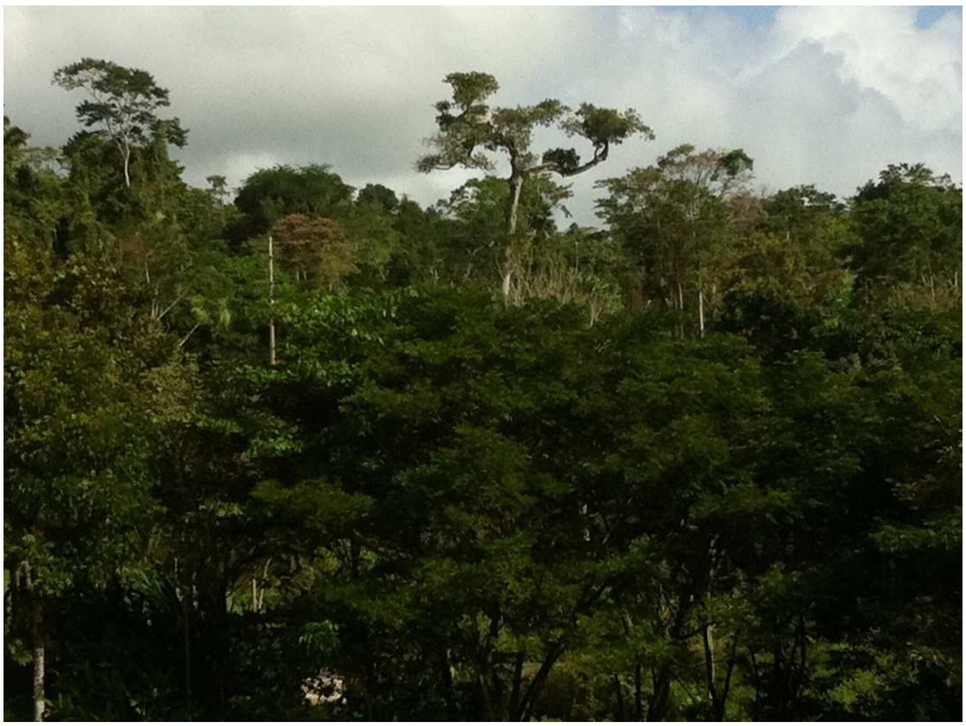
Carbon Storage and Timber Stocks in the Golden Stream Corridor Preserve Toledo District, Belize



PACT
Protected Areas Conservation Trust

YA'AXCHÉ
CONSERVATION TRUST

October 2011

Scientific Forest Services and Systems
Forest Management, Stock Surveying, Carbon Assessment
Precision Forestry, Better Management

Report prepared for Ya'axché Conservation Trust under:

Contract No PF.001

As part of a project titled:

Forest Inventories for Assessment of Environmental Services and Sustainable Extraction Practices

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Cover photo: Ya'axché or Ceiba tree (<u>Ceiba pentandra</u>) near the GSCP as seen from off the southern highway.

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1. Executive Summary

This report details the results of a timber/carbon inventory carried out by YCT personnel on the Golden Stream Corridor Preserve (GSCP) during the months of April to June 2011. The report is targeted for a generalist audience but at the same time it is intended to be capable of clearly articulating statistically reliable estimates of timber and biomass stocks. The inventory was coordinated and managed by YCT and funded primarily through a grant obtained from the Protected Areas Conservation Trust. The consultant, and author, provided a seven day training course to YCT personnel who carried out the inventory. Guidance on optimal inventory procedures and equipment was also provided to YCT, who were responsible for procuring equipment and carrying out the inventory. This arrangement was beneficial for YCT staff who became intimately involved with the study.

In addition to providing the first reliable estimates of timber and carbon value of the GSCP, the implementation of the inventory also had beneficial effects on indigenous communities. Eight members of neighbouring communities and two members of relevant organizations were trained in forest inventory theory and methods as part of this study. Eight of the community members went on to carry out the data collection under the supervision of YCT. For the time being, these community members will possess a skill that is both marketable and intellectually beneficial in that the exposure received allows for greater understanding of the mechanisms of forest conservation via REDD.

The inventory on the GSCP, for the most part, represents a 'first of its kind' innovative timber/carbon inventory for Belize. It is hoped that the usefulness of the data generated from the inventory would serve to act as an example of the value of forest inventory data not only to timber operations but to forest conservation via REDD (Reduced Emission from Deforestation and Degradation).

The results of the inventory support what has been widely speculated about the once abundant timber resource of southern Belize: the resource has been degraded to only a fraction of its former status due mainly to past logging and other disturbances. If a sustainable timber operation were to be implemented on the GSCP today, it would yield an estimated gross revenue of BZ$53,600 per annum, barely enough to cover the operational costs of logging. On the upside, the carbon resource of the GSCP, though not spectacular, is encouraging. Based on observed market prices, the value of total avoided emissions of the GSCP forest ranges from BZ$5 to 27 million, assuming certificates are issued for one-hundred percent of the estimated stock. Even at the lower end of this estimate, annual payments can be quite a significant source of revenue to fund further conservation of the only broadleaf forest corridor connecting the Maya Mountains to the southern coast.

2. Introduction

The Ya'axché Conservation Trust (YCT) manages the Golden Stream Corridor Preserve (GSCP), an area of forest straddling the Golden Stream River in southern Belize. The GSCP was once part of a larger land holding which has a long history of use for logging and agriculture. Presently the GSCP is managed as a private biodiversity preserve which prohibits agricultural land use but may consider sustainable timber harvesting. Other sources of revenue which are compatible with biodiversity conservation, such as carbon offsets, are considered as possible management options. It was necessary to assess both the timber and carbon potential of the GSCP in order to determine what, if any, level of timber harvesting can be allowed sustainably as well as to determine the value of the carbon resource. This report details the findings of a timber/carbon inventory conducted from April to June 2011. The aim of the inventory was to reliably estimate total standing timber and biomass stocks on the GSCP to allow the Ya'axché Conservation Trust to consider potential revenue generation schemes from environmental services and sustainable extraction.

The GSCP bears the scars of past land use activity such as milpa farming and selective logging, the most recent of which occurred 8 to 15 years ago (Bowen-Jones and Pop, 2000). Past land uses as well as biophysical factors were taken into account during the design of the inventory. The inventory, the first of its kind for Belize, combined two objectives – carbon and timber – in one sampling scheme. Tradeoffs had to be made between intensive data gathering for carbon stock estimation and efficiency for timber stock estimation. The resulting inventory design produced adequate precision for both purposes – carbon and timber.

Community involvement and uplifting has been a primary focus of YCT's outreach program. The inventory was designed around the reliance on community workers who could be trained to an adequate level of expertise in order to carry out data gathering tasks and work self-sufficiently in the field. This was accomplished through an intense 7-day training exercise coupled with supervisory visits into the field during the course of the inventory. By all assessments the field inventory was successfully carried out by community members. The results of the inventory are presented in this report along with recommendations for sustainable harvest levels of timber and future data gathering needs.

3. Methods

3.1 Sample Design

A stratified random sampling design with probability proportional to frequency was employed in sampling carbon stocks and standing timber resources in the hurricane disturbed forests of the GSCP.

3.1.1 Stratification

An ortho-rectified, atmospherically and topographically corrected Landsat image dated 2010 was used to identify different forest and non-forest cover types based on expert analysis of spectral response in the image. Highway, infrastructure installments, and other non-forest land features such as herbaceous and mangrove swamp, which together accounted for 197.77 ha, were identified and excluded from the sample area (Table 1). Streams, trails, and roads were identified within the remaining forest areas and appropriate buffers were applied, totaling 228.07 ha, and subsequently deducted from the area of forest. The remaining forest area totaled 5,673.6 ha within which four different forest strata were identified: 10 yr old 'wamil'; 20 yr old 'wamil'; broadleaf hill forest; and lowland broadleaf forest (inclusive of riparian and seasonally inundated forest). The local term 'wamil' refers to regenerating vegetation on fallow land. These strata accounted for 1.1%, 10%, 1.6%, and 87.2%, respectively, of the total forest sample area of 5673.6 hectares (Table 1).

Table 1. Area of the different cover types identified in the GSCP from satellite imagery.

	Area (ha)				
Cover Type	**Broad**	**Working[1]**	**% of Forest**	**% of Non-forest**	**% of Total**
10+ Year Old Wamil	66.59	63.6	1.1	--	1.1
20+ Year Old Wamil	591.26	563.9	10.0	--	9.7
Hill Forest	95.76	95.7	1.6	--	1.6
Broadleaf Forest	5,148.06	4950.4	87.2	--	84.4
FOREST Sub-total	***5,901.67***	***5,673.60***	***100.0***	--	***96.8***
Paved Surface	22.18	--	--	11.2	0.4
Recent Milpa	3.25	--	--	1.6	0.1
Mangrove Swamp	118.87	--	--	60.1	1.9
Swamp	53.47	--	--	27.0	0.9
NON-FOREST Sub-total	***197.77***	--	--	***100.0***	***3.2***
TOTAL	**6,099.44**	--	--	--	***100.0***

[1]Excludes the area of streams, trails, and roads in order to be conservative in the estimate of true forest area. These areas were used to extrapolate per hectare estimates of timber and biomass.

3.1.2 Sampling Intensity

In the absence of a pilot study from which an estimate of coefficient of variation within different forest strata could be obtained, a generalized sample size of 0.8% of the total sample area was thought to be able to provide reliable estimates with confidence limits which were within ±10% of the mean. This expectation was based on experience from previous forest inventories in similar forest types elsewhere in Belize. To achieve the desired precision, 45 ha would have to be sampled. A fixed area rectangular plot size of 0.5 ha was decided upon which required an installation target of 90 plots in order to achieve the desired sampling intensity and reliability of estimates.

The targeted number of plots in each stratum was decided according to area allocation which was then adjusted to provide reliable means for each stratum (Table 2). Due to various factors such as personnel issues, speed of working, and difficulty of movement through the forest, the actual number of plots installed was 63 for a sampling intensity of 0.6%. The *ex post* plot allocation per strata is provided in Table 2. Basically the only stratum compromised by the reduction was lowland broadleaf; however, even with fewer plots the sample intensity was 0.5%, which from experience should be sufficient to achieve the desired level of precision.

Table 2. Plot allocation and sampling intensity by forest strata.

Strata	Working Area	Allocated Plots	Adjusted Plots	Actual Plots	Sampling Intensity
10 yr Wamil	63.6	1	4	4	3.1%
20 yr Wamil	563.9	9	9	10[1]	0.9%
Hilly Broadleaf	95.7	2	4	3	1.6%
Lowland Broadleaf	4,950.4	78	73	46	0.5%
TOTAL	**5,673.6**	**90**	**90**	**63**	**0.6%**

[1]The number increased because a test plot was installed in this stratum during training.

3.1.3 Plot Distribution

Plot location was decided by means of random placement in the GIS with a minimum allowable distance between plots of 300 m to allow for plot length and a maximum allowable distance between plots of 500 m to allow for geo-statistical analyses (Figure 1). Theoretically, the sample area was systematically divided into as many 0.5 ha rectangular plots as would fit, after which plots were selected at random according to the constraints applied.

3.1.4 Plot Size

In disturbed species rich broadleaf forest, a plot size of 0.5 ha has been shown to be the minimum sample unit size required to reliably capture the variability in carbon and timber stocks in tropical forests. Furthermore, the plot shape has been shown from previous experience to be efficiently surveyed. Most carbon assessments in Belize and elsewhere in the tropics have relied on circular plots with 20 m radius (0.12 ha) in a nested design utilizing concentric circles to sample trees of different diameter classes. This approach is both unsuitable for tropical forest conditions in Belize and ineffective at capturing sufficient variability. Large trees which are rare can be under-represented by small plots.

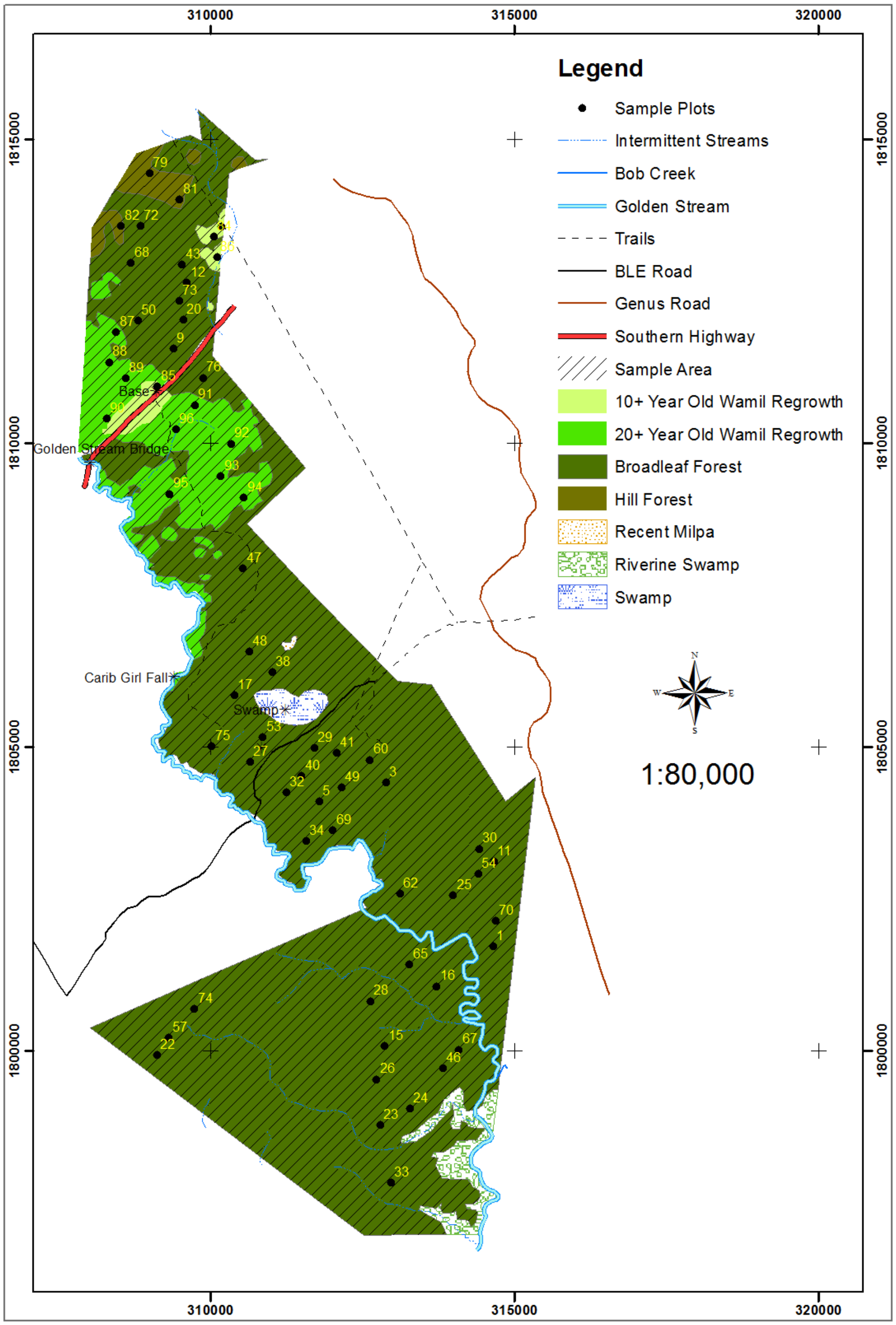

Figure 1. Sample plots randomly distributed across different forest strata in the GSCP.

3.2 Plot Design

Plots were 20 x 250 m rectangular belt transects aligned east to west. Each plot was sub-divided into 10 quadrats each 10 x 50 m in size and numbered 1 to 10 according to the layout in Figure 2. The basic unit of working was the quadrat and each was to be enumerated in turn. A nested sampling design was undertaken to reduce the sampling effort required to reliably sample trees of all sizes. Generally, tropical forests have many more small trees (<25 cm dbh) than large ones. Therefore, the same sampling that is applied to large trees cannot be efficiently applied to small trees. Large trees (≥25 cm) were more intensely sampled using 0.5 ha units (entire plot). Within the same 0.5 ha plot used for large trees, small trees 5 to 9.9 cm and medium trees 10 to 24.9 were sampled in sub-plots of 0.02 and 0.1 ha, respectively.

The plot design used in this study was larger and able to capture more variability than the established carbon sampling methodology used elsewhere (described in Appendix IV). Pearson *et al.* (2005) recommended sizes of circular or square nested plots be: 50 m^2 for trees 5-20 cm dbh; 620 m^2 for trees 20-50 cm dbh; and 1250 m^2 for trees >50 cm dbh. In contrast, this study utilized plots 200 m^2 for trees 5-10 cm dbh; 1,000 m^2 for trees 10-25 cm dbh; and 5000 m^2 for trees ≥25 cm dbh. Similar plot sizes and design are used in other forest inventories across the tropics.

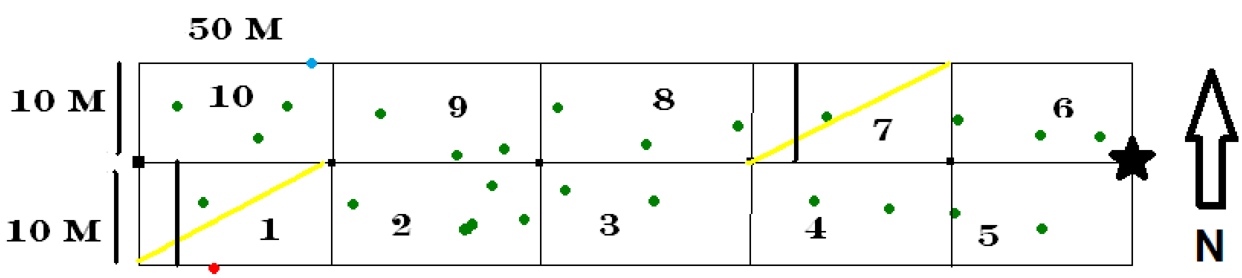

Figure 2. Design of a 0.5 ha sample plot used in this study. *Quadrats 1 and 7 comprised the 0.1 ha sample of trees ≥10 cm <25. The smaller section of quadrats 1 and 7 delimited by the thick black line represents the 0.02 ha sample of trees ≥5 cm <10. The red dot represents a tree just outside the edge of the plot. The blue dot represents an edge tree, every other of which would be counted as inside the plot.*

3.3 Plot Monumentation and Establishment

Plots were located in the forest using a Garmin 60CSx GPS with WAAS corrections accurate to 3-8 m. The coordinates on the GPS unit were recorded, being the centre point of the eastern perimeter of the plot (black star Figure 2). Plots were monumented using semi-permanent marker posts cut from the adjacent forest. Posts were sturdy ~5 cm thick hardwood sticks cut to eye height and flagged with fluorescent tape. The first post was placed at the starting point of the plot, this being the centre of the east end of the plot. A post was placed 10 m away due north and another due south of the starting point to mark the limits of the plot. A series of posts were placed 25 m apart due east along the centre line for a distance of 250 m. Every 50th m marker post was flagged with fluorescent tape and the total distance from the start of the plot was written on the flagging tape.

Plots were established by means of compass and tape survey carried out by team members. The error allowed on distance measurements along the centre line of the plot was ±0.1 m for every 50 m interval. The total error allowed on the length of the 250 m centre line was ±0.5 m. The total error allowed on compass bearings was ±1 degree over 250 m. The fate of edge trees along the plot were determined using compass and distance measurements based on the location of the centre of the tree in relation to plot boundaries. A yellow rope cut to exactly 10 m was used to determine in/out trees at the edge of the northern and southern extent of the plot. Every other tree with its centre positioned exactly on the plot boundary was enumerated.

3.4 Plot Enumeration

Plots were enumerated according to quadrats starting at quadrat 1 and working progressively east to west either in numerical sequence or spatial sequence (i.e. 1, 2, 3…10 or 1, 10, 2, 9…5, 6). It was easier for the team to follow a spatial sequence so as not to return to the starting point. In each quadrat, observations were recorded pertaining to the physical environment such as the presence of streams, roads, or rocky conditions.

In all quadrats all trees ≥25 cm were enumerated (0.5 ha). Trees ≥10 to 24.9 cm were enumerated in quadrats 1 and 7 only (0.1 ha). Trees ≥5 to 9.9 cm were enumerated in the first 10 x 10 m sub-quadrat (if heading in a westerly direction) in quadrats 1 and 7 (0.02 ha).

Diameter at breast height (dbh), taken at 1.3 m from the ground, was recorded to the nearest millimeter. Allowable error on dbh measurements was ±1 mm. All vines and obstructions were removed from the tree prior to measurement. Defects at 1.3 m were dealt with by measuring the diameter immediately above the defect; the same was done for forking and buttresses.

Height was recorded to the nearest meter by means of ocular estimation. Two height measurements were recorded: the first being commercial height or height to the first main branch; and the second being total height or height to the top of the crown. Commercial height was recorded only for trees of timber species ≥25 cm while total height was recorded for trees of all sizes of all species. Allowable estimation error was ±1 m.

Tree grade was visually estimated according to a scale of 1 to 3, with 1 being the best grade and 3 being the worst. Tree grade was recorded only for trees of timber species ≥25 and was a means of quantifying the prevalence of defects in the timber resource. Every tree in the sample was also assessed qualitatively for various factors such as forking, damage, or defects and an appropriate code was applied.

Quality control checks were carried out sporadically during the inventory, at the start by the consultant and subsequently by YCT personnel in the form of the project manager. QC checks involved examining whether standard operating procedures were being adhered to, re-measurement of a random sample of trees, and re-checking species identification. See Appendix for further details.

3.5 Species Identification

Tree species were identified when possible by the inventory team based on their exterior features such as bark, leaves, fruits and other physical characteristics. Common names in Creole, English, Spanish, or Ketchi were then translated where possible to scientific nomenclature using flora checklists compiled for Belize and the Peten region of Guatemala. Unknown species were recorded as such.

3.6 Data Processing

3.6.1 Total height vs. dbh regression

Although the inventory protocol called for total height to be estimated for all trees, ocular estimates were missing for 28 trees. Being such a small portion of the sample (around 0.7%) it was possible to interpolate missing height values from a modeled total height vs. dbh allometric relationship computed from the remainder of the dataset (Figure 3).

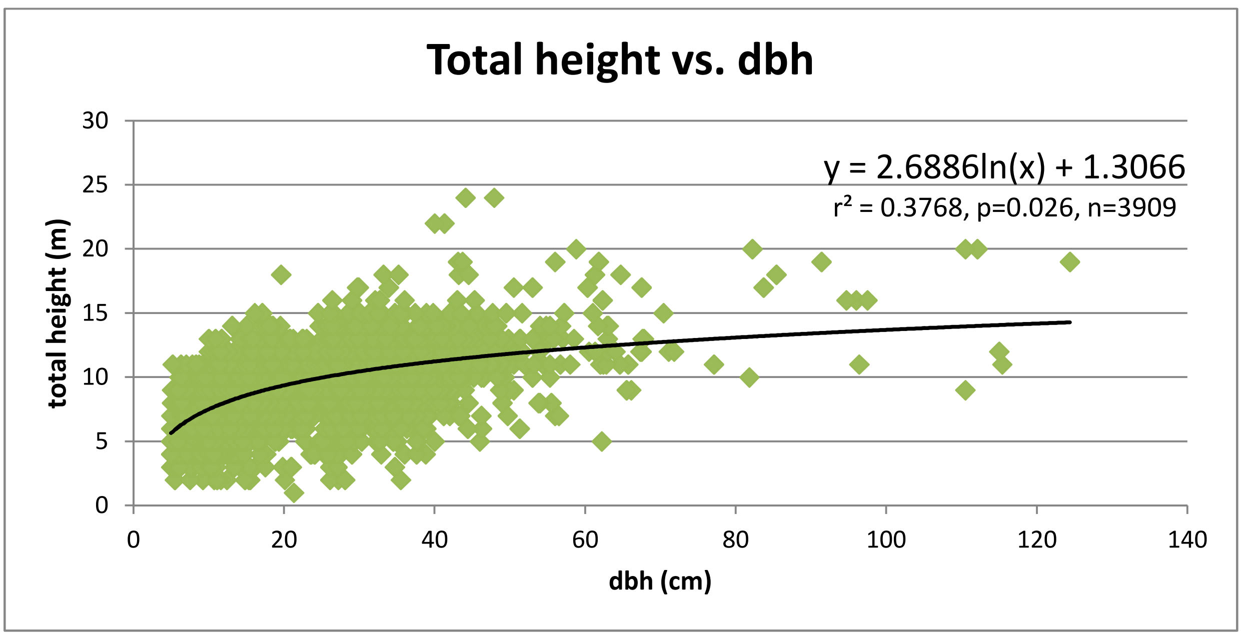

Figure 3. Regression of total height vs. dbh. *The regression equation was used to interpolate missing height data.*

It is worth mentioning that modeling the total height of trees from dbh based on a sample of the population was originally deemed infeasible due to the effect of hurricane Iris, hence total height was to be censused rather than sampled. The hurricane caused severe crown damage and in many cases complete crown removal after which trees re-sprouted a coppice crown (Figure 4). The natural allometric relationship known to exist between tree height and dbh was therefore expected to be compromised due to the disturbance. However, for such a small portion of the sample the errors introduced through the use of an allometric model was deemed negligible.

There were also over 208 missing values of commercial height or about roughly 35% of the population of commercial trees. A regression of commercial height versus dbh did not produce a reliable allometric equation. In order to fill the gaps in the data, the dataset mean commercial height was used. It is expected that the missing values filled in this manner contained greater error than those of total height. However, the effect of the errors was expected to be averaged over the dataset and thus provide a conservative estimate of timber stocks.

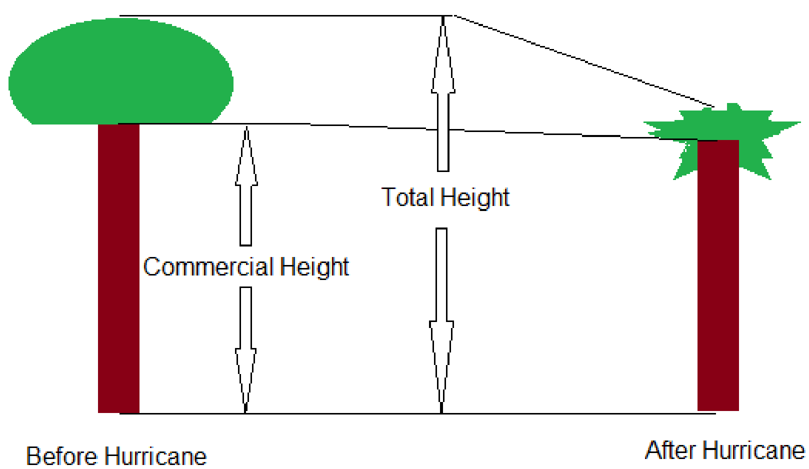

Figure 4. Illustration showing the effect of hurricane Iris on tree height.

3.6.2 Biomass

Biomass values reported here are for live above-ground biomass in trees over a certain diameter, typically 5 cm. The allometric equation for moist tropical forest (utilizing species specific wood density, diameter, and height) in Chave *et al.* (2005) was used as the primary and final equation for all woody trees ≥5 cm dbh. This equation is considered to be the most suitable for neotropical forests receiving annual rainfall of around 2000 to 4000 mm, which applies to the Golden Stream area. It is also more precise than equations which rely on diameter alone (Chave *et al.* 2005). Additionally, height was seen as critically important to include in an allometric equation used for GSCP forests since the height of the majority of trees was reduced through crown removal by hurricane Iris in 2001. Notwithstanding, biomass estimates from two other allometric equations were calculated for comparison: Chave *et al.* 2005 – wood density and dbh only for moist tropical forests; and Brown 1997 – dbh only for moist tropical forests (see Appendix IX). All equations were appropriate in terms of diameter ranges as they included the range of diameter found in the GSCP data, i.e. 5 – 124 cm.

Separate equations, sourced from the IPCC Good Practice Guidance for LULUCF (2004), were used for forest palms of the *Sabal* and *Attalea* genus and for *Pinus* species. For *Cecropia* species a separate allometric equation from Pearson *et al.* (2005) was used. All calculations were performed on individual tree records and then summed per plot and extrapolated to per hectare values. The carbon ratio in biomass used was 0.47 as per Inter-governmental Panel on Climate Change (IPCC) good practice guidance and Verified Carbon Standard (VCS) guidance.

Prior to calculating biomass it was necessary to deal with situations where trees had lost their crown due to hurricane damage. The biomass equation of Chave *et al.* (2005) for moist tropical forest, used in this study, assumes a full crown on a typical tree which accounts for around 30% of the biomass of the tree. Not accounting for missing crowns would lead to an over-estimation of biomass on such trees. Trees which had lost their crown (around 14% of the total sample) typically grew back a dwarfed coppiced crown so that the lost was not total. However, it is difficult to generalize how much of the biomass in the crown was recovered by coppicing. To be conservative, a full deduction was made. Thus, if a tree had lost its original crown and now stands 10 m tall with a coppiced dwarfed crown, the biomass value resulting from the Chave *et al.* (2005) equation was reduced by 30%. This approach was chosen over other methods (such as utilizing biomass expansion factors) as it makes no assumptions about the state of the tree prior to losing its crown, and in the absence of accuracy it is best to be conservative.

3.6.3 Timber

Volume figures reported here are for cylindrical volume over bark to the first main branch for commercial trees only. A 'commercial tree' is any tree ≥25 cm of a species that currently has commercial value on the local timber market. A conservative compensatory factor of -30% was applied to the cylindrical volume of each commercial tree over 3 m in height, irrespective of diameter, in order to account for tapering. In addition, based on the grade applied to each tree during the inventory (1-3), deductions were made to account for curvature, rot, or other defects.

For all pre-commercial trees and non-commercial trees, basal area was calculated instead of volume over bark. The term 'pre-commercial tree' applies to any tree <25 cm of a species that currently has commercial value on the local timber market. The term 'non-commercial tree' applies to any tree of any size belonging to a species that currently has no commercial value on the local timber market.

4. Results and Discussion

4.1 Overall Sampling Error

Based on a sample consisting of 63 plots, the sampling error (indicative of the standard error), resulting from the sample selected being just one of many possible samples, was expected to be 12.4 % which is better than the typical 20% allowed for forest inventories. This means that the sample size was larger than typically required for forest inventories, and thus sample estimates can be considered generally more reliable than what is acceptable. However, for carbon stock estimation, the 95% confidence interval (2 x Std Error) is required to be within 10% of the mean.

4.2 Species Richness

A total of 80 species were identified during the inventory. The possibility exists for more species as there were a total of 695 unidentified trees in the sample (17.6%) and an average of 898 stems ha^{-1} ≥5 cm. Berry *et al.* (2002) reports a stem density of 690.3 stems ha^{-1}, but no mention was made of diameter classes to which this applied. Not including unidentified trees in plots, sampling typically does not account for all species present in a population of trees. However, from the plot data, an idea of the total number of species in the population can be estimated based on the rate of detection per every new plot.

An analysis was performed on the matrix of species count data in order to produce a species accumulation curve which indicates that not all species were seen in any site (Figure 5). As seen in the graph, the species accumulation curve does not appear to approach its theoretical asymptotic limit. This suggests that unseen or veiled species exist on the GSCP which were not detected by the sample size of n=63.

From the species pool analysis, an estimated total number of possible species occurring in the inventory area can be determined. The analysis suggests that the total species present ranged anywhere from 87 to 100 species. The most likely estimate was for a total of 93 species of trees ≥5 cm on the GSCP. Wicks *et al*. (2006) reports a total of 98 species of adult trees in the GSCP, while Wicks *et al.* (2010) reports 114 species of trees but included TIDE owned lands to the south. Neither study reported a diameter limit so the estimates are not readily comparable.

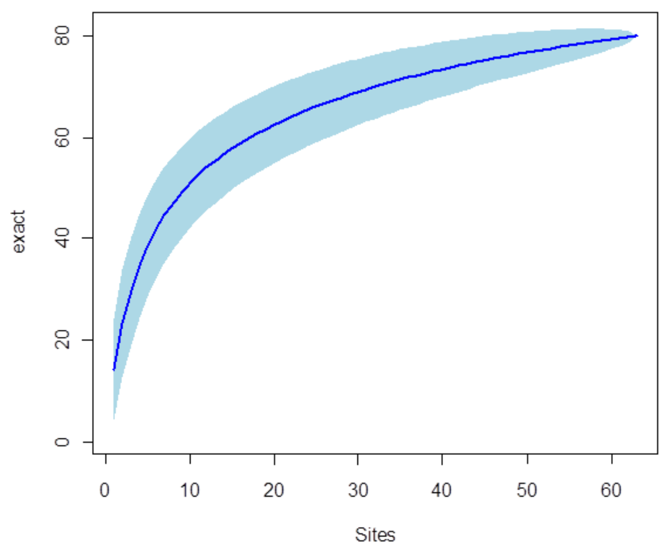

Figure 5. Species accumulation curve from the inventory plot data. *There is high probably that some species were not detected in the inventory due to the limited sample size. The dark blue line represents the model prediction. The light blue band represents the model uncertainty for any given number of plots. (Species accumulation analysis performed in R using Kindt's exact method; species pool estimation performed in R using the Chao and Jacknife model.)*

4.3 Community Composition

The stratification of the sample area into four forest types using the corrected Landsat image appeared to have represented the actual landscape variability well except for one discrepancy. The result of a Non-metric Multi-dimensional Scaling (NMDS) ordination suggested that there were 5 rather than 4 distinct forest types on the GSCP (Figure 6). The broad class 'Lowland Broadleaf' was best divided into 2 classes apparently along an elevation gradient. It appeared that the lower lying areas in the south of the property was covered by a variant of lowland broadleaf perhaps determined by waterlogged conditions. Lowland broadleaf in the northern half of the property was of another variant forest type as suggested by the ordination plot. Species abundance lists for all 5 forest communities are presented in Appendix VIII.

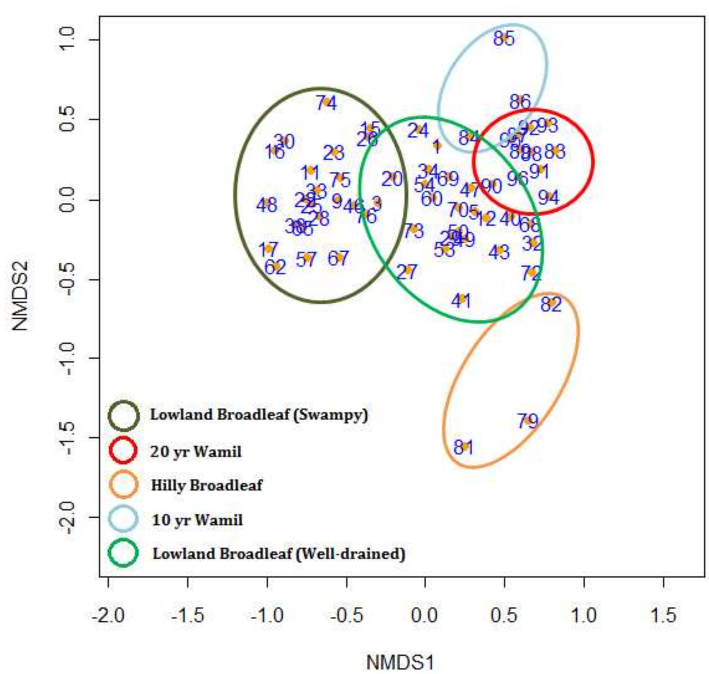

Figure 6. Non-metric Multidimensional Scaling ordination graph of plots in species space. *The ordination analysis positions plots on the graph based on how similar they are to each other in terms of species composition. (Bray dissimilarity was used in the ordination.)*

4.4 Biomass

4.4.1 Adequacy of the Sample

Live above-ground biomass per

hectare was normally distributed (Figure 7) which facilitated the use of parametric and geo-statistics to analyze and interpret the data.

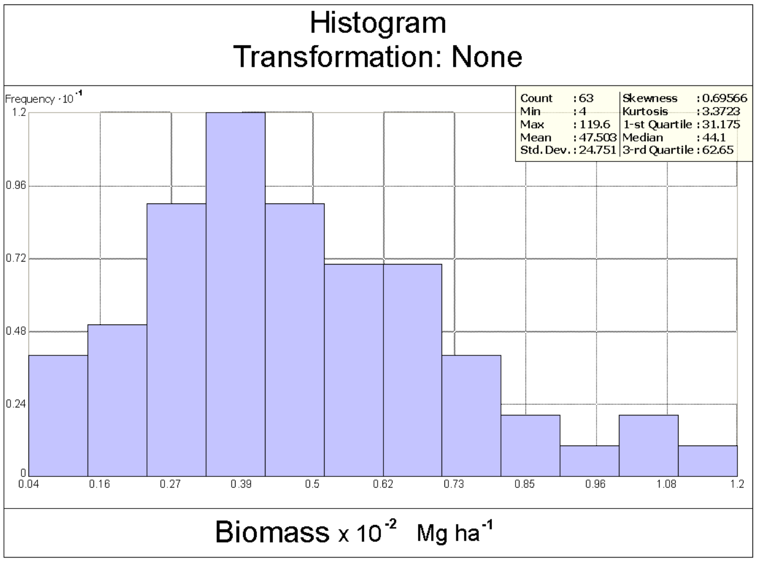

Figure 7. Histogram of biomass per hectare (n=63). *The data were normally distributed (p=0.051, Lilliefors Kolmogorov-Smirnov test).*

As noted by the highlighted row 'CI as % of the mean' (Table 3, below), there is higher variability in the distribution of biomass of large trees (≥25 cm) compared to smaller trees (<25 cm). In other words, a sample of n=63 with sample units of ≤0.1 ha was reliable for estimating the mean biomass per hectare of trees <25 cm, but a sample of n=63 with bigger units of 0.5 ha was not as reliable for trees ≥25 cm.

Table 3. Summary statistics and confidence of the sample means.

Statistic	Biomass Mg ha^{-1} ≥5 to 9.9 cm	Biomass Mg ha^{-1} ≥10 to 24.9 cm	Biomass Mg ha^{-1} ≥25 cm	TOTAL Biomass Mg ha^{-1} ≥5 cm
n	63	63	63	63
∑(sample)	398.466	1060.525	1533.594	2992.6
variance	10.709	74.698	348.252	612.5
CV	51.7 %	51.3 %	76.7 %	52.1 %
mean	6.325	16.834	24.343	47.5
StDev	3.272	8.643	18.662	24.7
Std Error	0.412	1.089	2.351	3.1
90 % CI	0.689	1.820	3.929	5.2
CI as % of mean	10.9	10.8	16.1	11.0
95 % CI[1]	0.825	2.178	4.702	6.2
CI as % of mean	13.0	12.9	19.3	13.0
Sampling Error	12.4%	12.4%	12.4%	12.4%

[1]95% confidence is the level recommended for use in the latest VCS documentation.

Ideally more than 63 plots were required to improve the confidence limits around the estimated mean biomass stocking for trees ≥25 cm; recall the original estimate was for 90 plots.

However, when all tree size classes are combined, the reliability of the total mean biomass stocking improves from 19.3% to 13%, approaching the target of 95% CI as 10% of mean, though not quite meeting expectations. The primary cause for this has more to do with the reduction in the target number of plots than an inadequacy in the sample design. The benefits of using large plots for forest sampling far outweigh those of small plots but the catch is that the large plots capture more variability and thus more plots are required to achieve desired levels of confidence.

The results of the sampling as it pertains to each forest stratum are summarized in Table 4 below. It clearly shows that for the two dominant forest strata (20-yr Wamil and Lowland Broadleaf), the precision was well within the desired criteria of 95% CI as 10% of the mean. Excluding Hilly Broadleaf would easily bring the overall precision within the desired range.

Table 4. Summary statistics and confidence of the sample means per forest stratum.

Stratum	No. Plots	Mean Biomass/ ha (Mg)	Std Dev (Mg/ha)	Variance (Mg/ha)	CV	Std. Error	95% CI	95% CI as % of mean
10-yr Wamil	4	29.95	16.06	257.92	54%	2.09	4.18	13.96
20-yr Wamil	10	65.86	18.47	341.14	28%	2.27	4.54	6.89
Hilly Broadleaf	3	31.00	27.15	737.12	88%	3.51	7.02	22.64
Lowland Broadleaf	46	46.11	24.56	603.19	53%	1.25	2.50	5.42

A more acceptable way to improve the reliability of these estimates to within the desired precision would be to install additional plots. One can calculate *ex-post* sample sizes for different forest strata that would result in estimates which were within the desired range of precision. Table 5 below shows the results of sample size calculation. As seen in the table, the recommended number of plots is slightly more (13%) than the original target of 90 plots. The results of the inventory could have been improved if all original 90 plots were surveyed.

Table 5. Results of ex-post sample size calculation performed per forest stratum.

Stratum	Area (ha)	Mean Biomass/ha (Mg)	Std Dev (Mg/ha)	Plot Size (ha)	Variance (Mg/ha)	CV	No. Plots	Rounded No. Plots
10-yr Wamil	63.6	29.95	16.06	0.5	257.924	54%	1	4
20-yr Wamil	563.9	65.86	18.47	0.5	341.141	28%	8	8
Hilly Broadleaf	95.7	31.00	27.15	0.5	737.122	88%	2	4
Lowland Broadleaf	4950.4	46.11	24.56	0.5	603.194	53%	86	86
Total number of plots required							**97**	**102**

4.4.2 Mean Live Above-ground Biomass per Hectare

Mean live above-ground biomass (Mg) per hectare in trees ≥5 cm was 47.5 ±6.2 (95% CI). This is rather low for tropical forests in the region but is to be expected in a hurricane impacted forest. It is too early to provide any estimate of uncertainty, but ongoing research in hurricane impacted forests in the Columbia Forest Reserve (a few miles north-west of GSCP) suggests that hurricane Iris had the effect of instantaneously decreasing live biomass by up to 50%. Furthermore, post-hurricane biomass accumulation appears to be dominated by low wood density species. Both of these factors, coupled with the stringent choice of allometric equation (must include a parameter for wood density and height), were likely to contribute significantly to the explanation of the low mean biomass observed on the GSCP.

The mean ratio of different components of live above-ground biomass can be estimated from the sample data. On average the importance of the different components in terms of their contribution to total biomass per hectare was: large trees > medium trees > small trees. The ratio of biomass in large trees : medium trees : small trees was 5 : 4 : 1. In terms of the ratio of biomass in small trees to large trees, it was around 1 : 4, and that of medium trees to large trees was 2 : 3.

These ratios are useful in that if data exists from a commercial inventory (≥25 cm trees only), the biomass in the other components can be estimated. Such ratios assist in the estimation of total live above-ground biomass and in the estimation of the value of the carbon resource when intensive sampling is not feasible. The data collected in the present study is the most intensive timber/carbon sampling scheme in southern Belize. Coupling timber with carbon in one sampling exercise further assists in the development of reliable ratios of live above ground biomass which can be applied to data from inventories designed solely for timber assessments.

Before any statistical or geostatistical analyses were performed on the data, the biomass per hectare data from the sample plots was visualized in the GIS. It was clear from the onset that there were strong trends in biomass related to vegetation type and location. The north of the GSCP appeared to have higher biomass levels in general than the south (Figure 8). It became necessary then to investigate the observed geographical trends in the data. One method by which this may be done is through geostatistical analyses.

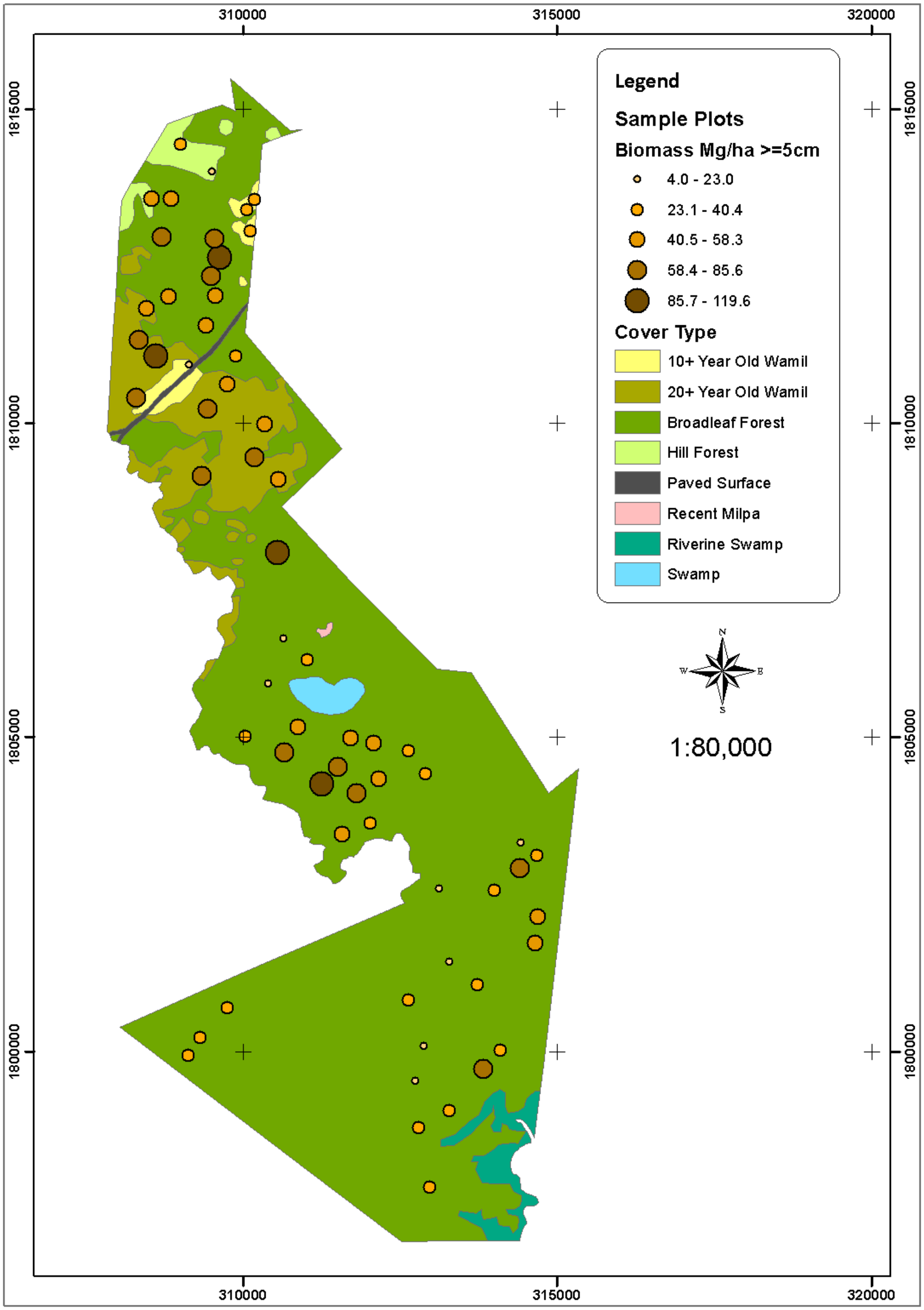

Figure 8. Plot size emphasized relative to biomass per hectare to show spatial patterns.

A radial basis function was applied to the georeferenced plot biomass data to predict landscape biomass levels across the GSCP. The root mean square error (RMSE) of the predicted versus measured biomass was ±20.468 Mg ha^{-1} with an overall mean prediction error of 0.723 Mg ha^{-1}. The very low mean prediction error suggested that predicted values were on average neither over- nor under-estimating biomass levels across the GSCP. However RMSE was large accounting for around 40% of the mean. This meant that on average there was only a 60% chance that predicted biomass at any given point was representative of the actual biomass and that the prediction was not biased. The result of the geostatistical analysis is presented below.

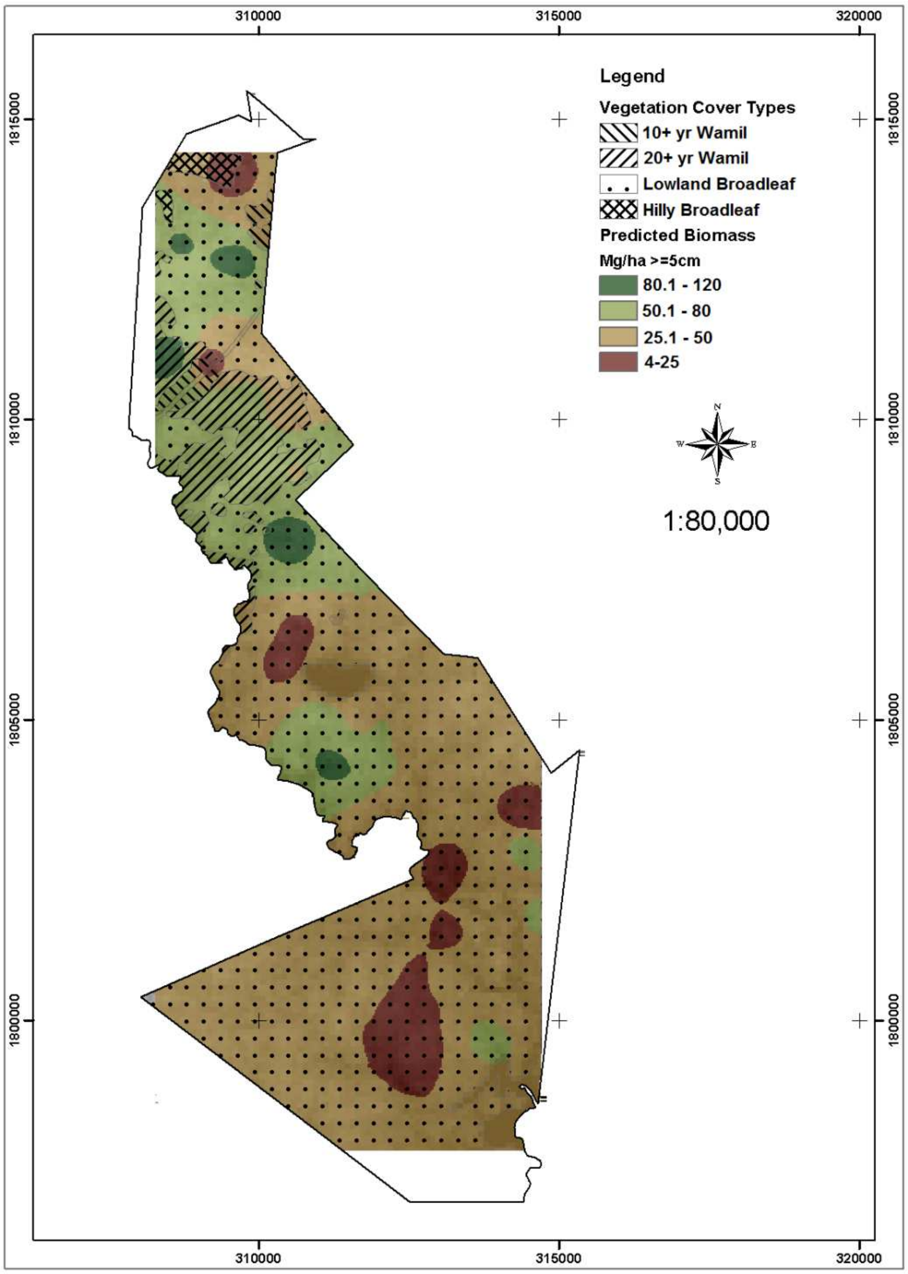

Figure 9. Predicted landscape biomass stocking indicating areas of high to low biomass.

It can be seen in Figure 9 that on average the highest biomass stocking per hectare was within re-growing 'wamil' around 20 years old. This is not intuitive as it was expected that on average highest biomass would be contained within the lowland broadleaf forest. However, disturbance patterns have to be taken into account when interpreting these results. The broadleaf forest was extensively logged in the 70's, 80's and 90's resulting in the removal of large quantities of hardwood species such as Mahogany. The logged over broadleaf forest was then struck 10 years ago by a category 4 hurricane with winds peaking at 145 mph which further reduced biomass by killing large trees and breaking the crowns off the majority of survivor trees. Forest dynamics in hurricane damaged forest is such that the majority of new growth is dominated by light woody species. In contrast, the 20 yr old 'wamil' was cleared 20 years ago for milpa farming and due to the absence of large trees at the time of the hurricane 10 years ago, biomass levels were not reduced as much as in the broadleaf forest. It can be expected then that growth has accelerated within the 20 yr old 'wamil' and that cohune palms will be dominant, leading to higher than expected biomass levels. This demonstrates the conservation importance, in terms of carbon conservation, of secondary forests.

A one-way ANOVA test on mean biomass per hectare across different vegetation types revealed a significant effect of vegetation type on biomass ($p=0.025$, $F=3.336$). Although, differences in sample sizes between forest strata may influence these results, the number of plots per strata was proportional to their area. The significance of the differences in mean biomass between strata should be interpreted with caution. Notwithstanding, 'lowland broadleaf' and '20-yr Wamil' exhibited the greatest difference (Figure 10), and had the majority of plots.

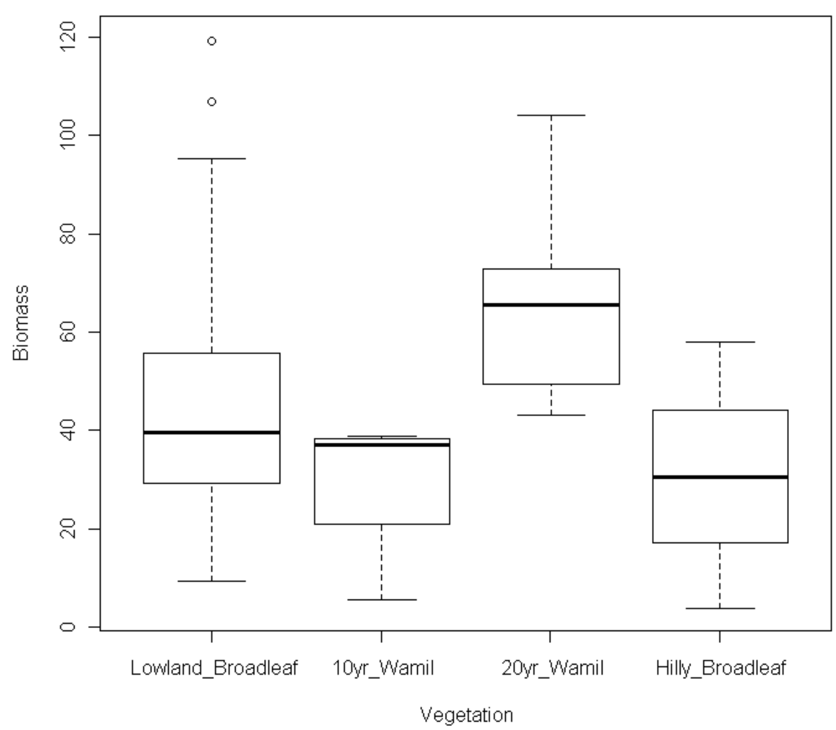

Figure 10. Box and whiskers graph showing biomass by forest strata. *Dark line is the median, limits of boxes are quartiles, and whiskers represent the data range. Circles represent outliers.*

Table 6 shows the actual mean biomass values within the different vegetation types. In addition to clear differences in mean biomass stocking across different forest strata, there is also a clear difference in mean elevation. It is known from studies in the Chiquibul forest that micro-scale variation in elevation (and hence drainage) can drastically influence species composition and abundance (Penn *et al.* 2004).

Table 6. Mean biomass (± std. error) and mean elevation in different forest strata.

Vegetation	Mean Biomass Mg ha^{-1}	Mean Elevation m
10 yr Wamil	29.95 ±8.03	30.75 ±2.09
20 yr Wamil	65.86 ±5.84	38.60 ±2.27
Hilly Broadleaf	31.00 ±15.67	54.00 ±3.51
Lowland Broadleaf	46.11 ±3.62	28.57 ±1.25

In order to investigate the difference in elevation across forest strata, the data were tested using a one-way ANOVA. The results were significant at the p=0.05 level. Figure 11 shows the relationship between forest strata and elevation and suggests an elevation gradient across forest strata with lowest mean elevation in Lowland Broadleaf and highest in Hilly Broadleaf. Notably, '20-yr Wamil', the strata with the highest mean biomass per hectare, appears to be growing on higher elevation sites suggesting better drainage. Forests growing on sites with good drainage generally exhibit better growth, which may imply higher biomass stocks. It is also not surprising that sites with good drainage were chosen for agricultural areas in the past.

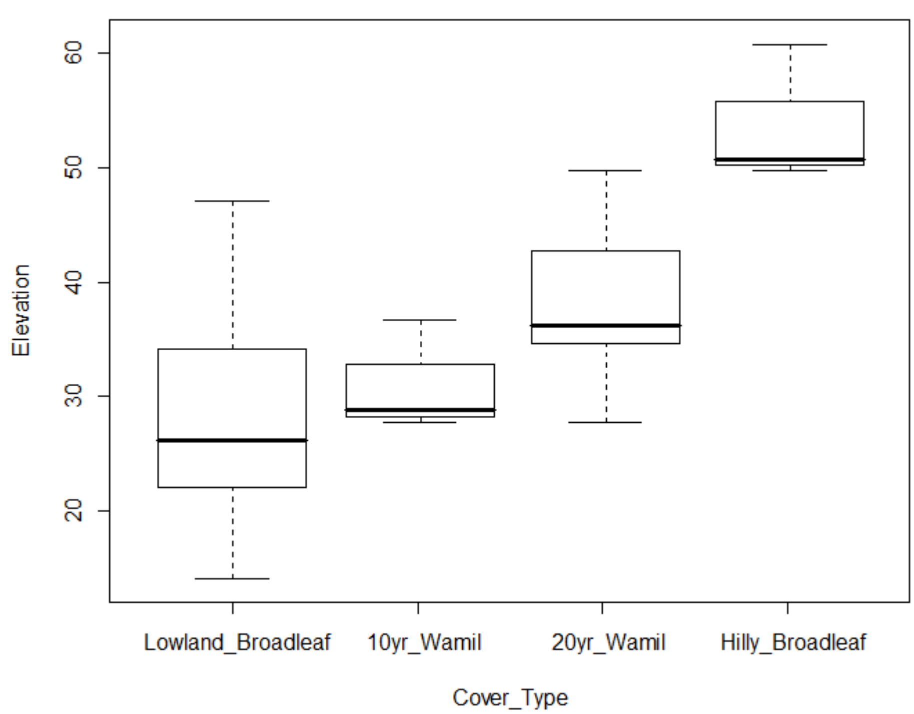

Figure 11. Box and whiskers graph showing elevation by forest strata. *Dark line is the median, limits of boxes are quartiles, and whiskers represent the data range. Circles represent outliers.*

Figure 12 (below) illustrates the spatial relationship between elevation and forest strata. Elevation increases from low lying areas in the south to upland and exposed hilly areas in the north. Biomass stocking also appears to follow this south to north trend (refer to Figure 9).

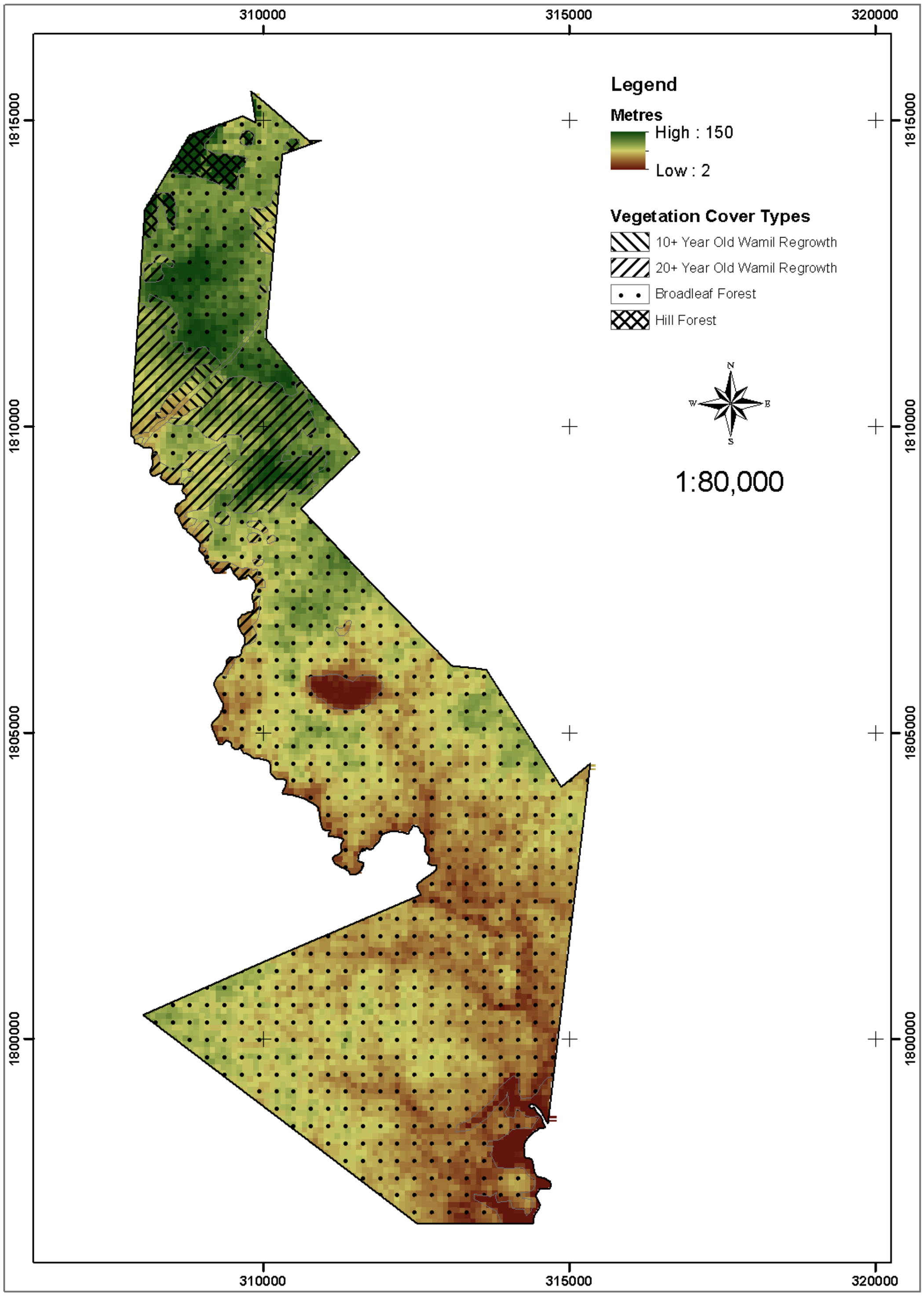

Figure 12. Elevation in relation to forest strata types in the GSCP.

4.4.3 Total Live Above-ground Biomass

There can at times be much skepticism regarding biomass estimates for tropical forests given the questions over choice and precision of allometric models and the variability inherent in tropical forests. Estimating the total biomass in the GSCP by relying on different sources of the total rather than a singular source was considered the most conservative approach.

The landscape biomass layer as predicted by the RBF provides a means to estimate total live above-ground biomass in the GSCP. Each 1 ha unit contains a predicted biomass value and this can be summed over all 5,673.6 ha. Another more traditional method is to extrapolate the sample mean to the entire sample area of 5,673.6 ha. Extrapolation can also be done within each forest stratum using stratum means to preserve inherent variability. The total per stratum is then summed to obtain an overall total. The results of the three different approaches to estimating total biomass stocks are presented in Table 7.

Table 7. Total biomass on the GSCP as determined using three different approaches. *Stratum totals are in brackets. There is not a large difference between the first two estimates.*

Method	Area (ha)	Mean Biomass Mg ha^{-1} ≥5cm ±95% CI	Total Biomass Mg ≥5cm
Traditional	5,673.6	47.5 ±6.20	269,496
Stratum mean	63.6[a]	29.95 ±4.18 (1,905)	270,273
	563.9[b]	65.86 ±4.54 (37,138)	
	95.7[c]	31.00 ±7.02 (2,967)	
	4950.4[d]	46.11 ±2.50 (228,263)	
Geostatistical	5,673.6	42.30 ±4.50	240,090

[a]10-yr Wamil; [b]20-yr Wamil; [c]Hilly Broadleaf; [d]Lowland Broadleaf

The first two methods agreed very well while the geostatistical total provided a sharp contrast to the results of the other two. It is not surprising that the geostatistical total was less than the total using the means, due to the fact that the geostatistical analysis takes into account the inherent variability across the landscape rather than leveling that variability out through an average. The more conservative estimate is usually preferred in carbon stock estimation.

Total live above-ground biomass (≥5 cm) contained within the sampled forest (excluding swamps, mangroves and other land cover types) ranges from 240,090 to 270,273 Mg. More specifically, the estimated total biomass contained within forests on the GSCP is around 259,953 ±30,183 Mg. The total is the mean of the three different methods and the error is taken to be half of the range. The error around the estimated total biomass on the GSCP is within 11.6 % of the total, which is near the targeted 10%.

4.4.4 Value of the Live Above-ground Carbon Resource

The VCS guidelines recommend using 47% as the proportion by mass of carbon in bone-dry wood (biomass) for the purposes of estimating forest carbon stock. Total live above-ground carbon in forests on the GSCP is thus estimated at 122,178 ± 14,186 Mg. One megagram (Mg) is equivalent to a metric ton (t) and the mass ratio of C to CO_2 is 3.667; therefore, the carbon dioxide equivalent of the carbon stock is 447,986 tCO_2eq. The prices commanded by avoided deforestation projects in the voluntary carbon market over the past few years have ranged from $6 to $30 USD per tCO_2eq. The value of the total live above-ground carbon resource on the GSCP as avoided emissions can thus be estimated at $2,687,916 USD (BZ$5,375,832) at the lower end of the spectrum to $13,439,580 USD (BZ$26,879,160) at the higher end. These figures represent simply the value of the carbon resource as avoided emissions and not the value that a REDD project on the GSCP would have. It does indicate, however, that a potential REDD project can generate substantial revenue for protection and management of the GSCP. Estimating scenario carbon stocks is outside the scope of this consultancy but under the assumption that the value of the REDD project is around BZ$5 million, and assuming a project period of 20 years, we can produce a rough estimate of annual payments of BZ$250,000 per annum for a REDD project.

4.5 Timber

4.5.1 Adequacy of the Sample

Volume and basal area per hectare were not normally distributed (Figure 13, left and right, respectively), which complicated the use of parametric statistics. Log-transformation did not produce a normal distribution in the transformed data which further complicated the analysis.

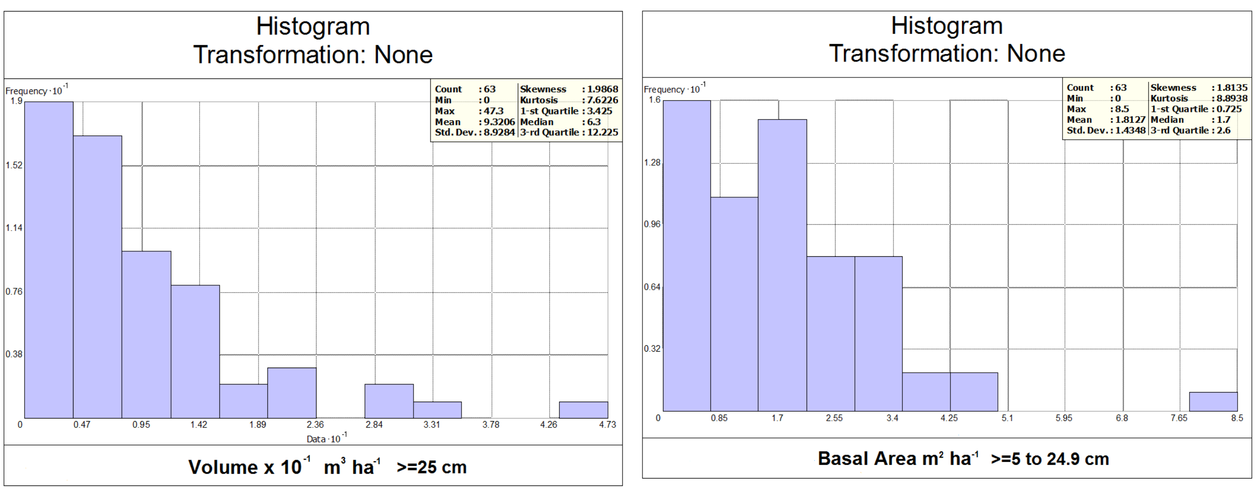

Figure 13. Histogram of plot volumes (m^3 ha^{-1}) ≥25 cm, left, showing an inverse-j distribution. *Right, histogram of plot basal area (m^2 ha^{-1}) ≥5 cm <25 showing a non-normal distribution.*

Typically, parametric statistics are reported for forest inventories of this type, despite the usual inverse-j distribution of the data. To maintain high standards of reliability in the estimates, the data was 'bootstrapped' which allowed the calculation of standard error and confidence intervals of the means by using simulated sampling similar to Monte Carlo simulation methods. The data is sampled with replacement 1000 times and each time the mean is calculated. From the distribution of the bootstrapped mean, an estimate of standard deviation of the mean and hence confidence interval can be obtained.

As noted by the 'CI as % of the mean' for the different estimates in Table 8, the sampling effort was adequate for reliably estimating the timber resource on the GSCP. For all estimates the CI as % of the mean was better than the target of 10 %. The mean volume per ha of trees ≥25 cm was 9.27 (±0.279 95% CI) m^3. For pre-commercial and non-commercial stems, the basal area per ha was 1.81 (±0.046 95% CI) m^2, rather low for disturbed forests of this type. This probably implies dominance by timber species among large trees, but little recruitment over all.

Table 8. Summary statistics and confidence levels for timber basal area and volume per hectare.

Statistic	Basal Area m^2ha^{-1} >=5 to 9.9cm	Basal Area m^2ha^{-1} >=10 to 24.9cm	Volume m^3ha^{-1} >=25cm	Total Basal Area m^2ha^{-1} >=5cm‡
n	63	63	63	63
∑	28.398	86.090	586.934	114.488
variance	0.318	1.313	79.725	2.077
CV[1]	16.190	10.658	11.931	10.040
mean	0.448	1.362	9.270	1.813
StDev[1]	0.073	0.145	1.106	0.182
Std Error[1]	0.009	0.018	0.139	0.023
90% CI[1]	0.015	0.031	0.233	0.038
CI as % of mean	3.408	2.244	2.512	2.114
95% CI[1]	0.018	0.037	0.279	0.046
CI as % of mean	4.080	2.685	3.006	2.530
Sampling Error	12.35%	12.35%	12.35%	12.35%

[1]*the source of the statistic is from the bootstrapped sample after 1000 permutations.*
‡*applies to pre-commercial stems <25 cm dbh and all non-commercial stems ≥5cm.*

4.5.2 Diameter Distribution Curves

A total of 27 presently commercial species were identified in the inventory out of a total of 80 identified species. The remainder was comprised of potentially commercial species, non-commercial species, or unknown species. This report details volumetric and financial data for presently commercial species only. The data in this section is presented as per hectare values of abundance, commercial volume (of stem), basal area, or dollars. For example, the diameter distribution curve pertains to abundance per hectare for all commercial species or non-commercial species. Stand tables show abundance per hectare of commercial species while stock tables show volume or basal area per hectare.

The diameter distribution curve of all timber species (Figure 14) is typical of logged over forests in Belize. There are a large number of trees in the smaller diameter class; the number rapidly decreasing going into larger diameter classes. Non-commercial species dominate the GSCP forest as observed when comparing the two diameter distribution curves (Figures 14 and 15). The diameter curves aim to show the general pattern of distribution of stems across the various diameter classes and are not typically log-transformed for forestry purposes. For exact abundance values per diameter class, see Stand Tables in Appendix IV.

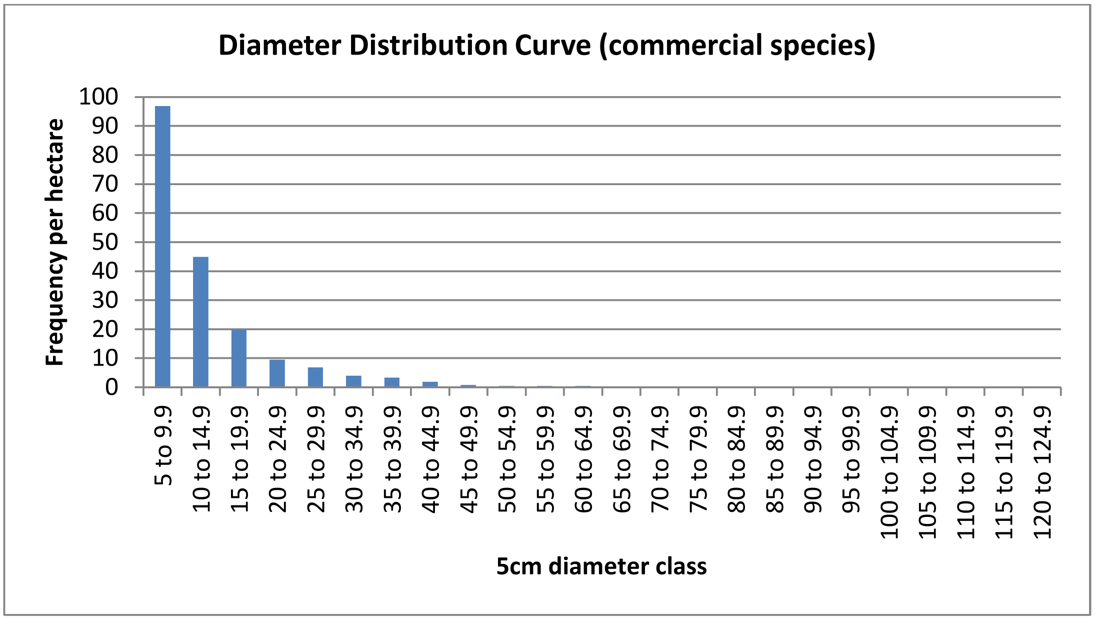

Figure 14. Diameter distribution curve for commercial (timber) species on the GSCP.

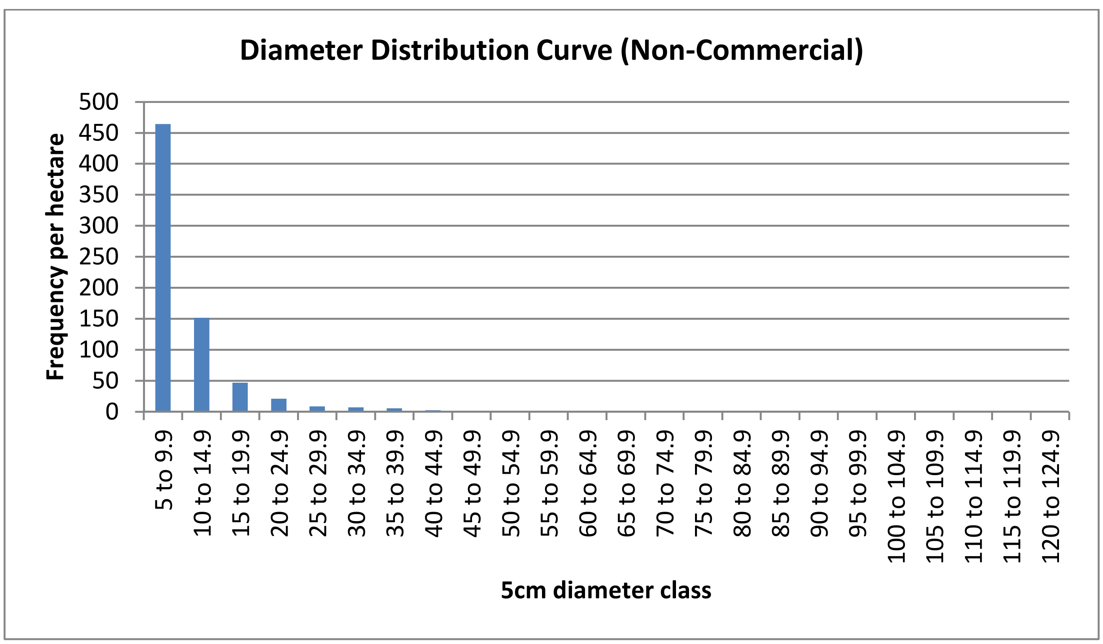

Figure 15. Diameter distribution curve for non-commercial species on the GSCP.

The ratio of abundance (stems ha^{-1}) of commercial to non-commercial species ≥5 cm per ha on the GSCP is on average 1 : 4, i.e. there is a 20% chance that a given tree ≥5 cm will belong to a commercial species. This is a poor ratio and indicates that the value of the forest as a whole for timber might be low. However, selective logging is such that only the larger trees of commercial species are harvested. In this case the ratio of commercial to non-commercial species ≥45 cm improves to 3 : 2, i.e. there is a 60% chance that a given tree ≥45 cm will belong to a commercial species. This is only an indicative index, however, as the economics of logging is such that a single well stocked species such as Mahogany can compensate for scarcity of other species. Species such as Mahogany are considered 'make or break' species, in that if a forest is poorly stocked with Mahogany yet richly stocked with other species it is probably not worth logging. As seen later in this report, this ratio has significant implications for the viability of forest management on the GSCP.

4.5.3 Mean Timber Stocks per Hectare

4.5.3.1 Stand and Stock Tables

Full stand and stock tables are reported in the Appendix due to their large extent. A summary stock table is presented here for stems ≥25 cm for select species of higher commercial importance. A quick look at Table 9 reveals that among these select higher importance species the most abundant on the GSCP was Nargusta. Mahogany was the second most abundant species of higher importance (actual rank among all commercial species was 3rd). Rosewood, a species currently receiving great attention due to over-exploitation in Toledo, was the 4th most abundant among the higher importance species (actual rank was 6th out of 27). Yemeri, a species receiving much attention on the local market as construction lumber, ranked at number 3 (actual rank was 4th). This is good news for species such as Mahogany and Rosewood, two of the most over-exploited species in Belize. They are still quite abundant, compared to less valuable species, despite decades of selective logging. This may indicate something about the resilience of these species to disturbance such as logging, hurricanes, and milpa farming.

Despite the good news for the two most valuable species, there is certainly a great lack of commercial volumes of the more traditional timber species such as Santa Maria and Sapodilla. In fact, there is a void of commercial volume (≥45 cm assumed Minimum Cutting Diameter [MCD]) as well as a void of ample replacement for all species in Table 9, except for Nargusta, Yemeri, and Rosewood. Curiously, there was an exceptionally good stocking of Mahogany at the tail end of the diameter distribution, but this is typical of forests in Belize. Past logging in richly stocked forest tended to ignore some of the largest trees as they typically displayed butt rot which reduces the amount of recoverable lumber from a log. For this reason many forest inventories in Belize show this same pattern of higher than usual stocking in the largest diameter classes for Mahogany. It can be considered a false sense of timber volumes.

Table 9. Snapshot of the stock table showing mean m^3 ha^{-1} for high value species.

Diameter Class	Nargusta	Mahogany	Yemeri	Rosewood	Salmwood	Bastard Rosewood	Pine	Santa maria	Sapodilla	TOTAL
25 to 29.9	0.72	0.00	0.04	0.10	0.11	0.01	0.00	0.01	0.00	**1.0**
30 to 34.9	0.70	0.00	0.04	0.05	0.04	0.01	0.00	0.01	0.00	**0.8**
35 to 39.9	0.87	0.00	0.09	0.07	0.01	0.00	0.00	0.01	0.00	**1.0**
40 to 44.9	0.64	0.02	0.08	0.09	0.00	0.00	0.00	0.00	0.00	**0.8**
45 to 49.9	0.33	0.00	0.03	0.02	0.03	0.03	0.05	0.00	0.00	**0.5**
50 to 54.9	0.10	0.00	0.10	0.03	0.00	0.00	0.05	0.00	0.00	**0.3**
55 to 59.9	0.24	0.07	0.04	0.02	0.00	0.00	0.00	0.00	0.00	**0.4**
60 to 64.9	0.27	0.11	0.00	0.00	0.00	0.06	0.00	0.00	0.00	**0.4**
65 to 69.9	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.1**
70 to 74.9	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.1**
75 to 79.9	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.0**
80 to 84.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.0**
85 to 89.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.0**
90 to 94.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.0**
95 to 99.9	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.0**
100 to 104.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.0**
105 to 109.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.0**
110 to 114.9	0.09	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.4**
115 to 119.9	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.3**
120 to 124.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.0**
TOTAL	**5.1**	**0.8**	**0.7**	**0.5**	**0.3**	**0.1**	**0.1**	**0.1**	**0.0**	**7.5**

In terms of potential crop volumes expected per hectare (i.e. volume ≥MCD and <100 cm) the values do not look encouraging. Note that potential crop volume differs from purely commercial volume; the latter refers to the volume of all trees that are of commercial size (i.e. ≥MCD). Potential crop volume is considered the sustainable yield for a species if a number of 'sustainable' criteria are first met. If the criteria are not met, the species cannot be harvested as the potential crop volume would be 'unsustainable'.

The sustainability of the potential crop volume was determined using the Forest Planning and Management Project recommended model which incorporates criteria such as minimum residual stocking, minimum cutting diameter, minimum seed tree stocking, annual mortality, and an ecological restriction on the harvesting of large trees ≥100 cm (Bird 1998). This is the model recommended for use in the broadleaf forests of Belize (see Appendix IV for the model in tabular form).

Table 10 shows the potential crop volumes per hectare (or the expected annual sustainable yield per hectare) and per compartment assuming a compartment size of 142 ha (5,673.6 ha ÷ 40 yrs – the standard rotation length for Belizean forests).

Table 10. Sustainable yield of all commercial species on the GSCP. *In this example, Potential Crop Volume = Sustainable Yield if certain criteria are met by the species (Appendix IV).*

Species	MCD (cm)	Potential Crop Volume m^3 ha^{-1}	Annual Sustainable Yield m^3 ha^{-1}	Total Annual Sustainable Yield m^3	Estimated Gross Annual Income (BZ$)[1]
Banak	50	**0.12**	**0.12**	**17.37**	**$3,678**
Barbajolote	50	**0.00**	NA	NA	NA
Billy webb	50	**0.00**	NA	NA	NA
Bitterwood	50	**0.18**	**0.18**	**25.11**	**$3,721**
Breadnut	50	**0.00**	NA	NA	NA
Cabbage bark	45	**0.00**	NA	NA	NA
Carbon	50	**0.00**	NA	NA	NA
Cortez	50	**0.00**	NA	NA	NA
Hobillo	50	**0.00**	NA	NA	NA
Hormiga	50	**0.00**	NA	NA	NA
Ironwood	50	**0.08**	ns	ns	NA
Mahogany	60	**0.11**	**0.11**	**15.13**	**$8,007**
Mayflower	50	**0.04**	ns	ns	NA
Mountain kaway	50	**0.14**	**0.14**	**19.25**	**$2,853**
Mylady (red)	45	**0.00**	NA	NA	NA
Nargusta	50	**0.85**	**0.85**	**120.73**	**$23,006**
Pine	35	**0.09**	ns	ns	NA
Poisonwood (black)	45	**0.00**	NA	NA	NA
Prickly yellow	50	**0.00**	NA	NA	NA
Redwood	50	**0.00**	NA	NA	NA
Rosewood	45	**0.07**	**0.07**	**9.95**	**$7,375**
Bastard Rosewood	50	**0.06**	ns	ns	NA
Salmwood	50	**0.00**	NA	NA	NA
Santa maria	50	**0.00**	NA	NA	NA
Sapodilla	50	**0.00**	NA	NA	NA
Tambran	50	**0.53**	ns	ns	NA
Yemeri	45	**0.17**	**0.17**	**23.44**	**$4,964**
TOTAL		**2.42**	**1.63**	**230.98**	**$53,603**

[1]Based on mill conversion efficiency of 50% and current market prices for rough cut lumber.
[2]Note that only at an MCD of 45cm is Rosewood sustainably harvestable on the GSCP. Generally, however, Rosewood is cut from as small as 35cm elsewhere in Toledo.

'ns' means that the potential crop is not sustainable.

'NA' means that a species has zero potential crop volume due to scarcity.

4.5.4 Total Standing Timber Stock

Based on the total per hectare figure for commercial volume of all timber species, 9.27 m^3 (Table 8), it can be estimated that the total commercial volume ≥25 cm of future and current timber on the GSCP is approximately 52,594 ±1,322 m^3. The confidence interval around the estimated total commercial volume on the GSCP is 2.5%, better than the targeted 10%. Total standing basal area of timber species <25 cm in diameter (a major part of future timber stocks) is approximately 10,286 ±216 m^2. Interestingly, a biomass expansion factor could be applied to these values in order to estimate biomass in the absence of absolute measurements.

In terms of actual current sustainable volume on the GSCP, the property-wide total is approximately 9,248 m^3. This is not a particularly encouraging stock especially considering that half would go to wastage during conversion to lumber.

4.5.5 Value of the Total Standing Timber Stock

Based on the above totals, and applying an average timber value across all species of BZ$1 per boardfoot of rough cut lumber, it can be estimated that the total value of the commercial timber stock ≥25 cm is approximately BZ$11,123,631. However, this figure is misleading as it assumes all 27 species could be commercialized and all volume of trees ≥25 cm liquidated at once. Clearly this is not how forest management operations work, so a better figure of the value of the standing timber stock is obtained by using the total current sustainable volume (9,248 m^3). Based on this, the estimated total value of the standing sustainable timber stock is approximately BZ$1,955,952 or close to 2 million BZ dollars. Although this figure is a more appropriate estimate of the value of the timber stock on the GSCP it must be interpreted with caution as under a forest management operation this total value would be amortized over a period of 40 years as gross income from annual harvests.

5. Conclusions

The estimated total carbon stock produced in this report represents the best estimate based on non-biased methods and estimation protocol. It must be noted, however, that the value placed on the total carbon stock, although a fairly robust estimate, is only indicative of the actual economic value of the carbon stock in the forest. The sale value of any REDD project ultimately depends on several factors: carbon stock per hectare, area of forest approved, market prices, achievable sale prices, without-project scenario carbon stocks, and other factors which may reduce or raise the value of the carbon credits such as leakage or biodiversity conservation benefits of the project. This report has presented a robust and defensible estimate of carbon stock per hectare on the GSCP.

The main forest types of the GSCP are characterized by the presence of severely damaged trees as a result of hurricane Iris in 2001. The findings regarding live above-ground biomass and timber stocking are relatively low for this region, most likely as a result of hurricane Iris as well as past intensive selective logging. This disturbed forest is perhaps likely to change in species composition and abundance as time progresses and as the processes of forest dynamics play their role. It is thus important to engage in continuous monitoring in order to understand the development and role the forest will play in national carbon storage.

For the time being, the estimates included in this report represent the first and most reliable estimates of standing carbon and timber stocks and their value on the GSCP. The inventory methods used in this study relied on a larger sample area and plot size than found in previous carbon assessments in Belize, resulting in reliable estimates of carbon and timber stocks. It is recommended that future data collection activities be carried out on the GSCP in order to refine these estimates and their reliability. One of the main activities required is the validation, through non-destructive sampling, of the biomass equations used. This process is quite intensive equipment- and data-wise. Additionally, there is the need to quantify the dead above-ground biomass, as there is the possibility that this biomass pool may account for a substantial percent of total above-ground biomass (around 30% or more). Further quality assurance/quality control can be carried out within a reasonable length of time to help in quantifying the uncertainty around the carbon stock estimates.

In terms of improvements on the current estimates, it may be worth going back and re-sampling the heights of trees more accurately using a measuring device such as a laser rangefinder to see how they compare with ocular estimations. The use of an accurate measuring device will increase the reliability of overall biomass estimates and bring height measurements in line with the precision of concurrent measurements of diameter. However, although the corrections of any errors in ocular estimation over the entire dataset would improve the precision of estimates, given the nature of allometric models and uncertainties in carbon stock estimation, it would perhaps not change the overall total biomass estimate beyond the present limits of confidence.

It must be noted that the estimate from the present inventory, given the fairly temporary nature of the plots, is to be considered a baseline estimate of carbon stock. There is still opportunity to transform the plots into permanent plots which have greater advantages for estimation of carbon stock changes and also facilitate efficient verification if YCT intends to pursue project development and validation. The plots have been monumented as per a static inventory but from experience, wood marker posts and flagging tape can persist in the forest for more than four years. It is not necessary to make all 63 plots fully permanent at once (*i.e.* with permanent marker posts, tree tags, mapped coordinates and painted point of measurement) but it may be worth revisiting all 63 plots in the next few months to mark the starting point of the plot with either a 1.3 m length of ½" inch PVC pipe or a 0.5 m length of ¼" rebar. If not at all feasible for all plots, although the costs are no more than the purchase price of the materials, then as many plots as possible would have to suffice. In terms of full permanence, it is recommended that a minimum of 30% of the inventory plots be permanently established. Of course this would only be warranted under REDD project development.

In terms of value of the two resources, timber and carbon; the latter should be the priority focus as a source of future green revenue for the GSCP. Not only is the value of the carbon stock of the GSCP greater than the timber stock but the negative implications of harvesting timber given the present state of the forest are too great to commit any serious planning to achieve sustainable forest management. Due to the disturbance caused by hurricane Iris it is unlikely that a seed-bank and diverse age structure of timber species would be established in the near future that would enable managed extraction (Mathew 2003). Timber harvesting on the scale of a 40 year rotation is not likely to provide a viable rate of return, and it can further degrade the timber resource if careful and precise surveys are not performed prior to harvesting. Additionally, the damages caused by logging machinery can exacerbated the effect of hurricane Iris which could result in further pioneer dominance across the landscape.

The above notwithstanding, it may be possible that small scale harvesting, such as with chainsaw milling, may be viable on the GSCP. A sustainable yield is possible for species such as Rosewood and Yemeri, but this has to be considered in light of species distribution across the landscape. Local extinction is possible in certain areas of the GSCP if careful selection of harvest sites is not performed. More studies are required in order to ascertain localized harvest levels according to species distribution.

Acknowledgements

The author gratefully acknowledges the assistance of project manager Gail Stott of YCT for her cooperation, assistance with data entry, and patience during the implementation of this study and write-up of this report.

Of course acknowledgement and congratulations are in order for the inventory crew who, without prior knowledge of the level of detail and precision required of them, were able to absorb and synthesize the training and consequently successfully carry out the sampling exercise without much incident.

The author is indebted to the reviewers who provided critical comments and insights to improve the scientific and technical value of the document.

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Appendix I Inventory plots

Table 1. Characteristics of each inventory plot.

Plot	Easting	Northing	Forest Type	Elev (m)	Biomass (Mg ha^{-1})	BA (m^2) ≥5 to 9.9 cm	BA (m^2) ≥10 to 24.9 cm	Vol (m^3) ≥25 cm
1	310401	1805868	Lowland Broadleaf	23	56.1	0.006	0.130	3.945
3	312896	1804416	Lowland Broadleaf	22	35.2	0.019	0.098	2.615
5	311798	1804104	Lowland Broadleaf	29	73.4	0.016	0.237	11.202
9	309400	1811552	Lowland Broadleaf	45	45.7	0.047	0.619	5.984
11	314669	1803119	Lowland Broadleaf	25	29.5	0.013	0.112	3.744
12	309618	1812635	Lowland Broadleaf	42	119.6	0.008	0.246	15.262
15	312866	1800086	Lowland Broadleaf	25	21.2	0.008	0.048	2.741
16	313722	1801065	Lowland Broadleaf	17	34.5	0.043	0.081	4.451
17	314018	1803325	Lowland Broadleaf	36	16	0.010	0.027	2.802
20	309557	1812031	Lowland Broadleaf	42	54.4	0.019	0.168	6.839
22	309120	1799937	Lowland Broadleaf	34	33.1	0.007	0.143	2.873
23	312792	1798781	Lowland Broadleaf	21	24.5	0.008	0.078	5.576
24	313279	1799057	Lowland Broadleaf	21	31	0.046	0.038	6.692
25	313994	1802559	Lowland Broadleaf	21	34	0.032	0.112	3.595
26	312735	1799533	Lowland Broadleaf	26	12	0	0.064	1.035
27	312664	1799197	Lowland Broadleaf	31	70.7	0	0.289	16.53
28	312631	1800821	Lowland Broadleaf	22	24.2	0.003	0.126	4.550
29	311712	1804984	Lowland Broadleaf	29	44.1	0	0.169	4.783
30	314417	1803326	Lowland Broadleaf	27	9.7	0.006	0.048	1.269
32	311248	1804258	Lowland Broadleaf	26	95.6	0.007	0	8.617
33	312971	1797834	Lowland Broadleaf	17	36.9	0.010	0.333	4.357
34	311571	1803452	Lowland Broadleaf	25	44.5	0.007	0.14	4.607
38	311019	1806236	Lowland Broadleaf	25	29.3	0	0.206	5.299
40	311502	1804523	Lowland Broadleaf	34	62.2	0	0.090	9.199
41	312078	1804907	Lowland Broadleaf	18	51.4	0.004	0.039	2.536
43	309538	1812937	Lowland Broadleaf	41	74.1	0.008	0.136	7.837
46	313824	1799716	Lowland Broadleaf	20	68.8	0.020	0.395	11.78
47	310536	1807942	Lowland Broadleaf	33	107.1	0	0.044	23.671
48	310641	1806575	Lowland Broadleaf	31	14.7	0.008	0.190	2.948
49	312155	1804336	Lowland Broadleaf	24	55.2	0.007	0.216	1.887
50	308809	1812021	Lowland Broadleaf	47	52.7	0.011	0.092	1.974
53	310863	1805161	Lowland Broadleaf	33	55.3	0.022	0.195	2.953
54	314404	1802911	Lowland Broadleaf	23	65.5	0.006	0.265	6.951
57	309317	1800214	Lowland Broadleaf	32	28.4	0.005	0.185	1.994
60	312625	1804791	Lowland Broadleaf	26	33.1	0	0.056	2.035

62	313122	1802587	Lowland Broadleaf	14	18.1	0.009	0.011	3.144
65	313276	1801426	Lowland Broadleaf	21	23	0	0.262	1.103
67	314089	1800021	Lowland Broadleaf	22	39.1	0.006	0.151	3.201
68	308699	1812962	Lowland Broadleaf	41	85.6	0.008	0	15.096
69	312014	1803629	Lowland Broadleaf	22	38.7	0	0.159	2.706
70	314689	1802144	Lowland Broadleaf	20	48.1	0.015	0.180	1.301
72	308855	1813580	Lowland Broadleaf	38	50.3	0	0.067	1.053
73	309491	1812338	Lowland Broadleaf	42	70.2	0.012	0.110	10.282
74	309739	1800694	Lowland Broadleaf	30	32.4	0	0.035	7.52
75	312320	1800097	Lowland Broadleaf	28	31.7	0.036	0.305	5.425
76	309881	1811076	Lowland Broadleaf	44	40.4	0.006	0.328	6.287
79	308999	1814447	Hilly Broadleaf	51	30.7	0	0	1.143
81	309497	1814010	Hilly Broadleaf	61	4	0	0	0
82	308532	1813572	Hilly Broadleaf	50	58.3	0.007	0.027	1.127
83	310183	1813557	10+ Yr Old Wamil	29	38	0.007	0.054	1.698
84	310057	1813399	10+ Yr Old Wamil	29	39.2	0.019	0.199	0.87
85	309129	1810937	10+ Yr Old Wamil	37	5.9	0	0	0
86	310112	1813061	10+ Yr Old Wamil	28	36.7	0.007	0	0.434
87	308451	1811825	20+ Yr Old Wamil	39	53.9	0	0.092	1.586
88	308339	1811333	20+ Yr Old Wamil	36	81.8	0	0.101	3.161
89	308607	1811065	20+ Yr Old Wamil	37	104.3	0	0.063	1.316
90	308294	1810406	20+ Yr Old Wamil	35	73	0.018	0.243	5.531
91	309747	1810629	20+ Yr Old Wamil	32	49.8	0.010	0.034	2.700
92	310339	1809992	20+ Yr Old Wamil	43	43.5	0	0.019	0
93	310171	1809456	20+ Yr Old Wamil	50	72.8	0	0.253	2.619
94	310551	1809110	20+ Yr Old Wamil	50	47.9	0	0.191	1.134
95	309333	1809166	20+ Yr Old Wamil	28	62.8	0	0.144	6.160
96	309436	1810233	20+ Yr Old Wamil	36	68.8	0.004	0.166	1.736

Appendix II Data transcription quality report

Transcription Quality Control Report

All plots were checked for transcription errors in plot details such as date, site codes, etc. but not all trees were examined. Five trees within each plot were randomly selected and checked for transcription errors for a total of 315 trees out of 3937 tallied during the inventory. This represents an 8% sample exactly.

Transcription errors were detected in 30% of all plots. Transcription errors were detected in a total of 50 tree records. This represents 15.8% of the 315 trees sampled which translates into an overall transcription error rate of 15.8% within all trees in the database. However, given the low error rate among plots (30%), it is expected that much of the undetected errors in tree records would exist in the same 30% of plots.

The overall transcription rate of 15.8% is greater than the recommended maximum allowable error of 10%. However, it is acceptable when combined with outlier detection analysis to seek and correct erroneous data falling outside normal ranges. In addition, no errors were detected in diameter or species entries – the two most important categories of data. Most errors were detected in tree numbering, quadrat numbering, tree height, tree grade, and tree codes, in that order. Most errors detected for tree height and grade were errors of omission. Therefore, overall, the errors existing in the database will not have significant bearing on the quality of the outputs produced. The data is thus of high quality.

Appendix III Data collection quality report

Data Collection (Inventory) Quality Control Report

Two plots were sampled immediately after enumeration. One plot had very minor errors which were within acceptable limits of a mean error of 0.1 cm for diameter and 1 m for ocular height estimation. The other plot had severe errors in tree diameter and it turned out that a team member untrained for the task had been measuring trees. The importance of adherence to roles within the team was stressed and the plot was re-measured. Following re-measurement diameter measurement fell to within the acceptable error limit of 0.1 cm on average.

Mean error for ocular total height estimation was 0.5 meters, while for timber height estimation it was zero. This is due to the increased difficulty of estimating total tree height as the top of the crown is often difficult to see. Tree grading was very accurate and no errors were detected.

Plot demarcation was within acceptable limits of error of 0.1 metres. Also no errors were detected in the description of quadrat environmental conditions through site codes.

The dataset is thus considered to be of high quality as long as the inventory team maintained composure during the course of the inventory. Due to time constraints the consultant was unable to follow individual teams in the field to conduct additional quality control. It was deemed infeasible to conduct quality control if not immediately after plot enumeration, as it would be difficult to trace individual trees when there are many stems of similar size belonging to the same species in a quadrat, as was the case.

The project manager, however, was able to occasionally supervise the field team to ensure the quality of data collection was maintained throughout the inventory. Supervision with the aim of quality control was conducted on a total of seven plots by the project manager. Another two plots were supervised directly by the consultant.

In total eleven plots, or 17.4%, were checked by means of random re-measurement of a few trees and checks of distance and bearing measurements for quality control purposes. Within these eleven plots were 873 trees which were either re-measured individually, or oversight was provided to the inventory crew for quality control purposes. This represents a sample of 22.6% of total trees enumerated in the inventory.

Appendix IV Sampling methodology used elsewhere

This brief description of the 'established' carbon sampling plot design used elsewhere in Belize and in the tropics is provided here for the reader to gain insight into the methodology and how it compares to this study. Firstly, the source of the 'established' carbon sampling methodology is Pearson *et al.* (2005) coming from Winrock International. It has been used in the Rio Bravo Conservation and Management Area, the Boden Creek Ecological Preserve, and the Bullrun Overseas property, and in other places in the tropics where Winrock operates. The methodology, however, parallels forestry inventories in north temperate species-poor mixed hardwood/coniferous forests. It is suitable for quick and *cheap* timber cruises in relatively open species-poor forests with high size class variability.

The 'established' methodology calls for 3 nested plots each to sample a discrete range of diameter. The overall extent of the nested plot is a circle of 20 m radius. The entire extent is one plot, and inside up to a radius of 14 m is another plot and inside that up to a radius of 4 m is yet another. From the onset the small total extent (0.12 ha) is lacking the size required for implementation in species rich tropical forests of high stem size variability and highly heterogenous (patchy) spatial distribution. The situation worsens; however, when the plot sizes for the discrete diameter ranges are examined.

Large trees ≥50 cm are sampled in circular units of 0.12 ha. From the cumulative scientific and practical experience in the published literature, such a small plot size is not adequate for sampling tropical broadleaf forests. Large trees are rare in tropical forests and a small plot size will consistently miss large trees, which can contribute disproportionately high to the overall per hectare biomass of a forest. Trees ≥20 but less than 50 cm are sampled in even smaller plots of 0.06 ha. Small trees ≥5 but less than 20 cm are sampled in minuscule plots of 0.005 ha. If this nested plot design were used with the same number of plots as in the present inventory, the sampling intensity of different diameter size classes would be: 0.1% for trees ≥50; 0.07% for trees ≥20 <50 cm; and 0.005% for trees ≥5 <20 cm. This is compared to the actual sampling intensity for different diameter ranges in the present inventory: 0.6% for trees ≥25 cm; 0.1% for trees ≥10 <25 cm; and 0.02% for trees ≥5 <10 cm. The overall sampling intensity for the 'established' method would have been 0.1% while the actual was 0.6%, a 500% improvement in sampling intensity, and just as substantial improvement in the reliability of estimates.

But the main disadvantage with the 'established' plot design is the choice of separation of diameter classes (Figure 1). It is known from long-term plot studies in tropical forests that different diameter size classes undergo different dynamics such as mortality, growth, and recruitment. Smaller trees <10 cm undergo rapid dynamics and it is difficult to predict what is going to happen inside this size class. The ≥10 <25 cm size class is more stable and recruitment and other dynamics are more predictable – this size class determines the short- to medium-term future of the forest. The size class ≥25 cm is considered the reproductive or mature size class and the abundance and distribution of trees in this size class determine the long-term future of the forest. Thus, under these assumptions, the most important component to understand is the ≥25 cm size class. Unfortunately, the 'established' plot design does not adequately sample the largest size class or any of the size classes for that matter. The primary shortcoming of the 'established' methodology is the blending of size classes undergoing different dynamics which undeniably obscures the value of repeated measurements.

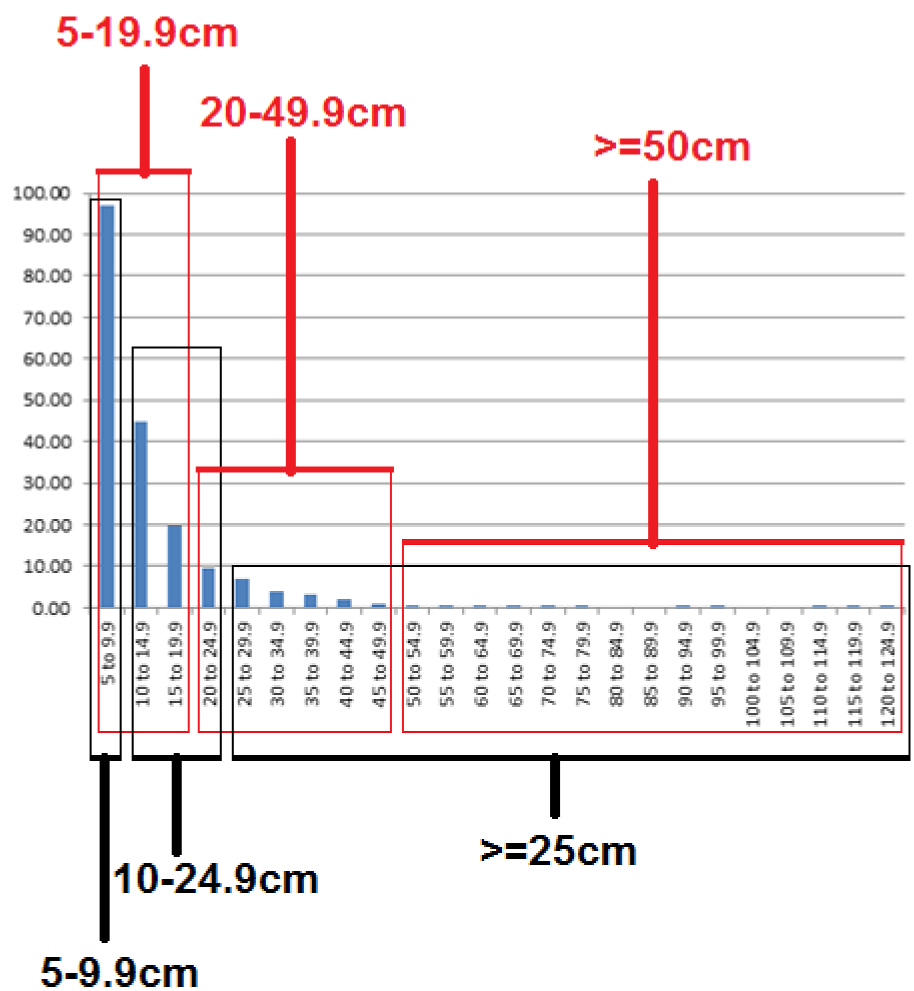

Figure 1. Separation of size classes in the different sampling schemes. *Red signifies the 'established' carbon sampling methodology; black signifies the YCT sampling methodology.*

Appendix V Yield model

Table 1. The FPMP sustainable yield model.

Species	Total Trees ≥30 cm	MCD	Potential Crop ≥MCD <100cm	Residual Trees	Next Felling Crop (NFC)	NFC ≥ Potential Crop?	Required Seed Trees	Residual Trees ≥ Required Seed Trees?	Current Crop Possible?
Banak	41	50	9	32	19	YES	14	YES	YES
Barbajolote	5	50	0	5	3	NA	14	NA	NO
Billy webb	45	50	0	45	27	NA	14	NA	NO
Bitterwood	113	50	9	104	62	YES	14	YES	YES
Breadnut	0	50	0	0	0	NA	14	NA	NO
Cabbage bark	14	45	0	14	8	NA	14	NA	NO
Carbon	0	50	0	0	0	NA	14	NA	NO
Cortez	5	50	0	5	3	NA	14	NA	NO
Hobillo	14	50	0	14	8	NA	14	NA	NO
Hormiga	9	50	0	9	5	NA	14	NA	NO
Ironwood	23	50	9	14	8	NO	14	NO	NO
Mahogany	27	60	5	23	14	YES	14	YES	YES
Mayflower	5	50	5	0	0	NO	14	NO	NO
Mountain kaway	50	50	14	36	22	YES	14	YES	YES
Mylady (red)	0	45	0	0	0	NA	14	NA	NO
Nargusta	965	50	90	875	525	YES	14	YES	YES
Pine	9	35	9	0	0	NO	14	NO	NO
Poisonwood (black)	5	45	0	5	3	NA	14	NA	NO
Prickly yellow	41	50	0	41	24	NA	14	NA	NO
Redwood	0	50	0	0	0	NA	14	NA	NO
Rosewood	90	45[1]	14	77	46	YES	14	YES	YES
Rosewood	18	50	9	9	5	NO	14	NO	NO

(northern)									
Salmwood	27	50	0	27	16	NA	14	NA	NO
Santa maria	9	50	0	9	5	NA	14	NA	NO
Sapodilla	0	50	0	0	0	NA	14	NA	NO
Tambran	81	50	36	45	27	NO	14	YES	NO
Yemeri	86	45	23	63	38	YES	14	YES	YES

Appendix VI Stand and stock tables

Table 1. Stand Table showing values of stems ha^{-1} in the different diameter size classes. *Note that due to rounding some non-zero values appear as zero (such as with Mahogany trees per hectare in the larger diameter classes).*

Species	5 to 9.9	10 to 14.9	15 to 19.9	20 to 24.9	25 to 29.9	30 to 34.9	35 to 39.9	40 to 44.9	45 to 49.9	50 to 54.9	55 to 59.9	60 to 64.9	65 to 69.9	70 to 74.9	75 to 79.9	80 to 84.9	85 to 89.9	90 to 94.9	95 to 99.9	100 to 104.9	105 to 109.9	110 to 114.9	115 to 119.9	120 to 124.9	TOTAL
Banak	0.0	0.2	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.6**
Barbajolote	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**1.0**
Billy webb	0.8	0.6	1.4	1.0	0.5	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**4.6**
Bitterwood	3.2	0.3	1.0	0.5	0.3	0.3	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**6.0**
Breadnut	2.4	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.2**
Cabbage bark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Carbon	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Cortez	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Hobillo	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Hormiga	2.4	0.6	0.5	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.7**
Ironwood	3.2	1.0	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**5.0**
Mahogany	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.3**
Mayflower	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2**
Mountain kaway	4.0	1.1	0.3	0.3	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**6.3**
Mylady (red)	4.0	1.3	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**5.6**
Nargusta	44.4	25.9	8.9	4.3	3.6	2.3	2.2	1.2	0.5	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**93.9**
Pine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Poisonwood (black)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Prickly yellow	0.0	1.0	1.0	0.3	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.0**
Redwood	0.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**1.3**
Rosewood	2.4	1.3	0.8	1.1	0.5	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**6.7**

Rosewood (northern)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2**
Salmwood	5.6	2.5	1.6	0.6	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**10.9**
Santa maria	3.2	1.4	0.8	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**5.7**
Sapodilla	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2**
Tambran	0.8	0.6	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2.6**
Yemeri	19.0	5.7	2.1	0.8	0.2	0.2	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**28.4**
TOTAL	**96.8**	**44.9**	**19.8**	**9.5**	**6.9**	**4.0**	**3.3**	**1.9**	**0.8**	**0.4**	**0.4**	**0.4**	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**189.8**

Table 2. Stock table showing basal area (m^2) in diameter classes <25 cm and volume m^3 ha^{-1} in diameter classes ≥25cm*. Horizontal totals are of volume only. Vertical totals are either basal area or volume totals for a particular diameter class.*

Species	5 to 9.9	10 to 14.9	15 to 19.9	20 to 24.9	25 to 29.9	30 to 34.9	35 to 39.9	40 to 44.9	45 to 49.9	50 to 54.9	55 to 59.9	60 to 64.9	65 to 69.9	70 to 74.9	75 to 79.9	80 to 84.9	85 to 89.9	90 to 94.9	95 to 99.9	100 to 104.9	105 to 109.9	110 to 114.9	115 to 119.9	120 to 124.9	TOTAL
Banak	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.3**
Barbajolote	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Billy webb	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2**
Bitterwood	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	**0.6**
Breadnut	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Cabbage bark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Carbon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Cortez	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Hobillo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Hormiga	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**

Ironwood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Mahogany	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	**0.8**
Mayflower	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Mountain kaway	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.3**
Mylady (red)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Nargusta	0.2	0.3	0.2	0.2	0.7	0.7	0.9	0.6	0.3	0.1	0.2	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	**4.2**
Pine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Poisonwood (black)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Prickly yellow	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2**
Redwood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Rosewood	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.4**
Rosewood (northern)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Salmwood	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2**
Santa maria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Sapodilla	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Tambran	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.2	0.0	0.3	**1.2**
Yemeri	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.4**
TOTAL	**0.5**	**0.5**	**0.5**	**0.4**	**1.5**	**1.2**	**1.4**	**1.1**	**0.6**	**0.4**	**0.5**	**0.7**	**0.2**	**0.1**	**0.0**	**0.0**	**0.0**	**0.2**	**0.2**	**0.0**	**0.0**	**0.6**	**0.3**	**0.3**	**9.3**

Appendix VII Species list for five forest communities

Table 1. Species list for five forest communities identified by multivariate analysis of inventory plot data. Table shows plot counts for trees ≥25 cm dbh. Unknown species were removed prior to the analysis and are not included here.

20 yr Wamil		10 yr Wamil		Hilly Broadleaf		Broadleaf Swampy		Broadleaf Well-drained	
Species	**No.**	**Species**	**No.**	**Species**	**No.**	**Species**	**No.**	**Species**	**No.**
Cohune	121	Cohune	3	Hog plum	9	Nargusta	187	Nargusta	158
Ficus	39	Ficus	1	Cohune	6	Fiddlewood	38	Cohune	153
Prickly yellow	19	Fiddlewood	1	Hobillo	2	Rosewood	27	Hog plum	57
Bay cedar	18	Tambran	1	Provision bark	2	Yemeri	16	Fiddlewood	44
Bitterwood	17	Yemeri	1	Yellow wood	2	Cohune	14	Tambran	16
Billy webb	11			Barbajolote	1	Mountain kaway	7	Bitterwood	15
Hog plum	9			Male Grape	1	Rosewood (northern)	5	Salmwood	14
Tambran	8			Poisonwood (black)	1	Billy webb	4	Billy webb	13
Nargusta	8			Pouteria	1	Bitterwood	4	Gombolimbo	13
Bri bri	5			Strangler Fig	1	Santa maria	4	Mountain kaway	12
Pouteria	3			Trumpet tree	1	Gombolimbo	3	Rosewood	10
Gombolimbo	3					Bri bri	2	Banak	9
Fiddlewood	2					Cabbage bark	2	Yemeri	9
Hormiga	2					Craboo	2	Ironwood	7
Salmwood	2					Pine	2	Male grape	6
Salmwood (soft)	2					Wild grape	2	Ficus	5
Quamwood	1					Alligator stick	1	Mahogany	5
Cabbage bark	1					Anparaqway	1	Pouteria	5
Strangler Fig	1					Banak	1	Prickly yellow	5
Trumpet tree	1					Cortez	1	Strangler Fig	4
Hobillo	1					Mahogany	1	Hormiga	3
						Mayflower	1	Yellow wood	3
						Pigeon plum	1	Anparaqway	2
						Pouteria	1	Bri bri	2
						Salmwood	1	Carbon	2
						Tambran	1	Guava stick	2

Mayflower	2
Mountain moho	2
Mylady (red)	2
Provision bark	2
Salmwood (soft)	2
Salmwood (white)	2
Wild grape	2
Alligator stick	1
Breadnut	1
Cabbage bark	1
Cachati (white)	1
Comparaguay	1
Craboo	1
Hobillo	1
Moho	1
Nokte	1
Pigeon plum	1
Poisonwood (white)	1
Quamwood	1
Redwood	1
Santa maria	1
Sapodilla	1
Trumpet tree	1
Wild monkey cap	1

Table 2. Species list for five forest communities identified by multivariate analysis of inventory plot data. Table shows plot counts for trees ≥10 and <25 cm dbh. Unknown species were removed prior to the analysis and are not included here.

20 yr Wamil		10 yr Wamil		Hilly Broadleaf		Broadleaf Swampy		Broadleaf Well-drained	
Species	**No.**	**Species**	**No.**	**Species**	**No.**	**Species**	**No.**	**Species**	**No.**
Bay cedar	61	Anparaqway	44	Trumpet tree	20	Nargusta	160	Trumpet tree	120
Bri bri	43	Bay cedar	4	Polak	3	Yemeri	36	Nargusta	89
Serrin	36	Bitterwood	1	Hormiga	1	Male grape	36	Bri bri	45
Hog plum	34	Bri bri	11	Hog plum	1	Pigeon plum	34	Moho (macapal)	26
Trumpet tree	29	Cotton tree	1	Cohune	1	Coco plum (white)	32	Anparaqway	24
Moho	29	Ficus	3	Cockspur	1	Craboo	18	Nokte	23
Nokte	24	Fiddlewood	2			Rosewood	18	Salmwood	23
Ficus	21	Gombolimbo	5			Santa maria	14	Fiddlewood	20
Fiddlewood	15	Moho	1			Wild grape	13	Yemeri	20
Billy webb	11	Moho (macapal)	1			Bri bri	12	Botan	19
Moho (macapal)	11	Nargusta	6			Garlic stick	12	Cockspur	16
Prickly yellow	11	Nokte	1			Fiddlewood	11	Serrin	16
Gombolimbo	8	Prickly yellow	1			Coco plum	9	Hog plum	14
Salmwood (soft)	8	Salmwood	1			Polewood	5	Garlic stick	11
Salmwood	7	Salmwood (soft)	6			Trumpet tree	5	Mylady (red)	10
Anparaqway	6	Salmwood (white)	1			Serrin	4	Pigeon plum	10
Bitterwood	6	Serrin	7			Gombolimbo	4	Bittersweet	9
Tambran	6	Trumpet tree	2			Cachati (white)	3	Gombolimbo	9
Nargusta	5	Yemeri	1			Moho	3	Ironwood	9
Mountain kaway	5					Moho (macapal)	2	Moho	9
Hormiga	4					Billy webb	2	Billy webb	6
Salmwood (white)	4					Mountain kaway	2	Vismia comparaguay	6
Yellow wood	3					Botan	2	Bitterwood	5
Breadnut (red)	3					Pouteria	1	Breadnut	5
Myte	2					Banak	1	Male grape	5
Pouteria	2					Vismia comparaguay	1	Tambran	5
Redwood	2					Strangler Fig	1	Ficus	4

Cotton tree	1
Anparaqway (red)	1
Barbajolote	1
Vismia comparaguay	1
Strangler Fig	1
Mountain moho	1
Cojotone	1
Quamwood	1
Polewood	1
Cockspur	1

Mayflower	1
Salmwood	1
Mahogany	1
Copal (white)	1
Ficus	1
Alligator stick	1
Candlewood	1

Mountain kaway	4
Provision bark	4
Wild grape	4
Yellow wood	4
Cohune	3
Copal (white)	3
Polewood	3
Prickly yellow	3
Quamwood	3
Redwood	3
Santa maria	3
Banak	2
Bay cedar	2
Comparaguay	2
Hormiga	2
Malagate	2
Myte	2
Pouteria	2
Rosewood	2
Alligator stick	1
Cantemo	1
Coco plum (white)	1
Guava stick	1
Mayflower	1
Poisonwood (white)	1
Salmwood (white)	1
Sapodilla	1
Strangler Fig	1
Yellow stick	1

Table 3. Species list for five forest communities identified by multivariate analysis of inventory plot data. Table shows plot counts for trees ≥5 and <10 cm dbh. Unknown species were removed prior to the analysis and are not included here.

20 yr Wamil		10 yr Wamil		Hilly Broadleaf		Broadleaf Swampy		Broadleaf Well-drained	
Species	**No.**	**Species**	**No.**	**Species**	**No.**	**Species**	**No.**	**Species**	**No.**
Serrin	16	Anparaqway	18	Breadnut	1	Nargusta	43	Trumpet tree	27
Moho	15	Serrin	13	Hogplum	1	Coco plum (white)	27	Nokte	26
Nokte	11	Mountain kaway	3	Trumpet Tree	1	Pigeon plum	20	Nargusta	20
Bay cedar	8	Anparaqway (red)	3			Yemeri	14	Serrin	17
Bri bri	5	Ficus	2			Male grape	13	Cockspur	14
Hog plum	4	Salmwood (white)	1			Bri bri	12	Anparaqway	13
Cockspur	4	Salmwood	1			Serrin	9	Bri bri	13
Ficus	4	Pouteria	1			Polewood	9	Yemeri	11
Fiddlewood	3	Nargusta	1			Coco plum	9	Male grape	8
Gombolimbo	3	Moho (macapal)	1			Garlic stick	8	Pigeon plum	6
Pouteria	3	Moho	1			Craboo	6	Salmwood	6
Mountain kaway	2	Hog plum	1			Santa maria	4	Vismia comparaguay	6
Nargusta	2	Bri bri	1			Wild grape	4	Polewood	5
Yellow wood	1	Bitterwood	1			Rosewood	3	Garlic stick	4
Moho (macapal)	1					Trumpet tree	3	Moho	4
Anparaqway	1					Fiddlewood	3	Wild grape	4
Garlic stick	1					Mylady (red)	3	Anparaqway (red)	3
Copal (white)	1					Cockspur	2	Bitterwood	3
Redwood	1					Anparaqway	2	Ironwood	3
Bitterwood	1					Malagate	2	Moho (macapal)	3
Billy webb	1					Copal (white)	1	Mountain kaway	3
Salmwood (soft)	1					Ficus	1	Breadnut	2
Ironwood	1					Cachati (white)	1	Copal (white)	2
						Moho	1	Hormiga	2
						Hormiga	1	Mylady (red)	2
								Salmwood (white)	2
								Alligator stick	1

Billy webb	1
Ficus	1
Gombolimbo	1
Hog plum	1
Malagate	1
Pouteria	1
Provision bark	1
Redwood	1
Salmwood (soft)	1
Strangler Fig	1
Yellow wood	1

Appendix VIII Standard Operating Procedures in Field

Scientific Forest Services and Systems (SFS)

Forest Management, Sampling, Stock Surveying, Remote Sensing, Carbon Assessment

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Precision Forestry, Better Management

Procedures for plot establishment and enumeration:

1. Use the GPS to locate the start of the centre line at the eastern side of the belt transect. Record the Eastings and Northings displayed on the GPS.
2. Established a thick and sturdy post at this point with three separate ties of flagging tape and a markered '0' on one tie.
3. Established a sturdy post 10 m away to the south and to the north of the starting post. This serves as a reminder of the plot extent to the south and to the north of the centre line.
4. Established and clean a centre line by means of compass survey using marker posts with double ties of flagging tape at each 50 m interval up to 250 m.
5. The error allowed on measurements in 50 m intervals is +/-10 cm. The total error allowed on the length of the 250 m centre line is +/-50 cm.
6. The total error allowed on compass bearings is +/- 1 degree over 250 m.
7. In all quadrats, except 1 and 7, survey all trees ≥ 25 cm.
8. In quadrats 1 and 7, survey all trees ≥10 cm.
9. Also in quadrats 1 and 7, survey all trees ≥5 cm but <10 cm within the first 10 x 10 m heading west.
10. The total error allowed for diameter measurements is +/- 1 mm.
11. For each quadrat, make and record observations concerning the bio-physical characteristics of the forest and terrain as per the list of codes on the field sheet.
12. Record species names in English where possible or in Spanish or K'etchi or other Maya dialect if only those are available. If the species is not known, record it as 'unknown'.

Procedures for tree measurements:

1. Tree Diameter: Ensure that the diameter is recorded at 1.3 m from the ground according to the following diagram. All vines should be removed and the tape held perpendicular to the stem of the tree.

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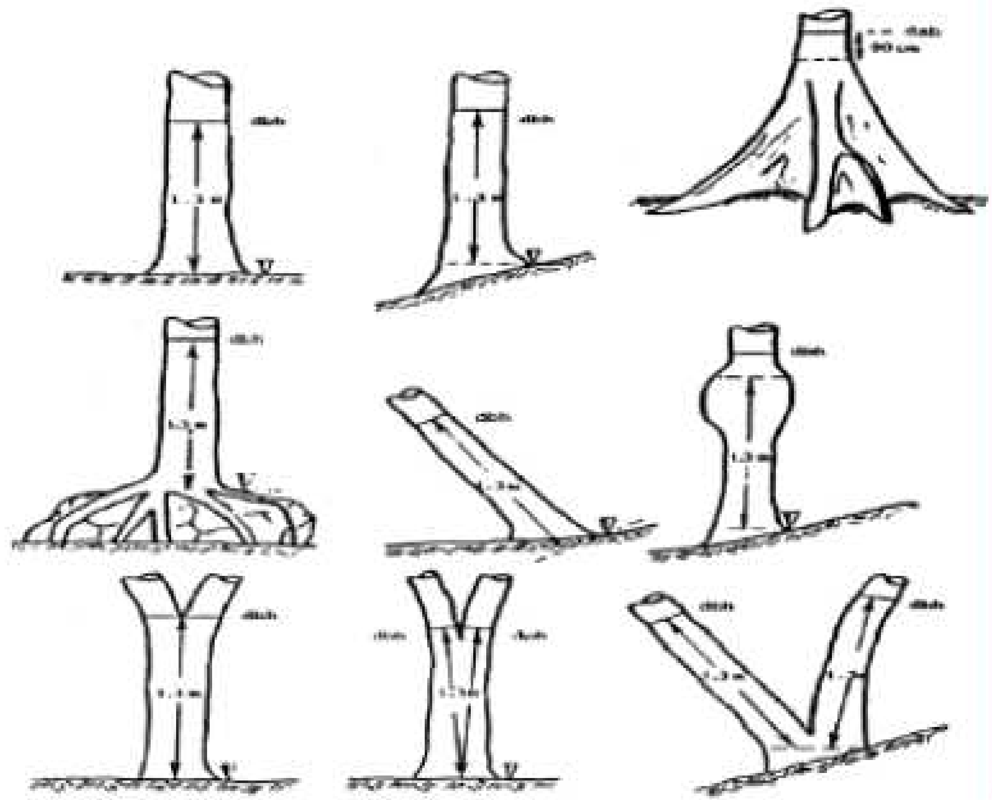

2. For all trees the total tree height is estimated visually to ±1 metre. For timber species the height to first major branch is estimated visually to ±1 metre.
3. Tree Grade: Ensure that for all timber species the tree grade is assessed according to the diagram on the field sheet.
4. Other codes for each tree should be applied as per necessary and according to the available codes on the field sheet.

Appendix IX Comparison of three biomass equations

In order to explore the effect of choice of allometric equation on biomass estimates, two other equations were used to derive biomass: Chave *et al.* (2005) using wood density and diameter; and Brown (1997) using diameter. Both were applicable to moist tropical forests. These two equations were compared to the selected equation used in the study: Chave *et al.* (2005) using wood density, diameter and height.

The results show a clear difference in biomass estimates between the three equations. The equations which did not incorporate a height estimate produced higher biomass estimates in all size classes except for the very smallest. Differences were especially great between 25 – 70 cm dbh and above 95 cm dbh (Figure 1). Allometric equations employing height as a predictor variable are thought to be generally more precise than other equations (Chave *et al.* 2005).

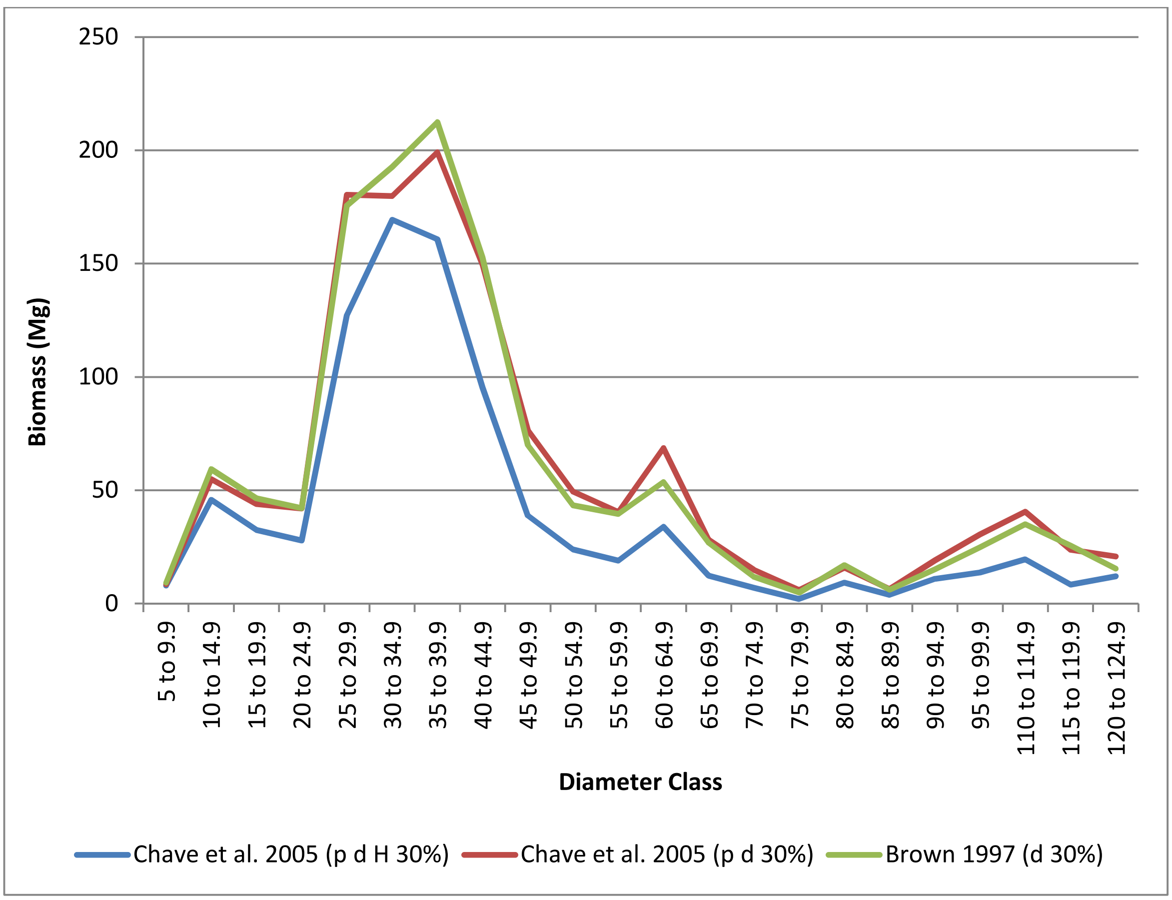

Figure 1. Comparison of total sample biomass (Mg) per diameter class from three different allometric equations.
'p' = species specific wood density, 'd' = diameter, 'H' = height, '30%' denotes that the biomass of trees which lost their crowns was reduced by 30%. The equation used in this study was the most conservative.

The tabular statistics tell a similar tale. The Chave and Brown equations which do not include height, produced similar per ha mean biomass (Tables 1 and 2, below). Compared to the estimates in Table 3 in the main text, the estimates here are around 40% greater.

Table 1. Statistics of mean biomass (Mg) per ha obtained using Chave et al.'s 2005 equation not including height.

Statistic	Biomass Mg ha^{-1} ≥5cm	Biomass Mg ha^{-1} ≥10cm	Biomass Mg ha^{-1} ≥25cm	TOTAL Biomass Mg ha^{-1} ≥5cm	TOTAL C Mg ha^{-1} ≥5cm
n	63	63	63	63	63
∑	448.826	1407.559	2298.675	4155.1	1952.9
variance	10.978	114.727	637.948	954.1	210.8
CV	46.508	47.941	69.224	46.8	46.8
mean	7.124	22.342	36.487	66.0	31.0
StDev	3.313	10.711	25.258	30.9	14.5
Std Error	0.417	1.349	3.182	3.9	1.8
90% CI	0.698	2.255	5.317	6.5	3.1
CI as % of mean	9.791	10.093	14.573	9.9	9.9
95% CI	0.835	2.699	6.364	7.8	3.7
CI as % of mean	11.719	12.080	17.443	11.8	11.8
Sampling Error	12.35%	12.35%	12.35%	12.35%	12.35%

Table 2. Statistics of mean biomass (Mg) per ha obtained using Brown's 1997 equation.

Statistic	Biomass Mg ha^{-1} ≥5cm	Biomass Mg ha^{-1} ≥10cm	Biomass Mg ha^{-1} ≥25cm	TOTAL Biomass Mg ha^{-1} ≥5cm	TOTAL C Mg ha^{-1} ≥5cm
n	63	63	63	63	63
∑	483.667	1478.629	2243.830	4206.1	1976.9
variance	12.300	126.185	598.294	999.7	220.8
CV	45.682	47.861	68.676	47.4	47.4
mean	7.677	23.470	35.616	66.8	31.4
StDev	3.507	11.233	24.460	31.6	14.9
Std Error	0.442	1.415	3.082	4.0	1.9
90% CI	0.738	2.365	5.149	6.7	3.1
CI as % of mean	9.617	10.076	14.458	10.0	10.0
95% CI	0.884	2.831	6.163	8.0	3.7
CI as % of mean	11.511	12.060	17.305	11.9	11.9
Sampling Error	12.35%	12.35%	12.35%	12.35%	12.35%

The implications regarding the choice of allometric equation are important and should not be taken lightly. Since the equation used in this study provided the most conservative estimate of mean biomass, and since it explicitly incorporated height variation, it was considered the most appropriate. Table 3 below shows differences in the total property-wide estimate of biomass stocks using the three equations.

Table 3. Differences in total carbon stock estimate on the GSCP according to three different allometric equations.
Uncertainty in total biomass is represented by the 95% CI.

Allometric Equation	Sample Area (ha)	Total Biomass (Mg)
Chave *et al.* 2005: p, d, H	5,673.6	259,953 ± 30,183
Chave *et al.* 2005: p, d	5,673.6	374,458 ± 44,254
Brown 1997: d	5,673.6	378,996 ± 45,389

Appendix X Response to comments

Section notes: comments are numbered in the order received.

YCT Terrestrial Ecologist

1) The (correlation) graphs would be more informative if they had number of data points mentioned (n).
   Regression replaced by a calculation of average height to fill missing height values. This is a more conservative approach to filling in the missing data since it does not make any assumptions about the distribution of tree height.

2) The very low R^2 (7%) of the modeled relation between tree height v dbh requires much more caution for the interpolation of the commercial tree height data - especially given the high proportion of missing values (35%) for commercial tree height. Consequently, how reliable are the timber volume calculations and all derived estimates? (e.g. in 5.4.1, but really all through the results and conclusions).
   Refer to response re: comment #1.

3) It would be interesting if we were able to see the species composition of the 5 different communities that you refer to.
   Species abundance list combining all unique identifications for the group of plots comprising a particular forest community was added as Appendix VIII.

Steven Brewer (The comments are not repeated here as they were received as tagged comments and corrections in Adobe Acrobat. To maintain clarity and context, the comments are best read from Brewer's version of the pdf).

4) Page 7 – Section 3.1, paragraph 1, line 1: reworded.
5) Page 7 – Section 3.1.1, paragraph 1, line 8: 'wamil' defined.
6) Page 7 – Section 3.1.2, paragraph 1, line 1: reworded.
7) Page 8 – Section 3.1.2, paragraph 2, line 4: reworded.
8) Page 8 – Section 3.1.2, Table 2: acreage changed to area (and all other instances).
9) Page 8 – Section 3.1.4, paragraph 1, line 1: hectare changed to ha
10) Page 8 – Section 3.1.4, paragraph 1, line 3: reworded
11) Page 8 – Section 3.1.4, paragraph 1, sentence 3: deleted
12) Page 10 – Section 3.2, paragraph 1, sentence 6: reworded
13) Page 12 – Section 3.6.1, Figure 3: linear replaced by logarithmic regression
14) Page 13 – Section 3.6.2, paragraph 1, line 4: neotropics changed to neotropical
15) Page 14 – Section 4.1: reworded.

16) Page 14 – Section 4.2, paragraph 1: reworded.
17) Page 15 – Section 4.2, paragraph 2: reference to model asymptote reworded.
18) Page 15 – Section 4.2, paragraph 2: reference to species pool reworded.
19) Page 15 – Section 4.2, Figure 5: Species accumulation model added to legend.
20) Page 15 – Section 4.3, Figure 6: Dissimilarity index added to legend.
21) Page 15 – Section 4.3, paragraph 1: 'ecotype' removed.
22) Page 17 – Section 4.4.1, Figure 7: Test of normality and p-value added.
23) Page 18 – Section 4.4.2, paragraph 1: reworded.
24) Page 20 – Section 4.4.2, paragraph 4, line 6: reworded for clarity.
25) Page 20 – Section 4.4.2, paragraph 6: reworded for clarity.
26) Page 22 – Table 4: standard error added.
27) Page 24 – Section 4.4.2: last three paragraphs and Figure 13 removed.
28) Page 25 – Section 4.4.3, paragraph 4, sentence 1: reworded.
29) Page 25 – Section 4.5.1, paragraph 1: reworded.
30) Page 26 – Section 4.5.1, paragraph 2: reference to 'bootstrapping' clarified.
31) Page 26 – Section 4.5.2, Figure 13: It is standard practice in forestry to display diameter distribution curves on an arithmetic scale rather than a log scale. While the value of log scales in aiding comparison across diameter classes when large disparities exist is recognized, it is not easy to interpret actual values from one class to the next. Additionally, zero values, which are common, cannot be logged. Diameter distributions are typically interpreted along with stand and stock tables which provide the actual values per diameter class.

FFI Carbon Specialist (The comments are not repeated here as they were received as tagged comments and corrections in Microsoft Word. To maintain clarity and context, the comments are best read from the reviewer's version of the Word document).

32) Page 5 – Executive Summary, last paragraph: clarification of total carbon estimate.
33) Page 8 – Section 3.1.2, Table 2: acreage changed to area (ref: Brewer's comment).
34) Page 10 – Section 3.2, paragraph 2: reference to Pearson *et al.* 2005 added in Appendix.
35) Page 10 – Section 3.2, paragraph 2: Comparison of plot sizes to Pearson *et al.* 2005 added to facilitate cohesiveness of the main text. Appendix contains more details.
36) Page 10 – Section 3.3: SOP added to the appendix.
37) Page 11 – Section 3.4, paragraph 4: YCT carried out the inventory under advice and supervision from SFSS, advice which included the precise measurement of height with a laser hypsometer. Unfortunately funding constraints did not allow such levels of precision. The sampling situation was unique in that without a measurement of height, sampling would grossly over-estimate individual tree biomass since most trees lost their crowns including portions of the upper bole and were reduced in height due to the 2001

hurricane. The only alternative to allow for a rapid survey (time was also constrained by finances) was ocular estimation by one trained and calibrated team member. It was felt that even with the inconsistencies associated with ocular height estimation; the benefits of doing so outweighed the consequences of relying on diameter alone, and would provide a more conservative estimate of biomass in the hurricane ravaged GSCP. A comparison between biomass estimates using dbh and height versus dbh alone was included in the text.

38) Page 11 – Section 3.4: description of QA/QC added.
39) Page 12 – Section 3.6.1, Figure 3: Although the fit was below the typically accepted 60%, the regression was significant at the p=0.05 level and was thus used to fill in the small number (less than 1%) of trees missing total height measures.
40) Page 13 – Section 3.6.2 and other relevant sections: comparison of biomass estimates using three different equations was added as an Appendix.
41) Page 14 – Section 4.1: clarified ref Brewer's comments.
42) Page 14 – Section 4.1: although QA/QC was carried out, time constraints did not allow for full re-measurements of 20% of plots. The QA/QC report in the Appendix is meant to be informative rather than strictly quantitative.
43) Page 17 – Section 4.4.1: Table added showing the number of plots per strata required to achieve the desired level of precision of biomass estimates.
44) Page 17 – Section 4.4.1: Table added showing summary statistics and level of precision for each forest stratum.
45) Page 18 – Section 4.4.2: Discussion added ref: potential reasons for low mean biomass on the GSCP.
46) Page 24 – Section 4.4.2, last paragraph: section replaced.
47) Page 24 – Section 4.4.3, first sentence: reworded.
48) Page 25 – Section 4.4.3, Table 5: strata means added. Unit is Mg Biomass per ha.
49) Page 26 – Section 4.4.4: Metric tonne unit corrected. Clarification of the estimated value of the carbon resource.
50) Page 34 – Section 5, paragraph 3, sentence 3: reworded for clarity.
51) Page 34 – Section 5, paragraph 3: recommendations added for further quality assurance/quality control.
52) Page 39 – Appendix III, paragraph 1: Quality control checks were performed on two plots one of which was subsequently re-measured. The number of plots available for calculating measurement error was thus too small.
53) Page 39 – Appendix III, paragraph 2: Mean error for height estimation was check with a laser rangefinder accurate to 1 mm over 250 m. Quality control measurements were rounded to be consistent.
54) Page 39 Appendix III, last paragraph: reworded to clarify methods of quality control.