WALAILAK JOURNAL
http://wjst.wu.ac.th Agriculture Technology and Biological Sciences

Assessment of Tree Carbon Stock in the Kalrayan Hills of the Eastern Ghats, India

Lingassamy Arul PRAGASAN

Department of Environmental Sciences, Bharathiar University, Coimbatore 641046, India

(*Corresponding author's e-mail: arulpragasan@yahoo.co.in)

Received: 21 April 2014, Revised: 22 November 2014, Accepted: 21 December 2014

Abstract

The aim of the present study was to determine the tree carbon stock in the tropical forests of the Kalrayan hills in the Eastern Ghats, India. The total area of the Kalrayan hills (1,055 km^2) was divided into 34 grids of 6.25 × 6.25 km^2. A transect of 0.5 ha was established in each grid and all trees ≥ 30 cm girth at breast height were inventoried. Carbon stock of each tree species was determined through a non-destructive method based on an allometric equation using the inventory data. A sum of 8,951 trees representing 169 species were recorded from 34 transects. The total tree carbon stock estimated for the 17 ha of the Kalrayan hills was 38.88 t/ha. The average carbon stock per transect was 19.44±3.39 t/0.5 ha (±SE) and the minimum and maximum value was 3.65 t/0.5 ha and 83.09 t/0.5 ha respectively. One way ANOVA revealed a significant variation in carbon stock between the 11 tree girth classes recognized ($F_{(10, 363)} = 11.376$, $p < 0.0001$). The average carbon stock of a single tree was 0.064 t/tree. Among the 169 species, *Albizia amara* shared a maximum of 7 per cent of the total carbon stock followed by *Gyrocarpus asiaticus*, *Nothopegia heyneana*, *Hardwickia binata* and *Anogeissus latifolia*. The tree carbon stock (t/ha) of the Kalrayan hills is very low when compared to other regions.

Keywords: Carbon stock, Kalrayan hills, Eastern Ghats, tropical forest, India

Introduction

Forest ecosystems act as an active carbon pool that accounts for 60 % of the total land surface [1]. Increase in anthropogenic activities, industrialization and urbanization lead to a major decline and degradation of tropical forest ecosystems of the world. Tropical forests cover only 7 % of the earth's land surface and play a major role in the global carbon cycle [2]. They act as a source and sink for atmospheric carbon. The rapid conversion of tropical forests for human use is a major source of carbon dioxide, one of the GHGs which cause global warming [3]. The developmental activities and increased transportation activities are increasing the concentration of greenhouse gases [4]. Increasing carbon emission is one of the major concerns over global warming which is well addressed in the Kyoto Protocol [5] since it leads to a drastic change in climate and natural disasters worldwide.

Trees act as a major CO_2 sink which capture atmospheric carbon and store them as fixed biomass [4]. Assessment of the standing biomass of trees is essential for the determination of carbon stocks. Forest biomass can be estimated either directly through destructive methods (felling of trees) [6] or indirectly through allometric methods using floristic inventory data to determine the biomass [7]. The allometric method is often preferred since it is less time consuming, less expensive and preferred in terms of conserving the green cover.

The drastic change in the climate in recent years has increased the importance of data collection on forest carbon stocks in different regions. Such data are available for most of the major forest regions worldwide [6-11]. However, no such data is available for the Kalrayan hills of the Eastern Ghats in India. This forest area is one of the few biodiversity rich large fragments of the Eastern Ghats. Hence, the present study was undertaken to address the following questions: 1) What is the carbon stock (t/ha) potential of tree species in the Kalrayan hills?, 2) Is the tree carbon stock distributed uniformly in the Kalrayan hills?, and 3) Is there any relationship between carbon stock with tree density and species richness?

Materials and methods

Study area

The present study was carried out in the tropical forests of the Kalrayan hills (Latitude - 11º 38.0' - 12º 04.0' N; Longitude - 78º 26.5' - 78º 53.5' E) of the Eastern Ghats, India (**Figure 1**). The Kalrayan forests cover an area of about 1055 km^2. The range of altitude for the hill forests was from 220 to 1,250 m above mean sea level. The study area is composed of masses of Charnockite associated with gneisses and varied metamorphic rocks, and soil type is red, loamy and lateritic in nature [12]. The climate data of Salem, the nearest station to the Kalrayan hills for the past 20 years reveals that the mean annual temperature was 28.3 °C and the mean annual rainfall was 1,058 mm. The bulk of the rainfall was received during August to October, and the mean annual rainy days was 61 days.

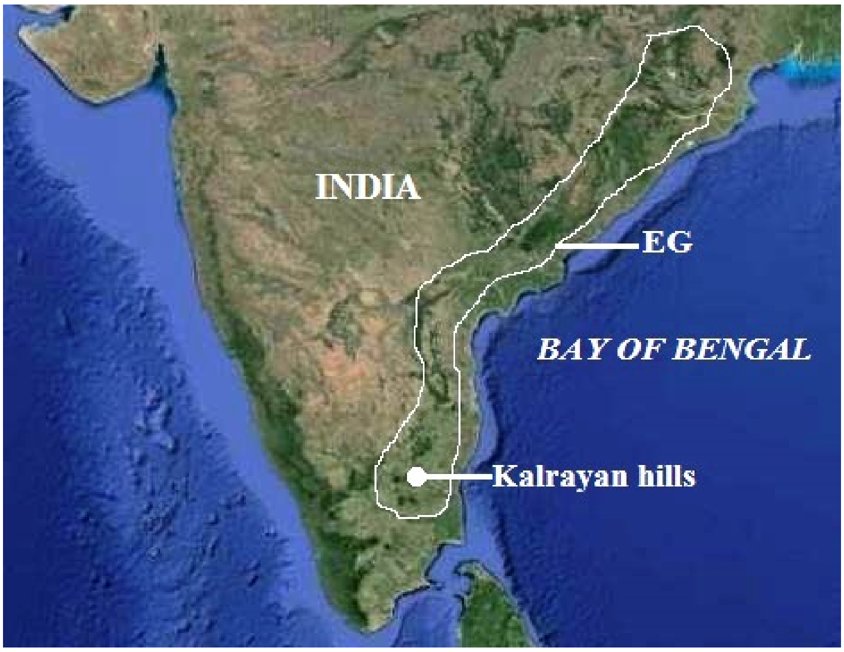

Figure 1 Location of the Kalrayan hills in the Eastern Ghats of India.

Methods

The Kalrayan forest was divided into 34 grids of size 6.25 × 6.25 km. For every grid, a transect of 0.5 ha (5 × 1,000 m) was laid, and all the trees ≥ 30 cm girth at breast height (GBH) were inventoried and their GBH were measured using a measuring tape [12]. The inventory data were used for the assessment of the carbon stock of tree species in the Kalrayan forest. The total carbon stock (TCS) of each tree was determined using the following equation;

$$TCS = (AGB + BGB) \times 0.5 \quad (1)$$

where, 'AGB' is aboveground biomass, 'BGB' is below ground biomass, and '0.5' is the conversion factor [13-15].

The aboveground biomass was estimated through the allometric equation following Chave [16];

$$Y = 34.4703 - 8.0671\ D + 0.6589\ D^2 \quad (2)$$

where 'Y' is the AGB per tree in kg, and 'D' is diameter of the tree at breast height (DBH) in cm, obtained from GBH i.e. DBH = π/GBH.

The below ground biomass was estimated following MacDicken [17];

$$BGB = AGB \times (15/100) \quad (3)$$

In the present study, to estimate forest biomass the allometric equation using the tree DBH as an independent variable was used following Brown *et al*. [7], since DBH is the most widely used parameter which relates to the total biomass volume and age of the tree [18], and also it is very easy to get accurate DBH data unlike tree height [19].

Statistical analysis

Regression analysis was done to check the relationship of carbon stock with species richness and density of trees for the 34 transects inventoried in the Kalrayan hills. Based on the GBH, trees were categorized into 11 girth classes viz. 30 - 60 cm class, 60 - 90, 90 - 120, 120 - 150, 150 - 180, 180 - 210, 210 - 240, 240 - 270, 270 - 300, 300 - 330 and > 330 cm. Analysis of variance (ANOVA) was performed to check the significance of variation in carbon stock among the tree species categorized into the eleven girth classes.

Results

Forest structure

A sum of 8951 trees representing 169 species in 120 genera and 44 families were recorded from the 34 transects sampled in the tropical forests of the Kalrayan hills [12]. The species richness of trees per transect was 33.65±2.34, and it varied from 17 species to as high as 71 species. Tree density per transect was 263.26±7.53 and it ranged from 176 to 330 trees per transect. The basal area per transect was 7.58±0.95 m^2, and it varied from 2.34 m^2 to 23.94 m^2 per transect.

Tree carbon stock

The total tree carbon stock estimated for the 17 ha in the Kalrayan hills was 38.88 t/ha (**Table 1**). The average carbon stock per transect was 19.44±3.39 t/0.5 ha, and it varied from 3.65 to 83.09 t/0.5 ha respectively. The average carbon stock of a single tree was 0.074 t/tree.

Contribution of tree species

Of the total 169 species inventoried, *Albizia amara* contributed the greatest (44.17 tonnes, 6.7 %) to the total carbon stock, followed by *Gyrocarpus asiaticus* (5.9 %), *Nothopegia heyneana* (5.4 %), *Hardwickia binata* (5.0 %), and *Anogeissus latifolia* (4.8 %), and these 5 species together shared 28 % of the total carbon stock estimated for the Kalrayan hills (**Appendix 1**). The carbon stock by a single tree was highest for *Antiaris toxicaria* (4.11 t/tree) followed by *Terminalia bellirica* (1.42 t/tree), *Beilschmiedia bourdilloni* (1.39 t/tree), *Ficus benghalensis* (1.08 t/tree) and *Drypetes roxburghii* (0.90 t/tree) (**Appendix 1**).

Family composition

Among the 44 families recorded, Combretaceae contributed most with 79.56 tonnes to the total tree carbon stock estimated for the Kalrayan hills, followed by Mimosaceae (65.74 tonnes), Euphorbiaceae and Anacardiaceae (**Appendix 2**). The carbon stock contribution by a single tree was highest for

Moraceace (0.443 t/tree), followed by Myrtaceae (0.438 t/tree), Dipterocarpaceae (0.311 t/tree), Combretaceae (0.305 t/tree) and Lauraceae (0.251 t/tree) (**Appendix 2**).

Table 1 Tree carbon stock determined for the 34 grids in the Kalrayan hills of Eastern Ghats, India.

Grid no	SR	DN	AGB	BGB	TB	TCS
Grid 1	42	312	91.11	13.67	104.77	52.39
Grid 2	40	300	48.79	7.32	56.10	28.05
Grid 3	39	275	46.02	6.90	52.92	26.46
Grid 4	32	217	28.55	4.28	32.83	16.42
Grid 5	46	329	74.65	11.20	85.85	42.92
Grid 6	46	277	125.74	18.86	144.60	72.30
Grid 7	43	230	95.33	14.30	109.62	54.81
Grid 8	36	226	144.50	21.68	166.18	83.09
Grid 9	20	176	13.02	1.95	14.97	7.49
Grid 10	28	185	10.87	1.63	12.51	6.25
Grid 11	30	330	49.34	7.40	56.74	28.37
Grid 12	32	238	14.27	2.14	16.41	8.20
Grid 13	26	220	9.37	1.41	10.78	5.39
Grid 14	71	265	32.31	4.85	37.16	18.58
Grid 15	31	272	16.54	2.48	19.02	9.51
Grid 16	31	240	33.82	5.07	38.89	19.44
Grid 17	27	224	12.12	1.82	13.94	6.97
Grid 18	24	225	7.53	1.13	8.67	4.33
Grid 19	17	275	10.17	1.53	11.70	5.85
Grid 20	19	301	10.50	1.57	12.07	6.03
Grid 21	17	241	13.94	2.09	16.03	8.01
Grid 22	20	277	14.16	2.12	16.28	8.14
Grid 23	20	191	6.35	0.95	7.31	3.65
Grid 24	35	310	23.52	3.53	27.05	13.53
Grid 25	24	326	13.72	2.06	15.78	7.89
Grid 26	24	288	10.57	1.59	12.15	6.08
Grid 27	24	297	11.00	1.65	12.65	6.32
Grid 28	25	283	11.26	1.69	12.95	6.48
Grid 29	19	321	44.23	6.63	50.87	25.43
Grid 30	59	317	36.47	5.47	41.94	20.97
Grid 31	65	291	29.22	4.38	33.61	16.80
Grid 32	48	229	19.81	2.97	22.78	11.39
Grid 33	32	218	19.29	2.89	22.19	11.09
Grid 34	18	245	21.53	3.23	24.76	12.38

Notes: SR = Species richness (no. of species/0.5 ha); DN = Density (no. of trees/0.5 ha); AGB = Aboveground biomass (t/0.5 ha); BGB = below ground biomass (t/0.5 ha); TB = Total biomass (t/0.5 ha); TCS = Total carbon stock (t/0.5 ha).

Tree girth class

Among the 11 girth classes recognized, the 60 - 90 cm girth class contributed most with 27.6 % to the total carbon stock estimated for the Kalrayan hills, followed by the 30 - 60 cm class (20.5 %), 90 - 120, 120 - 150 and 180 - 150 cm classes (**Figure 2**). One way ANOVA revealed that there is a strong significant variation in the distribution of carbon stock of trees categorized into the 11 girth classes ($F_{(10,363)}$ = 11.376, $p < 0.0001$).

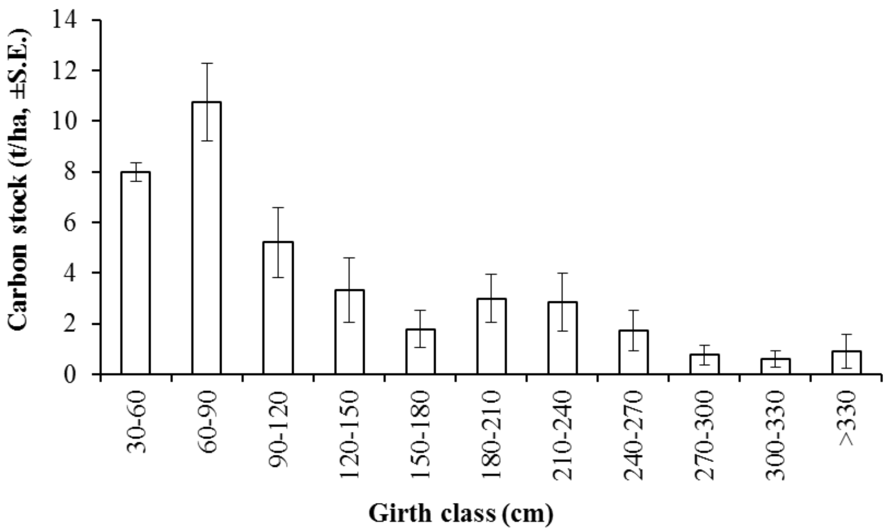

Figure 2 Distribution of carbon stock of trees categorized in to 11 girth classes.

Relation of carbon stock with species richness and density

Regression analysis showed that the carbon stock of trees in the Kalrayan hills had no relationship with species richness and density of trees (**Figure 3**).

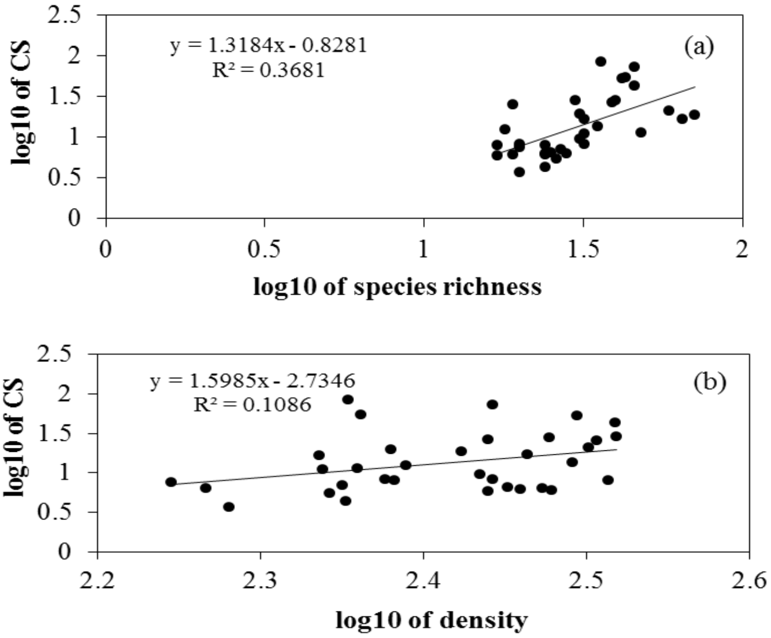

Figure 3 Regression analysis between the carbon stocks (CS) of trees with species richness (a) and density (b).

Discussion

Currently, the interest in the determination of biomass and carbon stocks of trees in the forest ecosystem is increasing worldwide to ensure sustainable management of forest resources and for many applications from commercial use of wood to the understanding of the global carbon cycle. Forest biomass is important for commercial uses (e.g. fuelwood assessment) and national development planning as well as for scientific uses such as studies of ecosystem productivity, energy and nutrient flows, and for assessing the contribution of changes in tropical forest lands to the global carbon cycle [20]. In the present study, the total tree biomass estimated from a large scale of 17 ha was 77.77 t/ha. The total tree carbon stock determined for the Kalrayan hills was 38.88 t/ha. The carbon stock value of the present study is very much less than other regions. It is almost seven and a half times lower than the carbon stock of the Montane rain forest in New Guinea [21] (**Table 2**).

Table 2 Comparison of total carbon stock (TCS) of the Kalrayan hills with other tropical forests worldwide.

Forest type and location	TCS*	Ref.
Tropical reserve forest, Kalrayan hills, Eastern Ghats, India	38.88	PS
Tropical dry evergreen forest, Rayapatti, India	42.01	[11]
Tropical moist forests, Bangladesh	48.88 - 118.45	[22]
Tropical dry evergreen forest, Arasadikuppam, India	51.89	[11]
Tropical dry evergreen forest, Kuzhanthaikuppam, India	51.89	[11]
Tropical dry evergreen forest, Maramadakki, India	52.36	[11]
Tropical dry evergreen forest, Araiyapatti, India	59.62	[11]
Tropical dry evergreen forest, Oorani, India	65.24	[11]
Tropical dry evergreen forest, Shanmuganathapuram, India	73.55	[11]
Tropical dry evergreen forest, Thirumanikkuzhi, India	77.12	[11]
Tropical dry evergreen forest, Karisakkadu, India	79.77	[11]
Tropical moist forests, Bangladesh	86.25 - 120.75	[23]
Tropical dry evergreen forest, Puthupet, India	99.53	[11]
Tropical evergreen forests, Myanmar	5.75 - 115.00	[24]
Tropical moist evergreen forests, Sri Lanka	109.25 - 299.00	[25]
Montane rain forests, Jamaica	131.68 - 179.40	[26]
Tropical rain forests, Malaysia	132.25 - 166.75	[27]
Lower Montane forests, El Verde, Puerto Rico	134.21	[28]
Tropical seasonal rain forest, Xishuangbanna, China	138.73	[29]
Tropical rain forests, Khade, Ghana	152.84	[30]
Tropical rain forests, New Guinea	164.45	[31]
Tropical rain forests, Khado Chang, Thailand	167.10	[32]
Tropical rain forest, Cambodia	200.10 - 238.63	[33]
Tropical rain forests, Western Ghats, India	263.47	[34]
Montane rain forests, New Guinea	290.38	[21]

Notes: Ref. = References; PS = Present study
*TCS was calculated based on the biomass data available

Conclusions

The present study concludes that the total carbon stock of the tropical forests in the Kalrayan hills is very low when compared to the range reported for other tropical forests. The distribution of the tree carbon stock among the 34 transects sampled varied greatly. The plant family, Combretaceae was the predominant contributor to the total tree carbon stock. While, *Albizia amara* contributed the greatest tree carbon stock in terms of species. The lower tree girth classes 30 - 60 and 60 - 90 cm together contributed greatly to the total carbon stocks. The present study provides valuable information on the forest biomass and carbon stocks useful for proper forest management of the Kalrayan hills which is highly threatened from anthropogenic activities such as illegal felling of trees, forest land encroachment and sand mining, leading to forest fragmentation and biodiversity loss, besides the invasion of weedy species like *Lantana camara* degrading the forest land. Concerted efforts by effective checking of deforestation, removing of weedy species, and also, providing alternative livelihood and wood substitutes to the local tribes are the immediate measures to conserve the already degraded Kalrayan hills. Further, planting trees in the degraded forest lands are suggested to curb the increasing carbon concentration in the atmosphere, and thereby to check the global warming and drastic change in climate through fixed tree biomass carbon stocks in the forest ecosystem.

Acknowledgements

I sincerely thank Dr. N. Parthasarathy, Professor, Department of Ecology and Environmental sciences, Pondicherry University, Puducherry for all his support and encouragement.

References

[1] R Fischer, A Armstrong, HH Shugart and A Huth. Simulating the impacts of reduced rainfall on carbon stocks and net ecosystem exchange in a tropical forest. *Environ. Model. Software* 2014; **52**, 200-6.
[2] HEM Nascimento and WF Laurance. Total aboveground biomass in central Amazonian rainforests: A landscape-scale study. *Forest Ecol. Manage.* 2001; **5793**, 1-11.
[3] BL Chavan and GB Rasal. Sequestered standing carbon stock in selective tree species grown in University campus at Aurangabad, Maharashtra, India. *Int. J. Eng. Sci. Tech.* 2010; **2**, 3003-7.
[4] NH Ravindranath, BS Somashekar and M Gadgil. Carbon flows in Indian forests. *Clim. Change* 1997; **35**, 297-320.
[5] S Salazar, LE Sanchez, P Galindo and I Santa-Regina. Above-ground tree biomass equations and nutrient pools for a paraclimax chestnut stand and for a climaxoak stand in the Sierra de Francia Mountains, Salamanca, Spain. *Sci. Res. Essays* 2010; **5**, 1294-301.
[6] S Brown, AJR Gillespie and AE Lugo. Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Sci.* 1989; **35**, 881-902.
[7] BRSA Wilson and JT Daff. Australia's state of the forests report Department of Agriculture, Fisheries and Forestry, Government of Australia, 2003.
[8] PG Murphy and AE Lugo. Structure and biomass of a subtropical dry forest in Puerto Rico. *Biotropica* 1986; **18**, 89-96.
[9] WF Laurance, SG Laurance, LV Ferreira, JMR Merona, C Gascon and TE Lovejoy. Biomass collapse in Amazonian forest fragments. *Science* 1997; **278**, 1117-8.
[10] DB Clark and DA Clark. Landscape-scale variation in forest structure and biomass in a tropical rain forest. *Forest Ecol. Manage.* 2000; **137**, 185-98.
[11] S Mani and N Parthasarathy. Above-ground biomass estimation in ten tropical dry evergreen forest sites of peninsular India. *Biomass Bioenerg.* 2007; **31**, 284-90.
[12] LA Pragasan and N Parthasarathy. Landscape-level tree diversity assessment in tropical forests of southern Eastern Ghats, India. *Flora* 2010; **205**, 728-37.
[13] S Brown and AE Lugo. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica* 1982; **14**, 161-87.

[14] RK Dixon, S Brown, RA Solomon, MC Trexler and J Wisniewski. Carbon pools and flux of global forest ecosystems. *Science* 1994; **263**, 185-90.
[15] LA Pragasan. Carbon stock assessment in the vegetation of the Chitteri Reserve Forest of the Eastern Ghats in India based on non-destructive method using tree inventory data. *J. Earth Sci. Clim. Change* 2014; **S11**, 001.
[16] J Chave, C Andalo, S Brown, MA Cairns, JQ Chambers, D Eamus, H Folster, F Fromard, N Higuchi, T Kira, JP Lescure, BW Nelson, H Ogawa, H Puig, B Riera and T Yamakura. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 2005; **145**, 87-99.
[17] KG MacDicken. *A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects USA*. Winrock International Institute for Agricultural Development, 1997.
[18] T Satto and HAI Madgwick. *Forest Biomass*. Martinus Nishoff, Boston, M.A., USA, 1982.
[19] M Segura. Allometric models for tree volume and total aboveground biomass in tropical humic forest in Costa Rica. *Biotropica* 2005; **37**, 2-8.
[20] AJR Gillespie, S Brown and AE Lugo. Tropical forest biomass estimation from truncated stand tables. *Forest Ecol. Manage.* 1992; **48**, 69-87.
[21] PJ Edwards and PJ Grubb PJ. Studies of mineral cycling in a Montane Rain forest in New Guinea, I-Distribution of organic matter in the vegetation and soil. *J. Ecol.* 1977; **65**, 1943-69.
[22] R Drigo, Md Shaheduzzaman and JA Chowdhury. *Inventory of Forest Resources of South Sylhet Forest Division*. Assistance to the Forestry Section - Phase II. FAO/UNDP project BGD/85/085, Field Document No. 3, Rome, Italy, 1998.
[23] R de Milde, Md Shaheduzzaman and R Drigo. *The High Forest in Chittagong District*. Vols. I and II, FAO/UNDP Project BGD/79/017, Field Document No. 3, Rome, Italy, 1985.
[24] FAO. *Forest Department of Burma. National Forest Survey and Inventory of Burma.* FO:BUR/79/001, Working Papers Nos. 5,7-12, Forest Department of Burma, Rangoon, 1984-1985.
[25] FAO/UNDP. *Pre-Investment Study on Forest Industries Development*. Ceylon, Final Report, Vol. II. Forest Resources and Management. FAO/SF:60/CEY-5, Rome, Italy, 1969.
[26] J Turner, SP Gessel and MJ Lambert. Sustainable management of native and exotic plantations in Australia. *New Forest.* 1999; **18**, 17-32.
[27] TC Whitmore. *Tropical Rain Forests of the Far East*. Clarendon Press, Oxford University Press, London, 1975.
[28] CF Jordan. Productivity of tropical forest and its relation to energy storage. *J. Ecol.* 1981; **59**, 127-42.
[29] P Shanmughavel, Z Zheng, S Liqiing and C Min. Floristic structure and biomass distribution of a tropical seasonal rain forest in Xishuangbanna, southwest China. *Biomass Bioenerg.* 2001; **21**, 165-75.
[30] GJ Greenland and JML Gowel. Nutrient content of the moist tropical forests of Guana. *Plant Sci.* 1970; **12**, 154-74.
[31] NJ Enright. (1979). Litter production and nutrient partitioning in rain forests near Bulolo, Papua New Guinea. *Malays. Forest.* 1979; **42**, 202-20.
[32] T Kira, H Ogawa, K Yoda and K Ogina. Primary production by a tropical rain forest of southern Thailand. *Bot. Mag.* 1974; **77**, 425-9.
[33] K Hozumi, K Yoda and T Kira. Production ecology of tropical rain forests in south western Cambodia. II. Photosynthetic function in an evergreen seasonal forest. *Nat. Life S.E. Asia* 1979; **6**, 57-81.
[34] SN Rai. Above ground biomass in tropical rain forests of Western Ghats, India. *Indian Forest*. 1984; **8**, 754-64.

Appendix

Appendix 1 Carbon stocks of tree species sampled from the 17 ha of the tropical forests in the Kalrayan hills.

Species (Family)	DN	TB	TCS	AC
Albizia amara (Roxb.) Boivin (Mimosaceae)	809	88.25	44.13	0.05
Gyrocarpus asiaticus Willd. (Hernandiaceae)	418	78.57	39.29	0.09
Nothopegia heyneana (Hook.f.) Gamble (Anacardiaceae)	88	71.87	35.93	0.41
Hardwickia binata Roxb. (Caesalpiniaceae	145	66.37	33.19	0.23
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr. (Combretaceae)	212	63.84	31.92	0.15
Terminalia bellirica (Gaertn.) Roxb. (Combretaceae)	22	62.46	31.23	1.42
Givotia rottleriformis Griff. (Euphorbiaceae)	236	51.67	25.83	0.11
Ficus benghalensis L. (Moraceae)	17	36.59	18.29	1.08
Dimocarpus longan Lour. (Sapindaceae)	75	36.20	18.10	0.24
Moringa concanensis Nimmo ex Gibs. (Moringaceae)	223	34.96	17.48	0.08
Commiphora caudata (Wight & Arn.) Engler (Burseraceae)	120	33.47	16.74	0.14
Celtis philippensis Blanco (Ulmaceae)	46	29.96	14.98	0.33
Tamarindus indica L. (Caesalpiniaceae)	21	25.02	12.51	0.60
Canthium dicoccum (Gaertn.) Teijsm. & Binn. var. *dicoccum* (Rubiaceae)	318	23.70	11.85	0.04
Drypetes roxburghii (Wall.) Hurusawa (Euphorbiaceae)	13	23.52	11.76	0.90
Dalbergia paniculata Roxb. (Papilionaceae)	88	22.98	11.49	0.13
Lannea coromandelica (Houtt.) Merr. (Anacardiaceae)	82	22.19	11.10	0.14
Schleichera oleosa (Lour.) Oken (Sapindaceae)	64	21.72	10.86	0.17
Drypetes sepiaria (Wight & Arn.) Pax & Hoffm. (Euphorbiaceae)	193	19.47	9.73	0.05
Ficus mollis Vahl (Moraceae)	60	17.51	8.76	0.15
Sterculia urens Roxb. (Sterculiaceae)	32	17.00	8.50	0.27
Ficus nervosa Heyne ex Roth (Moraceae)	2	15.66	7.83	3.92
Vitex altissima L.f. (Verbenaceae)	17	13.74	6.87	0.40
Acacia planifrons Wight & Arn. (Mimosaceae)	337	13.50	6.75	0.02
Terminalia chebula Retz. (Combretaceae)	8	13.20	6.60	0.82
Ficus microcarpa L.f. (Moraceae)	9	12.35	6.18	0.69
Chloroxylon swietenia DC. (Flindersiaceae)	389	12.24	6.12	0.02
Acacia leucophloea (Roxb.) Willd. (Mimosaceae)	234	12.05	6.02	0.03
Diospyros ovalifolia Wight (Ebenaceae)	46	11.83	5.91	0.13
Euphorbia antiquorum L. (Euphorbiaceae)	403	11.29	5.64	0.01
Terminalia arjuna (Roxb. ex DC.) Wight & Arn. (Combretaceae)	7	11.25	5.63	0.80
Erythrina stricta Roxb. (Papilionaceae)	14	10.93	5.47	0.39
Premna tomentosa Roxb. (Verbenaceae)	173	10.74	5.37	0.03
Sapindus emarginatus Vahl. (Sapindaceae)	79	10.69	5.34	0.07
Strychnos potatorum L.f. (Loganiaceae)	117	10.60	5.30	0.05
Pongamia pinnata (L.) Pierre (Papilionaceae)	28	10.09	5.05	0.18
Manilkara hexandra (Roxb.) Dubard (Sapotaceae)	29	9.70	4.85	0.17
Aglaia elaeagnoidea (Juss.) Benth. var. *courtallensis* (Gamble) K.K.N. Nair (Meliaceae)	52	8.93	4.46	0.09

Species (Family)	DN	TB	TCS	AC
Mimusops elengi L. (Sapotaceae)	7	8.85	4.42	0.63
Commiphora berryi (Arn.) Engler (Burseraceae)	212	8.77	4.39	0.02
Acacia chundra (Roxb. ex Rottl.) Willd. (Mimosaceae)	214	8.45	4.23	0.02
Beilschmiedia bourdilloni Brandis (Lauraceae)	3	8.33	4.16	1.39
Antiaris toxicaria (Pers.) Lesch. (Moraceae)	1	8.22	4.11	4.11
Terminalia paniculata Roth (Combretaceae)	7	8.04	4.02	0.57
Atalantia monophylla (L.) Correa (Rutaceae)	270	7.98	3.99	0.01
Pleiospermium alatum (Wall. ex Wight & Arn.) Swingle (Rutaceae)	310	7.91	3.96	0.01
Pterocarpus marsupium Roxb. (Papilionaceae)	27	7.73	3.86	0.14
Strychnos nux-vomica L. (Loganiaceae)	12	7.47	3.73	0.31
Ficus amplissima J.E. Smith (Moraceae)	9	7.44	3.72	0.41
Syzygium cumini (L.) Skeels (Myrtaceae)	5	6.93	3.46	0.69
Remaining 119 species	2648	491.72	245.86	0.09
Total (for 17 ha)	8951	1322.06	661.03	0.07

Notes: DN = Density (no. of trees/17 ha); TB = Total biomass (t/17 ha); TCS = Total carbon stock (t/17 ha); AC = Average carbon stock per tree (t/tree)

Appendix 2 Contribution of plant family to the total tree carbon stocks in the Kalrayan hills.

Family	SR	GR	DN	AGB	BGB	TB	TC	AC
Alangiaceae	1	1	46	1.76	0.26	2.02	1.01	0.02
Anacardiaceae	7	7	326	93.87	14.08	107.95	53.98	0.17
Annonaceae	2	2	56	1.62	0.24	1.87	0.93	0.02
Apocynaceae	2	2	146	4.56	0.68	5.24	2.62	0.02
Arecaceae	2	2	4	0.83	0.12	0.96	0.48	0.12
Bignoniaceae	3	2	148	4.06	0.61	4.67	2.33	0.02
Burseraceae	4	3	387	45.40	6.81	52.21	26.10	0.07
Caesalpiniaceae	4	4	247	81.92	12.29	94.20	47.10	0.19
Capparaceae	1	1	1	0.05	0.01	0.06	0.03	0.03
Celastraceae	3	3	28	6.13	0.92	7.05	3.52	0.13
Combretaceae	6	2	261	138.37	20.76	159.12	79.56	0.30
Cordiaceae	4	2	25	0.68	0.10	0.79	0.39	0.02
Dipterocarpaceae	1	1	11	5.95	0.89	6.84	3.42	0.31
Ebenaceae	6	1	337	22.66	3.40	26.06	13.03	0.04
Erythroxylaceae	1	1	130	3.10	0.46	3.56	1.78	0.01
Euphorbiaceae	12	8	997	98.24	14.74	112.98	56.49	0.06
Flacourtiaceae	2	2	24	3.49	0.52	4.01	2.00	0.08
Flindersiaceae	1	1	389	10.64	1.60	12.24	6.12	0.02
Hernandiaceae	1	1	418	68.32	10.25	78.57	39.29	0.09
Lauraceae	4	4	31	13.53	2.03	15.56	7.78	0.25
Leeaceae	1	1	1	0.02	0.00	0.02	0.01	0.01
Loganiaceae	2	1	129	15.71	2.36	18.07	9.04	0.07
Lythraceae	1	1	2	0.67	0.10	0.77	0.39	0.19

Family	SR	GR	DN	AGB	BGB	TB	TC	AC
Melastomataceae	2	1	13	1.19	0.18	1.37	0.69	0.05
Meliaceae	8	7	153	19.52	2.93	22.45	11.23	0.07
Meliosmaceae	1	1	1	0.07	0.01	0.08	0.04	0.04
Mimosaceae	8	3	1832	114.33	17.15	131.48	65.74	0.04
Moraceae	13	4	121	93.32	14.00	107.31	53.66	0.44
Moringaceae	1	1	223	30.40	4.56	34.96	17.48	0.08
Myrtaceae	2	2	8	6.09	0.91	7.01	3.50	0.44
Oleaceae	3	1	26	1.22	0.18	1.40	0.70	0.03
Papilionaceae	7	5	169	47.39	7.11	54.50	27.25	0.16
Poaceae	1	1	216	4.00	0.60	4.61	2.30	0.01
Rhamnaceae	2	1	102	3.97	0.59	4.56	2.28	0.02
Rubiaceae	11	10	621	39.66	5.95	45.61	22.81	0.04
Rutaceae	8	7	611	16.30	2.45	18.75	9.38	0.02
Sapindaceae	5	5	259	62.02	9.30	71.32	35.66	0.14
Sapotaceae	3	3	46	18.43	2.76	21.20	10.60	0.23
Simaroubaceae	1	1	5	0.93	0.14	1.07	0.53	0.11
Solanaceae	1	1	3	0.05	0.01	0.06	0.03	0.01
Sterculiaceae	8	5	62	17.99	2.70	20.69	10.35	0.17
Tiliaceae	4	1	33	1.08	0.16	1.25	0.62	0.02
Ulmaceae	3	3	87	27.55	4.13	31.68	15.84	0.18
Verbenaceae	6	4	216	22.52	3.38	25.90	12.95	0.06

Notes: SR = Species richness (no. of species); GR = Genera richness (no. of genera); DN = Density (no. of trees/17 ha); AGB = Aboveground biomass (t/17 ha); BGB = below ground biomass (t/17 ha); TB = Total biomass (t/17 ha); TCS = Total carbon stock (t/17 ha); AC = Average carbon stock per tree (t/tree)