Forest, Agriculture and Development in a Changing Landscape:

Land-cover change analysis of St. Croix, USVI, using Landsat satellites from 1992-2002

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Overview

This project was conducted to answer specific questions about the changing landscape of the Virgin Islands. "How much of St. Croix is forested and how much is in agriculture? Is St. Croix's landscape experiencing changes, and if so, what type of change? How much of St. Croix is developed and what are the trends in new development? What does this mean for agriculture? If we can detect changes, what is causing them?" We ask these questions, in part, because studies in other parts of the world have shown linkages between human decision making and the natural and agricultural resources available to them. The results indicate that St. Croix is experiencing a relatively high degree of change where grassland, secondary forests and development interact in a cycle.

Introduction

Land-Use Land-Cover Change (LULCC) is a field of study dedicated to quantifiably describing the natural and cultural elements in a landscape and measuring how change occurs over time. The primary tool in this and other LULCC projects is a GIS (Geographic Information System) that stores, links and manipulates all of the maps and other spatial data in the project. The process is to create classified, land-cover maps that take the complex landscapes we live in and simplify them into a few meaningful categories. By creating two classified maps of St. Croix for two different dates, we can then compare them and determine what type of change occurred, when and where.

Methods

Imagery

Landsat Thematic Mapper satellite images were used for this project because they are well-suited to island-wide studies and contain rich data based on reflected light. Relatively cloud-free images were obtained for August 14, 1992 and January 12, 2002 and were processed and calibrated to account for atmospheric and other variations. Additional data layers were added or "stacked" on top of the satellite images using the remote sensing software, ERDAS Imagine 8.4. These data layers included; slope, elevation, USGS soil layer, a naturalized vegetation index and others so that the final images for each date was a 13-layer stack containing rich spectral and spatial data.

Ground Data Collection

To create accurate classifications one needs robust, ground-truth data obtained from a set of points called training samples. In the summer of 2005, 242 points were randomly distributed across St. Croix. Detailed land-cover data was collected by uploading the points to GPS units and navigating to them and recording observations. The 1992 satellite image was classified by overlaying the same points on a 1992 black and white aerial photograph and classifying them with traditional photo-interpretation techniques. Data from one half of the points was used to "train" the computer model and classify every pixel in the image of St. Croix based on the data collected at those points. The other half of the points was used to objectively assess the accuracy of the classification. All classified maps contain some degree of error. One of this system's greatest strengths is the ability to quantify accuracy and determine what types of errors exist and thereby allow the user to more meaningfully interpret the results.

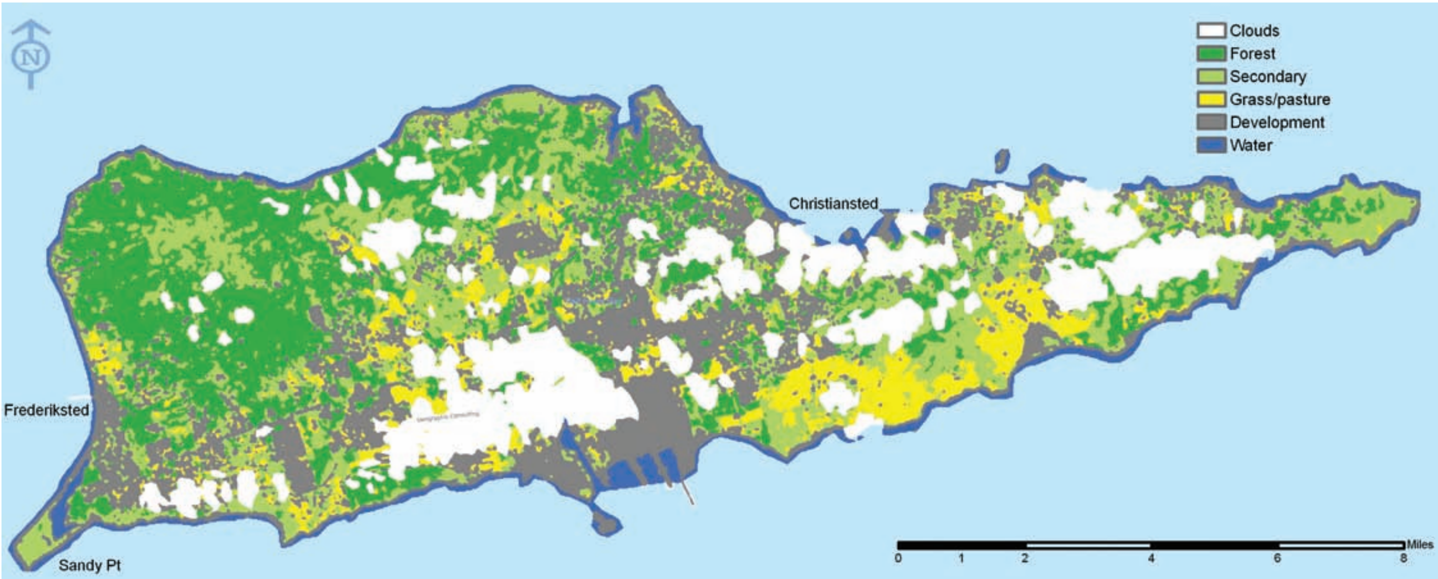
Classification

Image classification is the process of taking the large quantity of complex data and simplifying it into meaningful categories. Classified images were created with five land-cover categories; Forest, Secondary Forest, Grass/Pasture, Developed and Water. A description of the classes appears in Table 1. Based on the field data, each of the 242 points was assigned to one of these five categories and then half of the points were superimposed on top of the stacked image. Data from the layers below each point (reflectance, slope, elevation, soil, etc) is extracted and a "signature" is created for each of the five land-cover classes. The signature consists of numerical values from each of the 13-layers in the image. When the classification was completed, the remaining points were compared to the classified im-

Table 1. Five land-cover classifications and their descriptions

Class	Description
Forest	Forest canopy usually above 30 ft tall, with 2 or more layers, frequently comprised of native tree species
Secondary Forest	Shorter, younger, single layer forests including coastal scrub and regenerating pastures. Frequently comprised of weedy trees such as manjack (*Cordia alba*), tan-tan (*Leucaena leucocephala*) and casha (*Acacia macracantha*)
Grass/Pasture	Primarily pastures, but also golf courses, large lawns and coastal grassland
Development	Primarily parking lots and roof tops in urban and residential areas, but also some bare soil and beach sand
Water	Sea water and salt ponds

Figure 1. Land cover map for St. Croix, 2002.



age to determine the accuracy of the classification and the types of errors present.

Change Detection
Perhaps the greatest advantage to creating classified maps of an area on two dates is that one can identify where change is occurring. "Change detection" in GIS is a process where we compare maps for two dates and results in a new map that describes the type of change that occurred, quantifies results and shows their spatial distribution. To ensure that the results are easy to understand, the maps are usually simplified before the comparison.

The 1992 and 2002 5-class maps were simplified (re-coded) by merging the two forest classes into a single class and combining grass and developed into one class. The result is 3-class image with; Forest (F), Non-forest (N) and Water (W). In this way, only significant changes are detected, such as clearing a forest area for pasture or development. Subtle changes, such as a forest developing from secondary into mature forest type are often associated with a higher degree of error are not captured using this method. Reducing the detail greatly increased the accuracy of the images. Comparing the two 3-class images, every pixel in the image was classified into one of nine (3 x 3=9) possible outcomes (Table 2). The first letter in the code represents the land-cover in 1992 and the second letter describes the land-cover in the 2002 image.

Table 2. The 9 possible outcomes for the comparison of the 1992 and 2002 3-class images on St. Croix.

FF	Stable Forest
FN	Deforestation
FW	Forest to Water *
NN	Stable Development
NF	Reforestation
NW	Bare ground to water *
WW	Stable Water
WN	Water to bare ground *
WF	Water to forest *

** These 4 classes together represent water and tidal fluctuation and are considered a single class in the analysis.*

Results/Discussion

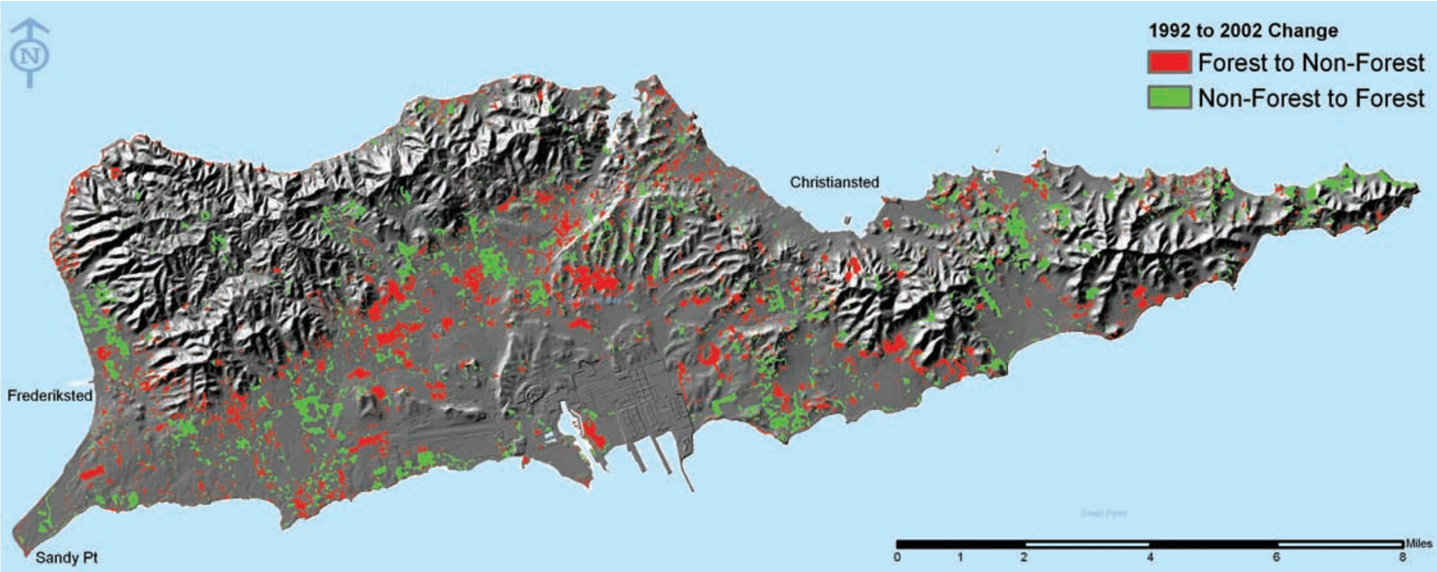
Classified Image 2002
The classification process resulted in separate 5-class maps for 1992 and 2002. For the more recent image (Figure 1), the accuracy of the classification process was assessed using point data collected on the ground from a time relatively close to the LandSat image date. To our knowledge, this is the only land-cover map of St. Croix based on actual reflectance values and not photo-interpretation and is the only classified map of St. Croix assessed for accuracy. The overall accuracy is 75.27%, which is acceptable for a single map, but too low to use in a comparison between two dates. This method is effective because results are based on actual reflectance data and the results can be measured for accuracy, including the types of error encountered for each class (Table 3). Points that align with clouds in the Landsat image are considered unclassified. Forested areas tend to be concentrated in the higher elevations of St. Croix, especially the north-west corner of the island (Figure 1). The secondary forests tend to occur as a buffer around forests and along the island's coasts. Large pastures are concentrated primarily along the south shore with smaller patches in the central valley. Development is primarily focused in the central valley, along Center Line Road between Christiansted and Fredericksted.

Table 3. Accuracy assessment of 2002 5-class image.

Class name	Reference total	Classified total	Number correct
Forest	33	28	21
Secondary forest	19	25	15
Grass/pasture	14	16	10
Developed	20	18	15
Water	19	18	18
unclassified	16		
Totals	**121**	**105**	**79**
Overall accuracy 75.27%			

Change Detection
Accuracy for the simplified, 3-class images for 1992 and 2002 was 82.88% and 91.43%, respectively (Table 4). This high level of accuracy allows us to analyze change with confidence. Pixels having the same classification for both dates are referred to as "stable" and one principle finding of this study is that 83.1% of St. Croix did not change. Approximately one half or of the study area or 22,674.2 acres (9,175.6 ha) is covered in Stable Forest, while 13,531 acres (5,475.8 ha) are Stable Non-forest and another 2,804 acres (1134.73 ha)

Figure 3. Distribution of reforestation and deforestation in relation to the topography of St. Croix.



are Stable Water (Figure 2). The remaining 16.9% of the study area changed during the 10 year study period, which is a relatively high percentage of change in a landscape. When the change areas are mapped along with topography, one can see that change tended to occur in the lowlands and not on slopes (Figure 3).

We further verified the results by comparing them to an independent data source, aerial photographs from 1992 and 2004. The top two photos in Figure 4 show a highlighted area that was identified as reforestation by this project. The photographs verify the area changed from pasture in 1992 to forest in 2004, likely because pasture maintenance was terminated. The lower part of the figure shows an area this project identifies as deforestation. When overlaid on the photograph one can see that the forest in 1992 is replaced by houses and roads. This is a robust, visual confirmation that the results from the Landsat satellite classification are accurate.

This research indicates land-cover change in St. Croix primarily results from a cessation of human activity such as bulldozing, mowing or grazing. Humans cleared 3,435 acres (1,390.1 ha) of forest or bush for either development or agriculture (this includes land cleared by fire). Similarly, 3,833 acres (1551.2 ha) were reforested into some type of forest cover. Four separate categories detected changes in water levels due to tides, evaporation and rainfall (Table 2). They can all be lumped into a single category of natural change that accounts for only 667 acres. In the maps and figures deforestation is shown as red and reforestation is green.

Interestingly, forest gain and forest loss occurred in roughly equal amounts (Figure 2). Change areas have many other characteristics in common. Analysis using the spatial statistics software, FragStats 2.0, found that patches of reforestation and deforestation are the same average size (1.7 acres) while patches from other categories are 10-30 times larger (from 19 to 33 acres). Two other indices were used to measure how the patches of each cover type were distributed relative to each other. The results describe both types of change as having small patch size and closely mixed with other cover types, while stable patches are much larger and clustered together in more homogeneous groups.

Analysis reveals land-cover change patterns in St. Croix for the 10 year period occurred in distinct, telling patterns. Forest was not cleared for agriculture and development, as is the case in developing economies. Instead, pasture is the cover class most likely to change. Overall, there is a pattern where secondary forest land is converted to grassland while similar acreage of grassland regenerates into secondary forest. However roughly ¼ of that change area, or 3% of the island, is permanently converted into development and removed from the cycle. Developed is considered a "one-way change" or a permanent land-cover because parking lots and buildings

Figure 2. Percentages of the study area occupied by various stable and changing land-cover types.

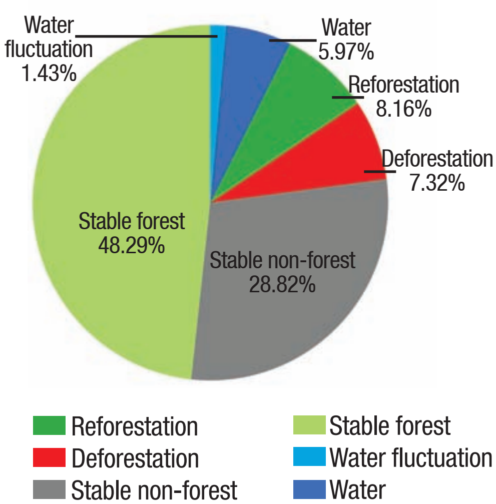


Table 4. Accuracy assessment for the two 3-class images.

1992

Class name	Reference total	Classified total	Number correct
Forest	52	44	39
Non-forest	38	47	33
Water	21	20	20
unclassified	10		
Totals	**121**	**111**	**92**

Overall Accuracy = 82.88%

2002

Class name	Reference total	Classified total	Number correct
Forest	52	52	48
Non-forest	34	35	30
Water	19	18	18
unclassified	16		
Totals	**121**	**105**	**96**

Overall Accuracy = 91.43%

are rarely converted back to forest or grass. It is difficult to quantify, but we conclude that grass/pasture is the cover type that is most likely to change. This results in an overall reduction in pasture and agricultural land over time.

The Causes of Change

We propose that reforestation and deforestation on St. Croix are two parts of the same disturbance pattern. This pattern is pastures and non-agricultural, grassy lots being infrequently managed and re-growing into patches of tan-tan (L. leucocephala) and other woody weeds. Simultaneously, other plots that have regenerated into weedy patches are bull-dozed or burned. Some of these properties remain in grass for a number of years and others are developed for housing.

Additional support of these findings comes from data collected by the Virgin Islands Department of Agriculture (VIDA) for the United States Virgin Islands Agricultural Census. This data is independent from our spatial data because it is colleted via anonymous farmer surveys and is not mapped. Though the absolute numbers differ, the Agricultural Census found the same trend of an overall reduction in pasture and agricultural land (Figure 5). Their results strongly support the method of using Landsat satellite images to accurately detect real changes on the ground. In addition, the maps generated by this project also describe where changes occurred and their spatial patterns.

For the Future

An additional strength to this method of land-cover change analysis is that once can analyze change again in 2012 to determine if the pattern continues. It is recommended to use this land-cover change layer in conjunction with other data layers, such as zoning change requests, maps of designated agricultural lands, or even maps of real estate values. These data sets are not easily available today in uniform digital formats, but current work in the territory is moving toward greater data sharing. This will eventually allow the greater use of GIS as a land management tool.

Figure 4. Red patches represent deforestation and green patches indicate reforestation. When overlaid on an aerial photograph the patches consistently match real events occurring on the ground.

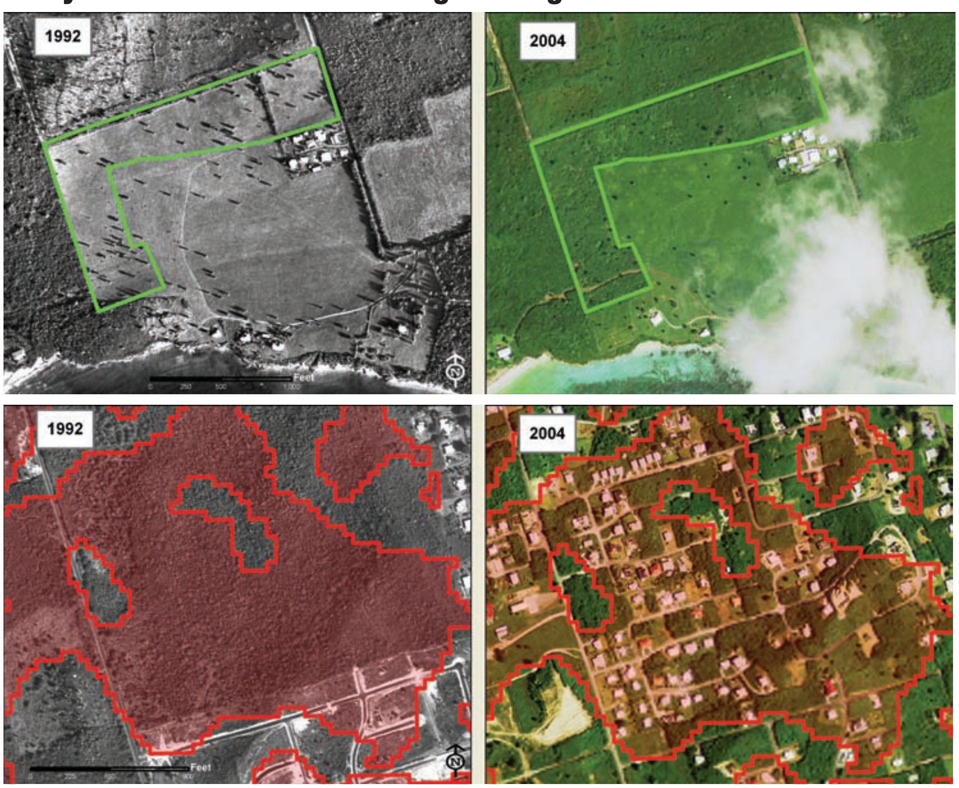


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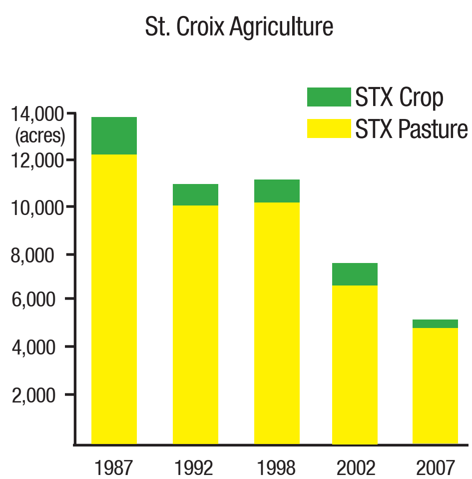
Figure 5. Summary of V.I. Agricultural Census Data showing a decrease of land in pasture and crop land in St. Croix over a 20-year period.



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