Mapping Martinique's Forests and Other Natural Lands for Land Planning and Development

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Abstract.—The Regional Council of Martinique has chosen the French national forest inventory to realize Martinique's forest and other natural lands map. The project is divided into the three following steps: (1) nomenclature proposal and study area delineation; (2) mapping of the vegetation based on 2005 airborne orthophotographs, Geographic Information System-based slope and accessibility analysis maps, and a land cover change map based on the comparison of 2004 and 1951 airborne covers; crossed maps will be produced to show areas that can potentially be developed for agriculture, forestry, or land protection; (3) and presentation of the results.

Context

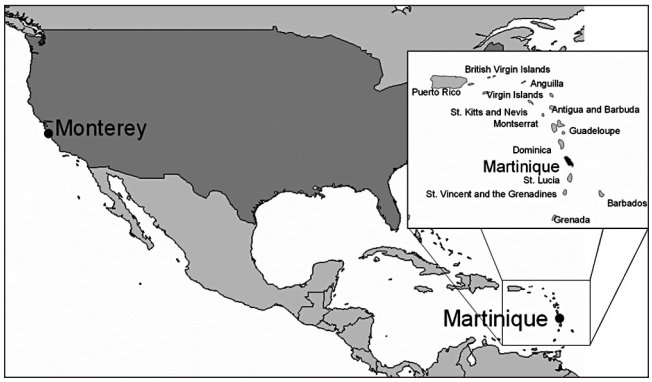
The Island

Martinique is a French overseas department in the Caribbean West Indies with the Atlantic Ocean on its east and the Caribbean Sea on its west, as shown in figure 1. It has a surface area of 1,128 km^2 (278,735 acres) and measures 70 km (43 mi) from north to south and 30 km (18 mi) from east to west. It is the smallest of France's four overseas departments. Its geographic relief is diverse, with a group of mountains in the north topped by the Pitons du Carbet (1,196 m, or 3,924 ft) and the still-active volcano of Montagne Pelée (1,397 m, or 4,583 ft). The rest of the island is hilly except along the mideastern coast, where the Lamentin Plain is located (Ministère de l'outre-mer 2005).

Climate

The island's climate is tropical, with an average annual temperature of 26 °C (78 °F), and is extremely humid from 80- to 87-percent humidity, depending on the season. Its heat, due to sunshine, is cooled by trade winds coming from the Atlantic Ocean.

Figure 1.—*Martinique's localization and a closeup of the Caribbean West Indies.*



Martinique has two seasons: a dry warm season from December to May with extensive drought from February to April and maximum sunshine, and a humid warm season from June to November with high hurricane risk.

Mountainous areas in the north have a cooler and more humid climate than shore areas. Trade winds from the Atlantic Ocean are blocked by the relief, producing important orographic precipitation. For example, average rainfall produces more than 5 m of water a year at the top of the Montagne Pelée.

Population

The most recent population census conducted in 1999 listed 381,427 inhabitants. The population density is high, with 338 inhabitants per square kilometer (875 inhabitants per square mile). Detailed data show that inhabitants are unequally distributed: three nearby cities (Fort de France, Le Lamentin, and Schoelcher) contain 40 percent of the population and the remaining

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60 percent of the population is generally distributed throughout the southern part of the island. The mountains in the north have a low population density.

Vegetation

Martinique is covered by approximately 47,500 ha (117,375 acres) of forest; no precise data exist for other natural lands. The public-owned forest, representing around 12,000 ha (29,650 acres) is well known and managed by the French national Forest Service, whereas private forests and other natural lands are not well known. Forest fragmentation is highly variable: densely populated areas show a high level of forest fragmentation and areas with fewer population or steeper slopes have much bigger stands. A wide variety of forest types exists, ranging from dry forest to rain forest. The tree diversity is high (Palli 2007, Portecop and Petit le Brun 2003). Also present are rare forest types, including mangrove forest. Protecting the sparsest types of forest is a major issue: Whereas this land used to be naturally shaped by relief and rainfall, it is currently under a great deal of pressure stemming from urbanization and agricultural policy. All districts have used up their available lots and, in general, they look to forest areas for new urban projects. Although comprehensive development area maps exist, communities manage to obtain authorization, and, for the most part, cities are growing over the island's forests. In addition to urbanization, agriculture also represents a source of pressure for forests. More and more young farmers are unable to find land to start their businesses, while some existing farms are looking to increase their surface area. The simplest solution often involves forest clearing. On the other hand, the amount of fallow land is increasing.

A Small-Scale Wood Industry

Martinique's forest also supplies a small-scale wood industry. The wood is mainly used for local-style furniture. About 2,000 ha (4,942 acres) of mahogany forest produce approximately 4,000 m^3 (141,260 cubic ft) of wood each year. Almost all harvested areas are in public-owned forests, although politicians wish to expand harvesting in private-owned forests. Some forest-accessible stands could be cleared and replanted with mahogany; abandoned farmlands could be used in the same way.

A Lack of Forest Data

Overseas departments, unlike mainland France, do not have forest inventories. Vegetation maps (Poupon 1982, Rosette 1985) are old and inaccurate and restricted to climax vegetation (Fiard 1994, Portecop 1978).

As a result, a monitoring study of Martinique's territory is needed to improve data and maps of the island's forests and other natural lands. Politicians and institutions need a tool to manage their territory.

Purpose of the Study and Procedure

Purpose of the Study

In light of all the previous observations, Martinique's politicians decided to conduct an inventory of their natural territories, including forests, heath, and fallow lands. This study, based mostly on photo interpretation and Geographic Information System (GIS) processing, is the first step of a large-scale program conducted over many years, starting with this general study and followed by more specific studies. The main objective of this first step is to produce maps of vegetation, accessibility, slopes, and land use history on forest and other natural areas. These maps will be used to define areas that could potentially be developed toward agriculture or forestry.

The second step of this large-scale program will use the results of the previous study considering properties, environmental constraints, water resources, agricultural or forestry potentials, landscape, and tourism. Other precise thematic studies will be conducted.

The Regional Council of Martinique launched a call for tenders in May 2005 for the first phase of the program. The French national forest inventory (NFI) was chosen to conduct the study.

Procedure

The project itself is divided into three parts, as follows.

Part 1, probably the most strategic, consists of proposing different typologies to be used on the different maps requested for the project. It is associated with a field trip to train some NFI

team members who are not used to Martinique's vegetation. At the same time, a first map is produced to delimit the study area that includes forest, heath, and fallow lands.

Part 2 is the main operational part, in which all maps are compiled and the GIS map crossings are done. The maps are statistically controlled in the field to guarantee a high level of accuracy.

Part 3 involves presenting the results to the various parties concerned by the study.

After each part is completed, the work is validated by an expert group.

Results To Be Delivered

The results produced during this study are mainly GIS maps, including a 2005 vegetation map, a land use map showing changes that have occurred since 1951, and accessibility and slope maps. These maps are intersected to produce different maps showing areas with forestry or agriculture potential.

Data Available for the Study

The study is based on photo-interpretation work; most of the data were GIS and/or photographic material. Since the late 1990s, every 5 years, the National Geographic Institute has produced an accurate orthophotographic layer for the entire French territory, including the overseas land. We were able to use the two most recent layers, from 2000 and 2005. Having two layers is interesting because the quality of each layer varied greatly and it is extremely useful to use both layers on difficult cases even if the map's reference date was 2005. The only drawback is that the emulsion is not infrared but is a natural color that makes it much more difficult to see differences between vegetation types. In addition, we have paper prints of the airborne photographs to use for stereoscopic vision; the use of these prints is necessary to decide on some kinds of vegetation types related to canopy height (Boureau 2002). Another set of airborne photographs is also available for 1951 cover. It is used for a comparison with the 2005 cover to map land use changes.

All GIS processing about map accessibility and slopes use a vectored map with different themes, such as roads and rivers and a digital terrain model updated in 2006.

A complementary agricultural map is also used, showing the different types of agriculture existing in each block. The divisions of this map are based on statements by landowners, however, which may have impacted the accuracy of the map's content. Furthermore, the outlines of the map's various divisions are somewhat vaguely defined. Despite these obstacles, the map is nevertheless a useful tool that helps identify fallow lands.

All these data are supplemented with bibliographic research and discussions with local specialists.

Teams Working on the Study

Four people from the French NFI in Bordeaux are working on this project, including one project manager who used to work in Martinique's forests and three cartographers. Working with three cartographers is an important choice. The quality of work is greatly improved because the cartographers are able to compare their analyses when they have doubts, which is quite common when performing photo interpretation. We are assisted with GIS processing by another cartographer living in Martinique.

The Regional Council of Martinique is supervising the project with the assistance of the French national Forest Service. Each step of the work is validated by a group of experts that is composed of people involved in the two main problematic issues of the agriculture and forestry project.

Results and Outcomes

Study Area

The study area map sets up the perimeter of the study that will be used for the compilation of the other maps. It includes forest, heath, and fallow lands, the three main land types that are targeted by the study. The detail of what should be included in these three types is detailed using the international Food and Agriculture Organization of the United Nations (FAO) definitions (FAO 2000) for forest and heath. The last type is much more difficult to determine. Focusing on the study's objectives, fallow lands are considered to be any field where no distinct agricultural activity is present. It is important that fallow lands

be included because interpretation doubts usually exist about whether they are truly abandoned or neglected; ignoring them would be a loss of interesting areas.

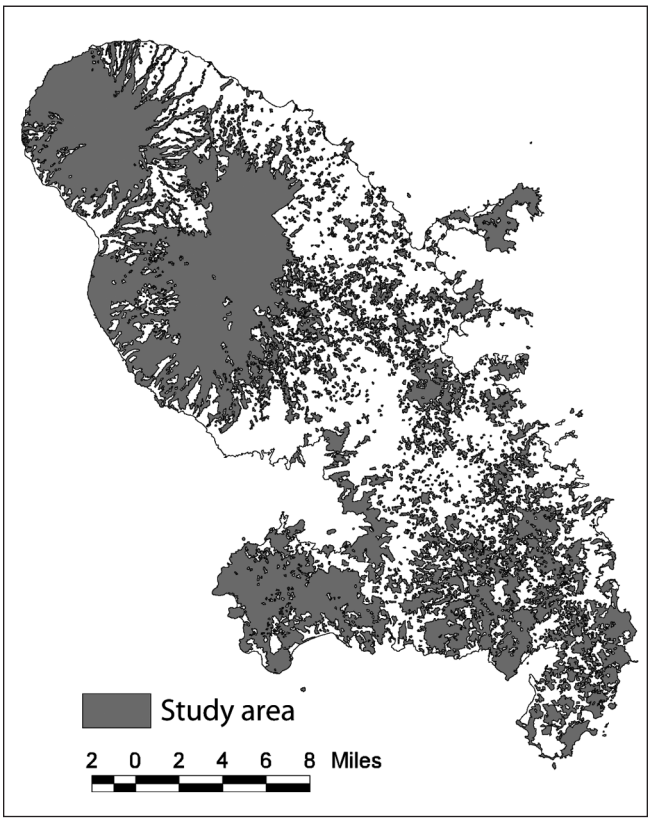
The reference for this work is the 2005 orthophotographic layer. Delineation is performed directly in ArcView. In general, the work scale is around 1:3,000, giving a good accuracy of the layout.

The next step is to determine the thresholds of this layer. The contract requests a minimum width of 75 m (246 ft) and a minimum surface area of 2.25 ha (5.56 acres) because it is common practice in mainland France (IFN 2003). Discussions reveal that these specifications were too weak for the expected outcome of the study for two reasons: (1) mapping with a 2.25-ha limit would omit a large number of fragmented areas and (2) producing a synthesis for a larger surface area would be much more time consuming. The minimum surface area is reduced to 0.5 ha, and we keep the minimum width at 75 m. As a result, the minimum surface area is almost in line with FAO recommendations, and it will be easy to present the results according to international definitions.

Practically speaking, delineation of the study area began before the field trip and was finished afterward. This practice enabled us to select areas that were difficult to identify on orthophotos and to visit them in the field. After the field trip, the study area was updated according to what we saw there.

Once the map is validated by the expert group, the next stage will continue within the study area, as shown in figure 2.

Figure 2.—*General view of Martinique with the study area in gray.*



Vegetation Types Map

The vegetation map is quite significant for Martinique: it is probably the longest part of the project and politicians and other stakeholders have high expectations about it.

The method used for mapping is an adaptation of the one traditionally used in mainland France. It is mostly based on direct delineation on a computer screen and was previously controlled with stereoscopic couple photographs (IFN 2005). The thresholds used are lower, but this does not significantly change the usual practices (see "Study Area"). Two other major differences exist between the method used for Martinique and the one used for mainland France. As is the case for the study area, 2005 orthophotos with a natural color emulsion are used. This practice is a major constraint because, in general, it is highly preferable to use an infrared emulsion to differentiate vegetation types. The second major difference is, of course, the highly diversified tropical vegetation.

Previous vegetation maps had been produced (Poupon 1982, Rosette 1985) but never with a very high level of precision in terms of layout. These maps are used to correlate our observations.

Even if the available material is an important constraint for the vegetation typology definition, 18 types are proposed (see table 1). Our analysis of the project led us to build the typology with a correspondence to the United Nations Educational, Scientific and Cultural Organization's forest classification and FAO land cover definition whenever possible for each type that was useful for the study. Once the map is established, experts and field observation will validate it.

Table 1.— *Summarized presentation of the nomenclature of plant formations that will be mapped as part of the study's geographic scope.*

Family	Name	Definition	Martinique's correspondence with adapted international UNESCO classification[a]	Correspondence with FAO definition
Forest	Mangrove	Mangrove	Mangrove	Forest
Forest	Beach forest	Beach forest	Beach forest	Forest
Forest	Young dry forest	Young forest with homogeneous low cover and high density of shrubs and small trees	Evergreen seasonal tropical forest in lower horizon	Forest
Forest	Medium dry forest	Mid-evolved forest with heterogeneous cover with shrubs and trees	Evergreen seasonal tropical forest in lower horizon	Forest
Forest	Older dry forest	More evolved stands with a homogeneous tree cover	Evergreen seasonal tropical forest in lower horizon	Forest
Forest	Semimoist forest	Forest ranging between 0 and 300 m in elevation with a pluviometry range between 1,800 and 2,500 mm/year	Evergreen seasonal tropical forest in mid/higher horizon	Forest
Forest	Rain forest	Forest ranging between 200 and 1,000 m in elevation with a pluviometry range between 2,500 and 5,000 mm/year	Ombro-evergreen seasonal tropical forest and submontane ombrophilous tropical forest	Forest
Forest	Altimontane shrubs and trees	Altimontane shrubs and trees	Shrubs and trees on higher volcanic crests	Forest
Forest	Bamboo	Bamboo cover of more than 25%	NA	Forest
Forest	Mahogany high forest	Forest with mahogany cover of more than 75%	NA	Forest
Forest	Mosaic forest/housing	Forest fragmented with housing; forest cover of more than 10 and less than 75%	NA	Other lands with tree cover
Fallow land	Fallow land with a high cover of shrubs	Tree cover of less than 10% and shrub cover of more than 40%	NA	Other wooded lands
Fallow land	Fallow land after banana trees	Tree cover of less than 10% and banana tree cover of less than 40%	NA	Other wooded lands and other lands
Fallow land	Fallow land after other croplands	Tree cover of less than 10% and other croplands cover of less than 40%	NA	Other wooded lands and other lands
Fallow land	Other fallow lands	Tree cover of less than 10% and shrub cover of less than 40%	NA	Other wooded lands and other lands
Agriculture with tree cover	Croplands with sparse trees	Tree cover over of more than 10% with an agricultural main use	NA	Other wooded lands
Heath	Savanna	Permanent heath with forest cover of less than 10%	NA	Other wooded lands and other lands
Heath heath lands	Altimontane Low shrubs; tree cover of less than 10%	Altimontane shrubs	Other lands	

[a] *Joseph (1998).*

FAO = Food and Agriculture Organization of the United Nations. NA = Not applicable. UNESCO = United Nations Educational, Scientific and Cultural Organization.

Vegetation types are separated into the following four families:

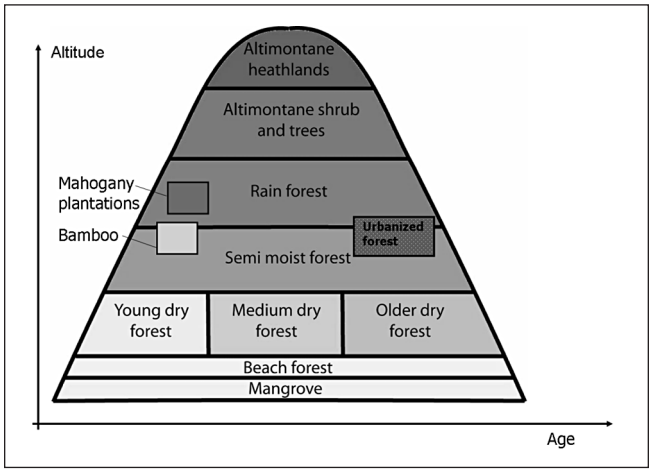
1. Forest types (figure 3**)**. Because it is impossible to distinguish the specific constitution of each type, our typology is based on what is seen from the airborne photographs using stereography. Three main factors are used to determine the type: (1) transparency of the cover, (2) average tree height, and (3) crown aspect/density. The combination of these factors with field knowledge and

external complementary information such as altitude and rainfall enable the identification of the appropriate type.

Other types, such as mangrove, mahogany plantations, and bamboo, have more specific aspects. These types are usually easily recognizable on photos. Urbanized forest areas have a dedicated type. They are highly common and have a peculiar aspect, in that they are composed mostly of species that produce food supplements. Beach forest has a specific species constitution and is subject to considerable human pressure stemming from urbanization and tourism. Only a few beach forests will be in the study area (less than 75 m in width).

2. The second family includes the different kinds of fallow lands depending on the type of agriculture that was previously practiced. Fallow lands vary greatly depending on what was present before and generally do not have the same development potential. Fallow lands that used to contain banana trees have a fast dynamism and can become forests much faster than fallow land that used to be a meadow.
3. The third family contains two kinds of heath (or high grasslands) that are not subject to high height pedoclimatic conditions.
4. The last family has just one type: areas with tree cover that are used for agriculture.

Figure 3.—*Forest typological diagram.*



Accessibility and Slopes

The purpose of the study is to underline areas with development potential. Areas accessible in terms of road servicing and areas that are not too steep to work on are extracted in two layers using the methodology described in the following text. (See figure 4.)

The first layer concerns theoretical accessibility. It is made from the vectorized road layer, with buffers created around roads that are suitable for trucks. The type of road is also attached to the buffer. Buffers have the diameter of the maximum skidding length; we used 75 m, considering that Martinique's conditions are commonly difficult (Anon. 2001). Moreover, these buffers are intersected by rivers, the most common obstacle for wood harvesting. The opposite side of the river is removed, giving us a reachable area for skidding.

The second layer is a simplification of a digital terrain model in different slope classes taken from the value of the maximum working capacity for mechanized agriculture and forestry, considering that 20 percent of the slope is the limit for mechanized agriculture and 30 percent of the slope is the limit for mechanized forestry skidding, as shown in table 2.

These two layers are then intersected to extract potentially developed area by vegetation type.

Figure 4.—*Road buffer map, slopes classes map, and vegetation map are intersected to show areas with development potential.*

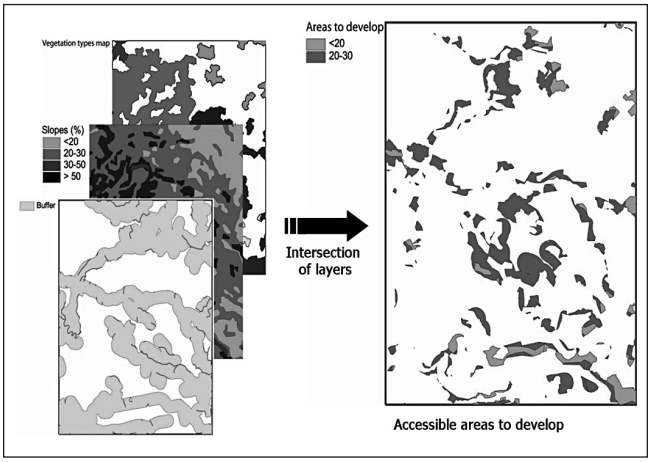


Table 2.—*Slope classes*

Slope	Definition
< 10%	Optimal for all types of use
10 to 20%	Mechanized agriculture still possible and optimal for mechanized skidding
20 to 30%	Optimal for mechanized skidding but mechanized agriculture no longer possible
30 to 50%	Mechanized skidding more complicated but still possible
> 50%	May not be used

Land Use Change

Politicians were curious to see changes in land use that have occurred over the past 50 years. A full airborne photograph cover was available. This cover had been realized in 1951 and the 2005 cover was compared with it.

We have only paper prints of the aerial cover, which we have to scan and then orthorectify to superimpose them on the 2005 cover. The 1951 cover had to be orthorectified, which presented difficulties because so many changes have occurred.

The comparison was done only within the study area (see table 3) to see the range of possibilities. This is not a comprehensive land use change map. Changes are determined on every plot that was mapped as forest or heath in 2005. Polygons from 2005 are modified according to previous land use, as observed on the 1951 photographs.

Maps Crossing

Synthesis maps are produced by intersecting the different layers. These maps are tools for finding the potential areas to develop. The maps will be used by the stakeholders to enable them to focus on the interesting areas.

Current Status of the Project

At the moment when this article was written, the study area had been delimited and the forest types had been listed. They have been submitted for validation by local administrations. The 1951 airborne photographs have been orthorectified. Tests have been carried out for every layer and all of our methodological problems have been resolved.

Conclusion

This project is a local tool for improving land planning and the management of the island. It will have numerous effects on various topics. This is the first time that Martinique will have highly accurate maps for assessing its policy concerning land planning and management for both forestry and agriculture. Many people are waiting for the results of the project and it will be the basis for many other studies. These are some of several reasons why our work has to be perfect.

If we consider the impact of this study in France, forest statistics for one of the country's overseas territories are going to be relevant for the first time. If this study is carried out on the other territories, France will have good data for its entire surface area. It will be possible to use the results to answer to international questionnaires about forests, such as the Forest Resources Assessment for FAO or the Kyoto Protocol. At this time, only two French departments, Martinique and French Guyana, are being inventoried. In these two locations, the inventory is more focused on remote sensing. Other departments are observing our project to see if it turns out well.

On the whole, this project could be considered a pilot study not only for France but also for other tropical islands with similar

Table 3.—*Land use change table between 1951 and 2005.**

Land use in 1951	Land use in 2005		
	Forest	Heath	Agriculture
Forest	1	1	0
Heath	1	1	0
Agriculture	1	1	0

**1 = mapped; 0 = not mapped.*

conditions. It is important for us to mutually communicate with the Regional Council of Martinique and the French NFI. This project will be useful to show to the decisionmakers the advantages offered by such a program in similar territories.

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