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ESTIMATING CARBON STOCKS IN SUB-TROPICAL PINE *(Pinus roxburghii)* FORESTS OF PAKISTAN

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The study estimated the carbon stocks (t/ha) of the native sub tropical pine (*Pinus roxburghii*) forests of Pakistan. Vegetation and soil carbon stocks were assessed in two forest sites of sub-tropical pine forests (Ghoragali, 1729 ha and Lehterar, 1254 ha). Overall, 76 plots of 1 ha each were established between 2006-08, representing a sampling intensity of 2.5% of the total forest area. In each 1 ha plot, overstorey tree diameters at breast height and tree heights were measured. Soil samples (composite n=5) were collected at 0-15 and 15-30 cm depths in each 1 ha plot. Stem biomass was calculated from measured stem diameter, height, standard taper functions and wood density estimates. Total above and below-ground tree biomass was calculated using appropriate biomass expansion factors from the scientific literature to predict branch, foliage and root biomass. Soil carbon (0-30 cm) was calculated by using Walkey-Black organic carbon concentrations multiplied by mean soil bulk density measurements. The study revealed that overall (Vegetation + Soils) C_ Stocks (t/ha) in both the forest ecosystems of Ghoragali and Lehterar forests were 126 $\pm$2.94 and 99 $\pm$ 1.58 t/ha respectively.
Keywords: Sub tropical forest, carbon stocks, tree biomass, soil carbon

INTRODUCTION

Of all terrestrial ecosystems, forests contain the largest store of C (IPCC 2001; Schlesinger 1997; SCOPE 1984). Worldwide, forests cover $4x10^6$ ha (30% of land area) and, relative to non-woody vegetation, have a large biomass per unit area of land (FAO, 2005). The main C pools in forests are plant biomass (above- and below-ground), coarse woody debris, litter and soil (containing organic and inorganic C; IPCC 2003; Richards and Evans 2004). These C pools continue to increase over the life cycle of a forest towards a state of equilibrium when respirational CO_2 losses by plants and soils and decomposition of biomass equals rate of growth (Acker *et al.*, 2002; Smithwick *et al.*, 2002). Where forest growth is disturbed or the forest is destroyed, CO_2 and other greenhouse gases (i.e. methane 'CH_4', nitrous oxide 'N_2O') are released back into the atmosphere via respiration, combustion or decomposition (IPCC 2003; Richards and Evans 2004; Schlesinger 1997).
The ability of forests to both sequester and emit greenhouse gases coupled with ongoing widespread deforestation, has resulted in forests and land-use change being included in the United Nations Framework Convention on Climate Change (UNFCCC) and in the Kyoto Protocol (KYOTO, 1997; UNFCCC, 1992).

The amount of C stored in plant biomass globally exceeds that of atmospheric CO_2, and nearly 90% of the plant biomass C is stored in tree biomass. This emphasizes the importance of forest ecosystems in the global carbon cycle and the necessity to accurately evaluate the amount of C stored in forest ecosystems (Körner, 2006).The importance of forest conservation and new afforestations are recognised within the Kyoto Protocol and other voluntary and regulated carbon trading mechanisms. To meet the requirements of these carbon markets, reliable, but cost efficient, means of estimating forest carbon pools and fluxes are needed. These have so far been lacking for Pakistan's native and managed forest ecosystems. We quantified the mean forest carbon stocks for two major forest types in Pakistan.

MATERIALS AND METHODS

The two forest sites are Ghoragali and Lehterar forest sub divisions are located in the Murree hills (33^0 54' 30" N and 73^0 26' 30" E).The forests of Ghoragali and Lehterar (Murree Hills) receive 1140 mm rainfall/ year and are pure stands of *Pinus roxburghii* managed under the 'Shelter wood' silvicultural system.

Tree biomass

Forest inventories were conducted in the two forest sites to determine the present growing stock. Sampling was done using fixed area plots at sampling intensity of 2.5% total forest area between 2005 and 2008. Overall, 76 plots (each 1 ha) were inventoried. Stem biomass was determined by calculating stem volume (m^3/ha.) and multiplying this by generic dry wood density (t/m^3). The biomass (t/ha) of other tree components (leaves, branches and roots) were estimated from stem biomass using published Biomass Expansion Factors (BEF) for this tree species (Rana *et al.,* 1989; Chaturvedi and Singh, 1982).

Vegetation carbon stocks

The calculations of the carbon sequestered as biomass was done by multiplying the total biomass by conversion factor that represents the average carbon content in biomass. It is not practically possible to separate different biomass components in order to account for variations in carbon content as function of the biomass component. Therefore, the co-efficient of 0.50 for the conversion of biomass to C, (Brown and Lugo, 1982; Roy *et al.*, 2001; Malhi *et al.*, 2004) was used here for conversion from biomass to carbon stocks (t/ha) = 0.50 x Biomass (t/ha). This co-efficient is widely used internationally, thus it has been applied in this study for calculation of total carbon in upper storey vegetation of sub tropical pine forests of Pakistan.

Soil carbon stocks

Composite soil samples were collected at 0-15 and 15-30 cm depths from each inventory plot, using an auger. Soil carbon concentration (g C/g of soil) was established using the Walkey-Black titration method. Soil bulk density (t/m^3) was determined for a sub-sample of inventory plots using a 100 x 150 mm soil core (1178 cm^3). Soil carbon stocks (t C/ha) in the upper 30 cm of soil was then established.
Data collection for desired objectives were recorded using standard procedures (FAO, 2005) and analysed statistically by using student *t test.*

RESULTS AND DISCUSSIONS

Overall stem density of *P. roxburghii* in Ghoragali was 210 trees/ha. (having greater than 20cm dbh) and 668 plants of regeneration having less than 20cm dbh) which overall make 878 trees/ha. with mean basal area 28.47 m^2/ha (R^2 =0.97). While in sub tropical pine forests of Lehterar the stem density of trees having more 20cm stem diameter were 148 tree/ha. (R^2 =0.93). The stem density of regeneration (trees less than 20cm dbh) was 628 trees/ ha with mean basal area of 23.08 m^2/ha. The overall stem density (including regeneration of less than 20cm dbh) of *P.roxburghii* in Ghoragali and Lehterar is 878 and 776 trees/ha, respectively, with a maximum stem diameter of 64 cm (Figure 1) which is within the expected range of 700-1600 trees/ha between altitudes of 1300-1750m

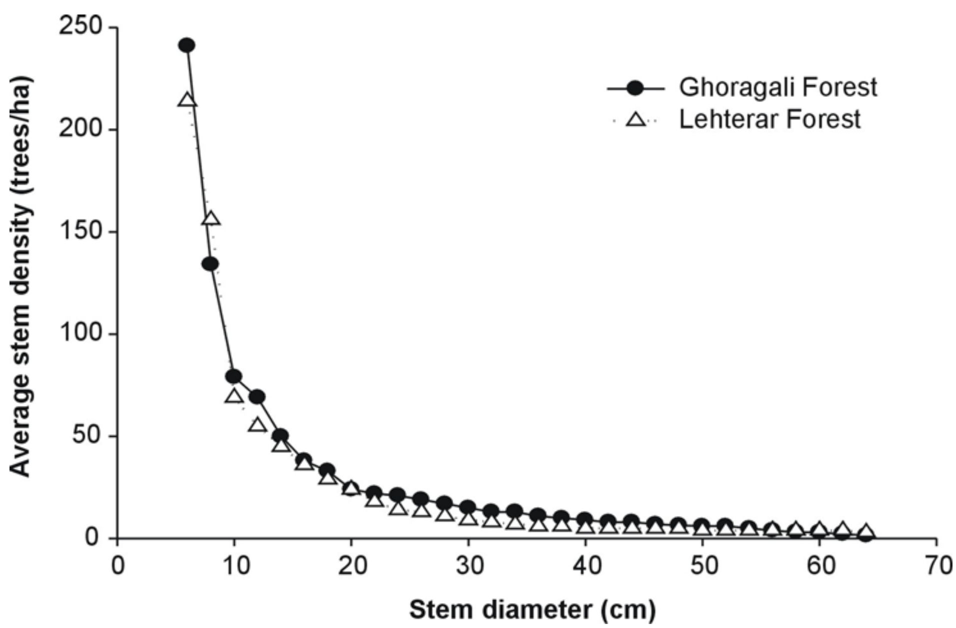

Figure 1. The relationship between stem density (trees/ha) and stem diameter (cm) of *Pinus roxburghii* in Ghoragali and Lehterar Forests of Pakistan

(Surendra *et al.,* 1994). The *P. roxburghii* stem density of 575 trees has been determined by Rana *et al*. (1989) in Himalayan forest of India at an altitudinal range of 1200-1800m. The stem density in both the forests decreased with increasing stem diameters and the relationship between stem density and stem diameter of *P.roxburghii* was best represented by a power function (Table 1).

Field measurement revealed that the average height of *P. roxburghii* in Ghoragali and Lehterar forests increased with increasing stem diameter. The maximum height of *P. roxburghii* in Ghoragali and Lehterar forests was 34.64 and 31.08 m at the maximum stem diameter of 64 cm. The relationship between stem height and diameter of *P. roxburghii* showed a linear relationship in both forests (Table 2).

Table 1. The relationships between stem density (trees/ ha) and stem diameter (cm) for *Pinus roxburghii* in Ghoragali and Lehterar forests of Pakistan

Sr. No.	Forest	Species	Relationship Type	Equation	R^2
1	Ghoragali	*Pinus roxburghii*	Power	$Y= 409.14X^{-1.3736}$	0.97
2	Lehterar	*Pinus roxburghii*	Power	$Y= 330.54x^{-1.37}$	0.93

Table 2. Relationship between stem height (m) and stem diameter (cm) of *Pinus roxburghii* in the Ghoragali and Lehterar forests of Pakistan

Sr. No.	Forest	Species	Relationship Type	Equation	R^2
1	Ghoragali	*Pinus roxburghii*	Linear	Y= 0.9726(x)+ 5.0872	0.94
2	Lehterar	*Pinus roxburghii*	Linear	Y= 0.9609(x)+3.523	0.96

Stem volume (m^3 /ha) of *P. roxburghii* increased with the increasing basal area (m^2/ha). However on average basis the stem volume (m^3/ha) in *Pinus roxburghii* was 243 m^3 /ha. in Ghoragali at average basal area of 30.38 m^2/ha, while in Lehterar the average stem volume was 197 m^3/ha. at an average basal area of 26.11 m^2 /ha (Figure 2).

Biomass estimates of a forest sample are generally not directly measured. Instead, estimates for each tree are made and these are summed to give a total stand estimate (Zianis *et al.,* 2005). The simplest way to estimate above-ground biomass at the individual tree level is to use allometric equations. Allometric equations can be general or species-specific and can use diameter alone or diameter with height to produce biomass estimates of the whole-tree or of tree components (Chave *et al.,* 2005). By using one or two measurements, allometric equations offer a simple approach to estimating tree biomass (Keith *et al.,* 2000; Lambert *et al.*, 2005). An alternative to using allometric equations to produce estimates of individual tree biomass, is to use stand-level estimates of stem wood biomass ('SWB'; i.e. kg ha^{-1}) that are converted to stand-level estimates of above-ground tree biomass ('AGTB'; i.e. including non-stem components) using expansion or conversion factors (AGO, 1998; Zianis *et al.,* 2005).

In this study tree stem biomass (t/ha) was calculated by multiplying wood density (t/m^3) with stem volume (m^3/ha). A regression equation was developed for stem biomass as a function of basal area (m^2/ha). The stem biomass increasing with the increasing stem diameter. The relationship between stem biomass and basal area was determined in each forest site. Regression equations for stem biomass of dominant species in each forest site has shown more linear relationship ($y_0 + ax + bx^2$) with stem diameter (Table 3).

The allocation of biomass to stem is greater in *P. roxburghii* (63%) as compared to contribution of other tree components like branches (11.57%), twigs (3.38%), leaves (3.21%) and roots (18.5%) as given by Rana *et al.* (1989). In the forest of Ghoragali and Lehterar, the mean total tree biomass was 237 and 186 t/ha (Table 4).

It should also be mentioned that most studies are concerned with evaluating forest biomass pools, not carbon pools. It has traditionally been assumed that the carbon content of dry biomass of a tree was 50% (Brown and Lugo, 1982; Roy *et al.,* 2001; Malhi *et al.,* 2004), however it should be emphasized that wood carbon fraction may exhibit some small variation (Elias and Potvin, 2003). Assuming that carbon is 50% of dry biomass, the total carbon stocks in upper storey vegetation of sub tropical pine (*P. roxburghii*) forest is calculated as 119 t/ha in Ghoragali Forest and 93 t/ha in Lehterar forests (Table 4). The total soil C stocks were determined at depths of 0-30cm in both forest sites and was found to be 7.40 and 6.24 t/ha at Ghoragali and Lehterar respectively (Figure 3). Student t-test results showed ($P < 0.05$) significant variation in means of C stocks between these two forests sites.

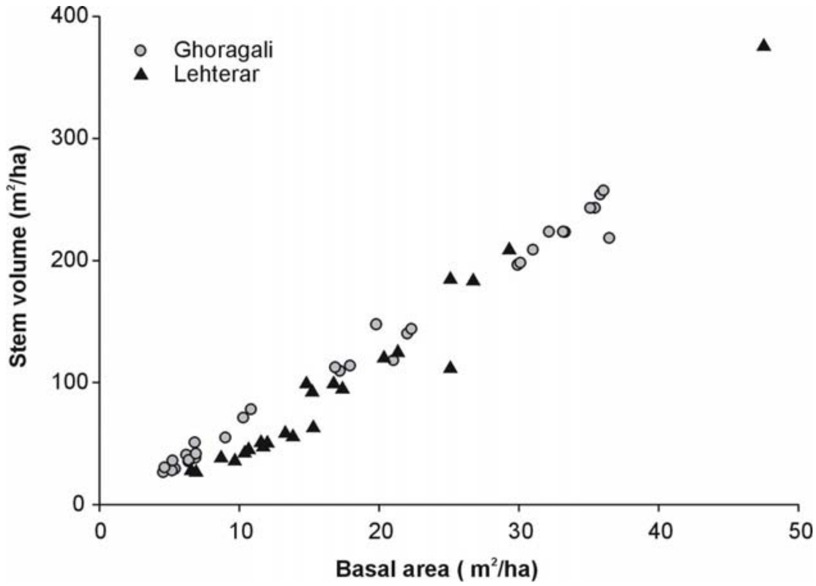

Figure 2. The relationship between stem volume (m^3/ha) and basal area (m^2/ha) of *Pinus roxburghii* in Ghoragali and Lehterar Forests in Pakistan

Table 3. Regression equations of stem biomass of *P. roxburghii* in both the forests sites

Sr. No.	Forest Sites	Species	Y_0	a	B	R^2
1	Lehterar	*Pinus roxburghii*	22.99	0.7524	0.1194	0.98
2	Ghoragali	*Pinus roxburghii*	8.464	2.05	5.65	0.98

Table 4. Calculation of above and below ground total carbon stocks (t/ha) in Ghoragali and Lehterar Forests of Pakistan

Forest site	Avg. basal area (m^2/ha)	Avg. stem volume (m^3/ ha)	Tree density (t/m^3)	Avg. stem biomass (t/ha)	Total tree biomass (t/ha)	Total tree C (t/ha)	Soil C (t/ha)	Total C (t/ha)
Ghoragali	30.38	243	0.617	149	237	119	7.40	126
Lehterar	26.11	197	0.617	117	186	93	6.24	99

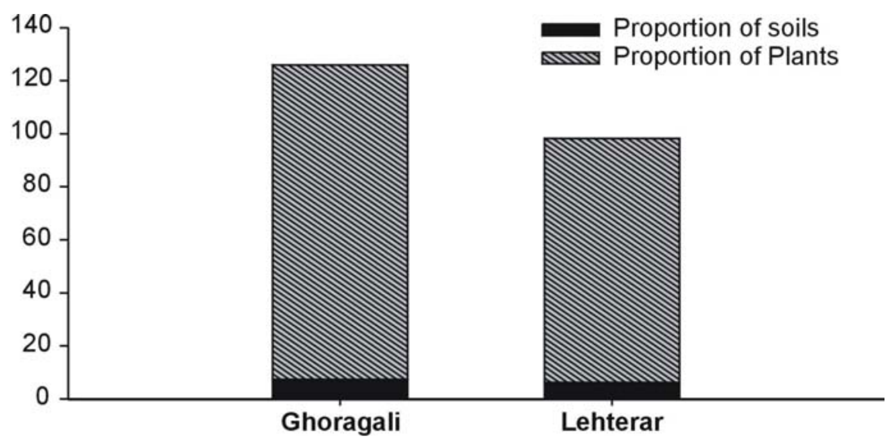

Figure 3. Total C stocks (t C/ha) in plant biomass and soils of Pine (*Pinus roxburghii)* forests of Ghoragali and Lehterar in Pakistan

CONCLUSION

The overall carbon stock (plant + soil) in two forest sites in sub tropical pine (*P. roxburghii*) forest is 126 ± 2.94 t/ha in Ghoragali and 99±1.58 t/ha in Lehterar (Table 4). However, on the average basis sub tropical Pine (*P. roxburghii*) Forest ecosystem is having 112.5± 2.26 t/ha. of carbon which comprises of 94% from plant material and 6% from topsoils.

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