1}$).

Cedrus deodara						*Pinus wallichiana*					
BA	**GSV**	**AGBM**	**BGBM**	**TTBM**	**BMC**	**BA**	**GSV**	**AGBM**	**BGBM**	**TTBM**	**BC**
0.03	0.15	0.11	0.02	0.13	0.06	0.001	0.007	0.005	0.001	0.01	0.003
0.08	0.37	0.26	0.05	0.31	0.15	0.034	0.148	0.112	0.022	0.13	0.067
0.10	0.58	0.40	0.08	0.48	0.24	0.044	0.152	0.115	0.023	0.14	0.069
0.16	1.00	0.69	0.14	0.83	0.42	0.049	0.218	0.164	0.033	0.20	0.098
0.27	1.87	1.30	0.26	1.56	0.78	0.114	0.635	0.478	0.096	0.57	0.287
0.28	2.04	1.42	0.28	1.70	0.85	0.212	1.398	1.053	0.211	1.26	0.632
0.28	2.19	1.52	0.30	1.83	0.91	0.133	1.010	0.761	0.152	0.91	0.457
0.30	2.45	1.70	0.34	2.05	1.02	0.131	1.082	0.815	0.163	0.98	0.489
0.29	2.54	1.76	0.35	2.11	1.06	0.149	1.294	0.975	0.195	1.17	0.585
0.41	3.65	2.54	0.51	3.05	1.52	0.210	1.973	1.487	0.297	1.78	0.892
0.38	3.57	2.48	0.50	2.97	1.49	0.312	3.080	2.321	0.464	2.79	1.393
0.28	2.67	1.86	0.37	2.23	1.11	0.252	2.609	1.966	0.393	2.36	1.180
0.46	4.50	3.13	0.63	3.75	1.88	0.274	2.932	2.209	0.442	2.65	1.326
0.36	3.66	2.54	0.51	3.05	1.53	0.340	3.755	2.829	0.566	3.40	1.698
0.38	3.95	2.75	0.55	3.30	1.65	0.418	3.075	2.317	0.463	2.78	1.390
0.40	4.24	2.94	0.59	3.53	1.77	0.288	3.775	2.845	0.569	3.41	1.707
0.47	5.00	3.47	0.69	4.17	2.08	0.321	3.839	2.893	0.579	3.47	1.736
0.31	3.41	2.37	0.47	2.84	1.42	0.369	3.307	2.492	0.498	2.99	1.495
0.44	4.86	3.38	0.68	4.05	2.03	0.294	3.708	2.794	0.559	3.35	1.676
0.47	5.22	3.63	0.73	4.35	2.18	0.357	4.605	3.470	0.694	4.16	2.082
0.31	3.51	2.44	0.49	2.93	1.46	0.274	3.615	2.724	0.545	3.27	1.634
0.38	4.34	3.01	0.60	3.62	1.81	0.315	4.227	3.185	0.637	3.82	1.911
0.37	4.30	2.98	0.60	3.58	1.79	0.295	4.047	3.049	0.610	3.66	1.830
0.50	5.83	4.05	0.81	4.86	2.43	0.372	5.181	3.904	0.781	4.68	2.342
0.38	4.62	3.21	0.64	3.85	1.92	0.270	3.802	2.865	0.573	3.44	1.719
0.32	3.92	2.72	0.54	3.26	1.63	0.200	2.885	2.174	0.435	2.61	1.304
0.34	4.17	2.89	0.58	3.47	1.74	0.206	3.004	2.264	0.453	2.72	1.358
0.20	2.42	1.68	0.34	2.02	1.01	0.140	2.072	1.561	0.312	1.87	0.937
0.25	3.16	2.20	0.44	2.64	1.32	0.143	2.142	1.614	0.323	1.94	0.969
0.40	5.08	3.53	0.71	4.23	2.12	0.217	3.296	2.483	0.497	2.98	1.490
0.21	2.65	1.84	0.37	2.21	1.10	0.131	2.006	1.511	0.302	1.81	0.907
0.18	2.29	1.59	0.32	1.91	0.95	0.090	1.394	1.050	0.210	1.26	0.630
0.23	2.92	2.03	0.41	2.43	1.22	0.102	1.602	1.207	0.241	1.45	0.724
0.22	2.85	1.98	0.40	2.38	1.19	0.131	2.067	1.558	0.312	1.87	0.935

BA= Basal area; V= Volume; AGBM= above ground biomass; BGBM= below ground biomass; TTBM= Total tree biomass; BMC= Biomass carbon.

Appendix 2. Growing stock (m^3 ha^{-1}) and Biomass carbon (t ha^{-1}) table of *Abies pindrow* and *Picea smithiana* based on basal area (m^2 ha^{-1}).

Abies pindrow						*Picea smithiana*					
BA	**V**	**AGBM**	**BGBM**	**TTBM**	**BMC**	**BA**	**V**	**AGBM**	**BGBM**	**TTBM**	**BMC**
0.033	0.153	0.086	0.017	0.10	0.051	0.02	0.13	0.07	0.015	0.09	0.04
0.055	0.241	0.136	0.027	0.16	0.081	0.05	0.36	0.21	0.041	0.25	0.12
0.054	0.374	0.210	0.042	0.25	0.126	0.06	0.46	0.26	0.053	0.32	0.16
0.115	0.903	0.507	0.101	0.61	0.304	0.11	0.87	0.50	0.100	0.60	0.30
0.221	1.835	1.031	0.206	1.24	0.618	0.22	1.72	0.99	0.199	1.19	0.60
0.206	1.835	1.031	0.206	1.24	0.619	0.21	1.70	0.98	0.196	1.18	0.59
0.189	1.692	0.950	0.190	1.14	0.570	0.17	1.48	0.85	0.170	1.02	0.51
0.184	1.733	0.973	0.195	1.17	0.584	0.20	1.74	1.00	0.201	1.20	0.60
0.208	2.018	1.133	0.227	1.36	0.680	0.21	1.88	1.08	0.217	1.30	0.65
0.321	0.322	0.181	0.036	0.22	0.109	0.35	3.24	1.87	0.374	2.24	1.12
0.339	3.472	1.950	0.390	2.34	1.170	0.36	3.38	1.95	0.390	2.34	1.17
0.218	2.295	1.289	0.258	1.55	0.773	0.25	2.48	1.43	0.287	1.72	0.86
0.330	3.524	1.979	0.396	2.38	1.188	0.39	3.92	2.26	0.452	2.71	1.36
0.264	2.882	1.619	0.324	1.94	0.971	0.31	3.17	1.83	0.365	2.19	1.10
0.218	2.430	1.365	0.273	1.64	0.819	0.24	2.48	1.43	0.286	1.72	0.86
0.330	3.739	2.100	0.420	2.52	1.260	0.30	3.18	1.83	0.367	2.20	1.10
0.379	4.286	2.407	0.481	2.89	1.444	0.48	5.25	3.03	0.606	3.64	1.82
0.233	2.689	1.510	0.302	1.81	0.906	0.26	2.98	1.72	0.343	2.06	1.03
0.352	4.120	2.315	0.463	2.78	1.389	0.34	3.92	2.26	0.452	2.71	1.36
0.335	3.964	2.227	0.445	2.67	1.336	0.36	4.17	2.40	0.481	2.88	1.44
0.246	2.965	1.666	0.333	2.00	0.999	0.25	2.95	1.70	0.341	2.04	1.02
0.346	4.194	2.356	0.471	2.83	1.414	0.34	4.10	2.36	0.473	2.84	1.42
0.316	3.909	2.196	0.439	2.64	1.318	0.32	3.88	2.24	0.448	2.69	1.34
0.508	6.316	3.548	0.710	4.26	2.129	0.54	6.73	3.88	0.776	4.66	2.33
0.250	3.142	1.765	0.353	2.12	1.059	0.30	3.78	2.18	0.436	2.61	1.31
0.245	3.109	1.747	0.349	2.10	1.048	0.28	3.58	2.07	0.414	2.48	1.24
0.256	3.286	1.846	0.369	2.22	1.108	0.34	4.42	2.55	0.510	3.06	1.53
0.167	2.161	1.214	0.243	1.46	0.728	0.20	2.65	1.53	0.306	1.83	0.92
0.216	2.799	1.572	0.314	1.89	0.943	0.22	2.97	1.72	0.343	2.06	1.03
0.303	3.972	2.231	0.446	2.68	1.339	0.43	5.77	3.33	0.665	3.99	2.00
0.179	2.372	1.332	0.266	1.60	0.799	0.19	2.47	1.42	0.285	1.71	0.85
0.138	1.848	1.038	0.208	1.25	0.623	0.17	2.32	1.34	0.267	1.60	0.80
0.177	2.380	1.337	0.267	1.60	0.802	0.21	2.96	1.71	0.342	2.05	1.02
0.168	2.286	1.284	0.257	1.54	0.770	0.24	3.33	1.92	0.385	2.31	1.15

BA= Basal area; V= Volume; AGBM= above ground biomass; BGBM= below ground biomass; TTBM= Total tree biomass; BMC= Biomass carbon.

Appendix 3. Growing stock (m^3 ha^{-1}) and Biomass carbon (t ha^{-1}) table of Pinus roxburghii based on basal area (m^2 ha^{-1}).

Pinus roxburghii					
BA	**V**	**AGBM**	**BGBM**	**TTBM**	**BMC**
0.008	0.06	0.05	0.009	0.05	0.0027
0.078	0.47	0.36	0.071	0.43	0.21
0.158	1.06	0.79	0.159	0.95	0.48
0.493	3.43	2.57	0.515	3.09	1.54
0.675	4.91	3.68	0.737	4.42	2.21
1.198	8.99	6.74	1.349	8.09	4.05
1.115	8.49	6.37	1.274	7.64	3.82
1.555	12.01	9.01	1.802	10.81	5.41
0.936	7.42	5.57	1.113	6.68	3.34
0.917	7.36	5.52	1.104	6.63	3.31
0.610	4.95	3.72	0.744	4.46	2.23
0.450	3.69	2.77	0.554	3.32	1.66
0.009	0.12	0.09	0.019	0.11	0.06

BA= Basal area; V= Volume; AGBM= above ground biomass; BGBM= below ground biomass; TTBM= Total tree biomass; BMC= Biomass carbon.