Proposals for a National Forest Biomass Monitoring System in Guyana

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Executive Summary

A system of permanent monitoring plots is proposed to measure and detect changes in forest biomass. The plots will be circular, of 18 m radius (0.1 ha) with an inner subplot of 8 m radius (0.02 ha). Trees over 20 cm dbh will be measured on the main plot, and over 5 cm dbh on the subplot. Plots will be organized in clusters of 5, based on a cross design with a central plot, and four plots on 100 m arms at right angles. Clusters will themselves be organised into transects of 3 clusters in a line, one km apart.

It is proposed that 900 plots, grouped as 180 clusters and 60 transects be established nationally in all major forest types. This will include non-productive Muri and Dakama scrub forests, and sensitive savannah-hill forest mosaics, as these constitute important areas for biomass sequestration and potential forest loss, in addition to the sampling of productive forest.

Associated with this monitoring system will be data collection to establish coefficients and allometric functions for the major biomass pools: Tree boles, crowns and roots, lianas and epiphytes, understorey shrubs and herbaceous plants, standing and fallen deadwood, litter and soil carbon.

This work will comprise two types of sampling units. Associated with monitoring plots will be 4 temporary 3 x 3 m quadrats which will be destructively sampled by weight for fallen deadwood, litter, and small plant biomass. Soil samples will be taken for organic carbon determination. These data will provide data that can be correlated with scores for deadwood and litter depth on the monitoring plots to derive biomass estimates for these carbon pools.

A second type of sample will be the detailed measurement of felled trees and tree roots to establish a data set of 300 plus sample trees for crown, bole and root biomass. Tree root excavations will be facilitated in cooperation with mining communities using hydraulic hoses. These data will allow the elaboration of local and current Tier 3 allometric functions for Guyana.

Completing the biomass analysis work will require establishment of a simple biomass laboratory at GFC headquarters. This will comprise 2 drying ovens of 400 lt capacity each, electronic balances, and adequate space to store and process field samples.

The plots, coefficients and allometric functions will give biomass estimates, together with conventional forestry data on volume, species, forest and soil type, that are tightly geo-referenced and sampled over scales of 0.1 ha, 4 ha (clusters) and 2 km (transects). These will be used to supervise classification of LANDSAT imagery to determine areas and area changes of biomass and forest type cover classes. From this the monitoring system will be able to directly report carbon stocks and fluxes for REDD accounting. This is the primary objective of the system. Its secondary objective is to provide a system of continuous national forest inventory providing strategic information on timber volumes and increments, NTFPs, biodiversity and other ecosystem services.

Contents

List of Abbreviations

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
FRIU .... Forest Resources Information Unit
GFC .... Guyana Forestry Commission
GIS................................... Geographic Information System
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
VCS .... Voluntary Carbon Sector
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. It relates to item 6 of the consultant's terms of reference, which is stated as:

> *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.*

The complete terms of reference are detailed in Annex A.

Objectives

The National Biomass Monitoring System (NBMS) as proposed in this document, is intended to provide data for REDD project assessments of current forest biomass, and forest biomass change over time in response to REDD-oriented government policies relating to forestry and land use planning.

The full details of REDD implementation are still a matter for inter-governmental negotiation, but it is clear that the goal is a compensation package provided to countries having substantial areas of tropical mixed forest (TMF) that will be sufficient to encourage and allow implementation of policies to effectively protect and sustainably manage those forests.

Whatever financing system is ultimately agreed, an essential part will be a national network to monitor initial forest biomass, and biomass change over time. In the context of REDD, biomass is the primary criterion. Other forest conservation issues such as biodiversity are not primary concerns, though it may be that they will become so as the REDD concept evolves.

Standards

The International Panel for Climate Change (IPCC) in its technical reports details standards for the calculation of forest biomass (IPCC, 2006). Of particular note is the definition of Tier 1-3 coefficients and expansion factors, and the various carbon pools to be considered (see Figure 1 below). It may be noted that for many carbon trading schemes, only above ground bole and crown biomass are normally considered (VCS, 2006; Merger, 2008) but the ultimate standards REDD will adopt are as yet unknown, and all carbon pools need to be allowed for, and their assessment is recommended in GOFC-GOLD (2008). Tier 1 and 2 coefficients are those based on global or regional average data, accessible through the scientific literature. Specifically, FAO have a provided a manual for forest biomass estimates (Brown, 1997) which includes a range of Tier 1 coefficients (global average coefficients) and some Tier 2 data. Ter Steege (2001) prepared a more detailed schedule of Tier 2 coefficients specifically for Guyana.

However, for the most accurate and credible estimates of biomass, locally derived and current allometric equations and expansion factors are desirable. These are classed by IPCC (2006) as

Tier 3 estimates. The present report describes the procedures which should be adopted under the REDD readiness programme to undertake this.

In the same way, monitoring systems may rely on Tier 1-3 estimates of inventory and growing stock. Tier 1 estimates would use rule-of-thumb figures for tropical forest volumes; Tier 2 would be based on regional or outdated inventories, whilst Tier 3 implies a current biomass-oriented national forest inventory. The best estimates currently available for Guyana of total forest biomass are those of ter Steege(2001), which are Tier 2 in this respect, being based on relatively old inventory data (1970-72) to determine mean stockings by forest type, together with Tier 2 biomass coefficients.

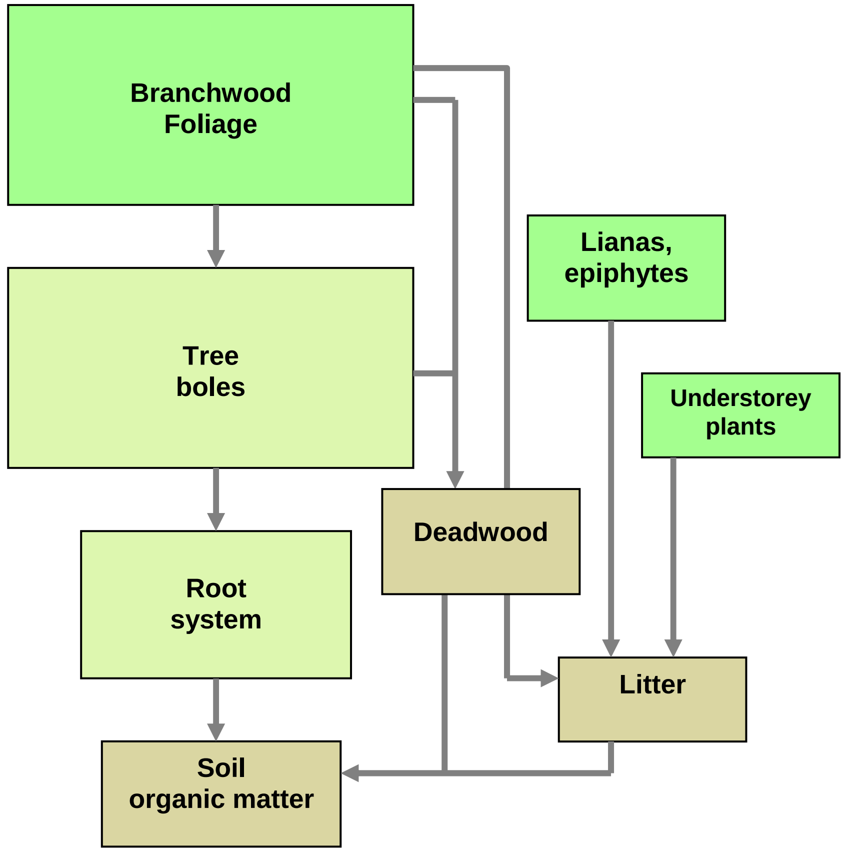


Figure 1 : Carbon pools for forest monitoring
About 85% of ecosystem biomass for tropical high forest is in the tree component (boles, crown and roots - Brown, 1997). Arrows show direction of carbon fluxes.

Requirements

The proposed monitoring system therefore has to be based on Tier 3 coefficients and data in all respects. It must be sufficiently sensitive to detect relatively low incidences of deforestation and degradation, as is believed to be the case in Guyana at present. Accordingly, the following components will be needed for implementation of the system.

- A network of permanent plots, specifically designed to measure biomass change in all the major carbon pools, covering all forest types in Guyana including high forest, scrub forest, savannah margins and woodland mosaics, montane forests.
- Coefficients and allometric equations relating tree biomass components and necromass pools (deadwood, litter, soil carbon) to easily measured variables such as tree diameter. These models need to be developed as an integral part of setting up the monitoring system through appropriate destructive sampling.
- A remote sensing and GIS framework to determine through ground truthing with the biomass plots and supervised classification an appropriate algorithm to map forest type areas and sensitively monitor pixels for forest cover or type change.
- Integration of the whole into an information system that will routinely provide all necessary reports for REDD forest biomass and cover change monitoring.

Biomass monitoring plot design

Alternative concepts

Almost all types of sample plot have been used at some stage in Guyana. This include large and small rectangular plots, circular plots and point sampling. The relative advantages and disadvantages of these for permanent monitoring plots can be summarised as follows:

<u>Larger square plots</u> (0.25 to 1 ha or more) are efficient for research and growth and yield studies, but require considerable time to establish. The 1-ha design commonly employed in tropical forest growth studies (see Alder & Synnott, 1992) take about 4 days to lay out and measure. Plots of this type have been recommended by GFC for growth and yield work, and form the basis of work done by the Tropenbos-Guyana and the ECTF with Barama Timber Co. A number of such plots have also been established by Iwokrama.

<u>Circular plots</u> (0.02-0.1 ha) are often used as temporary plots in forest inventory as they are very rapid to establish. These plots are used by GFC for management inventories, established at 200 m intervals along transect lines. Plots of this type are often established as square tracts (Kangas & Maltamo, 2006). This plot type is also widely used as a permanent plots in plantation forestry, and has been used also for PSPs in mixed tropical forest, for example in Quintana Roo, Mexico(Alder, 1997).

<u>Rectangular plots, transects and strips</u> are an older design that have been favoured in various inventories and growth studies. Linear transects, measuring trees within a short distance of a centre line (eg 5 m) have also been used as permanent plots in tropical forest (eg by Lowe, 1992). However these designs are not generally favoured nowadays for large tree inventories or as PSPs in the tropics because of statistical difficulties and inefficiencies in their use. They can also be problematic in practice, where the centre line is blocked by large trees or broken terrain. Most of Guyana's colonial-era forest surveys were performed using strip plots.

<u>Point sampling</u> has also been used widely in forest inventory and, rarely, for establishing permanent plots. Point sampling was used in Guyana for the CIDA/IFP inventory of 1990-94. Point sampling has strong statistical advantages, and is possibly the statistically most efficient method of inventory. However, in practice it is often inaccurate because there are many more problematic edge trees with this type of plot, and operate bias, training, and checking are major issues to ensure consistency. For permanent plots there are also intractable theoretical problems with dynamic area calculation that varies with tree size. Point sampling nowadays is rarely favoured except for rapid estimate surveys.

For biomass monitoring plots at a national level, there are compelling advantages in using clusters of small circular plots. No time is spent cutting plot edges and quadrat boundaries, and the problems caused by large trees impeding such edges disappears. Clustering the plots is advantageous statistically and logistically and aids their use in ground truthing remote sensing data, which is a primary objective. Winrock(2008) have specifically proposed plots of this type for REDD monitoring in Bolivian moist tropical forest.

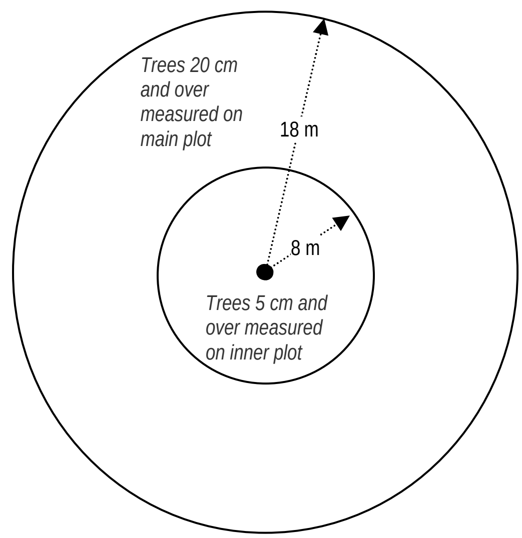
On the other hand, 1-ha square plots, which have been widely used and recommended for growth and yield studies in Guyana and elsewhere in the tropics, are inefficient for this purpose. Fewer plots can be established for a given budget, reducing sampling precision, and they are much less suited than dispersed cluster units for examining changes in the forest mosaic due to deforestation and degradation, which is the primary objective of the REDD monitoring.

For these reasons, circular PSPs, similar in design to GFC Management Inventory plots but grouped into clusters for each sample unit, are recommended for the National Biomass Monitoring System in Guyana.

Recommended design

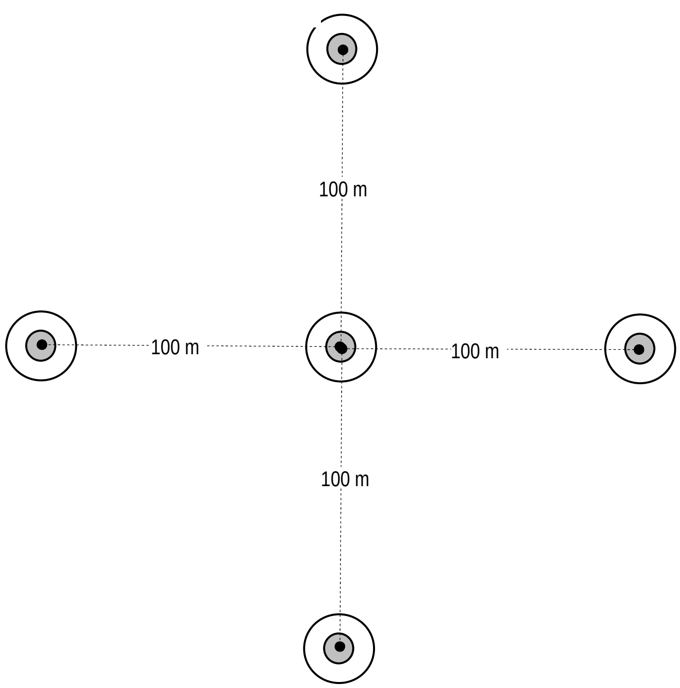
It is recommended that circular permanent plots of 18 m radius (1018 m^2) are used, with an inner sub-plot of 8 m radius (201 m^2) , as shown in Figure 2 opposite. This design is also familiar in Guyana from its use in management inventory.

Fig 2 Monitoring plot design



In addition to the normal features of an inventory plot, there would also be special sampling details for necromass (litter and fallen dead wood) and soil carbon on some plots. These are discussed in detail in the section **Necromass and soil sampling** below (page 10).

Fig 3 Cluster of monitoring plots



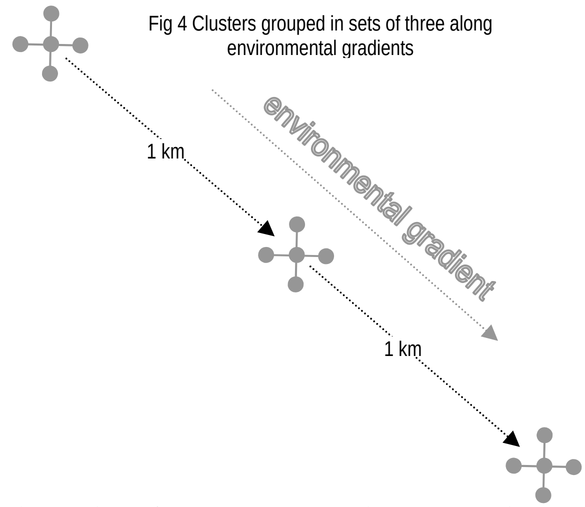
The plots would be established in clusters of 5, on a cross-shaped design as shown in Figure 3. Each arm of the cross would be 100 m, from plot centre to plot centre. This gives good local sampling of the forest mosaic, and provides a unit that is large enough to average several pixels in medium resolution satellite imagery (eg LANDSAT with 30 m pixel resolution).

The clusters would themselves be grouped into transects of 2 km, as shown in Figure 4, along across any discernible environmental gradient (slope, soil type, vegetation type, exploited-unexploited forest, etc.). This provides for sampling at the larger scale across ecotones.

On the plots, trees of 20 cm dbh and above would be measured over the whole plot, and trees of 5 cm and above on the inner plot. Note that these are different standards to those applied in

Guyana management inventories, where the limits are 35 cm and 10 cm respectively. The lower sampling limit is needed because these are biomass plots, and understorey vegetation contributes substantially to the biomass. Smaller trees also give a more sensitive indication of forest dynamics.

Fig 4 Clusters grouped in sets of three along environmental gradients



Plot demarcation and measurement procedures

The procedures for plot demarcation and measurement described below are initial recommendations, and may be modified in the light of experience, especially during the pilot phase.

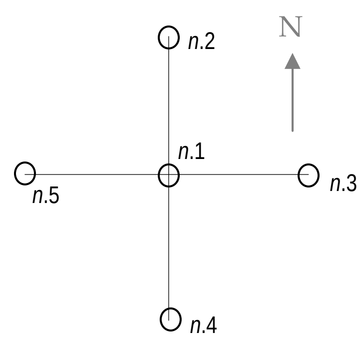
<u>Cluster and plot numbering</u>
Each cluster of 5 plots will have a unique national serial number, from 1 up. For cluster number 1, the plots should be numbered 1.1 for the central plot, then 1.2 for the northernmost, then proceeding clockwise, 1.3 to 1.5, as shown in Figure 5.

<u>Plot geo-referencing</u>
Each plot centre will be accurately geo-referenced in UTM coordinates and decimal degrees. Where canopy cover prevents a stable reading, then a position should be taken in a suitable gap or clearing, and the bearing and distance to the plot centre accurately recorded.

<u>Locating and marking the plot centre</u>
The cluster centre will be predetermined on the map at the planning stage, and given a geo-reference. The GPS should be used to navigate to this point in the field. If the canopy is dense, preventing accurate readings, then a reading should be taken in a nearby gap, and a survey line established to locate the plot centre.

If the plot centre falls in a place impossible to measure, such as a river, steep rocky area, etc., then it should be re-located a short distance to a place where it can be properly placed.

Fig 5 Plot numbering scheme for cluster *n*



The plot centre should also be moved 10 m if it falls immediately adjacent to a large buttressed tree, as this will make the work of measuring the plot difficult.
Once the plot centre has been determined, a marker post should be placed at the plot centre. These posts must be durable and clearly visible. White PVC pipe of 5-6 cm diameter (2-2.5”) is light to carry and suitable.

These PVC pipes should be cut into lengths of 1.2 m, and buried in the soil to a depth of 60 cm, with 60 cm emerging above ground. If rocks prevent digging at the plot centre, the stake must be strongly and securely fixed using a cairn of large stones built to support the stake.

The post should be labelled down its length using thick (6 mm) black permanent marker pen of good quality. The permanence of the marker should be tested before field use. The label should show the designation NBMP *n.m*, where NBMP stands for National Biomass Monitoring Plot, and *n.m* indicates the cluster and plot number.

<u>Marking and measuring larger trees on the main plot</u>
All trees of 20 cm diameter and over should be numbered, labelled and measured within a distance of 18 m of the plot centre.

Lay a measuring tape 18 m along the radius from the plot centre in a northerly direction. Number any trees within the plot in sequence starting from 1 as the tree nearest the plot edge.

Edge trees, falling at a distance close to 18 m should be carefully and strictly measured. The centre-line of the bole should be checked against the tape, when pulled taut from the plot centre and held horizontally. If the centreline is in, then the tree should be included, if it is out, it should be excluded. If it is impossible to say, then if the tree would have an odd number, include it, but if it would be an even numbered tree, exclude it.

Trees should if possible be measured at 1.3 m height above ground. For consistency, before starting, cut sticks (from saplings growing outside the plot) of exactly 1.3 m length. Use these to gauge measurement height. For large buttressed trees of good form, use a ladder to climb above buttress, and measure at a point approximately 1 m above the convergence of the buttress.

At initial demarcation, the point of measurement (POM) should be marked with chalk or tree crayon around the tree, and the measuring tape placed over the marks. Any loose bark should be brushed off by hand before measurement. A tag, numbered using writeable aluminium should be nailed approximately 10 cm above the POM. The nail should be placed with at least 2 cm protruding

Aluminium alloy nails of 2.25″ (57 mm) length, of the type used by the USDA Forest Service for their PSP work, are ideal, and recommended for this purpose.

After measurement, a ring should be painted over the exact line of the chalk marks, using a 13 mm (1/2″) brush. Red oil-based paint should be used. Note that if the POM is painted before measurement, diameter tapes will rapidly become unusable due to contamination with wet paint, and it is therefore important that painting is done after measurement.

Tree number should also be painted on the stem, below the point of measurement.

Some trees are impossible to measure accurately. These include ones with extensive aerial roots, trees with strangler figs, trees with very high buttresses or fluted boles. In this case the tree should be measured approximately with the diameter tape, labelled and marked as for other trees, but the appropriate coded note (see below) given to ensure that it is known that it cannot be properly measured.

If a tree has a branching stem well below 1.3 m, it should be measured and numbered as two trees, with the appropriate coded note. If it branches above 1.3 m, it should be treated as a single tree, measured at 1.3 m.

Where there are bumps, outgrowths, branches etc at 1.3 m, the tree may be measured just below the deformity or branching, with the point of measurement suitably marked. A coded note should be used to record the problem.

Measuring smaller trees on the inner plot

Once all trees of 20 cm or more have been measured, then trees above 5 cm on the inner plot should be measured. The inner plot includes any tree whose centre is within 8 m of the plot centre.

Apart from tree size, all measurement procedures are identical to the larger trees except that tree numbers should not be painted – only nails and labels should be used. This is because it is difficult to paint numbers clearly on small trees. However a ring must be painted at the point of measurement, as for larger trees.

Small trees are numbered consecutively, starting one higher than the last large (20 cm+) tree measured.

Height measurement

The 4 tallest trees on the plot should be measured for total height to the top of the crown, using a Suunto clinometer or equivalent instrument. Height measurements must be made at a distance sufficient that gives an angle of view of 45° (100%) or less.

The height to the first crown length branch, and the height to the top of buttress should also be recorded.

The distance and bearing of the height trees from the plot centre should be recorded. This is used to re-establish the plot centre if the marker post is lost.

Species identification

The species should be identified by local name and code, from the national species list. If there is uncertainty, a question mark should be put against the identification.

Tree quality indicators (live trees)

The sample plot recording form (Fig 3) shows a number of columns for recording tree quality assessments. These include stem straightness, forking, decay, crown health, logging damage, fire damage. *Do not apply these scores to trees which are completely dead.*

These are scored according to the descriptions below. During the pilot phase a photographic record of the various classes will be built up to assist training and consistency.

Stem straightness: (1) 100% of length straight up to the point of crown break; (2) 75% of stem straight, 25% with sweep or curvature; (3) 50% of stem with sweep or curvature; (4) largely malformed, but perhaps 25% of bole straight; (5) No straight sections to the bole at all.

Forking: (1) There is no forking below the crown; (2) There is a single fork, 50% or more up the stem; (3) The stem is forked below 50% of bole height, but still has usable sections; (4) The stem has multiple forks, but is still of tree form; (5) The tree or shrub is multi-stemmed from the ground.

Decay: (1) There is no evidence of decay; (2) The stem sounds hollow, but no external decay; (3) There is some external evidence of decay at the base or upper the stem; (4) Extensive external evidence of decay and fungal fruiting bodies; (5) Whole stem severely decayed, tree may be partially broken, largely moribund, but with some green foliage or epicormic growth.

Crown Health (1) Crown green and healthy, with no sign of dieback; (2) Limited dieback on a few branches; (3) More extensive die-back, whole branches dead, but not more than 50% of crown; (4) Extensive evidence of dead branches in the crown, but about 25% green foliage; (5) Crown appears entirely dead.

Logging damage (1) No sign of logging damage; (2) Minor bark or crown damage; (3) More extensive damage, whole branches broken in crown, or areas of bark stripped off over lengths of 1-2 m on stem; (4) Severe logging damage, half crown broken, buttresses and base of tree severely damaged, bark stripped off over lengths of more than 2 m; (5) Crown completely broken, or with few minor branches intact.

Fire damage (1) No fire damage; (2) Light charring on bark on lower 2 m of bole; (3) Heavy charring extending more than 2 m up bole, burnt wood exposed at base of tree. (4) Base of tree severely burnt, charring up whole of tree into the crown; (5) Extensive burning of wood (not just bark) on bole and branches.

Dead trees

For trees which are completely dead, measure or estimate DBH/DAB. Estimate the height of the bole or stump, if broken off, in metres. If the stump is less than 1.3 m, estimate diameter 30 cm from the top of the stump. Dead trees should not be labelled or numbered, but recorded separately on the form.

Stumps

Cut stumps for felled trees should be identified by species (usually simple as they are likely to be common timber trees) and measured for diameter and height.

Dead wood and litter score

This score is designed ultimately to correlate with data from the necromass plots.

On a line from the plot centre to the NW of the plot (or as close to this direction as practical if blocked by a large tree), count all pieces of dead wood on the ground transecting the line and estimated to be more than 2 cm in diameter.

Also along the same line, measure litter depth to the nearest cm at 3 m intervals.

These scores will be correlated with similar scores and actual measurements on the necromass quadrats as a 2-phase sample.

Nibbi, Kufa
Count individual plants seen on trees 20 cm+ which lie within the plot. Root counts are not necessary, as biomass will be correlated from the felled tree samples. Plants occurring on branches outside the plot should also be tallied, provided the host tree falls within the plot.

Lianas, climbers
A count of lianas or climbers on measured trees should be tallied. No diameter measurement is needed. This is used to build a score that will be correlated with the felled tree biomass sampling work.

The field recording form proposed for these plots is shown in Annex B.

Establishment of pilot plots

To test the above proposals, and also to further the training and demonstration objectives of the TOR, the project will establish 3-4 transects (45-60 plots). This will test and refine techniques, as well as training a cadre of experienced field personnel able to operate effectively when the REDD readiness programme moves into its full implementation.

These pilot transects will be located in accessible areas in a range of forest types. Provisionally proposed are the 24 Mile reserve near Bartica, where a 2-km transect will cover mixed forest, white sand, and hilly areas, and areas around Mabura/Pibiri in good quality mixed forest, in the savannah hill forest transition near Lethem, and in the north west in *Alexa* dominated forest types.

Determination of biomass coefficients

Introduction

The development of current Guyana-based biomass coefficients and equations for the main carbon pools (Figure 1) is important for the accuracy and scientific credibility of the NBMS. This will complete the provision IPCC Tier 3 compliant data and coefficients for all aspects of the monitoring system (IPCC, 2006).

The approach is based on the statistical principle of 2-phase sampling. This is commonly employed in forest inventories to calculate tree and stand volumes by (a) measuring tree diameters on plots, (b) conducting an independent study to relate tree volume to diameter, and (c) combining the two sets of information to derive stand volume. Statistical theory provides for a rigorous method of calculating sampling errors for this approach (Kangas & Maltamo, 2006).

In this case, equations will be used to derive bole, crown, and root biomass from tree diameter. Soil carbon, deadwood, and litter biomass will be derived from correlations between objective scoring methods (see page 8) and actual measurements of these quantities on a sub-sample of quadrats.

Necromass and soil sampling

Quadrat location and layout

On a sub-sample of clusters, necromass sampling quadrats will be established. The sub-sample will include all pilot plots, together with early plots established under the main programme wherever access permits removal of the necessary biomass samples.

Protective clothing, in the form of rubber boots and waterproof work gloves with substantial cuffs, are recommended for this work.

Fig 6 Necromass quadrats are located outside the main plot, 20 m from the plot centre, approximately on NE, SE, SW and NW bearings.

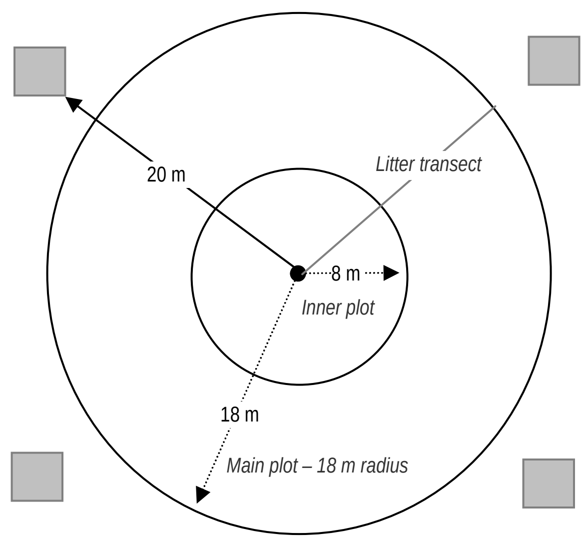
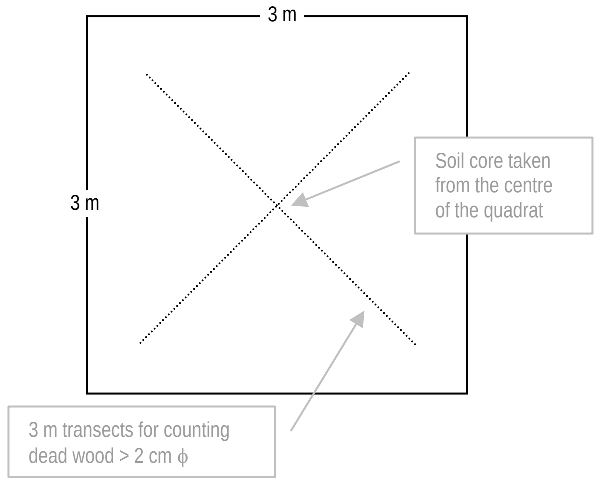


Figure 6 shows how the quadrats will be placed. There inner corners will be at 20 m from the plot centre, on bearings as close as practical to NE, SE, SW and NW (45°, 135°, 225° and 315°), given intervening trees that may make alignment of the bearing awkward to survey. They will be numbered clockwise 1-4. Given that the plot number will be something like 3-2 (cluster 3, plot 2), the full quadrat number for this plot would be 3-2-1 to 3-2-4.

The quadrats are outside the plots because they are sampled destructively. If inside, this might interfere with the subsequent growth performance of the plot. The quadrats are temporary, and will not be re-measured in future. If quadrats fall in locations that are very difficult, such as large piles of fallen debris, swamps, etc. it is recommended they are either relocated, if a suitable spot can be found within a few metres, or omitted. This arguably introduces some bias, but the overall effect of this on estimates will be small relative to the costs that would be incurred trying to undertake such samples.

The quadrats are 3 m by 3 m. The corners are temporarily marked out with sticks, and the edges with flagging. Figure 7 shows the quadrat layout in detail.

Figure 7 Design of necromass quadrats



Preliminary observations

Before commencing destructive sampling, three scoring methods are applied:

1. A digital photo of the quadrat is taken. This will be used to evaluate possible subjective scoring categories, and, if adopted, develop training materials. A standard distance and flash setting should be used, and a record of the photo number kept. On downloading, the photo files names should be changed to correspond to the quadrat numbers, such as Q03-2-1.

2. Two 3 metre transects are laid in an X formation. On each transect, a count is made of the number of pieces of deadwood greater than 2 cm diameter that intersect the transect.

3. At each end of the X transects, litter depth to the nearest cm should be measured with a ruler. This measurement should be made before the quadrat is excessively trampled or disturbed.

Destructive sampling

The destructive sampling of the small plant and necromass pools are sampled as follows:

<u>Herbs, seedlings and small plants less than 5 cm dbh.</u> These are cut at ground level, and separated into green (leaves and petioles) and woody material. Each is weighed separately and the weight recorded. The material is then sub-sampled, as described below in the sub-sampling procedure. Lianas and aerial roots should not be included – they are treated separately with the tree allometric sampling.

<u>Coarse litter (Woody pieces larger than 2 cm diameter)</u> This must be cut at the quadrat boundary, so as to exclude any material outside the quadrat. It should be possible to do this with cutlasses or a bow saw, but a chainsaw may prove to be a necessary piece of equipment for large timber laying on the ground. All the material should be bagged and weighed, and then sub-sampled as described below.

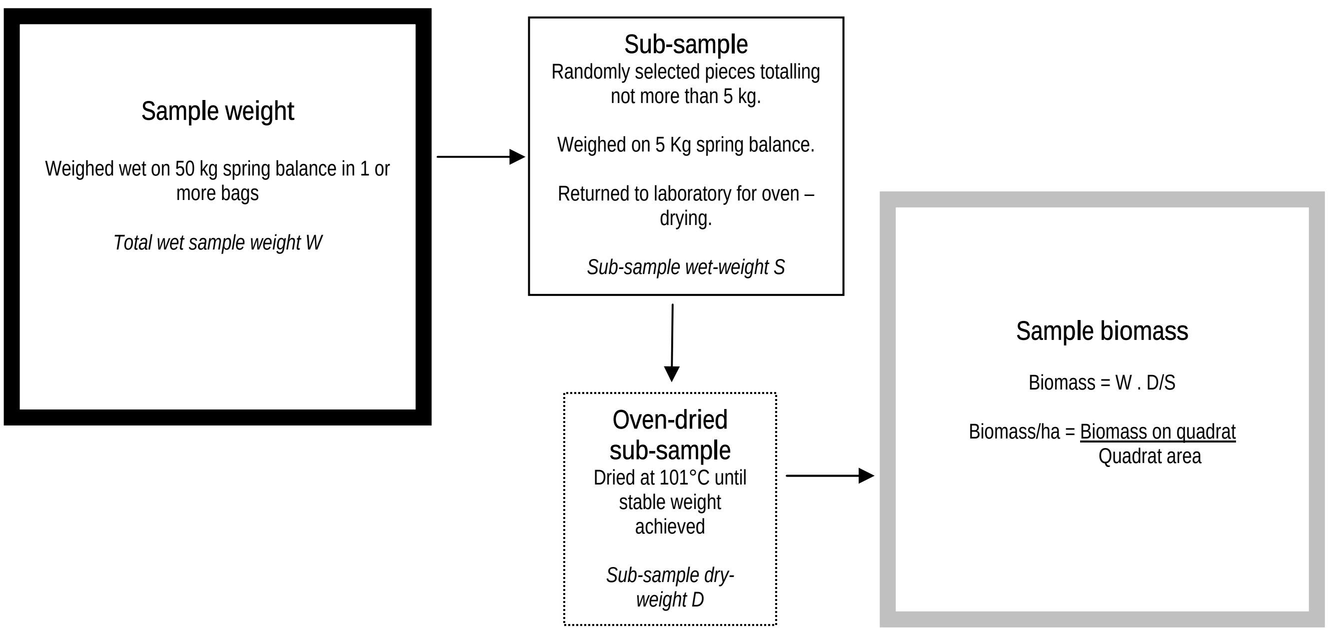
<u>Fine litter (leaves and other loose organic matter)</u> This should be scraped up into bags, weighed and sub-sampled.

Soil core A soil core should be extracted with a suitable coring tool of standard diameter, and if possible 45 cm length. The core should be bagged in 3 samples, representing 0-15 cm, 15-30 cm, and 30-45 cm. The samples are returned for laboratory analysis of organic matter content. Preliminary discussions suggest that NARI can perform organic matter content analysis for the samples on contract.

Sub-sampling procedure

Each of the biomass fractions sampled is weighed as found. Moisture content may vary greatly, depending on ambient conditions. To compensate for this, all weighed samples are sub-sampled. The sub-sample is then taken back to the laboratory, oven-dried, and re-weighed. This establishes a dry-weight:wet-weight ratio for that particular sample that can be used to calculate the dry-weight equivalent of the original sample. The diagram (Fig. 8) illustrates the process.

Figure 8 Sampling, sub-sampling, oven-drying and biomass calculation procedure



The procedure is basically very straightforward. However, good record keeping and careful labelling of all samples is necessary to avoid confusion. A substantial number of bags of material also need to be carried from the field and back to the laboratory for processing. This requires that plots sampled in this way have good access.

Biomass laboratory

A biomass laboratory for determining sample dry weights is required. IPCC (2006) states the required procedures. Wood, leaf and litter samples should be dried at 101°-103°C until they attain constant weight. Higher temperatures cause loss of volatile organic materials. Lower temperatures are not sufficient to fully dry samples.

Equipment required for the laboratory are two drying ovens of around 400 lt internal capacity, with five shelves, using standard 110 v or 220 v power supply. Two electronic balances of 5 kg capacity reading to 0.1 g are required. The laboratory should have ample space for sorting and storage of samples awaiting processing, a computer and desk for data management. The present inner office of the REDD Secretariat at GFC would provide a suitable venue. Costs of the ovens are estimated to be US$3000 each, and the balances $100 each. Total cost of equipment delivered to Georgetown would be around $8,000.

It is recommended that procurement of this equipment is started as soon as possible, to avoid the laboratory set-up becoming a bottleneck to progress.

Tree biomass sampling

Requirements and sample selection

There is a need to develop allometric functions that relate tree biomass components (bole, crown and roots) to dbh. At present, studies such as ter Steege's 2001 assessment of Guyana's forest biomass rely on external data, from Brazil and French Guyana.   These constitute Tier 2 (regional) estimates, and are insufficiently accurate for REDD monitoring.

Development of such equations requires destructive sampling of a number of trees to directly determine their biomass and relate it to dbh. The sample should comprise at least 300 trees, covering a range of size classes and species. It should include some shrub species such as Dakama, Muri and the savannah Sandpaper Tree as these occur commonly in significant forest types for biomass estimation.

Sample locations should be selected where trees will be destroyed in any case. Suitable sites are adjacent to current or planned mining areas, at potential log landings, or other land use conversion areas. For root sampling, ready access to the hire of hydraulic hoses will allow rapid root excavation with minimal damage, so mining areas are likely to be the best locations.

Sampling for bole and wood biomass

Sample trees will be measured for dbh and height, according to the same criteria used on the sample plots, and the liana count and nibbi/kufa count made.

The tree will then be felled and the bole measured conventionally, as for volume sampling (Figure 9). Diameters are recorded at the base and in lengths of 2-3 m to the base of the crown.

Figure 9 – Bole measurement method

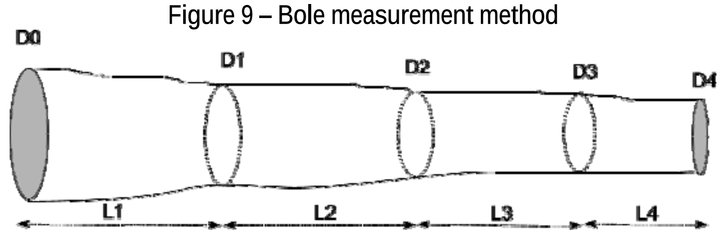
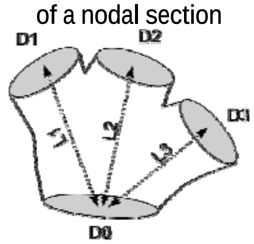


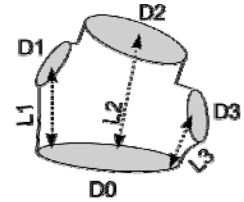
Figure 10 Measurement of a nodal section



Where the crown breaks is a stem section where two or more branches join. This node is measured as shown in figure 10, with the lower and each upper diameter measured, as well as the length from the base of each branch to the base of the node. Note that the node does not have to be physically cross cut to make these measurements – they are made over bark with diameter tape.

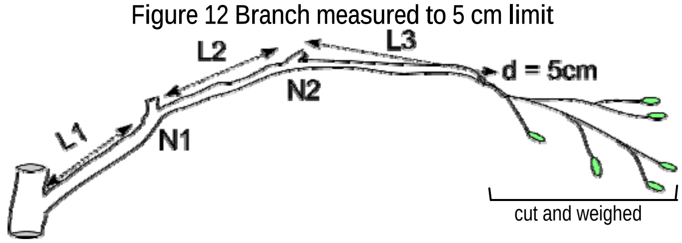
A branch section is then chosen arbitrarily for measurement. It should be one of the largest crown length branches, and in a condition that can be measured (ie not smashed during felling). The sections of this branch are measured in diameter and length sections up to the next node. Some of the nodes will appear as in Figure 11, with a dominant exit branch, and lateral side branches. They are measured in the same was as for Figure 10.

Figure 11 Node with dominant exit branch



At each node, the largest branch it is practicable to measure is recorded, but note that all exit branch basal diameters must be recorded, although the dependant branch itself is not measured further.

Figure 12 Branch measured to 5 cm limit



This process continues until a final branch is encountered which drops below 5 cm diameter overbark (see Figure 12). At this point, all the remaining sub-branches, twigs and leaves are cut off and bagged for weighing. Leaves and petioles are separated from woody material and weighed and recorded separately. Each fraction (woody or green) is sub-sampled for dry-weight analysis in the laboratory.

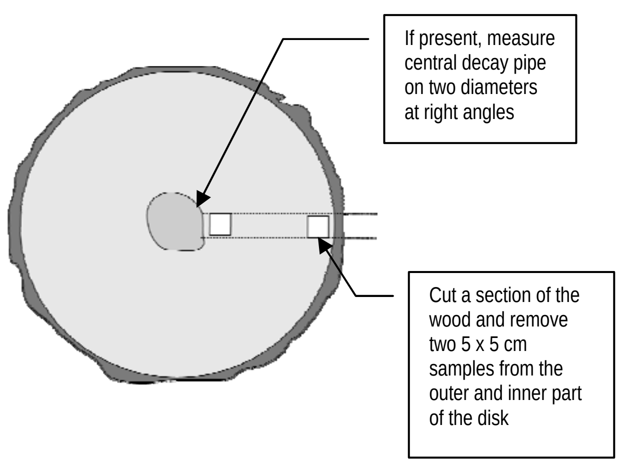
This process should be repeated for 2-3 subsidiary branches in order to get a good correlation between basal diameter and dependent twig and leaf biomass.

Wood density and stem decay disks

To determine wood density, and also adjust volume measurements for any central 'pipe' of decay, disks 5 cm thick will be cut from the base of the felled bole, at the mid point, and at the top, just below the crown node.

Figure 13 shows the measurements and samples that will be taken on these disks. The central area of decay, if any, will be measured on a major and minor axis perpendicular to each other. Then samples will be cut, 5 x 5 cm, from the outer edge and near the centre of each disk. If the disk is less than 20 cm diameter, then whole disk will be taken. The dimensions of the sample (L x H x W, or for disks, W x D) will be recorded whilst fresh in the field, as the sample will shrink on drying. These samples should also be weighed fresh. These samples are then returned to the laboratory for drying to determine bulk density and moisture content.

Figure 13 Wood disk decay measurement and bulk density samples



Root sampling

Root biomass sampling is difficult, but in Guyana can probably be progressed more effectively than in many other places, because of the prevalent use of hydraulic hoses in small scale mining.

The general approach will be expose root systems using hydraulic hoses, and then measure them for biomass by cutting them up with a chain saw or other implement and weighing them. The weighed material will be sub-sampled for moisture content determination in the laboratory

Figure 14 A scheme for root sampling using radial segments and distance zones

The direct measurement of the whole root system may be slow and difficult because of the extended nature of some roots. A suitable sub-sampling system will be devised based on measurement of random sectors over a fixed radius (eg 5 m), which will be explored as fully as possible and recorded in metre sections. This will provide a function for the decline in root biomass with distance that will tend towards zero, and whose parameters can be estimated from the data collected. Integrating this function will give total root biomass. The sampling process is illustrated approximately in figure 14.

Lianas and epiphytes

Lianas and epiphytes occurring on sample trees will be cut up and weighed separately, with sub-samples for dry-weight taken. Particular attention will be paid to Nibbi and Kufu, which will be recorded separately.

Adaptations during the pilot programme

The above conceptual sampling method will be improved and adapted for efficiency during the pilot phase. It should be possible to devise a sub-sampling scheme for roots to reduce time requirements without sacrificing too much accuracy, but this requires an examination of practicalities on the ground.

Satellite remote sensing

Suitable satellite imagery

In optical wavelengths (visible to near infra-red), LANDSAT imagery has been recommended by most sources as most suitable for monitoring purposes. The GOFC-GOLD(2008) sourcebook tabulates various platforms with availability and cost and concludes "*In summary, LANDSAT-type data around years 1990, 2000 and 2005 will most suitable to assess historical rates and patterns of deforestation.*" (op.cit, p19). Pöyry (2008) have provided a detailed report to GFC on the use of SRS to monitor logging activities, and provide detailed algorithms and procedures based on LANDSAT imagery, which they similarly conclude provides the best current option based on cost, coverage availability over Guyana, and resolution.

LANDSAT has a resolution of 30 m. This is sufficient to register logging roads and log landings, as well as clearings for farms, powerlines, roads, housing, etc. It is affected by cloud cover, like any optical sensor, but the frequency of imagery means that selection of cloud free coverage has not proven to be an insurmountable problem.

However, other optical platforms offer different scale resolutions and may have strengths in appropriate contexts. CBERS, designed primarily for Brazil's needs, has a resolution of around 250 m, giving a more synoptic level of classification than LANDSAT. It also has sensors at higher resolutions, down to 20 m. Alternatively, IKONOS resolves to 5 m, giving fine detail over smaller area, but is prohibitively expensive to use at Guyana's national scale.

In the microwave spectrum, radar imagery is effective in providing synoptic coverage and distinguishing broad biomass classes. Radar imagery has the advantage of not being inhibited by cloud cover, but interpretation beyond simple cover classes is difficult, as there is nothing equivalent to the differential spectral band responses that are available from optical sensors. JERS radar imagery was used as the basis for the Guyana 2001 National Vegetation Map, in combination with a variety of other sources. JERS is no longer functional, but the more advanced ALOS satellite with its PALSAR sensor provides a replacement. However, access to this imagery is much less open than LANDSAT, and is probably restricted to specific project arrangements. In general the situation with radar imagery is one of rapid evolution, but little immediate stability for the development of a system for routine use in a country such as Guyana.

Application to REDD monitoring

The Pöyry (2008) report defines a pathway towards developing a monitoring system geared towards the detection of logging, mining and other change. All the image coverages and software acquired for this purpose, together with other capacity building elements, can also be adapted for REDD monitoring. If the GFC is pursuing this route for monitoring of logging, then dual functionality for REDD is relatively easily achievable.

Alternatively, if the pathway suggested by Pöyry (2008) is not being followed, some specific REDD monitoring activities are required. This involves the routine acquisition of LANDSAT imagery, which is now a well exercised process in GFC. This is followed by a supervised classification based on key indicators from the monitoring plots, including biomass, forest type and other possible criteria. Once a classification algorithm has been researched based on an optimum correlation to the plot data, this can be maintained and applied automatically over subsequent years to generate with relatively little effort summaries of total carbon and carbon change (net fluxes).

Equally, as new and improved formats of imagery become routinely available, the classification process can be recalibrated, between plots and imagery, to update the national carbon accounting.

Constraints to the greater use of satellite imagery

Present limitations to the easier and wider use of SRS within GFC are:

- Access to high-quality imagery from the latest platforms. Generally GFC is restricted by budgetary constraints to using low-cost sources such as LANDSAT. An improved budgetary situation would allow, for example, routine access to radar imagery free from cloud cover constraints.
- Lack of adequate ground truthing data. The monitoring plot program described in this report, once in place, will substantially resolve this.
- Cost of software. The ArcGIS platform currently used is expensive and must be licensed to be extended to additional workstations. However, there are increasingly effective open source alternatives (see eg http://grass.itc.it) for SRS processing. The consultant will test these during this project and assess their feasibility as a longer term solution.
- Training. The project should provide for both in-house and external training for suitably identified candidates.

Conclusions

Overview

This report provides detailed recommendations for a network of biomass monitoring plots, and sampling activities designed to develop local and current, IPCC Tier 3 compliant, biomass coefficients. This work is fundamental to the various options that exists for using SRS images to classify forest cover types and estimate change. Without the baseline plots and biomass coefficients, SRS can at best only offer general and uncertain information about Guyana's forest biomass. This will be insufficient to monitor relatively low rates of deforestation which are likely to be seen in the coming decade.

During the WWF-supported project, of which this report forms one activity (See Annex A), the techniques described here will be piloted and refined. Outreach and consultation activities will be conducted with Amerindian communities and other stakeholders regarding the scope and objectives of this work, which continue the process already started of communicating REDD at as both a conceptual process and a set of practical and tangible processes to be conducted on the ground.

Key report recommendations

- A network of 900 permanent sample plots of 1/10 ha circular design should be established to measure and monitor biomass.
- These should be organised into clusters of 5 plots, and transects of 3 clusters, giving a total of 60 transects.
- Associated with the PSPs should be quadrats to sample fallen deadwood, litter, and soil carbon.
- A separate destructive sample should be taken of trees measured for crown, bole and root biomass, to establish Tier 3 allometric biomass functions for Guyana.
- A biomass laboratory should be established within GFC to determine dry-weights from field samples.

Linkage to other project outputs

This report specifically addresses TOR 6 in Annex A, as noted in the Introduction. Further work is now proceeding on the ground under the direction of MvK to pilot the monitoring plots and biomass sampling. This relates to TORs 4, 7, 8 and 10. DA is is focussing on TOR 1-2, with a view to delivering outputs relative to these by early May 2009. Further integration of the work will then proceed to target completion of the remaining TORs within the timeline to mid-September 2009.

Denis Alder
Marijke van Kuijk
Georgetown, 12th February 2009

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Annex A - Terms of Reference

Denis Alder[1-3, 6], Marijke van Kuijk[4-5,7-12]

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 A - Data recording forms for the Biomass Monitoring Plots

GFC Biomass Monitoring Plot

Cluster No.		Team Leader	
Plot No.		Measurement date	

Georeferencing	Longitude	Latitude	UTM coordinates				
			Zone		X		Y

If no GPS fix possible at the plot centre, give distance and bearing from the above georeference to the plot centre	Distance (m)		Bearing °	

Trees 20 cm dbh and above - use 18 m radius plot

													For height trees only					
Tag number	Species common name	Species Code	Diameter, cm	Height of POM, m	Stem straightness 1-5	Forking 1-5	Decay 1-5	Crown health 1-5	Logging damage 1-5	Fire damage 1-5	Lianas, climbers (count)	Nibbi, Kufa (count)	Distance from tree, m	% to base of tree	% to top of tree	% to top of bole	Bearing from centre, °	Distance from centre, m
Continue on an additional sheet if necessary																		

GFC Biomass Monitoring Plot - Part 2

Cluster No.	
Plot No.	

Soil type	Forest type

Trees 5-20 cm on 8 m radius sub-plot

Tag number	Species common name	Species Code	Diameter, cm

Stumps and dead trees on 18 m plot

Species common name *leave blank if not identifiable*	Species Code	Diameter, cm	Height, m	Reason dead *S=cut stump, F=fire, D=decay, L=logging damage, U=Unknown*

Notes

Litter transect

Transect distance	Deadwood count Pieces > 5 cm □	Litter depth, cm
0-3 m		
3-6 m		
6-9 m		
9-12 m		
12-15 m		
15-18 m.		