Using Geo-informatics to Manage Natural Vegetation Habitats in Trinidad

Mr. Amarnath Chinchamee
The University of the West Indies
Department of Surveying and Land Information ,St. Augustine campus, Trinidad & Tobago
(868)662-2002 x2108, 497-6707
amarnath.chinchamee@utt.edu.tt

Dr. Raid Al-Tahir
The University of the West Indies
Department of Surveying and Land Information ,St. Augustine campus, Trinidad & Tobago
(868)662-2002 x2108
Raid.AlTahir@sta.uwi.edu

Prof. Serwan M. J. Baban
Southern Cross University
P. O. Box 157, Lismore, NSW 2480, Australia
+61 (0)2 66 203766
sbaban2001@yahoo.com

Abstract

Trinidad is undergoing rapid economic development, aiming to achieve the developed nation status by 2020. Coupled with a fast pace of industrialization, illegal settlement and urbanization, the natural resources are being depleted. It is evident that Trinidad urgently requires accurate data to provide decision makers with the critical information required for planning and managing the environment. Biophysical Land Units (BLUs) were developed and defined for Trinidad. The land use/cover map along with data such as geology, soil, rainfall, aspect, elevation and slope were the components used to develop these BLUs. This was achieved by the use of a comprehensive GIS, which was built on ESRI ARCMAP 9.0. The developed BLUs can assist in reforestation efforts by identifying what plant communities can grow in certain areas.

Key words: Land use/cover, Remote Sensing, GIS, Biophysical Land Units, Trinidad

1. Introduction

Scientists, governments, NGO's and the population as a whole have expressed increasing concerns about deforestation, forest fragmentation, and other worldwide forest-related environmental issues, particularly in the tropics (Hill and Foody, 1994; Roy *et al.*, 1991). There are a number of ecosystem services related to the world's tropical forests. These services include the provision of food and raw materials (Lambin, 1994), protection against soil erosion and landslides (Baban, 2001), protection against sedimentation and flooding (Douglas 1999), impact on water resources, water cycling and impacts on rainfall patterns (Koninck, 1999), support of biological diversity (Andresen, 2003) and the maintenance of carbon storage in regenerating tropical forests (Foody *et al.*, 1996).

The Caribbean, due to its geographical location and geological history of the islands contains some 13,000 species of vascular plants (Adams, 2001). Their rich biodiversity is in serious threat, with a conversion rate of 46km^2 of some 2978km^2 of forest to non-forest per year, indicating a deforestation rate of 1.5% per annum (Eyre, 1998).

The main threats include development, industry, tourism, squatting, logging, expansion of agriculture and fragmentation (CARICON/TFAP, 1993). However the extent of the problem is not known since the loss cannot be quantified by deforestation and conversion rates. There are other social, economic, and ecological values to consider.

To effectively manage and conserve the natural vegetation and the ecosystem in which they survive, data is not only required, but at a faster rate than it is currently gathered. In Trinidad for example, the current information base for decision-making is a forest inventory map that was published in the 1980's and was developed based on aerial photographs acquired during the 1960's. This implies that the current map contains data from over five decades ago. Additionally, data of close to 50% of the total land cover is absent, primarily because the project's objective was to develop a forest inventory of state lands only. Furthermore, it focused only on forest cover without giving considerations to other land use/cover in Trinidad. For proper monitoring of this resource, production time of these maps must be reduced drastically.

Garcia and Murguia (1996) and Carrol (1996) have developed the concept of using Biophysical Land Units (BLUs) as the quantifiable spatial representations of the location, extent and dynamics of multiple ecological components determining vegetation distribution. These components are the pieces of an ecosystem or ecotype and may include soil types, geology and topography (elevation, slope and aspect) (Baban and Wan-Yusof, 2002).

For defining these BLUs, remote sensing has been very successful in mapping and monitoring land use/cover, while GIS has been utilized to combine secondary information sets into the necessary physical and ecological layers to map and analyse the distribution of land cover/use types (Wadsworth and Treweek, 1999; Baban and Wan-Yusof, 2002).

The establishment of the BLUs requires the extraction, processing and manipulation of various spatial data sources. These layers can then be overlaid on each other for the development and analysis of the BLUs. A GIS can successfully achieve this since it has the ability to handle large volumes of spatial and temporal datasets and it is equipped with analyzing capabilities that can relate the physical and biological controls of the environment to an individual land use/cover.

Furthermore, weights can be derived for each component of the BLUs based on the results of the ecological combination and criteria developed (Baban and Wan-Yusof, 2003). In addition scenarios can be constructed to determine the influence each factor is to a particular land use/cover and based on its importance these factors can be ranked.

2. The StudyArea

Trinidad is a tropical island, of about 4,800km^2, located in the southern West Indies, between the Caribbean Sea and the North Atlantic Ocean, northeast of Venezuela, between latitudes 10° and 11° 30’ north and lying between 60° and 62° west longitude (Figure 1). It is situated at the southern end of the chain of Caribbean islands known as the Windward Islands. Trinidad lies 32 km from Tobago at its closest point and approximately 13 km away from the Venezuelan mainland.

The tropical mountainous island of Trinidad contains a combination of natural and non-natural vegetation communities, and is characterize by a unique topography and geology form that of the other Caribbean islands.

Trinidad sits on the South American continental shelf and unlike the northern Caribbean islands, which are mostly volcanic and arising from deep water; its northern mountain range is an extension of the coast range of Venezuela, and is the eastern branch of the Andean Mountains (EMA, 1996). Additionally, the island is directly affected by the discharge of the Orinoco River of South America, and because of this South American influence, the species diversity is rich (Kenny *et al*., 1997).

Figure 1: Trinidad is the southern
most Caribbean island (Source: Google Earth, 2006)

3. Method

3.1. The Development of the Land Use/cover Map

A supervised classified satellite image for Trinidad was developed from a Landsat (ETM+) image acquired on January 29th 2001 with spatial resolution 30m. Additional ETM+ images for 1999 and 2000 as well as a collection of 38 topographic maps at a scale 1:25 000, issued by Lands and Survey Division in the 1970's, and a forest inventory map at a scale 1:150,000, issued by the Ministry of Agriculture during 1980's were available for use in this study.

The Landsat (ETM+) satellite images were first geometrically corrected using ground control coordinates from the set of 1:25,000 topographic maps of Trinidad. After which, the images were corrected for atmospheric effects while the problem of clouds and cloud shadows were tackled by developing a mask to remove them.

Parallel to this, a shaded relief map was constructed to deal with the effect of shadows from the terrain and differential illumination caused by the mountainous nature of the island. As a result, the image was divided into two sections; sunlit and shadowed; to be treated as separate images in the subsequent processes and eventually merged together to form one complete image (Baban and Wan-Yusof, 2001).

The image were then classified into six forest classes; Evergreen Forest, Savanna, Mangrove, Shrub-forest (Marsh), Teak and Pine, in addition to Agriculture, Urban and Water (Figure 2). Finally, a 3x3 size mode filter was applied to remove some of the inevitable noise, smooth the classified output and reveal only the dominant classification (Lillesand and Kiefier, 2000). An overall accuracy of 93% was achieved after applying the 3x3 filters. Areas that had been previously masked by clouds and their shadows were filled with information extracted from the other images (Baban *et al.,* 2008).

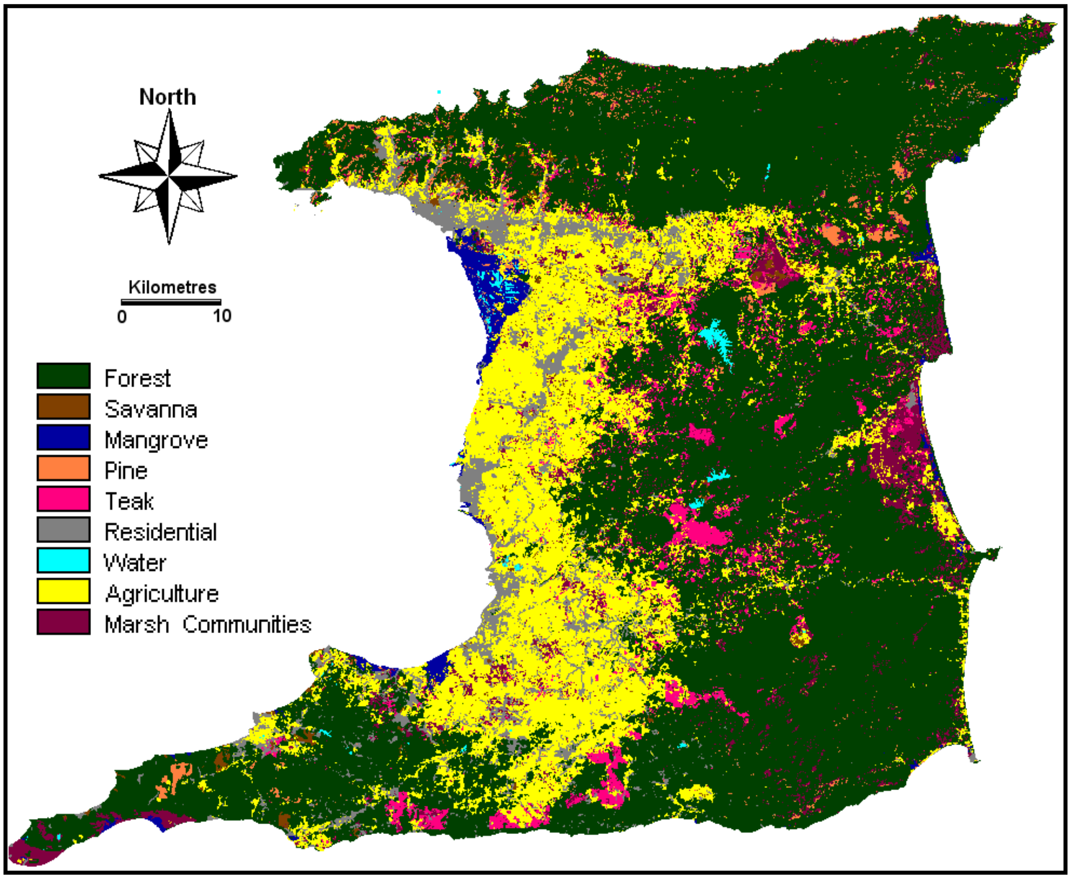

Figure 2: Land use/cover map using of Trinidad
developed using the Maximum Likelihood classifier (After Baban et.al, 2008)

3.2. Additional data set

Previous work done in mountainous Tropical Islands similar to Trinidad suggests that elevation, slope, soil and geology were the primary factors influencing the distribution of land use/cover (Baban and Wan-Yusof, 2002). Hence, data sets relevant to these aspects were acquired to establish the corresponding layers. A digital elevation model was developed based on contour lines digitized on the set of 1:25,000 topographic maps of Trinidad. These contours lines were appropriately interpolated in ArcGIS9 to create the DTM. ArcGIS9 was also used to derive slope aspect and elevation ranges from the developed DTM.

Digitizing was also used to convert information on the hardcopy maps of Trinidad's geology, soil and rainfall to vector layers. The rainfall layer was incorporated into this research as it is considered to be a driving force for land cover/use distribution (Richards, 1997).

3.3. The Development of the Biophysical Land Units (BLUs)

The classified land use/cover layer already developed was imported into ArcGIS9 to identify the physical boundaries of the six datasets which includes aspect, elevation, slope, rainfall, geology and soil via a GIS overlay.

These six datasets, can be statistically referred to as the independent variables, while the land use/cover layer is the dependant variable. The seven GIS layers: aspect, elevation, slope, rainfall, geology, soil and land use/cover, had varying number of classes ranging from five classes to eleven classes (Table 1). They were overlaid using a GIS function which resulted in the developed BLU data layer (Figure 4).

Datasets		Aspect	Elevation (m)	Slope	Rainfall (mm)	Geology	Soil Type
No. of classes		5	9	8	8	11	6
Class ID	#1	North	0 – 5	0° - 5°	<1500	Clay	Clay
	#2	East	5 – 10	5° - 10	1500 – 1750	Clay, Marl	Clay Loam
	#3	South	10 – 15m	10° - 15°	1750 – 2000	Clay, Sand	Fine Sandy Clay
	#4	West	15 – 20	15° - 20°	2000 – 2250	Mud	Fine Sandy Loam
	#5	Flat	20 – 25	20° - 25°	2250 – 2500	Quartzite, Phyllite	Peaty Clay
	#6	-	25 – 50	25° - 35°	2500 – 2750	Sand	Sandy Clay Loam
	#7	-	50 – 100	35° - 45°	2750 – 3000	Sand and Gravel	-
	#8	-	100 – 500	45° - 90°	>3000	Sand, Mudstone	-
	#9	-	500 – 950	-	-	Sandstone	-
	#10	-	-	-	-	Shale, Slate	-
	#11	-	-	-	-	Slate, Siltstone, Sandstone	-

Table 1:Categorization of the biophysical controls

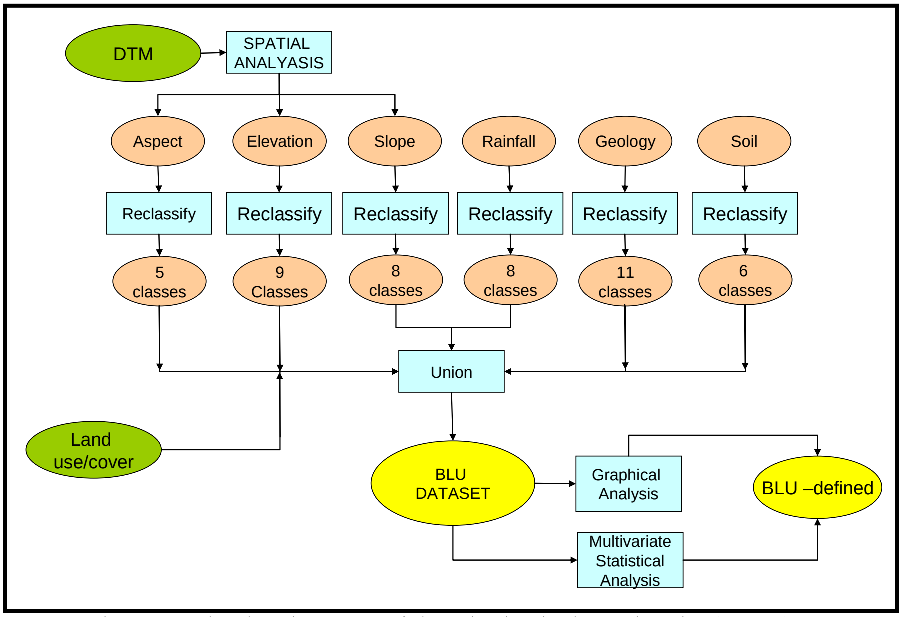

Figure 4: The development of the Biophysical Land Units (BLUs)

4. Analysis

The analysis of the defined BLUs was carried out using two approaches. The first approach utilized graphs and compared the frequency of the various groups within the independent variables on the dependant variable. While the second approach utilized multivariate statistics to identify the significant of the independent variable on the dependant variable.

4.1. Graphical analysis of the BLUs

i. Aspect

All of the land cover types except pine and mangrove had a distinct preference to Flat slope. Pine was the only land cover class which spreads itself relatively even amongst the north, west and flat slopes and only mangrove appears to favor the west facing slopes (Figure 5). Based on the information on Figure 3, it can be said that mangrove and pine are dependant on aspect, since these two land use/cover classes display variations from the other classes in this BLU component. All other classes are dominated by flat slopes and share a fairly even distribution of the other slope classes.

ii. Slope

Figure 6 indicates that all land use/cover classes are mainly distributed within the 0°to 5° range of slope. Mangrove, in particular, is only present in this range of slope classes. This indicates that this data layer may not prove to be a discriminate control, since all classes prefer the same range of slope angles. It was however observed that the island is dominated by a 0° to 5° slope range (77%). Also evident, was mangrove tends not to grow in slope outside this range, while Forest, Pine, and Shrub extend only up to 35°.

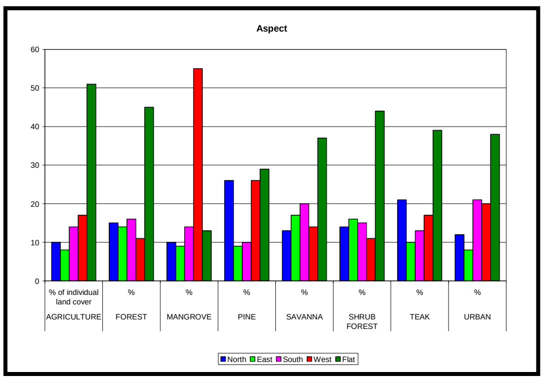

Figure 5: Distribution of Land use/cover against aspect

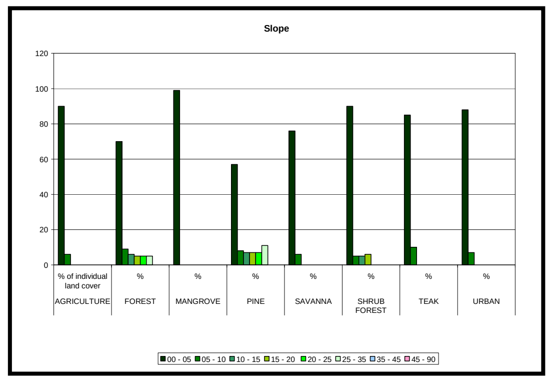

Figure 6: Distribution of Land use/cover against Slope

iii. Elevation

Figure 7 suggests that mangrove prefers to grow on the first elevation range (0–5m) and that this information can be used to extract areas where mangrove are likely to be found. Teak tends to be seen in two predominant classes, between elevation ranges of 20m to 50m, with 50% of the teak grown with the 20m to 25m range. There are two peaks in agriculture, one between the 5m to 10m range and the other at 25m to 50m even going up to 100m, suggesting that agriculture are grown in the low lands and the highlands. Another observation which can be made is that agriculture, forest, pine, savanna and shrub-forest can be found in a larger range of elevation, than mangrove and teak.

iv. Rainfall

The distribution of land cover/use against rainfall is depicted in Figure 8. Mangrove again proves that this layer provides sufficient information to differentiate it form the other classes, with mangrove having a likeness to a very low to moderate rainfall (1750-200mm). The only other land use/cover classes with tends to have a preference to a low to moderate rainfall is agriculture, with agriculture opting to be in areas with a lower rainfall than mangrove (1500-1750mm). Forest, pine shrub-forest and teak can be found with areas of any amount of rainfall (large range), where as savannas are found in areas with moderate rainfall (1750-2250mm).

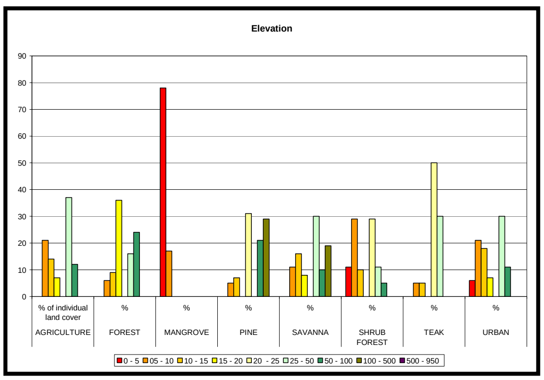

Figure 7: Distribution of Land use/cover against Elevation

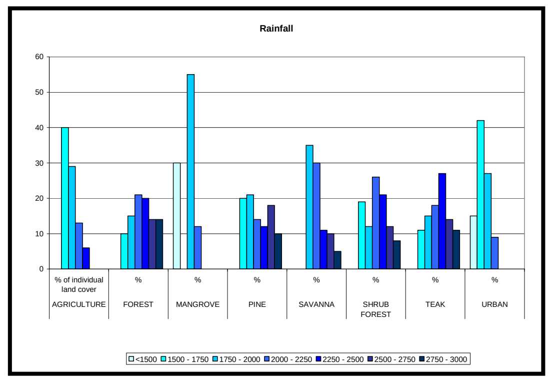

Figure 8: Distribution of Land use/cover against rainfall

v. Geology

The distribution of land cover/use against geology is shown in Figure 9. Some 95% of the mangrove on the island is found on locations where mud, sand and gravel represent the dominant geology. This figure also suggests that there is an even distribution of forest amongst 4 geology classes, while agriculture, savanna, and shrub-forest are dominated in areas where sand and gravel exist. Apart from forest, pine is the only other land use/cover that can be found in areas where slate, siltstone and sandstone exist; in fact this is the largest single group of geology that controls the distribution of pine. Hence the distribution of mangrove, pine and forest appear to be dependant on geology.

vi. Soil

The distribution of land cover/use against soils is depicted in Figure 10. Once again mangrove can only be found in areas that are not suitable for the other land use/cover types. 93% of the mangrove is found on peaty clay or clay, with 80% of the mangrove found in areas where there is peaty clay. No other class dominates peaty clay. Close to 50% of Pine distribution seem to prefer sandy clay loam, while all other classes including forest prefer clay.

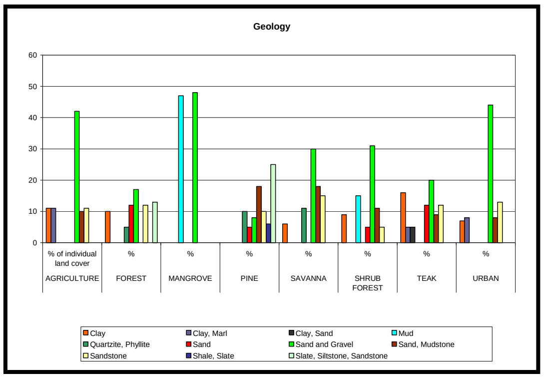

Figure 9: Distribution of Land use/cover against geology

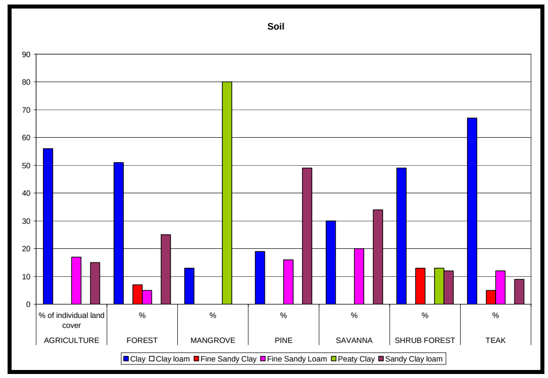

Figure 10: Distribution of Land use/cover against soil

Table 2 illustrates the dependence of each land use/cover classes amongst each Biophysical Land Units components (6 independent variables). This table was derived based on the observations made from the graphical comparison of each of the land use/cover classes and each of the six dependant variables. The tick indicates a dependency of that land use/cover type on a particular BLU component, based on Figure5 – Figure10.

From the table, of all the BLU components, elevation appears to be the most influential, since all the land use/cover classes are dependant on elevation. While elevation appears to be a very dominant factor in the land use/cover distribution, aspect seems to have very little effect overall.

	Aspect	Slope	Elevation	Rainfall	Geology	Soil
Agriculture			✓	✓		✓
Forest		✓	✓	✓	✓	
Mangrove	✓	✓	✓	✓	✓	✓
Pine	✓	✓	✓	✓	✓	
Savanna			✓	✓		
Shrub Forest			✓	✓		✓
Teak		✓	✓			

Table 2: Dependency of land use/cover classes on the BLU using the graphical method

The effect rainfall has on the distribution of these land use/cover classes also appears to be the second most influential factor. This BLU component may be useful in identifying agriculture, forest, mangrove, pine savannas and shrub-forest. While geology was useful in isolating forest, mangrove and pine; soil was useful in agriculture, mangrove and shrub forest.

4.2. Multivariate statistical analysis

Following the earlier method of the graphical analysis, the use of statistics by means of multivariate statistics analysis was carried out. This multivariate analysis was conducted on 380 stratified random sample points (Table 3). For each land use/cover a multiple regression analysis was performed that generated the regression coefficients, the standardized error, its significance value and an overall “F”, where “F” is a measure of the goodness-of-fit of the regression model. If the generated “F” value is smaller in magnitude than the tabulated “F”, then the least-square estimate for that equation is suitable (Neave, 1981).

Land use/cover	Number of point sample
Agriculture	66
Forest	61
Mangrove	44
Pine	40
Savanna	25
Shrub Forest	51
Teak	44

Table 3: Stratified random sample used in generating the Multivariate analysis

The results of the multiple regression analysis from these 380 sample-points and derived multiple regression equations to represent each land use/cover type are shown on Table 4 and equations 1-7. In a multiple linear regression equation, $\mathbf{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \varepsilon$, where $\beta_0, \beta_1, \beta_2, \ldots\ldots\beta_k$ are unknowns constants called regression coefficients estimated by least squares.

	Measure of goodness of fit (f)		Regression coefficients							
				Constant	Aspect	Elevation	Rainfall	Slope	Soil	Geology
Agriculture	Gen	4.513	β	.294	.018	-.031	-.0205	.001	-.032	.010
	table		sig	.001	.179	.004	.693	.963	.002	.230
Forest	Gen	19.405	β	-.173	.012	.009	.011	.133	-.003	-.022
	table		sig	.020	.353	.001	.000	.000	.709	.002
Mangrove	Gen	27.774	β	.506	-.037	-.056	-.024	.002	.033	-.006
	table		sig	.000	.000	.000	.010	.922	.000	.326
Pine	Gen	11.423	β	-.257	.009	.009	.037	-.030	.023	.023
	table		sig	.000	.385	.385	.000	.205	.005	.000
Savanna	Gen	2.388	β	-.006	-.009	-.009	-.005	-.072	.038	.003
	table		sig	.958	.612	.612	.763	.072	.006	.799
Shrub forest	Gen	2.967	β	.261	.002	.002	.034	-.001	-.017	-.017
	table		sig	.001	.858	.858	.004	.978	.076	.018
Teak	Gen	15.411	β	.135	.000	.000	-.030	-.039	-.034	-.002
	table		sig	.041	.981	.981	.002	.102	.000	.729

Table 4 SPSS results generated

Agriculture = 0.010G – 0.032S -0.005R + 0.001SL – 0.031E + 0.018A +0.294 Eq. (1)

Forest = - 0.022G – 0.003S + 0.043R + 0.133SL – 0.031E + 0.011A - 0.173 Eq. (2)

Mangrove = – 0.006G + 0.033S – 0.043R + 0.002SL – 0.056E – 0.037A + 0.506 Eq. (3)

Savanna = 0.003G + 0.038S – 0.005R – 0.072SL + 0.034E – 0.009A – 0.006 Eq. (4)

Pine = 0.023G + 0.023S + 0.037R – 0.030SL + 0.005E – 0.009A – 0.257 Eq. (5)

Shrub forest = –0.017G – 0.017S +0.034R – 0.001SL – 0.024E + 0.002A – 0.261 Eq. (6)

Teak = –0.002G – 0.034S –0.030R – 0.039SL + 0.059E + 0.000A – 0.135 Eq. (7)

Where G = Geology, S = Soil, R = Rainfall, SL = Slope, E = Elevation and A = Aspect.

From the data generated in Table 4, an analysis of the dependence of each land use/cover classes amongst each other six BLU component was done (Table 5). Of all the BLU components elevation and soil appears to be the most influential, since all the land use/cover classes except pine are dependant on elevation, while only forest does not have associated with soil. Aspect again seems to have very little effect overall.

The effect rainfall and slope seems to be moderate, while geology was useful in isolating forest, pine and shrub forest.

	Aspect	Slope	Elevation	Rainfall	Geology	Soil
Agriculture			✓			✓
Forest		✓	✓	✓	✓	
Mangrove	✓		✓	✓		✓
Pine		✓		✓	✓	✓
Savanna		✓	✓			✓
Shrub Forest			✓	✓	✓	✓
Teak		✓	✓	✓		✓

Table 5: Critical associations between land use/cover classes and the BLU components following multivariate analysis

4.3. A comparison of both methods

The table generated from both the graphical analysis (Table 2) and the multivariate analysis (Table 5) looks very similar to each other. When both are overlaid on each other the similarities/differences of the two approaches in deriving the association of land use/cover with the biophysical components can be seen (Table 6).

From Table 6, it appeared that the results from the two methods are generally similar, with few anomalies. The relationship between pine and elevation was one such case where there appeared to be differences in the two approaches. One reason for this can be as a result of vast elevation range of the distribution of pine; no other class has such a large elevation range. Although, the graphical analysis identified elevation an important factor in the distribution of pine, the multivariate analysis could not identify it as a critical factor.

COMPARISON TABLE

	BLUs Components	Aspect		Slope		Elevation		Rainfall		Geology		Soil	
	Method 1 / 2	1	2	1	2	1	2	1	2	1	2	1	2
Land use/cover	Agriculture					●	●	●				●	●
	Forest			●	●	●	●	●	●	●	●		
	Mangrove	●	●	●		●	●	●	●	●		●	●
	Pine	●		●	●	●		●	●	●	●		●
	Savanna				●	●	●	●					●
	Shrub Forest					●	●	●	●		●	●	●
	Teak			●	●	●	●		●				●

Table 6: Comparison of the association of the BLU components and the land use/cover over the graphical analysis and the multivariate analysis

Regardless of the little difference the two approach yield similar results. However, a fundamental difference between the two approaches is that the multivariate ranks the BLU component, something that could not have been achieved from the graphs. While the graphical analysis made individual comparison on the each independent variables (aspect, elevation, slope, rainfall, geology and soil) against the dependant variable (land use/cover), the multivariate analysis compared the independent variables to the dependant variable simultaneously (Shaw and Wheeler, 1985).

A break down or the summary of the weights that the BLU components have on the land use/cover type can be seen on Table 7. These weights were derived based on the results of the multivariate analysis. Elevation is ranked highest over the other component in the distribution of mangrove and teak, while slope appears to be the most critical for forest and savannas. Rainfall seems to be the most important component for the distribution and growth of shrub forest and pine, while agriculture appears to be mostly driven by the soil conditions.

From the multivariate analysis, elevation and slope seem to be the two most critical components. Four out of the seven land use/cover types put them in the first or second rank. For agriculture, mangrove, shrub forest and teak, elevation seem to be the influencing factors, while slope is critical in forest, pine, savanna and teak distribution.

	Rank			
	1st	2nd	3rd	4th
Agriculture	Soil	Elevation		
Forest	Slope	Rainfall	Elevation	Geology
Mangrove	Elevation	Aspect	Rainfall	Soil
Pine	Rainfall	Slope	Geology	Soil
Savanna	Slope	Soil	Elevation	
Shrub Forest	Rainfall	Elevation	Geology	Soil
Teak	Elevation	Slope	Soil	Rainfall

Table 7: Summary of the rank of the BLU components over the land use/cover using the multivariate analysis

Rainfall appears to follow in the list of critical factors after elevation and slope, with three land cover types dependant of it. These three classes are forest, pine and shrub forest (Table 6). Geology did not appear to be as significant as previously though, since no land use/cover rank it in the first two critical factors, while soil was ranked first in agriculture and second in the distribution of savanna.

5 Discussion

Current information on the status and the extent of natural resources and the development process is essential for sustainable management. The information base map for Trinidad was outdated and prior to the results from this study, decision makers were at a disadvantage owing to the lack of available data on the natural vegetation habitats.

Based on the results generated form both analyses, the associations with the land use/cover types and the physical characteristics which drives them are now known. BLUs can be used effectively for different applications related to the optimal choice of land use/cover for an area.

In the case of reforestation, only the land cover types which are suited for a particular environment should be used in that process based on their BLUs. This is to say, the BLUs would assist in determining what natural plant communities most suitable for that particular area which are identified for reforestation.

While on the other hand, areas can be identified for reforestation based on the forest communities that are in threat and the location of there BLUs. Once natural plant habitats have been considered to be in a serious threat, the location of the reforestation process could now be determined based on what the desired BLUs for those plant community are.

In the planning process this information can assist the policy makers in determining the most suitable location for industries; suggesting that these industries be located on lands where the biophysical properties of those lands may not be as crucial for natural plant communities. There may also be situations where "prime forest lands" must be allocated to industries based on other consideration such as infrastructure, location of other industries, or access to ports or harbors. The developed BLUs can now assist in locating alternating site where these plant communities could exist.

The management process of the natural plant habitats is now enhanced by this additional information, where decision makers can not only now decide on the most appropriate locations for industries, agriculture, and housing but also areas for forest reserves and reforestation. Additionally, the most suitable plant communities can be used based on the biophysical properties of locations identified for the reforestation efforts. Based on this, the methodology now needs to incorporate a way to identify natural plant communities that are in threat and locations of reforestation.

Reference:

Adames, D. C., 2001. Caribbean Islands Regional Overview. Centers of Plant Diversity, the Americas.

URLhttp://www.nmnh.si.edu/botany/projects/cpd/ma/ma-carib.htm

Andresen, E., 2003. Effect of forest fragmentation on dung beetle communities and functional consequences for plant regeneration. Ecography 26, 87-97.

Baban, S. M. J., and Wan-Yusof, K., 2001. Mapping land use/cover distribution in a mountainous tropical Island using remote sensing and GIS. International Journal of Remote Sensing. 22 (10), 1909–1918.

Baban, S. M. J. and Wan-Yusof, K., 2002. Defining biophysical land units mountainous tropical environments using remotely sensed information, field data and GIS, Asian Journal of Geoinformatics. 2 (4) 19 – 28.

Baban, S. M. J., and Wan-Yusof, K., 2003. Modelling Optimum Sites for Locating Reservoirs in Tropical Environments, Water Resources Management, 17, 1– 17.

Baban, S. M. J., 2001. Managing natural habitat loss in the Caribbean region using remotely sensed data and GIS: Examining Trinidad and Tobago as a case study. Proceedings of the Urban and Regional Information Systems Association – URISA 2001 Caribbean GIS Conference, Wyndham Rose hall, Montego bay, Jamaica. 153-163.

Baban, S. M. J., AL-Tahir, R. and Chinchamee, A., 2008. Meeting the needs of development in tropical mountainous environments: A methodology for mapping land use/cover using remote sensing. International Journal of Geoinformatics (In Review).

CARICOM/TFAP, 1993. Trinidad and Tobago National Forestry Action Programme: main issues, summary of the report, priority project profiles. For presentation at the CARICOM/TFAP Roundtable III meeting, November 1993. Forestry Division, Ministry of Agriculture, Land and Marine Resources: Pos Trinidad.

Carrol, C. S., 1996. Defining biophysical land units, In: Raster imagery in geographic information system, (Morian, S. and Baros, S.L., eds) Onward Press, USA, 289-293.

Douglas, I., 1999. Hydrological investigations of forest disturbance and land cover impacts in South-East Asia: a review. Philosophical Transactions of the Royal Society of London. Series B, 354, 1725–1738.

EMA, 1996. Trinidad and Tobago: state of the environment 1996 report.

Eyre, A. L., 1998. The tropical rainforest of the eastern Caribbean: present status and conservation. Caribbean Geography. 9 (2) 101-120.

Foody, G. M., Palubinskas, G., Lucas, R. M., Curran, P. J., and Honzak, M., 1996. Identifying terrestrial carbon sinks: classification of successional stages in regenerating tropical forest from LANDSAT TM data. Remote Sensing of Environment, 55, 205–216.

Garcia, D.F.L., and Murguia R.G.G., 1996. Modeling vegetation distribution in mountainous terrain. In: Morian S. and Baros S. L. (editors). Raster Imagery in Geographic Information Systems. Onward Press. USA, 165-171.

Hill, R. A. and Foody, G. M., 1994. Separability of tropical rain-forest types in Tamopata-Candamo Reserved Zone, Peru. International Journal of Remote Sensing. 15, (13) 2687–2693

Kenny, J., Correau, P., and Katwaru, L., 1997. Extensive Extracts from A Survey of the Biological Diversity Trinidad and Tobago. Environmental Management Authority of Trinidad and Tobago. URL:<http://www.ema.co.tt/nbsapweb/Kenny-et-al.htm.>

Koninck, R. D., 1999, Deforestation in Vietnam. International Development Research Center, Ottawa, Canada.

Lambin, E. F., 1994. Modelling Deforestation Processes: A Review. TREES Series B. Research Report No. 1, EUR 15744 EN (Brussels: European Commission).

Lillesand, T.M. and Kiefier, R.W., 2000. Remote sensing and image interpretation, John Wiley and Son Inc

Neave, H. R, 1981, Elementary Statistics Tables: for all users of statistical techniques. Alden Press, oxford, London.

Richards, P.W., 1997. The tropical rainforest: an ecological study. Cambridge University Press, Cambridge, England.

Roy, P.S., Ranganath, B.K., Diwakar, P.G., Vohra, T. P. S., Bhan, S. K., Singh, I.J. and Pandian, V.C., 1991. Tropical forest type mapping using remote sensing. International Journal of Remote Sensing. 12 (11) 2205 – 2225.

Shaw, G. and Wheeler, D., 1985. Statistical Techniques in Geographical Analysis. John Wiley & Sons. Chichester, New York, Brisbane, Toronto, Singapore.

Wadsworth, R., and Treweek, J., 1999. Geographical Information Systems for Ecology, An Introduction. Longman, England.