A baseline assessment of forest carbon in Guyana

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Executive Summary

This report reviews allometric functions for calculating tree biomass from several sources, and compares them with total volume equations derived from 1849 felled sample trees from the Interim Forestry Project (IFP) 1990-94. The volumes for the latter are re-calculated to a gross, overbark basis to 10 cm top to provide a comparison basis. It is found that the recent pan-tropical biomass equations of Chave *et al* (2005) provide an accurate correspondence to the IFP data and may therefore be applied with confidence in Guyana.

Inventory data from three eras, the FAO FIDS inventory 1968-73, the IFP 1990-94 data, and modern GFC management level inventories (MLI) from 2002 onwards are converted onto a common design basis and forest classification. For this purpose, the standard GFC vegetation types are re-grouped into simplified vegetation classes that are common to all the inventory coding systems. From this stand tables, volume tables, and biomass tables by diameter classes and vegetation classes are derived. Finally, from GIS analysis of the vegetation map, forest areas are derived and applied to the per ha biomass figures to derive total above ground biomass, and total tree biomass including roots.

It is found that Guyana's overall mean tree biomass per ha including roots is 372 t ha^{-1}, or 682 tCO_2-e ha^{-1} of sequestered CO_2. The predominant closed forest types of Guyana (lowland and hill mixed forest, Wallaba and Clump Wallaba forest) together cover 156,465 km^2, or 75% of Guyana's land area. These forests have an average woody biomass of 442 t ha^{-1} and sequestered CO_2 of 810 tCO_2-e ha^{-1}. Other forests within the broad FAO definition cover (10%+ canopy cover) include Dakama, marsh and swamp mosaics and mangroves cover a further 31,113 km^2 and have woody biomass of 234 t ha^{-1} or 429 tCO_2-e ha^{-1}. In total, closed forest accounts for 12.7 $GtCO_2$-e, and all forest and woodlands, 14.3 $GtCO_2$-e ha^{-1}, considering only tree biomass (boles, crowns and roots).

Including other estimated ecosystem components, necromass (deadwood, litter) and soil carbon, total sequestered carbon dioxide in high forest is 15.63 $GtCO_2$-e, or 998.9 tCO_2-e ha^{-1}. Including other vegetation types (savannahs, marsh, swamp, mangrove, scrub, Dakama forest), the total sequestered carbon dioxide in natural ecosystems in Guyana is 18.40 $GtCO_2$-e.

These figures revise upwards substantially estimates in the FAO *Global Forest Resource Assessment* 2005. That estimated total forest carbon as 1.72 GtC, versus 3.90 GtC in this report (trees only) or 4.26 GtC (including necromass and soil carbon). However, this analysis is consistent with other studies such as ter Steege(2001), and the FAO figure is considered to be based on confusion relative to forest and land area definitions.

Deforestation and degradation are estimated at 640 km^2 per annum, or 12.8 million tC, or 46.9 million tCO_2-e per annum. This amounts to a rate of 0.4% in terms of forest area. This is based on comparison of current high forest area (156,465 km^2) with that reported in 1963 (181,430 km^2). It is also consistent with satellite estimates from Earthtrends (2003).

In conclusion, the report summarises headline statistics in plain language: Guyana has about 16 million ha of closed high forest, which sequester 16 billion tonnes of carbon dioxide in trees, litter and soils, or about 1000 tonnes of CO_2 equivalent per hectare.

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List of Abbreviations

CI ....Conservation International
CIDA ....Canadian International Development Agency
DAB................................Diameter above buttress
DBH................................Diameter at breast height (1.3 m)
ECTF...............................Edinburgh Centre for Tropical Forestry
FCPF...............................Forest Carbon Partnership Facility
FRA ....FAO Global Forest Resource Assessment 2005
FRIU ....Forest Resources Information Unit
GEMFORM....................Guyana Empirical Model for Forest Management
GFC ....Guyana Forestry Commission
GIS..................................Geographic Information System
GLFC..............................Global Land Cover Facility, University of Maryland
GOFC-GOLD.................Global Observation of Forest Cover and Land Dynamics
IFP ....Interim Forestry Project 1990-94
IPCC...............................International Panel for Climate Change
NARI..............................National Agricultural Research Institute
NBMS/P ....National Biomass Monitoring System/Plot
POM ....Point of measurement
PSPs................................Permanent Sample Plots
REDD ....Reducing Emissions from Deforestation and Degradation
SRS ....Satellite Remote Sensing
TMF................................Tropical Moist Forest
USDA ....United States Department of Agriculture
USGS..............................United States Geological Survey
VCS.................................Voluntary Carbon Sector
WFI.................................FAO World Forest Inventory reports 1958, 1963
WWF ....World Wide Fund for Nature

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Introduction

Consultant's Terms of reference

This report is an output from the *Forest Carbon Stock Assessment Project for Guyana*, undertaken by the Guyana Forestry Commission with support from WWF and Conservation International (CI). It relates to items 1 and 2 of the consultant's terms of reference, which is stated as:

> 1. *For Guyana's main forest types and other land uses compile models for carbon sequestered in woody biomass using methodologies that are IPCC compliant and documented with coefficients and expansion factors according to IPCC Tier 1-3 sources.*
>
> 2. *From existing GFC historical inventory datasets, vegetation and land use maps, remote sensing coverage and other relevant information, compile a baseline assessment of historical carbon emissions from deforestation and degradation in Guyana from 1950 to the present, using the models from 1.*

The complete terms of reference are detailed in Annex A.

Objectives

The 13th Conference of Parties (COP) of the UN Framework Convention on Climate Change (UNFCCC), meeting at Bali in December 2007, agreed to "*the urgent need to take further meaningful action to reduce emissions from deforestation and forest degradation*". This led to the establishment of the Forest Carbon Partnership Facility (FCPF) during 2008, described as:

> *…FCPF would assist developing countries in their efforts to reduce emissions from deforestation and land degradation (REDD). It would have the dual objectives of building capacity for REDD in developing countries, and testing a program of performance-based incentive payments in some pilot countries, on a relatively small scale, in order to set the stage for a much larger system of positive incentives and financing flows in the future.*
>
> *… the Facility would help about 20 interested developing countries to arrive at a credible estimate of their national forest carbon stocks and sources of forest emissions, as well as assist the country in defining their reference scenario based on past emission rates for future emissions estimates.*

(see http://go.worldbank.org/57X9QKTON0)

The present report is a component of this process, intended to establish from currently available forest inventory, vegetation maps, and other sources, the historical and current baselines for forest carbon stocks and their rate of change prior to the implementation of any REDD policies. It is a provisional report based on currently available information. As will be noted, accurate baseline information requires a new national biomass inventory and Guyana-derived allometric functions. Specifications for this are described in an earlier report under the present project (Alder & van Kuijk, 2009).

Allometric models for volume, biomass and carbon

Definition and purpose of allometric models

Allometric models or equations relate one measurement of an organism to another. These commonly include easily measured parameters such as diameter and height related to more complex measurements such as volume, leaf area, and biomass. The purpose of the allometric function, in this context, is to simplify and make feasible large scale sampling and estimation of these complex parameters (Mountford & Bunce, 1973).

Height and diameter are the most common dependant variables. However, height is relatively difficult to measure for individual trees in tropical forests, and the most practical allometric models for tropical forestry are generally based on tree diameter alone (Alder, 1998; Williams & Schreuder, 2000) .

The traditional volume tables, tariffs and equations of forestry are examples of allometric models, although this terminology was not formerly much used in the forestry context. Volume is closely related biomass, by the equation:

$$B = \rho V \qquad \{eq.1\}$$

Where B is biomass in tonnes (t), V is volume in m^3, and ρ is average wood density, in t m^{-3} . In biomass inventories, existing volume equations or tables can be used together with wood density to estimate biomass (IPCC, 2006).

Volume equations for Guyana

Two major volume studies have been undertaken in Guyana. The first, by FAO around 1970, was part of the FIDS project, and resulted in a set of volume tables, grouped by species according to taper series (Bratt, 1971). These are still in use by GFC today in printed form, and were re-analysed graphically by Alder (2000). The second was part of the Guyana-CIDA IFP from 1990-93, and comprised measurements on 1849 felled trees from 137 species. This data set is available electronically as individual tree over and under bark upper stem measurements with defect codes on each section, although there seem to have been no published models or tables as an output from the IFP. The data was re-analysed by Alder (2000, 2001) and forms the basis of current volume calculation methods in the GEMFORM software used by GFC for forest inventory and sustained yield calculations.

Table 1 shows the size distribution of IFP sample trees by diameter and height. Figure 1 shows all 118 species sampled, with sample size and range of form factors. The common species name is that used by the IFP, together with the best attribution of genus and species that can be made retrospectively from the GFC's herbarium lists. Some names such as Silverballi, Kakaralli have many qualifying terms and may relate to many species and several genera.

Gross bole volume is the overbark volume to the highest point of measurement (usually 10 cm top diameter), including any defective sections. It is shown as V in the formulae below. This volume is the appropriate one for estimating biomass expansion factors, and is most relevant for the present study. Earlier analysis of this volume data (Alder, 2000, 2001) has focussed on net volume, defined as underbark bole volume, excluding defective log sections, and to a 30 cm top diameter. Net volume form factors and form heights have been tabulated in Alder (2000, 2001) and are used in the GEMFORM software for calculating timber volumes, allowable cuts, etc.

Form factor (f) and form height (f_h) are defined as:

$$f = k.V/(d^2h) \qquad \{eq.2\}$$

$$f_h = k.V/d^2 \qquad \{eq.3\}$$

In these equations, d is tree dbh in cm, h is bole height in m, V is volume in m^3, and k is the constant 0.00007854, derived from (¼ π/10000).

Neither of these relationships is important to the present issue of biomass allometry, except that they provide a basis for efficient practical volume models. Form factor is however a useful indicator of the taper group of a species. Species with higher form factor will be more cylindrical in form, whilst those with lower values will be more strongly tapered.

Table 1 : Number and size distribution of IFP volume trees

	Bole height class (m)								
Diameter class (cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	Total
10-19	1	5	2						8
20-29		8	72	53	4				137
30-39		3	97	201	61	4			366
40-49		5	79	275	146	18	2		525
50-59			33	162	162	37	3		397
60-69			11	66	93	46	6		222
70-79			8	19	50	32	6	1	116
80-89			1	5	11	15	8		40
90-99			1	3	4	11	5	2	26
100-109						5	5		10
110-119						1			1
120-129									
130-139							1		1
Total	1	21	304	784	531	169	36	3	1849

Figure 1 overleaf shows the sample distribution graphically for all species covered in the IFP study. It also shows the sample standard deviation of form factors for each species. Figure 2 shows all the volume data as a graph of volume versus tree dbh (or diameter above buttress, dab). The species which were most commonly sampled are shown individually. These include 212 trees of Greenheart (*Chlorocardium rodiei*), 109 Baromalli (*Catostemma spp*.), 108 Wallaba (*Eperua spp*), 105 Kakaralli (*Eschweilera spp*) , 63 Morabukea (*Mora spp*), 59 Haiariballi (*Alexa spp*). These 6 species comprised 35% of the sample, the remainder being distributed over 112 locally-named species.

Figure 1 : IFP volume sample form factors and sample size by species

Error bars are the standard deviation of each species sample. Species names are those used by IFP

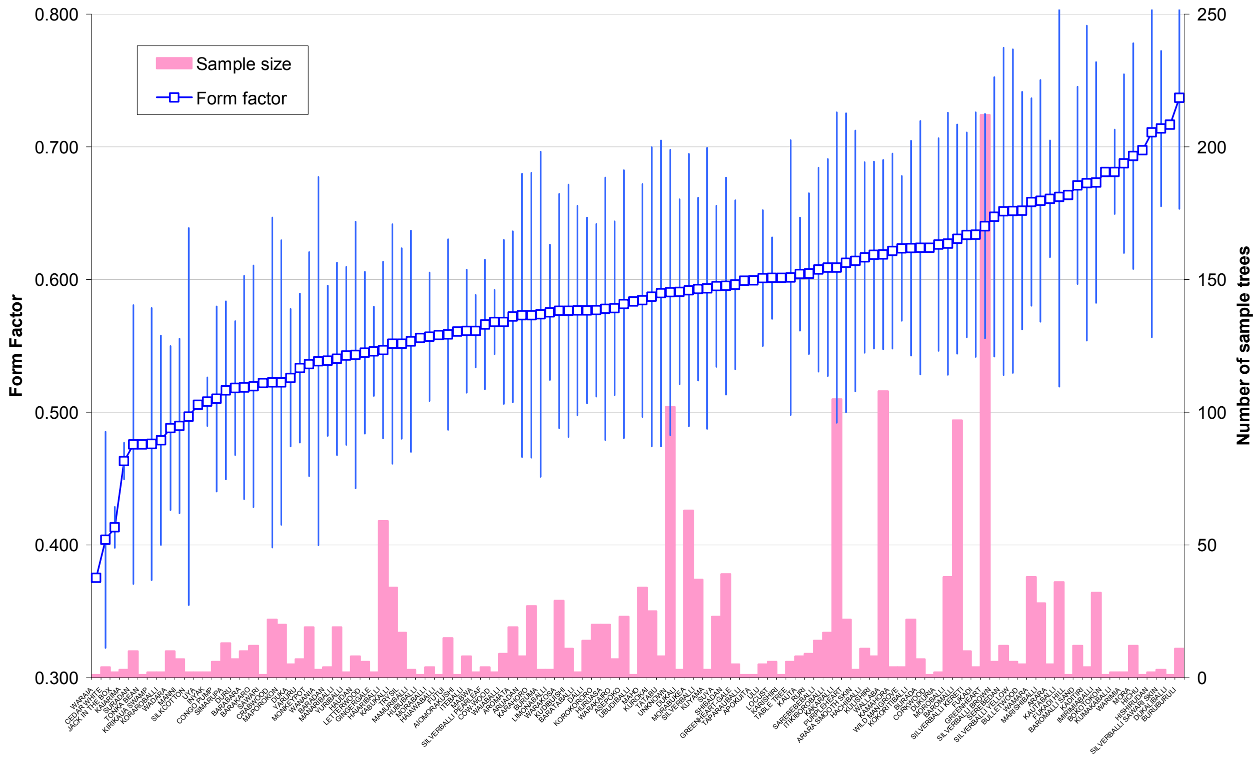
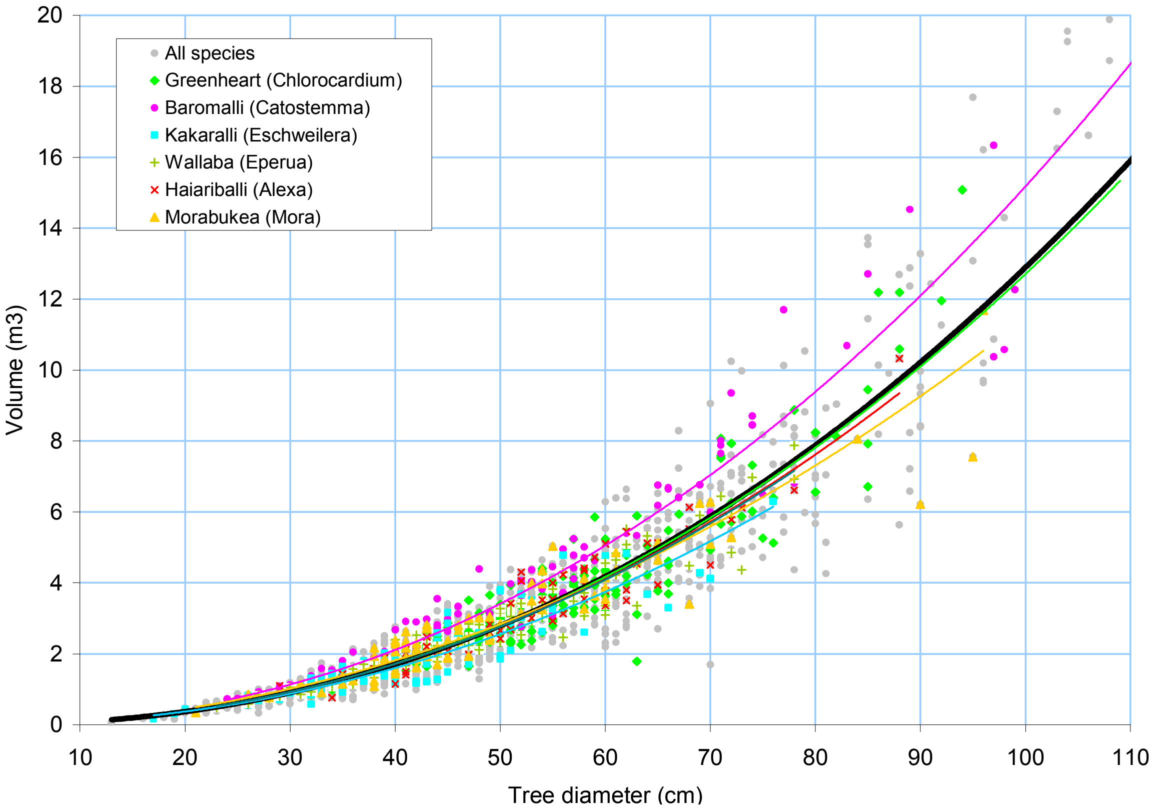


Figure 2 : IFP volume data and general volume equation

The general equation is ln(V) = -7.600 + 2.206 ln(D) , with R2 0.92 and 1849 sample trees.



In Figure 2, the regression lines for volume on diameter are shown for the six individually sampled species, and also the general regression for gross overbark volume on diameter for all 1849 sample trees, as a solid black line. The equation for this line is

$$\ln V = -7.60027 + 2.2055 \ln(D) \qquad \{eq.4\}$$

This fitted with an R^2 of 92% to 1849 data points. Transforming this to an unbiased volume equation requires Meyer's (1944) correction (Alder, 1980). The regression standard deviation σ_y for this equation was 0.202584, giving a correction of $\exp(\sigma_y^2/2)$ or 1.0207. This gives a final corrected equation for gross overbark volume to a 10 cm top diameter of

$$V = 0.0005107\ D^{2.2055} \qquad \{eq.5\}$$

This general gross volume equation (eq.5) can used as the basis, together with the appropriate biomass expansion factors and wood density estimates discussed below, for forest biomass estimates. In this report, the equation is used to validate the local accuracy of pan-tropical equations for above ground biomass.

Above-ground biomass expansion factors and equations

As noted in equation {1}, volume can be converted to biomass if wood density is known. Wood densities for 16,468 timber species have been tabulated by Zanne *et al* (2009). This database is used in this report to convert inventory volumes to biomass in tonnes/ha (t ha^{-1}).

Brown (1997, §3.1.3) suggests that in the absence of better information, bole volume estimates overbark to a 10 cm top can be converted to above-ground biomass via a biomass expansion factor from the empirical equation:

$$\left.\begin{array}{ll} f = exp(3.213 - 0.506 \ln(B)) & \text{for } B<170 \text{ t ha}^{-1} \\ f = 1.74 & \text{for } B\geq 170 \text{ t ha}^{-1} \\ B_a = f.B & \end{array}\right\} \qquad \{eq.6\}$$

where B is bole biomass per ha (derived from equation {1} applied using individual species or regional average wood densities), and B_a is the total above-ground biomass. This procedures is likely to be problematic at low biomass stockings – below 100 t ha^{-1} , the expansion factor rises rapidly above 2.5 to probably unrealistic values. However, Brown's procedure is an IPCC (2006) Tier 1 method, and therefore provides acceptable estimates in the absence of other information.

ter Steege (2001) derived estimates of average biomass stockings in Guyana using the equation of Lescure *et al* (1983) for French Guyana. This relates tree above ground biomass W (in kg) to diameter D (in cm) as:

$$W = 0.05653\ D^{2.7248} \qquad \{eq.7\}$$

No information on wood density or bole volume is required and its applicability in Guyana is therefore based on the assumption of a similar species composition and tree form to French Guyana.

Another applicable equation is that proposed by Chave *et al* (2005). They examine world wide datasets with 2410 trees from 27 study sites across the tropics, including Lescure's data from French Guyana, and studies from Pará, Amazonia near Manaus, and Rondonia in Brazil which may be considered regionally applicable to Guyana. They find that differences in the biomass equations between study sites are small once wood density variation is accounted for, and the major significant factor is broad forest type. They produce four sets of equations for dry, moist, wet and mangrove forests.

The general equation of Chave et al (2005) is in the form:

$$W = \rho.exp(\beta_0 + \beta_1.ln(D) + \beta_2.ln(D)^2 + \beta_3.ln(D)^3) \qquad \{eq.8\}$$

where as before, W is tree above ground biomass in kg, ρ is wood specific gravity, D is tree diameter at dbh in cm, and the β_i are coefficients which depend on forest type, as tabulated in Table 2 below. Note that the β_2 and β_3 coefficients are common across forest types, and β_1 is the same for mangrove and wet forest.

Table 2 : Pan-tropical biomass equation coefficients for major forest types
(from Chave *et al*, 2005)

<table>
<tr><th colspan="2">Tropical forest type</th><th>β_0</th><th>β_1</th><th>β_2</th><th>β_3</th></tr>
<tr><td>Dry</td><td>Over 5 months dry season, with marked water stress, rainfall below 1500 mm yr^{-1}, may be semi-deciduous</td><td>-0.667</td><td>1.784</td><td rowspan="4">0.207</td><td rowspan="4">-0.0281</td></tr>
<tr><td>Moist</td><td>Marked dry season 1-4 months, rainfall 1500–3500 mm yr^{-1}</td><td>-1.499</td><td>2.148</td></tr>
<tr><td>Wet</td><td>High rainfall ($\geq$3500 mm yr^{-1}) lowland forests, no significant dry season</td><td>-1.349</td><td rowspan="2">1.980</td></tr>
<tr><td>Mangrove</td><td>Coastal forests dominated by mangrove species</td><td>-1.239</td></tr>
</table>

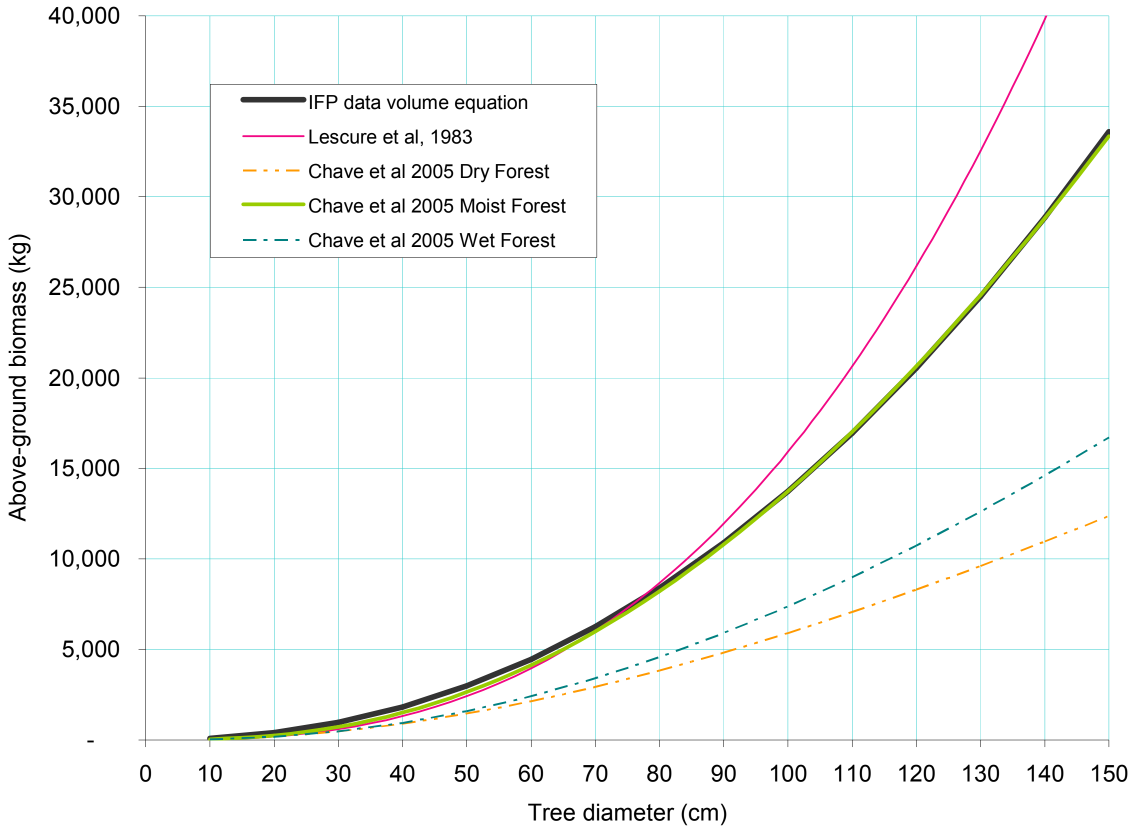
These various tree volume and biomass equations { 5, 7 and 8} can be compared graphically using some assumptions for average wood density and biomass expansion factor, and are shown in Figure 3. Wood density is assumed to be 0.60 (tropical American mean, Brown, 1997, §3.1.2), and expansion factor 1.74 (eqn. 6).

It is notable on figure 3 that biomass estimates derived from volume equation {5} combined with Brown's (1997) Tier 1 wood density and expansion factor estimates agree almost precisely with Chave et al's (2005) pan-tropical tree biomass equation for tropical moist forest.

Lescure et al's (1983) equation performs similarly over the main range of stand table data (10-100 cm) but appears to give rather high estimates for the largest trees.

Figure 3 : Comparison of tree biomass equations

Bole volume (IFP equation) converted to biomass with density 0.6 and expansion factor 1.74. Chave et al equations using wood density 0.6. See text equations {5}-{8} for details.



The dry and wet tropical forest types in Chave *et al*'s models show much lower biomass for a given diameter than the other equations. This is no doubt due to differences in average tree height on these less productive forest types. This emphasises the importance of correct forest classification especially relative to average height.

Tree root biomass

Table 3 : Root:Shoot ratios
after ter Steege (2001)

Forest type	R:S ratio
Mixed forest	0.220
Wallaba forest	0.487
Dakama Forest	0.703
Muri scrub	1.725
Other types	0.220

Below ground tree biomass is usually calculated or expressed as a root:shoot (R:S) ratio relative to above ground biomass. This method is implicit in IPCC (2006) equations for forest biomass calculation. Brown (1997) gives R:S ratios for lowland moist tropical forests from 0.04 to 0.33, with a mean of 0.12. ter Steege (2001) reviews various studies from adjoining regions (Surinam, Brazilian Amazon) which give much higher typical values (from 0.25 to 0.63). Higher R:S ratios are found in drier forests and poorer soils, where trees of small stature are associated with large underground root systems searching for nutrients or moisture. ter Steege (2001) adopted data from Venezuelan studies on similar forest types for R:S ratios on Wallaba forest (0.487), Dakama forest (0.703) and Muri scrub (1.725). For all other moist forests, he used an R:S ratio of 0.22 (see Table 3). In the further analysis in this report, a general R:S ratio of 0.22 is used. Using higher ratios in Wallaba, Dakama and scrub is based on limited data, and rather over-emphasises a very uncertain biomass component. For this reason a standard ratio is preferred. The studies proposed in Alder & van Kuijk (2009) may in future provide new data which will enable locally derived ratios to be derived and applied with known statistical confidence.

Necromass and soil organic matter

ter Steege (2001) reviews available information on necromass (dead wood and litter) and soil organic matter. Necromass data is limited to some studies in adjacent countries, including Brazil, Surinam, French Guyana and Venezuela. He cites values ranging from 11.8 to 34.8 t ha^{-1}, with a mean of 27 t ha^{-1}. This is applied in Table 14 (see page 24) as an expansion factor of 8.6% relative to tree biomass.

Table 4 : Soil Organic Matter
to 1 m depth, after ter Steege (2001)

Soil type	t ha^{-1}
Brown sand	65
Clay	167
Laterite	136
Loam	65
Pegasse	490
White sand	43

For soil organic matter, estimates of totals can be derived from soil bulk density and soil organic matter %, and are available from soil surveys and research studies in Guyana. These are reviewed and summarised by ter Steege (2001, Table 7) by soil types, and are reproduced in Table 4 opposite down to 1 m depth. ter Steege (2001) also notes that organic matter may be present at significant concentrations down to 8 m depth, but information on this is too limited to be reliably included in the present analysis. Somewhat conservative figures based on these estimates are used in Table 14 (p.24), with forest soils assumed at 65 t ha^{-1}, swamps and marshy areas at 167 t ha^{-1}, and scrub, savannah and Dakama formations as 43 t ha^{-1}.

Ongoing tree allometry and biomass studies in Guyana

The present project includes pilot studies for tree crown and root allometry, and for the capture of understorey biomass, necromass and soil organic matter (Alder & van Kuijk, 2009). The Guyana RPLAN (GFC, 2009) will among other things scale these pilot studies up to a national scale, and allow the current estimates and models to be updated with more accurate, up-to-date and locally derived IPCC Tier 3 estimates (*op. cit.* Component 8). However, it is likely to be 3-5 years before these activities produce definitive results, assuming REDD funding on some scale is approved for Guyana.

Biomass, Carbon and CO_2-equivalent ratios

The above models are directed at calculating biomass, in t ha^{-1}. For carbon accounting purposes, estimates need to be expressed either in terms of tonnes carbon per ha, tC ha^{-1} or tonnes of carbon dioxide-equivalent per ha, tCO_2-e ha^{-1}. IPCC (2006) recommends a conversion factor of 0.5 for biomass to carbon. For CO_2-equivalent, tonnes of carbon are multiplied by the ratio 44/12, which is the ratio of their atomic weights.

Summary of allometric models adopted

For tree volume volume overbark to 10 cm top, equation {5} will be used, based on the IFP tree volume studies conducted in Guyana 1990-92 (1849 felled samples). For biomass, published wood densities from Zanne et al (2009) are applied with the pantropical biomass equations of Chave et al (2005), shown in equation {8} and Table 2. For root biomass a general root:shoot ratio of 22% is applied. Necromass is calculated via an expansion factor of 8.6% applied to tree biomass. For soil carbon, conservative estimates from ter Steege (2001) are applied by vegetation class, being 65 t ha^{-1} for lowland, hill and Wallaba forest, 167 t ha^{-1} for swamps and marshy areas, and 43 t ha-1 for scrub, savannah and Dakama formations. In terms of IPCC Tiers (IPCC, 2006), bole biomass are Tier 3, and the other components are Tier 2.

Forest Volumes and Carbon Stocks

Forest areas

A recent vegetation map of Guyana (ter Steege, 2001b) is shown in Figure 4. Table 5 shows the related key to forest types and forest and other land use areas. These areas are calculated from the GIS shape file used in the map. The map itself was developed by ter Steege from a variety of sources including satellite imagery, soil maps, research plots and forest inventory plots.

Figure 4 : Vegetation map of Guyana *(after ter Steege, 2001b)*

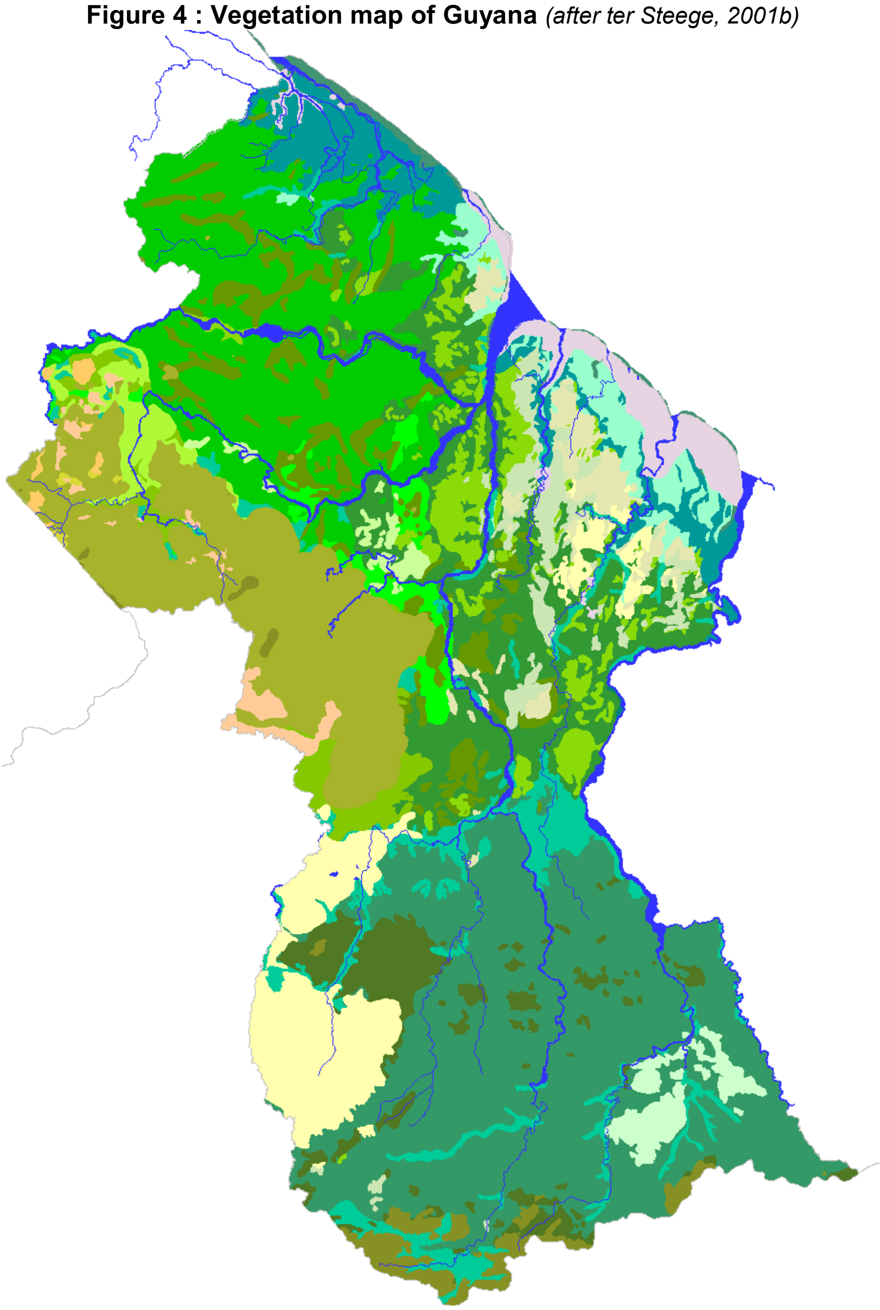


Table 5 : Vegetation type areas and key to map (Fig. 4)

Code	Vegetation Types	Map	Area (km^2)
1.1	Mixed forest Central/NE Guyana		20,858
1.2	Mixed forest NW Distict		28,393
1.3	Mixed Forest Pakaraimas		3,233
1.4	Mixed Forest South Guyana		47,789
1.5	Mixed Forest on steep hills		7,817
1.6	Mixed Forest on steep hills Pakaraimas		3,339
1.7	Mixed Forest on steep hills South Guyana		6,922
1.8	Mixed Forest/Swamp complex		2,513
2.1	Clump Wallaba Forest		1,016
2.2	Clump Wallaba/Wallaba Forest		2,522
2.3	Wallaba Forest		7,329
2.4	White Sand Forest South Guyana		136
2.5	Dakama Forest		4,234
2.6	Muri scrub/white sand savannah		3,810
3.1	Open Swamp		4,604
3.2	Marsh Forest		9,891
3.3	Coastal Swamp Forest		7,865
3.4	Forested Islands in Rivers		765
4.1	Mangrove Forest		1,262
5.1	Lowland grass/shrub savannah		11,287
6.1	Upland scleromorphic scrub		525
6.2	Upland grass/shrub savannah		1,940
6.3	Broadleaf upland meadow		196
7.1	Submontaine Forest Pakaraimas		23,549
7.2	Montaine Forest Pakaraimas		275
8.1	Submontaine Forest Southern Guyana		3,090
9.0	Clearings, cultivated land, large mines		4,687
	Rivers, lakes, streams		5,123
TOTAL			214,970

Much of this land area is allocated to State Forest, Amerindian areas, or other types of protected area reserves, as shown in Figure 5. The areas of forest types within state forest are as shown in Table 6 (GFC, 2008). Of the total State Forest area of 114,369 km², 60% is allocated to long or short term logging permissions of various categories. The remainder will be allocated in coming years as requirements and accessibility permit. The unallocated areas are mainly in the south of the country, as shown in Figure 5.

These are considerable areas of forest. The total land area of Guyana is similar to that of Great Britain, whilst the *forested* area alone is greater than the *total* land area of England, double the land area of Austria or Ireland, and three times that of Denmark, Netherlands or Belgium.

Table 6 vegetation type areas in state forest

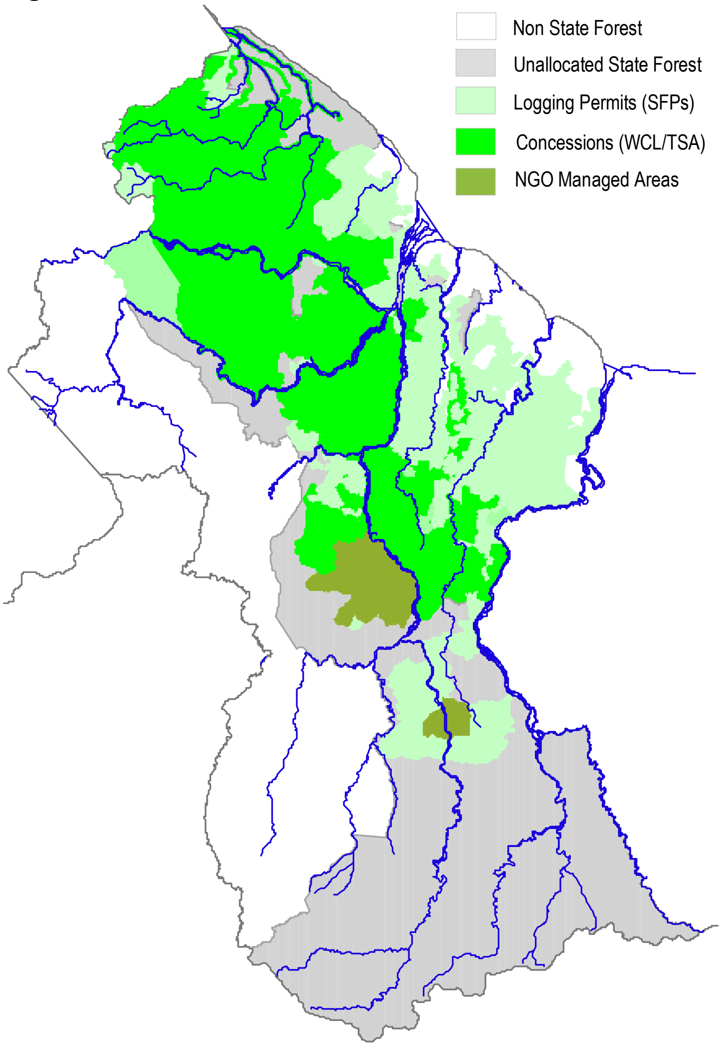
Vegetation types	km2
1.1 Mixed Forest Central / NE Guyana	20,507
1.2 Mixed Forest NW District	27,718
1.3 Mixed Forest Pakaraimas	3,094
1.4 Forest on basic rocks in Pakaraimas	43,332
1.5 Mixed Forest South Guyana	7,812
1.6 Mixed Forest on Laterite Hills	1,095
1.7 Forest on Laterite in Pakaraimas	2,576
2.1 Clump Wallaba Forest	1,014
2.2 Wallaba Forest	225
2.3 White Sand Forest South Guyana	6,971
2.4 White Sand Forest South Guyana	106
2.5 Dakama Forest	3,012
2.6 Muri Scrub/White Sand Savannah	1,550
3.1 Open Swamp	919
3.2 Open Coastal Swamp	7,790
3.3 Marsh Forest	6,326
4.1 Mangrove Forest	584
5.1 Savannah	1,136
7.1 Submontane Forest Pakaraimas	5,606
8.2 Montane Forest South Guyana	2,996
TOTAL	144,369

Other, independent estimates of forest area are provided by EarthTrends (2003). Using MODIS imagery, they estimate the areas for different categories of forest shown in Table 7 below.

Table 7 : MODIS forest area estimates
from Earthtrends (2003)

Canopy cover %	Area (km^2)	Area %
Below 25%	23,660	11.0%
25%-49%	12,030	5.6%
50%-74%	13,770	6.4%
over 75%	165,510	77.0%
Guyana total	214,970	100%

Figure 5 State Forest allocated and non-allocated areas



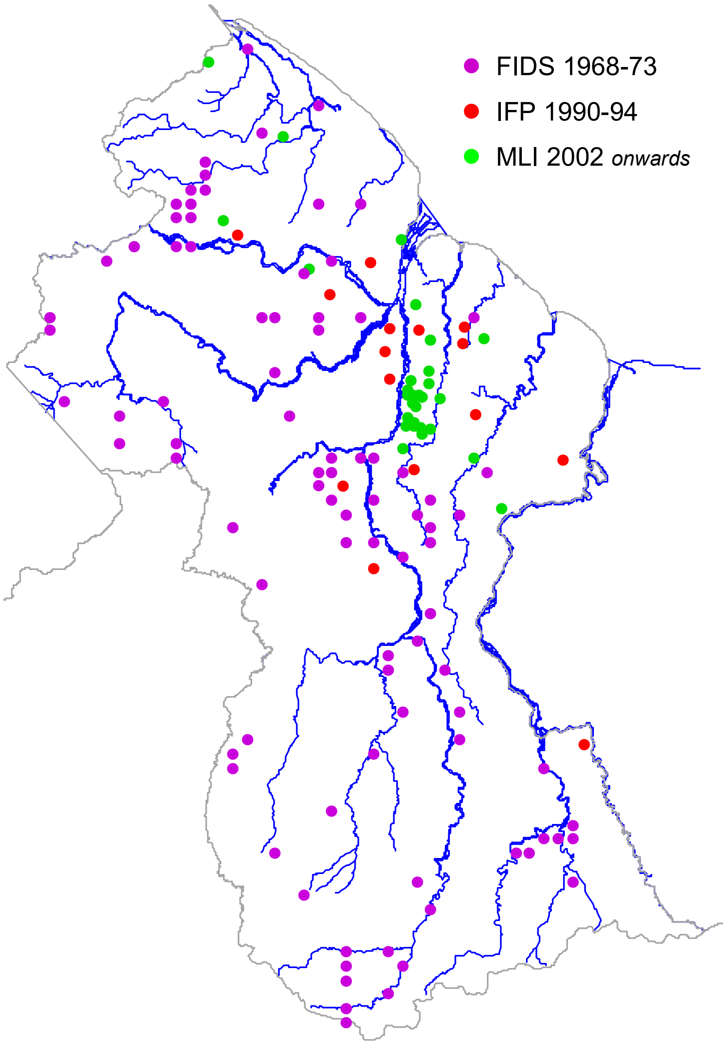
It will be noted that the MODIS classification is based on a global algorithm that will not be absolutely accurate, especially for lower cover classes. Scrub such as Muri may also be classified by the algorithm as forest on account of its canopy density and depth, although it would not be classified as such in Guyana (GLCF, 2002).

Forest inventories

Wright (1999) has reviewed forest inventories done in Guyana since the 1950's. There were four main phases. Prior to 1965 the colonial administration had undertaken numerous line surveys for individual concessions and permits, but there was no overall estimate of forest growing stock. Following independence, from 1966 to 1975, the FAO-supported Forest Industry Development Survey (FIDS) was undertaken as a national inventory, with most field work from 1969-73. There was then a hiatus with only limited inventory activity, until the CIDA-financed Interim Forestry Project (IFP), from 1990-95, which produced a second comprehensive survey. Thereafter the Guyana Forestry Commission developed its own stronger inventory capacity with support from Tropenbos (Netherlands) and the UK DFID. From 2002 regular management level inventories (MLI) have been undertaken on all new logging areas allocated, and processed through GEMFORM (Alder, 2000, 2001, 2008). ter Steege (*pers. comm.*, 2001) converted the old IFP and FIDS data files into Access databases, and used them as a resource for biomass studies and the Guyana vegetation map (ter Steege, 2001, 2001b).

For the present study, the FIDS, IFP and recent MLI inventories have been combined into a single database to give a national assessment of forest growing stock. Of course, the inventories cover different time periods (FIDS 1968-73, IFP 1990-94, MLI 2002 onwards). They also have rather different national coverage, as shown in Figure 6. The locations shown are estimated from place names and descriptions for the IFP and FIDS data, as georeferences were not recorded. For MLI data, they show the centroids of inventoried areas.

Figure 7 Inventory zones for FIDS, IFP and MLI surveys



The FIDS was the most comprehensive national inventory, although it suffered in modern terms for several shortcomings, mainly relating to the limited technology of the era. The IFP did not sample the southern part of the country, and used a slightly eccentric design, with angle count plots with high BAF factors, so that typically only 3-4 trees were sampled on many plots. However, the data appears robust and valid because of the very large number of plots used. The MLI survey is concentrated in new production areas, and as such does not have national coverage (it is not designed to be a national inventory).

Table 9 Areas of vegetation classes and distribution of inventory plots

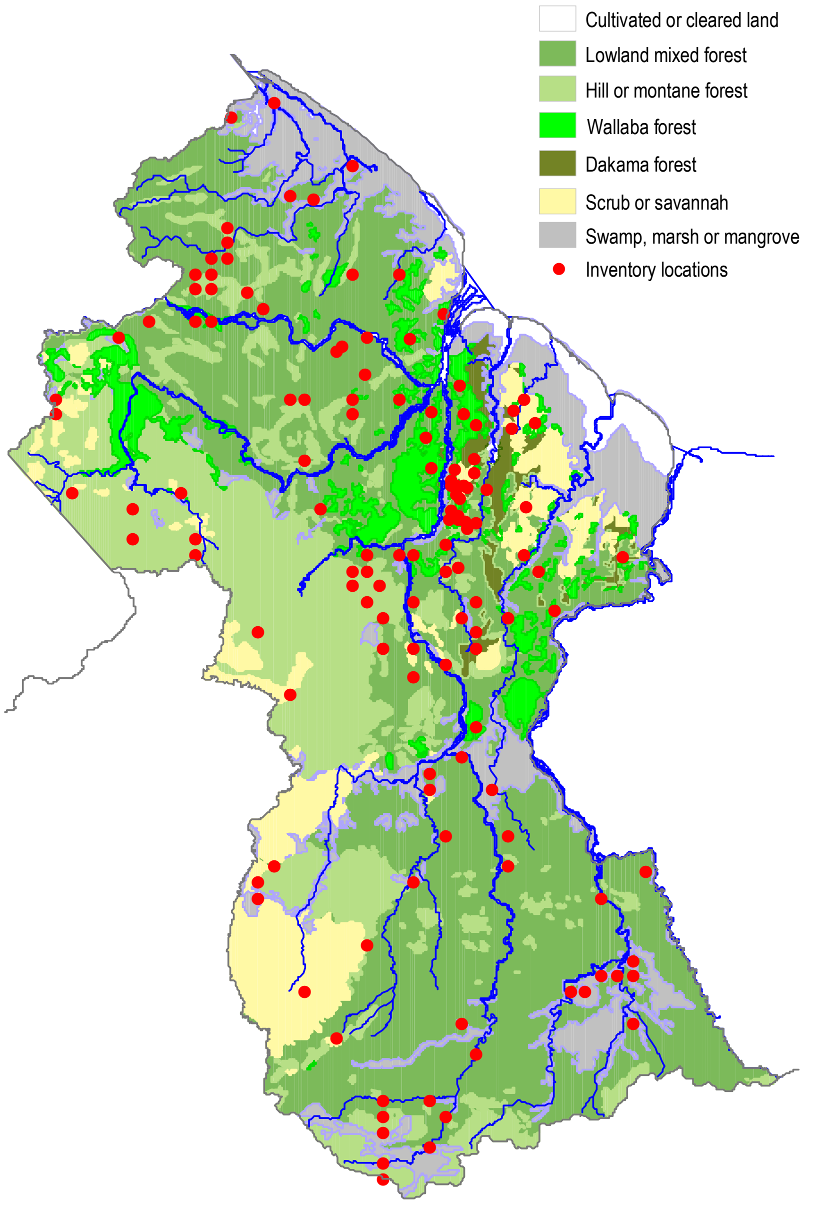
Vegetation Class	Area km^2	Inventory Plots FIDS	IFP	MLI
Cultivated/urban/cleared	4,687			
Lowland Mixed Forest	100,408	548	5169	2294
Hill/Montane Forest	45,190	241		145
Wallaba Forest	10,867	12	1506	233
Dakama Forest	4,234		576	154
Scrub or Savannah	17,562	5	40	13
Swamp/Marsh Forest	26,899	48	407	55
Total	**209,848**	**854**	**7698**	**2894**
Waterways, open water	5,122			
Guyana total area	**214,970**			
Sample area, ha		*171*	*123*	*289*

Plots were stratified according to the vegetation types used in the different inventories into broad classes. Figure 8 shows merged vegetation types which can be identified from the forest type and plot codes given in the various forest inventories. Theoretically, it should be possible to intersect the vegetation map and plot locations to stratify plots. However, given the positional approximations in both data sets, it is better to use actual forest types recorded on the inventories. Table 9 shows the areas of merged forest types (referred to hereafter as vegetation classes) and the number of sample plots attributable to each of them from each of the inventories.

In comparing inventory plot numbers it will be noted that FIDS plots were mostly 0.2 ha clusters of 5 × 0.04 ha sub plots. IFP plots were point samples with an average BAF of 6 m²/ha, giving an area equivalent to 0.016 ha for a 35 cm dbh tree, whilst the MLI plots are 0.1 ha for trees 35 cm and above. The bottom line of the table shows the total sample areas of all the inventories, with the MLI being the most intensive, and the IFP, in spite of the large number of plots, being the least.

It will be noted that few plots are in scrub or savannah areas. Provisional data will be presented for these areas, but further sampling is required for more accurate estimates.

Figure 8 Simplified vegetation classes and inventory areas



For swamp and marsh forest the samples are also very restricted, and do not include any mangrove.

Stand tables of stem numbers and bole volume

Table 10 shows the stand tables of stem numbers by diameter classes compiled for each vegetation class and inventory. It will be noted that for the FIDS inventory, the smallest tree tallied was 12" (30.48 cm), hence there is no data in the 10-19 and 20-29 cm diameter classes. Figure 9 compares the weighted mean stand table for all vegetation classes for each inventory, and the overall weighted mean stand table. Weighting is by sample size for each locality.

Table 10 Stand tables of trees/ha by diameter classes for each inventory and vegetation class

Means for all classes are weighted by number of plots – see Table 9

Inventory/Veg. Class	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110+
FIDS 1968-73											
Lowland Mixed Forest			42.2	19.7	12.0	7.1	2.7	0.9	0.5	0.3	0.3
Hill or Montane Forest			45.2	20.5	10.8	5.1	1.8	1.2	0.6	0.4	1.8
Wallaba Forest			63.7	28.6	17.7	4.8	1.1				
Swamp/Marsh			30.7	16.8	11.0	7.2	2.2	1.5	0.4	0.8	0.3
Mean FIDS			42.4	19.8	11.6	6.5	2.4	1.0	0.5	0.4	0.7
IFP 1990-94											
Lowland Mixed Forest	266.4	107.2	49.1	23.3	10.6	6.1	3.1	1.9	0.9	0.5	0.7
Wallaba Forest	300.9	126.0	61.8	35.3	18.9	8.0	4.0	1.9	0.8	0.4	0.4
Swamp/Marsh	192.4	82.3	39.4	21.8	10.1	5.6	2.4	1.8	1.4	0.6	0.7
Dakama Forest	622.4	157.2	37.8	10.6	4.0	1.4	0.5	0.1	0.1	0.0	0.0
Scrub or Savannah	297.6	47.8	13.7	3.9	2.3	0.5		0.3			
Mean IFP	299.2	111.4	48.4	23.6	11.2	5.8	2.9	1.7	0.8	0.4	0.5
MLI 2002-2008											
Lowland Mixed Forest	191.6	87.2	43.1	18.6	10.2	5.5	2.7	1.6	0.9	0.4	0.4
Hill or Montane Forest	210.7	59.0	44.8	18.7	9.3	5.3	1.4	1.2	0.5	0.7	0.3
Wallaba Forest	198.3	75.1	51.2	23.9	12.5	6.6	2.2	0.9	0.4	0.3	0.0
Swamp/Marsh	222.7	86.4	45.6	13.5	5.8	2.7	0.5	0.2	0.2		
Dakama Forest	285.7	108.1	31.5	4.2	1.8	0.3		0.1		0.1	
Scrub or Savannah	119.2	42.3	34.6	8.5	0.8	0.8					
Mean MLI	198.3	85.7	43.2	18.1	9.8	5.2	2.4	1.4	0.8	0.4	0.3
Mean, all inventories	252.5	97.0	46.7	22.0	10.9	5.7	2.8	1.6	0.8	0.4	0.5

Figure 9 Mean stand tables for three inventories compared

The y-axis is logarithmic, typically giving a linear trend (as here) to natural stands of mixed-age forest

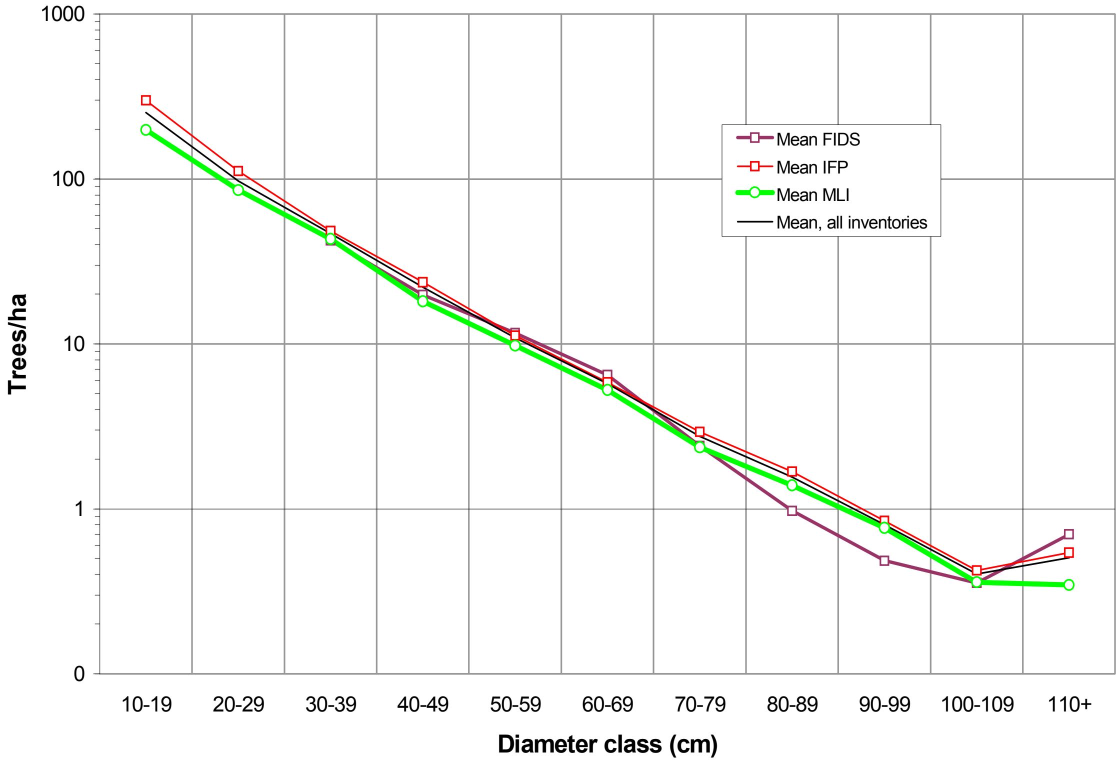
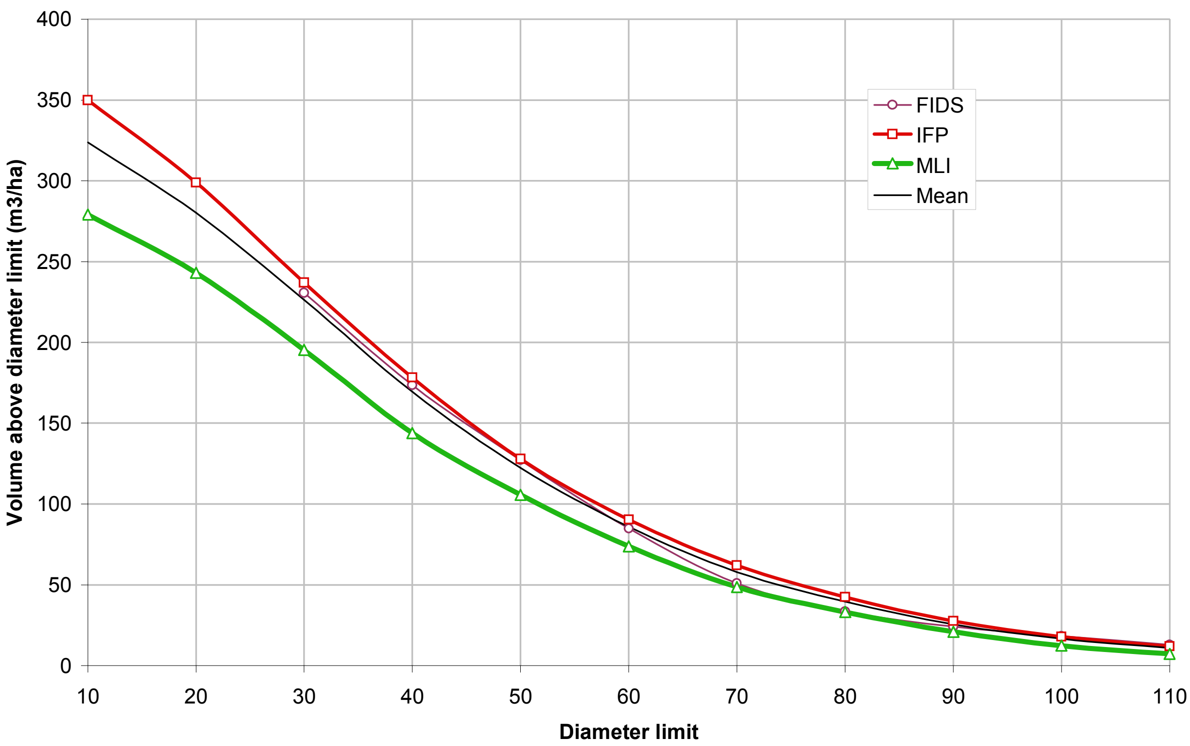


Table 11 Stand tables of trees/ha by diameter classes for each inventory and vegetation class

	Volume (in m3, to 10 cm top, overbark, gross) per ha by 10 cm classes and totals above 10 and 30 cm											
Inventory/Veg. Class	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110+	10+	30+
FIDS 1968-73													
Lowland Mixed Forest			56.7	46.1	43.9	37.4	19.7	8.3	5.6	4.8	5.3		227.6
Hill or Montane Forest			60.8	48.0	39.2	26.8	13.2	11.1	7.2	5.9	33.1		245.4
Wallaba Forest			85.7	66.9	64.6	25.3	7.9						250.4
Swamp/Marsh			41.2	39.4	40.0	38.1	15.8	14.7	4.7	11.7	4.8		210.4
Mean FIDS			57.1	46.3	42.4	34.1	17.3	9.3	5.9	5.4	13.0		230.6
IFP 1990-94													0.0
Lowland Mixed Forest	45.3	59.3	59.6	49.7	35.3	29.5	20.9	16.7	10.8	6.8	14.6	348.4	243.8
Wallaba Forest	52.2	71.7	75.9	75.7	63.3	39.0	26.8	16.9	9.4	5.6	9.0	445.5	321.6
Swamp/Marsh	32.0	47.9	47.1	46.1	32.7	27.4	16.0	15.9	15.6	9.2	16.0	306.0	226.1
Dakama Forest	103.9	85.6	44.5	22.7	13.5	7.1	3.6	1.2	0.7	0.5	0.6	284.0	94.4
Scrub or Savannah	46.9	24.2	18.3	8.5	9.0	2.3		2.4				111.6	40.5
Mean IFP	50.9	61.9	58.7	50.5	37.4	28.3	19.6	14.9	9.6	6.0	12.0	349.9	237.1
MLI 2002-2008													0.0
Lowland Mixed Forest	34.9	48.7	51.5	39.1	33.4	26.5	17.5	13.8	10.0	5.4	8.7	289.4	205.9
Hill or Montane Forest	37.9	31.7	53.9	39.4	30.0	25.3	9.2	11.1	5.5	9.8	5.5	259.1	189.5
Wallaba Forest	36.4	41.5	61.1	51.4	41.1	30.9	14.5	8.1	4.5	3.7	0.8	293.9	216.0
Swamp/Marsh	40.5	46.6	51.2	27.6	18.5	12.9	3.4	1.5	1.9			204.1	117.0
Dakama Forest	52.8	58.0	35.0	8.5	5.5	1.5		0.5		0.9		162.7	51.9
Scrub or Savannah	26.7	27.3	41.3	16.9	2.4	3.3						117.9	63.9
Mean MLI	36.2	47.6	51.5	38.2	31.9	25.1	15.5	12.2	8.6	5.1	7.3	279.1	195.4
Mean, all inventories	43.6	53.9	56.8	47.1	36.4	28.0	18.4	13.8	9.1	5.7	10.9		226.3

Figure 10 Volumes above diameter limits for the three inventories



Because the lowland mixed forest has the greatest number of plots (see Table 9), the mean values are close to those for this vegetation class. Figure 9 is plotted on semi-logarithmic axes. For mixed-age forest, this tends to give a straight line diameter distribution, as can be seen from the chart. This is useful in that it allows the missing FIDS data for the smaller classes to be interpolated. It is also important for biomass estimation because stem numbers in the 0-10 cm class were not sampled on any of the inventories, and need to be estimated to get total tree biomass.

Also notable on Figure 9 is the consistency of the inventories. They show very similar overall distributions. The FIDS data is somewhat deficient for the largest trees. This may reflect the fact that the hill or montane forest is mainly sampled in the FIDS data, and tends to have fewer large trees. However, it is also true for the lowland mixed forest in the FIDS data, and again may reflect a higher sampling intensity in the southern forests. A further, though somewhat unlikely possibility, is that the 1970's measurements were at a pre-equilibrium stage in forest structure, and there has been net growth into the largest classes since then.

It will also be noted that tree numbers are significantly lower on the MLI inventories than the other two for trees up to 80 cm. The difference appears small on the logarithmic scale, with trees numbers being around 10% less. Again there may be several reasons. Most of the MLI plots are concentrated in the Demerara Division, on white and brown sand mosaic soils. These are poorer that the laterite and clay soils found in the south and north west. Also this division has borne the brunt of past exploitation, and the lower stem number son this most recent inventory may indicate forest degradation. This is a key possibility and is discussed more fully in the next chapter.

Table 11 shows volumes. These are relatively low for tropical high forest. The Wallaba forest has the highest average volumes on all inventories, but probably is not significantly different from the mixed lowland forest. For trees 30 cm and above, the FIDS and IFP inventories, using different techniques and some 20 years apart, give very similar results, 230 m3/ha and 237 m3/ha respectively. The MLI inventory shows significantly lower volumes, of 195 m3/ha. This is associated with the lower overall stockings on this most recent inventory.

It would be possible to interpolate smaller size class volumes for the FIDS dataset, using the regular diameter distribution model noted previously, but this is not done here as volume is not particularly germane to the purpose of this report. In the next section, on biomass, a full interpolation of small size classes and comparison of total biomass results are discussed. For the IFP inventory, volume above 10 cm dbh is 350 m3/ha, whilst for the MLI data, it is 279 m3/ha. These are in the range of 300 m3/ha+ that would be typical of tropical high forest, but the MLI results are a little low, and do tend to strengthen the impression that significant degradation may be occurring.

Biomass and carbon stocks

For biomass calculation, the equations of Chave *et al* (2005) were applied (see equation {8} and Table 2 on page 10) on a tree by tree basis. Swamp and marsh forest used the WET forest type equation, whilst savannah and scrub formations use the DRY type. Other types, which are the majority of data, use the MOIST coefficients. Wood densities are derived species by species from the database of Zanne *et al* (2009). These were available for 134 Guyanese species, including all common forest trees, and mostly originate from the studies on wood density of Fanshawe (1961) and Gérard *et al* (1996). For the remainder, a weighted average wood density of 0.71 was calculated and applied as a default value. It will be noted that this average wood density is higher than the average for South America of 0.6 suggested by Brown (1997), or the value indicated by ter Steege (2001) of 0.66. However, to the author's knowledge, it is the first time that a sample-weighted wood density has been calculated for Guyana based on such comprehensive inventory, volume and species wood density data, and must be regarded as a more reliable average figure. Table 12 shows the biomass values calculated for all the inventories and vegetation classes by size class.

Table 12 Biomass estimates by size class for the FIDS, IFP and MLI inventories

Interpolated figures are shown in blue italic

	Above-ground tree biomass in tonnes/ha by 10 cm classes												
Inventory/Veg. Class	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110+	Total
FIDS 1968-73													
Lowland Mixed Forest	*20.0*	*31.4*	*48.7*	57.4	50.3	51.5	46.3	25.0	10.4	7.4	5.8	6.7	360.9
Hill or Montane Forest	*21.2*	*33.3*	*51.7*	59.1	51.4	45.0	32.3	16.0	14.4	9.2	8.0	41.1	382.7
Wallaba Forest	*19.5*	*30.5*	*47.4*	78.5	67.9	70.9	26.1	10.2					350.9
Swamp/Marsh	*11.2*	*17.5*	*27.2*	25.1	25.2	27.5	28.4	11.9	11.1	3.8	9.1	3.6	201.5
Mean FIDS	*19.7*	*30.9*	*48.0*	56.0	49.1	48.3	40.8	21.4	11.4	7.6	6.5	16.1	355.8
IFP 1990-94													
Lowland Mixed Forest	*20.4*	31.0	50.5	58.7	54.2	41.2	36.8	26.8	22.4	14.5	9.3	20.1	385.9
Wallaba Forest	*24.0*	35.0	60.9	74.4	81.6	73.4	47.1	33.4	21.8	12.6	7.5	11.8	483.3
Swamp/Marsh	*10.6*	15.8	26.7	28.2	28.2	21.5	17.6	10.8	11.1	10.7	6.9	11.5	199.7
Dakama Forest	*28.5*	60.8	53.0	28.1	14.3	8.4	4.3	2.2	0.7	0.4	0.3	0.3	201.2
Scrub or Savannah	*10.8*	28.1	15.0	12.2	5.3	4.3	1.3		1.5				78.6
Mean IFP	*21.0*	33.4	50.5	55.7	52.9	42.2	33.9	24.3	19.2	12.3	7.8	15.8	369.1
MLI 2002-2008													
Lowland Mixed Forest	*15.9*	23.4	40.2	48.5	40.3	36.5	30.3	20.9	16.8	12.5	7.0	11.2	303.6
Hill or Montane Forest	*13.3*	26.4	26.7	52.5	41.1	33.7	29.4	11.9	14.1	6.4	12.4	7.7	275.5
Wallaba Forest	*14.7*	24.5	34.3	59.3	55.1	47.2	36.6	17.9	10.0	5.7	4.8	1.1	311.3
Swamp/Marsh	*11.5*	19.9	26.1	29.6	17.6	12.0	7.9	2.0	1.2	1.3			129.1
Dakama Forest	*17.2*	32.4	36.3	22.1	5.3	3.4	0.8		0.2		0.5		118.2
Scrub or Savannah	*7.1*	13.7	14.7	20.2	8.6	1.5	3.0						68.8
Mean MLI	*15.6*	24.0	38.5	47.7	39.1	34.9	28.6	18.6	14.9	10.7	6.6	9.4	288.6
Mean, all inventories	*18.1*	28.7	43.8	53.7	49.3	40.8	33.1	22.7	17.6	11.6	7.4	14.3	341.1

As has been noted previously in relation to stem numbers and volumes, the FIDS inventory did not sample below 30 cm dbh (12"). None of the other inventories sampled below 10 cm. To interpolate these missing data, graphical methods were used, based on the regular distributions that can seen in the data (see Figures 9 and 10). The interpolated data are shown in blue above.

The overall mean figure of 341 t ha^{-1} above ground biomass is weighted by plot numbers in the inventories. Table 13 shows the areas for each vegetation class, above and below ground biomass estimates (see p 11), carbon and CO_2-equivalent (see p. 12) using average estimates from all three inventories. This can be taken as the 2009 stock position, as accurately as may be calculated with current information. The next chapter deals with the dynamics of change since 1950, and estimates of forest area loss, degradation, and consequent CO_2 emissions as a result of these processes.

Table 13 Total sequestered carbon as tree biomass in Guyana

	Area	Tonnes per hectare				Total, millions tonnes			
Vegetation Class	*km²*	*Above ground biomass*	*Biomass incl. roots*	*Carbon*	*CO_2 equiv.*	*Above ground biomass*	*Biomass incl. roots*	*Carbon*	*CO_2 equiv.*
Lowland Mixed Forest	100,408	361	440	220	807	3,621	4,417	2,209	8,098
Hill/Montane Forest	45,190	342	418	209	766	1,547	1,888	944	3,461
Wallaba Forest	10,867	460	561	280	1,028	499	609	305	1,117
High forest subtotal	156,465	362	442	221	810	5,668	6,914	3,457	12,676
Dakama Forest	4,234	184	224	112	410	78	95	47	174
Scrub or Savannah	17,562	77	93	47	171	134	164	82	300
Swamp/Marsh Forest	26,899	192	235	117	431	518	632	316	1,158
Cultivated/urban/cleared	4,687					-	-	-	-
Total land area	209,847	305	372	186	682	6,397	7,805	3,902	14,309

It will be noted that the weighted average tree biomass for all high forest types is 442 t ha^{-1}. This compares with ter Steege's (2001) estimate for central Guyana brown sand soils of 312 t ha^{-1}, and a simple average for all soil types of 304 t ha^{-1}. It appears from the data presented (*ibid.,* Table 5) that, whilst using the FIDS data, he does not make any adjustment for the missing data below 30 cm (12"), which probably accounts for the lower figures.

Comparison with FAO estimates published in the *Global Forest Resource Assessment 2005* (FAO, 2006) are also interesting. The FRA has a forest area for Guyana of 151,050 km^2 , which is similar to the high forest subtotal in Table 13 above of 156,465 km^2. In the notes to the FRA data, this FAO figure is said to be of 1999 vintage and based on an expert opinion (*ibid.,* Annex 3, Table 2). The FRA then applies what is described as a South American average carbon per ha estimate of 110 tC ha^{-1}. This results in a total estimate of 1,722 million tC ha^{-1}, compared with 3,902 million tC ha^{-1} from table 13 above. It will be noted in Table 13 that the average for the total land area is 186 tC ha^{-1}, and for high forest alone, 221 tC ha^{-1}, compared with the FRA's 110 tC ha^{-1}. It is believed that the latter figure for South America includes substantial areas weighted towards to more open end of FAO's general 10% minimum canopy cover definition for forest (FAO, 2002). Accordingly, it is suggested that the FRA figures for Guyana need to be revised in line with the current estimates.

Table 13 does not include additional carbon estimates for soils and necromass. For completeness, estimates for these figures are added in Table 14, calculated using the factors detailed on page 12. However, these figures are very uncertain. The survey of soil carbon and necromass being piloted in this project, if completed on a national scale, will provide more accurate, Tier 3 estimates for these figures. Large quantities of carbon may be contained in the soil and litter layers, especially in wetlands and organic-rich soils such as pegasse. These can easily exceed the above ground vegetation in such ecosystems. The figures given in Table 14 are conservative, lower limit, estimates.

Table 14 Ecosystem carbon including soil and necromass

Necromass and soil components approximately estimated. See page 12.

Vegetation Class	Area	Carbon tonnes per hectare					Total carbon, millions tonnes					CO_2 equiv.
	km^2	*Above ground biomass*	*Roots*	*Necro-mass*	*Soil carbon*	*Total*	*Above ground biomass*	*Roots*	*Necro-mass*	*Soil carbon*	*Total*	*Gigatonnes*
Lowland Mixed Forest	100,408	180	40	19	33	271	1,810	398	190	326	2,725	9.99
Hill/Montane Forest	45,190	171	38	18	33	259	774	170	81	147	1,172	4.30
Wallaba Forest	10,867	230	51	24	33	337	250	55	26	35	366	1.34
High forest subtotal	156,465	181	40	19	33	272	2,834	623	297	509	4,263	15.63
Dakama Forest	4,234	92	20	10	22	143	39	9	4	9	61	0.22
Scrub or Savannah	17,562	38	8	4	22	72	67	15	7	38	127	0.46
Swamp/Marsh Forest	26,899	96	21	10	84	211	259	57	27	225	568	2.08
Cultivated/urban/cleared	4,687		-	-		-	-	-	-	-	-	-
Total land area	209,847	152	34	16	37	239	3,199	704	336	780	5,018	18.40

Changes in forest carbon from 1950

Forest areas

In colonial era British Guiana Forestry Department reports[1] from 1955 through to 1965, the legal land area of the colony is quoted as 83,000 mi², and the area of forest land as 70,000 mi². These are equivalent to 214,970 km² and 181,300 km² respectively. The legal area remains the same today. Rees (1963) gives the breakdown of forest areas shown in Table 15. It can be seen that the total of the closed high forest types totals 181,430 km², consistent with the department reports noted above.

Table 15 Guyana forest areas in 1962
(after Rees, 1963)

	mi²	km²	
Coastal strip	2,200	5,698	
Swamp and Marsh Forest	2,050	5,310	
Rain Forest	29,300	75,887	181,430
Seasonal Forest	5,900	15,281	
Dry Evergreen Forest	16,500	42,735	
Montane Forest	18,350	47,527	
Savannah	8,700	22,533	
Guyana total	83,000	214,970	

With current areas for comparable closed high forest types estimated at 156,465 km² based on mapping in 2001, this suggests a net forest area loss of 24,965 km² over 39 years, or 16% on a current basis.

An independent analysis based on satellite imagery by Earthtrends (2003) estimate a 3% loss in forest area from 1990 to 2001. This equates to an annual rate of deforestation of 0.3% over that period. Over the last 39 years, it equates to a cover loss of 12%. This is reasonably consistent, given that satellite interpretation without good ground controls can readily confuse areas of dense shrubby vegetation such as Muri scrub or Dakama forest with closed high forest.

From the above estimate, an average loss of 640 km² per annum has been occurring since the late 1950's. This amounts to 0.4% loss on a current area basis.

Forest degradation

Forest degradation is harder to quantify. The definition of 'degraded forest' is discussed in FAO (2002, Annex VII), where 18 different definitions of forest degradation are listed. However, that most applicable here is that due to ITTO: "*Forest land severely damaged by excessive timber and NWFP harvesting, poor management, repeated fire, grazing or other disturbances and land uses that damaged soil and vegetation to a degree which inhibited or severely delayed forest regrowth after abandonment*". In the same text, it is noted that the IPCC definition is "*A long-term reduction of tree crown cover towards but not exceeding the minimum accepted `forest' threshold*".

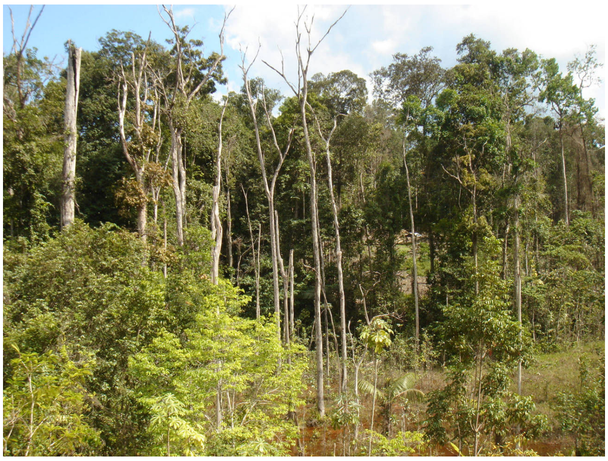
In the Guyana context, the 1961 FD report notes that "*There are large areas of salvage forest reduced to a poor condition by repeated creaming over the last half century.*" At that time there were 85 licensed sawmills operating, wood cutting leases covered 943,000 ha and log production was around 270,000 m3 (12 million ft³ Hoppus). It was noted that leases had decreased by 120,000 ha from the previous year *'as Greenheart had been worked out'*. Thereafter forest production

[1] The orginal reports cited here are held in the GFC Library.

decreased progressively. By 1972, FD annual reports indicated total production of 136,000 m^3 (6.1 million ft^3H).

Figure 11 Stages in forest degradation

These photographs were taken on transect of about 50 km along the Linden-Mabura Road, 2009, moving from high forest to Muri scrub.



(a) Old repeatedly logged forest with extensive die-back, fire damage, charred stems, and very broken canopy.

(b) Large trees have mostly disappeared. Relict stems are all severely charred by forest fire.

(c) Dakama forest (right of road) may develop as a on white sand. This may resist further degradation, but comprises only small trees. The soil is white sand, with the laterite on the road bed being artificially laid.

(d) Where fire and nutrient loss are more severe, the end result is Muri scrub forest. This cannot recover to high forest without active reforestation practices. The typical appearance of the white sand is clear.

This rose again gradually as additional areas were opened up and new industries established, so that by the mid-1990's production was of the order of 500,000 m3 roundwood equivalent, at which level it has remained, with some annual fluctuations, up to the present.

These production figures are well within sustainable capacity. GEMFORM projections with actual inventories show that sustained yields for accepted timber species will normally be around 0.5 m3/ha/yr (Alder, 2008). Given that there are some 8 million ha of currently allocated state forest, this could allow a production of the order of 4 million m3/yr. It is doubtful that current logging practices, undertaken within the context of the GFC's code of practice, lead to long-term degradation.

However, the photographs in 11 (a) and (b) are evidential of active and current degradation processes. These are in the context of the Georgetown-Lethem Road, and may be primarily associated with hydrological changes and increased fire incidence associated with the road. However, further research is needed onto the prevalence of these conditions in off road sites, as it is entirely possible that there are ongoing climate and biotic shifts (eg new soil pathogens) that are enhancing degradation in sensitive areas.

The network of forest monitoring plots proposed as a REDD initiative by Alder & Kuijk (2009) will be extremely important in providing this information, if implemented.

Carbon emissions from deforestation and degradation

Degradation and deforestation, as noted above, are estimated at some 640 km^2 per annum. Table 14 (page 24) shows that mean total forest carbon (including litter and deadwood) is 272 tC ha^{-1}. The endpoint of the deforestation/degradation process is a scrub/savannah formation, with estimated carbon values of 72 tC ha^{-1}, giving a net per ha loss of 200 tC ha^{-1}. On 640 km^2 annually, this is 12.8 million tC per annum, or as CO_2 released to the atmosphere, 46.9 million tCO_2-e.

Conclusions

In this report, we review available information on forest volumes, biomass equations, growing stock and changes since 1950 in order to estimate the current forest carbon stock and annual emissions from deforestation for Guyana.

For volume and biomass equations, the IFP volume tree sample is an important source of information. Taken from 1990-92, this consists of complete upper stem measurements on 1849 sample trees from 118 species. This data was re-computed to produce a gross over bark volume equation to 10 cm top diameter, and applied with FAO-recommended average expansion factors and wood density to obtain biomass estimates. These were compared with the Chave et al (2005) pantropical biomass equation, itself derived from 2410 trees sampled across 27 studies around the world. The two equations were found to be almost exactly coincident, and the Chave equation therefore used as the basic allometric model for biomass estimation. For other expansion factors for roots, necromass and soil carbon, reliance was placed on the work of ter Steege (2001), itself a compilation of other regional studies from French Guyana, Surinam, Brazil and Venezuela.

For forest areas, the main resource was the GFC vegetation map, produced by ter Steege (2001b). This is based on Landsat optical and JERS radar imagery from 1995-2001. Forest areas were derived from this map using GIS analysis. ter Steege's original 27 vegetation types were regrouped into 7 broad classes in order to provide a common basis for integration of the various different inventory datasets and carbon coefficients. These 7 vegetation classes were: (1) Lowland mixed forest, (2) hill/montane mixed forest, (3) Wallaba forest, (4) Dakama forest, (5) scrub or savannah formations, (6) swamp, marsh and mangrove forest, and (7) agricultural, cleared or urban areas. Categories (1) to (3) together constituted closed high forest, and cover an estimated 156,465 km^2, or 75% of Guyana's land area of 209,847 km^2. The legal area of Guyana, including waterways and territorial waters, is 214,970 km^2. These figures are in broad agreement with MODIS satellite estimates of closed forest, 165,510 km^2 (Earthtrends, 2003). This latter figure would include some swamp, mangrove and Dakama forest.

Forest growing stock estimates were derived from three inventory campaigns: The FIDS/FAO inventories of 1968-73, the IFP/CIDA inventories from 1990-94, and current management level inventories from 2002 onwards processed in the GEMFORM system (Alder, 2008). The original tree data from all these was available. This was standardised and reprocessed into a common format, with plot locales being classified according to the vegetation classes above. Volume and biomass were recalculated, tree by tree, applying actual wood densities published in the world database of Zanne *et al* (2009). These inventories included 854 cluster samples of 0.2 ha (FIDS), 7698 point samples (IFP) and 2894 plots of 0.1 ha (MLI). The FIDS sample has good national coverage, whilst the IFP and MLI are biased towards accessible forest areas in the northern part of Guyana.

From these inventories, allometric models and area estimates, stand tables by tree numbers and volume are produced (Tables 10-11), a table of biomass by diameter classes for each inventory and vegetation class (Table 12). These are summarised into national biomass estimates of tree stock in Table 13. Table 14 extends this to apply necromass and soil carbon estimates for total ecosystem sequestered carbon.

From this it is found that the average closed forest tree biomass above ground is 362 t ha^{-1}, and including roots, 442 t ha^{-1}. Carbon is 221 tC ha^{-1}, or as sequestered CO_2, 810 tCO_2-e ha^{-1}. Other ecosystems have lower values, giving national averages for the whole land area of Guyana (209,847 km^2) of 186 tC ha^{-1}, or 682 tCO_2-e ha^{-1}. Applied nationally to the closed high forest area of 156,465 km^2, there are 3.457 Gt (Gigatonnes, billions of tonnes) of tree carbon in Guyana's forests, equivalent to 12.676 Gt of sequestered CO_2. Including marsh, swamp, scrub and savannah ecosystems, Guyana has an estimated 14.309 Gt of sequestered CO_2, of which 89% are found in the closed forest that makes up 75% of the land area.

These figures are purely for carbon in living trees, bole, roots, and crowns. Including deadwood and litter, together known as necromass, and soil organic carbon (mainly as micro-organisms and humus), Guyana's closed high forests sequester a total of 15.63 Gt of CO_2, and Guyana's total land area sequesters 18.40 Gt.

These estimates are substantially higher than previously available figures. The FAO *Global Forest Resource Assessment* 2005 (FAO, 2006) estimated total carbon for Guyana as 1.722 Gt, less than half the figure here (3.902 Gt). Although the FAO report has a very similar forest area, it uses a low figure for carbon per hector of 110 tC ha^{-1}, said to be the South American mean. There is probably some confusion because FAO's broadest definition of forest includes areas with crown cover as low as 10% (FAO, 2002). Using a continental average for such open woodland areas and applying it to Guyana's closed high forest will inevitably underestimate.

Forest loss in Guyana is hard to estimate because earlier figures from 1950's and 60's reports are unclear. The FIDS survey, though comprehensive, did not produce a consolidated national report of forest areas (or if so, it is not extant or accessible). However, extensive photogrammetry was undertaken in the colonial era, and forest area is reported as 181,300 km^2 from the Forestry Department report of 1955. Rees (1961) provides a rare table of forest areas from 1963 which confirms this figure and breaks it down by forest types (Table 15) Using this as a basis, and by comparison with today's high forest area, a net loss over a period of 39 years of some 25,000 km^2 is computed. This is 640 km^2 or 0.4% per annum on a present day basis. Given that the losses mainly constitute a transition from forest to scrub or savannah through fire and degradation, the carbon loss is estimated at 12.8 million tC per annum, or 46.9 million tCO_2-e.

The estimates presented here are provisional and need to be refined. The earlier report under this project (Alder & van Kuijk, 2009) recommends a national system of monitoring plots, and biomass sampling for locally-derived allometric functions, which combined with suitable satellite imagery and biometric analysis, will both update these figures, and provide an accurate basis for measuring future changes.

In conclusion, and in terms of round figures, it can be said that Guyana's 16 million ha of closed high forest sequester 13 billion tonnes of carbon dioxide as living trees, or 16 billion tonnes including deadwood, litter and soils. There are approximately 1000 tonnes of CO_2 sequestered per ha in Guyana's closed forest areas. Nationally, including scrub formations, savannahs, wetlands and mangroves, Guyana sequesters 18.4 billion tonnes of carbon dioxide in living ecosystems.

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Annex A - Terms of Reference

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1. For Guyana's main forest types and other land uses compile models for carbon sequestered in woody biomass using methodologies that are IPCC compliant and documented with coefficients and expansion factors according to IPCC Tier 1-3 sources.
2. From existing GFC historical inventory datasets, vegetation and land use maps, remote sensing coverage and other relevant information, compile a baseline assessment of historical carbon emissions from deforestation and degradation in Guyana from 1950 to the present, using the models from 1.
3. Develop future projections of emissions as baselines based on status quo and reductions under various scenarios of improved forest management and incentives to reduce deforestation and degradation.
4. Develop systems for updating biomass field estimates across all land uses including estimates from deforestation and degradation.
5. Establish carbon, biodiversity and social criteria and spatially-explicit data to target incentives to the highest outcome potential.
6. Provide a detailed methodology, technical support and training for a national biomass monitoring system based on permanent plots and remote sensing including project level activities, and establish a capacity-building and monitoring plan, and protocol for the full implementation of this system.
7. Develop an integrated framework for monitoring data at the national level, to maintain and track statistical and spatial information on both deforestation and degradation, and positive protective and recuperative measures.
8. To ensure that all outputs from activities 1-5 are compliant with REDD reporting requirements and technical standards, to maintain open and transparent information on all methodologies, databases and technical coefficients, to produce technical reports as required on these matters.
9. Advise on the identification and implementation of specific areas of engagement through networking and communication, in conducting workshops with other countries and key entities/bodies such as the UNFCCC SBSTA and other key entities/bodies, to build support of Guyana's baseline and methodology.
10. Establish structure for implementation of pilot activities including the development of clear criteria for evaluation of suitable pilot projects, supporting capacity building exercises, and implement site level monitoring of plan and methodology.
11. Evaluate alternatives that address drivers of deforestation and degradation in demonstration sites.
12. Advise on the integration of REDD and land use planning into rural and community development planning.

Annex B – Symbols, Units and Conversion Factors

Algebraic symbols

B ....Bole biomass, tonnes
B_a ....Above-ground biomass, tonnes
d ....Tree diameter, dbh, cm
D..........................Tree diameter, dbh, cm
f...........................Crown expansion factor
f ....Form factor, no units.
f_h ....Form height, m
h ....Bole height, m
k..........................$\pi/40{,}000$ or 0.00007854
V..........................Volume, m^3
W.........................Above-ground tree biomass, kg
β_i ....Empirical coefficients
ρ..........................Wood density (oven dry), g cm^{-3} or t m^{-3}.

Units

" ....inches
ac ....acres
ft^3H.....................cubic feet, Hoppus measure (quarter girth squared)
ft^3........................solid cubic foot
ha^{-1} ....per hectare
km^2.....................square kilometres
m^3 ha^{-1}................cubic meters per hectare
m^3 ....cubic meters
mi^2......................square miles
t .... tonnes biomass, oven dry weight
tC........................tonnes Carbon
tCO_2-e ....tonnes Carbon dioxide equivalent
Gt ....Gigatonnes, billions of tonnes
t ha^{-1} ....tonnes per hectare
tC ha^{-1}.................tonnes of carbon per hectare
tCO_2-e ha^{-1} ....tonnes of carbon dioxide-equivalent per hectare

Conversion factors

1 ha = 2.471 ac
1 km^2 = 0.3861 mi^2
1 cm = 0.3937"
1 ft^3 = 0.02832 m^3
1 ft^3H = 0.02224 m^3
1 tCO_2-e = 3.667 tC