Tree volume and biomass allometric equations of Bangladesh

Bangladesh Forest Department

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In 2015, the Forest Department began a process to establish a National Forest Inventory and Satellite Land Monitoring System for improved forest and natural resource management. The process supports national objectives related to climate change mitigation and provides information in support of the UN-REDD programme aimed at Reducing Emissions from Deforestation and Forest Degradation (REDD+). The process also addresses domestic information needs and supports national policy processes related to forests and the multitude of interconnected human and environmental systems that forests support.

The activities implemented under the Bangladesh Forest Inventory process are collaboration between several national and international institutions and stakeholders. National partners from multiple government departments and agencies assist in providing a nationally coordinated approach to land management. International partners, including the United Stated Agency for International Development (USAID) and the Food and Agriculture Organization of the United Nations (FAO) are supporting the development of technical and financial resources that will assist in institutionalizing the process.

The results will allow the Forest Department to provide regular, updated information about the status of trees and forests for a multitude of purposes including for assessment of role of trees for firewood, medicines, timber, and climate change mitigation.

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1. Introduction

Bangladesh has a long history of forest inventories. The first forest inventory survey was conducted during 1769-1773 (FAO,2007).Till to date Bangladesh Forest Department implemented several sub-national inventories in the hill, sal & mangrove forests and a full scale national forest inventory during 2005-2006 for the country with the financial and technical assistance of different agencies such as Asian Development Bank (ADB), Food and Agriculture Organization of the United Nations (FAO), United Nations Development Programme (UNDP), World Bank (WB). These inventory data were analysed for estimating growing stock in terms of volume to prepare the forest management plans. Recently, specific inventories on carbon stock were performed in different forests of Bangladesh. First forest carbon inventory was conducted in the Chunoti Wildlife Sanctuary during 2008 and subsequently for the Sundarban Reserved Forest (SRF) during 2010. Forest department also conducted carbon inventories in six protected areas[1] during 2011 with the financial assistance of USAID.

FAO (2004) defined biomass as “organic material both above-ground and belowground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc.”. Above-ground biomass consists of all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. Below-ground biomass consists of all living roots excluding fine roots (less than 2mm in diameter). Total biomass could be estimated directly from the measurements of destructively harvested trees then weighing it (Brown and Lugo,1982) or converted the tree volumes to total above ground biomass using wood densities and expansion factor (Brown and Lugo,1984).

Biomass varies with the location, species etc. therefore it is necessary to obtain more accurate and precise biomass estimates in order to improve understanding of the role of the forests in the global carbon cycle.Since the development of stem volume and biomass equations is laborious and time consuming process – especially the destructive harvesting of large trees – existing equations need to be compiled and evaluated to facilitate identification of the gaps in the coverage of the equations. The compiled equations can also be used to test and compare and validate existing equations with new ones. Recently, remote sensing data have been used to estimate forest biomass (Zheng, et al.,2007, Saatchi, et al.,2011). However, estimation of biomass depends on ground truth data with measured dimensions of trees, and the empirical biomass equations are therefore needed to predict biomass as a function of recorded variables. The estimation of stem volume and tree biomass is needed to support national forest policies related to bio-energy, commercial timber and climate change adaptation and mitigation. United Nations Framework Convention on Climate Change (UNFCCC) and in particular the Kyoto Protocol recognise the importance of forest carbon sink and the need to monitor, preserve and enhance terrestrial carbon stocks, since changes in the forest carbon stock influence the atmospheric CO^2 concentration. Reduced Emissions from Deforestation and forest Degradation (REDD+) in developing countries has emerged as a likely component of the next international policy effort addressing climate change, to be implemented (FAO,2013). This programme would

[1] Dudpukuria-Dhopachari Wildlife Sanctuary, Teknaf Wildlife Sanctuary, Fashiakhali Wildlife Sanctuary, Inani National Park, Medhakachapia National Park and Sitakunda Reserved Forests

offer economic incentives for conserving forests and associated C-stocks, intended to offset the short-term economic factors that promote deforestation.

The aim of this compilation was to develop a database on tree-level stem volume and biomass equations for various tree species growing in Bangladesh. Equations for the biomass of different tree components were also considered. The compiled database is a guide to the original publications of these equations. In ecological studies on forest carbon and nutrient cycling, forest and greenhouse gas inventories; this database facilitates effective exploitation of existing information on tree volume and biomass allometry.

2. Data collection and compilation

This document gathered the existing biomass and volume equations that were developed during past inventories or through scientific studies in order to facilitate assessment of forest volume, biomass and carbon stocks. The hardcopy inventory reports archived in the library of Forest Department published technical reports and scientific papers of Bangladesh Forest Research Institute (BFRI) and other scientific papers published in different journals in different time are used for the preparation of this document.

3. Forests of Bangladesh

The forests of Bangladesh are classified into four categories based on the topographic conditions (a) Hill forests, (b) Plain land Sal forests, (c) Mangrove forests, and (d) Swamp forest (Figure **9**).

Hill Forests

The Hill Forests consist of moist tropical evergreen and semi evergreen forests, which extend from Teknaf Peninsula, north along Myanmar border to the Chittagong Hill Tracts (CHT) and the low hills in greater Sylhet district (Figure 1 and Figure 2). These forests are generally uneven-aged, multi-storied and rich in biodiversity. The majority of smaller understory trees are evergreen and most of the dominant trees are deciduous. The hill forests are abundant with numerous plants as well as animal species. Some important floras are *Dipterocarpus spp*. *Artocarpus chaplasha, Hopea odorata*, *Palaquium polyanthrum, Callophyllum polyanthum*, *Mangifera sylvatica*, *Legarstromia speciosa*, *Swintonia floribunda*, *Cedrela toona*, *Duabanga grandiflora* etc. Moreover there are bamboo, cane, climbers and fern etc. in these forests.

These forests are brought under plantation programme since 1871. At present, plantation activities are being conducted under development projects. Some valuable plantation species are *Tectona grandis*, *Gmelina arborea*, *Swietenia spp*, *Artocarpus chaplasha*, *Legarstromia speciosa*, *Albizzia spp*., *Chikrassia tabularis*, *Xylia dolabriformis*, *Anthocephalus cadamba*, *Hopea odorata* etc.

Figure 1. Natural forest of Cox's Bazar District

Figure 2. Plantation Forest of sylhet District

Plain Land Sal Forests

Plain land Sal forests are Tropical Moist Deciduous type of forests exists in most of the lowlands and floodplains in the central and western parts of the country (Figure 3 and Figure 4). This forest is intermingled with the neighboring settlements and fragmented into smaller patches. *Shorea robusta* is the main species there with other associates like *Albizzia procera*, *Dillenia pentagyna*, *Cassia fistula*, *Terminalia belerica*, *Terminalia chebula, Bauhinia acuminata*, *Lagerstroemia speciosa*, *Syzygium* spp. etc. Plantations of first growing species such as *Acacia auriculiformis*, *Acacia* *mangium*, *Eucalyptus camaldulensis* and medicinal plants also conducted under different development project in the forest.

Figure 3. Sal forest of Gazipur District

Figure 4. Sal forest of Gazipur District

Mangrove Forests

The Mangrove forest areas consist of natural mangrove forests and mangrove plantations in the southern part of Bangladesh. Mangroves are located in two main ecosystem types:

(1) Sundarban Reserved Forest (SRF) and

(2) Coastal plantations along with the Bay of Bengal.

The Sundarban is a unique and largest contiguous natural mangrove forest in the world (Figure 5 and Figure **6**). Sundarban harbors 334 species of trees, shrubs and epiphytes and 269 species of wild animals. World renowned Royal Bengal Tiger is the magnificent animal of the Sundarban. *Heritiera fomes* is the most important tree species in the forest which is distributed over 73% of the reserve. Extent of *Heritiera fomes* is followed by *Excoecaria agallocha*, *Avecinnia offcecinalis*, *Xylocarpus mekongensis*, *Sonneratia apetala* etc. There are some other non-wood forest products like *Nypa fruticans*, honey, wax, fish, crab etc which are also of high value. It is situated in the southern part of Satkhira, Khulna and Bagerhat districts, the south-western region of Bangladesh.

Plantations along the shore land of coastal districts of Bangladesh started in 1960-61 fiscal year with the objectives of protecting lives and properties from natural calamities such as cyclones and tidal bores and of stabilizing the newly accreted lands. This initiative got momentum from 1980-81 with the aid of development partners and afforestation programs are extended over foreshore islands, embankments and along the open coasts. *Sonneratia apetala* and *Avicennia officinalis* are the main species of the Coastal plantation.

Figure 5. Sundarban Reserved Forest

Figure 6. Coastal afforestation of Bhola District

Swamp Forests

The Swamp forest consists of semi evergreen forest types and inundated with freshwater, either permanently or seasonally (Figure 7 and Figure **8**). It is located in the north-eastern part of Bangladesh. *Acacia catechu* and *Barringtonia acutangula* are the main species of the forest.

Figure 7. Swamp Forest of Ratargul, Sylhet District

Figure 8. Swamp Forest of Ratargul, Sylhet District

Each of the forest types contains special types of plants and acts as an important carbon sink. Floral diversity is richer in the hill forests of Chittagong, Chittagong Hill Tracts and Sylhet region.

The forestlands of Bangladesh are broadly categorized as government forestland and private forestland. Of the Government forestlands, 638.06 thousand hectare (ha) is the Hill Forest, 120.69 thousand ha is the Plain Land Sal Forest, 607.7 thousand ha is the natural Mangrove Forest, 130 thousand ha is the coastal plantation and 23.59 thousand ha is the Swamp Forest under the jurisdiction of Forest Department (FD,2012).

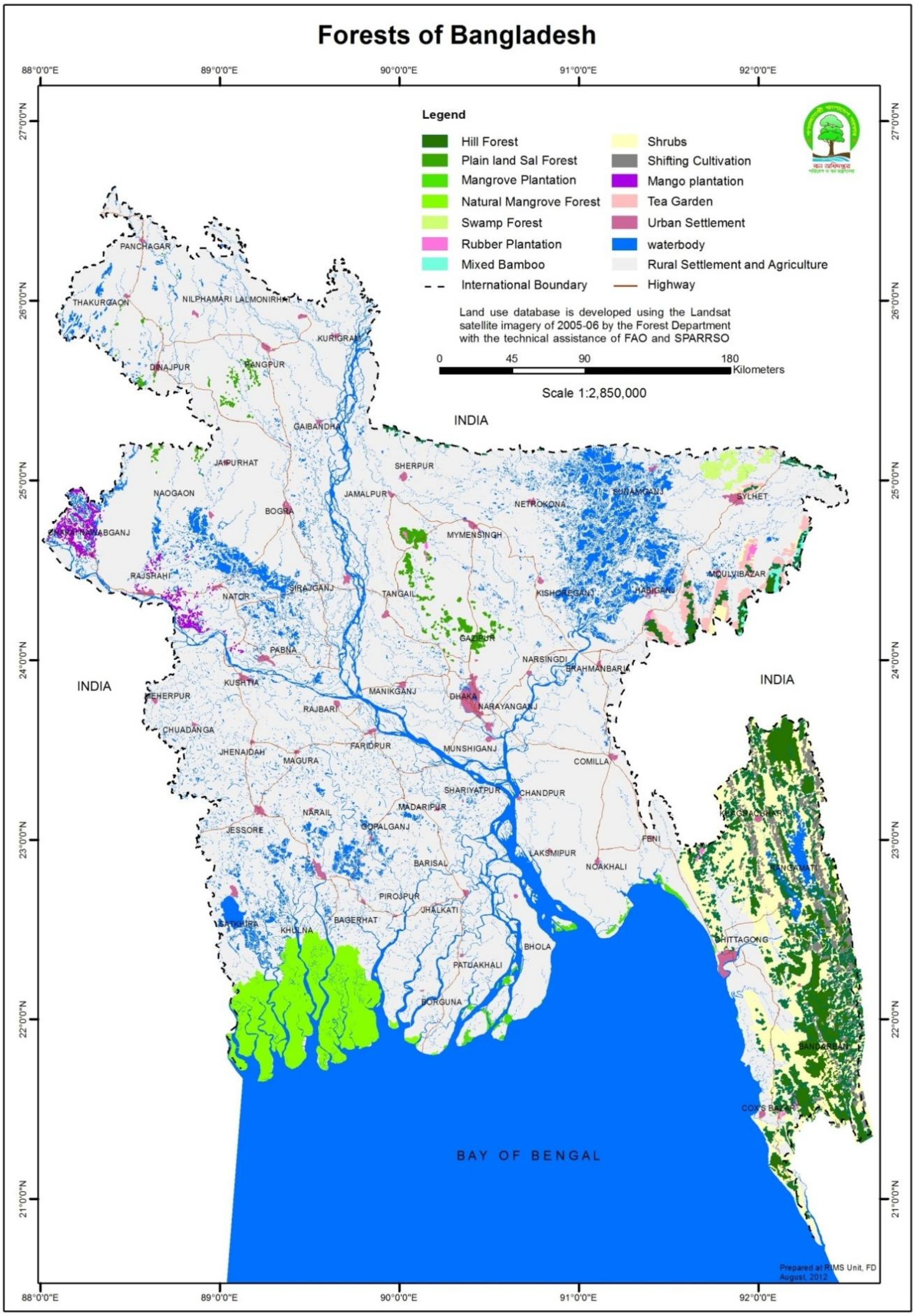

Figure 9: Distribution of forest types in Bangladesh (NFA 2007)

4. Tree volume and biomass equations

The estimation of standing volume and biomass of natural forest and plantation are important for their management and particularly for the comparison of potential forest productivity in Bangladesh. Biomass and volume estimation in Bangladesh has been mainly done using tree allometric equations. While robust site and species specific equations are recommended for the estimation. About 187 allometric equations for volume and biomass were developed with 84 species. Most of the allometric equations were for volume calculation and very few were for the biomass estimation (Hossain, et al.,2012).

4.1 Volume equations

An estimate of the total bole volume in a stand or plot is important for forests quantification of harvestable timber. Volume equations of Bangladesh are mainly developed for planning and management. All volume equations were developed to estimate only stem volume and ignored branch volume. However, there is no straightforward, commonly accepted definition for stem volume for the country. In general, the volume of stem wood extending from root collar up to the top of the stems is accounted in the equations developed. Several inventories were conducted in the natural forests and plantations of Bangladesh for stand volume calculation. The equations used for volume calculation that have been found in different scientific articles, reports and other documents have been complied in this document. Most of the volume equations are species specific, but some common equations were also observed. Simple linear, multiple linear, exponential and powered allometric equations were developed with different independent variables (Diameter at breast height, girth at breast height, form factor) and dependent variables (total volume, volume over bark, volume under bark).

Hill Forest

This forest type has 69 allometric volume equations, mainly for commercially important tree species. Different volume equations were observed for the natural forest (Table 1) as well as plantation (Table 2). The available volume equations have been classified for natural hill forest and plantation in hill forest.

Table 1: Volume equations of naturally growing different tree species of hill forests

Species	Equation	Location	Remarks	Sources
Dipterocarpus turbinatus	$V = -3.866 + 0.21768\frac{D^2H}{100}$; If $\frac{D^2H}{100} < 500$	Kassalong and Rankhiang Reserve of Hill Forest, Hill Forest of Chittagong hill tracts	D = Diameter at breast height over bark (inch), H = Tree height in feet V= Volume (cft)	(Ray,1971)
	$V = 16.161 + 0.17617\frac{D^2H}{100}$, If $\frac{D^2H}{100} > 500$			
Dipterocarpus turbinatus	V = 43 (10^{-5}) $D^{2.137}$	Hill forest of Chittagong	V=volume, (m^3) D= Diameter at breast height over bark (cm) These equation can also be used for plantation.	(Sakman,1983)
Swintonia floribanda	V = 268 (10^{-6}) $D^{2.33}$			
Tetrameles nudiflora, Pterygota alata , Callophyllum polyanthum	V = 844 (10^{-6}) $D^{2.08}$			
Mangifera sylvatica, Chickrassia tabularis, Michelia champaca	V = 99 (10^{-5}) $D^{1.901}$			
Artocarpus chaplasha, Syzygium grande, Cedrela toona , Gmelina arborea Paraserianthes falcataria, Lagerstroemia speciosa	V = 272 (10^{-5}) $D^{1.618}$			
Palaquium polyanthum , Aphanamixis polystachya, Trewia nudiflora, Anthocephalus cadamba , Gynocardia odorata, *Mesua ferrea , Duabanga grandiflora*, *Castanopsis tribuloides* and *Syzygium* spp	V= 209 (10^{-7}) $D^{2.908}$			
Miscellaneous species	V = 855 (10^{-6}) $D^{1.929}$			
Tectona grandis	V = 1000 A/(115+3.8 A)	Hill forest of Chittagong district	V=volume, (m^3) D= Diameter at breast height over bark (cm) A = Age (Year)	(Sakman,1983)
Dipterocarp spp. (*Hopea odorata*)	LnV= -9.780865+2.148566 lnDBH+0.9475224lnH	Hill forest of CHT,Chittagong, Cox's Bazar and Sylhet district	DBH = Diameter at breast height over bark (cm) H= Length upto crown point (m) ln = logarithom base e * This is a common equation for 24 species	(FD,1988)
Anisoptera glabra, Castanopsis tribuloides, *Duabanga grandiflora*, *Michelia champaca*, *Tetrameles nudiflora*, *Artocarpus chaplasha*, *Alstonia scholaris*, *Chickrassia tabularis*, *Swintonia*	lnV = -9.352781+1.998918 lnDBH + 0.8150925lnH			

floribanda, *Syzygium grande*, *Gmelina arborea*, *Vitex* spp., *Syzygium* spp.,*Lagerstroemia speciosa*, *Anthocephalus cadamba*, *Albizia procera*, , *Aphanamixis polystachya*, *Trewia nudiflora*, *Lophopetalum fimbriatum*, *Bombax ceiba*, *Cedrela toona*, *Palaquium polyanthum*, *Mangifera sylvatica*				
Other species traded as group:	lnV= -9.292138+1,998005 lnDBH+0.800028lnH			
Aphanamixis polystachya	LnV = -8.9863+1.9328lnD+0.6992lnH	Hill forest of Cox's Bazar, Chittagong and Sylhet district	V= volume (m^3), , D= Diameter at breast height over bark (cm) H= Total height ln = logarithom base e	(Revilla, et al.,1998d, Revilla, et al.,1998b) (Revilla, et al.,1998c)
Artocarpus chaplasha	LnV = -8.6639+2.1320lnD+0.2946lnH			
Bombax ceiba	LnV = -9.1013+1.9419lnD+0.5276lnH	Hill forest of Cox's Bazar, Chittagong and Sylhet district	V= volume (m^3), , D= Diameter at breast height over bark (cm) H = Total height (m) ln = logarithom base e	(Revilla, et al.,1998d) (Revilla, et al.,1998b) (Revilla, et al.,1998c) (Islam and Latif,in press)
Dipterocarpus turbinatus	LnV = -9.1872+1.6485lnD+1.1306lnH			
Dipterocarpus gracilis	LnV = -9.4406+1.8660lnD+0.9648lnH			
Dipterocarpus costatus	LnV = -9.1693+1.7651lnD+1.0011lnH			
Dipterocarpus turbinatus	LnV = -9.1872+1.6485lnD+1.1306lnH			
Duabanga grandiflora	$V = -0.5127+0.0004129D^2+0.001298H+0.0000247D^2H$			
Mangifera sylvatica	LnV = -8.9048+2.0808lnD +0.6926lnH			
Schima wallichii	$V= 0.05978-0.00003151D^2+0.01648H+0.00002781D^2H$			
Swintonia floribanda	lnV = -8.8621+1.8148lnD +0.8280lnH			
Syzygium grande	$V = 0.08566+0.0002378D^2 +0.01194H + 0.00002365D^2H$			
Terminalia belerica	LnV = 8.3245+1.78261lnD +0.6257lnH			
Tetrameles nudiflora	LnV = -8.4925+1.8522lnD +0.6879lnH			
Mixed Species	LnV = -8.3367+1.5932lnD+ 0.9400lnH			
Dipterocarpus turbinatus	$Log_e V_1$ = f (GBH) = 9.9621407 + 2.08627 Log_e GBH	Chunati Wildlife Sanctuary of Chittagong Hill Forest	GBH = Girth at breast height over bark(cm) H = Tree height (m)	(FD and BFRI,2008)
	$Log_e V_2$ = f (GBH, H) = -10.159316Log_e GBH + 0.940025Log_eH			

Table 2: Volume equations of different tree species planted in the hill forests

Species	Equation	Location	Remark	Sources
Gmelina arborea	V= 0.01559+0.01229 I_c + 0.000026181 D^2H	Hill forest of CHT	(I_c= 0 for locality 1 and I_c = 1 for locality 2) V = Volume under bark (m^3) D = Diameter at breast height over bark (cm) H = Height (m) * Crown diameter limit of 10 cm	(Cox 1984)
Syzygium grande	V = 0.03294 + 0.000025764 D^2H			
Dipterocarpus turbinatus	V = 0.043442 + 0.000028969 D^2H			
Syzygium grande	V = 0.079764 + 0.000023617 D^2H	Hill forest of CHT	V = Volume under bark (m^3) D = Diameter at breast height over bark (cm), H = Height (m) Crown diameter limit of 20 cm	(Cox, 1984)
Gmelina arborea	V= 0.09394 + 0.00011840 D^2 + 0.000030661/H + 0.083417/D^2H			
Dipterocarpus turbinatus	V = -0.05962 – 0.00030587 D^2 + 0.000035782 D^2H			
Syzygium grande	Vob = 0.0000294 + 0.0001930DBH ^{2} + 0.0002490DBHxH + 0.0000244 DBH ^{2} H	Hill forest of Chittagong, Cox's Bazar, Sylhet	Where, DBH = Inventoried or projected diameter at breast height (cm) H = Inventoried or projected tree height (m) Vob = Total tree volume over bark (m^3) Log = Natural logarithm base 10	(FD,1988)
Dipterocarpus turbinatus	Vob = 0.0003910 + 0.0001930 DBH^2 + 0.0001478DBHxH + 0.0000241 DBH ^{2} H			
Gmelina arborea	Log (Vob) = -8.4687076 + 1.8350200 Log DBH + 0.7848470 Log H			
Artocarpus chaplasha	Log (Vob)= -8.9449500 + 1.8285100Log DBH + 0.7353810Log H	Hill forest of Chittagong, Cox's Bazar, Sylhet	DBH = Diameter at breast height (cm) H = Tree height (m) Vob = Total tree volume over bark (m^3) Log = Natural logarithm	(FD,1988)
Alstonia scholaris	Vob = 0.0000294 + 0.0001930 DBH ^{2} + 0.0002490 DBH x H + 0.0000244 DBH^2 H			
Tectona grandis (CHT)	Log (Vob) =-9.4807600 + 1.6211600Log DBH + 1.1648300 Log H			
Paraserianthes falcataria	Vob = 0.0123000 + 0.0000404 DBH ^{2} H			
Lagerstroemia speciosa	Log (Vob) = -8.3443500 + 1.8285000 Log DBH + 0.7353800 Log H			

Shorea robusta	Vob = 0.0003910 + 0.0006455DBH ^{2} + 0.0001478 DBH x H + 0.0000241 DBH^{2} H			
Mixed species	Log (Vob) = -9.4807600 + 1.6211600 Log DBH + 1.1648300 Log H			
Sonneratia apetala (CHT)	Log (Vob) = -8.6615200 + 1.5865000 Log DBH + 0.7715200 Log H			
Avicennia officinalis (CHT)	Log (Vob) = -7.3329800 + 0.5641800 Log DBH + 0.2044300 Log H			
Ceriops decandra	Log (Vob) = -9.5258000 + 2.1229000Log DBH + 0.5993000 Log H	Plantations of Hill forest of Sylhet Forest Division	DBH = Diameter at breast height (cm) H = Tree height (m) Vob = Total tree volume over bark (m^{3}) Log = Natural logarithm Log (Sob)= Solid over bark Range 1= Juri Range Other range = Moulavi Bazar, Rajkandi, Kulaura, Habigonj, Raghunandan, satchari range of Sylhet Forest Diision	(Balmforth and Howlader,1988) (Drigo, et al.,1988)
Artocarpus chaplasha	Log (Vob) = -10.0581000 + 1.9464000 Log DBH + 0.9378000 Log H			
Tectona grandis (range 1)	Log (Vob) = -9.4808000 + 1.6212000 Log DBH + 1.1648000 Log H			
Tectona grandis (other range)	Log (Vob) = -9.4808000 + 1.6212000 Log DBH + 1.1648000 Log H			
Paraserianthes falcataria	Log (Vob) = -8.9942000 + 1.4963000 Log DBH + 1.1461000 Log H			
Lagerstroemia speciosa	Log (Vob) = -9.6744000 + 2.1065000 Log DBH + 0.6675000 Log H			
Shorea robusta	Log (Vob) = -10.0253000 + 2.1163000 Log DBH + 0.7588000 Log H			
Eucalyptus spp.	Log (Sob) = -9.4209 + 1.7480 Log DBH + 0.9310 Log H			
Anthocephalus cadamba	Log (Sob) = -10.4647 + 2.3911 Log DBH + 0.6373 Log H			
Gmelina arborea	Log (Sob) = -10.0399 + 2.1532 Log DBH + 0.7161 Log H			
Syzygium grande	Log (Sob) = -10.7345 + 1.4842 Log DBH + 1.7521 Log H			
Dipterocarpus turbinatus	Log (Sob) = -9.5258 + 2.1229 Log DBH + 0.5993 Log H			
Xylia dolabriformis	Log (Sob) = -9.4303 + 2.0988 Log DBH + 0.6042 Log H			
Acacia auriculiformis	V_{tob}= 0.000043645(D-3)^{2}H	Plantations of sylhet, Chittagong	D = Diameter at breast	(Revilla, et

	V_{tub}= 0.85342V_{tob} V_{5ub}= 0.99416V_{tub} V_{10ub}= 0.89330V_{5ub}	and Cox's Bazar forest division	Height over bark (cm) H = Height (m) Ln = Logarithon base e V_{tob} = Volume total over bark (m3) V_{tub}= Volume total under bark (m3) V_{5ub}= Volume at 5 cm under bark (m3) V_{3ub}= Volume at 3 cm under bark (m3) V_{20ub}= Volume at 20 cm under bark (m3)	al.,1998d) (Revilla, et al.,1998b) (Revilla, et al.,1998c)
Acacia mangium	V_{tob}= 0.000038834(D-3)^{2}H V_{tub}= 0.85018V_{tob} V_{5ub}= 0.99945V_{tub} V_{10ub}= 0.99970V_{5ub}			
Cassis siamea	V_{3ub}= -10.1767+2.0642 lnD+0.8291 lnH			
Pinus carribea	V_{3ub} = -9.7505+1.9354 lnD+0.8517 lnH			
Gmelina arborea	V_{tob} = -.46871+1.63502lnD+0.78487lnH			
Syzygium grande	V_{tob}= 0.00018987 + 0.000029903D^2 + 0.000024887DH + 0.000024466D^{2}H			
Dipterocarpus turbinatus	V_{tub} = 0.0025211 + 0.0025211 + 0.00010003 DD^2 + 0.00014779DH + 0.000024065D^{2}H			
Artocarpus chaplasha	V_{tob} = -8.94495+1.82851lnD+0.73538lnH			
Swintonia floribanda	V_{20ub}= 0.01059+0.00002887D^{2}H (if D-H<1200)			
	V_{20ub} = 0.09790+0.00002499D^{2}H (If D^{2}H≥ 1200)			
Tectona grandis	V_{tob} = -9.4808+16212lnD+1.1648lnH V_{5ub} = 0.1217+0.2257D^{2}H V_{10ub} = 0.0000465D$^{1.58}$H$^{1.603}$ V_{20ub} = 0.0645+0.2322D^{2}H			
Eucalyptus camaldulensis	V_{tob} = 0.000042692(D-3)^{2}H V_{tub} = 0.83847V_{tob} V_{5ub} = 0.95916V_{tub} V_{10ub} = 0.89239V_{5ub}			
Paraserianthes falcataria	V_{tob} = -8.9942+1.4963lnD+1.1461lnH			

Mangrove forest

Natural mangrove forest is dominated by very few species and volume equations have also been found for the dominated species of this forest types. There are different equations available for a species from different inventories for the natural mangrove forest as well as for the mangrove plantations. They are described in Table 3 and Table 4respectively.

Detailed inventory was carried out in SRF during 1958-61, 1981- 1983 and 1997-1998. Volume equations have been developed for the major species to estimate the volume. During 1981-83, for *Heritiera fomes* and *Excoecaria agallocha*, volume regressions were calculated separately for each of the three height classes for which data were collected. The height classes are 1.≥15.2 m, 2.<15.2 to ≥10.7 m, 3.<10.7 to ≥6.1 m.Two regressions were calculated for *Bruguiera gymnorhiza*, one for each of the first two height classes. Three significantly differently regressions were found to obtain volume only for *Heritiera fomes*. Two different regressions have been developed for *Excoecaria agallocha* and only one for *Sonneratia apetala*. Inventory has been conducted during 1997-1998 in SRF for the preparation of updated management plan. In this inventory BFRI assisted to improve the existing volume equations available for the forest and developed new equations for the major species and weight equation for *Ceriops decandra* and *Nypa fruticans*. During the study, the new equations were found to be more efficient then the equations used by (Chaffey, et al.,1985) for the inventory conducted 1983- 1985 for volume calculation.

In all the inventories in the mangrove plantation areas, *Sonneratia apetala* was found the most important mangrove species covered by majority of the planted areas of the four Coastal Afforestation Divisions. *Avicennia officinalis* was the principal species of Chittagong Division (Drigo, et al.,1987). Later inventories also showed that *Sonneratia apetala* is the most suitable species for the newly accreted land in the coastal divisions.

Table 3*:* Volume equations of naturally growing mangrove tree species

Species	Equation	Location	Remarks	Sources
Heritiera fomes	$1V_{ub}$ = 1.51076 – 65.9963 x D	Sundarban Reserved Forest	$1V_{ub}$ = Volume (m^3) under bark for height class 1 (≥15.2 m) $2V_{ub}$ = Volume (m^3) under bark for height class 2 (<15.2 ≥10.7 m) $3V_{ub}$ = Volume (m^3) under bark height class 3 (<10.7 ≥6.1 m) $2,3V_{ub}$ = Volume (m^3) under bark for height class 2 and 3 $1,2,3V_{ub}$ = Volume (m^3) under bark for height class 1, 2 and 3 D = Diameter at breast height over bark (cm) Ln = Logarithm at base e	(Chaffey, et al.,1985)
	$2V_{ub}$ = 10.2821 x LnD – 0.37283 x D – 25.1612			
	$3V_{ub}$ = 12.2165 x LnD – 0.5125 x D – 28.3046			
Excoecaria agallocha	$1V_{ub}$ = 4.4314 x LnD – 0.073475 x D-13.949			
	$2,3V_{ub}$ = 5.96108 x LnD – 0.15932 x D – 16.8329			
Sonneratia apetala	$1,2,3V_{ub}$ = 5.11582 x LnD – 0.0707 x D – 15.9104			
Xylocarpus mekongensis and *Xylocarpus granatum*	$1V_{ub}$ = 3.08019 x LnD – 0.03026 x D – 10.3302			
	$2,3V_{ub}$ = Ln(0.001056 x D -2 -0.023601 x D+0.17149) (If D<12, Height class 1 will be applied)			
Bruguiera gymnorhiza	$1V_{ub}$ = 1.48179 x LnD + 0.02088 x D – 6.63463			
	$2,3V_{ub}$ = 1.71691 x LnD + 0.01095 x D – 7.48278			
Avicennia officinalis and *Ficus* spp.	$1,2,3V_{ub}$ = 3.28405 x LnD – 0.05561 x D – 10.8153			
Miscellaneous species	$1,2,3V_{ub}$ = 3.28405 x LnD – 0.05561 x D – 10.8153			
Heritiera fomes	V10E = - 0.02363 + 0.00001800*D^2H + 0.0002210*D^2	Sundarban Reserved Forest	V10E = Tree volume (m^3) having ≥10 cm under bark DBH with branches of 2 m long VTOTE = Tree volume (m^3) having ≥10 cm DBH with branches of 2 m long and non-merchantable crown/branch volume. BVCRE = Under bark tree bole volume (m^3) up to crown point VNME = Non-merchantable volume over bark If under bark DBH< 10 cm, V10E = 0 WT = Weight (kg) ULME = Length of utilized leaf (m) LM = Length of leaf (m) D = d.b.h. overbark (cm) D^2 = DBH^2, DBH (cm) H = total tree height (m) D^2H = D^2*H	(Revilla, et al.,1998d)
	VTOTE = 0.008298 + 0.00001529*D^2H + 0.0003505*D^2			
	BVCRE = -0.0044196 + 0.00001364*D^2H + 0.0002378*D^2			
	VNME = VTOTE – V10E			
Excoecaria agallocha	V10E = 0.00003149*D^2H			
	VTOTE = 0.00003797*D^2H			
	BVCRE = 0.00003070*D^2H			
	VNME = -0.005021 + 0.0001890*DH			
Sonneratia apetala	V10E = -0.0083256 + 0.00003824*D^2H - 0.0001201*D^2			
	VTOTE = 0.00003848*D^2H			
	BVCRE = 0.000002284*D^2H + 0.0001526*DH			
	VNME = 0.03426 + 0.000002895*D^2H			
Avicennia officinalis	V10E = 0.00003704*D^2H - 0.002267*H			
	VTOTE = 0.0002572*D^2 + 0.00002387*D^2H			
	BVCRE = 0.0057935 + 0.00002695*D^2H			

	VNME = VTOTE – V10E		$D^2H^2 = D^2 * H^2$	
Bruguiera gymnorhiza	V10E = - 0.01971 + 0.00003729*D^2H			
	VTOTE = 0.00004555*D^2H			
	BVCRE = 0.00006299VTOTE*VTOTE			
	VNME = VTOTE – V10E			
Xylocarpus mekongensis	V10E = - 0.01806 + 0.0001358*D^2 + 0.00002695*D^2H			
	VTOTE = 0.0002887*D^2 + 0.0002752*D^2H			
	BVCRE = 0.00002939*D^2H			
	VNME = VTOTE – V10E			
Xylocarpus granatum	V10E = -0.008143 + 0.00003819*D^2H			
	VTOTE = 0.00009118*D^2H - 0.000004678*D^2H^2			
	BVCRE = 0.007231 + 0.00002885*D^2H			
	VNME = VTOTE – V10E			
Ceriops decandra	VOL = 0.001429 – 0.001111*D + 0.0004294*D^2			
	WT = 1.337 – 0.8816*D + 0.3876*D^2			
Nypa fruticans	ULME = -1.0802 + 1.4524*LM – 0.1081*LM^2			
	WT = -1.4555 + 1.1953*ULME			
	Alternatively, WT = -1.3734 + 0.8882*LM			

Table 4: Volume equations of different tree species planted in the coastal forests

Species	Equation	Location	Remarks	Sources
Sonneratia apetala	Log (Vob) = -8.6615200 + 1.5865000 Log DBH + 0.7715200 Log H	Chittagong Coastal Afforestation Division	Where, DBH = Diameter at breast height over bark (cm) H = Tree height (m) Vob = Total tree volume over bark (m^3) Log = Natural logarithm	(FD,1988)
Avicennia officinalis	Log (Vob) = -7.3329800 + 0.5641800 Log DBH + 0.2044300 Log H			
Sonneratia apetala	$V_{7ub} = 0.0041 + 0.00002463D^2H$	Noakhali, Bhola, Patuakhali Afforestation Division	V_{7ub} =Volume at 7 cm under-bark (m3) D= Diameter at breast height over bark (cm) H = Height (m)	(Revilla, et al.,1998b)
	$V_{7ub} = -0.00088 + 0.0000297D^2H$	Chittagong coastal Afforestation division		(Revilla, et al.,1998c)
Avicennia officinalis	$V_{7ub} = -0.012 + 0.00002580D^2H$			
Sonneratia apetala	V_t = -8.66152 + 1.58656 lnD + 0.77152 lnH	Chittagong Coastal Afforestation Division	Vt= Total volume inside the bark (m^3) V_{t10} = Volume inside bark to 10 cm top diameter D = Diameter at breast height over bark (cm) H = Height (m) ln = Logarithm base e	(Drigo, et al.,1987)
	V_t = -9.29715 + 1.70514 lnD + 0.95088 lnH	Noakhali Coastal Afforestation Division		
	V_t = -9.23507 + 1.69673 lnD + 0.92309 lnH	Barishal Coastal Afforestation Division		
	V_t= -8.75215 + 1.75034 lnD + 0.64233 lnH	Patuakhali Coastal Afforestation Division		
	V_{t10} = -13.63792 + 2.73639 lnD + 1.30860 lnH	Chittagong Coastal Afforestation Division		
	$V_{t\,10}$ = -19.62856 + 4,04311 lnD + 2.37599 lnH	Noakhali Coastal Afforestation Division		
	V_{t10} = -15.69425 + 3.15776 lnD + 1.67549 lnH	Barishal Coastal Afforestation Division		
	V_{t10} = -14.33283 + 3.69540 lnD + 0.51765 lnH	Patuakhali Coastal Afforestation Division		
Avicennia officinalis	V_t = -7.33298 + 1.56418 lnD + 0.20443 lnH	All Coastal Afforestation Divisions		
	V_{t10} = -11.16265 + 2.78288 lnD + 0.22273 lnH			

Plain Land Sal Forest

Shorea robusta is the only dominant species of this forest types. As part of the forest Inventory carried out during November 1999 - 2000, a tree volume study was under taken in order to test the validity for using existing sal plantation volume tables for the sal coppice forest. Two best fit volume equations were derived from the measurement data as stated in (FD,2001). The volume equations developed by Das, Rahman et al.(1992) also can be used for sal coppice forests as the study did not find statistically significant difference between these volume estimates. Volume equations developed by BFRI (Latif, et al.,1986, Latif and Islam,1984) was used to calculate the volume of other natural species of the sal forest.

Usable volume tables are available in Bangladesh for the plantations of eucalypts (Davidson, et al.,1985), *Acacia mangium* (Latif, et al.,1993), *Acacia auriculiformis* and *Cassia siamea* (Latif, et al.,1995), *Gmelina arborea* (Latif, et al.,1984) are used by the sal forest inventory to calculate the volume of the plantations (FD,2001). They are listed in Table 5 and Table 6.

Table 5: Volume equations for the natural species of the plain land *sal* forest

Species	Volume equation	Location	Remarks	Sources
Shorea robusta	$V = 0.00010347 \times D^{2.501816}$	Dhaka, Tangail and Mymensingh Forest Divisions	D = dbh(cm)	(FD,2001)
	$V = 0.00017448 \times D^{2.403486}$	North Bengal		
Adina cordifolia	$V = 0.0003208 \times D^{2.1338}$	Dhaka, Tangail and Mymensingh Forest Divisions		(Latif, et al.,1986) (Latif, et al.,1984) (FD,2001)
Albizia procera	$V = 0.0009847 \times D^{2.502194}$			
Bombax ceiba	$V = 0.0002114 \times D^{2.3088}$			
Syzygium spp.	$V = 0.00552016 - 0.0028213 \times D + 0.0007843 \times D^2$			
Terminalia belerica	$V= 0.0003208 \times D^{2.1338}$			
Others	$V = 0.0005131 \times D^{2.08627}$			

Table 6: volume equations for the plantations of the plain land sal forest

Species	**Volume equation**	**Location**	**Remarks**	**Sources**
Acacia auriculiformis	V= 0.000272465 x $D^{2.2389}$	Dhaka, Tangail, Mymensingh and north Bengal Forest Divisions	D = dbh (cm)	(Ahmed and Donato,2010, Davidson, et al.,1985) (Latif, et al.,1993) (Latif, et al.,1995) (Latif and Islam,1984)
Acacia mangium	V = 0.0002721 x $D^{2.2178}$			
Cassis siamea	V = 0.00018374 x $D^{2.4038}$			
Eucalyptus Camaldulensis	V= 0.0002043 x $D^{2.38682}$			
Gmelina arborea	V = 0.0003699 x $D^{2.1472}$			
Tectona grandis	V= 0.00051676 x $D^{2.12337}$			
Terminalia arjuna	V= 0.00017605 x $D^{2.222144}$			
Others	V = 0.0005131 x $D^{2.08627}$			
Dalbergia sissoo	V = 34.9 D^2H -5209	Khulna	D = DBh (cm) H = height (m)	(Khan and Faruqe,2010)

4.2 Biomass equations

Biomass of plants includes total dry weight of leaves, buds, flowers, fruits, branches, and stems, above and below-ground roots in a certain time. Biomass value of a forest or the individual species is often used for the comparison of net primary productivity, nutrient cycling and carbon stocking. Moreover, it can be used as a very important tool for managing any natural forest and plantation. There are the different methods of biomass estimation. Among the methods, allometric relationship technique is less destructive (Zianis and Mencuccini,2004).Estimation of above and below-ground biomass by non-destructive means requires the development of allometric equations among different tree dimensions (DBH, GBH, Basal area, TH etc. and biomass of different part of trees). Biomass equations (Simple, curvilinear and multiple) varied greatly among sites. It is preferable to use species specific and site specific regression models for biomass estimation. Conversely, the use of generalized equation can lead to a varying proportion of error in biomass estimation for a particular species. Biomass of different species varies with sites, forest types and management practices. In general natural forest has less standing biomass compared to plantation (Baishya, et al.,2009). Standing biomass and their proportion in the above and below-ground parts are not only affected by the geographical location and microclimates but also vary with the species, sites, forest types, management practices, stand structure and age of stand. Apart from the environmental factors, the biomass proportion in different part of tree species also depends on plant architecture. Each of the plant architectural models varies considerably in their canopy structure and even the same species vary in their branching complex at different stages of development. However, in Bangladesh there are few works on allometric equations on biomass estimation compared to volume equations. This section summarizes the available biomass allometric models of different tree species of different forest types:

Hill forest

The tree species diversity is quite high in the natural forest of hilly areas of Bangladesh compared to others. Irrespectively, most of the afforestation scheme with the native and exotic species was also established in this area. However, only one study (Alamgir and Al Amin,2008) focused on the organic carbon content in tree biomass with 20 common species.

Table 7: Allometric equations of organic carbon content in tree biomass of naturally growing and plantation in hill forest

Species	Equation	Location	Remarks	Sources
Albizia lebbeck	Y= -0.197329 + 22.166233 (BA)	Chittagong South Forest Division	Y = organic carbon content in tree biomass (tonne) BA = Basal area (m^2) DBH ≥15 cm	(Alamgir and Al Amin,2008)
Albizia procera	Y = -0.421075 + 24.809910 (BA)			
Albizia saman	Y= -0.148089 + 13.267731 (BA)			
Alstonia scholaris	Y = -0.371891 + 17.020147 (BA)			
Aphanamixis polystachya	Y= -0.355382 + 23.712272 (BA)			
Artocarpus chaplasha	Y = -0.581639 + 28.192082 (BA)			
Artocarpus heterophyllus	Y = -0.125404 + 15.474200 (BA)			
Artocarpus lacucha	Y = 0.453032 + 23.313679 (BA)			
Bombax ceiba	Y = -0.255484 + 15.542905 (BA)			
Dipterocarpus turbinatus	Y =-0.516093 + 31.986985 (BA)			
Dubanga grandifolia	Y = -0.353313 + 20.954494 (BA)			
Gmelina arborea	Y = -0.117007 + 4.377647 (BA)			
Hopea odorata	Y= -0.103491 + 20.372012 (BA)			
Lagerstroemia speciosa	Y = -0.074635 + 15.326061 (BA)			
Shorea robusta	Y = -0.152190 + 23.543551 (BA)			
Swetenia mahagoni	Y = -0.079143 + 15.535524 (BA)			
Swintonia floribanda	Y = -0.236538 + 20.314057 (BA)			
Syzygium grande	Y = -0.221170 + 23.537777 (BA)			
Tectona grandis	Y = -0.243989 + 21.267652 (BA)			
Terminalia bellirica	Y = -0.221347 + 21.446552 (BA)			
All species except above species	Y = -0.118030 + 17.749190 (BA)			

Mangrove forest

Allometric equations to estimate the above ground biomass of different parts (leaves, branches, stems and barks) of *Ceriops decandra* and *Aegialitis rotundifolia* were derived by (Hossain, et al.,In Press , Siddique, et al.,2012) respectively from the Sundarban. The equations were presented in the following **Table 8**.

Table 8: Allometric equations for *Ceriops decandra* and *Aegialitis rotundifolia* of mangrove forest

Species	Equation	Location	Remarks	Sources
Ceriops decandra	Leaf = $1.95G^{2.99}$	Sundarban Reserved Forest	G= girth at collar region	(Alamgir and Al Amin,2008)
	Branch = $3.09G^{0.23}$			
	Bark = $2.23G^{0.77}$			
	Stem with bark = $2.27G^{3.22}$			
	Total above ground = $2.41G^{4.70}$			
Aegialitis rotundifolia	$Leaf = 13.96G_{CH} - 12.38T_{H}^{2} - 0.01G_{MH}^{2} + 0.08G_{CH} \times T_{H} \times G_{MH}$	Sundarban Reserved Forest	$G_{CH=}$ girth at collar height, T_H = total height, G_{MH}= Height of girth measuring point.	(Siddique, et al.,2012)
	$Branch = 3.09G_{CH}^{2} - 22.887T_{H}^{2} - G_{HM}^{2} + 0.13G_{CH} \times T_{H} \times G_{MH}$			
	$Stem = 3.67G_{CH}^{2} - 137.16T_{H} - 0.02G_{MH}^{2} + 0.12G_{CH} \times T_{H}^{2} \times G_{MH}$			
	$Total = 5.49G_{CH}^{2} - 251.36T_{H} - 0.07G_{MH}^{2} + 0.75G_{CH} \times T_{H} \times G_{MH}$			

5. Discussion

On an average, 92 t/ha of carbon is stored by the existing tree biomass in the forests of Bangladesh (Table 9) (Shina, et al.,2007). Forest soils in Bangladesh, as well as Asia, store carbon at a rate of 115, 100 and 60 t/ha in moist, seasonal and dry soils, respectively (ESSD,1998). This assessment of biomass and carbon stock is declining due to the human impact such as encroachment, over extraction and illicit felling.

Table 9: Biomass and carbon density in the forests of Bangladesh

Forest types	Aboveground biomass (t/ha)	Underground biomass (t/ha)	Total biomass (t/ha)	Carbon stock (t/ha)
Closed large-crowns	206–210	32	242	121
Closed small-crowns	150	23	173	87
Disturbed closed	190	29	219	110
Disturbed open	85	13	98	49
Average				92

Inventory Report of Revilla (1998d) in the Hill Forest areas of Cox's Bazar Forest Division showed that, a comparison with the 1984 FAO/UNDP inventory, the area of the natural forest had decreased by about 12% while the forest plantations had decreased by 8 % during the 12 years period. The tree volume/ha had decreased by about 19 % during the same period. In another inventory report of Revilla (1998b) of Hill Forest areas of Chittagong Forest Division showed that the natural and plantation forest is increased during the 12 years period. The report mentioned that the recorded increased in the area of natural forest is more likely due to the inclusion of areas that are omitted in 1984 into the 1996 estimate. The report also mentioned that the number of trees (30 cm + dbh) per hectare in all four strata in the natural forest had decreased by 67 % over the period. Inventory report of Revilla et al. (1998c) showed that the area of natural forest of the Hill Forest of Sylhet region had decreased by about 17 %, scattered trees by 69 % and short rotation plantations by 18 % while long rotation plantations increased by 76 % over the 12 years period. The number of trees (30 cm + dbh) per hectare in the natural forest had decreased only slightly but the pole size trees (10 - 30 cm) had decreased by more than 65 %. The inventory reported very low yield in the natural and plantation forest.

According to the inventory report of Revilla (1998e), the coastal plantations have increased the area since the last photography (1984) and forest inventory (1984-1987) but the stocking per hectare had decreased. A comparison of this inventory with the National Forest Inventory (MOEF and FAO,2007) of 2005-2007 showed that the area of coastal plantations had decreased about 41 % within 9 years period.

The tree resources of the SRF had decreased dramatically over the last 37 years from the Forest inventory in 1959 to the Overseas Development Agency (ODA) inventory in 1983 and the Forest Resources Management Project (FRMP) inventory in 1996. Estimates of the three inventories show that main species *Heritiera fomes* had decreased from 211 trees/ha in 1959 to 125 in 1983 and 106 in 1996 based on 15 cm + dbh trees, or about 50 % over the 37 year period. For *Excoecaria agallocha* species, the number of trees/ha had decreased from 61 in 1959 to 35 in 1983 and only 20 in 1996, or a decrease of about 67 % for the same period. In terms of all species, the decrease had been form 296 in 1959 to 180 in 1983 and 144 in 1996, or about 51 % over the 37 years period (Revilla, et al.,1998d).

Carbon inventory conducted during 2010 in the SRF was compared with the inventory conducted during 1996, though the inventory of 1996 was done to know the timber stocking for preparing the management plan and non-tree pools were largely ignored in the inventory. Trees are the most ready indicator of forest change and degradation, so this change assessment should still yield quite valuable insight. Comparing the two time points, the 2010 tree carbon pools were significantly higher than those from the same plots in 1997, suggesting an increase in C storage over this time period (Table 10) (Ahmed and Donato,2010). The estimated total increase, accounting for trees only, was 41 Mg/ha (95 % Confidence Interval-CI: ±17 Mg/ha).

Table 10: Comparison of mean C pools in SRF between the 1996-97 and 2009-10 inventories.[2]

Carbon pool	**1997 inventory**		**2010 inventory**		**Change (2010 minus 1997)**	
	C density (Mg/ha)	95 % CI	C density (Mg/ha)	95 % CI	Δ C density (Mg/ha)	95 % CI
Trees aboveground (stems + foliage)	46	± 4.3	80	± 11	(+) 34	± 12
Trees belowground (roots)	27	± 2.3	35	± 4.2	(+) 7.2	± 4.8
Saplings + seedlings aboveground	1.6	± 0.2	1.3	± 0.1	(-) 0.3	± 0.2
Saplings + seedlings belowground	1.0	± 0.1	1.0	± 0.1	0.0	± 0.1
TOTAL (tree + sapling /seed only)	76	± 6.6	117	± 15	(+) 41	± 17

Source: (Ahmed and Donato,2010)

Converting this difference to changes in Carbon stocks (multiplying the mean per-hectare change by the entire land area of SRF) indicates an increase of 16.9 Mega ton (Mt) of carbon storage over this time period (95% CI: 10.0 – 23.7

[2] **Note:** Only tree and sapling/seedling pools could be compared because these were the only pools measured in the 1996-97 inventory.

(+) and **(-)** in change column indicate increases or decreases, respectively, during the 1997 to 2010 time period. Estimates for 2010 pools are slightly adjusted from previous section because this analysis included plots that were land in 1997 but now submerged in 2010 (land subsidence, etc.). These were excluded from the land-based Carbon density estimate for the current Carbon stock analysis, but were included as negatively changing plots in the change assessment. The difference is minor.

Mt). Over the 13-year time interval, this change in carbon stocks suggests an average annual sequestration rate of 1.3 Mt carbon per year (95% CI: 0.8 – 1.8 Mt Carbon per year).

Detailed plain land Sal Forest inventory during 2001 was estimated approximately 22,000 ha of natural *Shorea robusta*, woodlots at 17,000 ha, and agroforestry areas at 1500 ha. Mean volume of mature *Shorea robusta* varies between 42 and 71 m^3 per hectare in the Central Forest Divisions (FD,2001). National Forest Inventory (MOEF and FAO,2007) of 2005-2007 reported about 34,000 ha of natural Sal forest in the country. There remained several possibilities for varying the result between two inventories.

6. Conclusion

A review on allometric equations of stem volume and above-ground biomass of different tree species of Bangladesh has been presented here. This compilation will be a basic tool of assessing timber stock, forest biomass, volume/biomass increment and carbon stock as well. The volume allometric equations were derived during the forest inventories of hill forest, plain land Sal forest and Sundarban reserved forest. Conversely, swamp forest and its species were less focused. Irrespectively, only 9 equations of biomass and 21 equations of carbon estimation were derived for 2 mangrove species and 21 species of hill forest respectively. It also identifies that allometric equations of volume and biomass were recorded for only 84 species in Bangladesh. Allometric equations of total above-ground biomass are comparatively accurate in assessing the carbon stock and carbon flux and sequestration than the existing volume equations. These allometric volume equations only concerned with the commercial volume of stem ignoring the branches and foliage volume. Therefore the use of these volume equations in estimation of carbon stock and flux will give underestimation.

Reliable methods of estimating forest biomass and carbon stocks as well as volume of growing stock at spatial and temporal scales for different biomes are needed to assess the flux and sequestration over time. Studies are required to develop allometric equations of biomass for all the remaining tree species to increase the accuracy in carbon estimation and monitoring. A joint research (involving Forest Department, Forest Research Institute and academic institution- like Forestry and Wood Technology Discipline, Khulna University; Institute of Forestry and Environmental Sciences, University of Chittagong etc.) can be conducted and research grant can be provider to derive the biomass and volume allometric equations.

The database of allometric equation for Bangladesh needs to be constantly updated and checked in order to ensure the insertion of all the new published equations. A strategy for assessing natural forest biomass needs to be designed and implemented, and, in order to improve the quality of biomass assessment and to develop new and more accurate models, it is also necessary to develop and provide access to a comprehensive wood density and raw data database at a national scale. However, this document can be used as a source of reference for the future study.

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