forestry
department

MINISTRY OF
AGRICULTURE

ANALYSIS OF FOREST ENVIRONMENT RELATIONSHIPS
DOLPHIN HEAD, JAMAICA

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Draft report, November 2002

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1. INTRODUCTION

In the framework of preliminary studies for the proposed Dolphin Head national park, an assessment of land and vegetal resources, called a biophysical inventory, was carried out in January and February 2001 by the Forestry Department. A sampling of 50 sample plots (0.05 ha/sample plots) was done, including measurements about the trees with DBH => 10cm, the soil characteristics and the landform features. The soil samples were analysed by the Rural Physical Planning Division (soil laboratory). The photo-interpretation and the biophysical inventory compilation were done by the Forestry Department.

The widely accepted idea that the soils are invariably nutrient-poor and/or physically fragile often link the rainforests and their soils and as corollary, the heavily exploited rainforest is likely to be slow to recover because its soils will not sustain rapid regrowth. According to Proctor (1992, 1995), these ideas about rainforests soils are based on slender evidence because hard facts about the relations between rainforests and their soils are difficult to obtain. It seems easier to find relationships between rainforests and the physical characteristics of their soils such as drainage and hydromorphy/flooding (Duivenvoorden and Lips 1995, Lescure and Boulet 1985) and their landform characteristics such as slope and topographic position (Duivenvoorden and Lips 1995, Ter Steege *et al*. 1993). The soil macronutrient levels are sometimes strongly correlated with the plant community richness, e.g. the potassium (Gentry 1988) and the phosphorus (Gartlan *et al.* 1986). In Jamaica, the growth of the Blue Mountains forests is limited by nitrogen and phosphorus shortage (Healey 1989) and only by phosphorus shortage (Tanner 1977).

The present analysis of forest-environment relationships for Dolphin Head forest reserve will also permit to understand the tree species richness of the forest stands located on the hilltops and the lower slope/valleys and to confirm the use of these two forest types in the photo-interpretation of the modified mesic limestone forest category in Jamaica.

2. DOLPHIN HEAD AREA

Dolphin Head is situated in the north-west of Jamaica, south of the port of Lucea, on the south border of Hanover and north border of Westmoreland parishes. The proposed site covers 1109 hectares, with approximately three quarters of area in Hanover and one quarter in Westmoreland. Over 85% of the site is government owned, which is roughly divided into seven (7) blocks: Quasheba Mountain, Raglan Mountain, Geneva Mountain, Bath Mountain, Baulk Pen, Retirement and Dolphin Pen (Table 1).

Table 1. Tenure of Dolphin Head area

Name (1)	Tenure	Jamaican Gazette
Quasheba Mountain	Forest reserve	23-09-1965 (page 423)
Raglan Mountain	Forest reserve	27-07-1961 (page 334)
Geneva Mountain	Forest reserve	03-11-1961 (page 535)
Dolphin Head - Bath Mountain block	Forest reserve	01-12-1950 (page 414)
Dolphin Head - Baulk Pen block	Forest reserve	01-12-1950 (page 414)
Retirement	Crown land	
Dolphin Pen	Private land	

(1) Forestry Department, 2001.

The Dolphin Head area is host to 606 plant species, of which 36 species are non-indigenous and more or less naturalised, 171 species are endemic to Jamaica and 25 species are restricted to Dolphin Head area (Proctor 2002). The site is identified as a high priority candidate protected area in Jamaica’s System of Protected Areas (Government of Jamaica 1997). The ease of accessibility to this area (close to the road between Montego Bay and Negril) should render this area an excellent eco-tourism site.

3. CLIMATE

The climate is a tropical maritime climate with mean daily temperatures ranging from a high of 28°C to a low of 26°C in August and February in lowland respectively (Maharaj *et al.* 2001). The temperature data show few variations in lowland, but in the tropics there is an average decrease of 0.56 °C expected for each 100 meters increase in elevation (Lauer, 1993), i.e. a potential variation of 3.0 °C between Lucea and the Dolphin Head Peak.

Rainfall and evaporation data are available for few stations close to Dolphin Head area. Askenish is the nearest station to Dolphin Head with the highest rainfall (447 mm) for the month of June (wet season) and a minimum of 87 mm for the month of December, for an annual mean of 3 108 mm recorded over a period of 30 years (1951-1980) (Maharaj *et al.* 2001).

An important factor for the water budget (site water balance) and soil processes in the tropics is the evapotranspiration, that is, a measure of the total amount of water lost by transpiration and evaporation. The results of potential evapotranspiration calculations are generally very variable depending of the formula used (Penman, Thornthwaite, etc.) and the methodology of water collection (evaporation pan, evaporimeter, etc.) . The ratio of annual precipitation to evaporation or evapotranspiration is highly correlated to vegetation. In the humid and semi-humid tropic, the general values of ratio of annual rainfall to potential evapotranspiration are between 2.6 and 1.6 for an annual rainfall of 3000-3500 mm (Lauer, 1993).

The nearest station for evaporation estimation is Smithfield, where the annual rainfall was 2790 mm for the period of 1951 to 1980 (Maharaj *et al.* 2001). The mean annual evaporation (standardised evaporation pan between 1970 and 1978) was calculated to be 1366 mm per year (Scholten and Andriesse 1986). As shown in Table 2, the "theoretical" water balance is positive for Dolphin Head area, but including the drying characteristics of limestone substrate, this water balance analysis is probably inaccurate for the driest months of the year.

Table 2. Climatic data for selected meteorological stations close to Dolphin Head area

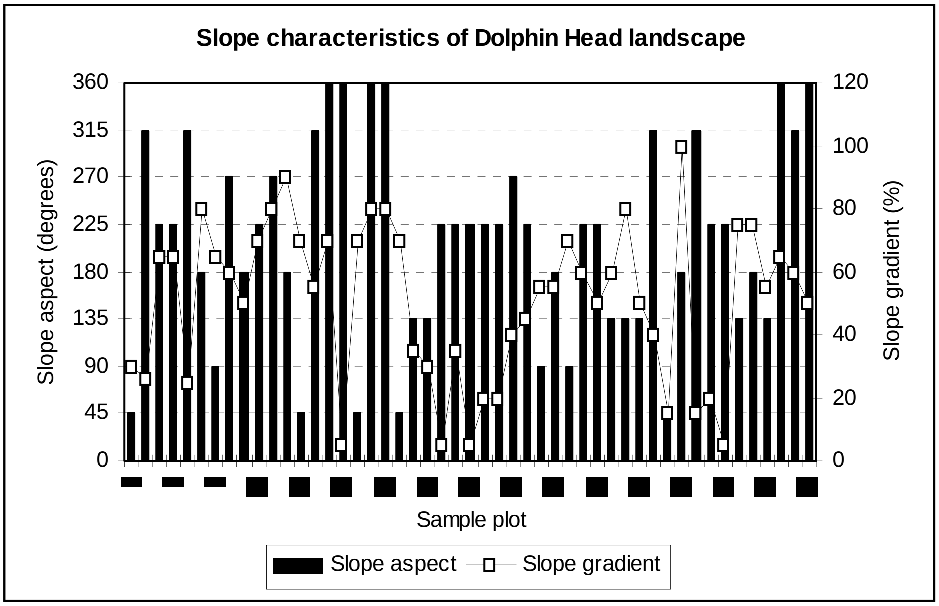
Station (period)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Mean rainfall 1951-1980 (mm)													
Askenish						447						87	3108
Mean evaporation 1970-1978 (mm)													
Smithfield	89	94	114	137	130	132	140	127	119	99	91	94	1366

Forest life is affected by these differences and has to adapt to the cooler conditions in the mountains and warmer temperatures in the lowlands. In this part of the world, the Holdridge life zones system is probably the best climate-vegetation classification to use. The zones are defined by geometrically progressive limits of mean annual precipitation and mean bio-temperature. According this Holdridge classification, the Dolphin Head area is included in the tropical moist forest zone (Forestry Department map).

4. GEOMORPHOLOGICAL LANDSCAPE

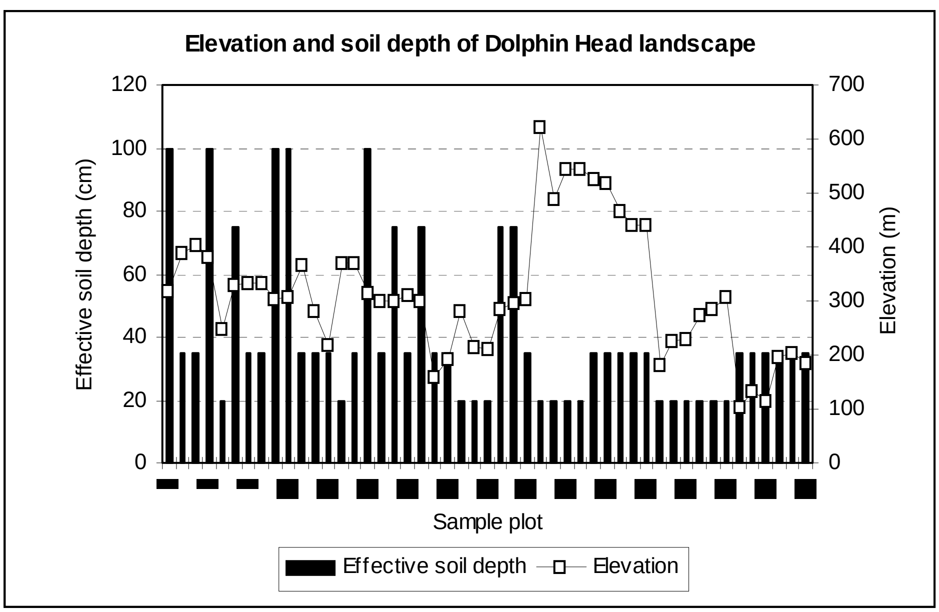
The Dolphin Head area is predominantly composed of white limestone hills (Mid Eocene to Lower Miocene in age), isolated by alluvial plains to the south (Georges Plain) and carbonaceous shale hills (Richmond beds) to the north (Price 1960, Stark 1964). The structure is karst landscape type, i.e. a rugged topography, formed by numerous deep dolines (cockpits), collapse structures, sinkholes and solution cavities of various kinds, between which conical (kegel-karst) or tower (turm-karst) shaped hills rise to several metres (Sweeting 1958, Zans *et al*. 1962). The average depth of the cockpits is 100 to 120 metres and the cockpit wall slopes are in average 30 to 40 degrees (with some vertical cliffs), making transit in a pre-defined direction extremely difficult (Draper and Fincham 1997) (Figure 1).

Figure 1. Slope characteristics of Dolphin Head area



Karst phenomena are formed according to the following way: the organic acids resulting from litter decay and carbonic acid through the reaction of CO_2 and water ($CO_2 + H_2O = H_2CO_3$) cause the so-called acidolysis (= acid-induced weathering). For calcium carbonate, the reaction is as follows: $CaCO_3$ (calcite) + $H_2CO_3 = Ca(HCO_3)_2$. $CaCO_3$ is less soluble but $Ca(HCO_3)_2$ is highly soluble ($Ca^{++} + 2HCO_3^{-}$) and will be washed out (Zech 1993, Lugo *et al*. 2001). There is hardly any surface drainage in such areas, for precipitation quickly passes underground into an extensive sub-terrain drainage system. The direction of flow of underground water is controlled first, by the direction of the dip, joint and fault within the limestone; secondly, by the changes in the lithology of the limestone; and thirdly, by the height and relief of the karst basis (Sweeting 1958).

Figure 2. Elevation and soil depth of Dolphin Head area



The elevation of the Dolphin Head area is comprised between 155 m and the highest point, Mark Tree (Dolphin Head peak) at 545 m (Price 1960) (Figure 2).

The fact that the Dolphin Head area is generally surrounded by non-limestone terrain and also it is the most highest and isolated area of white limestone in western Jamaica clearly indicate an ecosystem with a potential high biodiversity. Because the very specific and difficult adaptation to limestone environment, the specific and restricted limestone species can no longer shift to non-limestone habitats (Vermeulen and Whitten 1999).

5. SOILS

The total area of Dolphin Head soils is classified as "Bonnygate Stony Loam" (no. 77) type (Price 1960, Stark 1964). In this classification unit, about 75% is Bonnygate soil type and 25% is small areas of other minor types of soils. According to the landform, the general corresponding FAO-UNESCO soil classes are "Orthic Luvisols" and "Eutric Nitosols" (FAO, 1990). The corresponding classes in the USDA classification are "Lithic Tropudalfs" and "Ultic/Typic Tropudalfs" (Soil Survey Staff, 1975).

Landform and physical soil characteristics survey was carried out in the field for fifty (50) sample plots. Forty-nine (49) soil samples were collected using the first thirty (30) centimetres of the mineral soil and were sent to the Rural Physical Planning Division (RPPD) for the following analysis described in Table 3 below.

Table 3. Description of the soil analysis carried out by RPPD

Soil Element	Method of analysis
Sand, Silt, Clay (%)	Hydrometer method.
Organic Carbon (OC in %)	Walkley and Black method. Organic matter (%) = organic carbon (%) x 1.724.
Total Nitrogen (N in %)	N_2 - Kjeldahl method.
Soil Acidity (pH-H_2O)	pH-H_2O method.
Soil Acidity (pH-KCl)	pH-KCl method.
Cation Exchange Capacity (CEC in meq/100 g)	Neutral 1M Ammonium acetate (NH_4OAc) extraction method (adjusted to pH 7.0).
Available Potassium (K_2O in ppm)	0.5 N Acetic acid and Flame photometer method. K (ppm) = K_2O (ppm) x 0.83.
Available Phosphorus (P_2O_5 in ppm)	Truog extraction method / 0.002 N Sulphuric acid at pH 3.0 and spectrophotometer. P (ppm) = P_2O_5 (ppm) x 0.44.

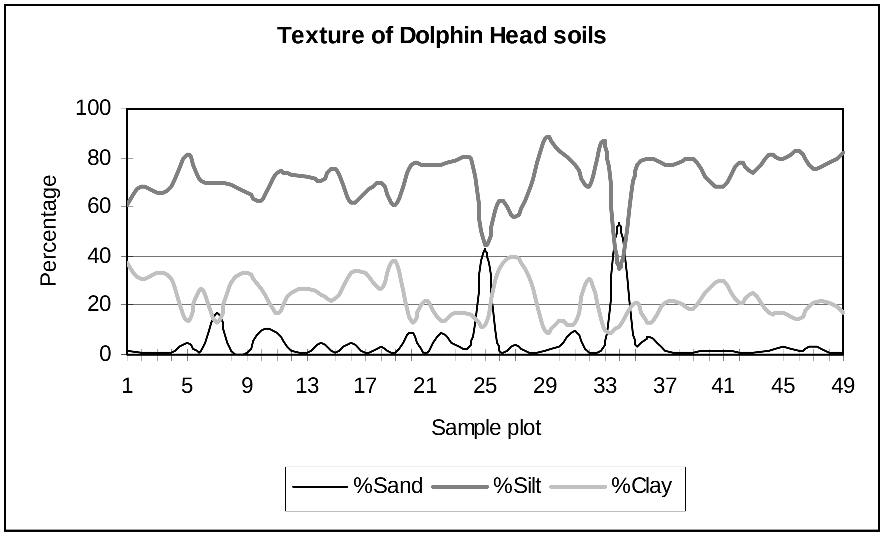
5.1 Physical characteristics of soils

In tropical karst areas, the topography influences the soil. The steep slopes are marked by the absence of soil, while flat hilltops are covered by a leaf litter over the limestone forming a layer of acid peat/humus that isolates the plants growing on it from the surrounding alkaline limestone. In horizontal limestone rock surfaces, deep soil accumulation is typically restricted to uvalas (closed large depressions), pits and dolines (Vermeulen and Whitten 1999).

The "Bonnygate Stony Loam" soil unit is mainly characterised by physical soil limitations such as shallow soils, stony surface, steep slopes, high erosion hazard and low moisture supplying capacity (Hewitt, 1964) (Figures 1 and 2).

The soils are very rapidly drained above the bedrock, predominantly shallow (1 to 35 centimetres), strong brown to reddish brown loamy and clayey soils, stony and in places with many limestone rock outcrops (50% or more) (Figure 2). The soil texture is always very fine and the texture class is mostly silt loam, composed in average with 5% of sand, 72% of silt and 23% of clay (Figure 3).

Figure 3. Texture characteristics of Dolphin Head soils



5.2 Chemical characteristics of soils

The "Bonnygate Stony Loam" type has a mildly alkaline pH and a low natural fertility in nitrogen, phosphate and potash. This soil unit has a high potential for producing timber and natural forest (leave in natural forest where practicable) and a medium potential for coffee and food trees (where large enough spots of deep soil occur). It has a low potential for most other crops traditionally grown in Jamaica (Hewitt, 1964).

The clay and organic matter contents seem to influence the capacity of soils to exchange mineral nutrients essential to tree growth. The increase of organic matter tends to have a positive effect on the increasing of soil fertility by a better cation exchange capacity. Inversely, the increasing of clay content tends to act negatively on the cation exchange capacity because the higher clay content probably increases the absorption power of the soils. According to the type of clay, the release of mineral nutrients is more difficult and is a slow process mainly in neutral to basic soils such as the Dolphin Head limestone soils (Figure 4).

The pH gradient from pure limestone rock to leaf litter covering the soil over limestone, coupled with different moisture regime supply, create a variety of conditions for chemical process in the soils and the availability of macro and micro nutrients for the plants. The mean value of the pH-eau of Dolphin Head soils is 7.4 with a standard deviation of 0.5.

The organic matter content presents a relatively good relationship with the availability of nitrogen and potassium. The relationship between the organic matter and nitrogen is very plausible because the soil laboratory method used measures the total nitrogen (including organic nitrogen). A higher content in organic matter creates a better soil exchange capacity to keep and to release the major cations such as potassium, calcium and magnesium (Figure 5). Where there is more vegetation, the soil organic matter content is higher and vice-versa, where the soil organic matter content is adequate, the probability of a good tree regeneration and establishment is higher.

In general, the Dolphin Head soils are very poor and not suitable for agriculture and their characteristics are comparable to some other limestone soils in Jamaica, except for the texture, organic matter content, pH and phosphorus content. The texture and organic matter content could easy be explained by the internal variation of limestone soil group, e.g. the soil texture attached to the name is not the same (Table 4).

Figure 4. Relationships between clay content, organic matter and cation capacity exchange

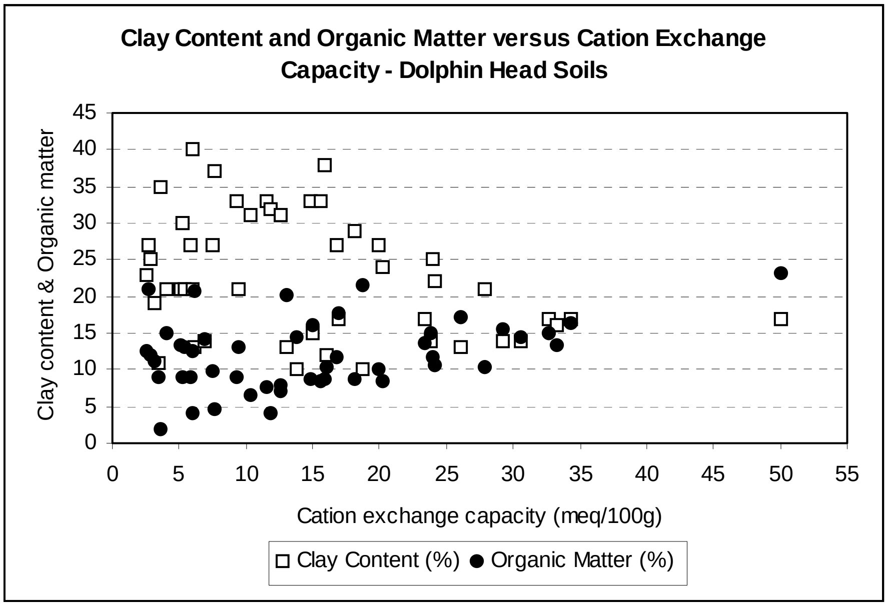
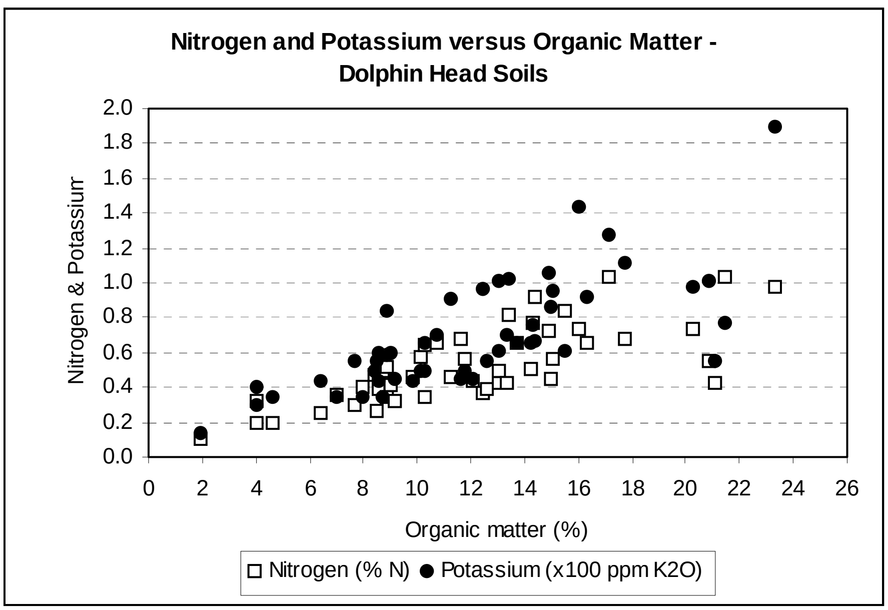


Figure 5. Influence of organic matter content on nitrogen and potassium availability



The phosphorus content in Dolphin Head soils (Bonnygate stony loam) is very low and closely comparable to the poorest soil type (Windsor stony clay) of the Scholten and Andriesse's study (1986), mainly for the values of texture and cation capacity exchange (Table 4).

In average, the soils under the hill top type of modified mesic limestone forest present a better fertility than the soils found under the lower slope/valley type, probably because the organic matter is less washed away by the rain on the relatively flat top than on the steep slope. The Dolphin Head soils contain two times less of potassium and seven times less of phosphorus than the minimum level of soil fertility used for agriculture purposes in Jamaica respectively (Table 4).

Table 4. Comparison of Dolphin Head soils with other Jamaican soils over limestone and critical levels of fertility

Soil Analysis (1)	**%Sand**	**%Silt**	**%Clay**	**%C**	**%OM**	**%N**	**C/N**	**pH-H_2O**	**pH-KCl**	**CECmeq**	**K_2Oppm**	**Kppm**	**P_2O_5ppm**	**Pppm**
Soils under Modified Mesic Limestone Forest - Lower slope / Valley (15 sample units / 0-30 cm maximum) - Bonnygate Stony Loam														
Dolphin Head area (mean)	6	71	23	6.6	11.3	0.47	14.6	7.1	6.7	12.41	63	52	8	4
Soils under Modified Mesic Limestone Forest - Hill Top (34 sample units / 0-30 cm maximum) - Bonnygate Stony Loam														
Dolphin Head area (mean)	5	73	23	7.2	12.3	0.55	13.4	7.5	7.0	16.16	72	60	8	4
Characteristics of Three Jamaican Soils over Limestone (Scholten and Andriesse, 1986) (2)														
Chudleigh Clay Loam (0-6 cm)	4	33	63	5.7	9.8	0.57	10.0	5.1	4.5	23.10	115	95	41	18
Windsor Stony Clay (0-17 cm)	11	56	33	3.8	6.5	0.38	10.0	4.8	4.3	14.20	48	40	14	6
St. Ann Clay Loam (0-10 cm)	4	49	47	3.8	6.6	0.32	12.0	5.7	5.1	17.50	99	82	197	86
Critical levels for agricultural purposes - Rural Physical Planning Division (Soil Laboratory), Ministry of Agriculture														
Low Fertility				< 2.6	< 4.5	< 0.2	> 13.0	< 6.0		< 15	< 140	< 116	< 60	< 26
High Fertility				> 5.7	> 9.8	> 0.5	< 11.4	> 7.0		> 25	> 225	> 187	> 100	> 44

(1) %C: Orgacic carbon (%); %OM: Organic matter (%); %N: Total nitrogen (%); pH-H_2O and pH-KCl: soil acidity; CECmeq: Cation exchange capacity (meq/100g); K_2Oppm: Available potassium (K_2O in ppm); P_2O_5ppm: Available phosphorus (P_2O_5 in ppm); for methods of soil analysis: see Table 4.

(2) Scholten, J.J. and W. Andriesse, 1986. "Morphology, genesis and classification of three soils over limestone, Jamaica". Geoderma 39:1-40.

6. FOREST CHARACTERISATION

The vegetation of Dolphin Head area is classified "evergreen seasonal forest" (Beard 1944), "wet limestone forest" (Asprey and Robbins 1953), "mesic limestone forest" (Kelly *et al*. 1988), "mesic forest over limestone" (Grossman *et al*. 1992), "Lowland/submontane seasonal evergreen forest" (Li *et al*. 2000) or "modified mesic limestone forest" (Forestry Department 2002). According to a botanical point of view, there is a great floristic variation and a high number of local endemic species in this forest type, not only between hill top, mid-slope and valley, but also between nearby sites of identical topographic situation and habitat type (Grossman *et al*. 1992, Lugo *et al*. 2001).

According to the photo-interpretation (1:15000 scale) and the forest structure, we can clearly divide the Dolphin Head forest stands over limestone into two main groups: (1) the "hilltop vegetation", i.e. the dry peaks vegetation characterised by a high tree diversity with individuals being found close together, but generally having a very small diameter and low canopy, (2) the "lower slope/valley vegetation", i.e. this vegetation shows a much smaller species diversity, with bigger trees in diameter and height for the same species.

Six hundred and six (606) plant species belonging to 102 families have been identified. Of these, 171 species (30%) are endemic to Jamaica, of which 25 species (5 tree/small tree species and 13 shrub species) are endemic from Dolphin Head. Three of the 5 tree/small tree species endemic from Dolphin Head are non-identified (noted sp. nov. ined. by Proctor 2002).

The average height of endemic tree/small tree species is between 5 to 10 metres with one exception, the Red Nickel (*Ormosia jamaicensis*). This species is a large fast growing tree reaching around 25 metres high, with a maximum height of 35 m (Mathew, 1999). This endemic species is a member of the Papilionaceae (Fabaceae) family (Leguminosae order) and until recently, the only representative of the genus in Jamaica (Adams 1972, Proctor 1982). Proctor (2002) lists a new tree species in this genus, Ormosia sp. nov. ined.

The tree produces flattened pods (4-6 cm long) containing 1 or 2 scarlet seeds with a black spot about 1.5 cm in length and 1 cm thick. Some lupin alkaloids (jamaidine, jamaicensine) were isolated from the plant. The alkaloids of the lupin group are toxic and some find use in veterinary medecine and in insecticide preparations (Adams *et al*. 1963). Research activities are currently being carried out using the Red Nickel to develop a commercial drug (Natural Resources Conservation Authority 2000).

A biophysical inventory was carried out by the Forestry Department in the Dolphin Head area according to the methodology summarised in Table 5. The plant identification was done by Senior Forester Mr. Bowen Grant from the Forestry Department with the help of Dr. George R. Proctor for the tree specimens difficult to identify. The following sub-sections describe the biophysical forest survey results of fifty (50) temporary sample plots (0.05 ha/plot) established in Dolphin Head area.

Table 5. Summary of biophysical inventory design and measurements

Parameters	Methodology (1)
Sample plots number [Allowable error = 10%] [P = 95%, α = 5%]	Required sample plots number = Minimum 150-175 by WMU or Minimum 10-12 sample plots by forest type
Sample plot allocation	Preliminary photo-interpretation at 1:15 000 scale Stratified random allocation Minimum distance between plots = 100 m (exceptionally 50 m) Number of plots along the line transect = minimum 3
Sample plot shape	Rectangular fixed-area (nested structure) for natural forests & plantations
Sample plot (subplot & sub-subplot) size	Plot 25 x 20 m [for big trees with DBH => 10 cm] Subplot 5 x 10 m [for tree saplings with DBH < 10 cm and height => 2 m] Sub-subplot 1 x 2 m [for tree regeneration with height < 2 m]
Tree studies (diameter & height) with Spiegel relascope (wide scale)	Maximum 3 samples nearest the plot centre and selected as follows: 1st tree species A [DBH 10-20 cm], 2nd tree species B [DBH 20-30 cm] and 3rd tree species C [DBH > 30 cm] Height levels measurements for hardwoods (6): ground, stump, first fork (crown point), second fork, third fork and top Height levels measurements for conifers (3): ground, stump and top Tree visible defects & bark thickness for each tree study
Terrain & soil attributes	For each sample plot (soil augering 30 cm depth & measurements at the centre of the sample plot or nearest)

(1) Biophysical Inventory Manual (Forestry Department, June 2000).

6.1 Sampling error and effort

The allowable (or expected) error for a management (biophysical) inventory at the level of the inventoried area (forest reserve, protected area or management area) should be around +/- 10 % at 95 % level of probability (α = 5%). This allowable error is a weighted sampling error of all forest types combined.

Fifty sample plots (0.05 ha/plot) were established in Dolphin Head area, i.e. a total sampling of 2.5 hectares or 0.23% sampling. One thousand seven hundred ninety one trees (1791 trees) with DBH => 10 cm of 128 species were identified and measured (+ 1 unknown/unidentified species). The accuracy of the collected data is presented in Table 6. The weighted sampling error for the standing tree parameters (DBH => 10 cm) is below 10% (or close in the case of the volumes), which is acceptable for the purpose of a forest conservation and management plan.

Table 6. Statistics of the biophysical inventory in Dolphin Head area

Statistics (1)	Stems	BA	VTob	VCob
Mean	697	21.54	180.77	72.26
Coefficient of Variation	28.1%	35.4%	47.4%	57.8%
Sampling Error (P = 95%)	7.8%	9.8%	13.1%	16.0%

(1) Forest area = 1109 ha; Number of sampling units = 50.
Stems = Number/ha >= 10 cm DBH; BA = Basal area (m^2/ha).
VTob = Total volume overbark (m^3/ha).
VCob = Crown point volume overbark (m^3/ha).

The number of species normally increases with the increasing of sample plot area or number of sample individuals until certain limits where only few individuals of rare species are added at each sample individual or plot and then, the cost of the survey becomes very expensive. The relationship between the number of species and the surveyed area (or number of sample plots or number of individuals) shows the best representation by using a semi-logarithmic curve (log scale on axis X) or by log-log or power curve (log scale on axis X and Y). The choice of the equation form is simply a matter of preference (Hayek and Buzas 1997).

Figures 6 and 7 present the relationships between the sampling area, the number of sample trees with DBH => 10 cm respectively and the number of species (semi-logarithmic equation). The two graphs show that the sampling method was efficient to survey most of the tree species (DBH => 10cm) present in Dolphin Head area.

Figure 6. Relationship between number of tree species and sampling area for modified mesic limestone forest

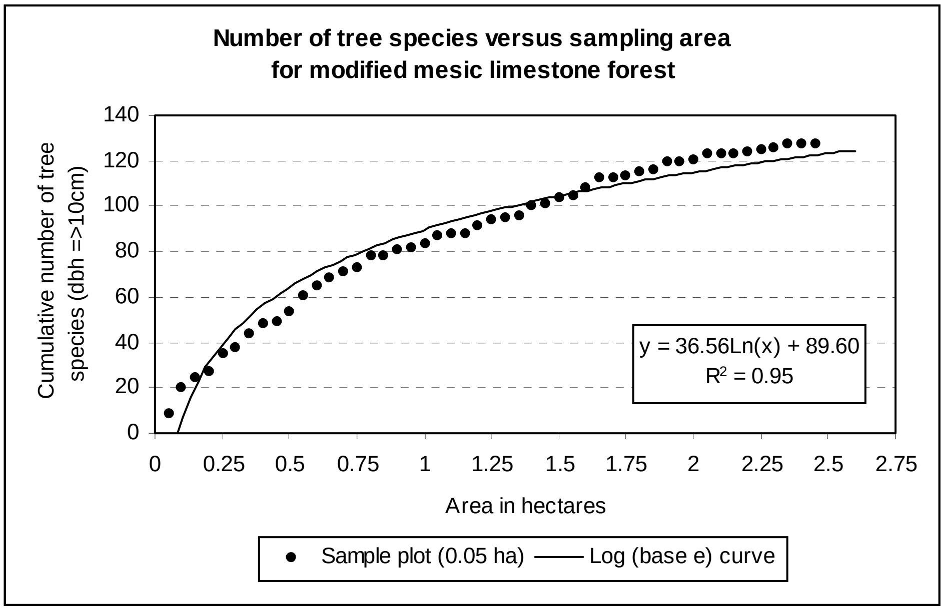
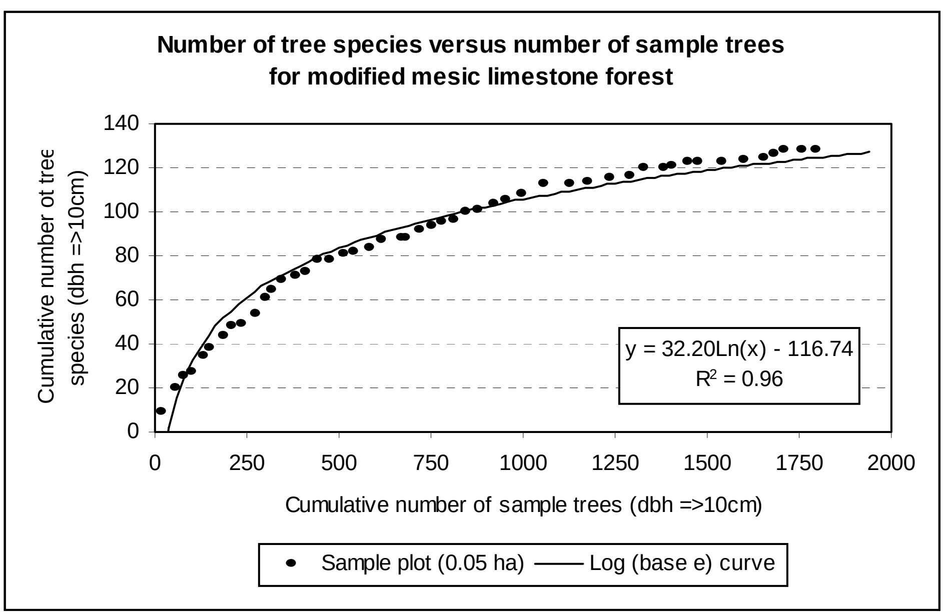


Figure 7. Relationship between number of tree species and number of sample trees for modified mesic limestone forest



Eliminating the plot area factor, the ratio number of species and number of individuals per plot (or a regression equation) can be used to compare different studies. On the limestone soils of Dolphin Head area, 20 to 24 tree species (DBH => 10 cm) are encountered per 100 individuals (trees). This tree diversity is the same that reported in the Puerto-Rican forests on karst (Table 7).

Table 7. Comparison of tree species number and density between Jamaican and Puerto-Rican forests on limestone (karst)

Forest type	**Equation (1)**	**Number of sample plots**	**R^2**	**Tree species number (x = 100 individuals)**
Jamaica - Dolphin Head area (2)				
Modified mesic limestone forest - Lower slope/valley	y = - 9.34 + 6.43 * LN(x)	15	0.40	20
Modified mesic limestone forest - Hill top	y = - 18.55 + 9.29 * LN(x)	34	0.56	24
Puerto Rico (3)				
Moist and wet forests on karst (on limestone)	y = - 13.79 + 20.01 * LOG(x)	39	0.37	26
Dry forests on karst (on limestone)	y = - 30.27 + 24.95 * LOG(x)	26	0.52	20

(1) x = number of individuals per sample plot; y = number of tree species per sample plot; LN = base "e" logarithm; LOG = base 10 logarithm.
(2) Present study.
(3) Lugo *et al.* 2001.

6.2 Forest and non-forest areas

At the scale 1:15000, the minimum photo-interpreted area represents approximately 0.5-1.0 hectare in the field. The photo-interpreters can find a multitude of forest land use/cover types and non-forest types, particularly in a fragmented forested landscape. On the other hand, the sampling plan tries to cover the most representative forest types according to the time and money available for the field survey.

Firstly, it is difficult to survey in the field all forest types with a very small total area and then, it is necessary to group some interpreted forest land use/cover types. The second reason to group the forest land use/cover types is to obtain a good accuracy of the calculations, particularly when some forest land use/cover types are very variable from one stand to another and finally, for the clearness of the tables of inventory results. The grouping is done to the nearest type on the basis of the area of each type, the number of sample plots per surveyed type, the density/height class for the natural forest and the plantation year (age) for the forest plantations (Table 8).

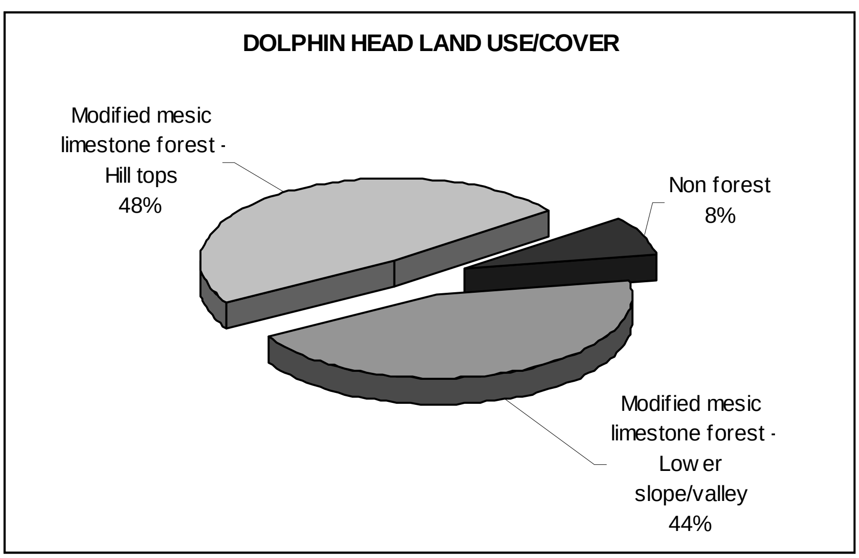
According to the photo-interpretation, the mesic limestone forest found in Dolphin Head area is a modified/disturbed variant with different structure from the hill tops (48% of forest area) to lower slope/valley (44% of forest area). Approximately 8% of the area is non-forest, mainly in fields - food crops (4.3%) (Table 8 and Figure 8).

Table 8. Definition of land use/cover type groups for Dolphin Head area

Land use/cover type (LU)*				Area		# Sample	LU Group		
PU	SU	CD	H	ha	%	units (SU)	Name	# SU	Area (ha)
DM	FC	C	2	17.4	1.5		Modified mesic limestone forest - Lower slope/ Valley (DM)	15	533.2
			3	28.2	2.3	3			
			4	20.4	1.7	3			
		B	2	5.4	0.4				
		C	2	239.0	19.9	3			
			3	191.8	15.9	4			
		D	4	2.8	0.2				
FC	DM	D	3	28.2	2.3	2			
MM	FC	C	3	15.8	1.3	1	Modified mesic limestone forest - Hill top (MM)	35	575.5
			4	29.9	2.5	1			
		B	3	354.2	29.4	23			
			4	61.5	5.1	1			
		C	3	60.1	5.0	3			
			4	54.1	4.5	6			
PA				6.8	0.6		Non Forest	0	94.0
SC				1.6	0.1				
FC	FT			4.4	0.4				
	MM	C	3	11.4	0.9				
			4	17.7	1.5				
				52.2	4.3				
Total				1203	100	50		50	1203

* PU : Landuse type (Primary code), SU : Mixed type (Secondary code), FC : Fields - Food crops,
PA : Fields - Pasture, SC : Plantation - Sugar cane, FT : Fields - Fruit trees garden.
CD (Cover density class) = A : > 75%, B : 50-74%, C : 20-49%, D : 1-19%.
H (Height class) = 1 : > 25 m, 2 : 16-24 m, 3 : 7-15 m, 4 : < 6 m.

Figure 8. Land use/cover for Dolphin Head area

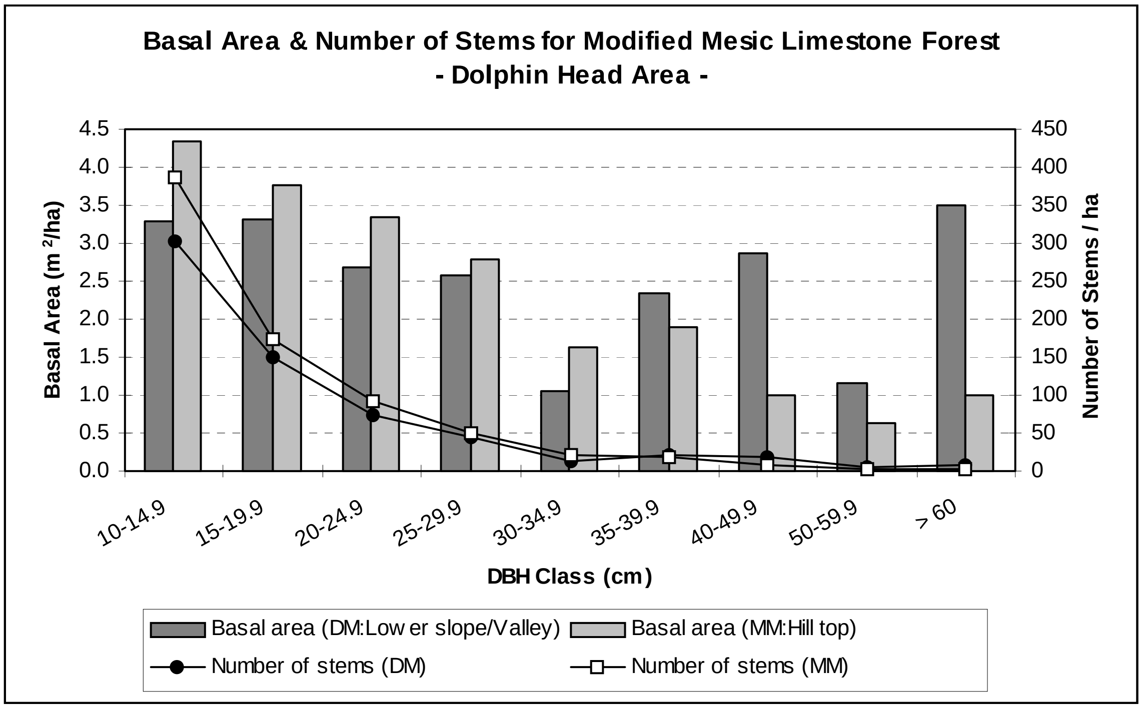


6.3 Number of individuals and basal area (DBH => 10cm)

The number of individuals (or stems/ha => 10 cm DBH) normally varies according to the species and the forest type. The basal area (m^2/ha) is a good measure of the tree dominance, combining in the same value the number of individuals (trees) per hectare and the area of trees per hectare at the level of diameter at breast height (DBH).

The forest stands on the hill tops (mostly MMB3 type) present a higher density of smaller trees than the lower slope/valley forest type (mostly DMC2 and DMC3 types). For DBH class => 35 cm, the basal area is higher for the lower slope/valley type than hill top forests. The average number of stems and basal area are 639 individuals/ha and 22.79 m^2/ha respectively for the lower slope/valley type of the modified mesic limestone forest while for the hill top type, these values are 750 individuals/ha and 20.38 m^2/ha respectively (Figure 9).

Figure 9. Basal area and number of stems per DBH class (=> 10cm) for Dolphin Head area



Thirty tree species (DBH => 10cm) make up approximately 75% percent of the total basal area per hectare in Dolphin Head area, i.e. 77.1 percent and 74.1 percent for the modified mesic limestone forest lower slope/valley and hill top types respectively. One-third of the total basal area is made up of only eight tree species in each modified mesic limestone forest type. Four (4) tree species are common to the two types of forest and they are *Terminalia arbuscula* (Combretaceae), *Ocotea martinicensis* (Lauraceae), *Hernandia jamaicensis* (Hernandiaceae) and *Brosimum alicastrum* (Moraceae). Two other dominant tree species characterise the hill top type of modified mesic limestone forest, i.e. *Amyris balsamifera* (Rutaceae) and *Oreopanax capitatus* (Araliaceae). Finally, the tree species *Alchornea latifolia* (Euphorbiaceae) and *Cecropia peltata* (Cecropiaceae) are among the six most dominant tree species for the lower slope/valley type of the modified mesic limestone forest (Figure 10).

The common dominant tree species to the two types of modified mesic limestone forest are normally found in the western region of Jamaica and on the limestone geological substrate. The tree species *Alchornea latifolia* and *Cecropia peltata*, mainly found in the lower slope/valley type of modified mesic limestone forest, indicate a higher degree of disturbance (forest gaps) of this type than the hill top type. The species *Amyris balsamifera* is common in woodlands on limestone, while *Oreopanax capitatus* is very common in secondary and marginal woodlands in moderately wet areas between an elevation of 100 to 1500 metres (Adams 1972).

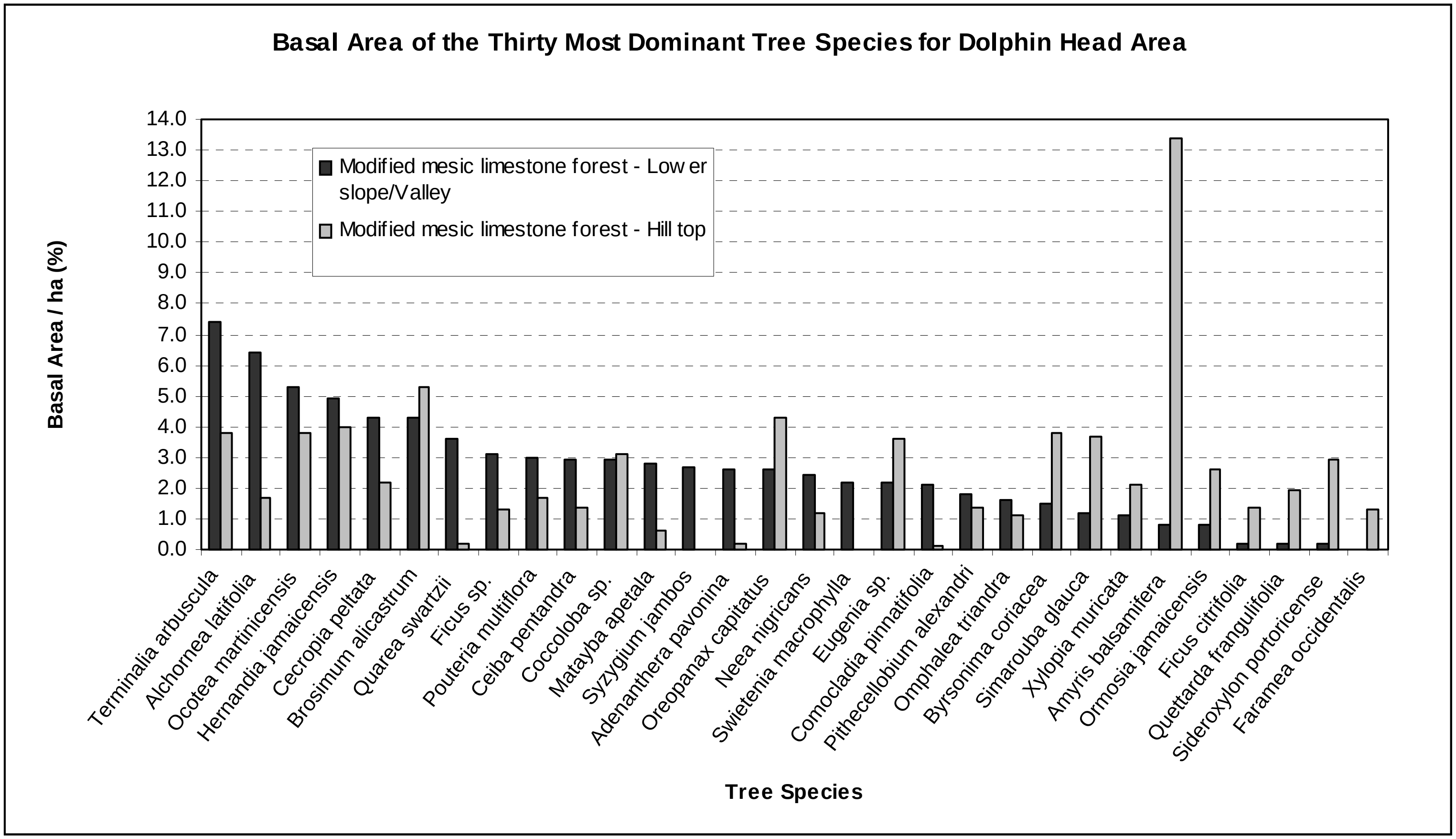
Some other tree species, such as *Adenanthera pavonina*, *Spathodea campanulata* and *Syzygium jambos*, are good indicators of the higher degree of disturbance or modification (gaps) of the mesic limestone forest (lower slope/valley type) (Table 9). Tree species *Omphalea triandra* and *Simarouba glauca* are mainly found on limestone soils (Adams 1972).

The species *Ormosia jamaicensis* is one of the three large endemic tree species from Dolphin Head area. The two other large tree species are new and non-identified species (*Ormosia* sp. nov. ined., *Sideroxylon dolphinensis*, sp. nov. ined., Proctor 2002). After his study of the ecological conditions of *Ormosia jamaicensis* (Red Nickel) in Dolphin Head area, Mathew (1999) concludes that the Red Nickel species is found in a broad range of habitats but his sampling did not found tree specimens at the extremes of available moisture (very wet areas or dry tops). According to the data presented in Table 9 below, the number of *Ormosia jamaicensis* trees is clearly dominant in the hill top type of the modified mesic limestone forest but the sample trees have a smaller average diameter (DBH).

Table 9. Tree species indicators of Dolphin Head modified mesic limestone forest

Tree species indicators (dbh => 10cm)	**Modified mesic limestone forest**			
	Lower slope/valley		**Hill top**	
	Trees / ha	**BA (m^2/ha)**	**Trees /ha**	**BA (m^2/ha)**
Invasive species (disturbance, gaps)				
Adenanthera pavonina (Red Bead Tree)	33	0.59	2	0.04
Alchornea latifolia (Teeth Ache)	24	1.47	6	0.34
Cecropia peltata (Trumpet Tree)	36	0.99	25	0.44
Spathodea campanulata (African Tulip Tree)	11	0.27	1	0.03
Syzygium jambos (Rose Apple)	24	0.63	0	0.00
Timber plantation species				
Swietenia macrophylla (Honduras mahogany)	32	0.51	0	0.00
Endemic tree species (Dolphin Head)				
Ormosia jamaicensis (Red nickel)	1	0.18	12	0.54
Other species (Western parishes, on limestone)				
Amyris balsamifera (Oilwood)	3	0.18	78	2.72
Brosimum alicastrum (Breadnut)	25	0.97	21	1.08
Hernandia jamaicensis (Garlic Pear)	21	1.12	5	0.20
Ocotea martinicensis (Rock Sweetwood)	45	1.20	24	0.77
Omphalea triandra (Popnut)	15	0.37	7	0.22
Simarouba glauca (Bitter Damson)	13	0.28	39	0.76
Terminalia arbuscula (White Olive)	16	1.69	29	0.77

Figure 10. Basal area of the thirty most dominant tree species for Dolphin Head modified mesic limestone forest



6.4 Volume and aboveground living biomass (DBH => 10cm)

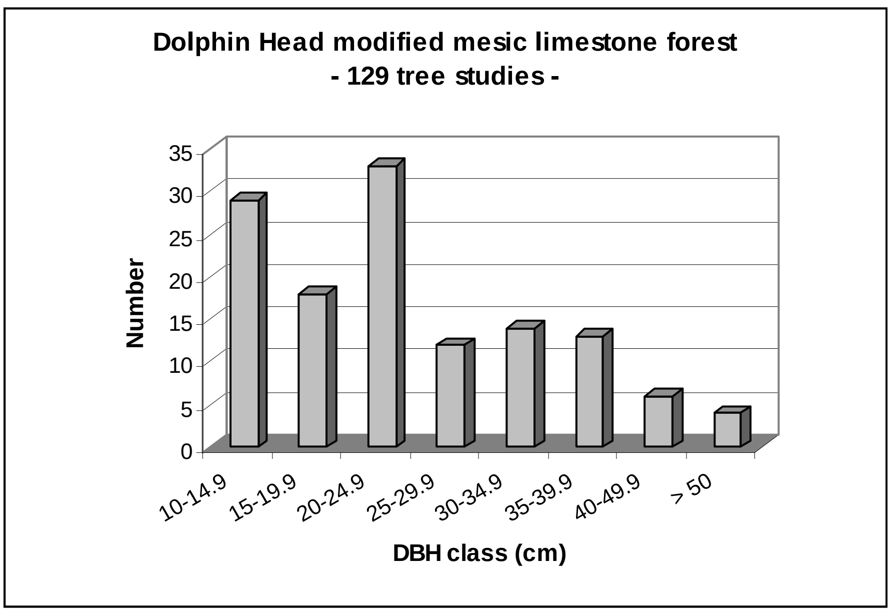
The biophysical inventory carried out by the Forestry Department in Dolphin Head area included one hundred twenty nine (129) complete tree studies (Table 10). The objective of the tree study in biophysical inventory is to derive reliable local relationships of total tree volume over bark and crown point volume over bark (for calculations of aboveground living biomass) to DBH (the easier tree parameter to measure). These are achievable and less costly only through a series of measurements taken on standing trees with a Spiegel relascope-Wide scale (Biophysical inventory manual, Forestry Department 2000).

Table 10. Summary of tree study data for Dolphin Head area

Tree study data	Modified mesic limestone forest
Number of species	54
Number of sample trees	129
Minimum DBH (cm)	10.2
Maximum DBH (cm)	79.6

The selection of tree to be completely studied was systematic within the sample plot with a maximum of three sample individuals, i.e. one sample tree of different species per each following three DBH classes (if any): 10-19.9 cm, 20-29.9 cm and 30 cm and more. The number of studied trees per DBH class is presented in Figure 11, which figure also indicates that most of the Dolphin Head trees have a small DBH below 25 cm.

Figure 11. Distribution of tree studies per DBH class for Dolphin Head area



6.4.1 Local volume tables

To obtain the local volume equations after the entry of tree study data, firstly the biophysical inventory software (MS Access - BPIprog) carries out all the calculations of stem-volume and that for the single entry (DBH) model to express the total volume (over bark) and crown point volume (over bark). Secondly, the MS Excel software is used to fit the best curve model and to calculate the coefficients of regression equation for the chosen volume-type.

The volume equations for the Dolphin Head local volume tables are calculated for all tree species combined. For a probability of 95%, the coefficients of regression for the total volume (over bark) and crown point volume (over bark) equations are presented in Figures 12 and 13 respectively. Both coefficients of determination (R^2) are statistically significant.

Figure 12. Graph and coefficients of total volume (over bark) equation

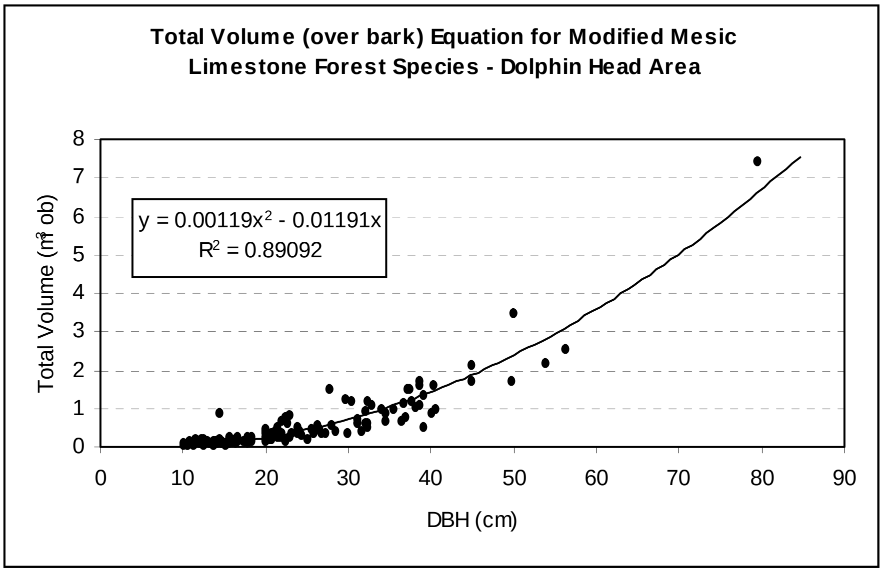
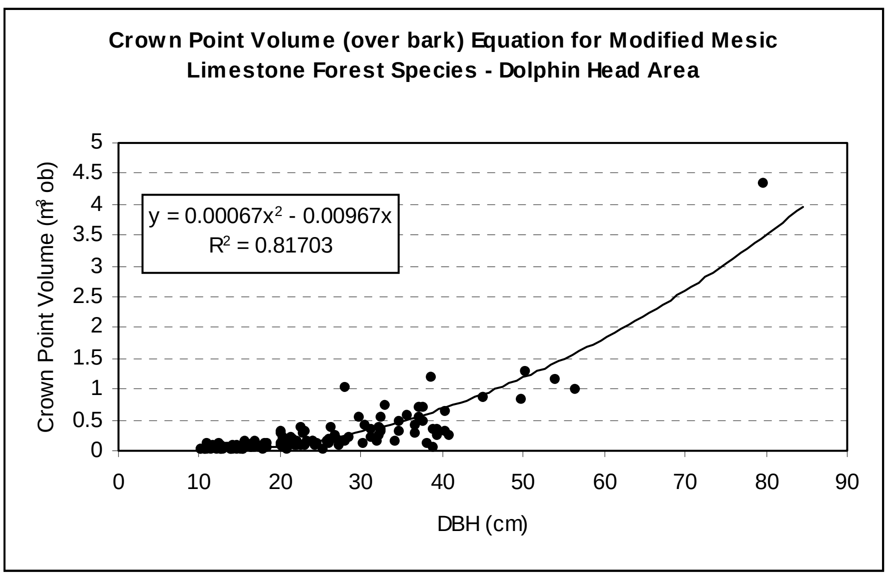


Figure 13. Graph and coefficients of crown point volume (over bark) equation

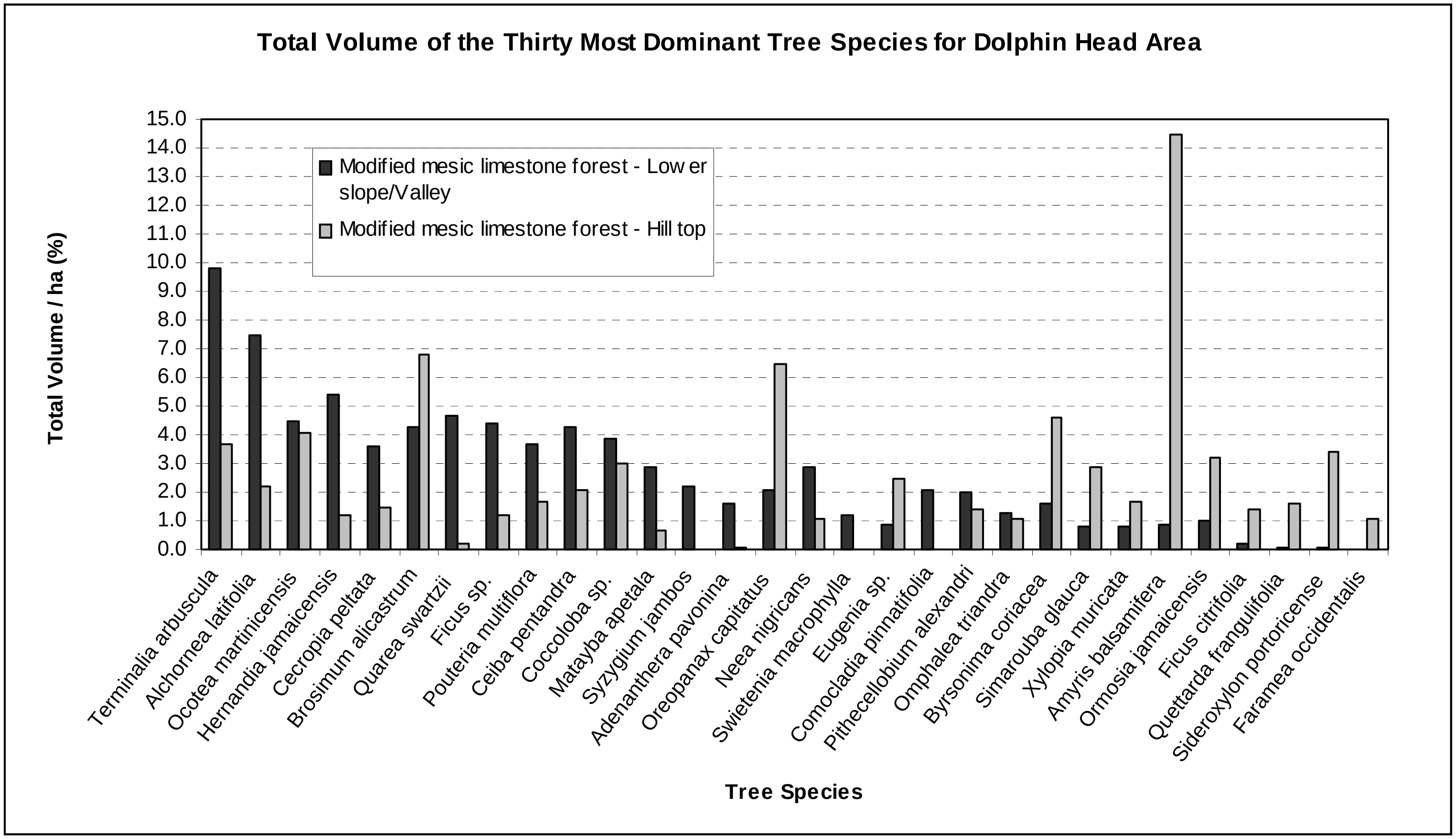


6.4.2 Total and crown point volumes

The total and crown point volumes per hectare for trees with DBH => 10cm are 205 m^3/ha and 87 m^3/ha respectively for the lower slope/valley type of the mesic limestone forest while for the hill top type, these values are 158 m^3/ha and 59 m^3/ha respectively.

As the basal area, thirty tree species make up over 75% percent of the total volume per hectare in Dolphin Head area, i.e. 80.8 percent and 75.5 percent for the modified mesic limestone forest lower slope/valley and hill top types respectively. The same eight tree species, as the basal area results, represent more than one-third of the total volume per hectare (Figure 14).

Figure 14. Total volume of the thirty most dominant tree species for Dolphin Head modified mesic limestone forest



6.4.3 Aboveground living biomass of forest and carbon stocks

The calculations of aboveground biomass (over-storey living biomass, not including roots, litter, dead wood and under-storey) follow the methodology proposed by Brown (1997) on the basis of the crown point volume (over bark) data from the standard forest inventory. The following equation for the broadleaf species of Dolphin Head area was used:

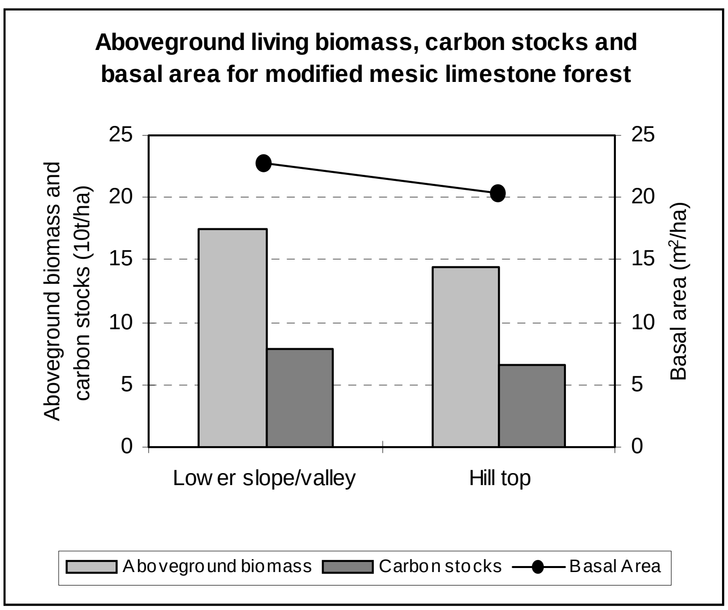
> Aboveground biomass (t/ha) = VOB * WD * BEF, where
> VOB = Crown point volume over bark, all trees with DBH => 10cm.
> WD = Volume-weighted average wood density (t of oven-dry biomass per m^3 green volume).
> BEF = Biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of inventoried volume).
> For Broadleaf species: WD = 0.6 and BEF = Exp(3.213 – 0.506 * Ln(VOB*WD)).

The carbon storage was estimated on the basis of the aboveground living biomass of forest. The following factor was used (Woomer and Palm 1998):

> Value of aboveground biomass is multiplied by a factor of 0.45. This factor normally varies between 0.4 and 0.5 according to the type of organic matter.

The seven forest blocks (1203 ha) of Dolphin head area contain 176600 metric tons of biomass, specifically for aboveground living trees with DBH => 10cm, which stock 79500 metric tons of carbon (C). The average aboveground living biomass for the lower slope/valley type of modified mesic limestone forest is 175 metric tons per hectare while for the hill top type, the average biomass is 145 metric tons per hectare (Figure 15).

Figure 15. Aboveground living biomass, carbon stocks and basal area for Dolphin Head area



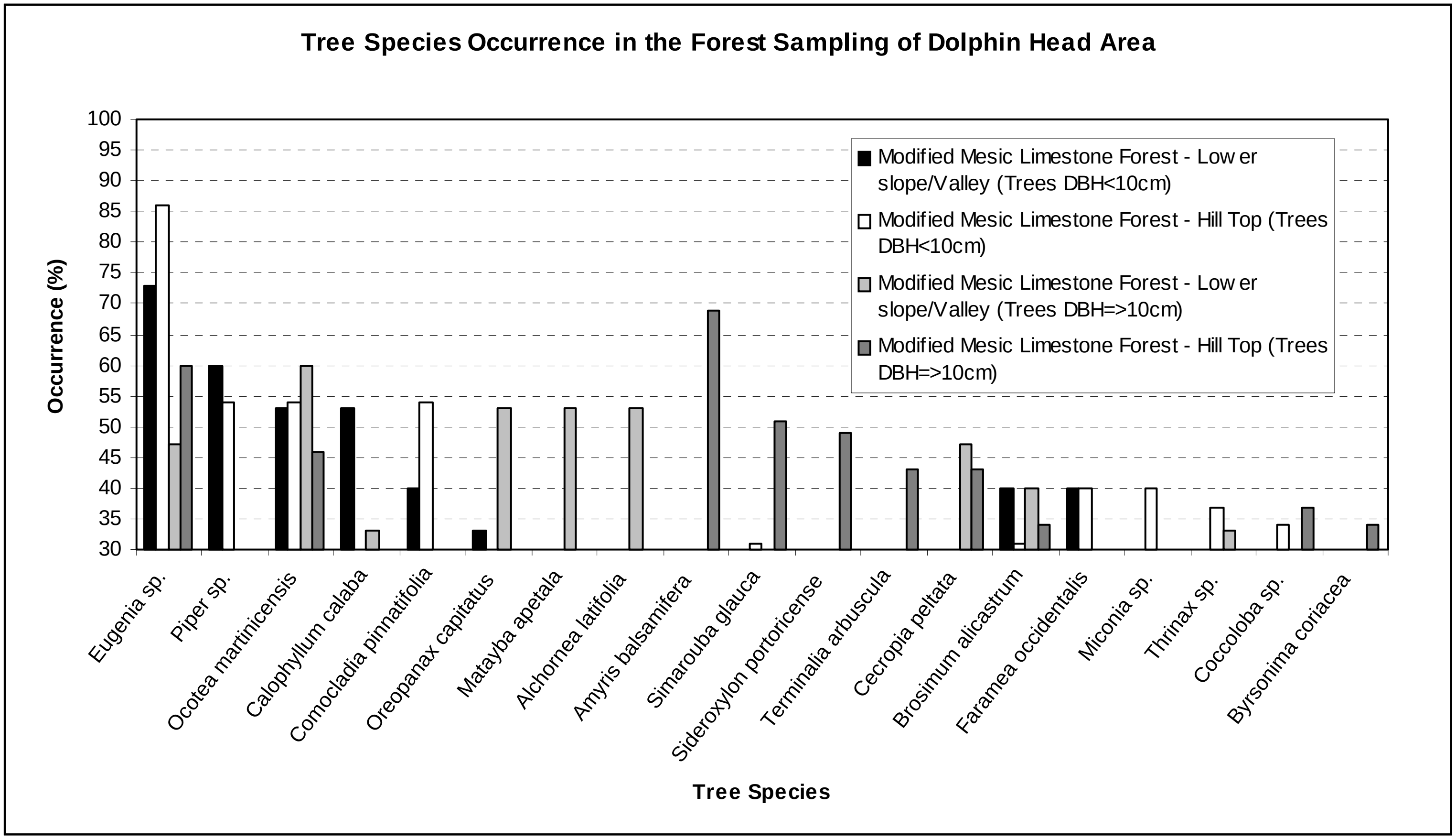
6.5 Tree regeneration (DBH < 10cm)

The inventory of tree regeneration was carried out according to two categories: saplings (DBH < 10cm; Height => 2m) and regeneration (DBH < 10cm; Height < 2m). The number of times (in percent) that the tree species occurs in the sample plots, named occurrence of tree species, is used to analyse the tree regeneration. There is a relationship between the number of trees per species (abundance or density) in a forest stand and the number of plots in which those trees occur (Hayek and Buzas 1997).

Two tree genus and one tree species with DBH < 10cm are found more than 50% of times in the sample plots in both types of modified mesic limestone forest (lower slope/valley and hill top). The tree genus are *Eugenia sp.* (Rodwood, Myrtaceae) and *Piper sp.* (Jointer, Piperaceae) and the tree species is *Ocotea martinicensis* (Rock sweetwood, Lauraceae). Jointer species are not necessarily tree recruitments because these species are small trees usually with DBH < 10cm. Rodwood species are both small trees and tree recruitments because there is the presence of bigger trees (DBH => 10cm). As mentioned in sections 6.3 and 6.4, Rock sweetwood is one of the most dominant tree species in basal area and volume for trees with DBH => 10cm and, the regeneration data of this tree species shows a very good potential in Dolphin Head area (Figure 16).

The timber species *Calophyllum calaba* (Santa Maria, Clusiaceae) presents an occurrence of 53% for trees with DBH < 10cm in the lower slope/valley type of the modified mesic limestone forest (Figure 16). Santa Maria is common in woodlands and on limestone in areas of higher rainfall (Adams 1972). In general, the species tolerates disturbed sites and a great variety of soil drainage (Weaver 1990), but Santa Maria grows best in moist coastal sands and clays and in the moist foothills (Francis 1998). It is common to find dense young seedlings and saplings around mother-trees because the seeds germination is very good in natural conditions and the seedlings tolerate light shade (mid-tolerant) during the first growing years (Weaver 1990).

Figure 16. Tree species occurrence over 30% of sample plots in Dolphin Head area



6.6 Tree species diversity

The first stage of the tree species diversity assessment is the listing of plant species found in the studied area (see Proctor 2002). The second stage normally is a quantitative global estimation or measure of tree species diversity per forest type in the inventoried area. On the basis of the standard inventory results for trees with DBH => 10cm, it is possible to calculate some global measures of tree species diversity for future comparison with other inventoried areas in Jamaica (watershed management unit, forest reserve, protected area, etc.).

The basis of these tree species diversity measures is N (# of individuals), S (# of species), BA (basal area) or proportion of N or BA by species, giving a family of indices proposed by different authors. The diversity indices and methodologies used in the present study, with their significations, are listed in Table 11 below.

Table 11. Indices and methodologies used to assess the tree species diversity

BIODIVERSITY INDICES	
Species (S)	Total number of recorded species
Individuals (N)	Total number of censured individuals
Basal area (BA)	$Dbh^2 \times (\pi /4)$ where Dbh = diameter at breast height
Relative dominance (DO)	Total basal area for a species / total basal area for all species x 100
Relative density (DE)	Number of individuals of a species / total number of individuals x 100
Frequency (FR)	Number of sampling units in which a species occurred
Relative frequency (RF)	Frequency of a species / sum of all frequencies x 100
Relative diversity (RD)	Number of species in a family / total number of species x 100
Importance value index (IVI)	Relative dominance + relative density + relative frequency of a species
Family importance value (FIV)	Relative dominance + relative density + relative diversity
Fisher's index of diversity (α)	$N/S = (e^{S/\alpha} - 1) / (S/\alpha)$
Margalef's index of species richness (D)	D = (S-1) / ln(N)
Shannon's information index (H)	H = -SUM (p*ln(p)) where p = (n/N) and n = # of individuals by species
Pielou's measure of eveness (J)	J = H / ln(S)
Reciprocal of Simpson's concentration index ($1/\lambda$)	$\lambda = SUM (p^2)$ where p = (n/N) and n = # of individuals by species
Jaccard's index of similarity (C_J)	$C_J = j / (a+b-j)$ where j = # of species in common found in both sites, a = # of species in site A and b = # of species in site B.
Sorenson's index of similarity (C_N)	$C_N = 2jN / (aN+bN)$ where jN = Sum of the lower of the two abundances recorded for species in both sites, aN = total # of individuals in site A and bN = total # of individuals in site B
Source: DALLMEIER and COMISKEY 1998; HAYEK and BUZAS 1997; MAGURRAN 1988.	

As demonstrated in section 6.1, the total number of tree species recorded (S) is clearly subject to sampling intensity, mainly when the sample size is not adequate to assess most of the tree species. Most biodiversity indices are very correlated to the sample unit area (sample size) and the independence from sample size is often used as a criterion to judge the effectiveness of diversity indices. Some biodiversity indices such as Fisher's alpha index (log series) and Simpson's index, are less sensitive to sample size (Magurran 1988). After comparison of the forest diversity assessment using small sample plots or large sample plots (50 ha/plot), Condit *et al*. (1998) found that the Shannon's[1] and Fisher's indices present a good stability with a change of sample size while the Simpson's index is poorly constant with changing sample size. These authors also conclude that the Fisher's index can be used to predict the number of species in larger samples.

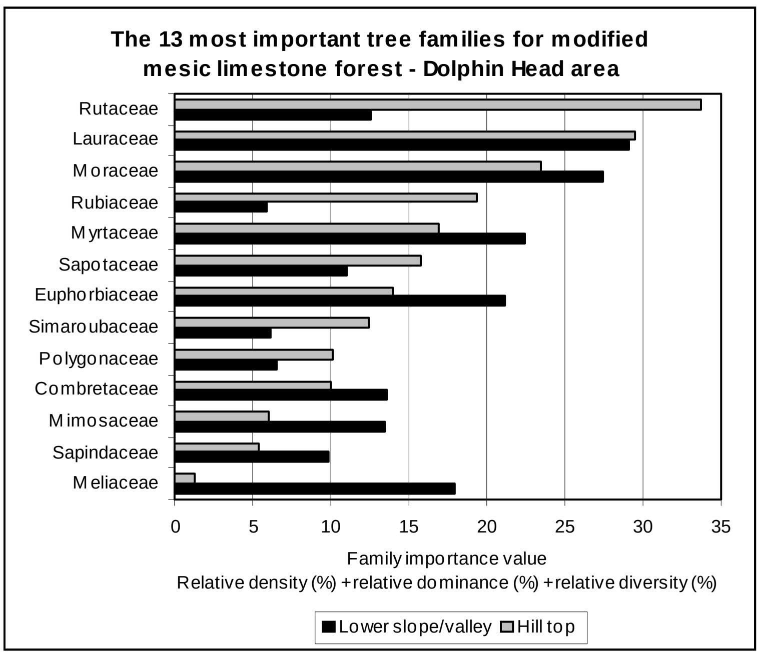
[1] The name Shannon-Wiener index is sometimes used because the two authors independently derived the function which has become known as the Shannon index of diversity (Magurran 1988).

6.6.1 Richness of tree families and species

The tree richness (DBH => 10cm) in Dolphin Head area is analysed using the Family Importance Value (FIV = Relative density + Relative dominance + Relative diversity of the 13 most important families) and the Importance Value Index (IVI = Relative density + Relative dominance + Relative frequency of the 15 most important species). The maximum value of FIV or IVI is 300, i.e. the total of the three relative measures (100 x 3) respectively.

The thirteen most important tree families (DBH => 10cm) for modified mesic limestone forest represent approximately the two third of the tree richness (FIV = 197 and 198). Globally, the tree family richness of the lower slope/valley type of modified mesic limestone forest is similar to the hill top type. However, some differences in the represented families exit between the two types of forest. Seven families have a relatively constant and important presence in both types of modified mesic limestone forest and there are: Lauraceae, Moraceae, Myrtaceae, Euphorbiaceae, Combretaceae, Rutaceae and Sapotaceae. The importance of the Meliaceae family in the lower slope/valley of Dolphin Head area is explained by the presence of forest plantations of Honduras mahogany (Figure 17).

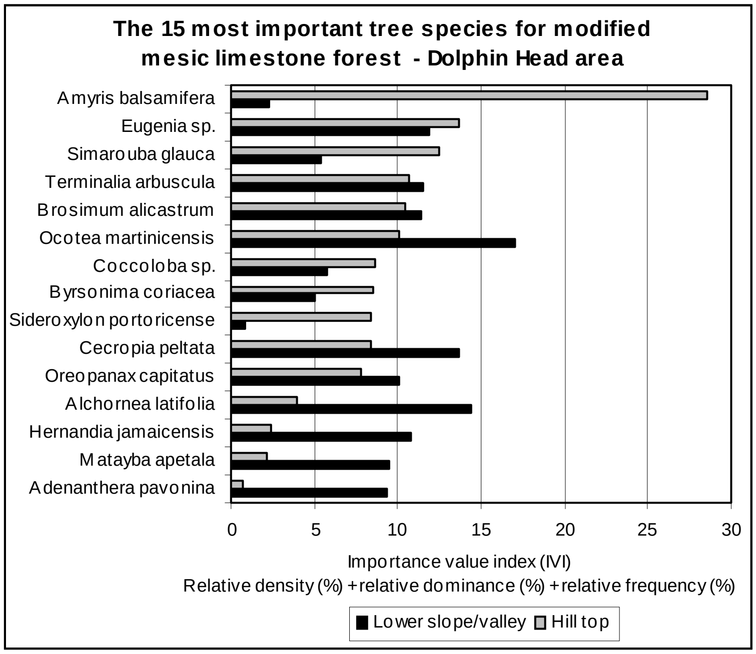
Figure 17. Family importance value for Dolphin Head modified mesic limestone forest



The fifteen most important tree species (DBH => 10cm) for modified mesic limestone forest represent approximately 45% of the global tree species richness and the importance value index (IVI = 139 and 137) is also similar for both types of forest (Figure 18).

Five of the fifteen most important tree species are common and frequent in the two types of modified mesic limestone forest. There are *Ocotea martinicensis* (Rock sweetwood, Lauraceae), *Cecropia peltata* (Trumpet tree, Moraceae/Cecropiaceae), *Eugenia sp.* (Rodwood, Myrtaceae), *Terminalia arbuscula* (White olive, Combretaceae) and *Brosimum alicastrum* (Breadnut, Moraceae). Two tree species present a large variation of the importance value index (IVI) between the two types of modified mesic limestone forest. *Adenanthera pavonina* (Red bead tree, Mimosaceae), a naturalised and invasive tree species mainly found in the lower slope/valley type, has IVI values of 9.39 and 0.68 for the lower slope/valley and hill top types respectively. *Amyris balsamifera* (Oilwood, Rutaceae), a common aromatic tree found on limestone and representing the most important species in the hill top type, presents IVI values of 2.26 and 28.52 for the lower slope/valley and hill top types respectively (Figure 18).

Figure 18. Importance value index for Dolphin Head modified mesic limestone forest



Based on Kelly (1988, 1991), the list of threatened tree species for Jamaica includes thirty-five (35) species. Two threatened tree species, found in Dolphin Head field survey, are classed vulnerable. *Ormosia jamaicensis* (Red nickel) represents 1-12 individuals with DBH => 10cm per hectare while the presence of *Terminalia arbuscula* (White olive) is much higher, i.e. 16 to 29 individuals with DBH => 10cm per hectare.

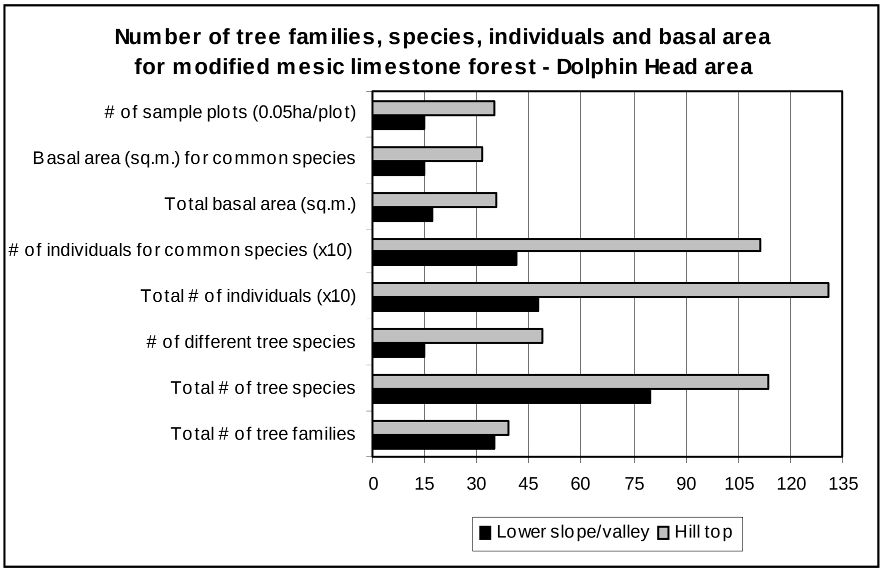
The list of threatened tree species compiled by Kelly (1988, 1991) is based on the Adams's Jamaican plant list (1972) and the Proctor's additional list (1982). In view of the new Jamaican plants species found in the last 20 years and specially the new endemic shrub and tree species found by Proctor (2002) in Dolphin Head area, the Kelly's list of threatened plants for Jamaica should be updated.

6.6.2 Diversity of tree species

The sampling size for the hill top type of modified mesic limestone forest is higher than for the lower slope/valley type. For this reason, the number of tree families, species, individuals or basal area for the hill top type is also higher than for the lower slope/valley type. This is also true for the number and basal area of the common tree species in both forest types and for the number of different tree species between the two forest types (Figure 19).

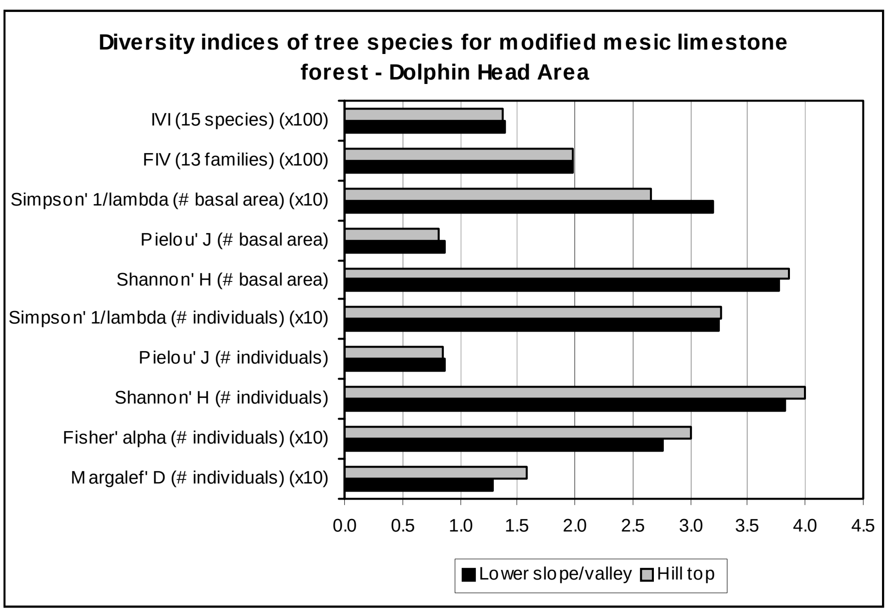
As suggested by different authors *in* Dallmeier and Comiskey (1998), we compared different diversity indices (H, J and 1/lambda) using the number of individuals (N) by species (abundance value) and the basal area (BA) by species (dominance value). The analysis, using the number of individuals per species, shows a higher diversity of tree species measuring with the Shannon's H index for the hill top type of modified mesic limestone forest, while the Pielou's J and the Simpson's 1/lambda indices do not clearly separate the two forest types. Using the basal area per species, the conclusion is the same with the Shannon's index, but the Pielou's and Simpson's indices give a higher diversity of tree species for the lower slope/valley forest type because of the probable influence of the higher basal area (bigger trees) in this forest type (Figure 20).

Figure 19. Number of tree families, species, individuals and basal area in Dolphin Head forest



If only one index is used, the Fisher alpha index should be the best and when the log series applies perfectly to the data distribution, the Fisher's alpha is closely related to Simpson's index (Leigh 1999). The Fisher alpha value is higher and indicates a higher tree species diversity of the hill top type of the modified mesic limestone forest (Figure 20).

Figure 20. Richness and diversity of tree families and species in Dolphin Head forest



As for the values of FIV and IVI, the diversity indices were calculated using directly the original data from the sampling, i.e. from the 15 sample plots (0.75 ha) and 35 sample plots (1.75 ha) sampled in the lower slope/valley and hill top types respectively. The tree richness and diversity measures were also calculated using the standardised data, i.e. the number of individuals, families, species and basal area per hectare for each forest type. The tree richness values (FIV, IVI) and the tree diversity values (D, H, J, 1/lambda) are the same because all these measures are relative measures (total = 100 or 1). On the contrary, the Fisher alpha index presents the same conclusions but the index values are not the same, because the index uses a fixed log series distribution based on the number of trees and number of tree species.

6.6.3 Comparison with other Jamaican tree diversity studies

As suggested by Dallmeier and Comiskey (1998) and demonstrated in the previous sections, the use of standardised numerical values of tree diversity per forest type following a statistical methodology is the only way to make scientifically reliable the comparison between various forest diversity studies.

Despite the different sampling sizes, the tree species diversity of Dolphin Head modified mesic limestone forest is higher than the Blue Mountains modified closed broadleaf forest. The disturbance factor in the Buff Bay Pencar modified closed broadleaf montane forest, due to the coffee cultivation and Caribbean pine plantations, could explain the higher presence of homogeneous young secondary forest type constituted of naturalised and exotic tree species and consequently, the lower diversity index values of tree species (Table 12).

However, Proctor (2002) notes that the huge diversity of the Dolphin Head flora is especially found among the woody dicotyledons, both shrubs and trees. Over limestone-derived soils in Jamaica, Kelly *et al*. (1988) conclude that the peak of tree species richness is found at an intermediate rainfall regime. Their study results show a number of 81, 135 and 118 tree species for an annual rainfall gradient of 1000, 1600 and 4000 mm respectively. In Puerto Rico, the highest count of tree species per sample unit of 0.1 ha was found on a northern karst (limestone) forest (Lugo *et al.* 2001).

Table 12. Comparison of tree species diversity in Blue Mountains and Dolphin Head areas

Comparison of tree (dbh => 10cm) species diversity in Jamaica													
FOREST TYPE	SU	N	BA	F	S	D	α	Abundance (# individuals)			Dominance (Basal area)		
								1/ λ	H	J	1/ λ	H	J
Blue Mountains forest reserve - Buff Bay Pencar WMU (1)													
Modified closed broadleaf forest - Lower montane	0.90	546	19.34	31	55	8.57	15.26	15.69	3.19	0.80	13.32	3.08	0.77
Modified closed broadleaf forest - Upper montane	1.50	539	16.70	31	47	7.31	12.38	11.92	2.92	0.76	11.30	2.86	0.74
Dolphin Head forest area (2)													
Modified mesic limestone forest - Lower slope/valley	0.75	639	22.83	35	80	12.23	24.16	32.50	3.83	0.87	32.05	3.78	0.86
Modified mesic limestone forest - Hill top	1.75	750	20.42	39	114	17.07	37.42	32.68	4.00	0.85	26.76	3.87	0.82

SU = Sample size (ha); N = # individuals/ha; BA = basal area (m^2/ha); F = # families; S = # species;
D = Margalef's index; α = Fisher's index; 1/λ = Reciprocal of Simpson's index; H = Shannon's index;
J = Pielou's index.
(1) Buff Bay Pencar biophysical inventory (Forestry Department, 2001); (2) Present study.

6.7 Richness of non-timber tree species

The richness of tree species used for non-timber products can be evaluated according to two groups, i.e. the fruit tree species group and the medicinal tree species group. As a broad and first approximation for the Jamaican vegetation, the proposed group of “fruit trees species” contains 27 tree species (Devi Prasad 1986) and the proposed group of “medicinal tree species” includes 20 tree species (Asprey and Thornton 1953-55).

A higher density of fruit trees species is found in the lower slope/valley type of modified mesic limestone forest. The medicinal tree species are also mostly represented in the lower slope/valley forest type (Table 13). The higher presence of the species, such as *Syzygium jambos*, *Mangifera indica*, *Cocos nucifera*, *Spondias mombin*, *Cecropia peltata* and *Alchornea latifolia*, in the lower slope/valley type of modified mesic limestone forest is mainly explained by the higher degree of disturbance (abandoned cultivated land, fruit tree planting).

Table 13. Presence of fruit and medicinal tree species in Dolphin Head area

Tree species name	**Modified mesic limestone forest**	
	Lower slope/valley	**Hill top**
Fruit tree species (individuals with DBH => 10 cm/ha)		
Syzygium jambos	24	0
Mangifera indica	4	1
Cocos nucifera	3	0
Spondias mombin	3	0
Mammea americana	0	1
Medicinal tree species (individuals with DBH => 10cm/ha)		
Cecropia peltata	36	25
Alchornea latifolia	24	6
Zanthoxylum martinicensis	7	4
Bauhinia divaricata	3	3
Ceiba pentandra	1	2
Haematoxylum campechianum	0	2
Guazuma ulmifolia	0	1

7. FOREST TYPE CLASSIFICATION

The geology of Dolphin Head area is relatively uniform, i.e. a white limestone plateau. The vegetation of Dolphin Head area, named "modified" mesic limestone forest, is classified according to a geo-climatic gradient or more specifically a limestone-rainfall gradient (Kelly *et al*. 1988). The classification of sample plots into two forest types, i.e. 15 sample plots in the lower slope/valley type (DM) and 35 sample plots in the hill top type (MM) of the modified mesic limestone forest, was a priori done at the stage of the photo-interpretation and before the data processing.

As presented in the previous sections, the tree species patterns show higher values of richness and diversity for the hill top type of modified mesic limestone forest than for the lower slope/valley type. An overall mutivariates analysis of the relationships forest type-environment is carried out to explain this difference in the tree richness and diversity between the two landform-forest types. This analysis is done using the Systat software (Version 9, SPSS Inc. 1998).

7.1 Forest type and dendrometric characteristics of trees

The dendrometric characteristics of trees with DBH => 10cm per sample plot (0.05ha/plot) are the total number of species, the new (additional) species, the number of individuals and the basal area. Individually, these dendrometric characteristics of trees show no statistical significant difference between the two forest types, using the Student's t statistic on two groups (pooled variance, degrees of freedom = 47). A statistical significant difference must show a value over 0.05 at 95% of probability or a Student's t over +/- 1.96 (Sokal and Rohlf 1995). Using a lower Student's t around +/- 1.20 (p = 80% or α = 0.2), the total number of tree species and the number of individuals tend to present some statistical signification (Table 14).

Table 14. Statistical difference of dendrometric characteristics of trees between the forest types

Dendrometric characteristic of trees / sample plot (0.05 ha)	Student's t	Probability
Total number of species	-1.131	0.264
Additional number of species	0.097	0.923
Number of individuals	- 1.232	0.224
Basal area	0.776	0.442

On the basis of the basal area of each tree, i.e. a total of 1742 individuals, the difference between the two forest types (DM and MM) is statistically significant. The Student's t test gives a value of 3.308 for a probability of 0.001 or a F value of 10.942 (t^2). The DM and MM basal area means are 0.036 m^2/tree and 0.027 m^2/tree respectively.

The difference between the forest types (DM and MM) is probably explained by the dendrometric characteristics of trees combined. The forest types being a priori known by photo-interpretation, the simple discriminant analysis (or simple canonical variate analysis) is a method giving the possibility to interpret the descriptors permitting to discriminate the two groups (forest types) and that, by determining the relative contribution of various explanatory descriptors to the distinction among the two groups (forest types) (Legendre and Legendre 1998, ter Braak 1987).

Using the four dendrometric characteristics of trees combined improve the explanation of the two groups but they do not significantly discriminate the two forest types. The F statistic on the Wilks' lambda (0.8810) takes the value of 1.4864 for a probability of 0.2226. The Wilks' lambda measures to what extent the groups (forest types) differ in the positions of their centroids and the possible value range is from 0 (maximum dispersion of the groups) to 1 (no dispersion among groups), i.e. the smaller Wilks' lambda values denoting greater likelihood of significant group differences (Legendre and Legendre 1998, ter Braak 1987).

7.2 Forest type and tree species diversity

The diversity indices discussed in the above section 6.6 give a relative comparison of the similarity or dissimilarity of tree species diversity between the lower slope/valley and hill top modified mesic limestone forest types. For a quantitative and statistical analysis, two methods can test the similarity of the forest type diversities: (1) the analysis of confidence limits of the Shannon's H index and, (2) the calculations of Jaccard's (C_J) and Sorenson's (C_N) coefficients of similarity.

If many sample units (plots or individuals) are surveyed per forest type for the determination of the Shannon's index H, the H distribution curve follows approximately a normal distribution, and a reasonable expression for the calculation of variance of the diversity index H can be used to estimate the confidence limits of the value. Then, the statistical signification of the Shannon's index difference between the two groups (forest types) can be tested by using the Student's t (Magurran 1988, Hayek and Buzas 1997).

The Student's t test on the tree diversity measure of Shannon's H, based on the number of individuals (abundance), gives a statistical significant difference between the lower slope/valley and hill top types, in comparison with the calculated Student "t" value of 1.96 at the probability of 95% (α = 5%). The Student's t test on the H values, based on basal area (dominance), shows a statistical non-significant difference between the forest types (Table 15).

Table 15. Statistical difference of Shannon's H tree diversity between the forest types

Modified mesic limestone forest	Shannon's H	Variance H	Confidence limits (+/-)	Student's t (observed)	H absolute difference
Number of individuals Lower slope/valley (DM)	3.8271	0.0019	0.0858	3.3029	0.1774
Number of individuals Hill top (MM)	4.0045	0.0010	0.0610		
Basal area Lower slope/valley (DM)	3.7762	0.0018	0.0827	1.5794	0.0844
Basal area Hill top (MM)	3.8606	0.0011	0.0643		

The Jaccard's C_J coefficient calculations are based on the number of tree species in common while the number of individuals for tree species in common forms the basis of the calculations of the Sorenson's C_N coefficient. The Jaccard's and Sorenson's coefficients are designed to equal 1 in the cases of complete similarity, which indicate that the two sets of tree species are identical in the two forest types. The value 0 is obtained when the two forest types have no species in common (Magurran 1988).

The comparison between lower slope/valley and hill top types of Dolphin Head forest shows a relative dissimilarity between the two forest types, as measured by the values around 0.5 of the Jaccard's and the Sorenson's coefficients (Table 16).

Table 16. Similarity of tree species diversity between the forest types

Modified mesic limestone forest	Total number of species	Total number of individuals	Number of common species	Lower number of individuals for common species	Jaccard's coefficient (C_J)	Sorenson's coefficient (C_N)
Lower slope/valley	80	479	65	414	0.5039	0.4623
Hill top	114	1312				

7.3 Forest type and landform-soil characteristics

As explained in sections 4 and 5, some relationships exist between the fertility of soils and the landform features. It also appears in the analysis of tree species diversity in section 6 that the tree species occurrence and density are related to the broad landform classes such as lower slope/valley and hill top.

On the total of thirteen landform and soil characteristics measured in the sampling and taken individually, only the soil acidity (pH-eau) shows a statistical significant difference between the two forest types for probability < 0.05 or Student's t > 1.96. Some other landform and soils characteristics could be statistical significant if the probability is fixed below 0.2, e.g. slope gradient, slope position, elevation, cation exchange capacity and nitrogen content (Table 17).

Table 17. Statistical difference of landform and soil characteristics between the forest types

Landform and soil characteristic / sample plot (0.05 ha)	Student's t	Probability
Elevation	1.168	0.249
Slope position	1.385	0.172
Slope gradient	-1.709	0.094
Slope aspect	0.130	0.897
Effective soil depth	0.342	0.734
Silt content	-0.555	0.581
Clay content	0.352	0.726
pH (eau)	-2.182	0.034
Organic matter	-0.676	0.502
Cation exchange capacity	-1.163	0.251
Nitrogen	-1.164	0.250
Potassium	-0.948	0.348
Phosphorus	-0.056	0.956

Discriminant analysis, using the thirteen landform and soil characteristics presented above, does not statistically separate the two forest types. The F statistic on the Wilks' lambda (0.7368) takes the value of 0.9618 for a probability of 0.5052.

7.4 Forest type and landform-soil-tree characteristics

Using one landform characteristic (elevation), one soil characteristic (pH-eau), one dendrometric characteristic of tree (basal area) and the number of tree species, the discriminant function statistically differentiates between the lower slope/valley type and the hill top type of the modified mesic limestone forest. The F statistic on the Wilks' lambda (0.7972) takes the value of 2.7989 for a probability of 0.0373 (degrees of freedom: 4, 44). This standardised discriminant function correctly classifies 73% of the sample plots for the lower slope/valley type and 85% for the hill top type, giving an overall misclassification of 18% of the sample plots (Figure 21).

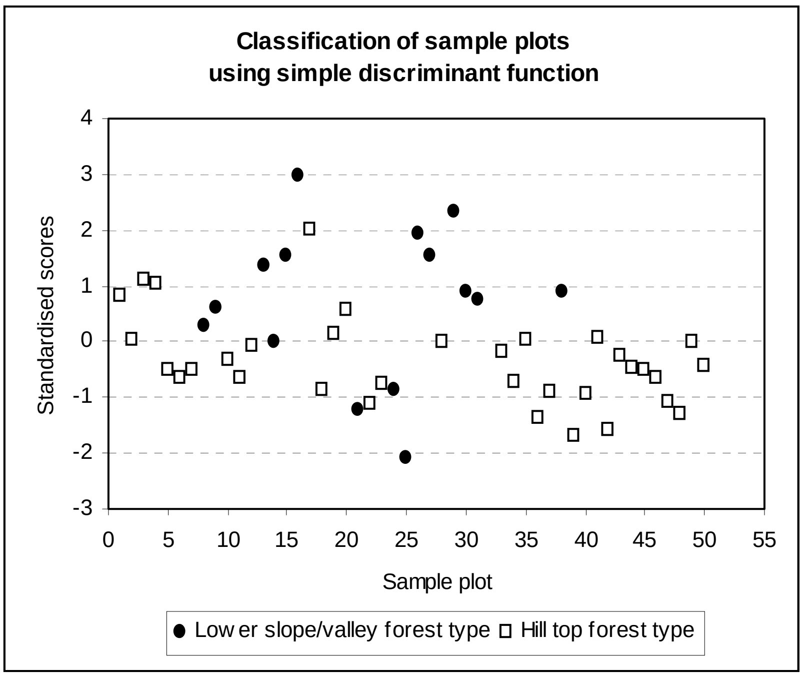
With two groups or two forest types (simple discriminant function), only one axis using the descriptors is traced to classify the sample plots. The eigenvalue of the discriminant function measures the dispersion of the variables scores on the ordination axis and its value is 0.254 for axis 1 (100%). The sign and value (standardised coefficient) of the variables indicate the relative importance of each variable for prediction (Legendre and Legendre 1998, ter Braak 1987). The standardised coefficients for the simple discriminant function, presented in Table 18, show that the total number of species best accounts for the among forest type variation (Table 18).

Table 18. Standardised coefficients of the discriminant function between the forest types

Landform-soil-tree characteristic / sample plot	Axis 1 Standardised coefficients
Total number of tree species	0.910
Basal area	-0.794
pH (eau)	0.573
Elevation	-0.482

As shown in Figure 21, the most of the lower slope/valley (DM) sample plots are located in the positive quadrant of the discriminant function graph while the hill top (MM) sample plots are mainly plotted in the negative quadrant of the graph. The sample plots are distributed along a gradient formed by the descriptor group (total number of tree species and pH-eau) in the positive quadrant (positive side of the axis 0) and the second descriptor group (basal area and elevation) situated in the negative quadrant.

Figure 21. Classification of sample plots by forest type using discriminant analysis



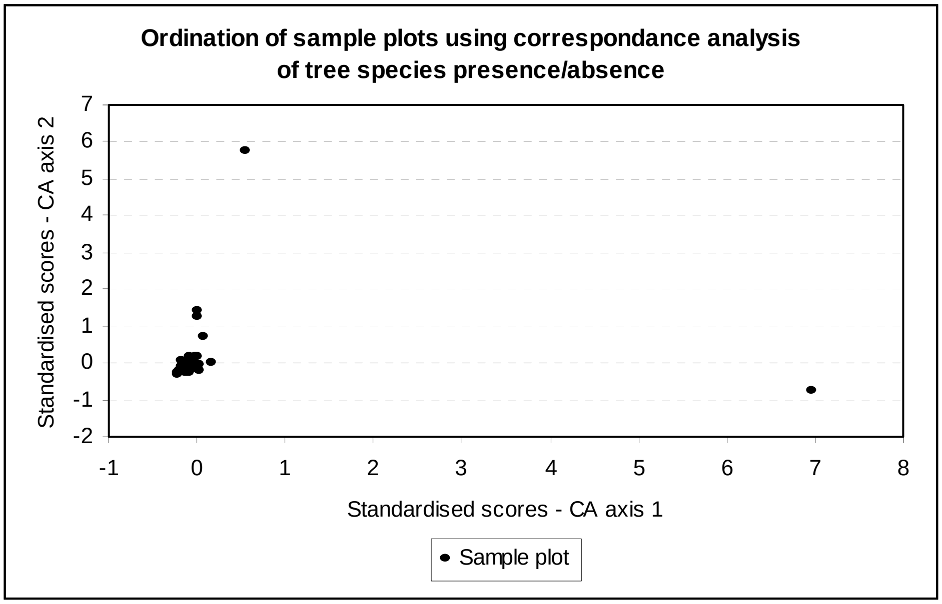
The number of tree species (DBH => 10cm) per sample plot is an important variable in the discrimination or grouping of the two types of modified mesic limestone forest in Dolphin Head area (Table 18). To verify the influence of each tree species, a correspondence analysis (CA) with the tree species presence/absence (DBH => 10cm) is used to order the sample plots.

Figure 22 presents only the ordination axis for the sample plots. The 128 tree species are not represented because the graph is too charged. Except for the sample plots 16 and 26, the correspondence analysis functions do not significantly separate the sample plots. The sample plots 16 and 26 and few other outsiders are mostly plots located in the lower slope/valley forest type. Sample plot 16 is ordered according to CA axis 1 (coordinates 6.97 and -0.77) and the most important tree species plotted on the tree species graph is *Syzygium jambos* (Rose apple). The sample plot 26, ordered following the CA axis 2 (coordinates 0.54 and 5.74), is located in a forest plantation block of *Swietenia macrophylla* (Honduras mahogany).

The conclusion is that the presence/absence of tree species alone can not significantly separate the sample plots. The tree species indicators of disturbance or management actions such as

Rose apple and Honduras mahogany tend to separate some sample plots from the main grouping of sample plots. These disturbed plots were sampled mostly in the lower slope/valley type of modified mesic limestone forest because the landform and soil characteristics are more appropriate for cultivation, pasture or forest plantation (Figure 22).

Figure 22. Ordination of sample plots using correspondence analysis



8. CONCLUSION

Positive results have been obtained by Tanner (1977) and Kelly *et al*. (1988) in the understanding of the Jamaican forest type and structure interrelations with soil, landform and climatic data. The landform classification of the Jamaican limestone forest was also recommended and used for the study of the vegetation, e.g. the study of the lower and upper western slope vegetation for the John Crow Mountains wet limestone forest (Grubb and Tanner 1976), the study of the hill top and slope types for the south-coast dry limestone forest (Kapos 1986) and the study of the hilly and flat sub-communities for the north-coast dry limestone forest (Radenbaugh and Seaborne 1996).

In Dolphin Head area, there are interrelations between the tree species and characteristics of the modified mesic limestone forest and the landform and soil factors. It was difficult to find strong statistical evidence due to the great variability of the limestone-derived soil characteristics and the tree species found on limestone substrate. However, the differentiation in two landform types for the photo-interpretation and the data compilation, i.e. lower slope/valley and hill top types, should be adopted for the future biophysical inventories of the modified mesic limestone forest in Jamaica.

The role of the soils in the distribution, composition, diversity and growth of Jamaican forests is fundamental and not fully understood. The soil analysis should be integrated into the biophysical inventory and monitoring framework of the Jamaican forests.

9. REFERENCES

Adams, C.D. 1972. *Flowering plants of Jamaica*. University of the West Indies, Mona, Jamaica. 848 p.

Adams, C.D., Magnus, K. and Seaforth, C. 1963. *Poisonous plants in Jamaica*. Department of Extra-Mural Studies, University of the West Indies, Mona, Jamaica. 40 p.

Asprey, G.F. and Robbins, R.G. 1953. *The vegetation of Jamaica*. Ecological Monographs 23(4): 359-412.

Asprey, G.F. and Thornton, P. 1953-1955. *Medicinal plants of Jamaica*. W. I. Med. J. 2(4): 233-252, 3(1): 17-41, 4(2): 69-82 and 4(3): 145-168.

Beard, J.S. 1944. *Climax vegetation in tropical America*. Ecology 25(2): 127-158.

Boyd, C. 1999. *Cutting down the rainfall? A rapid ecological assessment of tropical limestone forest at Dolphin Head, Jamaica*. MSc dissertation, University College, London. 88 p.

Boyd, C. and Mathew, P. 1999. *Rapid ecological assessment of moist tropical limestone forest, Dolphin Head, Jamaica*. Report to the Dolphin Head Trust. 41 p.

Brown, S. 1997. *Estimating biomass and biomass change of tropical forests: A primer*. FAO Forestry Paper no. 134, Rome. 55 p.

Condit, R., Foster, R.B., Hubbell, S.P., Sukumar, R., Leigh, E.G., Manokaran, N., Loo de Lao, S., LaFrankie, J.V. and Ashton, P.S. 1998. *Assessing forest diversity on small plots: calibration using species-individual curves from 50-ha plots*. In Dallmeier, F. and Comiskey, J.A. (Eds.). Forest biodiversity research, monitoring and modeling: conceptual background and old world case studies. Man and the Biosphere Series Vol. 20, UNESCO, Paris and The Parthenon Publishing Group, Carnforth. pp. 247-268.

Dallmeier, F. and Comiskey, J.A. (Eds.). 1998. *Forest biodiversity in North, Central and South America, and the Caribbean: research and monitoring*. Man and the Biosphere Series Vol. 21, UNESCO, Paris and The Parthenon Publishing Group, Carnforth. 768 p.

Devi Prasad, P.V. 1986. *Edible fruits and vegetables of the English-speaking Caribbean*. Caribbean Food and Nutrition Institute, Kingston. 68 p.

Draper, G. and Fincham, A.G. 1997. *Geomorphology of Jamaican limestones*. In Fincham, A.G. Jamaica underground: the caves, sinkholes and underground rivers of the island. The Press University of the West Indies, Kingston, Jamaica. pp. 29-33.

Duivenvoorden, J.F. and Lips, J.M. 1995. *A land-ecological study of soils, vegetation, and plant diversity in Colombian Amazonia*. Tropenbos Series 12, The Tropenbos Foundation, Wageningen, The Netherlands. 438 p.

FAO. 1990. *Soil map of the world – Revised legend*. World soil resources report 60, FAO/UNESCO/ISRIC, Rome. 119 p.

Forestry Department. 2000. *Biophysical inventory manual*. Trees for Tomorrow Project, Kingston, Jamaica. 158 p.

Forestry Department. 2002. *Photo interpretation manual*. Trees for Tomorrow Project – Phase II, CIDA/ORM/Tecsult, Quebec, Canada. 155 p. and appendices.

Francis, J.K. 1998. *Tree species for planting in forest, rural and urban areas of Puerto Rico*. General technical report IITF-3, USDA Forest Service, IITF, Rio Piedras. 82 p.

Gartlan, J.S., Newbery, D.M., Thomas, D.W. and Waterman, P.G. 1986. *The influence of topography and soil phosphorus on the vegetation of Korup Forest Reserve, Cameroun*. Vegetatio 65: 131-148.

Gentry, A.H. 1988*. Changes in plant community diversity and floristic composition on environmental and geographical gradients*. Ann. Missouri Bot. Gard. 75 : 1-34.

Government of Jamaica. 1997. *Policy for Jamaica's system of protected areas*. Kingston, Jamaica. 47 p.

Grossman, D.H., Iremonger, S.F. and Muchoney, D.M. 1992. *A rapid ecological assessment of Jamaica: Phase I - An island-wide characterisation and mapping of natural communities and modified vegetation types*. The Nature Conservancy, Conservation Data Centre-Jamaica, Rural Physical Planning Unit, Arlington, Virginia. 44 p.

Grubb, P.J. and Tanner, E.V.J. 1976. *The montane forests and soils of Jamaica: a reassessment*. Journal of the Arnold Arboretum 57: 313-368.

Hayek, L.C. and Buzas, M.A. 1997. *Surveying natural populations*. Columbia University Press, New York, 563 p.

Healey, J.R. 1989. *A bioassay study of soils in the Blue Mountains of Jamaica*. In Proctor, J. (Ed.). Mineral nutrients in tropical forest and savanna ecosystems. Special publications series of the British Ecological Society number 9, Blackwell Scientific Publications, Oxford. Pp. 273-287.

Hewitt, C.W. 1964. *Soil technical guide sheets*. Agricultural Chemistry Division, Ministry of Agriculture and Lands, Kingston, Jamaica. 144 p.

Kapos, V. 1986. *Dry limestone forests of Jamaica*. In Thompson, D.A., Bretting, P.K. and Humphreys, M. (Eds.). Forests of Jamaica. The Jamaican Society of Scientists and Technologists, Kingston, Jamaica. pp. 49-58.

Kelly, D.L. 1988. *The threatened flowering plants of Jamaica*. Biological Conservation 46: 201-216.

Kelly, D.L. 1991. *The threatened flowering plants of Jamaica: a reappraisal*. Jamaica Naturalist 1: 19-26.

Kelly, D.L., Tanner, E.V.J., Kapos, V., Dickinson, T.A., Goodfriend, G.A. and Fairbairn, P. 1988. *Jamaican limestone forests: floristics, structure and environment of three examples along a rainfall gradient*. J. Trop. Ecol. 4: 121-156.

Lauer, W. 1993. *Climatology*. In Pancel, L. (Ed.). Tropical forestry handbook - Volume 1. Springer-Verlag, Berlin. pp. 95-164.

Legendre, P. and Legendre, L. 1998. *Numerical ecology*. Second english edition, Elsevier, Amsterdam. 853 p.

Leigh, E.G. jr. 1999. *Tropical forest ecology*. Oxford University Press, New York. 245 p.

Lescure, J-P. and Boulet, R. 1985. *Relationships between soil and vegetation in a tropical rain forest in French Guiana*. Biotropica 17: 155-164.

Li, X., Waller, R.W., Sayre, R.G., Boucher, T.M., Sotomayor, L., Kernan, K., Goyert, W.M., Helmer, E.H., Ramos, O.M., del Mar Lopez, T., Quinones, M., Wood, E.C., Nelson, J.J., Coan, M. and Areces-Mallea, A.E. 2000. *Mapping land use and natural vegetation for the islands of Jamaica, Puerto Rico, and Dominica*. The Nature Conservancy, International Institute of Tropical Forestry – USDA Forest Service, Eros Data Center – U.S. Geological Service, Arlington, USA. 24 p. and 1:250 000 scale colour map.

Lugo, A.E. and 16 co-authors. 2001. *Puerto Rican karst – A vital resource*. General Technical Report WO-65, USDA Forest Service. 101 p.

Magurran, A.E. 1988. *Ecological diversity and its measurements*. Princeton University Press, Princeton. 179 p.

Maharaj, R., Mitchell, S. and James, S. 2001. *Hazard and fluvial assessment – A technical component of the Dolphin Head proposed national park project*. Draft report to the Dolphin Head Trust, Department of geography and geology, U.W.I., Kingston, Jamaica. 31 p.

Mathew, P. 1999. *Study of the ecological conditions and plant species associated with Ormosia jamaicensis, the red nickel tree, on Dolphin Head, Jamaica*. MSc dissertation, University College, London. 55 p.

Natural Resources Conservation Authority (NRCA). 2000. *Towards a national strategy on biological diversity in Jamaica*. Draft report, May 2000, Kingston, Jamaica. 69 p.

Price, R.W. 1960. *Soil and land-use surveys no. 12 – Parish of Hanover, Jamaica*. Imperial College of Tropical Agriculture, University College of the West Indies, Trinidad. 25 p.

Proctor, G.R. 1982. *More additions to the flora of Jamaica*. Journal of the Arnold Arboretum 63: 199-315.

Proctor, G.R. 2002. *Vascular plants of Dolphin Head forest reserve*. Report to the Dolphin Head Trust, Kingston, 42 p.

Proctor, J. 1992. *Soils and mineral nutrients: what do we know, and what do we need to know, for wise rain forest management?* In Miller, F.R. and Adam, K.L. (Eds.). Wise management of tropical forests. Proceedings of the Oxford conference on tropical forests 1992, Oxford Forestry Institute, Oxford. pp. 27-35.

Proctor, J. 1995. *Rainforests and their soils*. In Primack, R.B. and Lovejoy, T.E. (Eds.). Ecology, conservation and management of Southeast Asian rainforests. Yale University Press, New Haven, USA. pp. 87-104.

Radenbaugh, T.A. and Seaborne, A.A. 1996. *The status of plant communities in the Duncans Bay area on Jamaica's north coast*. Caribbean Geography 7(2): 97-112.

Scholten, J.J. and Andriesse, W. 1986. *Morphology, genesis and classification of three soils over limestone, Jamaica*. Geoderma 39: 1-40.

Soil survey staff. 1975. *Soil taxonomy – A basic system of soil classification for making and interpreting soil surveys*. Agriculture handbook no. 436, Soil Conservation Service, USDA, Washington, D.C. 754 p.

Sokal, R.R. and Rohlf, F.J. 1995. *Biometry*. Third edition, W.H. Freeman and Company, New York. 887 p.

SPSS Inc. 1998. SYSTAT version 9 for windows.

Stark, J. 1964. *Soil and land-use surveys no. 15 – Parish of Westmoreland, Jamaica*. Imperial College of Tropical Agriculture, University College of the West Indies, Trinidad. 22 p.

Sweeting, M.M. 1958. *The karstlands of Jamaica*. The Geographical Journal 124: 184-199.

Tanner, E.V.J. 1977. *Four montane rain forests of Jamaica: a quantitative characterization of the floristics, the soils and the foliar mineral levels, and a discussion of the interrelations*. Journal of Ecology 65: 883-918.

Ter Braak, C.J.F. 1987. *Ordination*. In Jongman, R.H.G., ter Braak, C.J.F. and van Tongeren, O.F.R. Data analysis in community and landscape ecology. Pudoc, Wageningen. pp. 91-173.

Ter Steege, H., Jetten, V.G., Polak, M.A. and Werger, M.J.A. 1993. *Tropical rain forest types and soil factors in a watershed area in Guyana*. Journal of Vegetation Science 4: 705-716.

Vermeulen, J. and Whitten, T. (Eds.). 1999. *Biodiversity and cultural property in the management of limestone resources*. Directions in development series, The World Bank, Washington, D.C. 120 p.

Weaver, P.L. 1990. *Calophyllum calaba L. Maria, Santa-Maria*. In Burns, R.M. and Honkala, B.H. (Eds.). Silvics of North America: 2. Hardwoods. Agric. Handbook 654, USDA Forest Service, Washington, D.C. pp. 172-178.

Woomer, P.L. and Palm C.A. 1998. *An approach to estimating carbon stocks in tropical forests and associated land uses*. Commonwealth Forestry Review 77(3): 181-190.

Zans, V.A., Chubb, L.J., Versey, H.R., Williams, J.B., Robinson, E. and Cooke, D.L. 1962. *Synopsis of the geology of Jamaica*. Bulletin no. 4, Geological Survey Department, Kingston, Jamaica. 72 p.

Zech, W. 1993. *Geology and soils*. In Pancel, L. (Ed.). Tropical forestry handbook - Volume 1. Springer-Verlag, Berlin. pp. 1-93.

10. APPENDIX 1: PROCESSING RESULTS OF BIOPHYSICAL INVENTORY