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The tallest canopy and the highest carbon stock for a forest stand in Sri Lanka

The height of the canopy of a forest has been noted as an important structural parameter in characterizing particular forest types in Sri Lanka (Ashton *et al*. 1997, Koelmeyer 1957, Peeris 1975). However, only limited studies have been carried out on the carbon stocks of different natural forest types, which is also an important structural parameter of forests. As per the scientific literature mentioned above, the tallest canopy forests are wet zone lowland rain forests in the south western part of the country. The forests are dominated by trees of the family Dipterocarpaceae and reach a maximum canopy height of 45 m (Gunatilleke *et al*. 2008).

A preliminary botanical survey conducted in the hitherto unexplored Udakeeruwa forest in the eastern intermediate zone climatic zone, in Badulla district, revealed an unusually tall canopy of a natural forest patch dominated by dipterocarp trees. With the guidance of the local community, it was possible to record the height of a newly fallen mature tree of *Dipterocarpus zeylanicus*. The total height from the base of the stem to its apex green point was recorded as 72.3 m. However, there could have been an error of 1–2% since the natural green apex point was difficult to recognise in the fallen tree. Moreover, some slender woody branches of the top part of the tree were broken away. This observation prompted a further study into the forest canopy height levels, and forest carbon content, which is often higher in taller forests.

There were two objectives for this study: (1) to understand the natural forest vertical structure with particular reference to canopy height, and (2) to investigate total carbon content of the tree flora. The studied forest area is located adjacent to Udakeeruwa Village (7.050902 N, 81.233480 E; alt. 513 m a.s.l.), in Badulla District, Sri Lanka. The area falls within the eastern intermediate climatic zone with mean annual rainfall from 2,000–2,500 mm (Survey Department 1988). It was observed that the dipterocarp-dominated tall canopy forest patch under investigation is not widespread locally but confined to a small geographic area of approximately 2 km^2, in a valley bottom surrounded by low hills (Fig. 1A).

Study of forest vertical structure and canopy height: Vertical structure of the forest was studied by drawing a forest profile diagram. A transect of size 100 m × 5 m, which was representative of the least disturbed area of mature forest was selected. A profile diagram was drawn to show the overall vertical appearance of the forest. Scaled line drawings of all trees above or equal to 50 cm girth at breast height were made. Trees of higher girth classes were measured to better highlight taller trees in the profile diagram. The height of each tree was measured using a Suunto hypsometer (Suunto Oy Company, Finland) which is based on simple trigonometric principles. The vertical forest profile (Fig. 2) drawn for the sample site shows that large diameter trees are vertically organized into three strata; canopy (55–67 m), sub canopy (30–40 m) and under story (15–25 m). It is interesting to note that none of the natural forest canopies elsewhere in Sri Lanka are reported to be 55–67 m high. This unusual height may be due to the following reasons: **(a)** the forest being situated in a valley flanked by two hills ensures it is well protected from strong winds and hence trees can grow to great heights with no natural obstructions; **(b)** the hills on both sides run north to south, which limits the period of direct sunlight reaching the valley floor (Fig. 1B). Therefore, it is likely that strong competition for light has promoted vertical growth; and apparently, the valley being a fertile area, can sustain high biomass forests.

The tallest tree recorded was a 67 m *Shorea dyeri* (Diperocarpaceae). This tree is 6.3 m shorter than the fallen *Dipterocarpus zeylanicus* measured previously in the same forest stand. However, even when used correctly, the Sunnto hypsometer can have an error of about 2.5% (Brack & Wood 1998). So far, the tallest tropical tree in the world has been measured as 94.1 m using laser technology; a tree in Borneo, tentatively identified as *Shorea* species (Dockril 2016).

***Assessment of forest carbon*:** Enumeration was done for woody plants (mainly trees and some lianas) having a girth at breast height of 10 cm or above (Table 1). Trees were enumerated in 20 plots, 10 ×10 m in size. All the plants species enumerated were identified using field guides and referring specimens to the National Herbarium of Sri Lanka. Plots were laid randomly in areas judged to be representative of dipterocarp forest in the field. Girth values of plants were used in calculating species specific carbon content using the following allometric equations:

Above ground biomass in kg (AGB) =21.297–6.953 (DBH) + 0.740 $(DBH)^2$ (Brown1997). DBH=diameter at breast height in centimetres.

Below Ground biomass in kg (BGB) =AGB (kg) × 0.127 (Brown & Iverson 1992). Total biomass in kg=AGB+BGB; total carbon content=total biomass [kg] × 0.474 (Martin & Thomas 2011).

The overall analysis of the girth data shows that the total carbon stock of the woody flora of a 2,000 m^2 area is 140,816.85 kg (704.08 Mt/ha). That amount of sequestered carbon is distributed among 53 woody plant species (Table 1) with 627 individuals. The five leading woody species in descending order of percentage carbon stock are *Dipterocarpus zeylanicus* (59.75%), *Shorea dyeri* (22.74%), *Mallotus fuscescens* (5.06%), *Artocarpus nobilis* (2.16%) and *Bhesa ceylanica* (1.68%). The total forest carbon stock per ha in this forest is higher than that of comparable forest types in the wet zone of Sri Lanka, assessed by Chave *et al*. (2008). Once AGB data from Chave *et al*. (2008), is converted to total carbon content, it amounts to 403.35 Mt/ha for woody plants equal to or above the 1 cm diameter at breast height used in that study. The pattern of distribution of carbon content among species is highly asymmetric, with 82.49% of the total carbon stock in two species: *Dipterocarpus zeylanicus* and *Shorea dyeri*. Both species are massive trees of the Dipterocarpaceae family (Fig. 1C). Moreover, 91.39% of the total carbon stock is within the first five leading species. The balance of 8.51% carbon stock is spread over 49 other woody species.

Table 1. Estimated carbon content of different woody species

No	Plant species	Carbon (kg)	No	Plant species	Carbon (kg)
1	*Dipterocarpus zeylanicus*	84,140.72	28	*Stemonurus apicalis*	58.40
2	*Shorea dyeri*	32,022.16	29	*Rourea minor*	38.07
3	*Mallotus fuscescens*	7,120.89	30	*Syzygium aqueum*	29.38
4	*Artocarpus nobilis*	3,039.43	31	*Syzygium makul*	27.46
5	*Bhesa ceylanica*	2,369.72	32	*Areca catechu*	26.16
6	*Mangifere zeylanica*	1,510.13	33	*Strombosia ceylanica*	17.15
7	*Hydnocarpus venenata*	1,443.29	34	*Eugenia rufo-fulva*	16.95
8	*Artocarpus heterophyllous*	1,162.45	35	*Palaquium hinmolpedda*	15.19
9	*Ficus drupacea*	846.82	36	*Acacia pennata*	12.92
10	*Myristica ceylanica*	803.25	37	*Semecarpus nigro-viridis*	10.68
11	*Horsfieldia iryaghedhi*	796.32	38	*Caryota urens*	9.49
12	*Goniothalamus hookeri*	739.18	39	*Cinnamomum verum*	9.49
13	*Garcinia quaesita*	671.77	40	*Uncaria elliptica*	9.28
14	*Macaranga peltata*	567.25	41	*Euonymus walkeri*	9.28
15	*Dimocarpus longan*	545.53	42	*Pandanus ceylanicus*	9.11
16	*Agrostistachys indica*	444.73	43	*Nothopegia beddomei*	8.41
17	*Uvaria semecarpifolia*	429.17	44	*Connarus monocarpus*	6.84
18	*Timonius flavescens*	321.46	45	*Mangifera indica*	5.37
19	*Aporusa acuminata*	264.24	46	*Calophyllum calaba*	5.35
20	*Calophyllum tomentosum*	251.17	47	*Gomphia serrata*	4.75
21	*Alstonia scholaris*	229.18	48	*Diospyros ebenoides*	2.78
22	*Litsea longifolia*	183.36	49	*Glochidion nemorale*	2.78
23	*Antidesma* sp.	152.23	50	*Pterospermum suberifolium*	2.78
24	*Entada pusaetha*	137.54	51	*Crptocarya wightiana*	2.72
25	*Dalbergia pseudo-sissoo*	110.07	52	*Gomphandra coriacea*	2.71
26	*Flacourtia indica*	86.80	53	*Salacia oblonga*	2.65
27	*Olax zeylanica*	81.86		Total carbon	140,816.85 kg/2,000 m^2

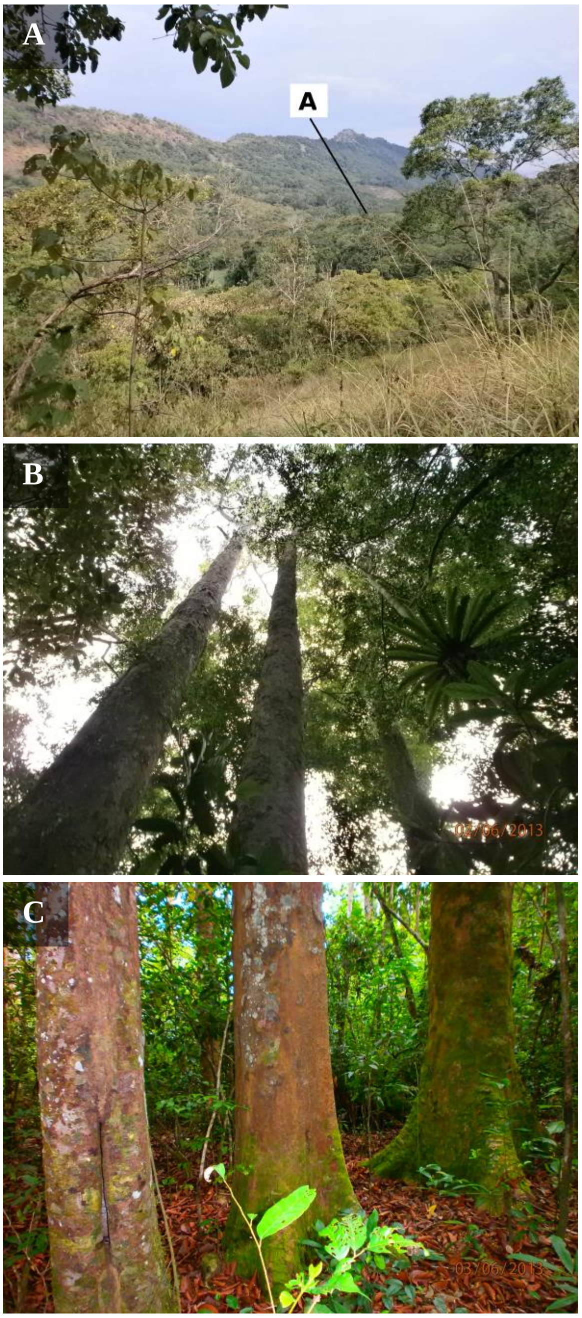

Figure 1. (**A**) The study site in relation to larger landscape view; **(B)** Lofty dipterocarp trees in the forest; and **(C)** Frequent occurrence of large trees close to each other largely contributes to high level of carbon stock in the forest.

The dipterocarp-dominated forest stand at Udakeeruwa can be classified as the tallest canopy natural forest in Sri Lanka. Dipterocarp-tree species are the prominent component of the uppermost layer of the forest canopy. This forest stand has the potential for attracting eco-tourists, researchers and other interest groups on account of its outstanding botanical features and charisma. Meanwhile, due attention has to be paid to strengthening its conservation in a socially beneficial manner, considering the on-going anthropogenic pressures on the forest. It seems likely that taller trees, than those noted here, are to be found in this forest. The use of advanced techniques like laser scanning (Dockril 2016) for the accurate non-destructive measurement of tree heights might be used and could add valuable data to help conserve the forest.

The present initial study on forest carbon stocks of Udakeeruwa forest enriches the current knowledge base on the carbon sequestration potential of another forest in a remote locality in Sri Lanka. As per available literature, the forest carbon stock of this forest is the highest for a natural forest in Sri Lanka, which calls for policy and programs to protect this carbon rich natural forest for climate benefits. Information on taller tree species with higher carbon stocks provide guidance on plant selection for restoration forestry for enhancing ecosystem services in degraded sites having climatically similar conditions.

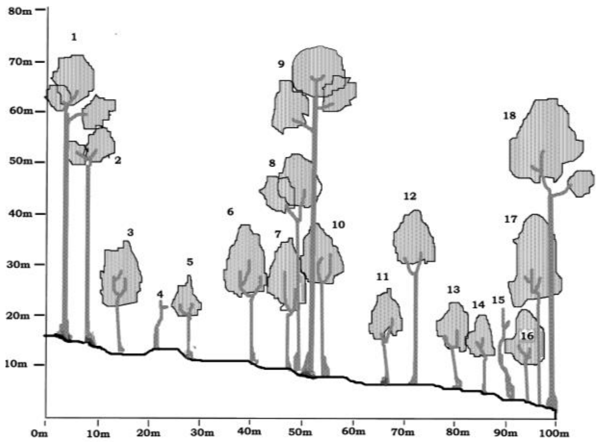

Figure 2. Profile diagram of a forest patch at Udakeeruwa; *Bhesa ceylanica* (7), *Dipterocarpus zeylanicus* (2, 8, 12, 18), *Mallotus fuscescens* (3, 5, 6, 10, 11, 14, 16), *Pometia pinnata* (13, 17), *Shorea dyeri* (1, 9) and dead stumps of large trees (4, 15); transect size: 100 m × 5 m; minimum GBH of selected trees: 50 cm.

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