LAND USE ANALYSIS OF EARTH UNIVERSITY PROPERTY IN COSTA RICA

FROM 1973 TO 2001 USING REMOTE SENSING DATA.

By

MARIO ANDRES GIRALDO

Under the direction of Fausto O. Sarmiento

ABSTRACT

This study reconstructs the land use history of EARTH university property in Costa Rica, from 1973 to 2001, producing land-cover maps based in the interpretation and classification of aerial photographs from 1973, 1981, 1992 and1998, and a Landsat ETM+ image from 2001. Also, a hierarchical Geographic Information System database of the administrative units of the property was developed, including information for different agriculture and pasture lots. Furthermore, change-detection analyses were performed identifying and quantifying areas conserved through the time, as well as those under active process of transformation. As a contribution for the long term administrative planning process of the property sub-units, individual updated maps were developed, integrated with the land use map for the whole property. Finally, suggestions about topics for consideration when performing agricultural decisions and practices in harmony with the natural ecosystem are stated.

INDEX WORDS: GIS, Remote Sensing Data, Agricultural Planning, Rural Landscape Classification, Costa Rica, Land Use, Land Cover, Natural Regeneration.

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CHAPTER 1

INTRODUCTION

EARTH: Agriculture School for the Humid Tropic Region

The "Escuela de Agricultura de la Region Tropical Humeda", for its Spanish name reduced to the acronym EARTH, has the leadership of innovation for agricultural education in Costa Rica and the humid tropics (Figure 1). Its important links with the government and its high reputation within the community reflect its academic relevance. After 10 years of dedication to the formation of new leadership in agriculture for the humid tropics its traditional approach in the planning processes will be subject to a deep review. Such a review is motivated by the potential collapse of its traditional planning system of land use, which was found to be insufficient to deal with the diversity of activities generated as a result of combined entrepreneurial views of the agrarian processes with the principles of sustainable development. This situation is enhanced with the complexity added by: (1) its academic view of "learning by doing", (2) its desire to respond to a complex human diversity (more than 16 countries are represented in its community), (3) the large size of the property, and (4) the need to make efficient resource management, integrating industrial processes and human settlements within the agrarian ecosystem (EARTH 1990).

Some activities performed at EARTH University property include: campus facilities with academic purposes, labs and classrooms, dorms for students, faculty, staff and guests; packing plant for bananas, a food processing factory and a banana paper factory; semi commercial plantations with academic and extension purpose, eco-tourism areas, conservation areas harboring a rich tropical forest remnant; commercial forest plantations, dairy facilities, high yield monoculture with commercial purposes (i.e. Oil palm, Banana, Pineapple and Passion fruit), watersheds and riparian vegetation. As an example figure 2, shows adjacent areas of different kinds of land use of the property as they are: Forest bordering mechanized monocultures and transition vegetation between pasture and forest.

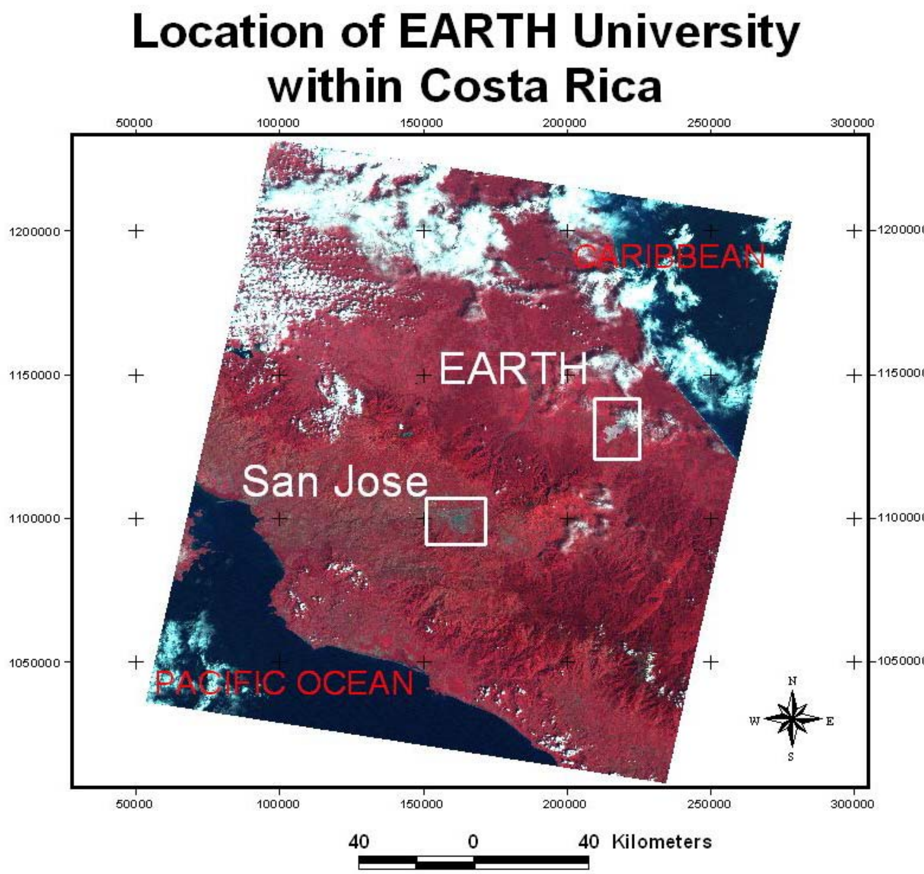


Figure 1. Geographic position of the EARTH University property within Costa Rica.

Figure 2: (A) Forest and monoculture. (B) Mixed vegetation

Rural Planning through GIS and RS

Land use is the common thread that runs through some of the most vital issues facing Central America's communities today. Concerns like economic growth, natural resources protection, and quality of life are directly affected when a poorly planned process of land use is performed. Local decision makers are then prime candidates to become beneficiaries of information derived from RS (Remote Sensing science) and other geospatial technologies, because of the critical importance of their work and because they deal with land use planning and regulation on a daily basis (Arnold 2000).

Needs of redesigning a multiple objective planning process which includes different dimensions of activities presently done at EARTH University property are considered, so that versatility and interactivity of a geographic information system data (GIS) base will provide the big picture of this system and its constitutive elements. Also it allows to support an efficient long term planning process helping managers to understand the complex forces present in the land use and land cover of the area. Therefore the first step toward the development of GIS infrastructure to support the planning process in the EARTH University property should be the land use study of the area and the comprehension of the natural elements involved within it.

Following those considerations, the combination of RS data with GIS has proved to be an extremely valuable tool with which agricultural decision-makers have been able to locate, assess, and manage natural resources and therefore planning its infrastructure. In this way, GIS and RS technologies support the decision making process through the correct interpretation of the local association between agriculture and natural resources, providing scientific elements for addressing strategies required for planning sustainable development, supplementing empirical knowledge and administrative decisions funded in the oral tradition (Aspinall 2002, Brooner 2000). As an example of them empirical tools figure 3 shows a draft map used in the daily administrative process at EARTH University.

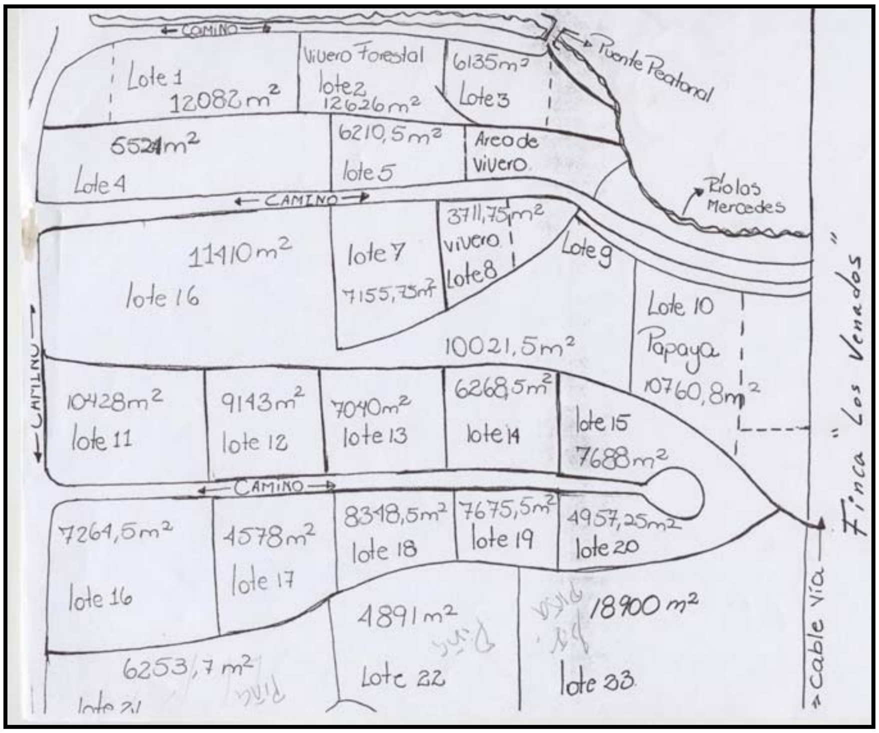


Figure 3. Hand made draft of the cropping areas for the administrative unit "Venados"

These technologies are an appropriate source to obtain critical scientific elements required to support daily planning process and to design the land use of agrarian communities. Geospatial technologies can provide the key information that allows local natural resource managers to place their case-by-case land use decisions within the broader context of the community and region to visualize alternative sustainable futures (Arnold 2000, Beltran and Belmonte2001, Runquist et al. 2001).

Land use and land cover studies using GIS and RS have showed their capabilities to deal with the complexities of the rural environment, where the decision maker not only deals with agrarian decisions but also incorporates into the analysis, some community and environmental elements. Then, GIS and RS offer under a single system the ability to integrate all variables and also to provide the infrastructure to subset the system into its individual elements, exploring their individual posibilities of development (Jensen 2000, Skop and Schou 1999, Williamson and Goes, 2001).

In this sense, the utility of GIS and RS techniques to support the planning process of rural areas has been well documented (Brooner 2002, Jensen 2000). For example, the work of Bugg et al. (2002) showed, through the review of the developments involved in data collection, database construction, and data management, how it is possible to develop multiple objectives planning establishing the potential of using large complex data set. Also Li and Yeh, (2001) offer a good example of the way that agricultural fields can be submitted to strategic zoning in areas exposed to rapid agricultural land loss using a GIS, RS and cellular automata analysis.

The GIS database is not limited in its applicabilities to the planning process. Multiple applications can be derived from the GIS database once its implementation achieves a mature state when all the sub systems make contributions to feed the system. For example, integration of GIS with automatic systems allow the development of practices of precision agriculture, where it is possible to make a rational use of system inputs decreasing the amount of man hours involved in routine process (Zhang and Taylor 2001). The prediction of the environmental costs associated with agricultural practices can be assessed through the integration of the GIS infrastructure with the accounting database (Skop and Schou 1999). Through the process of agro-ecological zoning, it is possible to increase the efficiency of the land use under commercial plantations and also increase the potential final yield (Caldiz et al. 2001). Through all these applications the farming process become a compact and integrated system where the assessment of the natural risk involved into the decisions of agricultural practices is now supported by scientific information that allow to make rational assumptions about the potential outputs applying techniques of ecological forecasting and modeling of hypothetical scenarios.

Remote Sensing data

The advantages of using Landsat images, images provided by the NASA satellites "Landsat" combined with aerial photographs (photos obtained by photographic platforms installed in airplanes), to understand the differential composition of the vegetation in large natural and agricultural areas have been pointed out for several studies: Brondizio et al. 1996, Ma et al. 2001, Pereira et al. 2002, Read et al. 1999, Wear and Bolstad 1998. In the humid tropical environment of Costa Rica for example, a time series of land cover information for the period from 1960 to 1996 was generated using a combination of Landsat Thematic Mapper (TM) and black and white aerial photographs. In this study the classification scheme showed to be useful to clear differentiation among the final five categories: pasture, crops, forest, scrub and urban (Read et al. 1999).

Also, land cover maps used for change detection analyses were produced for tidal floodplains of the State of Amapa, Brazil, using interpretation of aerial photographs of 1970 and digital image classification of Landsat TM 5 from 1990. With those techniques and data sources it was possible to detect changes in the study site, perceiving increases in the area extent of secondary growth and decreases in natural forest.

Aerial photography has long been established as a tool for land cover and land use mapping, for vegetation classification, and for monitoring spatial and temporal changes. High resolution and the ability to schedule flights that minimize low cloud cover are some of its advantages over other sources of remotely sensed data. Also, when the study is limited to small areas, the small surface covered is another advantage by avoiding to purchase and then subset large data sources. A widely used method of obtaining area representation from aerial photography is to analyze the image using a digital image processing system where the 9 X 9 in. image is scanned and then area calculation is performed. In this process, a geometrical rectification to a map base of the image is required in order to correct for topographic relief displacement and distortions caused by the camera atitude variations, placing all the images of objects in the correct planimetric position (Jensen 2000).

Once the aerial photograph has been rectified to the map base, it is a straightforward task to utilize the system software and the cursor to create a polygon around the area of interest. This on-screen digitalization, generates polygons as well as attribute tables including valuable information about the polygon measures such as perimeter and area, which allows the user to make calculations and to obtain total values for all the polygons sharing the same spatial characteristic (Jensen 2000,Warren 1997).

The importance of digital remotely sensed imagery such as Landsat Multispectral Scanner (MSS) and TM for the analysis of the components of the natural or agrarian ecosystem is based in different patterns of reflectance of the visible light by different kind of vegetation, soil and water bodies. The interaction of the light with leaf pigments produces different patterns of reflectance, which are affected by different physiological responses of the plant to environmental factors.

These patterns of reflectance are collected by the optical mechanical system sensitive to spectral bands in the electromagnetic spectrum. In this way the MSS system is sensitive to four different bands: green, red, and two versions of reflective infrared whereas the TM system is sensitive to: blue, green, red, reflective infrared, mid infrared and, thermal infrared. The blue band is useful in water analysis, the red band is one of the most important for vegetation discrimination, the reflective infrared allows study of the biomass present in the scene, and the mid infrared is related with the amount of water in the plant tissue. The Landsat 7 Enhanced Thematic Mapper plus (ETM+) bands 1-5 and 7 have 30 x 30m spatial resolution with the thermal infrared band No 6 with 60x60m resolution. It is also equipped with a 15x15 m resolution panchromatic band which increases its capabilities (Jensen 2000).

Landsat images provide an unprecedented ability to observe large geographic areas while viewing a single image, therefore, the high resolution of aerial photographs are complemented with the high discriminatory power of Landsat images increasing the single capabilities provided for each of those data sources individually.

CHAPTER 2

PURPOSE AND STUDY AREA

Objectives

The purpose of this study is to reconstruct almost 30 years of land use and land cover of the EARTH University property from 1973 to 2001 producing land cover maps based in the interpretation and classification of aerial photographs from 1973, 1981, 1992 and1998, and Landsat ETM + image from 2001 supported by field work performed in 2002 and 2003. Performing change detection analysis, the landscape fragmentation and land use of the property are identified and quantified with the purpose of generating suitable explanations for those changes.

Those analyses consider the impact in the ecosystem of EARTH University campus since appearing within the landscape in 1992, as a land use transformation agent with the purpose of generate recommendations supported by the land use change analysis for the long-term planning process of the property under the philosophy of sustainable development. As a final contribution the geographic database created through this project could support the development of a land use master plan of the EARTH University property for the next 10 years.

In this context, the output database is expected to include not only and update distribution of the land use categories within the property, but also a thematic map of the administrative subunits distinguishing between each one of the different cropping and pasture areas. This hierarchical idea of the data base supported by the power of the GIS system attempt to provide the different administrative regents and decisions-makers within EARTH University property, not only with an integrated geographical tool depicting the units but also with the spatial distribution of the sub-units under their responsibility with the aim of be used in the long term decision making process with daily implementation.

Study Area

The study examines the property of EARTH University located at 10 ^{0} 11' to 10 ^{0} 15' North latitude and 83^{0} 40' to 83^{0} 55' West longitude, in the Atlantic costal plain of Costa Rica, approximately 70 km East of San Jose, the capital city of Costa Rica, and 100 km West of the Caribbean shoreline. The land holdings of EARTH equal 3300 ha (approximately 7312 acres), centered within the Caribbean flat lands of Costa Rica in a life zone of the Wet Tropical Forest (Figure 1.). This area is a continuation of the Nicaragua basin formed by alluvial and marine deposits and limited by the Caribbean Sea and the Talamanca cordillera. This area is also characterized by infrequent small hills arising less than 10 meters above the plain (EARTH 1990, Sancho et al. 1989).

The average annual temperature is 24.9 ^{0}C with lest than 2 ^{0}C of variation between the coldest and warmest months. Annual rainfall exceeds 2500 mm distributed throughout the year with a dry period from January through April (EARTH 1990). The rivers "Destierro", "Parismina" and "Dos novillos", flowing in direction North East originate in a large watershed in the slopes of the Turrialba volcano and the Talamanca cordillera define the borders of the property. The low elevation and its characteristics of drainage basin make the property a floodplain exposed to regular flooding events affecting localized areas, mainly the central portion of the farm, which is drained by small gullies that occasionally become swampy areas.

The area has a long tradition of agricultural and livestock activities with an unequal distribution between pasture, agriculture and forest reserves. Bananas have been the main product cropped in large plantations under monoculture system. An important urban area, Pocora, is located in the southern border of the property and shares with the EARTH University community their dependence for the clear water provided mainly by the Dos Novillos River. This community is an important source of the labor required in the agrarian and post harvest activities of the farm (EARTH 1990).

CHAPTER 3

METHODS

Field data collection

On June 2002 a field trip was made for acquisition of the data sets: maps and aerial photographs from the geographic institutes of Costa Rica as well as from private and public agencies such as the National Institute of Biodiversity (InBio), Universidad de Costa Rica (UCR), Center for Tropical Agriculture (CATIE), Organization for Tropical Studies (OTS) in “La selva” biological station, and National Geographical Institute (IGN). A field reconnaissance of the study area was made to obtain data for training in the classification process (Russo 2002), and to meet with local inhabitants to generate a first description of the area and to obtain ground control points using a global positioning system receiver (GPS).

On May 2003 a second field trip to the study area was made with the purpose of perform a ground truthing exercise to assess the accuracy of the interpretation of the aerial photographs and to obtain detailed information concerning the lots distribution within the cropping parcels, to be included into the database as a second level of information.

Data Acquisition and preprocessing

Black and white aerial photographs for the study area were purchased from the National Geographical Institute of Costa Rica for the years 1973, 1981, 1992, and 1998. The year 1973 required three consecutive photos to include the study area.

The aerial photographs were scanned at 600 DPI using an Epson flatbed scanner with the software "Expression 863 XLT". Some explorative adjustments were performed to reduce the opacity of some features present in some of the photos until a satisfactory image of the study area was obtained (Verbyla 1997). The 1992 photo is the first registered using a 1:50000 scale topographic map of the study area from 1990 as source for ground control points (GCPs). The map corresponds with the hoja Guacimo No 3545 I, from the National Geographic Institute of Costa Rica. The geometrical correction of the images was performed in ERDAS Imagine 8.5 within the Lambert Conical Projection, which is the current standard for Costa Rica, using the following parameters:

Datum: Clarke 1866
Spheroid: Clarke 1866
First standard parallel: 9^{0} 56' 0.0''
Second standard parallel: 11^{0} 0' 0.0''
Central meridian: -84^{0} 20' 0.0''
Latitude of projection's origin: 10^{0} 28' 0.0''
False easting (meters): 500000.00
False northing (meters): 271820.522

After geometrical correction of the 1992 image, it was used to register the other images selecting not less than twenty GCPs surrounding the study area. At least four of them were selected as close as possible to each one of the corners of the photo in order to maximize the likelihood of a good match. The images were then warped using a linear transformation, nearest neighborhood intensity interpolation and a pixel re-sampling size of 1 m (ERDAS 1995, Frazier and Page 2000).

Some of the images required multiple geometrical corrections to reduce the values for Root Mean Square Error (RMSE), increasing the number of ground control points, emphasizing their fitness with the study area. The resulting images have an approximate ground pixel size from 1.05 to 2.54 m (Table 1).

Table 1. Scale, pixel size and Root mean square error for the aerial photographs after the preprocessing process.

Date of the photo	Scale	Ground pixel size	Root mean square error RMSE
January 20th 1973	1:25000	1.05	3.27
March 17th 1981	1:35000	1.48	4.12
February 3rd 1992	1:60000	2.54	3.28
March 3rd 1998	1:40000	1.69	2.06

The three different photos for the year 1973 were joined into a mosaic of a single image following the registration of the individual images. Finally the resulting image was compared with the others to assure matching (ERDAS 1995). The boundary of the property was then digitalized using as a reference, the aerial photo of 1998, the accuracy of this work was discussed with the administrators of EARTH University and after their approval the benchmarks defined for this photo were further used to defined the borders in the remaining images.

Polygons of the aerial photographs were then digitized directly onto the scanned, registered aerial photograph using the ESRI ArcView 3.2 Software, and then annotated with attribute information corresponding to the 10 land use classes: bamboo (*Bambusa guadua* L.), banana (*Mussa balbissiana* L), crops (mixed of annual and perennial), campus, floodplain, forest, grass, mixed, riparian, and road. Area statistics as well as perimeter statistics were calculated for each polygon and land use maps were then prepared for each date studied. With the purpose of comparison those polygons were further converted into raster format (Jensen 2000, Frazier and Page 2000).

A brief description of the categories and the acronyms used are presented in the table 2, also an example for each one are presented in figures 4, 5 and 6. The broad category Riparian could also be considered as a kind of forested woodland and because of that, included within the forest category; however, considering the specific function that those forest relicts offer to the landscape, stabilizing the water flow within the stream and serving as a biological corridor in the landscape, this study considered to keep both of them as independent categories. The category Mixed, considered those buffer areas in an intermediate stage between grassland or pastures and a forest. This category groups those forested areas that have been exposed to high levels of intervention, but later were recovered as a secondary forest. Also it includes those pasture areas abandoned long time ago where a high density of trees and companion vegetation are now present and already starting a process of transformation into a forest.

The category Banana (BN), was created as an independent category based in the long term tradition of cultivation in the Caribbean region of Costa Rica as mono crop, also because its particular demands of agrochemical inputs and its important weight into the economy of the region. The Bamboo ("Bambu" in Spanish), *Bambusa guadua* L. (BB) has been considered in Costa Rica as a particular kind of crop because of the significant commercial value that single pieces of this material have within the construction market, and also its trade as a fence post and firewood. Moreover, considering its particular distribution within the landscape Bamboo also has an ecological function as refugee for wildlife and water sources protection which also support the decision of being an independent category.

Finally, the category crop was created gathering all the individual activities of cultivation present within the property. Although it is a consolidated category, the database include attribute information for different cultivated species identified during the ground truthing exercise. These crops include: Platano (*Mussa acuminata* L), Guanabana (*Annona muricata* L.), Naranjas (*Citru*s spp.), Palmito *(Chamerops humilis*), Guayava (*Psidium guajava* L.), Pepper (*Pipper nigrus* L.), Yuca (*Manihote sculentum* L), Achiote (*Bixa orellana* L.), Maracuya (*Passiflora* spp.), Papaya (*Carica papaya* L.), Oil palm (*Elaesis guineensis*), Sugar cane (*Saccarum* spp.), Cacao (*Teobroma cacao* L), Tabaco (*Nicotiana tabaco* L.), Frijol (*Phaseolus vulgaris* L.), Maiz (*Zea mais* L.).

Table 2. Classes and criteria followed for labeling the polygons in the classification.

Acronyms	**Land use Classes**	**Description**
BB	Bambu	Areas showing Bamboo in pure stands
BN	Banana	Areas with banana as mono crop, including areas within the limits of the transporting cables.
CS	Campus	Construction or facility within the property and its adjacent transportation areas, includes: office buildings, classrooms, residencies, dormitories, processing plants, dairy facilities, stores and factories, among others.
CP	Crop	Areas under active cropping activity, others than banana, including different cropping systems as mono or poly crops with either annuals or perennials species.
FP	Floodplain	Areas appearing as affected by recent flooding process.
FR	Forest	Areas under tree vegetation showing a closed canopy. They can be either planted or naturally originated.
GR	Grass	Either pastures or grasslands showed clearly divided by fences, where scatter trees may be present.
MX	Mixed	Areas of savanna, originated as consequence either a forest clearing or an abandoned pasture.
RP	Riparian	Any dense vegetation surrounding and protecting a river or a stream.
RR	Road	Category where the main property road is present.

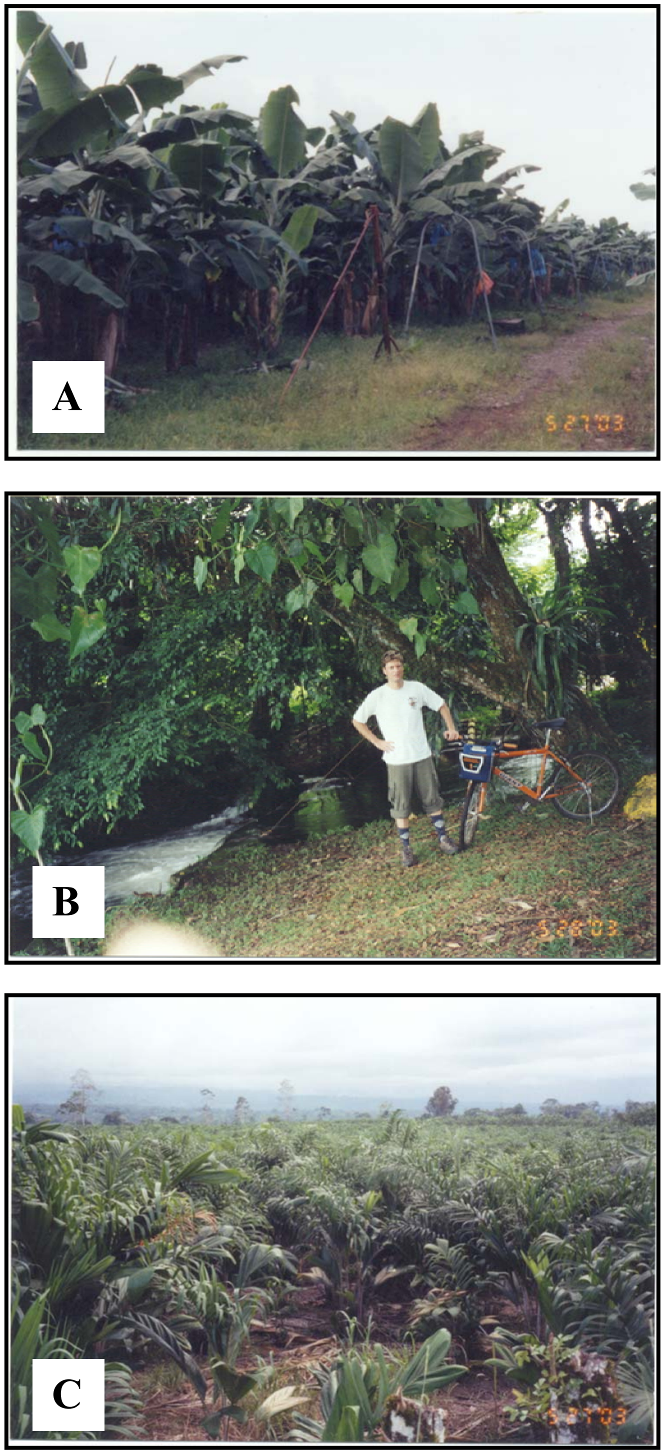


Figure 4: Categories of land use: (A) Banana plantation BN, (B)Riparian Vegetation RP, (C) Palmito plantation CP.

Figure 5: Categories of land use: (A)Grass GR, (B)Forest FR, (C)Bamboo BB.

Figure 6: Categories of land use: (A) Mixed MX, (B) Campus CS.

Landsat imagery acquisition and classification

A Landsat data file radiometrically and geometrically corrected was obtained from the U.S. Geological Survey (USGS) in standard National Land Archive Processing System Data Format (NDF). Subsets of the Landsat ETM+ for June 15th 2001, covering the study area were created drawing in them the boundaries of the EARTH University property as area of interest (AOI). However, with the purpose of obtaining a better discrimination of the rivers, the flood plains and water bodies the AOI was extended from the borders of the property to include the riverbanks and the riparian vegetation.

This subset was used to perform supervised and unsupervised classification with 15 starting classes, which were then clustered into a final number of 10 classes to match the categories analyzed in the aerial photographs. Well known sections of the property, supported also by information from locals were used as a source of signatures for the training areas in the supervised classification. With the purpose of comparing these data source with the vector polygons generated from aerial photographs on screen classification of the AOI was performed generating a vector file from the 2001 image. In order to incorporate this information within the GIS database, it was necessary to re-project data from the Universal Transverse Mercator (UTM) coordinate system to the Lambert Conformal coordinate system mentioned previously as the selected projection for this study.

Finally, an assessment of the accuracy of this classification was performed visiting 40 different points of the property during the ground truthing exercise in May 2003, comparing the land use observed in the ground for each area with that obtained from the classification, and also correcting the polygons boundaries where it was required.

Change detection analysis

Change detection analysis is a technique which performs a comparison between land cover classifications from different dates. In this study the post classification approach is used, comparing images and aerial photographs from different dates previously classified independently. The land cover maps generated from the aerial photographs were overlaid within the ARCView 3.2 environment and the command UNION from the geoprocessing wizard was used to perform the change detection. The results were summarized to prepare histograms as well as contingency tables in which the columns and rows represent each one of the different periods for which information was obtained.

Contingency tables were prepared comparing data from the years previous to the creation of the EARTH University campus with data from years after the creation of the University, also generating maps to elucidate the contrast between areas exposed to active transformation with areas remaining under the same land use. Finally with the purpose of achieving a better understanding of the data, the different interactions between the seven categories were clustered within six summary categories attending the interest of this study in the interaction between agriculture, livestock and natural forest. In this context the categories are arbitrarily created and because of that, the database has the potential to explore in the future new and diverse research questions, grouping the categories in new subsets of specific interactions, to allow perhaps the exploration in more detail the phenomena and its interaction stated through this work. Table 3 presents the summary categories, their definitions and the interactions that they clustered.

Table 3. Summary categories for the interactions formed by the contingency tables.

Summary category	Definition	Categories of Land use changes
Stable	Where the Land use remain the same	FR-FR, RP-RP, CP-CP, GR-GR, MX-MX, RP-RP
Crop lost	Cropping area changed to another land use	CP-FR, CP-CS, CP-GR, CP-RR, BN-GR, BN-CS
Transition crop	Land use transformed into cropping area or in a different if already crop	BB-BN, BB-CP, BN-CP, CP-BB, CP-BN, CS-CP, FP-BB, FP-BN, GR-BB,GR-BN, GR-CP,
Forest lost	Forest areas, or in transition to forest areas changed to another land use	FR-BB, FR-BN, FR-CP, FR-CS, FR-GR, FR-RR, MX-BN, MX-CP, MX-CS, MX-GR, RP-BN- RP-CS, RP-GR, RP-CP
Transition Forest	Other land use transformed into Forest area	BB-FR, BN-FR, BN-RP, CP-FR,CP-RP,CS-FR, CS-RP, FP-FR, FR-RP, GR-FR, GR-MX, GR-RP, MX-RP, MX-FR
Others	Other possible land use changes	CS-GR, CS-RR, GR-CS, GR-RR

The use of the word "Crop" in the summary table 3 has a different connotation that the same word used within the table of categories (Table 2). Its use here at the summary table is grouping all those activities related with cultivation and then, exposed to agricultural management. Because of that, Banana (BN), Bamboo (BB) and Crop (CP) are together in this category within the summary table of interactions.

The criteria followed to label some categories as: Crop Lost and Forest Lost, was based on the concept that those areas have changed their use permanently to certain use that might anticipate its continuation for long period of time. For instance, areas changing their uses through important investments in infrastructure such as: Road, Campus, or Banana. On the other hand, the label Transition in Table 3 implies that such area has changed its original use toward other but is always possible to return to its original use. That is the case of Banana areas turned into a cropping area (BN-CP), also flood areas recovered for cultivation purpose (FP-CP).

In the particular case of Transition forest, it includes interactions that are not mature enough and require more time in order to be defined within the permanent category Forest (FR). Examples of these circumstances are the transitions between cultivated areas and Riparian vegetation (CP-RP) and abandoned pastures and forest (MX-FR) where always exist the possibility of backed up administrative decisions and return to their original use.

CHAPTER 4

RESULTS

Accuracy assessment

The results for the assessment of the accuracy for the land use classification for the 2001 image showed 92.5% of accuracy when the land use observed for 40 different points on the ground during the ground truthing exercise of May 2003 was compared with that obtained for the image classification. The results of this assessment showed that the following three different areas were misclassified: A patch of forest classified as Mixed, a patch of crop (Palmito) classified as grass, and a patch of forest classified as floodplain. In order to increase the reliability of the database, the classified images for the remaining years were overlaid to corresponding aerial photos used as back ground**,** discussing its classification with local habitants with more than 15 years of residency in the area. This exercise showed that the photo interpretation was in concordance with the local knowledge of the area which contributed to establish accurate polygons boundaries where it was required.

Land use composition

Individual maps displaying the land use cover composition within the EARTH University property are showen in the figure 7, for 1973, figure 8, for 1981, figure 9 for 1992, figure 10 for 1998 and figure 11 for 2001.

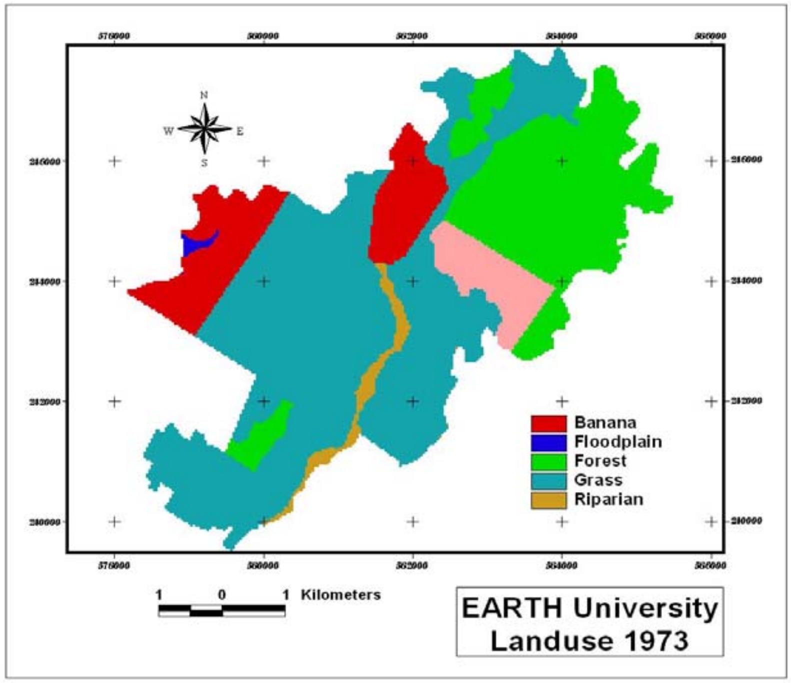


Figure 7. Land use cover for the EARTH University property: 1973

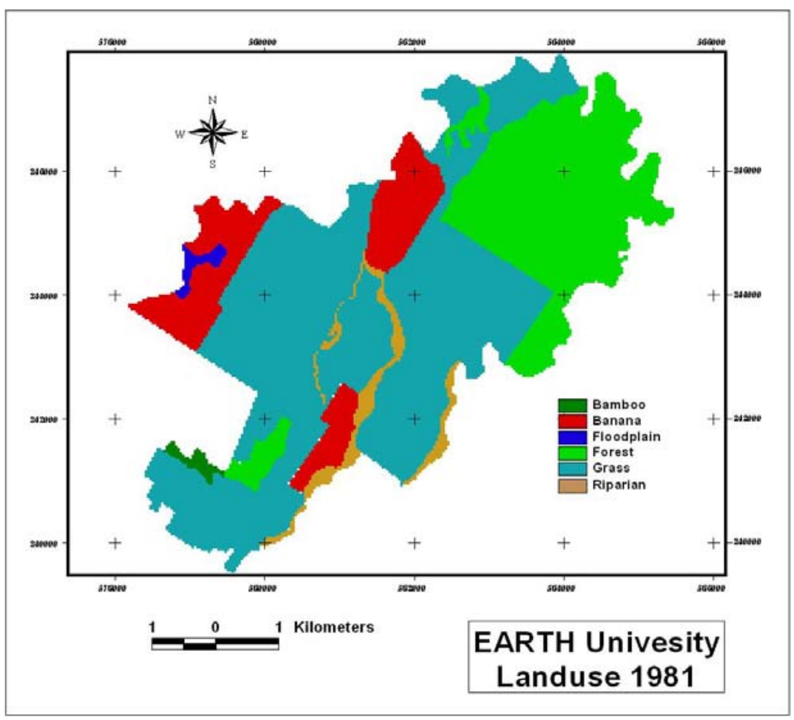


Figure 8. Land use cover for the EARTH University property: 1981

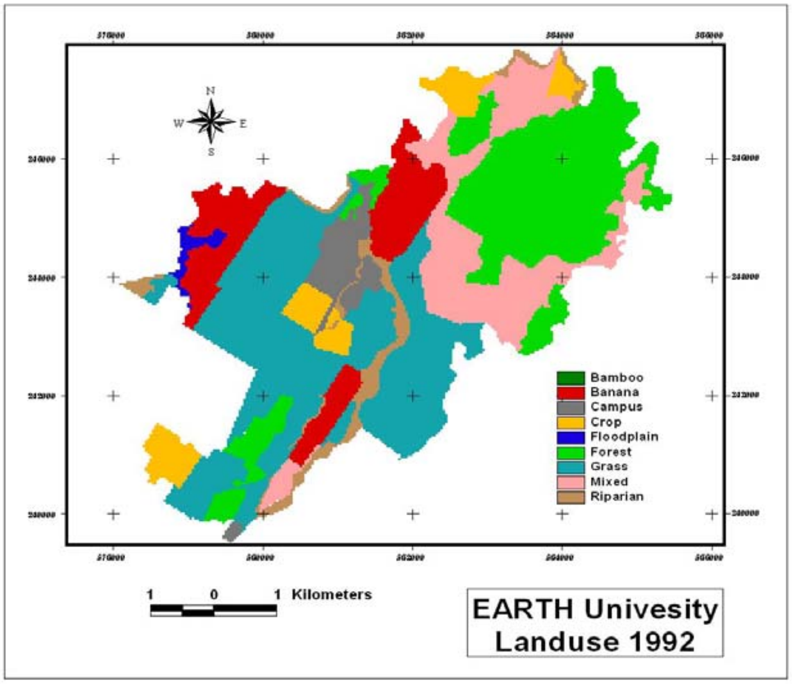


Figure 9. Land use cover for the EARTH University property: 1992

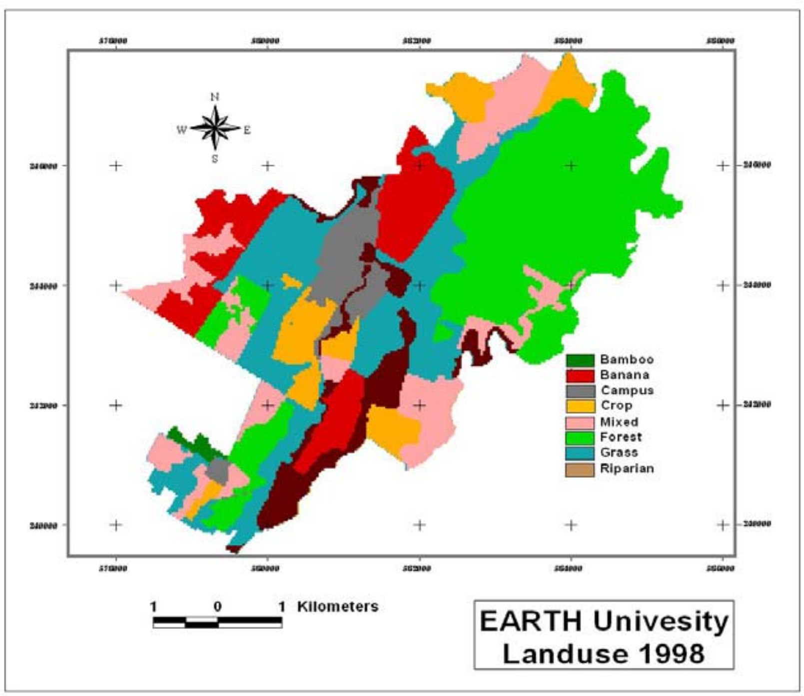


Figure 10. Land use cover for the EARTH University property: 1998.

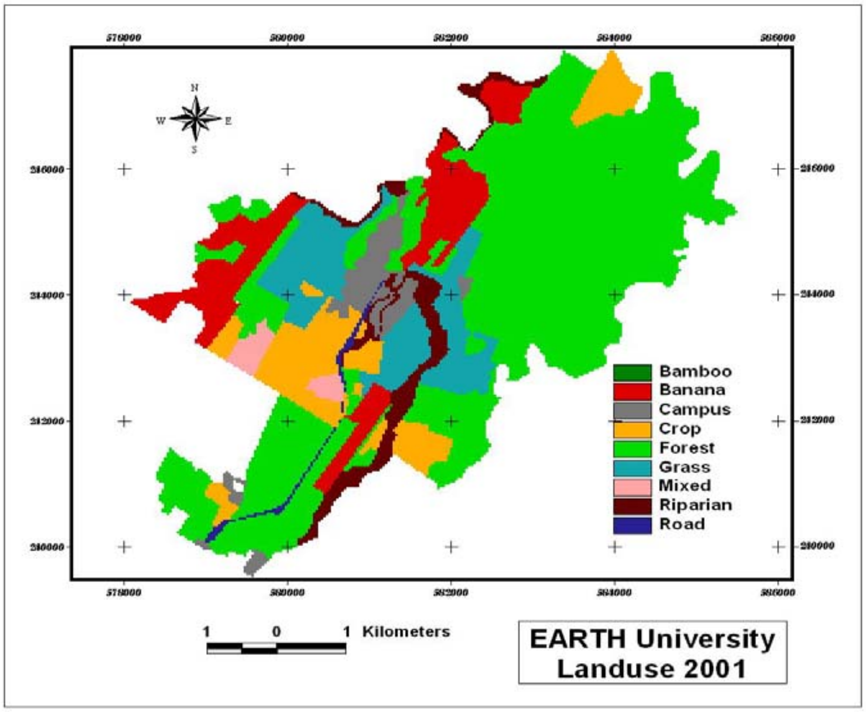


Figure 11. Land use cover for the EARTH University property: 2001

The calculated area for the EARTH University property found through this study is ranges between 3286.3 ha from the interpretation of the aerial photo of 1973 and 3327 ha., from the interpretation of the aerial photo of 1998. These values are in correspondence with the figure of 3300 Ha considered in EARTH University documents (EARTH 1990, Sancho et al. 1989). Besides the closeness of these values, the borders of the property are affected by the displacement of the rivers that are used as boundary lines producing small changes through time in the absolute value for some of the plots. This phenomenon is compensated later when the river returned to its original bed. Table 4 is a summary of the area distribution among categories for the five periods considered in this study.

Table 4. Area distribution in Hectares for category in each year of the study.

Category	1973	1981	1992	1998	2001
Bambu – BB		20.5	43.1	58.5	46.3
Banana – BN	410.7	441.7	377.1	356.7	372.0
Campus – CS			135.7	171.1	137.5
Crop – CP			183.2	281.8	330.00
Floodplain – FP	9.4	18.4	23.9		
Forest – FR	848.6	890.6	838.6	1069.0	1855.7
Grass – GR	1763.1	1811.1	1022.5	674.9	345.7
Mixed – MX	173.6		516.5	470.5	48.2
Riparian – RP	88.1	112.7	145.6	244.7	163.5
Road – RR					24.6
Total area studied	**3293.5**	**3295**	**3286.3**	**3327**	**3323.5**

Although the land use was classified within ten categories; only four of them: BN, GR, FR and RP, were consistent through the five periods considered. They account for more than 72% of the land cover of the property for the year 1992, and 82% for the year 2001 which is very relevant considering that in these two years a total of nine categories (the highest number for a year) were presented. Also the importance of those categories are showed in the earliest period studied, 1973, when they accounted for more than 94% of the land cover of the study area.

Figure 12, shows the evolution of the classes through the 30 years included in this study. Examination of the data set indicates the period around 1992 as the starting point for some categories remaining until the present: BB, CS, and CP.

It is in the same period around 1992, when the land use classified as a FP disappears. It is also important to notice the absence of areas under the category MX of 1981, when an interesting gap is present until the period of 1992, when this category re-appears with its highest value of land use for the 30 years studied.

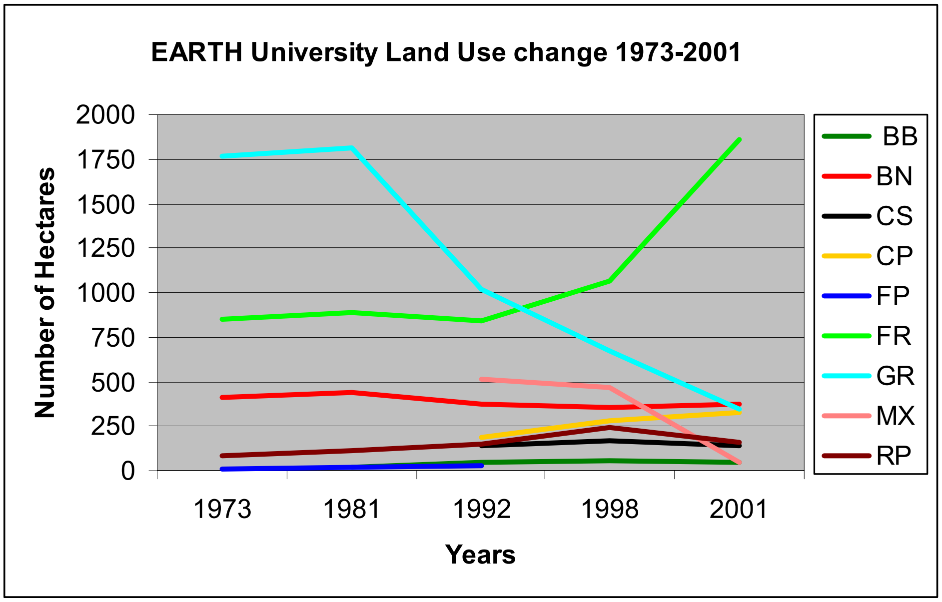


Figure 12. Changes in area for each category through the five periods considered in this study.

In fact from this point this category declined in area cover of the property until 2001 where it covered less than 10% of its original area back in 1992.

The class GR shows the second more highest values for the land cover of the property, achieving its peak in the period around 1981, and from then, presenting a continuous decline to become 19% of its highest covering. On the other hand, the category FR, presents opposite behavior, with the highest area values with more than 55% of the property around the year 2001, but only achieved after constant periods of increases starting in 1992. As a final observation, the category RP also showed constant increases since the year 1973 achieving its peak in 1998 when it covers three times its initial area.

A best understanding of the weight that each category has in land use of the property for each date examined in this study can be obtained analyzing the summary statistics depicted in histograms in figure 13 and figure 14.

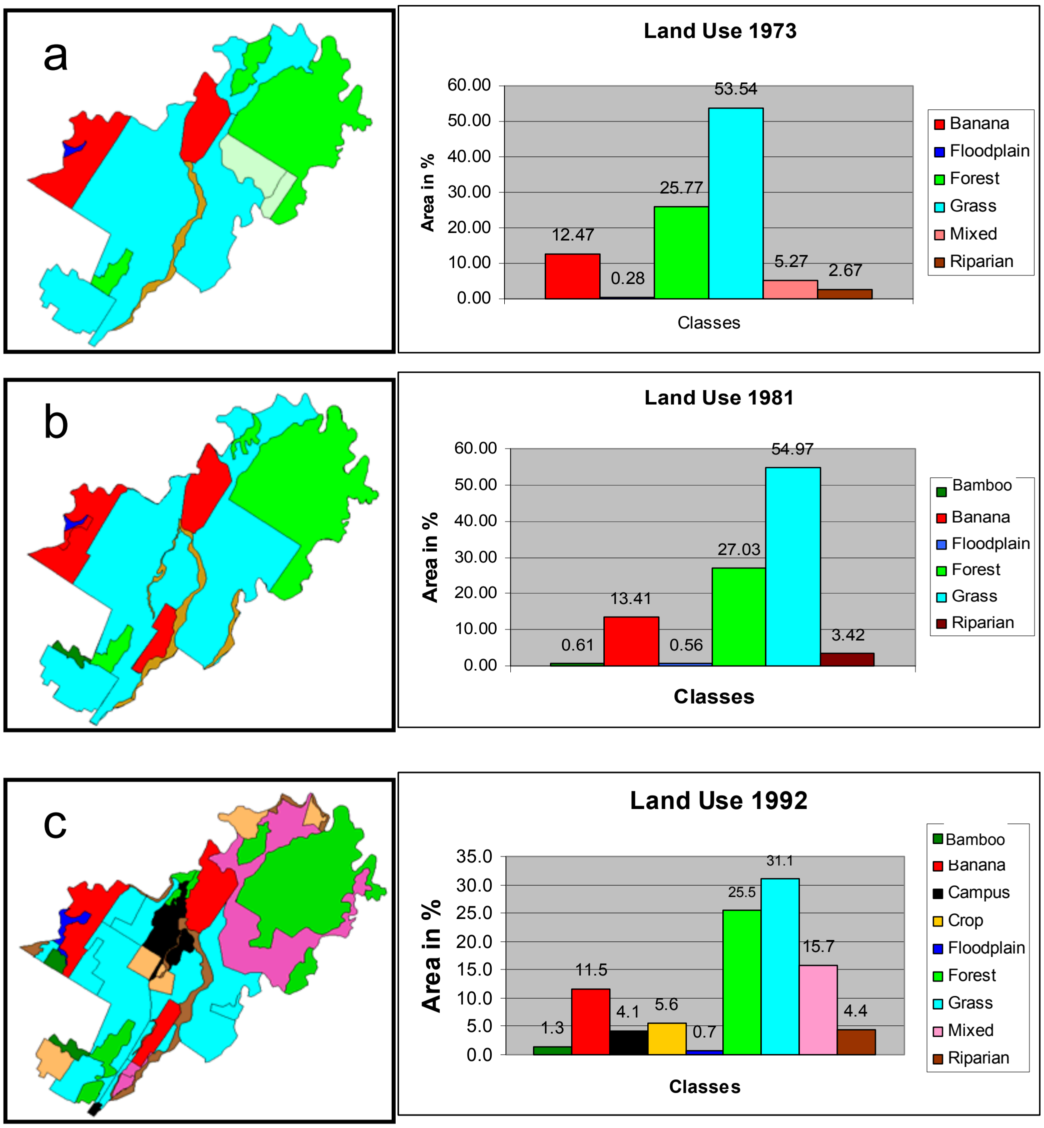


Figure 13. Distribution in percentage of the land use for the property EARTH for 1973 (a), 1981 (b) and 1992 (c).

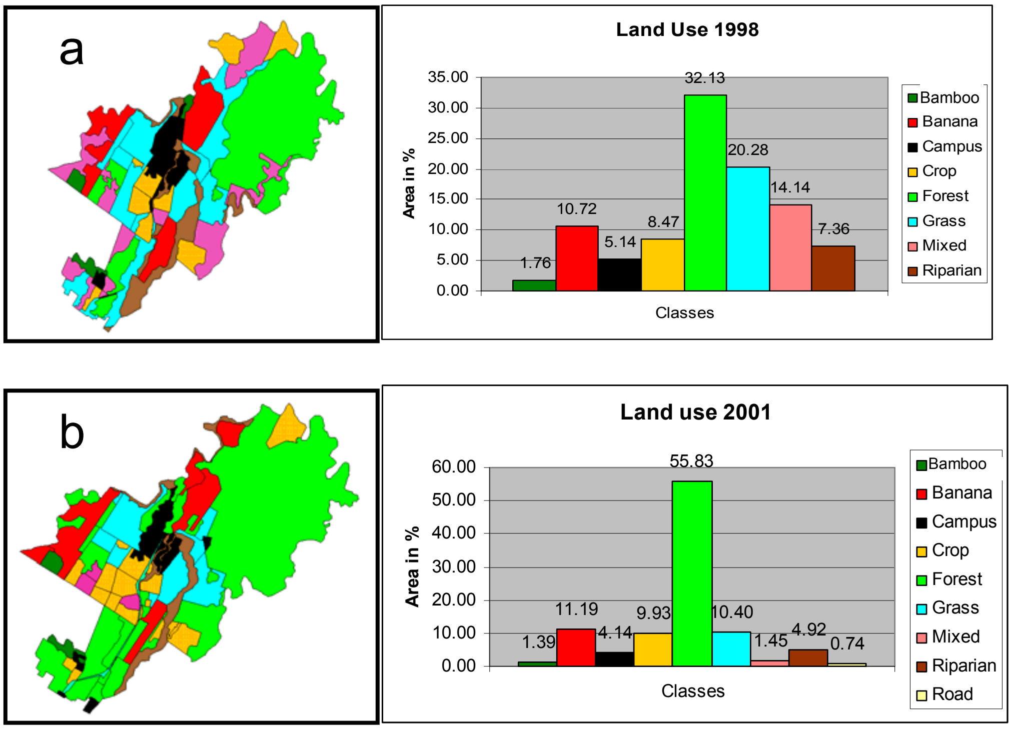


Figure 14. Distribution in percentage of the land use for the property EARTH for 1998 (a), 2001 (b).

The importance that GR had in the periods previous to 1992 is evident examining the dataset because it is accounting with more than 50% of the land covert of the property in 1973 and 1981, and more than 30% in 1992. On the other hand, it is FR the dominant category after 1992 accounting with more than 55% of the land cover in 2001. An interesting fact is the increase in the number of categories experimented in the land use of the property after 1992, when the raise of categories as, BB, CP and CS coincided with the important decreases of GR and the extinction of FP. The category BN has not experimented considerable variations in its overall participation of EARTH University land covers presenting values fluctuating between 10% and 14% in the 30 years studied here.

GIS analysis of land use changes related to 1992

EARTH University began academic activities around the year 1992 which is considered as an important moment for the transformations presented in the land use of the study area. Thus, using 1992 as reference point the following data are the results of performing through the GIS database analysis for the land use change of the study area.

Examining the information presented in table 5 the study area in general has suffered a major number of land use changes in the period posterior to 1992. In fact 58 changes were found, against the 30 accounted for the previous years.

Analyzing transformation among categories in both periods GR was the one showing the major number of hectares changed as well as the one being majority substituted by others in the land cover of the study area. However it is the period after 1992 when it lost the most of its participation in the land cover remaining in 2001 only around 330 hectares of the previous 990.

The category MX was mostly significant in the period posterior to 1992, when it showed a higher number of interactions than the observed in the previous period, being mainly transformed into FR. In the previous years the MX areas were mostly stables being affected only by apparently flooding events. BN showed to be exposed to processes of migrations around the study area which apparently have been more significant after 1992, where areas subjected to another land use were transformed into Banana plantations. However the overall participation in the land cover of the property has not been affected.

After 1992 CP and CS were the two more significant new land uses that the property experimented, sharing GR as a major contributor. The areas for CS are the ones apparently more stable among both, considering also, that its overall area has not changed and only 27% has been relocated.

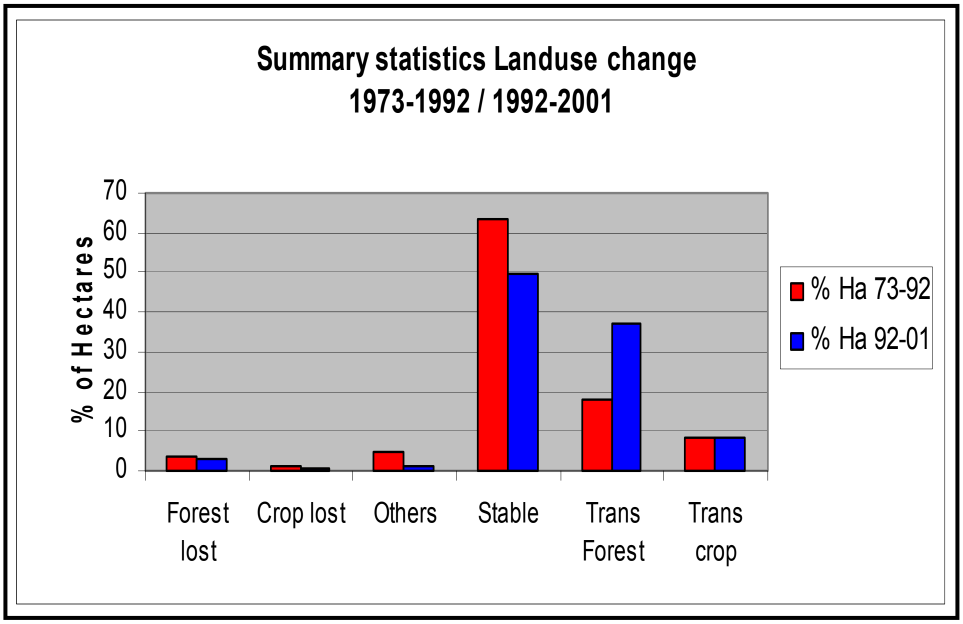
Table 5. Matrix of land use changes: (a). 1973-1992, (b). 1992-2001.

(a). Matrix of Land use Changes from 1973 to 1992										
1973/1992	**BB**	**BN**	**CP**	**CS**	**FP**	**FR**	**GR**	**MX**	**RP**	**TOTAL**
BN		**308.3**		0.1	15.0	3.5	42.0	10.0	10.1	**389.0**
FP		0.5			**8.9**					**9.3**
FR			11.6			**732.7**	2.7	99.7	3.3	**850.0**
GR	22.9	64.5	188.8	136.7		75.3	**990.3**	258.1	58.8	**1772.4**
MX					26.4			**146.7**		**173.1**
RP		1.9		0.3			4.0	1.7	**62.3**	**70.3**
TOTAL	**22.9**	**375.1**	**200.4**	**137.1**	**50.2**	**811.4**	**1039.0**	**516.3**	**134.6**	**3264.1**

(b). Matrix of Land use Changes from 1992 to 2001										
1992\2001	**BB**	**BN**	**CP**	**CS**	**FR**	**GR**	**MX**	**RP**	**RR**	**TOTAL**
BB	**38.2**	1.9	0.1	2.2	0.4					**42.8**
BN		**284.3**	6.3		71.2	6.1		9.9		**377.8**
CP	1.6	34.7	**74.6**	5.3	57.3	5.3		20.7	3.3	**202.8**
CS			2.9	**101.5**	15.3	3.4		10.8	3.3	**137.1**
FP	0.8	13.5			12.4					**26.8**
FR	0.2	1.1		0.5	**823.5**	0.2		6.8	3.0	**835.3**
GR	5.4	16.5	202.5	16.6	388.3	**323.0**	48.1	23.8	15.0	**1039.0**
MX		6.2	31.7	4.8	456.3	8.9		8.1		**516.0**
RP		13.2	11.5	3.9	25.6	5.1		**81.6**		**140.9**
TOTAL	**46.2**	**371.3**	**329.6**	**134.8**	**1850.3**	**351.9**	**48.1**	**161.7**	**24.6**	**3318.6**

On the other hand CP has suffered major transformation not only increasing its area from the one held previously to 1992, but also because after 1992 more than 77.5% had been relocated through the study area. FP was mostly relevant as a kind of cover in the period after 1992. However they were posterior replaced principally by BN and FR. Interesting is the transformation of the RP, increasing 57% of the area that previously held after 1992 besides of its contributions with others categories in the same period. The consolidation of a major road inside the property occurred after 1992, being more than 24 hectares directly under its influence.

The histograms of figure 15 present summary statistics for the land use cover applying the categories described in table 3 grouping the interaction of the contingency tables.



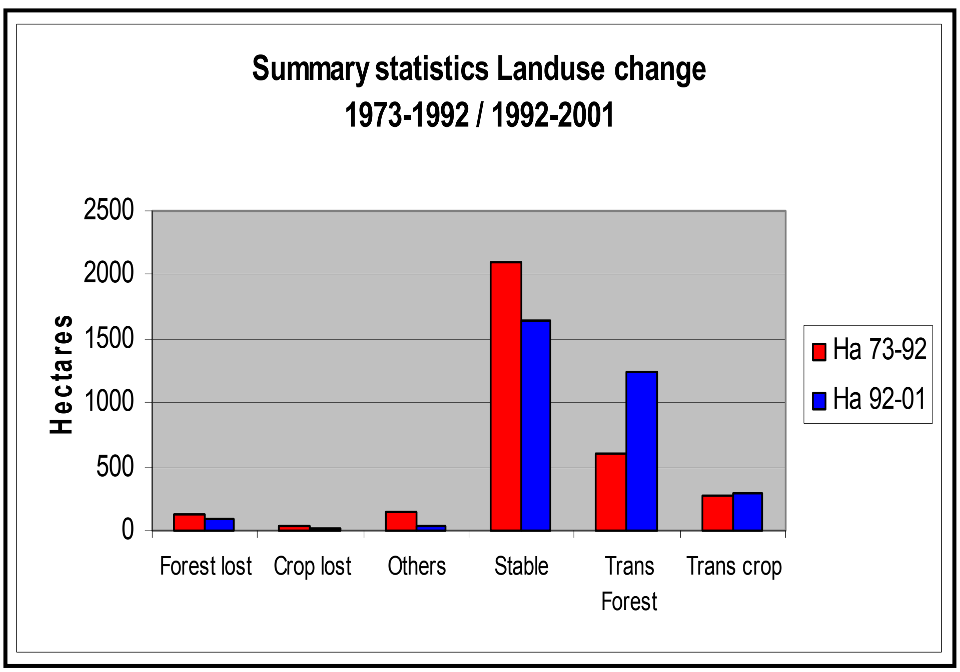
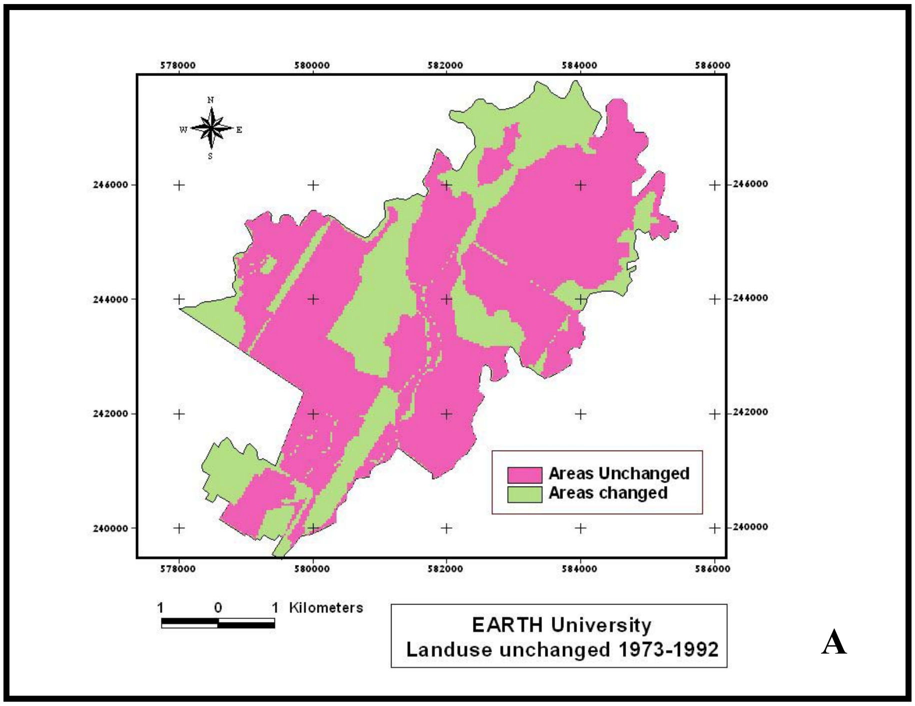


Figure 15. Summary statistics for land use changes for the periods before and after 1992.

Based on the results presented in figure 15, the period before 1992 has the most stability in the process of landscape transformation. In fact, during this period more than 2100 hectares (63% of the study area) conserved their original land use, in contrast with 1645 hectares (more than 49%) for the period posterior to 1992.

Analyzing the changes to the land use of the study area, most of them occur in the interactions grouped as Transition to Forest, and in the period posterior to 1992. In this period this category increased in more than 600 hectares over the previous 593 hectares found before 1992. On the other hand, the categories grouped as transition to crop have remained around the same figure of 280 hectares for both periods accounting for 8% of the cover of the study area. The categories with less contribution to the overall change of the land cover of the study area are those grouped as Lost Crop and Lost Forest. Lost Forest categories decrease after 1992 from 120 hectares (3.6%) to 90 hectares (2.7%) while Lost Crop categories accounting for around 1% of the study area for both periods.

Finally, the spatial distribution of the areas exposed to some kind of change in the periods before and after 1992, can be appreciated examining the reproduction of the maps in figure 16 depicting grouped areas of the property labeled as areas exposed to land use changes and areas not changed in the period between (a) 1973 and 1992, and between (b) 1992 and 2001. The maps present compacts unchanged areas before 1992 concentrated in three main sectors. After 1992 the process of land use change in the middle zone as well as in the southern region offers a view of stable land use areas more scattered and isolated.



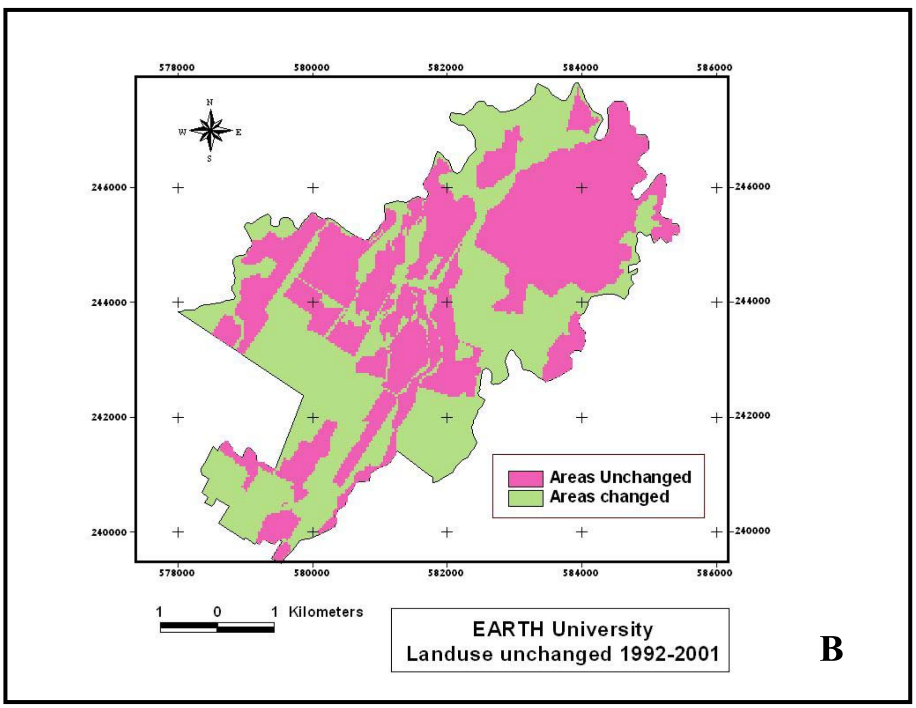


Figure 16. Changed and unchanged landuse areas before (a) and after (b) 1992.

Overall GIS analysis of land use changes

A summary of the changes of the land use for the study area are presented in table 6. The category GR appears as the most changing land use, conserving at the end of the 30 years only 333 ha (18%) of its original area covered. Tthus the GR areas were later replaced by land uses such as CS and CP, but also by categories as RP and BN, which could preserve their overall participation thanks to the substitution of such a GR areas. However it is FR that is the major substitute for the original GR, occupying more than 40% of its area. FR areas also are the most stable through the 30 years studied, conserving under the same land use 837 ha, corresponding to around 25% of the whole property. Important areas of unchanged land use are also presented under the categories BN and RP that together account for around 10% of the property.

Table 6. Matrix of land use changes from 1973 to 2001.

Matrix of Land use Changes from 1973 to 2001										
1973\2001	**BB**	**BN**	**CP**	**CS**	**FR**	**GR**	**MX**	**RP**	**RR**	**TOTAL**
BN	22.1	**275.5**	4.8		89.4	12.2		4.6		**408.6**
FP		1.9			7.4					**9.3**
FR		8.3			**837.2**			3.8		**849.3**
GR	24.0	79.2	324.4	136.5	741.9	**333.6**	48.1	81.9	24.6	**1794.3**
MX					170.9	2.7				**173.6**
RP			0.4	0.7	1.3	1.5		**66.3**		**70.2**
TOTAL	**46.1**	**364.9**	**329.5**	**137.2**	**1848.1**	**350.0**	**48.1**	**156.7**	**24.6**	**3305.3**

Grouping the cropping areas represented by the categories BN, BB, and CP they represent 22% of the land use of the property for the last period analyzed (2001), where the areas under Banana influence accounts for half (11%) of the participation of the cropping activities of the property. Comparing these values with the land cover for the year 1992, appears that the overall cropping area of the property have growth around 3% mostly thanks to the CP category.

As a final observation, the four land uses remaining through the 30 years of this study represent more than 1500 Ha (45%) of the study area. The categories grouped as Transition to Forest represent almost 1149 ha accounting for the 35% of the total area and the categories grouped as Transition to Crop accounts for a final 14% of the property, becoming the most important land use categories found in this study (Figure 17).

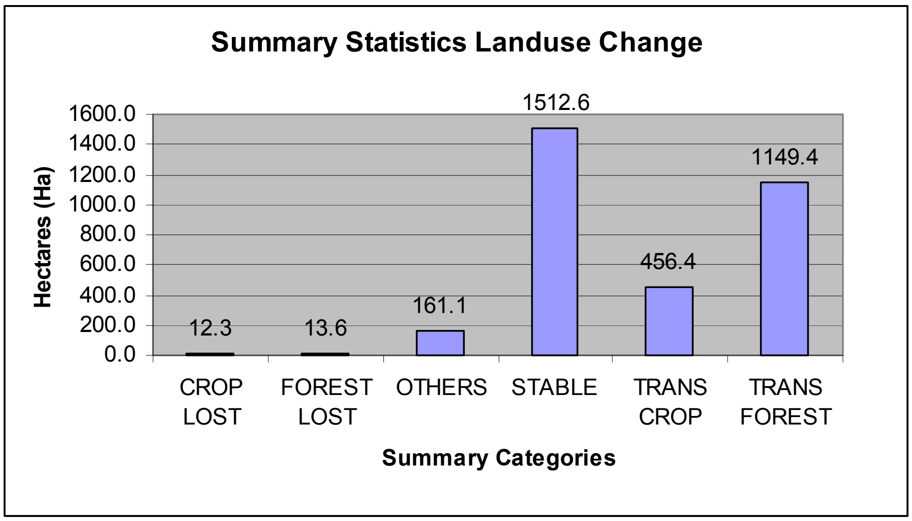


Figure 17. Summary statistics of land use change from 1973 to 2001

Integrated and hierarchical GIS database

The geographical database built in this study includes not only the digital files in vector and raster format of the land use cover maps for the EARTH University property for the years 1973, 1981, 1992, 1998 and 2001, joined with attribute data for each one of the areas of land use found, but also a secondary level of information concerning with the spatial distribution of the administrative sub units of the property. This database was also depeloped including attribute data for each particular subplot (Table 7) allowing the creation of individual maps for each one of the administrative units (Appendix 1 and 2).

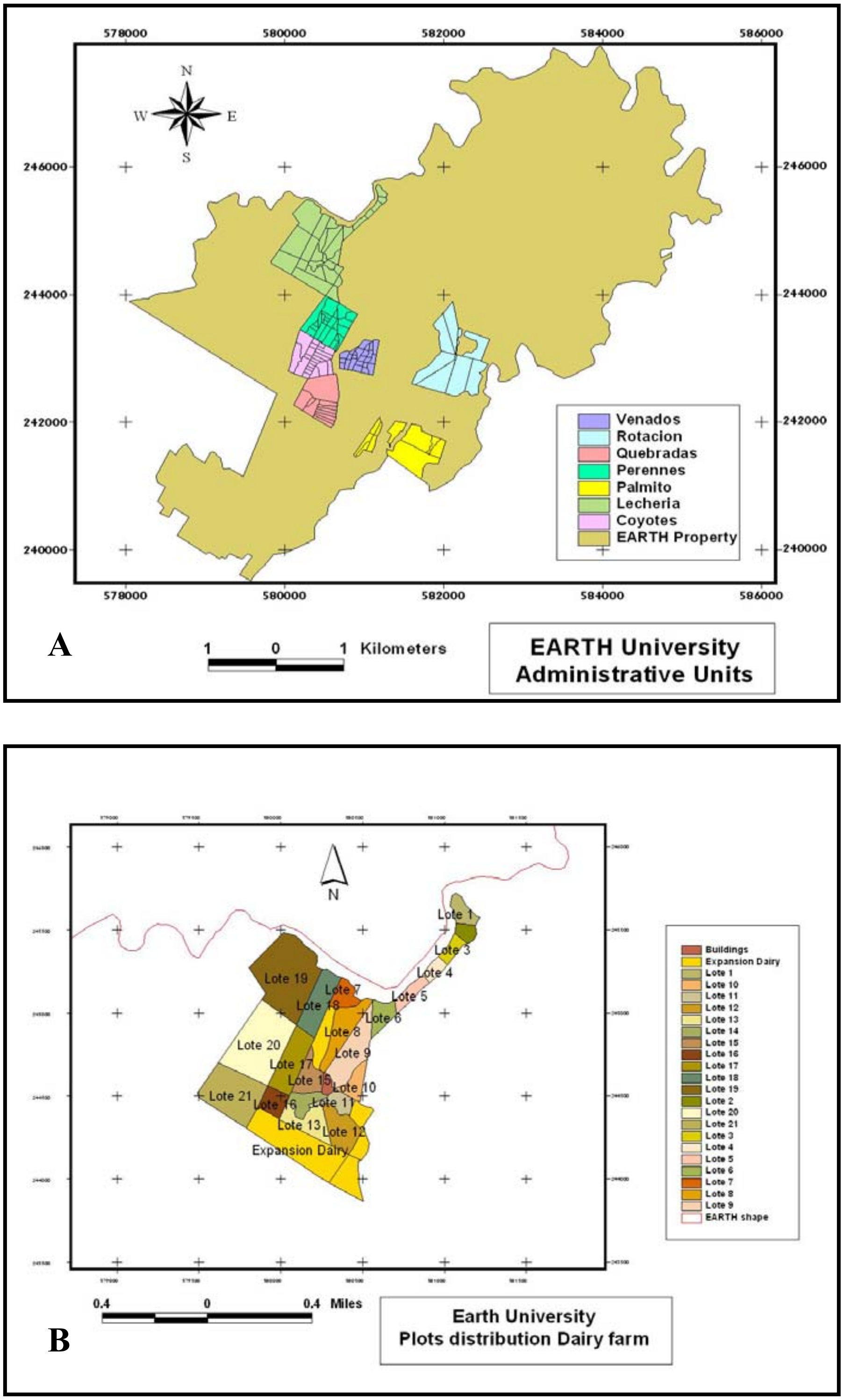


Figure 18. (A) Administrative sub units of EARTH University, (B) sample map of one sub Unit: “Lecheria” (Dairy farm).

These cropping areas are divided into seven different subunits where Banana plantations neither Bamboo areas are included (Figure 18). The name for this sub unit was kept from the original spanish name used within the property. Just two of the areas account for pasture under livestock operations holding 37 sub parcels or “Lotes” the remaining five units are under cropping activities divided into 89 sub parcels. This sublevel of the database includes areal information for each one of the sub parcels that the units have, as well as atribute information mostly for the perennial crops.

Table 7. Subplots distribution within Administrative units of crop and pasture.

EARTH University Area Distribution in Administrative Units of Crops and Pastures (Banana not included)														
Name	**Venados**		**Rotacion**		**Quebradas**		**Perennes**		**Palmito**		**Lecheria**		**Coyotes**	
Type	Crop		Pasture		Crop		Crop		Crop		Pasture		Crop	
No of Subunits	Plot name	Area Ha	Plot name	Area Ha	Plot name	Area Ha	Plot name	Area Ha	Plot name	Area Ha	Plot name	Area Ha	Plot name	Area Ha
1	Lote 20	0.6	Lote 7	8.4	Archeology	17.1	Expansion	1.0	Lote 19	4.7	Lote 1	1.8	Lote 2	15794
2	Lote 15	0.5	Lote 5	15.9	Expansion	4.9	Lote 3	2.1	Lote 23	1.3	Lote 2	1.1	Lote 3	11708
3	Lote 19	0.7	Lote 6	10.1	Lote 7	1.8	Lote 2	2.3	Lote 21	2.0	Lote 3	1.3	Lote 18	37039
4	Lote 14	0.8	Lote 4	12.7	Lote 6	1.3	Lote 1	1.9	Lote 20	1.6	Lote 4	1.1	Cacao	51033
5	Lote 18	0.7	Lote 3	11.0	Lote 5	1.4	Buildings	3.0	Lote 20	1.1	Lote 5	1.7	Lote 11	19153
6	Lote 16	0.9	Forest	1.1	Lote 4	1.4	Cacao	5.7	Lote 22	2.3	Lote 19	14.3	Lote 12	31777
7	Lote 11	1.2	Lote 2	9.6	Lote 3	1.5	Buildings	4.4	Riparian	1.7	Lote 18	5.0	Lote 13	17480
8	Lote 17	0.4	Building	0.1	Lote 2	1.4	Adhiote	0.5	Palmito	21.2	Lote 21	9.2	Lote 4	9846
9	Lote 12	0.7	Lote 1	8.7	Lote1	1.4	Lote 13	0.7	Palmito	15.7	Lote 20	12.8	Lote 5	7351
10	Lote 13	0.8			Lote 8	3.3	Lote 13	0.4			Lote 16	2.1	Lote 6	5435
11	Lote 9	1.2			Lote 9	0.8	Lote 13	0.3			Lote 17	5.4	Lote 7	5999
12	Lote 10	1.5					Lote 15	0.4			Lote 6	2.1	Lote 8	5064
13	Lote 8	0.2					Lote 16	1.0			Lote 8	4.6	Lote 10	8446
14	Lote 16	1.4					Lote 15	0.7			Lote 7	2.0	Lote 9	5676
15	Lote 7	0.3					Lote 15	1.4			Expansion Dairy	2.7	Lote 19	56813
16	Vivero	0.5					Lote 14	1.9			Lote 15	2.8	Lote 14	8452
17	Lote 4	1.0					Lote 9	2.2			Lote 10	2.0	Lote 15	7038
18	Lote 5	0.5					Lote 10	1.3			Lote 9	6.1	Lote 17	6628
19	Lote 3	1.3					Lote 11	0.6			Buildings	<0.1	Lote 16	13807
20	Lote 1	0.6					Canistel	0.4			Buildings	0.7	Mammon	6683
21	Lote 2	0.6					Araza	0.3			Expansion Dairy	2.9	Lote 1	20746
22	Expansion	1.6					Guanabana	1.0			Expansion Dairy	10.6		
23	Expansion	1.4					Lote 8	3.4			Expansion Dairy	2.5		
24	Expansion	1.0					Zapote	0.9			Lote 12	4.1		
26											Lote 11	1.9		
27											Lote 13	3.81		
Total Area	**370..1**	**21.5**		**78.2**		**36.7**		**38.8**		**52.0**		**107.9**		**35.2**

CHAPTER 5

DISCUSSION

Land use of EARTH University property

The analysis of the role that each category of land use plays within the 30 years covered by this work shows that the increase of areas exposed to flooding events from 1973 through 1992 (Table 4) can be associated with the natural occurrence of flooding events located mainly in the area limited by the Parismina river. This area is observed (Figure 8, 9 and 10) for these periods with almost no riparian vegetation (RP) that in those flat landscapes acts as natural stabilizer of the river flow. The sudden interruption of this category and its later transformation around 1992 into the categories BN, FR, and BB (Table 5), can be explained from a clear human intervention in a process of reclamation of this area and its later incorporation into the productive process of the property. The questions generated by this process can be answered by a chronosequence study of the vegetation.

The same active human intervention within the landscape can be associated with the evolution of the category RP. In the years prior to 1992 the increases of areas covered were steady, after that period it almost doubled extending its cover to the "Pocora" stream, and the "Dos novillos" and "Parismina" rivers, been able to evolve as a permanent FR cover after 1998 (Table 4 and 5).

Considering the period of almost 30 years of this study it is possible to recognize that FR replaced GR as the primary land use of the property and identify the period around 1992 as the intersecting point when the dominance was changed (Figure 12). These results are in agreement with the results of Russo and Soto (2000) for the Atlantic zone of Costa Rica where they found more than 100% of increase in the areas covered by pastures in the years previous to 1992.

Observing the high cover that the above categories present into the study area it is possible to affirm that the others categories acts as secondary covers (especially CP and BN) or even transitions within the dynamic GR to FR. Supporting this affirmation appear the land use change from the category MX to FR (Table 5), placing MX as a transitory state between GR and FR categories. Figure 19 offers a view of areas under cover of pasture (A) as well as planted forest into previous grassland areas (B).

It is also possible to support the previous conclusion studying the areas grouped under the category Transition to Forest (Figure 15 and 17), which are the second more relevant categories after those considered as Stable or Unchanged. This category is the summary group for all those process of change from the natural succession of forest until long-term abandoned areas, including changing process with potential of become forest if aging and mature process allowed.

With these precedents EARTH University property appears as suffering a large process of conversion, from long-term grazing events into a very complex forest-agriculture system, where the restoration of the primary element of the ecosystem, as the forest, is an attempt to be the foundation for a sustainable use of the land. As a major conclusion at this point stands the trend of the land use change for the EARTH property for the last 30 years directed to the establishment of forest areas, crop areas and the preservation of the riparian vegetation in the river basins. Also, it is clearly defined the areas under its campus domain and the plots distribution of the cropping and pasture units.

As was observed during the ground truthing exercise, the forest cover of the study area is not uniform or homogeneous in species composition or evolution. In fact, the EARTH University influence brought new and diverse arrangements of forest species in mono and poly cultivation, creating fuzzy boundaries between very different elements in the forest category as they are: mature forest stands, well defined secondary forest, timber plantations, regeneration areas and conservation zones (Figure 20), also an intense combination of buffer areas, agriculture plots and urban areas (CS included).

Considering the studies in secondary forest and natural successions by Brown and Lugo (1990 and 1994), the process at EARTH University property is following the inverse trend that they found as characteristic of the most secondary Tropical forest of the world in which processes of degradation and final substitution of the forest are the consequences for the establishment of agriculture and pasture lands in detriment of the natural vegetation.

In this context the model suggested by Brown and Lugo (1990) is very relevant: the appropriate management of four categories of land use interacting within the same landscape allowing people to obtain in a long-term process benefits not only from the land conversion itself but also from the various stages of the land use. Those categories are: Mature forest, defined as forest areas older than 60 years; Logged forest older than 20 years; Shifting cultivation and finally permanent agriculture and pasture. In this system the benefits for the ecosystem are later achieved when the forest stands are allowed to be mature enough (more than 30 years) and several turnovers of organic matter have been produced. Also when a diverse floristic composition is present producing goods as supplies for the different human needs.

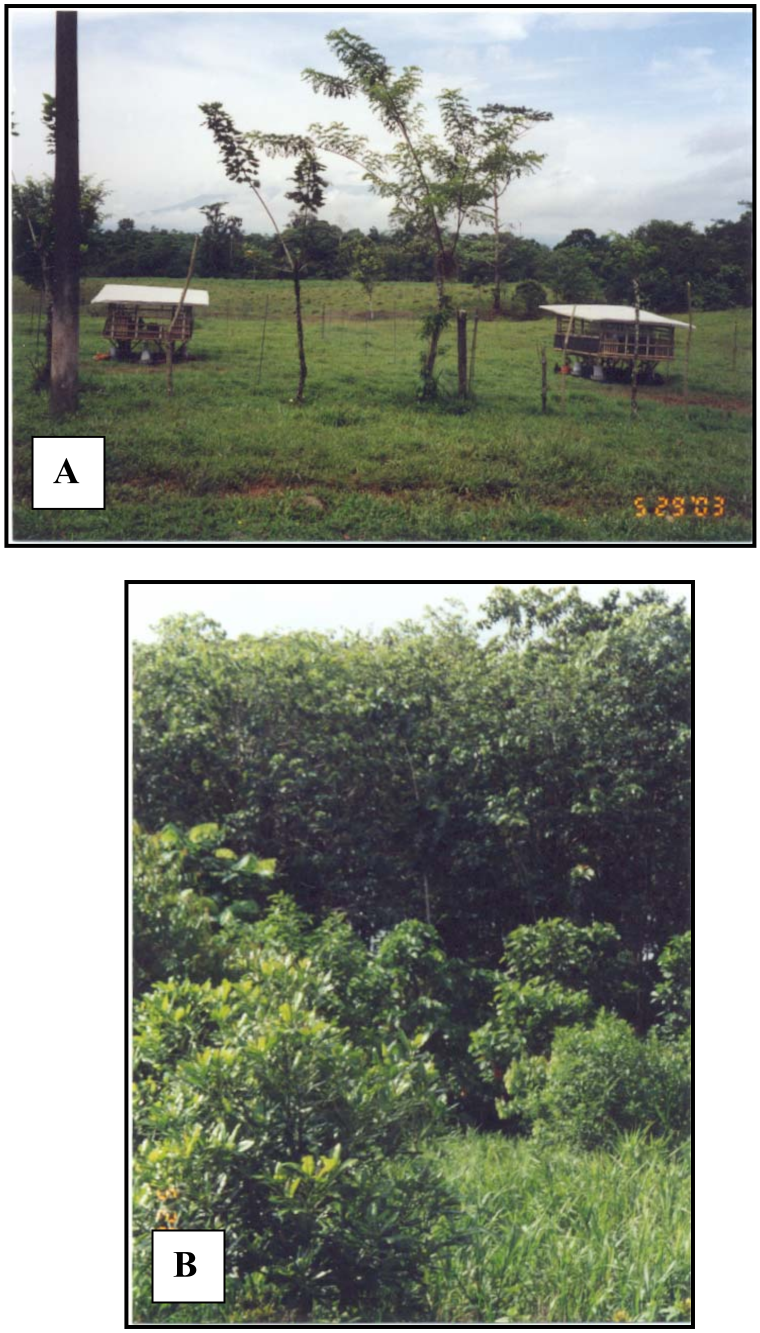


Figure 19. (A) Pastures, (B) Planted Forest into previous grassland areas.

The primary categories found in this study are in agreement with the four elements approach presented by Brown and Lugo (1990), where the role of intense agriculture activity in a complex mix between mono and poly crops, annual and perennials are a contribution to the required diversity for the system. This agreement suggests that the planning process, therefore the management function for the ecosystem, should be focused in finding an appropriate combination of the main land use elements found.

However, in spite of these positive elements, achieving the appropriate combination of the land use categories poses interesting challenges. One of them, the long-term cultivation of certain areas under Banana plantations, suggests that the further process of planning and sustainable management includes designing suitable strategies to interrupt continued exploitation of the same areas. Fallow periods with nutrient recycling through litter fall and organic matter accumulation are important options. In this view the unconventional arrangements between cropping areas and the natural vegetation present within EARTH University property are profiled as an important source of information about the way that crop rotation or substitution can be made.

Unconventional arrangements between crops and natural vegetation are some of the approaches used to understand and develop alternatives for cultivation for the Humid Tropics ecosystem without destruction of natural ecosystems. This approach is underlined by the concept of sustainable development ruling the management decisions of the property. However, this unconventional arrangement may generate the creation of additional independent categories, considering the peculiarities characteristics that they hold.

Figure 20. Two different stand of forest (A) Planted forest, (B) Natural forest.

This is the case of silvocultural arrangements within EARTH Univeristy where a high tree density, is kept in pasture zones for livestock, holding characteristics of a MX category with cattle activity. Another interesting example is the aim of developing a Banana production process without pesticide applications, using the natural nutrients cycling of the forest nursing a banana plantation within a closed canopy forest, in which the understory vegetation was removed and replaced by the Banana plants (Figure 21).

Figure 21. Organic Banana plantation within a natural forest.

Conservation stewardship and cultural landscapes

This alternative of conservation states that long-term forest conservation processes can be articulated in harmony and simultaneously with the process of satisfaction of human needs, where the required inputs for the human activity can be obtained from the natural ecosystem at the same time that conservation process are executed (Naveh, et al. 2002, Sarmiento 2001b). To articulate this process, the approach of conservation stewardship may be a useful alternative to address the aim of conservation of the natural environment when performing agriculture and livestock activities. In this context the high intensity of long-term human interventions within this landscape and the objectives of long-term planning process make possible to classify the relationship with the landscape within the context of community conservation of natural resources (Sarmiento 2001a).

This approach generates a transformation of the scenario into a landscape, where human and nature will coexist in a transactional way (Sarmiento 2001a). EARTH University property could fit within this category considering its aim of preserve large portions of its property long-time used as forest reserves. This reserve can go beyond the figure of natural park or conservation zone, frequently mentioned as "paper parks" in Latino America because its destruction regardless of its lawful protection (Sarmiento et al.2000) to become a productive area of environmental and productive benefits. This new association of old environmental actors will transform the previous predation of the natural resources and large scale landscape intervention into a human-nature connection with agroecological alternatives for the farming process becoming an alternative model for sustainable use of the humid tropics, extensive to similar ecosystems within Costa Rica (Mitchell and Buggey 2000, Sarmiento, et al. 2000, and 2001a)

Temporal and spatial resolution of the data sources

The data sources for this work provided a considerable amount of information that may support, not only the research questions addressed here but also a new variety of approaches to the study of the ecological association between agriculture activities and natural resources. However, technical characteristics of the data sources as well as the limitation associates with them have to be considered in order to get the best benefit of the database.

Considering the spatial resolution of the data, it was clear that the information provided for the Landsat image presents limitations when studying highly fragmented landscapes as the one studied here. The 15 and 30 meters resolution of the bands avoid the fine discrimination of features that become significant within the temporal frame of the study. In this case the better spatial resolution of the aerial photos that in some cases are inferior to 10 meters, complement the information of the satellite image becoming together a powerful landscape interpretation tool. The interpretation confirmed through the ground-truthing process generated well defined training areas that can be applied even in studies of wider areas within the same ecological landscape.

The temporal resolution of the data showed to be appropriated for the purpose of this study. The few land use changes in the period before 1992, confirmed that 10 years of interval was appropriate to understand the land cover dynamic, however if new research questions are interested for instances in explore the details of the historical livestock activities intensification process around 1981 set of images with a close interval would be required. In the scenario analyzed after 1992, the 6 years interval of the images provided very good information, the fragmentation was evident and the new land uses were distinguishable.

GIS Data base and further research questions

There are several examples of the potential application that the database developed in this study may have in the planning process of agriculture and livestock activities using the framework of sustainable development. The cases where a database of forest stands in the Caribbean zone is used to monitor the availability and location of seed production for further forest plantations (Castro and Ruerd, 1998) and the methodologies developed and applied by Bouman and Jensen (2000) to integrate into the land use database biophysical and socio-economical variables to address policy in applicable sustainability issues as: technological change, biocide limitation and soil nutrition depletion among others, are some of the next-step-uses for databases as the one generated here.

One of the most interesting and immediate applications, can be the integration of the GIS database within the administrative process of the cropping areas including banana, with the purpose to enhance the decision making process. With this idea, yield maps can be generated from the different subplots with the purpose of identify areas that have relative low production compared with the potential of the plantation. This information suggest a decision support system for complex areas where process of rotation, association and substitution can replace an intense monoculture systems (Stoorvogel et al. 2000).

The diverse changes found in the change detection analysis, can be grouped again into new categories following new and different parameters than the ones used here in order to assess new original questions. For instance, it can be used to determine the different compounds in the process of forest succession as well as the different levels of the forest restoration. To understand this dynamic, the category Transition to Forest is grouping interesting combination presenting relevant interactions of the land use change that may offer detailed clues about how the forest succession evolve within this environment and how the species composition may affect the long-term ecological process of the landscape.

With this connotation, the earliest developments of the forest can be explained studying changes from GR to RP or GR to MX. Subsequently, the advanced stage can be understood in the changes from RP to FR and MX to FR, and finally the big picture of the succession can be found within the changes from GR into FR. Those analyses can be performed to understand the natural and human made forest regeneration process within the study area at EARTH University, but also for those occurring in a regional scale of the landscape.

Also, the database developed through this study will be an important support in the process of identification and sub-classification of the different elements of the forest cover creating a second level in the dataset, similar to the one created for the cropping and pastures units

Other studies can be centered in the relative spread of the RP areas compared with the size of the river basin in which the need for posterior stream management can be addressed. Also, the detailed studied of species composition of the RP vegetation compared with the arboreal species of the FR areas will allow to understand the connectivity between vegetation patches and the function of the RP as a biological corridor within the property.

Conclusions

The land use of the EARTH University property during the 30 years considered in this study showed important changes from an extended grassland cover present in the period around 1973 to become a broad forest cover in the period prior to 2001.

The 1981data showed an important process of forest cleared and an intensification of the livestock activities. However an important forest stand now known as “La reserva” was preserved and conserved until today, constituting an important source for scientific research of that landscape.

The period associated with the creation of EARTH University in 1992 was found as a moment of major transformation into the land use of the study area, and EARTH University itself as the cause of this transition. From this point, diverse cropping activities were incorporated into the landscape, and new approaches for the livestock management were established, relieving at the same time the pressure against the forest resources.

It was found that most of the 50% of the property has remained under the same land use since the earliest 70’s. In this context the area under Banana production and pasture that fit into this criterion of land use should be the ones to receive special attention in the next planning process of the property considering the aim of natural resources conservation under the framework of sustainable development.

Important decisions have to be made about the way to achieve appropriate balance between the five major land uses of the property such as: banana plantations, crop areas, livestock areas, mature forest, and new forest stands, which are required to achieve the maturity of the landscape and then its sustainability through the time.

Important areas of attention for the decision makers are the changes grouped here as transition to forest. In this context the planning process is responsible to determine the final area covered by forest in relationship with the property size and the space assigned to the other uses. In doing so, the decisions should be centered in which transition areas should remain as buffer for the interactions required in the complex scenario of sustainable use of the resources. Also this category presents forest elements of diverse origin and composition that justify to be studied in more detail.

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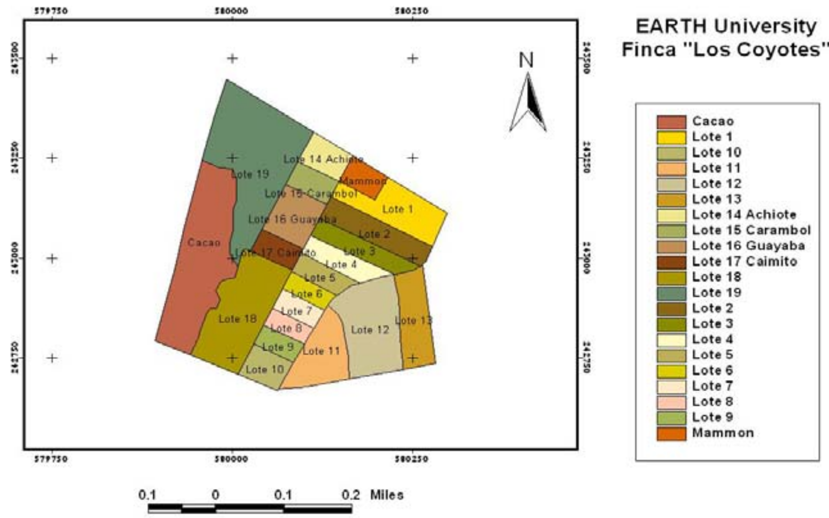
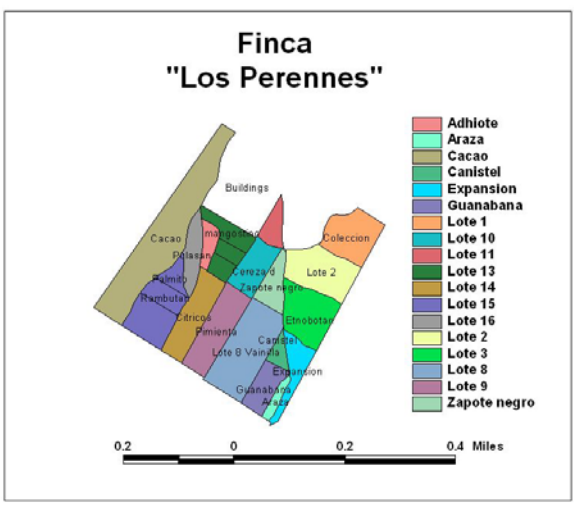
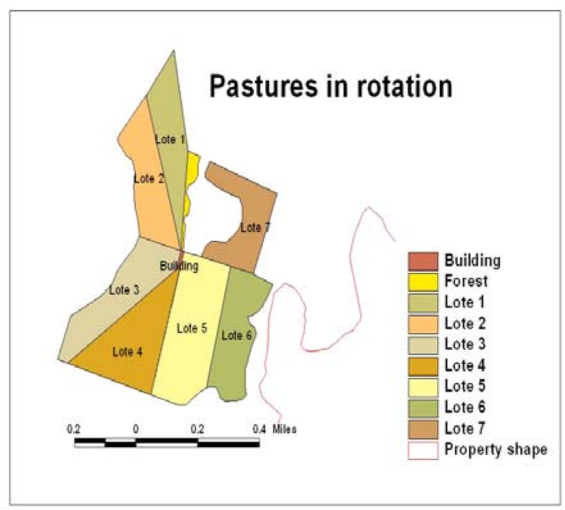
APPENDICES

Appendix 1: Individual maps for three Administrative units







Appendix 2: Individual maps for Administrative units (Continuation)