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Aerial photographs for detecting land use changes in Valencia Wildlife Sanctuary and Forest Reserve, Trinidad

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ABSTRACT. **The vast potential for negative impacts of land use change upon the environment has created an urgent need for the creation of a comprehensive view of land cover/use change. Such a perspective would serve as an invaluable tool that could be used by public administrators and environmental managers to manage the rate of change in land use in forested areas. Presently, the timing and extent of the changes in land use in the Valencia forest are not accurately known. Examination of the extent, trends, and time of land use change, and patterns within the forest, will assist land managers in understanding human impacts, and in formulating future management decisions. This paper develops a methodology that promotes the use of archival aerial photographs for mapping and quantifying the change in land use patterns in the Valencia forest. By using available aerial photographs of 1969 and 1994, it was found that there was an increase in area for every land use category in the forest reserve on the account of natural forest that showed a drastic decrease in land area. Fragmented forest had exhibited the largest increase in land area while abandoned agriculture showed the smallest increase in land area within the Reserve.**

1. BACKGROUND

Tropical forests in particular provide a large number of habitats for the highest levels of biodiversity on the planet (Meyers, 1992). They are particularly important for the *in-situ* conservation of biodiversity in the form of wildlife sanctuaries and nature reserves (Chalmers, 1981). Deforestation disrupts the nutrient cycling process, which in turn disrupts the various habitats provided for countless animal and plant species. Deforestation is a major contributor to global warming for the reason that healthy forests absorb and store carbon (Adger and Brown, 1995). As intact forests hold soils in place, deforestation leads to erosion of slopes, increased quantities and rates of water run-off, flooding and landslides. Furthermore, it causes a reduction in the amount of water that goes into underground reservoirs and storage aquifers, as well as the destructive siltation of fish spawning streams (FAO, 1993). On a different aspect, the social and economic benefits associated with tropical forests and their uses such as hunting, recreation, eco-tourism, medicinal and cultural activities may also be lost when these forests are removed.

The rise in the industrialization rate in Small Island Developing States (SIDS) and Caribbean islands has lead, in many cases, to increased demands on natural resources and increased environmental stress (CEP, 1996). Industries may also result in increased pollution of both terrestrial and aquatic environments. For instance, the quarrying activity, such that occurs within the Valencia forest reserve, Trinidad, has negative impacts on the environment such as water pollution from sediments, air pollution from dust, noise pollution from heavy machinery, and the loss of vegetation and wildlife (EMA, 1999).

Unsustainable agricultural/forestry practices tend also to impact significantly on the conversion of forestland. Plantation forests may have positive impacts on the environment, such as stabilization of the soil of degraded forests, or releasing natural forests from exploitation for timber resources. However, the establishment and maintenance of such forests may also disrupt the natural ecosystem functioning. These disruptions include increased consumption of water, increased acidification, sustenance of a low diversity of wildlife, and storage of more carbon than do natural forests (Cannell, 1999). For instance, studies have also shown that 95% of species diversity is lost after conversion of natural forest to pine plantations (Centeno, 1997).

Land use and ecosystem changes in tropical forests have become especially pronounced in recent decades. As the rates of change in many places have accelerated, so have the magnitude of these changes and their impacts. The vast potential for negative impacts of land use change upon the environment has created an urgent need for detecting the changes in land use and creating a comprehensive view of land cover/use change. Such a perspective would serve as an invaluable tool that can be used by public administrators and environmental managers to monitor and analyze the rate of change in land use. This is fundamental to ensure that appropriate management strategies are executed to safeguard the forest from any present and future problems of degradation.

Photographs and images of the Earth taken from the air and from space provide a great deal of information about the Earth's landforms, vegetation and resources. The development of these techniques over the last decades has proved their effectiveness and competitiveness in terms of low cost, wider coverage, and archival recording, as well as automation (Al-Tahir and Ali, 2004). Consequently, detection of land use change based on computer processing of aerial photographs and satellite images has been in a continuous expansion (Turner *et al*., 1993). Through comparing images obtained from different time frames and using GIS mapping techniques, land use and land cover change of designated areas can be competently mapped, monitored and studied (Wilkie and Finn, 1996; Al-Tahir and Ali, 2004).

2. Valencia Forest Reserve

Trinidad, a Caribbean island of 4,830 km^2, is covered mostly with forests that comprise 63.5% of the land (FAO, 1990). As part of that area, wildlife sanctuaries occupy 16,473 hectares, while nature reserves comprise 612 hectares (Chalmers, 1981). These areas are protected to ensure watershed stability, climate amelioration and environmental maintenance and to prevent over-hunting, degradation and over-exploitation of resources (EMA, 1999).

The Valencia wildlife sanctuary and forest reserve (known collectively as the Valencia forest) together comprise 2785 hectares and are situated in the northeast of Trinidad (Fig. 1) at the foothill of the Northern Range. The topography of the Valencia forest is flat, with undulations ranging from 10 to 100 meters above sea level and the drainage is imperfect. Terrace deposits of fine sand cover most of the area, consisting of about a quarter to one meter of loose sand overlaying cemented gravel forming an undulated pan.

The Valencia Wildlife Sanctuary is managed and maintained primarily for timber production, as well as to meet recreational and posterity

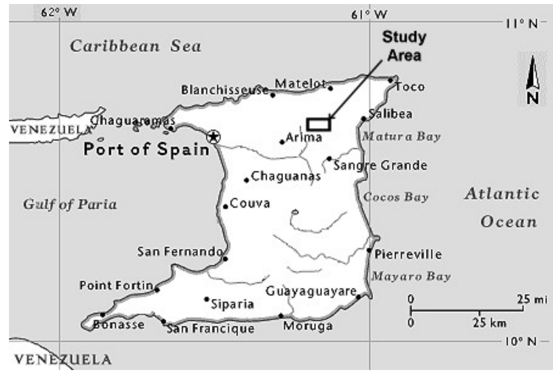

Figure 1. Location of the Valencia Wildlife Sanctuary and Forest Reserve

requirements, and to serve as a study and research grounds. In the past, various legal and illegal uses conflicted with the management objectives of the Valencia forest. Over-hunting was the first conflict with the original land use plans (Ramdial, 1972). Additionally, parts of the reserve were taken for power lines in the 1970's and 1980's. This action fragmented the Sanctuary and the Reserve, and allowed easier access into the interior parts of the forested area.

Mining of the forest for sand and gravel has been going on at a large scale since the 1960's that has left large areas with little or no vegetation. Areas of the reserve were clear-felled, the timber sold, and the money was used to purchase mining equipment (Kalpee, 1997). Mining quickly disrupted large areas of the reserve and increased the ease of access for hunters and subsistence farmers. These subsistence farmers have occupied some of these disrupted areas, thus preventing succession to natural forest. The rates of conversion of the natural forest within the Reserve and Sanctuary to subsistence agriculture were increased after the large fires of 1987 in which large portions of the remaining intact natural forest were destroyed.

Environmental degradation is presently occurring in the Valencia wildlife sanctuary and forest reserve due to squatting, indiscriminate quarrying activities, undesirable agricultural practices, and excessive logging. Sand and gravel mining within the Valencia forest has led to the loss of aquatic species, as the silt-laden discharge from the washing plants enter the Oropouche, Turure, and Quare rivers. As such, quarrying activity is the major source of pollutants within the Reserve (EMA, 1999). The extent of the changes in land use in the Valencia forest and their time of occurrences are not well known. Studying the extent, trends, and time of land use change, and patterns within the Valencia forest, will assist land managers in

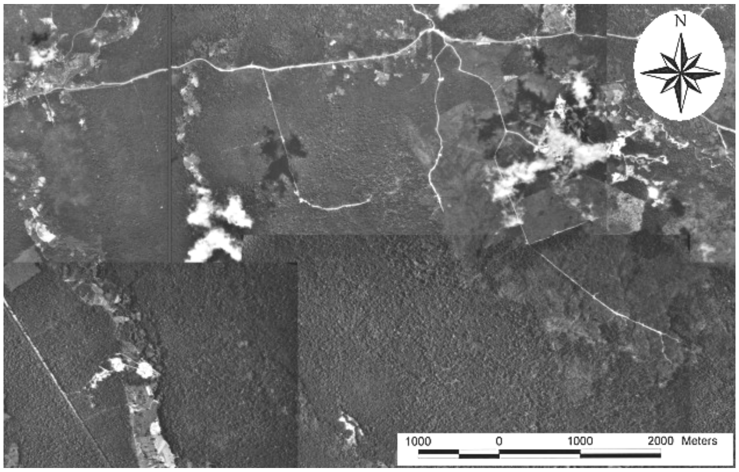

Figure 2. Aerial mosaic of 1969

understanding the details of human impact within this area, and in the formulation of future management decisions.

This study develops a methodology that promotes the use of archival aerial photographs to quantify the change in land use patterns in the Valencia Wildlife Sanctuary and Forest Reserve over an extended time period using aerial photographs, and to identify trends in the change of land use patterns and the implications of these trends for the future management of the area.

3. METHODOLOGY

Aerial photographs are usually requisitioned for the periodic exercise of producing and updating national base maps. Using aerial photographs as a source for land-cover information is, therefore, justified by the availability of these photographs, accessibility to several epochs, and their high resolution and geometric fidelity. The high resolution would also increase the ability to identify features in the scene, which in turn would improve the process of epoch-to-epoch image registration and minimize the error of registration (Al-Tahir and Ali, 2004).

There were several major national photography missions over Trinidad in the last sixty years. However, the entirety of Valencia forest was only covered by aerial photography missions of 1969 and 1994. At each date, Valencia forest was covered by six aerial photographs of a scale of 1:25,000.

The methodology adopted for this study consists of three major phases. The first phase is for preparation and preprocessing of data. This phase includes scanning, georeferencing, and constructing a mosaic of photographs to produce one photomap for each epoch. The second phase is for extracting and validating land use information. The third phase assesses and examines the patterns of land use changes in the area.

3.1. Data Preparation

The aerial photographs were first scanned using a desktop scanner at 300-dpi rate, which gives about 2-meter ground resolution suitable for the purpose of this study. Each photograph has to be registered to a map (georeferenced) to be brought into the same scale and frame of reference as other data sets. Georeferencing refers to the process of referencing imagery to a geographic referencing system using polynomial equations that establish the coordinate transformation function (rubber sheet transformation). This is accomplished with the aid of ground control points. While adequate spatial distribution of ground control points over the area is important, the more critical factor when dealing with multi-date data sets is that some of these points must appear in the different epochs to ensure consistent referencing between epochs (Al Tahir and Ali, 2004).

Geo-referencing of photographs was carried out based on 1:25000 topographic maps (sheets 15, 25, and 26) in the series E 804 (D.O.S. 316/1) edition (D.O.S. 1971). Some difficulty was experienced in obtaining points that would appear on the map as well as the photographs. This was particularly the case when dealing with road intersections in heavily forested areas, as they were present in the map but could not be identified in the photographs. The root mean square error for the process of georeferencing was in the range of 2 to 6 meters. This would set the accuracy of the quantitative analysis of land use areas in the 1969 and 1994 aerial photographs to a similar value.

Once all photographs were transferred to one reference system, they were concatenated to provide a photo mosaic for each epoch of 1969 and 1994 to facilitate the visualization and the interpretation of land use and land cover. This task was performed using built-in modules in IDRISI 32, a GIS/Remote

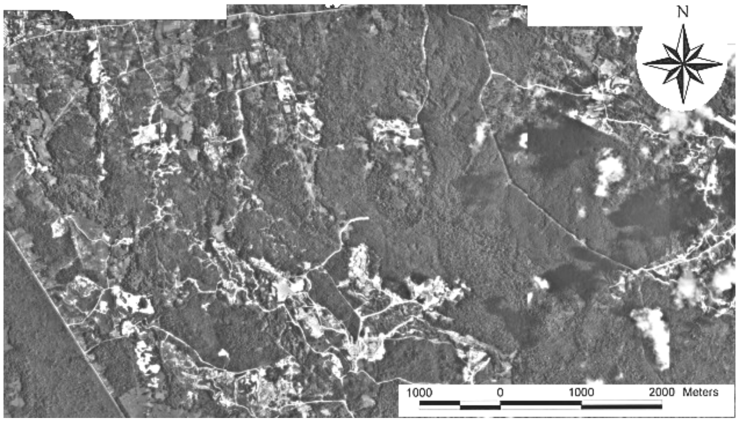

Figure 3: Aerial mosaic of 1994

Table 1. Adopted Land Use Categories for the Study Area

Category	Description
Forest	Natural, undisturbed vegetation.
Fragmented / Degraded Forest	Forested areas that have been disturbed, with gaps in the canopy.
Forest Plantations	Areas where trees such as pine are planted to replace natural forest.
Agriculture	Areas where crops are cultivated and farms are present.
Abandoned Agriculture	Areas where agriculture is no longer practiced. The land is covered with shrubs and small grasses.
Quarries	Areas used for mining of sand or gravel and where there is an absence of vegetation. Steep gullies and crevices are present.
Abandoned Quarries	Areas where quarrying is no longer practiced. Small shrubs and recovering vegetation are seen growing on the gullies and crevices.
Transport Networks	Roads that are paved or unpaved. These include roads connecting quarrying sites.
Pools Within Quarries	Bodies of water lying within the sinks and depressions within quarried sites.
No Data	Areas where cloud cover is present and underlying features are hidden.

sensing software. The large number of points in a homogeneous reference system ensures proper matching between the image edges. One may face an intricacy caused by the different brightens and contrast of the individual images, a case that can be resolved by manipulating image histograms prior to constructing the mosaic. Figures 2 and 3 depict the study region as it appears in 1969 and 1994, respectively. Many clouds could be seen in the concatenated images in 1969 as well as 1994.

3.2. Establishing Land Use Categories

This phase deals with delineating the different categories of land cover and land use in the study area. This study resorts to human skills in photo interpretation to identify and delineate land use and cover classes. Since the digital photographs are at high resolution, the analyst can safely distinguish several categories of land-cover types with a sufficient degree of certainty following well established photo interpretation principles. After careful inspection of the two sets of photographs and the 1:25000 topographic maps, a classification scheme was formulated to identify ten specific land use categories as shown in Table 1. Each of these land use categories was discerned from the others by a combination of tone and texture. Man made features normally associated with a specific land use, such as shacks and dirt paths, were utilized in the classification.

Forests were identified when dark areas that resembled treetops were seen in the photo. If lighter areas within these dark clumps with no resemblance to treetops were seen, these were considered to be spaces within the canopy and thus considered to be degraded or fragmented forest. In the 1969 photographs, the areas identified as forest plantations were observed to be lighter than forested areas with a regular grid pattern. In the 1994 aerial photographs, the grid patterns disappeared, the canopy darkened and forest plantations were less distinguishable from natural forests. Plantations were identified in the 1994 aerial photos based on, firstly, presence of young plantations in the 1969 aerial photos and, secondly, a canopy with a much smoother texture than natural forest.

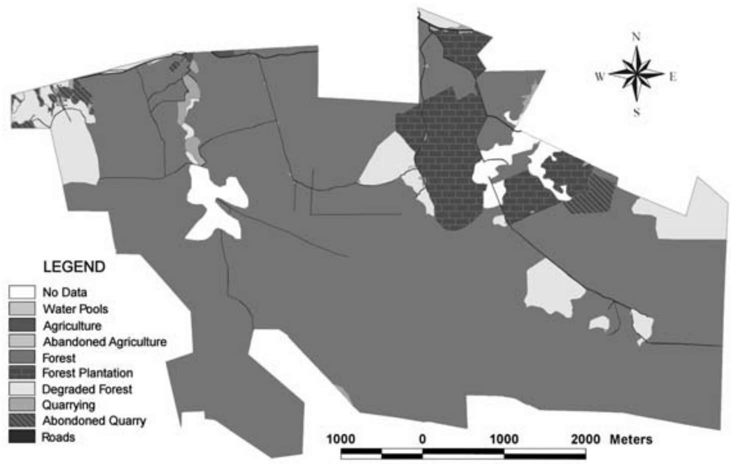

Figure 4. Land Use Categories in 1969

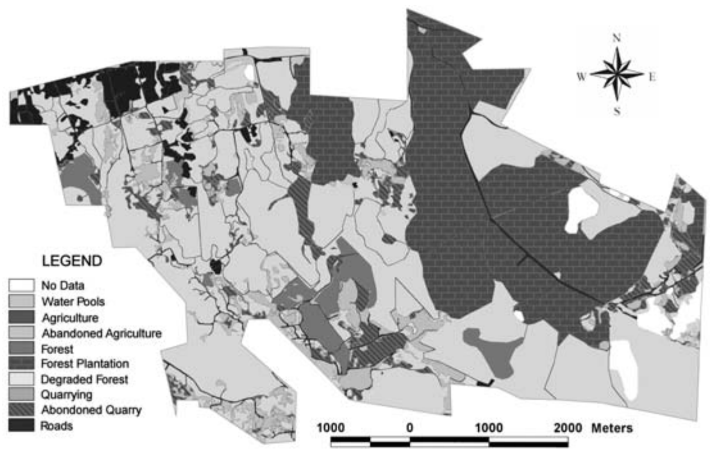

Figure 5: Land Use Categories in 1994

Agriculture was interpreted and identified when light areas with furrows and small rooftops from squatters were observed. Abandoned agricultural areas were observed to be areas that were slightly darker than the agricultural areas, and were positioned closely to squatters and present agriculture. More vegetation was present in the abandoned agricultural areas since they were darker in colour.

Quarries were observed to be a bright, white, outstanding areas within the photographs, with small rooftops in the middle or on the outskirts, considered to be temporary buildings associated with the operation. Abandoned quarries were identified as areas that were mainly close to presently operating quarries and were much lighter in colour than the present quarries, as they possessed small shrubs and growing vegetation. Pools within quarries were very few, but were identified as dark, circular regions within the bright, white, quarried areas.

Roads were characterized as white, long, and narrow linear features within the photographs. The identification of some of the roads in the 1:25,000 topographic map for the area assisted in the classification process. Areas of no data were seen as bright, white clouds on the photograph that prevented the interpretation of land uses below.

Boundaries of each classified area were then digitized on screen using IDRISI 32, and the area was assigned the relevant identification number and colour for later analysis. These finding were then validated through ground truthing. Visits were made to the Valencia wildlife sanctuary and forest reserve to ensure that the interpretations of the land uses and digitizing were accurate. Roads, both paved and unpaved connected to and moving south of the Valencia–Melajo Road, such as Tatoo and Tapana Roads were used as means of access into the reserve. From these roads, at every 1 km interval, the vegetation or land use seen on the right and left-hand sides of the roads was recorded.

Using this information any inaccurate digitizing or interpretations would be corrected using the IDRISI software. For this study, the field visits confirmed the land use classification except for one incident, in which some areas that were considered natural forests in 1994 due to the dark tone were later identified as pine plantation during the field visit. This coincided with the classification of these areas as pine plantation in the 1969 aerial photographs. Figures 4 and 5 present the land use categories for 1969 and 1994 respectively.

Table 2. Area for each Land Use Category in 1969, 1994 and changes

Land Use Classification	1969		1994		Change
	ha	%	ha	%	ha
Natural forest	2251.31	80.4	109.88	4.0	-2141.43
Fragmented/degraded forest	204.86	7.3	1352.29	49.1	+1147.43
Forest plantation	184.79	6.6	669.33	24.3	+484.54
Agriculture	2.81	0.1	92.99	3.4	+90.18
Abandoned agriculture	0.00	0.0	20.96	0.8	+20.96
Quarries	40.04	1.4	203.36	7.4	+163.32
Abandoned quarries	13.50	0.5	168.49	6.1	+154.99
Transport network (roads)	17.60	0.6	69.56	2.5	+51.96
Pools within quarries	0.00	0.0	4.58	0.2	+4.58
Unavailable data	83.65	3.0	62.77	2.3	-20.88

4. Results And Analysis Of Land Use Changes

The areas of all land use categories in both epochs were extracted. The change in land use was calculated by subtracting the areas of land uses in 1969 from those of 1994. The result is presented in Table 2. In the Table, areas of 83.65 and 62.77 hectares of land were unavailable to interpret in the aerial photographs 1969 and 1994 respectively, as they were covered by clouds and thus classified as unavailable data.

The major change that occurred in the Valencia was the drastic decrease of 2141.4 hectares of natural forest from 1969 to 1994. The majority of land in 1994 was no longer natural forest, as 95% of the original natural forest in 1969 was converted into degraded or fragmented forest.

The transportation network had spread throughout the entire forest by 1994, and had thus increased in number of roads as compared to 1969. Many roads were also seen to be connecting quarried areas in 1994, unlike in 1969. This was manifested by the quadrupled area of the roads from 17.60 hectares in 1969 to 69.56 hectares in 1994. As compared to other land uses, the impact of roads has been out of proportion to their area because they provide easy accessibility to the forest interior. This in turn, may have lead to further deforestation caused by anthropogenic activities such as squatting, agriculture and quarrying. In addition, roads fragment the remaining natural forests, preventing the dispersal of some species and disrupting both the ecological processes that occur within intact forests and the recovery of degraded forests.

Agriculture was concentrated on the northwestern portion within the forest in 1994 as compared to a much smaller amount of agricultural land in the north in 1969. Roads constructed for quarry operations may have provided accessibility to squatting populations within the Valencia forest allowing the expansion of agriculture from 0.1% of the total area in 1969 to 3.1% in 1994. Proximity to the population centre at Valencia village and public transport on the Eastern Main Road may also have been strong contributing factors.

Quarrying of sand and gravel occurs in the Valencia forest for the purpose of providing construction material and for the generation of economic revenue for the country. The increase of quarrying from 40.04 hectares in 1969 to 203.36 hectares in 1994 in the area also contributed to the drastic change in the area of natural forest. In fact, the actual increase in the percentage of the total area of quarries in the Valencia forest was not great (1.4% in 1969 to 7.4% in 1994). However, the creation of related infrastructure and the intensity of soil degradation make the effects of this activity far worse in terms of disruption to ecological processes and recovery of the natural ecosystems than forest fires or even agricultural practices.

The increase in forest plantations from 184.79 hectares in 1969 to 669.33 hectares in 1994 served to increase the area of forest vegetation within the Valencia forest, and thus compensated for the natural forest lost to other uses. Pine plantations may play an important role in reforestation for timber production within the Valencia forest. However, for other objectives such as conservation and hunting, the retention of degraded secondary forest should be the priority since these forests will eventually succeed to mature natural forest. Pine plantations therefore should not replace natural forest ecosystems as a management objective for the wildlife sanctuary.

Both abandoned agriculture and abandoned quarries resulted in an increase in natural vegetation throughout the Valencia forest in 1994. This is in contrast to 1969, when abandoned agriculture and quarries were located on the edges of the Valencia forest or close to roads. The natural re-vegetation process, from weeds to shrubs to native plants, will occur after agricultural and quarried lands are abandoned (Gelt, 1993). However the speed of recovery will be different for the different types of degradation. The re-growth of vegetation within these abandoned areas is useful for conservation purposes, and is imperative for further recovery of the natural forests in the Valencia forest.

Pools within quarried areas were not observed in the 1969 photographs but were clearly identified in the 1994 photos. Although pools are a potentially important new wetland habitat, the nature of the pools, and in particular, whether they are permanent or ephemeral was not distinguishable from the photographs. Ground truthing however revealed that some are indeed permanent and so create a new category of land uses in the Valencia forest.

5. Conclusion and Recommendations

The land within the Caribbean is used for a variety of reasons, many of which can lead to the degradation of the environment. Studies of land use change and the trends of this change over time are important in terms of future environmental management decisions to prevent further degradation. Aerial photography is a useful and important tool that aids in the study of land use change over time. This study used aerial photographs to establish trends in land use in the Valencia forest from 1969 to 1994. It was found that there was an increase in area for every land use category in the forest reserve except for natural forest, which showed a drastic decrease in land area.

The cause of this degradation is thought to be mainly due to a single catastrophic fire event in the second half of the 1980's that decimated much of the Valencia forest. The probability of the fire occurring and the intensity and extent of the damage to the natural forest from the fire event was probably exacerbated by changes in land use in the forest reserve such as quarrying and its related infrastructure. Increased human presence in tropical forest ecosystems and an ambivalent societal attitude towards environmental protection and conservation often leads to increased degradation due to fire. The increase in transport networks, agriculture, quarrying, as well as improper management, poor law enforcement, and lack of education and concern for wildlife, may all have contributed to the degradation of the natural forests within the forest reserve.

Consequently, one may suggest the following measures to improve the management of the forest and sustain its use.

Strengthening legislation. The existing legislation is inadequate to prevent excavation, forestry, squatting and other potentially environmentally harmful activities (CEP, 1996). The Reserve requires improved and stricter enforcement of forest protection legislation to decrease degradation and to eventually restore the vegetation within the area. This is particularly needed to safeguard the forest from direct human influences, specifically quarrying, slash and burn agriculture and road construction.

Public education. An awareness campaign should be conducted to sensitize the general population to the seriousness of the environmental degradation and forestry problems faced by the country. This may reduce the lack of concern for wildlife and the environment and may create a more positive and caring attitude towards nature and the environment, especially towards forest reserves and wildlife sanctuaries.

Zonation and buffer zones. The Valencia wildlife sanctuary and forest reserve could be zoned into areas where public access is strictly prohibited. For instance, abandoned quarries and abandoned agricultural areas within forest, as seen in Fig. 5 and Fig. 6, should be made inaccessible to the public. They should be left undisturbed to allow the vegetation to rejuvenate.

Apart from restricted zones, the Valencia wildlife sanctuary and forest reserve can be zoned into areas where eco-tourism can be encouraged. Tourists could enter these areas accompanied by a tour guide for purposes of bird watching, hiking, and simply enjoying nature. Zonation of this type could be quite advantageous to the Valencia forest and to the country itself as there could be positive benefits from tourism development and conservation of the forest in this protected area at the same time.

Relocation of squatters. Most squatters may be associated with some form of subsistence agriculture within the Valencia forest. Agriculture, usually in the form of slash and burn methods contributes to deforestation within the forest reserve. Squatters living within the reserve should be relocated to other areas outside of the forest reserve boundary.

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