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ORIGINAL PAPER

The inventory of the carbon stocks in sub tropical forests of Pakistan for reporting under Kyoto Protocol

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Abstract The United Nations Framework Convention on Climate Change (UNFCCC) requires reporting net carbon stock changes and anthropogenic greenhouse gas emissions, including those related to forests. This paper describes the status of carbon stocks in sub tropical forests of Pakistan. There are two major sub types in subtropical forests of Pakistan viz a viz Subtropical Chir Pine and Subtropical broadleaved forests. A network of sample plots was laid out in four selected site. Two sites were selected from sub tropical Chir Pine (*Pinus roxburghii*) forests and two from Subtropical broadleaved forests. Measurement and data acquisition protocols were developed specifically for the inventory carried out from 2005 to 2010. In total 261 plots (each of 1ha.) were established. Estimation of diameter, basal area, height, volume and biomass was carried out to estimate carbon stocks in each of the four carbon pools of above- and below-ground live biomass. Soil carbon stocks were also determined by doing soil sampling. In mature (~100 years old) pine forest stand at Ghoragali and Lehterar sites, a mean basal area of 30.38 and 26.11 $m^2·ha^{-1}$ represented mean volume of 243 and 197 $m^3·ha^{-1}$, respectively. The average biomass ($t·ha^{-1}$) was 237 in Ghoragali site and 186 $t·ha^{-1}$in Lehterar site, which is equal to 128 and 100 t C ha^{-1} including soil C. However, on average basis both the forests have 114.5± 2.26 $t·ha^{-1}$ of carbon stock which comprises of 92% in tree biomass and only 8% in the top soils. In mixed broadleaved evergreen forests a mean basal area ($m^2·ha^{-1}$) was 3.06 at Kherimurat with stem volume of 12.86 and 2.65 at Sohawa with stem volume of 11.40 $m^3·ha^{-1}$. The average upper and under storey biomass ($t·ha^{-1}$) was 50.93 in Kherimurat site and 40.43 $t·ha^{-1}$in Sohawa site, which is equal to 31.18 and 24.36 t C ha^{-1} including soil C stocks. This study provides a protocol and valuable baseline data for monitoring biomass and carbon stocks in Pakistan's managed and unmanaged sub-tropical forests.

Keywords: carbon stock models; managed and unmanaged subtropical forests; above and below ground biomass; forest inventory and volume.

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Introduction

Pakistan ratified the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC) in the year 2005. After its acceptance it has to come into force for maintaining its net greenhouse gas emissions over the Kyoto Protocol's first commitment period (CP1, the 5 years from 1 January 2008 to 31 December 2012).

Good Practice Guidance for LULUCF activities requires carbon stock changes to be estimated in an unbiased, transparent, and consistent manner, where uncertainties are determined and recorded over time (IPCC, 2003). Net carbon stocks in each forest type of Pakistan will be evaluated for reporting under Kyoto Protocol.

This paper describes the field protocols, the Volume, biomass and carbon models and the methods of obtaining soil carbon stock assessments.

Under the Kyoto Protocol, forests are defined as an ecosystem that having the ability to attain at least 5 m in height *in situ* with at least 30% canopy cover on a minimum area of 1 ha and a width greater than 30 m. Urban trees, shelterbelts, orchards and horticultural trees are not included in the forest definition. Five carbon pools must be reported in carbon stock assessment, which includes: (1) above-ground live biomass (AGB), living stems, branches, foliage; (2) below-ground live biomass (BGL), living roots; (3) dead wood (coarse woody debris, CWD) not contained in the litter, either standing, lying on the ground, or in the soil; (4) litter (fine litter, FL) litter, fumic, and humic layers; (5) soil organic carbon to a specified depth.

The present study was carried out to estimate carbon stocks in subtropical forest type of Pakistan. This forest type is further categorized into two forest types i.e. subtropical pine forests managed under a shelter wood silvicultural system and the sub tropical broad leaved evergreen forests, which has not been managed under any silvicultural system. This research was aimed at quantification of carbon stocks in aforementioned managed and unmanaged forest types to establish scientific protocol for proper documentation of carbon stocks estimations in all natural forests of the country. The specific objectives of the study were to: (1) determine stem density, stem volume and stem biomass in targeted forest types of Pakistan, and (2) to estimate the carbon stocks at three levels (upper storey, under storey and soils) of these forests.

Materials and Methods

Two forest sites, namely Ghoragali and Lehterar Forests, from subtropical pine forest and other two forest sites, namely Kherimurat scrub forest and Sohawa forest areas from subtropical broadleaved evergreen forest were selected for sampling as four replicates. These sites are the true representative of these forest types with reference to climate, species, soil and human activities. The sampling intensity of 2.5 percent was adopted due to species composition and terrain conditions. Overall 261 plots were laid out in the four sites (Table 1).

Table 1. Area, No. of plots sampled, plot to plot distances of sampled forests

S. No	Forest site	Area (ha)	No. of plots sampled	Plot to plot distance (m)
1	Lehterar	1254	32	566
2	Ghoragali	1729	44	663
3	Sohawa	4048	101	1005
4	Kherimurat	3360	84	917

Field procedures

Upper storey vegetation
Field protocols for the plot measurements are described in detail in Payton et al. (2008). The distance and bearing from the plot centre were measured of each stem that was located within the radius of the circular plot, established to give the required horizontal area. Within a plot, all trees greater than 2.5 cm diameter at breast height (DBH) were identified by species and their DBH measured. The heights of 16 trees per species were measured with Abney`s level, sufficient to construct plot-specific height/DBH functions. Volume ($m^3 ha^{-1}$) for all the sampling sites was measured using following formula (Philips 1994) and then multiplied by wood density ($kg \cdot m^{-3}$) of particular species to have total biomass ($kg \cdot ha^{-1}$).

$$\text{Volume of tree } (m^3) = (\pi/4) \times d^2 \times h \times f$$

where h is the tree height, d^2 is square of diameter and f is the form factor.

By using the calculated volume of the stem (m^3), the total stem biomass (kg) was measured with the help of wood density ($kg \cdot m^{-3}$). For the present study wood density values were sourced from technical reports, websites and were confirmed from parallel studies conducted on the sites for determining wood densities of the species present in these forest sites.

$$\text{Biomass (kg)} = \text{Volume } (m^3) \times \text{Wood density } (kg \cdot m^{-3})$$

Allometric equations or biomass expansion factors (BEF) were investigated for the subtropical tree species present in Pakistan. Using generic BEF, biomass of entire forest was determined.

Undersotrey vegetation
Native and exotic shrubs in the under-storey or in canopy gaps within the forest were measured by harvesting from circular plot of 9 m radius laid out from the center of 1 hectare or 56 m radius plot. All the harvested material was put into the labeled bags for further analysis. Dry weights were measured nearest to 0.01 kg after drying the samples in an oven at 72ºC for 48 h. The biomass was calculated species wise by considering dry weight (kg) as biomass (kg) (Oliver et al. 2009).

Soil Sampling
Samples of soils were collected from depths of 0–15 and 15–30 cm in three replications in each plot with the help of an auger and soil core sampler. Each sample was weighed in the field and stored in labeled bag for further laboratory analysis. The soil bulk density in the study sites was determined by using a soil core sampler of known volume 0.007854 m^3 (Diameter =100 mm, Height = 150 mm).

To estimate the amount of carbon in the forest soil, samples of soils were brought into the laboratory for further analysis. For determining the carbon concentration in the soil, the method of oxidizable organic carbon given by Walkley and Black (1934), outlined in (Alison 1965), (Rayment and Higginson 1992), and (Anderson and Ingram 1993), was used because of available resources.

Carbon stock calculations for upper & under storey vegetation

The total carbon stock in upper storey vegetation of the forests was determined by multiplication of the total plant biomass by convertible factor which is representative of the average carbon content in plant biomass. This convertible factor (0.50) shows 50% of total plant biomass is equal to C. This factor is used worldwide (Roy et al. 2001; Brown and Lugo 1982; Malhi et al. 2004). Thus it has been applied in this study for calculation of total carbon in upper & under storey vegetation of both subtropical broadleaved evergreen and subtropical Chir pine forests of Pakistan. Total organic carbon in soils of these forests was determined by estimating C concentration and bulk density at varying (0–15 and 15–30 cm) depths in each forest site.

Results and discussion

Stem density

The study revealed that in the subtropical pine forests of Ghoragali and Lehterar the density of *P. roxburghii* was 878 & 776 trees·ha^{-1} ranging from 7 cm to 64 cm dbh (Fig.1) with mean basal area 30.38 & 26.11 m^2·ha^{-1} respectively (R^2 =0.97, $p < 0.05$ & R^2 =0.93; $p < 0.05$). In both the forests, the relationship between *P. roxburghii* stem density and stem diameter was best represented by a power function (Table 2). This density value is within the expected range of 700–1,600 trees·ha^{-1} at altitudes of 1300–1750 m (Singh et al. 1994) and slightly greater than the stem density of 575 trees determined by Rana et al. (1989) in Himalayan forest of India at an altitudinal range of 1,200–1,800 m. This study revealed that total stem density of all the species in all the studied forests sites decreases with increasing diameter (Fig. 1). In the *P. roxburghii* forest this is brought about not only by natural thinning but also by active stem removal under the shelter wood system. This leads to a decrease in stem volume and stem biomass on an area basis in the larger stem diameters of the oldest periodic block I (age 76–100 years). The stem density of lower diameter classes indicated that Ghoragali has a greater number of trees than Lehterar. The reason for decrease in number of trees in lower diameter class of Lehterar is site quality and aspect. In the recent past years there was a fire in Ghoragali which has increased the saplings of *P. roxburghii* in disturbed sites that create large canopy openings and exposed topsoil (Quazi et al. 2003). However, stem density in the higher stem diameter class of Ghoragali is drastically reduced due to level of exploitation under shelterwood system.

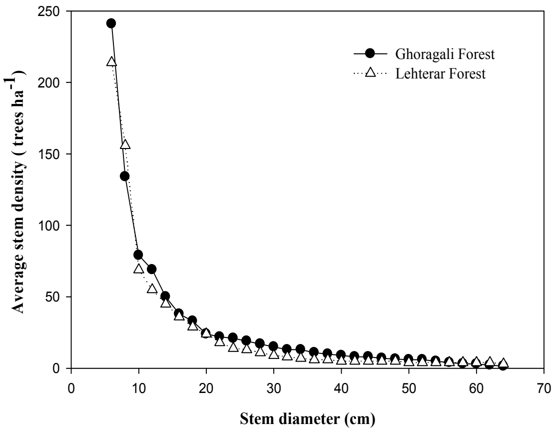

Fig.1 The relationship between stem density (trees·ha^{-1}) and stem diameter (cm) of *P.roxburghii* in Ghoragali and Lehterar Forests

There were two dominant species in the subtropical broadleaved evergreen forest of Kherimurat and Sohawa, *Acacia modesta* (Phulai) and *Olea ferruginea* (Kahu). The average stem density for *A. modesta* in Kherimurat and Sohawa was 197 and 179 (ranging from 6–36 cm dbh) trees·ha^{-1}, respectively, with mean basal area of 1.81 and 1.66 m^2·ha^{-1} respectively. This can be compared to average stem density of 146 trees·ha^{-1} in mixed Acacia forest of Yemen (Herzog 1998). For *O. ferruginea,* the average stem density (ranging from 6–30 cm dbh) in Kherimurat and Sohawa was 94 and 56 trees·ha^{-1} respectively, with mean basal area of 1.25 and 0.99 m^2·ha^{-1}, respectively (Fig. 2). The relationship between stem density and stem diameter for *Acacia modesta* in Kherimurat and Sohawa was best represented by an exponential function with an R^2 of 0.97 ($p < 0.05$) in Kherimurat, and 0.93 ($p < 0.05$) in Sohawa. Similarly, the relationship between stem density and stem diameter for *Olea ferruginea* was best represented by an exponential relationship (Table:2).

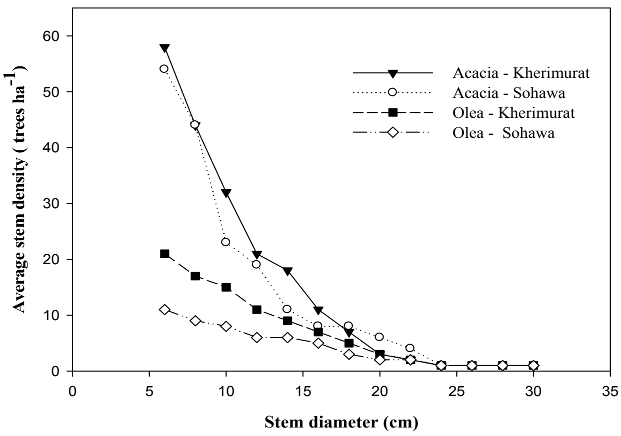

Fig.2 The relationship between stem density and stem diameter of *A. modesta* and *O. ferruginea* in Kherimurat and Sohawa Forests

Table 2: The relationships between stem density (trees ha^{-1}) and stem diameter (cm) for *P. roxburghii*, *A. modesta* and *O. ferruginea* in Ghoragali, Lehterar, Kherimurat and Sohawa forests

S.No	Forest	Species	Relationship Type	Equation	R^2
1	Ghoragali	*Pinus roxburghii*	Power	$Y= 409.14X^{-1.3736}$	0.97
2	Lehterar	*P. roxburghii*	Power	$Y= 330.54x^{-1.37}$	0.93
3	Kherimurat	*Acacia modesta*	Exponential	$Y= 121.3e^{-0.4473x}$	0.97
4	Kherimurat	*Olea ferruginea*	Exponential	$Y= 33.591e^{-0.2984x}$	0.96
5	Sohawa	*A. modesta*	Exponential	$Y=84.442e^{-0.3777x}$	0.93
6	Sohawa	*O. ferruginea*	Exponential	$Y= 15.277e^{-0.2318x}$	0.95

Hussain (1984) described the vegetation of the area under Pothowar Plateau and dry hills of the frontier province and reported significant stem density of *A. modesta* at higher altitudes and *O. ferruginea* in moist places. Naqvi (1997) classified this type of vegetation under Sub-mountain zone while Hussain and Ellahi (1991) described this area as dry subtropical broadleaved forests. Ahmed et al. (2006) has reported two communities in the foot hills of Sub tropical chir pine forests, the *A. modesta* on southern aspects and *O. ferruginea* on northern aspects with basal areas of

16 and 26 m^2·ha^{-1}, respectively.

Stem biomass

Stem biomass (t·ha^{-1}) was calculated by multiplying stem volume with stem density (kg·m^{-3}). A regression equation was developed for stem wood biomass as a function of basal area (m^2·ha^{-1}) for all three dominant tree species (*A. modesta, O. ferruginea* and *P. roxburghii*) in all the four forests sites. The relationship between stem biomass (m^3·ha^{-1}) and basal area (m^2·ha^{-1}) was determined for all species and presented in Figs.3-8 with co-efficient of determination (R^2).

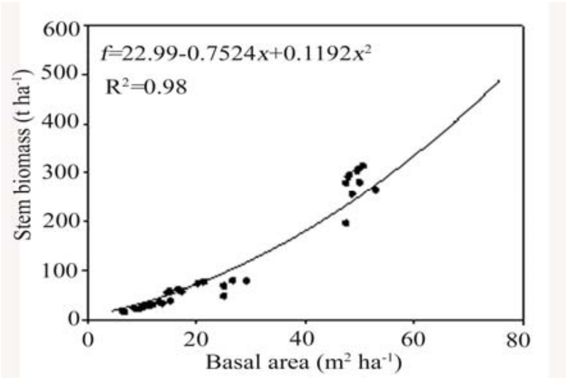

Fig. 3 Stem biomass (t·ha^{-1}) as a function of basal area (m^2 ha^{-1}) for *P. roxburghii* in Lehtera

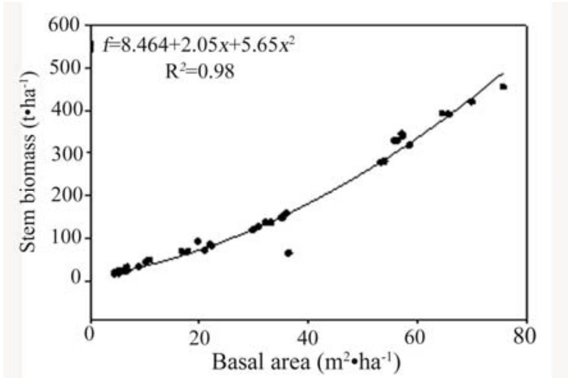

Fig. 4 Stem biomass (t·ha^{-1}) as a function of basal area (m^2·ha^{-1}) forest for *P. roxburghii* in the Ghoragali forests

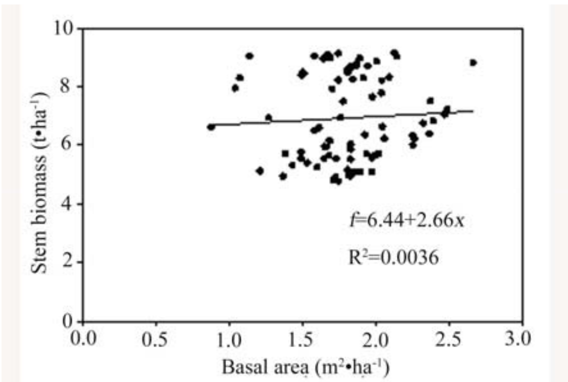

Fig. 5 Stem biomass (t·ha^{-1}) as a function of basal area (m^2·ha^{-1}) for *A. modesta* in Kherimurat forest

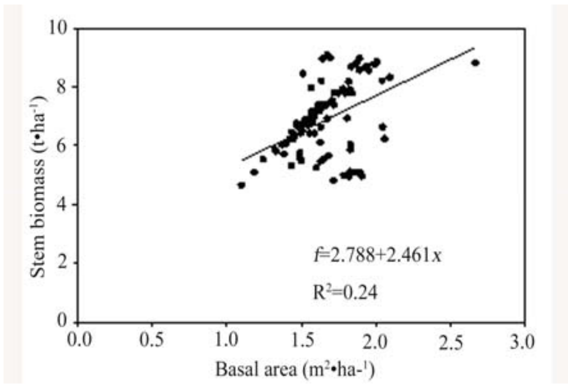

Fig. 6 Stem biomass (t·ha^{-1}) as a function of basal area (m^2·ha^{-1}) for *A. modesta* in Sohawa forest

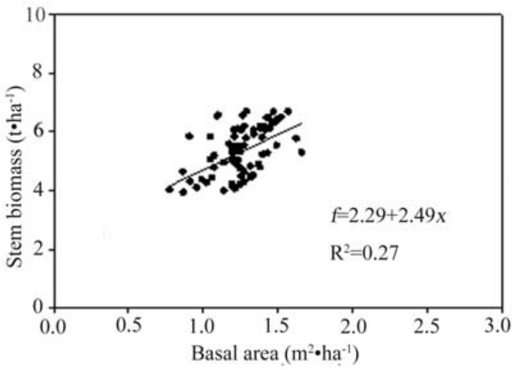

Fig. 7 Stem biomass (t·ha^{-1}) as a function of basal area (m^2·ha^{-1}) for *O. ferruginea* in Kherimurat forests

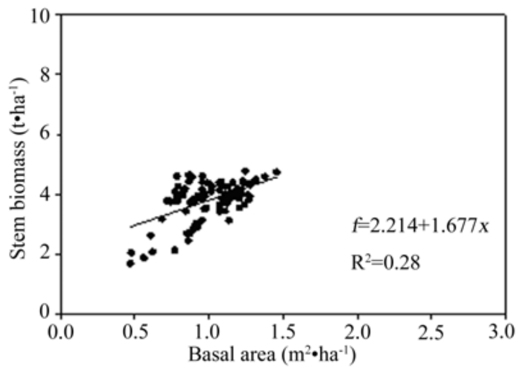

Fig. 8 Stem biomass (t·ha^{-1}) as a function of basal area (m^2 ha^{-1}) for *O. ferruginea* in Sohawa forest

Regression equations for stem biomass (t·ha^{-1}) of *P. roxburghii* in Ghoragali and Lehterar forests have shown a quadratic $\{f = y_0 + a(x) + b(x)^2\}$ relationship with basal area (m^2·ha^{-1}), whereas the dominant species in mixed broad leaved forests have shown weak relationships $\{f = y_0 + a(x)\}$ with basal area (m^2·ha^{-1}). The stem biomass (m^3 ha^{-1}) increased with the increasing basal area ($m^2 \cdot ha^{-1}$) as presented in (Table 2).

Branch, leaf and root biomass (BLRB)

The literature examples of biomass allocation in *P. roxburghii* was 63% to stem, which was considerably greater than allocation to other tree components such as branches 11.57%, twigs 3.38%, leaves 3.21% and roots 18.5% (Rana and Singh 1989). Talking about the biomass allocation in *A. modesta*, there was no literature available for it and biomass allocation in *A. nilotica* was used to determine the biomass in *A. modesta*. The stem biomass allocation in *A. nilotica* was 45% as compared to biomass of branches and leaves which was 40.26%. The roots of *A. nilotica* contribute 14.04% to total tree biomass (Toky and Bisht 1993). In contrast, the stem biomass in *O. ferruginea* was the one that is available for *O.europea* and it was as low as 14.87% in stem compared to branches 20.43% and leaves 31.40% (Villalobes et a*l*. 2000). The allocation of biomass in fruit of *O. ferruginea* was 16.40% which is almost equal to the allocation of biomass to roots 17%.

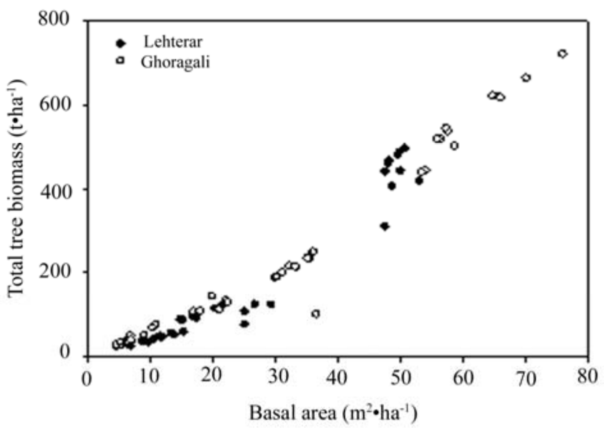

Fig. 9 Total tree biomass ($t \cdot ha^{-1}$) of *P. roxburghii* in Ghoragali and Lehterar forests

Total tree biomass (stem, branches, leaves and roots) in mature *P. roxburghii* forest in the Ghoragali forest was up to 718 $t \cdot ha^{-1}$ at a basal area of 76 $m^2 \cdot ha^{-1}$ while in Lehterar forests the biomass of mature stand has a maximum value of 495 $t \cdot ha^{-1}$ at a basal area of 51 $m^2 \cdot ha^{-1}$ (Fig. 9). The mean total tree biomass ($t \cdot ha^{-1}$) in silviculturally managed subtropical *P. roxburghii* forests of Ghoragali was calculated as 237 $t \cdot ha^{-1}$, while in Lehterar the mean total tree biomass was 186 $t \cdot ha^{-1}$. In the subtropical broadleaved evergreen silviculturally unmanaged forest at Kherimurat, the maximum total tree biomass of *A. modesta* was 19 $t \cdot ha^{-1}$ at basal area of 2.0 $m^2 \cdot ha^{-1}$ in comparison with 44 $t \cdot ha^{-1}$ at a basal area of 1.5 $m^2 \cdot ha^{-1}$ for *O. ferruginea*. In the comparable Sohawa forest, the maximum total tree biomass of *A. modesta* was 20 $t \cdot ha^{-1}$ at basal area of 1.72 $m^2 \cdot ha^{-1}$ in comparison with 30 $t \cdot ha^{-1}$ at basal area of 1.1 $m^2 \cdot ha^{-1}$ for *O. ferruginea* (Figs.10 &11). The mean total tree biomass ($t \cdot ha^{-1}$) in subtropical broadleaved evergreen forests of Kherimurat and Sohawa was calculated as 50.93 and 40.43 $t \cdot ha^{-1}$, respectively.

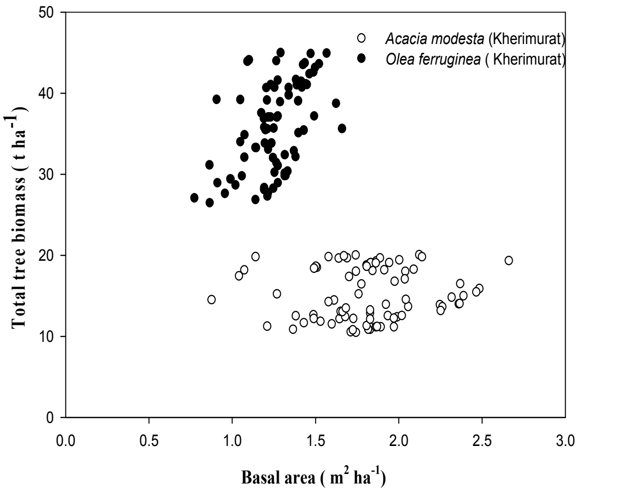

Fig. 10 Total tree biomass ($t \cdot ha^{-1}$) of *A. modesta* and.*O ferruginea* in Kherimurat forests

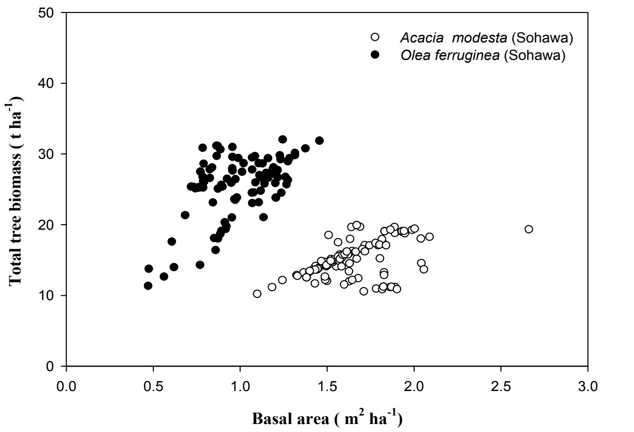

Fig. 11 Total tree biomass ($t \cdot ha^{-1}$) of *A. modesta* and *O. ferruginea* in Sohawa forests

In the present study, biomass expansion factors (BEF) were used for estimating the total tree biomass in all species. In the BEF of all the species the percentage of stem biomass has been taken as one derived from stem biomass calculated from the allometric conversion of field data. The proportional allocation of biomass to branches, foliage, roots (and fruits) were sourced from previous studies of the same or similar tree species (Rana and Singh 1989; Toky and Bisht 1993; Villalobes et al. 2000). The biomass of each component and total tree was related to the respective DBH of each tree within a plot for each species.

In current study, BEF of *Acacia nilotica* and *Olea europea* as determined by Toky and Bisht (1993) and Villalobes et al. (2000) have been used as BEF for *Acacia modesta* and *Olea ferruginea* because of similarities in physiognomy and growth habit. Moreover both the species are recommended for planting in areas of the same ecology as *Acacia nilotica* and *Olea europea* (PFI, 2005).

The study determined that total biomass in *P. roxburghii* at altitudinal range of 1,100–1,300 m lies between 197 to 243 t·ha^{-1}, the least being for Lehterar Forests and the greatest for Ghoragali forests. Rana et al. (1989) reported biomass for *P. roxburghii* between 193 to 782 t·ha^{-1} in Himalayan Pine Forests at an altitudinal range of 300–2200 m. The range of forest biomass (170–228 t·ha^{-1}) is comparable to the biomass range of 200–600 t·ha^{-1} generally found in the mature forests of the world (Whittaker, 1975). Moreover, the tree biomass in a *P. roxburghii* forest and *P. roxburghii* / mixed broadleaved forest (199 t·ha^{-1} and 192 t·ha^{-1}, respectively) was measured by Rana et al. (1989). This result is similar to that of 38 years old *P. roxburghii*r pine forest of the Himalayan region studied by Chatervuerdi and Singh (1982) and majority of the conifer of the temperate regions (133–202 t·ha^{-1}, based on the studies of Reichle, (1981). Biomass distribution presented by Rana and Singh (1989) in different components of the individual tree of *P. roxburghii* is stem (63.23%), branches (11.57%), twigs (3.38%), needles/leaves (3.21% and roots (18.5%). Biomass is much affected by age of the dominant plants and since the age differs among the forests, the relationship between productivity and the biomass in pine forest is rather loose (Lieth 1975).

Biomass of understorey vegetation

Woody understorey vegetation was almost absent in the pure *P. roxburghii* stands of the subtropical pine forests in Ghoragali and Lehterar, whereas there were different understorey species in the broadleaved evergreen (scrub) forests of Kherimurat and Sohawa. The *Dodonea viscosa (*Sanatha*)* is present in association with *Melhania fatteyporensis* in Kherimurat, and *D. viscosa* is found in association with *Grewia oppositifolia* in Sohawa.

Mean understorey vegetation biomass of Kherimurat and Sohwa is 0.150 t·ha^{-1} and 0.036 t·ha^{-1} respectively (Fig.12). The average biomass of woody understorey vegetation in of Kherimurat was comparatively higher than Sohawa forests. In some sampling plots of Sohawa, the biomass (t·ha^{-1}) of understorey vegetation showed maximum value of 0.06 t·ha^{-1}. The understorey biomass (t·ha^{-1}) of each plot in Kherimurat and Sohawa is presented in Fig. 12. These understory species are adaptable and tolerant to habitat types and environment stresses like temperature, erratic rainfall and aridity (Holmgren and Holmgren 1977; Gleason and Cronquist 1991; Speranza 1995); therefore distributional pattern seems to be not dependent on a particular soil condition (Bell et al. 2000; Hubbell 2001).

Soil carbon analysis

Carbon concentration in soils was determined through the Walkley-Black method of titration. The mean soil carbon concentration in the Ghoragali forest at depths of 0–15 and 15–30 cm was 2.94±0.54 and 1.99±0.57 mg·g^{-1}, respectively, while the soil carbon concentration in the Lehterar forest at depths of 0–15 and 15–30cm was comparatively lower at 2.54±0.37 and 1.56±0.35 mg·g^{-1}, respectively. The concentration of carbon in soils of Kherimurat forests at 0–15 and 15–30 cm depths was 1.54±0.77 and 0.99±0.57 mg·g^{-1}. Similarly, the carbon concentration in soils of Sohawa forests was 1.29±0.67 and 0.84±0.74 mg·g^{-1} at depths of 015 and 15-30 cm, respectively (Fig. 13).

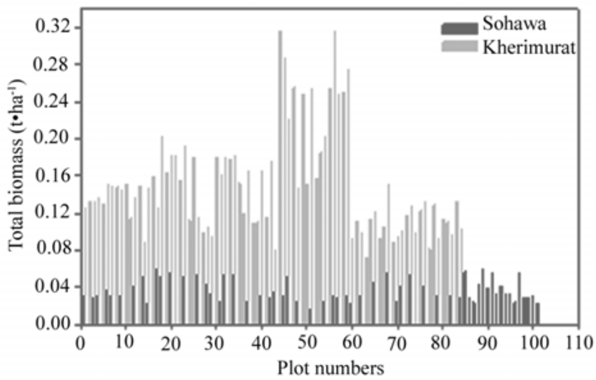

Fig. 12 Plot wise understorey biomass (t·ha^{-1}) in Kherimurat and Sohawa broad leaved evergreen forests

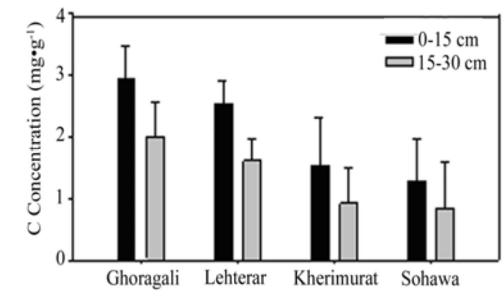

Fig. 13 Carbon concentration (mg·g^{-1}) in soils of two *P. roxburghii* forests (Ghoragali and Lehterar) and two broadleaved evergreen forests (Kherimurat and Sohawa)

To measure the total soil carbon (t·ha^{-1}) within the forests area the carbon concentration (mg·g^{-1}) and bulk density (g·cm^{-3}) have to be determined. Bulk density is a measure of the weight of the soil per unit volume (g·cm^{-3}), usually given on an oven-dry (110° C) basis. Variation in bulk density is attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. In the present study soils samples were collected to a depth of 30 cm and it was concluded that there were greater soil carbon stock in the managed *P. roxburghii* forests (9.2 and 8.03 t·ha^{-1} in Ghoragali and Lehterar) than in the unmanaged evergreen broadleaf forest (5.45 and 4.12 t·ha^{-1} in Kherimurat and Sohawa). Similar soil carbon contents were also reported by Shrestra et al. (2004) in mountainous forests of Nepal.

Total carbon stocks

Total carbon stocks in upper storey vegetation

The total carbon stocks (t·ha^{-1}) in the upper storey vegetation of two silviculturally managed and two unmanaged sites of sub tropical forest was calculated as 50% of total biomass ($t \cdot ha^{-1}$) as it has internationally been assumed that 50% of the dry biomass of a tree is elemental carbon (Brown and Lugo 1982; Roy et al. 2001; Malhi et al. 2004).

Total carbon stocks in understorey vegetation

The total carbon stocks in under storey vegetation of Sohawa and Kherimurat forests sites was determined by using the same conversion factor, i.e. 50% of dry biomass. The carbon stocks in understorey vegetation are 0.15 $t \cdot ha^{-1}$ in Kherimurat and 0.075 $t \cdot ha^{-1}$ in Sohawa forests.

Total carbon stocks in forest soil

The forest soil carbon stocks were calculated by multiplying the soil carbon concentration by the measured soil bulk density of each forest site (Birkeland 1984). The total soil carbon stock was determined at depths of 0–15 and 15–30cm in all forest sites and was in the range 5.08±0.98 and 4.12±1.30 $t \cdot ha^{-1}$ at 0–15 and 15–30cm depths, respectively in Ghoragali. Soil carbon stocks at Lehterar were 4.60±1.12 and 3.43±1.23 $t \cdot ha^{-1}$ respectively at 0–15 and 15–30cm. Soil C stocks were lowest in the Sohawa broadleaved evergreen scrub forest and found to be 2.33±1.36 and 1.79±1.07 $t \cdot ha^{-1}$ at 0–15 and 15–30cm depths, respectively. In Kherimurat, soil C stocks were also determined at two different depths and found to be equal to 3.29±1.10 and 2.16±1.87 $t \cdot ha^{-1}$ respectively. For the upper 30 cm, Ghoragali, Lehterar, Kherimurat and Sohawa had soil carbon stocks of 9.2, 8.03, 5.46 and 4.12 $t \cdot ha^{-1}$ respectively.

Total carbon stocks in ecosystem

Both vegetation and soil carbon contribute to the total forest ecosystem carbon stocks. The total forest carbon stock (plant + soil) in the managed sub tropical *P. roxburghii* forests was 128±2.94 $t \cdot ha^{-1}$ in Ghoragali and 100±1.58 $t \cdot ha^{-1}$ in Lehterar. However, on average basis both the forests have 114±2.66 t ha^{-1} of carbon stock which comprises of 92% in tree biomass and only 8% in the topsoil (Fig. 14), which shows considerable low in soil. The reason may include loss of topsoil through erosion, low litter fall and very low vegetation cover in the studied forest type. Student *t*- test was applied on the means of two forest sites in *P. roxburghii* stand to check the variations. Study revealed that there was significantly variation ($p < 0.05$) in soil carbon ($t \cdot ha^{-1}$) and in total carbon stocks in Ghoragali and Lehterar forests (Table 3).

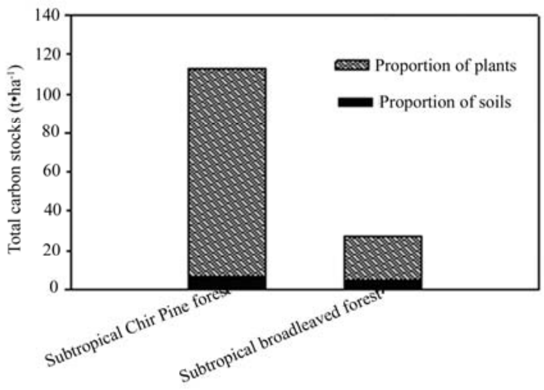

Fig. 14 Total carbon stocks ($t \cdot ha^{-1}$) in the plant biomass and soils of subtropical Pine and broadleaved evergreen Forest Ecosystems

The total forest carbon stocks (upper storey, under storey + soil) in the unmanaged sub tropical broad leaved evergreen forests were 31.18±1.73 t ha^{-1} in Kherimurat, and 24.36±1.59 $t \cdot ha^{-1}$ in Sohawa. However, the mean carbon stock in both the forests is 27.63±1.66 $t \cdot ha^{-1}$, which is comprised of 82.66% of total tree carbon and soil represented only 17.34% (Fig. 14).

Student *t–test* revealed that there is significant variation ($p < 0.05$) in basal area ($m^2 \cdot ha^{-1}$), stem volume ($m^3 \cdot ha^{-1}$), stem biomass ($t \cdot ha^{-1}$), total upper storey and understorey biomass ($t \cdot ha^{-1}$), total soil carbon ($t \cdot ha^{-1}$), and total carbon stocks in two unmanaged subtropical forest ecosystem of Kherimurat and Sohawa (Table 4)

Table 3: Results of student *t-test* for total C-stocks ($t \cdot ha^{-1}$) in *P. roxburghii* stands of Ghoragali and Lehterar

Parameters	Avg. basal area ($m^2 \cdot ha^{-1}$)	Total volume ($m^3 \cdot ha^{-1}$)	Total stem biomass($t \cdot ha^{-1}$)	Total tree biomass ($t \cdot ha^{-1}$)	Total tree carbon ($t \cdot ha^{-1}$)	Total carbon in soil ($t \cdot ha^{-1}$)	Total C in ecosystem ($t \cdot ha^{-1}$)
Ghoragali	30.38[a]	243[a]	149[a]	237[a]	119[a]	9.2[b]	128[d]
Lehterar	26.11[a]	197[a]	117[a]	186[a]	92[a]	8.03[c]	100[e]
P value	0.36	0.32	0.27	0.27	0.27	0.0005	0.005

*Figure with different alphabetic superscript significantly varies in each site.

Table 4: Results of student *t-test* for total C-stocks ($t \cdot ha^{-1}$) in mixed *Acacia* and *Olea* stands of Kherimurat and Sohawa

Forest sites	Avg.basal area ($m^2 \cdot ha^{-1}$)	Total volume ($m^3 \cdot ha^{-1}$)	Total stem biomass ($t \cdot ha^{-1}$)	Upper-storey biomass($t \cdot ha^{-1}$)	Under storey biomass ($t \cdot ha^{-1}$)	Total carbon in plants ($t \cdot ha^{-1}$)	Total carbon in soil($t \cdot ha^{-1}$)	Total C in ecosystem ($t \cdot ha^{-1}$)
Kherimurat	3.06[a]	12.86[c]	12.13[e]	50.93[g]	0.15[i]	25.54[k]	5.46[m]	31.18[o]
Sohawa	2.65[b]	11.40[d]	10.54[f]	40.43[h]	0.03[j]	20.23[l]	4.12[n]	24.36[p]
P value	0.001	0.004	0.003	0.001	0.002	0.001	0.004	0.009

*Figure with similar alphabetic superscript significantly varies in each site.

This research estimated that the mature managed sub tropical pine (*Pinus roxburghii*) forests contains carbon stocks of approximately 128 ±2.94 t·ha^{-1} in Ghoragali and 100 ±1.58 t·ha^{-1} in Lehterar forests. The result is quite close to the estimate mentioned by Dixon et al. (1994). Their study reported that the tropical forest in Asia holds a carbon density of 132–174 t·ha^{-1}. Brown and Lugo (1984) estimated that the tropical forests of Bangladesh hold approximately 55–90 t·ha^{-1} of carbon in forest ecosystems.

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