ASSESSMENT OF CARBON STOCK OF TREE VEGETATION IN THE KOLLI HILL FOREST LOCATED IN INDIA

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Abstract. Forest ecosystems covering approximately 30 % of the terrestrial area of the earth play a significant role in the atmospheric carbon cycle that influence global warming and climate change. Assessment of carbon stock in forest vegetation is necessary for atmospheric carbon mitigation plans. The present study aimed to assess the total carbon stock in tree vegetation of Kolli hill (KH), a reserve forest located in India. The land area of KH (508 km^2) was parted by 6.25 × 6.25 km^2 grids. In each grid, a transect of 0.5 ha (5 m × 1000 m) was laid randomly, and all live trees greater than or equal to 30 cm girth (=9.55 cm diameter) measure at breast height were sampled. Carbon stock of each tree was determined by non-destructive method. The carbon stock estimated for KH forest was 73.7±13.6 tC/ha. Maximum carbon stock was shared by *Alseodaphne semicarpifolia* var. *semecarpifolia* (14 %) among 157 species and Lauraceae (19 %) among 49 families recorded at KH. Statistical analysis revealed that the carbon stock values varied significantly among the eleven tree size classes (ANOVA, $F_{(10,187)} = 4.439$, $p<0.001$) and among the three major forest types ($F_{(2,15)} = 6.101$, $p<0.05$) recognized. Regression analysis was also performed to test the relationship of carbon stock with tree density, species richness and altitude. The present study provides valuable data useful for better management and monitoring of KH forest with regard to tree carbon storage in mitigation of global warming and climate change.
Keywords: c*arbon stock; Kolli hill; India; tropical forest; tree vegetation*

Introduction

Carbon dioxide, one of the greenhouse gases, has been increasing in concentration due to anthropogenic activities worldwide, and elevates the earth's average temperature by greenhouse effect. Increase in temperature causes global warming and climate change. It has been predicted that the mean global temperature will increase by 1.1°C to 6.4°C by the year 2100 (IPCC, 2007). Atmospheric carbon concentration was around 270 ppm at the beginning of industrial revolution, it has crossed 400 ppm by 2015 (NOAA, 2015), and scientists have predicted by 2070 carbon level will reach up to 500 ppm (Jackson et al., 2014). Climate change due to increase in carbon emissions leads to great challenges for carbon mitigation strategies, besides socio-economic, biological problems (Sicard & Dalstein-Richer, 2015) and origin of new catastrophic diseases (WHO, 2015). In recent years, all possible steps have been taken by the developed nations in order to plan for carbon mitigation, management and policy actions. Most industrialized counties have signed the Kyoto Protocol to reduce their carbon outputs, carbon tax and subsidy systems have been developed in support of carbon mitigation targets (Cao et al., 2010).

Forest ecosystems cover approximately 30 % of the terrestrial area of the world (Muraoka et al., 2015), and they are greatly recognized as important elements of global carbon as well as various other greenhouse gases that are believed to considerably affect climate (Teobaldelli et al., 2009). Trees exchange carbon dioxide with the atmosphere through biological processes and act as a major carbon sink by stocking carbon as fixed

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biomass, hence, assessment of tree carbon stock in forest systems is necessary to understand the potential of forests as carbon sinks.

Carbon stock of a tree is determined by its biomass. Tree biomass can be quantified using both destructive and non-destructive sampling methods. Destructive sampling method involves felling of trees is mostly adopted for plantation forests. Non-destructive sampling method, widely used for natural forests, involves estimation of biomass from forest inventory data by using either biomass equations (BE) or biomass expansion factors (BEF), conversion factors (wood density) or biomass conversion and expansion factors (BCEF). BE requires tree level data like diameter at breast height or additionally height, age, etc., BEF needs volume data from forest inventory and BCEF is a combination of the first two factors (Teobaldelli et al., 2009).

Although, many studies have been done to quantify the forest carbon stocks worldwide, there are still some forest systems which remain unexplored in India. The present study was undertaken in Kolli hill (KH) forest with the main objective to assess the carbon stock (tC/ha) of tree vegetation in the forest system. This paper also presents the analysis on carbon stocks by different tree species, families, forest types, and stem size classes. Further, an attempt was also made to discuss the relationship of tree carbon stock with species richness, density and altitude.

Materials and methods

The present study site KH is located in India, between latitudes 11°11.0' - 11°28.0' N and longitudes 78°17.0 - 78°29.0' E *(Fig. 1)*. The study site covering about 508 km^2 of land area falls under national reserve forest category consists of varied metamorphic rocks, and red lateritic soil. The site comes under tropical climate zone with four seasons: summer (late February to June), pre-monsoon (July to August), monsoon (September to November), post monsoon (December to mid February). The mean annual temperature for the past 20 years (data obtained from the regional meteorological center) is 28.3°C, and the rainfall is 1058mm per year.

The complete study site was parted by 6.25 km × 6.25 km grids, and that summed up to 18 grids. In each grid, a transect of 0.5 ha (5 m × 1000 m) was laid randomly, to facilitate sampling each transect was subdivided into fifty 5 m × 20 m (10 sq. m) quadrats, and all live trees greater than or equal to 30 cm girth (9.55 cm diameter) measure at breast height (1.37 m from the ground level) were sampled (Pragasan & Parthasarathy, 2010). Stem girth measure of each tree was noted using measuring tape. A sum of 3824 trees representing 157 species in 49 families was recorded from the 18 transects (900 quadrats) sampled. Tree density, species richness was calculated, and altitude was noted for each transect. Density was determined as the number of individuals per unit area: $Di = ni/A$, where Di is the density of species i, ni is the total number of individuals recorded for species i, and A is the total area sampled. Density for each transect was calculated as the sum of the densities of all the species (∑D), and expressed as individuals/ha. Species richness was determined as the numbers of different tree species recorded per transect and expressed as species/transect. Altitude was noted using global positioning system (GPS Garmin) and expressed as m asl.

Carbon stock of each tree was calculated as 50 % of its biomass following Timilsina et al., 2014 and others (Atjay et al., 1979; Brown & Lugo, 1982; Dixon et al., 1994; Takimoto et al., 2008; Bhat & Ravindranath, 2011; Mohanraj et al., 2011). Tree biomass was calculated as sum of its aboveground biomass and below ground biomass.

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Aboveground biomass was calculated using BE method formulated by Brown et al. (1989), adopted for tropical species: $Y = a - bX + cX^2$, where Y is aboveground biomass in kg, X is stem diameter at breast height in cm, and a, b and c are constant values 34.4703, 8.0671 and 0.6589, respectively. Stem diameter of each tree was calculated from its girth measure at breast height: $d = C/\pi$, where d is stem diameter in cm, C is stem girth measure at breast height in cm, and π is an universal constant value 3.14. Below ground biomass was considered as 15% of the aboveground biomass as adopted by Miria & Khan, 2015 and others (MacDicken, 1997; Alamgir & Al-Amin, 2008).

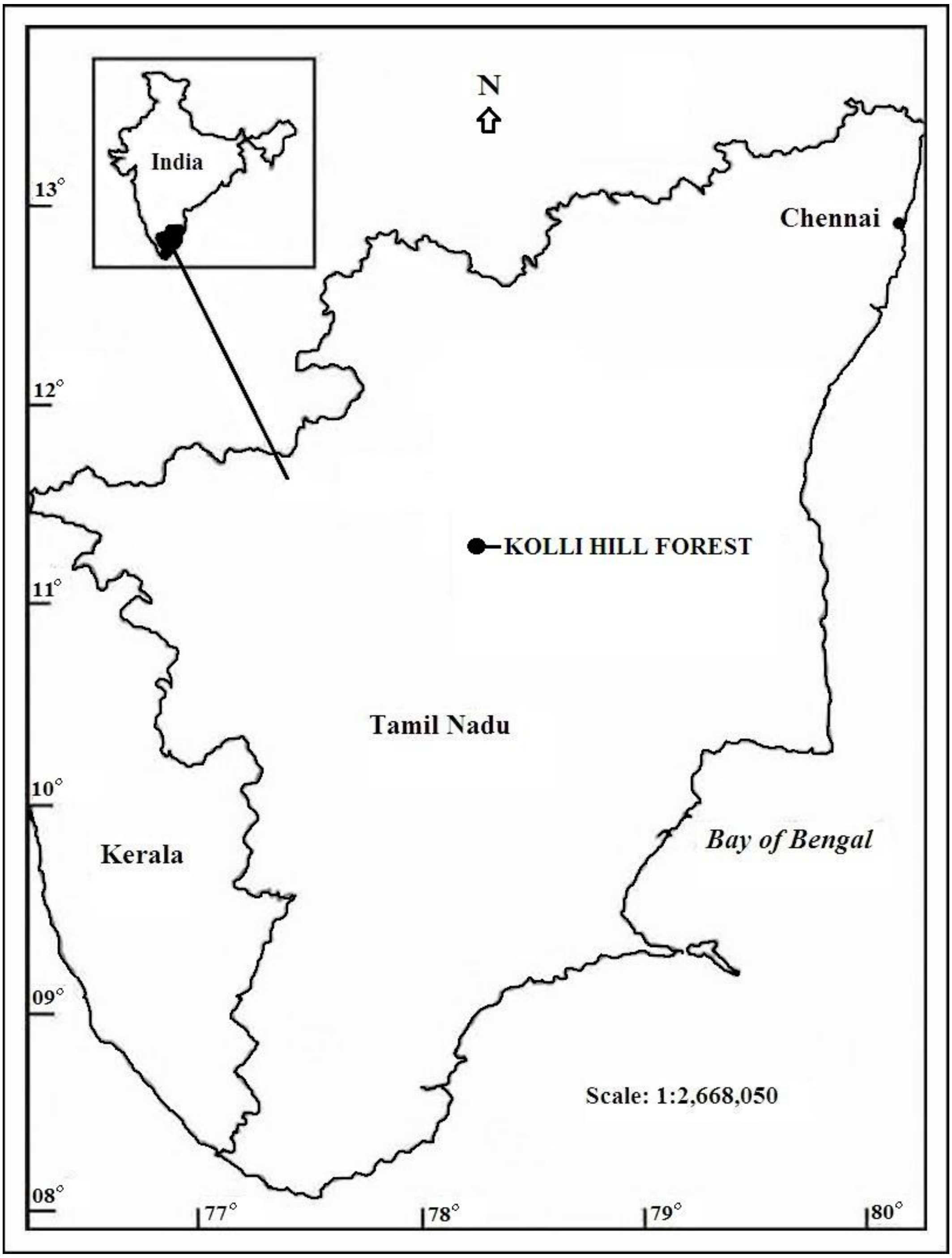

Figure 1. *Map showing the location of the study area, Kolli hill forest in India*

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Transects (n=18) sampled from the study site were categorized into, three forest types semi-evergreen (n=11), mixed deciduous (n=3) and scrub (n=4) forests (based on vegetation characters), three altitudinal ranges low altitude (less than 500 m asl, n=5), medium altitude (500-1000 m asl, n=7) and high altitude (above 1000 m asl, n=6). Trees (n=3824) sampled from the 18 transects were categorized (based on stem girth measure) into eleven stem size classes 30-60cm class, 60-90cm, 90-120cm, 120-150cm, 150-180cm, 210-240cm, 240-270cm, 270-300cm, 300-330cm and greater than 330cm.

Tree carbon stock (tC/ha) for each forest type, altitudinal range, stem size class was determined, and analysis of variance (ANOVA) was used to test the significance of variation in carbon stock among forest types, altitudinal ranges and stem tree size classes. Regression analysis was performed to test the relationship of carbon stock (tC/ha) with tree density (individuals/ha), species richness (species/transect) and altitude (m asl).

Results

Tree density and species richness

Tree density was recorded as low as 278 individuals/ha for Transect17 to a high of 632 individuals/ha for Transect4 *(Table 1)*, and the mean value for the 18 transects was 425±25 individuals/ha (±S.E.). Species richness was recorded minimum (10 species/transect) for Transect17 and maximum (42 species/transect) for Transect2 *(Table 1)*, and the mean value for the 18 transects was 27±2 species/transect.

Table 1. *Tree carbon stock estimated for the eighteen 0.5ha transects sampled from the Kolli hill forest located in India. SE-semi-evergreen; MD-mixed deciduous; SB-scrub*

Transect	Forest type	Altitude (m asl)	Density (individuals/ha)	Species richness (species/transect)	Carbon stock (tC/ha)
Transect1	SE	1128	590	33	141.7
Transect2	SE	973	586	42	204.5
Transect3	SE	1127	414	24	125.6
Transect4	SE	797	632	38	104.9
Transect5	SE	1301	522	31	173.6
Transect6	SE	912	294	42	70.7
Transect7	SE	1274	330	29	48.8
Transect8	MD	587	452	36	26.6
Transect9	SE	1100	370	17	72.5
Transect10	SE	1132	490	18	66.6
Transect11	SE	994	374	29	108.6
Transect12	SE	427	474	14	21.2
Transect13	SB	514	466	27	23.0
Transect14	MD	353	384	30	48.9
Transect15	SB	305	352	23	41.2
Transect16	SB	577	326	17	11.6
Transect17	SB	384	278	10	10.0
Transect18	MD	337	314	27	27.1

Carbon stock

Tree carbon stock was recorded minimum 10.0 tC/ha for Tansect17 and maximum carbon value 204.5 tC/ha was observed for Transect2 (*Table 1*), and the mean carbon value for the 18 transects sampled was 73.7±13.6 tC/ha.

Forest type

Among the three forest types recognized, carbon stock of semi-evergreen forest (103.5±16.6 tC/ha) was found three folds greater than the mixed-deciduous and almost five folds greater than scrub forests *(Fig. 2)*. The carbon stock (tC/ha) value among the forest types varied significantly (ANOVA: $F_{(2,15)} = 6.101$, $p<0.05$).

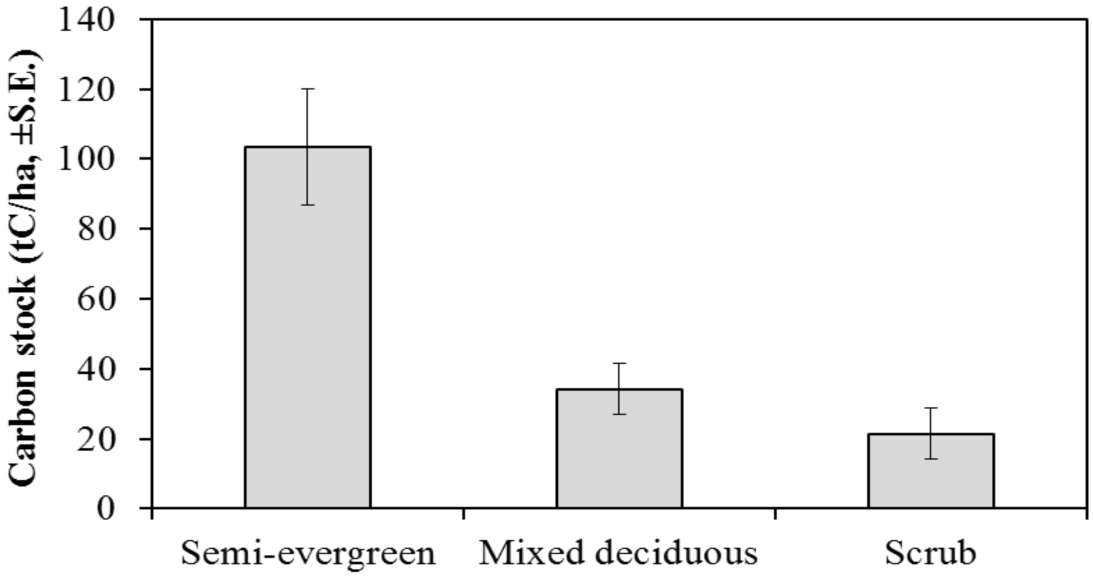

Figure 2. *Comparison of carbon stock between the three major forest types*

Altitudinal gradient

Among the three altitudinal ranges classified, carbon stock was recorded maximum for high altitude range (104.8±20.1 tC/ha) followed by medium (78.6±25.7 tC/ha) and low altitude range (29.7±7.0 tC/ha). The carbon stock (tC/ha) value among the three altitudinal ranges did not vary significantly (ANOVA: $F_{(2,15)} = 2.871$, $p>0.05$).

Stem size class

Of the total eleven stem size classes recognized, 120-150cm class recorded maximum carbon value (5.9±1.2 tC/ha), followed by 90-120cm class, 60-90cm, 180-210cm and 210-240cm class *(Fig. 3)*. ANOVA revealed a significant variation in carbon stock value among the 11 stem size classes ($F_{(10,187)} = 4.439$, $p<0.0001$).

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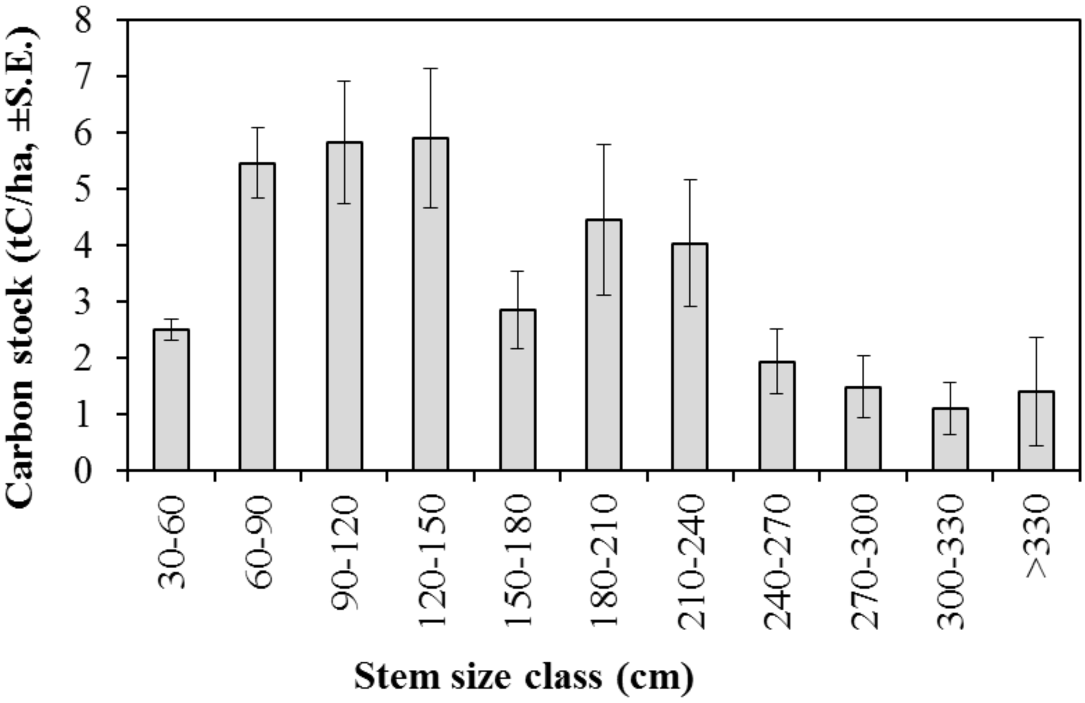

Figure 3. *Distribution of carbon stock among the eleven stem size classes*

Species

Out of the 157 species recorded, the total carbon stock was found maximum (92.34 tC/9ha, 14 %) for *Alseodaphne semicarpifolia* var. *semecarpifolia* followed by *Syzygium cumini*, *Memecylon edule*, *Canarium strictum* and *Mangifera indica (Table 2)*. The average carbon stock (tC/tree) was recorded maximum for *Sterculia foetida* (1.89 tC/tree) followed by *Ficus amplissima*, *Ficus beddomei*, *Mitragyna parvifolia* and *Ficus benghalensis (Table 2)*.

Table 2. *Carbon stock of tree species recorded from the Kolli hill forest, India*

Species (Family)	Number of individuals (for 9 ha)	Total carbon stock (tC/9ha)	Average carbon stock (tC/tree)
Alseodaphne semicarpifolia Nees var. *semecarpifolia* (Lauraceae)	128	92.34	0.72
Syzygium cumini (L.) Skeels (Myrtaceae)	137	69.36	0.51
Memecylon edule Roxb. (Melastomataceae)	654	44.41	0.07
Canarium strictum Roxb. (Burseraceae)	37	34.08	0.92
Mangifera indica L. (Anacardiaceae)	27	24.27	0.90
Neolitsea scrobiculata (Meisner) Gamble (Lauraceae)	134	22.90	0.17
Prunus ceylanica (Wight) Miq. (Rosaceae)	34	22.78	0.67
Artocarpus heterophyllus Lam. (Moraceae)	24	16.91	0.70
Ficus amplissima J.E. Smith (Moraceae)	9	14.69	1.63
Ficus microcarpa L.f. (Moraceae)	13	14.11	1.09

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Tamarindus indica L. (Caesalpiniaceae)	20	13.46	0.67
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr. (Combretaceae)	33	12.40	0.38
Myristica dactyloides Gaertn. (Myristicaceae)	31	12.25	0.40
Elaeocarpus serratus L. (Elaeocarpaceae)	44	11.76	0.27
Commiphora caudata (Wight & Arn.) Engler (Burseraceae)	75	11.75	0.16
Moringa concanensis Nimmo ex Gibs. (Moringaceae)	50	11.45	0.23
Ficus beddomei King (Moraceae)	8	11.18	1.40
Vitex altissima L.f. (Verbenaceae)	51	10.33	0.20
Euphorbia antiquorum L. (Euphorbiaceae)	345	9.80	0.03
Mitragyna parvifolia (Roxb.) Korth. (Rubiaceae)	7	9.79	1.40
Diospyros ebenum Koen. (Ebenaceae)	39	9.42	0.24
Bischofia javanica Blume (Bischofiaceae)	21	9.35	0.45
Ficus mollis Vahl (Moraceae)	13	8.75	0.67
Scolopia crenata (Wight & Arn.) Clos (Flacourtiaceae)	37	8.09	0.22
Gyrocarpus asiaticus Willd. (Hernandiaceae)	72	7.59	0.11
Celtis philippensis Blanco (Ulmaceae)	90	6.58	0.07
Nothopegia heyneana (Hook.f.) Gamble (Anacardiaceae)	53	6.43	0.12
Albizia amara (Roxb.) Boivin (Mimosaceae)	175	6.37	0.04
Ficus benghalensis L. (Moraceae)	5	5.60	1.12
Pterocarpus marsupium Roxb. (Papilionaceae)	20	5.58	0.28
Terminalia bellirica (Gaertn.) Roxb. (Combretaceae)	5	5.29	1.06
Memecylon grande Retz. (Melastomataceae)	54	4.94	0.09
Premna tomentosa Roxb. (Verbenaceae)	23	4.88	0.21
Chloroxylon swietenia DC. (Flindersiaceae)	54	4.50	0.08
Litsea deccanensis Gamble (Lauraceae)	25	4.46	0.18
Canthium dicoccum (Gaertn.) Teijsm. & Binn. var. *umbellata* (Wight) Sant. & Merch. (Rubiaceae)	34	4.35	0.13
Sterculia foetida L. (Sterculiaceae)	2	3.78	1.89
Symplocos cochinchinensis (Lour.) Moore (Symplocaceae)	21	3.54	0.17
Chrysophyllum roxburghii G.Don (Sapotaceae)	4	3.44	0.86
Diospyros barberi Ramaswami (Ebenaceae)	38	3.36	0.09
Pleiospermium alatum (Wall. ex Wight & Arn.) Swingle (Rutaceae)	191	3.32	0.02
Pterospermum xylocarpum (Gaertn.) Sant. & Wagh (Sterculiaceae)	24	3.29	0.14
Filicium decipiens (Wight & Arn.) Thw. (Sapindaceae)	10	2.66	0.27
Ficus drupacea Thunb. var. *pubescens* (Roth) Corner (Moraceae)	4	2.64	0.66
Commiphora berryi (Arn.) Engler (Burseraceae)	73	2.53	0.03

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Drypetes sepiaria (Wight & Arn.) Pax & Hoffm. (Euphorbiaceae)	49	2.45	0.05
Cassine glauca (Rottb.) Kuntze (Celastraceae)	16	2.26	0.14
Wrightia tinctoria (Roxb.) R.Br. (Apocynaceae)	29	2.23	0.08
Drypetes roxburghii (Wall.) Hurusawa (Euphorbiaceae)	15	2.21	0.15
Phoebe lanceolata Nees (Lauraceae)	9	2.20	0.24
Remaining 107 species	885	51.40	0.13

Family

Among the 49 families recorded, total tree carbon stock was found maximum (126.10 tC/9ha, 19 %) for Lauraceae followed by Moraceae, Myrtaceae, Melastomataceae and Burseraceae *(Table 3)*.

Table 3. *Carbon stock of 49 families recorded from the Kolli hill forest, India*

Family	Number of species (for 9 ha)	Number of individuals (for 9 ha)	Total carbon stock (tC/9ha)	Average carbon stock (tC/tree)
Lauraceae	11	307	126.10	0.41
Moraceae	14	111	77.35	0.70
Myrtaceae	3	140	69.41	0.50
Melastomataceae	3	709	49.47	0.07
Burseraceae	3	185	48.36	0.26
Anacardiaceae	6	92	32.33	0.35
Rosaceae	1	34	22.78	0.67
Euphorbiaceae	14	498	20.39	0.04
Combretaceae	3	40	17.94	0.45
Verbenaceae	5	91	16.56	0.18
Rubiaceae	11	113	16.06	0.14
Ebenaceae	6	132	15.82	0.12
Caesalpiniaceae	2	25	13.53	0.54
Myristicaceae	1	31	12.25	0.40
Elaeocarpaceae	1	44	11.76	0.27
Moringaceae	1	50	11.45	0.23
Mimosaceae	5	256	9.46	0.04
Bischofiaceae	1	21	9.35	0.45
Papilionaceae	4	39	8.88	0.23
Flacourtiaceae	3	39	8.20	0.21
Sterculiaceae	3	29	7.89	0.27
Hernandiaceae	1	72	7.59	0.11
Ulmaceae	3	97	7.17	0.07
Sapindaceae	5	59	6.33	0.11
Meliaceae	7	51	5.47	0.11
Rutaceae	7	285	5.11	0.02
Flindersiaceae	1	54	4.50	0.08
Apocynaceae	2	35	3.81	0.11

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Symplocaceae	1	21	3.54	0.17
Sapotaceae	2	6	3.49	0.58
Celastraceae	1	16	2.26	0.14
Annonaceae	2	26	1.49	0.06
Loganiaceae	2	38	1.42	0.04
Oleaceae	2	22	1.28	0.06
Bignoniaceae	2	5	1.22	0.24
Meliosmaceae	2	3	0.91	0.30
Asteraceae	1	7	0.84	0.12
Bombacaceae	1	1	0.72	0.72
Cordiaceae	3	18	0.53	0.03
Myrsinaceae	1	5	0.14	0.03
Tiliaceae	1	2	0.10	0.05
Erythroxylaceae	1	4	0.07	0.02
Araliaceae	1	1	0.06	0.06
Alangiaceae	1	4	0.05	0.01
Rhamnaceae	2	2	0.03	0.02
Proteaceae	1	1	0.02	0.02
Arecaceae	1	1	0.01	0.01
Lecythidaceae	1	1	0.01	0.01
Solanaceae	1	1	0.01	0.01

Regression analysis

Regression analysis revealed that there exist no relationship between carbon stock with tree species richness (r^2 = 0.301), density (r^2 = 0.398) and altitude (r^2 = 0.469) of for the 18 transects analyzed *(Fig. 4)*.

Discussion

Currently, international concern on the treat of increased concentration of greenhouse gases particularly atmospheric carbon concentration on global warming and climate change made the super power nations to convene meetings for serious discussions, on reduction of carbon emissions, carbon mitigation policies such as on carbon tax and subsidy. Clean Development Mechanism (CDM) forestry projects began from 2006 in light of carbon offsetting targets, then, the Climate Action Reserve (CAR) projects, Verified Carbon Standard (VCS) and the American Carbon Registry (ACR) came into action (Pearson et al., 2014). Although, several policies and carbon market business were taken, the rise in atmospheric carbon concentration and its consequence are at alarming rate. Carbon storage in terrestrial vegetation is one of the promising natural phenomena in regard to carbon mitigation strategy. Carbon sequestration in vegetation mostly occurs either by expansion of forests or by conserving them (Houghton, 1996), hence, forest expansions and sustainable forest management have a significant role in the protection of environment (Shah et al., 2014). On the other hand, shrinkage of forests may have a strong negative role in achieving carbon targets, and a long term influence and impact (Levy et al., 2004). So, understanding the dynamics of carbon stocks and carbon changes are a key for sustainable management of forest carbon sinks.

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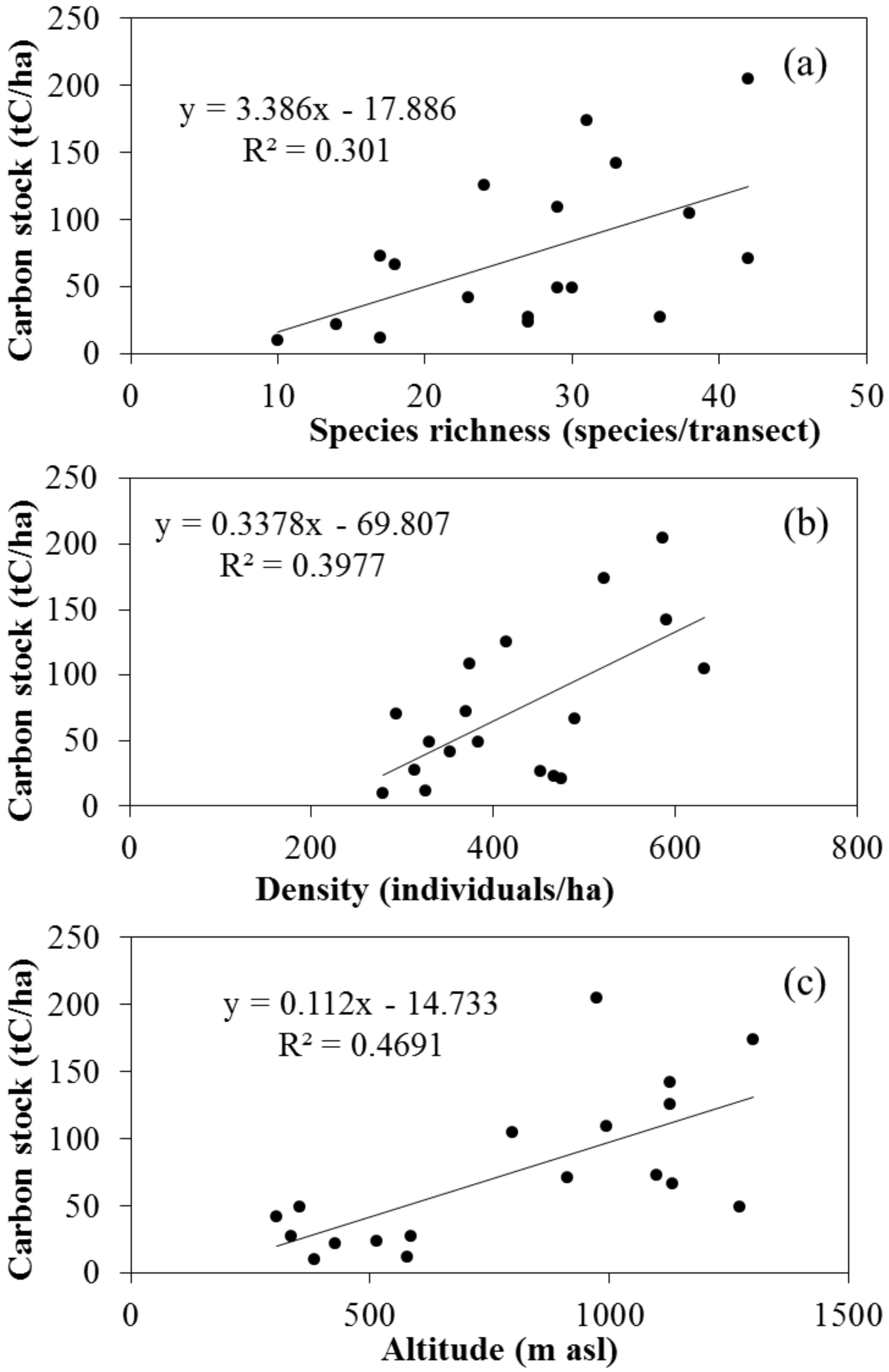

Figure 4. *Relationship of carbon stock with species richness, density and altitude of transect*

Several studies have been carried out to understand the role of forest ecosystem as carbon sink in different parts of the world. The carbon stock (tC/ha) recorded in KH (73.7 tC/ha) is greater than the carbon value reported for tropical forests at Bodamalai hills (10.94 tC/ha, Pragasan, 2015a), mixed species plantation forest (22.25 tC/ha) and Eucalyptus plantation forest (27.72 tC/ha, Pragasan & Karthick, 2013), Kalrayan hills

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(38.88 tC/ha, Pragasan, 2015b), Shervarayan hills (56.55 tC/ha, Pragasan, 2015c), Chitteri hills (58.55 tC/ha, Pragasan, 2014) in India, Nemarket Park in Auckland, New Zealand (45.9 tC/ha, Schwendenmann & Mitchell, 2014) lesser than Lower Montane forests at El Verde, Puerto Rico (134.21tC/ha, Jordan, 1981), tropical seasonal rain forest at Xishuangbanna, China (138.73 tC/ha, Shanmughavel et al., 2001), tropical rain forests at Khade, Ghana (152.84 tC/ha, Greenland & Gowel, 1970), New Guinea (164.45 tC/ha, Enright, 1979), Khado Chang, Thailand (167.10 tC/ha, Kira et al., 1974), Western Ghats, India (263.47 tC/ha, Rai, 1984), Montane rain forests at New Guinea (290.38 tC/ha, Edwards & Grubb, 1977); greater than the range reported for Pine forest at Himachal Pradesh, India (27.65-48.04 tC/ha, Shah et al., 2014); within the range reported for tropical evergreen forests at Myanmar (5.75-115.00 tC/ha, FAO, 1984-85), tropical moist forests at Bangladesh (48.88-118.45 tC/ha, Drigo et al., 1998); and lesser than the range reported for tropical moist forest at Bangladesh (86.25-120.75 tC/ha, Milde et al., 1985), Hardwood forest at Great Lakes, Northern America (96-224 tC/ha, Powers et al., 2011), tropical moist evergreen forests at Sri Lanka (109.25-299.00 tC/ha, FAO/UNDP, 1969), Red pine forest at Great Lakes, Northern America (130-195 tC/ha, Powers et al., 2011), Montane rain forests at Jamaica (131.68-179.40 tC/ha, Turner et al., 1999), tropical rain forest at Malaysia (132.25-166.75 tC/ha, Whitmore, 1975), tropical rain forests at Cambodia (200.10-238.63 tC/ha, Hozumi et al., 1979), sub-tropical Pine forest of Garhwal Himalayas, 203.02-230.84 tC/ha, Sheikh et al., 2012).

The order of carbon stock (tC/ha) by the three forest types recognized in the Kolli hills can be justified as scrub < mixed-deciduous < semi-evergreen forest, and a similar order was observed in Chitteri reserve forest (Pragasan, 2014) and Shervarayan hills (Pragasan, 2015c) located in India. The variation in carbon storage among the three forests types can be influenced by different factors such as leaf traits, microclimate, edaphic characters, etc. Scientists have proved that forest types can alter soil organic carbon stock through several factors, including litter inputs through litterfall, root turnover, litter quality, soil chemistry (Wang et al., 2010). These above factors can indirectly affect vegetation carbon stock that varies in magnitude with varying forest types.

In the present study, carbon stock was contributed maximum (14%) by *Alseodaphne semicarpifolia* Nees var. *semecarpifolia*. While, *Memecylon edule* Roxb. (8%) contributed predominantly to the total carbon stock estimated for the Chitteri reserve forest (Pragasan, 2014), and it was *Syzygium cumini* L. (9%) for the Shervarayan hills (Pragasan, 2015c). The carbon stock sequestered by a single tree was recorded maximum for *Sterculia foetida* L. (1.89 tC/tree) in the Kolli hill forest. While, *Mangifera indica* L. had the highest carbon value 1.73 tC/tree among tree species found in Chitteri reserve forest (Pragasan, 2014), and *Artocarpus heterophyllus* Lam. (2.76 tC/tree) in the Shervarayan hills (Pragasan, 2015c).

A few studies have been reported on relationship of carbon stock with species richness. In the present study, carbon stock had no significant relationship (r^2 = 0.301) with species richness *(Fig. 4)*, and similar trend was reported earlier from tropical forests (Pragasan, 2014; 2015c) as well as ago-ecosystems (Nakakaawa et al., 2009). While, some authors argue that conserving species richness increases carbon storage in forest system (Alavalapati, 2002; Kirby & Potvin, 2007). The difference of opinion in the above case may be influenced by the nature of production system and restoration principles adopted in those forest ecosystems.

It is well known that the carbon stock of a tree is directly proportional to its stem size, and hence, total carbon stored in a forest is mostly influenced by the number of

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trees in larger stem size category rather than total tree density. In the present study, no significant relationship (r^2 = 0.398) was observed between carbon stock and density *(Fig. 4)*, and a similar trend was reported for Shervarayan hills (Pragasan, 2015c), while, a strong positive relation was observed between carbon stock and density (r^2=0.689) at Chitteri reserve forest (Pragasan, 2014).

In the present study, carbon stock was greater at high altitude range (104.8±20.1 tC/ha, *Fig. 4*) when compared to low and medium altitude ranges, however, no significant variation was observed in carbon stock (tC/ha) values among the three altitudinal ranges (ANOVA: $F_{(2,15)}$ = 2.871, p>0.05). While, Sheikh et al. (2012), reported high carbon stock (tC/ha) at comparatively low elevation (1300 m asl, 230.84 tC/ha) than the medium (1400 m asl, 218.04 tC/ha) and high elevation (1500 m asl, 203.02 tC/ha). At KH, regression analysis revealed that carbon stock had no significant relationship with altitude of forest location, a similar trend was observed earlier (Pragasan, 2014), while a positive relation (r^2=0.570) was reported at Shervarayan hills (Pragasan, 2015c). According to Shah et al. (2014), the tree felling in higher altitude forests have failed to regenerate and lead to serious disturbances in the ecosystem functioning, particularly in forest moisture retention and local ecology, and this phenomenon emphasize strengthening protection for forest at high altitude range in KH, for maintaining the sustainability of carbon storage in vegetation particularly at high altitudes.

The results of the present study conclude that 1) Carbon stock of KH is 73.7 tC/ha, 2) Among the three forest types in KH, carbon stock is recorded maximum for semi-evergreen forest (103.5±16.6 tC/ha), 3) Among the three altitude ranges categorized in KH, carbon stock is found maximum for high altitude range (104.8±20.1 tC/ha), 4) Among the eleven stem size classes recognized in KH, 120-150cm class has recorded maximum carbon value (5.9±1.2 tC/ha), 5) Out of the 157 species recorded in KH, total carbon stock is found maximum (92.34 tC/9ha) for *Alseodaphne semicarpifolia* var. *semecarpifolia*, 6) Among the 49 families recorded in KH, total carbon stock is found maximum (126.10 tC/9ha) for Lauraceae, 7) Regression analysis reveals that there is no significant relationship of carbon stock (tC/ha) with tree species richness, density and altitude of forest location. The study provides valuable data on carbon stock of tree vegetation of KH forest useful for better management and monitoring of tree carbon stock in study site. Creating awareness on forest carbon sinks to the local inhabitants is at most the prime need for forest protection from illegal timber extraction that causes irreversible reduction in carbon stock, which negatively affects atmospheric carbon capture process for mitigation of global warming and climate change.

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