REMOTE SENSING ANALYSIS OF LAND COVER AND LAND USE, CENTRAL BELIZE

Final Report

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INTRODUCTION

In 1992, the Land Information Centre (LIC), Belize Ministry of Natural Resources and the Environment (MNRE), acquired Geographic Information System (GIS) capability (Fairweather, 1997). Among the first projects of the LIC was to incorporate into the GIS digitized land use maps of Belize that had been completed by the MNRE as part of a project initiated in 1987 by the Food and Agricultural Organization (FAO) and funded by the United Nations Development Programme (UNDP). Results of the mapping project were presented in a preliminary report including eight land use maps (Fairweather and Gray, 1994). This information has been used extensively by government and private organizations in planning and development decisions (Fairweather, 1997). The MNRE recognized the value of these 1989/1992 land use data sets, and the importance of maintaining maps of current land use. Acquisition of 1996 imagery by the LIC through a grant from the United States Agency for International Development (USAID) provided the means for updating land use maps.

In this project funded by the UNDP, the 1996 imagery was used to interpret and classify an area in central Belize (Fig. 1). Among the purposes of the study were to develop and refine the land use and land cover classification in a limited geographic area so that the classification and methods could potentially be applied nationwide to update current land use. The project area was selected because it is relatively cloud free in the 1996 imagery and includes a large percentage of the coastal and upland land cover and land use units that are present elsewhere in Belize. Extensive fieldwork and experience in interpreting Landsat TM imagery by the Bureau of Economic Geology (BEG) and the Center for Space Research (CSR) in a completed study of Belize deforestation (White and others,

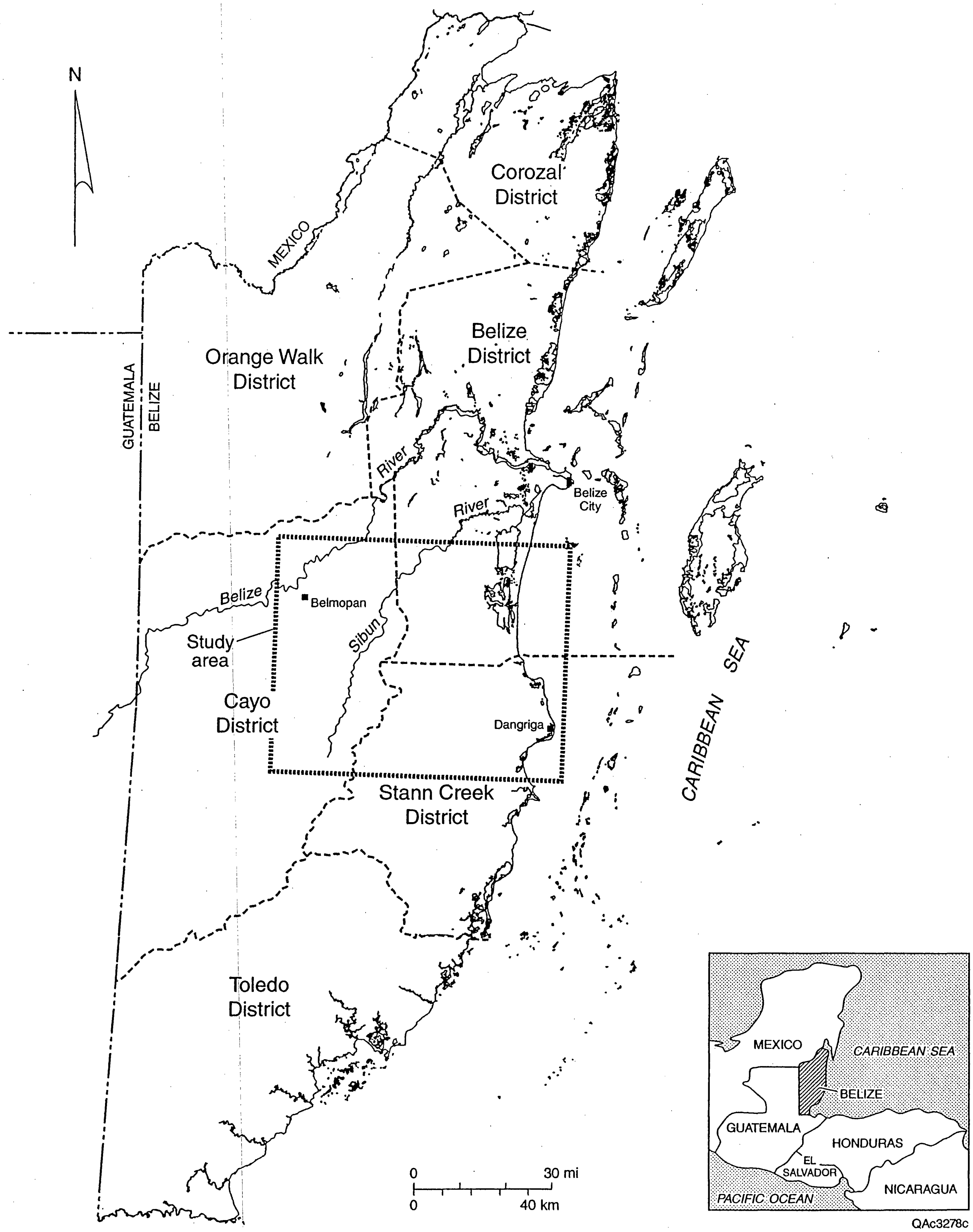

Figure 1. Index map of study area. Final study area is about 4x the size of the original proposed area, which was only the northeast quadrant of shown study area.

1996) provided the foundation for BEG and CSR researchers to refine the methods used in classifying and delineating Belize land use and land cover.

Objectives

The primary objectives of the project were to refine the current classification, resolve discrepancies, improve the methodology of analysis through computer-assisted classification, and classify and delineate land use in an area of central Belize. In so doing, methods would be established for preparing a series of much-needed updated maps of Belize to support management and sustainable development of natural resources.

Study Area

The study area is located in the eastern half of central Belize and includes portions of the Belize, Cayo, and Stann Creek Districts (Fig. 1). It extends from the Northern and Southern Lagoons on the coast, inland to Belmopan, and southeast to Dangriga. The area selected for study is larger than the proposed study area, which included only the southern end of the Belize District. The northern boundary, which crosses the Northern Lagoon, is defined by the northern extent of the 1996 Landsat TM scene used for the study. North of the boundary shown in Figure 1, cloud cover was extensive and land use could not be adequately classified on the 1996 imagery. In coastal areas near Dangriga, cloud cover was also a problem, and areas obscured by clouds were not classified.

The study area includes the following forest reserves: Manatee, Sibun, most of Sittee River, Grants Works (A), Silk Grass, Commerce Bight (A), most of Commerce Bight (B), and part of Mountain Pine Ridge (Fig. 2). Other protected areas in the study area include Blue Hole, Five Blues Lake, Monkey Bay, and a portion of Chiquibul National Park, and Monkey Bay Private Reserve.

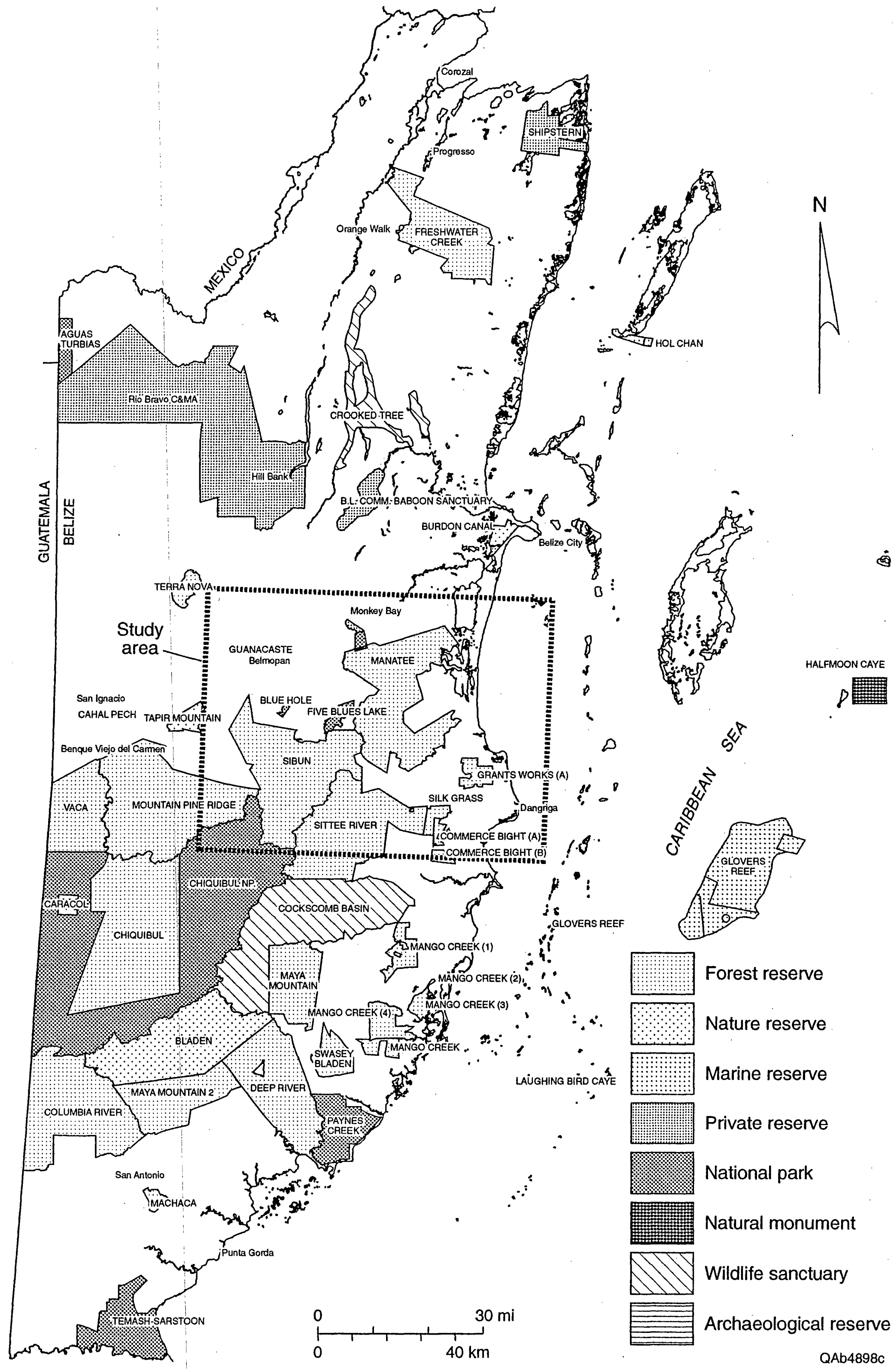

Figure 2. Map showing study area with respect to Belize protected areas. From Fairweather and Gray (1994).

COMPARISON OF CLASSIFICATION SYSTEMS AND METHODS

The 1989/1992 land use inventory (Fairweather and Gray, 1994) established a strong foundation for classifying and mapping land use in Belize and provided the basis for the classification system used in this study. Methods used in delineating land use in the earlier project are briefly described for comparison with the methods and classification used in this study.

The Land Use of Belize 1989/92 Project

General Methodology

Land use in the 1989/92 project was based on the interpretation of remotely sensed SPOT XS (multispectral) data plotted at a scale of 1:50,000 (Fairweather and Gray, 1994). The dates of the SPOT imagery acquisition were 1989, 1990, and 1992, with central and southern Belize covered primarily by 1989/90 imagery. SPOT imagery has a ground resolution of 20 m, which is a higher resolution than the 30-m Landsat TM data. The spectral range of TM, however, exceeds that of SPOT, allowing a more refined discrimination of land use classes.

Land use classes were interpreted by project staff of MNRE and delineated on acetate overlays on SPOT false-color composite plots, with a minimum mapping unit of 0.25 cm x 0.25 cm at a 1:50,000 scale. Field work, although not comprehensive, was an integral part of the interpretative work. Interpretation of land use was supported by other data sources including aerial photographs and existing maps (Fairweather and Gray, 1994).

Delineated areas were digitized into a GIS from which a series of eight color maps (Fig. 3) were printed at a scale of 1:200,000 and included in the preliminary report on land use

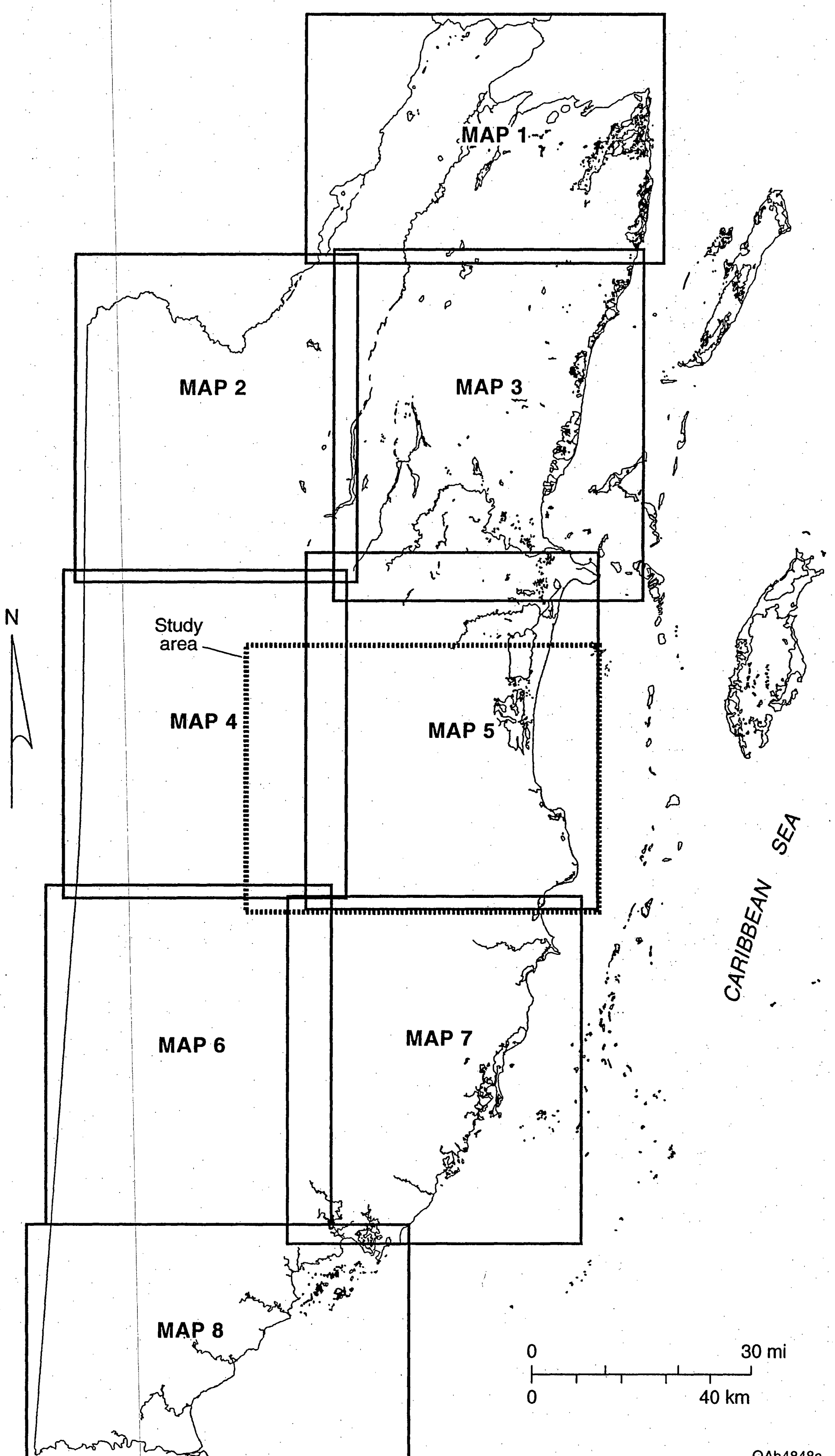

Figure 3. Index map showing location and number of 1989/92 land use project map sheets. From Fairweather and Gray (1994). Note that study area for this project is located primarily within map sheets 4 and 5.

(Fairweather and Gray, 1994). Also included in the report is a composite full-color land use map of Belize at a scale of 1:1,000,000.

Classification System for 1989/92

The 1989/92 land use classification has five main classes: Urban, Agricultural, Range Land, Forest and other Wooded Areas, and Unproductive Land (Fairweather and Gray, 1994). A total of 80 subclasses, many of which consist of mixed classes such as Broadleaf/Pine forest, were defined and are contained in the digital data. Only 40 subclasses are listed in the report, and only 28 are shown on the full-color maps (Table 1). Agriculture and Forest and Other Wooded Areas were each divided into 12 subclasses. Of the total national land area, Forests and Wooded Areas as a whole composed about 79 percent, Agricultural land about 10 percent, Range Land or Savannah about 9 percent, and Unproductive Land about 2 percent. The most abundant land cover subclass was Broadleaf Forest, making up about 65 percent of the total (Table 1).

Several problems were noted in delineating classes on SPOT imagery in the 1989/1992 land use report including difficulties with respect to transitional areas, cover density, spectral similarities, overlapping classes, and small isolated classes (Table 2). Specific problems in delineation of classes included separating broadleaf forest from thicket, and separating cleared areas associated with shifting cultivation, farming, and herbaceous and scrub secondary regrowth after clearing or farming.

Table 1. Classes and subclasses of land use and percentages in 1989/92. From Fairweather and Gray (1994). Subclasses similar to those defined in this study in bold.

Class and Sub-class	**Percentage of Nationwide Land Area**
1. Urban Areas	
Built-up	0.262
Non built-up	0.122
2. Agricultural Land	
Herbaceous crops	
Annual crops - mechanized (e.g., rice, maize)	1.848
(with Pasture)	(0.856)
Annual crops - non-mechanized	0.901
(with Milpa and Thicket)	(0.165)
(with Herbaceous and Scrub secondary regrowth)	(0.134)
Bananas	0.095
Sugar-cane	2.943
(with Herbaceous and Scrub secondary regrowth)	(0.972)
Tree Crops	
Citrus	0.595
Mango	0.076
Cocoa	0.009
Cashew	0.002
Shifting cultivation (Milpa)	1.71
(with Thicket)	(0.203)
Pasture	1.64
(with mechanized Annual crops)	(0.29)
Clearing for Farming	0.135
Shrimp Farming/aquaculture	0.012
3. Range Land	
Savannah (Herbaceous, Scrub or Tree)	8.827
(with Thicket)	(1.371)
4. Forest and other Wooded Areas	
Broadleaf Forest (including secondary)	65.12
(with Thicket)	(0.680)
(with Pine)	(0.260)
Open Broadleaf Forest (woodland)	0.552
Pine Forest	2.64
Open Pine Forest	0.34
Thicket and other degenerated Broadleaf Forest	3.89
Herbaceous and Scrub, secondary regrowth after farming or clearing	0.86
Bamboo and Riparian Vegetation	0.529
Coastal Strand Vegetation	0.114
Mangrove (Medium-Tall)	0.359
Mangrove (Dwarf)	1.077
Saline swamp vegetation with palmetto and mangrove	1.583
Marsh Swamp	1.926
5. Unproductive Land	
Bare Land	0.0351
Water Bodies	1.800

Table 2. Examples of areas or classes that were difficult to accurately delineate in the 1989/1992 land use project. From Fairweather and Gray (1994).

(1) Transitional areas between two classes
(2) Classes defined by density, such as open forest
(3) Areas that were not spectrally distinct, such as broadleaf forest and secondary regrowth
(4) Overlapping classes, such as sugar cane and annual crops
(5) Classes covering small isolated areas such as shifting cultivation

Classification of 1996 Land Use

General Methodology

The methodology used in mapping land use in this study is considerably different from that used in the previous 1989/92 land use project. In the earlier project, land use classes were visually interpreted, delineated, and manually digitized. In this study, land use classes were mapped through digital statistical methods applied to Landsat Thematic Mapper (TM) data.

Land use classes were derived as much as possible from the 1989/92 land use project (Fairweather and Gray, 1994). The classification system in this study consists of 14 land use types (Table 3). Similarities with the 1989/92 classification system can be seen by comparing Tables 1 and 3. Approximately 11 steps were used to complete the land use classification and mapping process (Table 4). Field surveys had an important role in defining land use types and resolving classification inconsistencies.

Problem Areas

Image classification problems similar to those mentioned in the 1989/1992 project were also encountered in this study. Problem areas included difficulties in separating thicket from mixtures of pine and thicket (normally classified as pine), classification of small mountainous broadleaf forest areas as riparian, classification of local coastal broadleaf areas as mangrove, classification of land partially obscured by a "halo" around clouds as residential/commercial, classification of some areas cleared for farming as residential/commercial, classification of some residential/commercial areas as farmland, classification of overgrown citrus orchards as secondary regrowth, and difficulties in distinguishing different types of crops. Accordingly, the classification was simplified to reduce inconsistencies and increase the accuracy of delineated classes. Among the class simplifications in this study compared to the 1989/92 land use project were to include open broadleaf forest with broadleaf forest or with savannah, and open pine forest with closed pine forest or savannah. Subclasses in agricultural lands defined in the 1989/1992 project were combined into a single class, farmland, which eliminated the difficulties and inconsistencies in distinguishing different types of crops on the imagery. Problem areas were reduced as much as possible through adjustments in image processing as noted in Table 4, but a small percentage of areas are misclassified. Some areas of known misclassification were manually selected on the computer screen and corrected.

Table 3. Land use-land cover units classified using 1996 Landsat TM imagery.

1. Forest and savannah

Broadleaf forest -- generally characterized by dense, tall, broadleaf forest, locally including secondary regrowth

Pine forest – characterized by pines, including areas of mixed pine and broadleaf thicket, and herbaceous understory

Riparian/bamboo – characterized by bamboo, vine covered trees and shrubs, and secondary regrowth from clearings along rivers; includes small anomalous forested areas in mountainous terrain that have a reflectance similar to riparian vegetation on the Landsat imagery

Natural thicket and secondary regrowth -- characterized by degenerated and stunted broadleaf forests, and areas of secondary broadleaf regrowth locally including abundant oaks, trumpet trees, and palms

Low secondary regrowth, herbaceous and scrub/shrub -- characterized primarily by regrowth of herbaceous vegetation less than 2 m high with scattered shrubs in previously cleared areas

Savannah and other grasslands -- primarily topographically low coastal plain grassland, or rangeland, with scattered stands of pines and palmettos, but also including grasslands in mountainous areas that have been cleared or burned

2. Wetland and coastal land

Mangroves, tall to medium height – includes mixed mangroves ranging in heights generally more than 3 meters

Mangroves, dwarf – includes mixed mangroves generally less than 3 meters in height, locally includes saline swamp with palmettos.

Marsh/swamp – characterized by mixtures of open water and emergent vegetation, salt and brackish near coast, fresh inland

Coastal broadleaf and strand vegetation – includes littoral and coastal broadleaf forests including relict beach ridges with abundant palms

Coastal savannah – Saline to brackish grasslands in coastal areas, includes some barren land and scattered poorly drained depressions supporting marsh vegetation

3. Developed land

Farmland -- includes cropland and cleared land, characterized by numerous citrus orchards and pastures in the study area

Residential/commercial development – characterized by land that has been cleared and developed for residential, recreational, and commercial purposes, including occasional shrimp farms, locally includes roads and clearings

Barren – unvegetated land associated with human activities, including areas that have been cleared of vegetation in preparation for planting of crops, or other types of development; locally including small naturally unvegetated coastal areas (salt pans) where accumulations of salt have inhibited the growth of vegetation

Table 4. General procedures used in classifying land use and land cover.

1. Plot false color composite of imagery combining bands 4,5,7 at a scale of approximately 1:110,000.
2. Visually interpret and delineate land use – land cover classes on acetate overlay.
3. Field check delineated land use classes for accuracy and consistency.
4. Select training sites for each class based on manual classification and field surveys.
5. Complete Maximum Likelihood supervised classification following Principal Component Analysis of the image (see text).
6. Post process data (see text) to correct scattered misclassified pixels.
7. Check classified areas against imagery, field notes, and photographs.
8. Identify problem areas, make adjustments in image processing, and reclassify image.
9. Conduct second field survey to check classified areas for accuracy and to identify problems.
10. Make adjustments in image processing and reclassify image.
11. Transfer classified data to GIS for analysis and formatting final map.

Field Surveys

Field surveys were completed in March and August 1998. The Forest Department provided transportation for field work, and staff of the LIC accompanied the team to most field sites (see acknowledgments). The most frequently encountered land use/land cover types at visited field sites were Broadleaf Forest, Thicket, Farmland, Herbaceous Regrowth, and Savannah (Fig. 4; Appendix). More than 120 sites were examined and located using a Global Positioning System (GPS) (Fig. 5 and Appendix). In addition, a low-altitude overflight (Fig. 5) was made in a fixed-wing aircraft, and numerous photographs were taken for reference and comparison with imagery and classified units. Representative sets of photographs (slides) taken during field surveys are on file at the LIC.

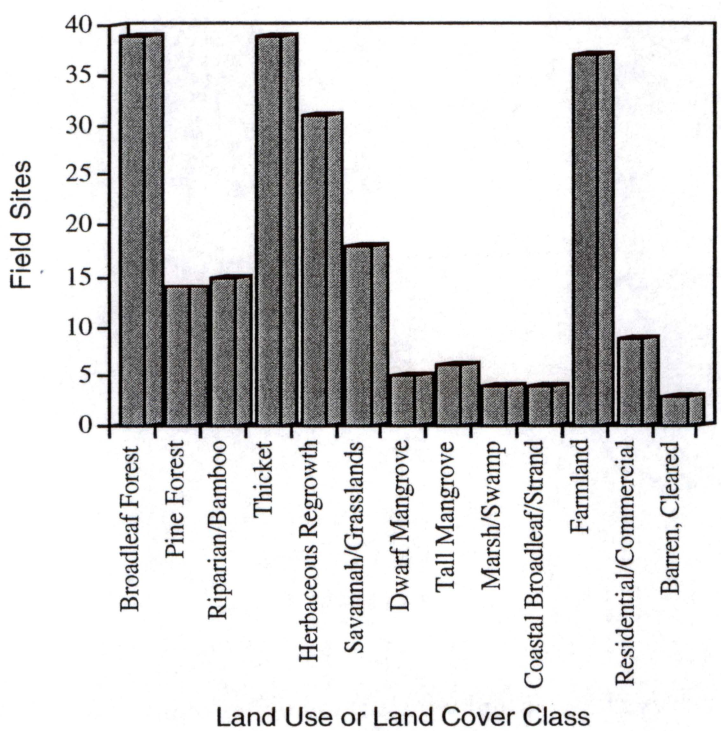

Figure 4. Number of field sites at which various land use and land cover classes were examined with reference to classes mapped on plots of the Landsat imagery.

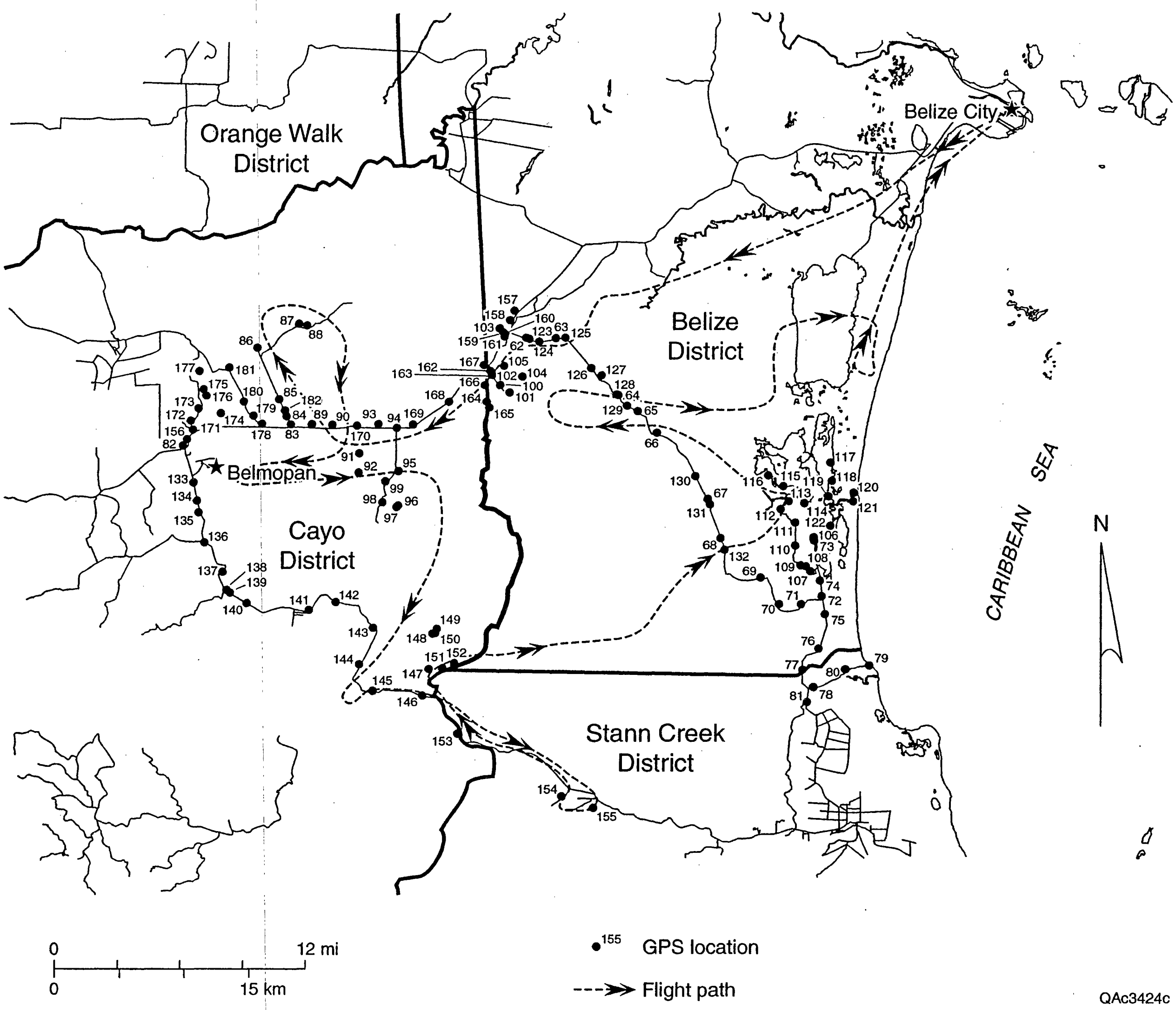

Figure 5. Location of field survey sites located with GPS and approximate location of flight line along which observations and photographs were made.

IMAGERY AND CLASSIFICATION APPROACH FOR 1996 LAND USE

Remotely Sensed Data from Earth Resources Satellites

The Landsat Earth Resources Satellite System has been operational since 1972, providing near-global coverage on a continuous basis. The first three Landsat satellites had an 18-day repeat orbit and carried a five-channel multispectral scanner (MSS) system that could acquire data at ~80-m spatial resolution. In addition to MSS, Landsats 4 and 5 (launched in 1982 and 1984) carry the seven-channel Thematic Mapper (TM) multispectral scanner, which acquires data in six channels at 30-m spatial resolution and the thermal channel at 120-m resolution. Each 185 km x 185 km scene contains information in the blue, red, near-infrared (two channels), mid-infrared (two channels), and thermal windows of the electromagnetic spectrum. Although the spatial resolution of Landsat TM is somewhat less than that of the three-channel (green, red, and near-infrared) French satellite SPOT, which was used for the Belize land cover study from 1989/92, the increased spectral information from the additional channels is often extremely useful for mapping vegetation and geologically related structures. Landsats 4 and 5 are currently operational. Landsat 7, which will also carry a TM sensor, is scheduled for launch in 1999 and will provide the opportunity for continued monitoring of change through a consistent data set.

Other instruments, including optical systems similar to Landsat TM, but with enhanced spectral and spatial resolution, are also planned for launch within the next 2 years. Additionally, synthetic aperture radar SAR, which has all-weather, day/night capability is now flying on three spacebased and several airborne platforms and is planned for three future systems by 2005. As an active instrument, radar provides additional capability for both vegetation and geologically based studies and potential for developing digital elevation models (DEMs).

Landsat Thematic Mapper Data in Belize Deforestation Study

The remote sensing component of the deforestation studies conducted by the BEG and CSR involved analysis of historical digital Landsat data. During the first study, data from eight scenes acquired over Belize in 1993, 1994, and 1996 were utilized to investigate changes from 1989-92 and 1994-96. The current study focused on more detailed classification of the area covered by Map 5 in the initial analysis.

Analysis of Landsat Thematic Mapper Data

Preprocessing of Landsat Digital Data

Several preprocessing steps were required to develop a radiometrically and geometrically consistent data set prior to analysis of the Landsat data. These included detection of clouds, normalization of data to mitigate the effects of atmospheric artifacts, and removal of instrument-related striping patterns.

Cloud Cover and Atmospheric Attenuation. As an optical sensor, Landsat TM imagery has inherent problems with cloud cover. Clouds must be detected and the area masked from further analysis. Although the spectral signature of clouds is distinct enough that thick clouds can usually be detected in the imagery, the data under the clouds in these imagery are lost to analysis.

Cloud shadows also distort imagery values. Detection of cloud shadows is often possible by using sun angle at the time of the overflight in conjunction with the shape of the clouds associated with shadows. However, automated identification of cloud shadows is extremely difficult and required knowledge of sun angles and satellite position. In this study, a combination of automated classification coupled with manual editing was required to handle this problem.

Atmospheric haze and thin clouds are also a problem for optical imagery. While features on the ground are not occluded as with thick clouds, their spectral values are modified. Numerical atmospheric models can theoretically be utilized to correct the data if radiosonde data are acquired simultaneously. However, for large areas where atmospheric water vapor varies across the scene, this approach is seldom practical, even if data can be acquired during an overpass. Alternatively, simple normalization techniques can often be used to provide an adequate minimal global "correction" to the imagery. These techniques involve either applying simple offsets to the entire image based on the values of each channel of a constant target or matching histograms of multiple targets. Histogram matching was investigated for this project but was not effective. Because no approach for normalization was adequate, no atmospheric correction was performed. Alternatively, training data for each class of target were selected from every year of data, and each image was classified independently.

Geometric Correction of Landsat Data. Multitemporal studies based on imagery require georeferencing of the data to a common coordinate system whereby all data at a given location on the ground are mapped to the same location in an image. For mountainous terrain, it is also important to include topographic information to adequately georeference data.

Ideally, all data in a multitemporal spatial data base would be registered to accurately known surveyed points, typically acquired via differentially corrected Global Positioning Satellite (GPS) data. The classification map contained in the 1989-92 report, as well as road and hydrologic maps should overlay the Landsat imagery if all data are properly georeferenced. Unfortunately, the maps were not currently well coregistered, and limited GPS data were available for correcting the entire data set.

When information is not available for adequate georeferencing, images are initially registered to each other. One scene is selected as the master scene and then the transformations required to map other scenes to the same geometric coordinates are computed. A set of common points called "ground control points" are manually selected from each image, and the optimal least squares polynomial transformation is computed to perform the image-to-image registration. The image data are then coregistered and can be mapped to whatever map coordinate system is available but later georeferenced again if necessary when new information is available.

For this study, image-to-image registration was performed and compared to GPS data acquired during the field visits. In general, there was good agreement with the GPS points, so the image-to-image registered data were used to develop the output maps. At a later date when additional GPS data and improved topographic information are available, the master image can be registered to these points; then the common transformation for the remaining images can be computed readily.

Instrument Artifacts in the Landsat Data. Sensor-dependent striping artifacts are often observed in Landsat data. The TM imagery for this study exhibited strong striping artifacts in many scenes that appeared to be caused by calibration of the raw data and were not as easily characterized or mitigated as for instrument-based striping problems. The data provided by EOSAT precluded investigation of specialized corrections. Striping manifested itself in misclassification of some imagery, although the effect on detecting deforestation was minimal. The effects were reduced, to some extent, by postprocessing the classification maps to correct erroneous results that had the same pattern as the striping artifacts.

Classification of Landsat Data

Automated classification of the Landsat data was performed where possible for both the original and updated study. A combination of the results from 1989/92, field data, and manual interpretation of imagery was utilized to select training sites for performing supervised classification of the imagery. In the initial study, which involved analysis of multiple scenes from three years, the classification phase of the analysis involved calculation of statistical features (principal components), classification of data from the statistically meaningful principal components, and postprocessing the classification map to remove local anomalously classified pixels.

Hierarchical Classification Scheme

The current study, which involves more detailed analysis of the single scene in 1996, utilized a hierarchical classification strategy whereby classes that were easily separable were extracted initially, then more similar classes were separated from each other in subsequent levels of the hierarchy. In all cases, maximum likelihood classification was performed on a subset of the principal components of the data.

1. Level 1 - water, land (all classes), clouds, and shadows were identified by the classifier. Data in the water and cloud classes were removed from the scene. Shadows associated with topography affected the spectral signatures of classes but were retained for analysis. Pixels associated with cloud shadows were removed from further analysis.

2. Level 2 - Land pixels were classified for the entire scene. Erroneous classifications were identified for training sites and where possible for other areas of the image using manual interpretation.

3. Level 3 - Subsets of the image where erroneous classifications occurred were reclassified using additional training sites within these subsets. Using local training sites often better discriminated between classes. This also provided a means of mitigating the effects of changes in reflectance associated with areas in shaded areas of rough terrain.

Principal Component Analysis

Principal component analysis (PCA) provides a means of not only reducing the dimensionality of a vector of multispectral data but also of providing better estimates of parameters when multiple channels are highly correlated and enhancing contrast between features.

Mathematically, PCA involves performing a rotational transformation (i.e., linear) of the data whereby the new axes are mutually orthogonal and aligned along the directions of decreasing variability in the original data. Statistically, the covariance matrix of the transformed data is diagonal, with values corresponding to the eigenvalues of the original covariance matrix of the multispectral data. The eigenvectors associated with each eigenvalue denote the weighting coefficients on the original channels. The advantage of PCA is that only the most significant components, as indicated by their variance (eigenvalues) can be selected for classification, thereby reducing the number of channels analyzed. In addition, particular components often correspond to specific features observed in the imagery. A three-channel principal component image typically is quite different in appearance from the display of any three-channel subset of the original data. PCA is often sensitive to histogram modification of data performed in multitemporal studies for matching constant targets between images as a means of atmospheric correction. Changes to the original data associated with the histogram modification result in changes in eigenvalues and thereby changes in classification results. Where possible, it is more desirable to perform physically based atmospheric correction using meteorological measurements.

Maximum Likelihood Classification

Classification of the selected principal components can be accomplished using many techniques. First, unsupervised clustering is typically performed to agglomerate the data into homogeneous groups and determine the separation between clusters associated with meaningful classes. This also aids in selection of the subset of PC's for further analysis. In this study, Isodata clustering, a common technique that involves iterative agglomeration, evaluation, and separation of data clusters, was utilized for this purpose.

Because training data were available, the final classification was performed via the Gaussian Maximum Likelihood (ML) classifier, the most common supervised classification technique. In maximum likelihood classifiers, pixels are assigned to preselected classes on the basis of a decision rule that maximizes the likelihood of having obtained the observed values, given the overall assignment of classes to the image. For Gaussian Maximum Likelihood classification, the likelihood function is defined by the normal distribution. Similar to Bayesian techniques, the goal is to assign each pixel to the class that has greatest probability of occurrence, given the observed data, the posterior probability. This probability is of course unknown. However, it can be computed from the product of the conditional probability of having observed the data if it had been drawn from a given class, the prior probability of having observed a given class, and a normalizing constant. The assignment which maximizes the resulting function, called the discriminant function, is selected. Although it is possible to use ML classification with data drawn from any population with any parametric, virtually all commercial packages assume that the data are distributed Gaussian. The validity of this assumption should be checked for each data set. Variations in implementation of ML classification allow selection of probability thresholds required for assignment of classes and separation requirements for individual classes. Pixels not satisfying the requirement are assigned to the "unclassified" class. The implementation utilized in this study also utilized a bias function which represented the overall separability of two classes to be selected subjectively.

Postprocessing of Classification Results

Because maximum likelihood classification assumes that each pixel is independent of its neighbors, no contextual information is utilized in assigning classes to pixels. The resulting classification map usually contains scattered misclassified pixels due to local outliers. For the first study, two postprocessing steps were performed which involved passing a 7x7 template followed by a 3x3 template over the classification map and assigning the central pixel to the class associated with the mode of the distribution of the classes. In the current study, only a 5x5 template was utilized in a single postprocessing step.

Selection of Training Sets

In the initial study, training sets were based on (1) the 1989/92 land use maps, (2) 1996 field surveys, and (3) visual interpretation of Landsat images. In the current study, additional training sites were selected from subsets of the data for the hierarchical classification scheme.

LAND USE DISTRIBUTION 1989/92 TO 1996 IN STUDY AREA

Digital analysis of the distribution of land use types shows broadleaf forest is the dominant land cover type in the study area (Plate 1 and Table 5). This land cover has an area of almost 200,000 ha, making up about 53 percent of the map area. In 1989/92, broadleaf forest classes composed about 61 percent of the study area (Table 6). The distribution in 1996 is generally similar to that in 1989/92 (Fairweather and Gray, 1994), with the exception of several areas along the Hummingbird and Coastal Highways that have been cleared primarily for orchards and other types of farmland. Locally, areas mapped as broadleaf forest in the 1989/92 project were classified as thicket on the 1996 imagery. In addition, some broadleaf areas were obscured by clouds in 1996 near Dangriga.

Pine forests occur on the coastal plain fringing the margins of savannahs, in scattered patches across savannahs, and in stands surrounded by broadleaf forest. Pine trees are also an integral part of the savannah land use class, and in many areas intergrade with thicket. Pines are common in sandy and gravelly soils that occur in terraces deposited along rivers, and in areas between La Democracia and Dangriga on the Coastal Highway. The pine forest class is not as extensively mapped on the 1996 imagery as on the 1989/92 land use maps. Percentages of pine forest on these two maps in the study area are 1.3 and 2.6 percent, respectively. Part of the difference is that broad areas of pine in the Dangriga area are obscured by clouds and thus unmapped on the 1996 imagery. Also, pines in the Mountain Pine Ridge Forest Reserve (Fig. 2) were not field checked and, thus, were not identified in the analysis and classification of land use.

Table 5. Areal extent and percentages of land use-land cover units classified using 1996 Landsat TM imagery.

Land Use/Land Cover	Area (ha)	Percent of Study Area
1. Forest and savannah		
Broadleaf forest	196,832	53.2
Pine forest	4,731	1.3
Riparian/bamboo	1,989	0.5
Natural thicket and secondary regrowth	13,055	3.5
Low secondary regrowth, herbaceous and scrub/shrub	5,192	1.4
Savannah and other grasslands	18,652	5.0
2. Wetland and coastal land		
Mangroves, tall to medium height	3,306	0.9
Mangroves, dwarf	4,522	1.2
Marsh/swamp	1,067	0.3
Coastal broadleaf and strand vegetation	6,882	1.9
Coastal Savannah	632	0.2
3. Developed land		
Farmland	23,428	6.3
Residential/commercial development	1,269	0.3
Barren	2,728	0.7
4. Other		
Water	68,006	18.4
Clouds and Shadows	17,872	4.8

Table 6. Areal extent and percentages of 1989/92 land use in study area. Based on data from Fairweather and Gray (1994).

1989/92 Forested and Woodlands Classes	Area (ha)	Percent of Study Area
Broadleaf	224,609	60.7
Bamboo/Riparian	2,881	0.8
Pine totals	9,689	2.6
Thicket	12,819	3.5
Mangrove, Dwarf	3,021	0.8
Mangrove, Tall	356	0.1
Barren/Thicket	47	0.01
Other	42,389	11.5
Subtotal	295,812	79.9
Water and other land use	74,406	20.1
Total	370,217	100.0

Riparian/bamboo vegetation is most abundant along the Sibun and Belize Rivers in the northwestern part of the map area. Vegetation with a similar spectral reflectance as riparian/bamboo also occurs in small, isolated polygons in areas of broadleaf forest in the north-central part of the map area. These anomalous areas comprise a small part of the total riparian/bamboo class. Total areas of riparian/bamboo on the 1996 land use and 1989/92 land use maps differ by about 1,000 ha. Broader, more continuous belts of riparian/bamboo were mapped along the Sibun and Belize Rivers in the 1989/92 project. Percentages of riparian/bamboo for 1996 and 1989/92 were 0.5 and 0.8 percent, respectively.

In coastal areas, mangroves are widespread and have a distinct spectral reflectance on the Landsat TM imagery. The distribution of tall and medium mangroves and dwarf mangroves on the map is in close agreement with those shown on maps by Zisman (1992). The total area of dwarf mangroves on the 1996 and 1989/92 land use maps are 4,522 ha and 3,021 ha, respectively (Tables 5 and 6). The area of medium to tall mangroves on the two maps is much different, however, with an area almost 3,000 ha larger occurring on the 1996 map. Much of the area mapped as tall and medium mangrove on the 1996 imagery was mapped as thicket on the 1989/92 land use map.

Farmland is the second most extensive type of land use in the study area (Table 5), with broad belts of farmland, principally orchards, occurring along the Hummingbird Highway between Belmopan and Dangriga (map). Savannahs and other grasslands compose about percent of the map area, with the largest occurrence extending inland on the coastal plain from Northern and Southern Lagoons (map). Herbaceous secondary regrowth is common along the western highway and east of Belmopan reflecting anthropogenic clearing of forests in those areas. The marsh/swamp class commonly occurs in association with depressions scattered across the coastal plain in savannahs.

SUMMARY AND CONCLUSIONS

Landsat TM imagery acquired by the LIC was used to classify land use and land cover in an area of central Belize encompassing parts of the Belize, Cayo, and Stann Creek Districts. A total of 14 land use/land cover units were classified and delineated using a maximum likelihood supervised computer classification, and principal component analysis.

Use of the 1996 Landsat TM imagery available through the LIC, provided a more up-to-date depiction of current land use relative to the 1989/92 land use maps. Many areas mapped as broadleaf forest on the 1989/92 land use maps had been cleared for agricultural and residential/commercial purposes by 1996. Among the most extensive changes were along the Western and Hummingbird Highways.

Reduction of the number of land use classes compared to the previous 1989/92 land use project increased the accuracy of delineated classes. Field surveys were essential in checking and revising delineations. Three to four iterations of the classified map were necessary to resolve problems and make corrections.

There is a margin of error inherent in image processing remote sensing data, and detailed on-the-ground analysis of a site may result in a revision of the land use class or boundary defined by imagery. The map and digital data are useful, however, in regional planning, resource management, and change analysis. Larger scale aerial photographs and field surveys should be used for site-specific land use information.

The success of the computer-assisted classification in this study indicates that land use and land cover can be classified on a regional basis in other areas in Belize to provide more up-to-date information on land use.

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APPENDIX. Location of field survey sites and land use/land cover class

GPS Site No.	Latitude			Longitude			Land Use/Cover Classes Identified at or near GPS site
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	
62	17	20	18.2	88	32	30.7	Thicket, Savannah (small)
63	17	20	18.1	88	31	15.1	Riparian/Bamboo, Broadleaf
64	17	17	55.5	88	28	32.3	Savannah, Thicket
65	17	17	16.9	88	27	41.2	Savannah with pine stands
66	17	16	21.7	88	26	51.2	Marsh
67	17	13	23.9	88	24	33.4	Thicket, Broadleaf
68	17	11	59.5	88	24	3.7	Thicket-Pine contact, Broadleaf
69	17	10	21.4	88	22	20.6	Savannah, bordered by stand of pines and palmettos
70	17	9	14.2	88	21	33.2	Farmland (citrus orchard)
71	17	9	15.1	88	20	35.5	Farmland (citrus orchard)
72	17	9	34.7	88	19	42.5	Thicket, Herbaceous Regrowth
73	17	11	53.7	88	20	3.8	Residential/Commercial Development
74	17	10	13.9	88	19	47.5	Barren (saltflat)
75	17	8	50.2	88	19	34.6	Savannah
76	17	7	22.7	88	19	49.9	Savannah, Thicket, Regrowth mixtures
77	17	6	28.9	88	20	30.2	Pine
78	17	5	45.5	88	20	1.6	Regrowth
79	17	6	41.3	88	17	39.5	Coastal Broadleaf and Strand Vegetation
80	17	6	30.5	88	18	39.9	Residential/Commercial Development
81	17	5	7.9	88	20	18.7	Riparian/Bamboo
82	17	15	40.7	88	47	16.9	Residential/Commercial, Regrowth, Broadleaf
83	17	16	36.8	88	42	36.7	Residential/Commercial, Regrowth
84	17	16	57.2	88	42	47.5	Farmland (citrus orchard), Broadleaf
85	17	17	39.8	88	43	7.9	Farmland (citrus orchard), Regrowth, Broadleaf
86	17	19	48.8	88	44	6.2	Riparian/Bamboo, Regrowth, Broadleaf, Farmland
87	17	20	49.9	88	42	17.5	Riparian/Bamboo, Broadleaf
88	17	20	46.5	88	41	57.3	Riparian/Bamboo, Broadleaf
89	17	16	37.6	88	41	42.6	Regrowth, Broadleaf
90	17	16	36.2	88	40	49.6	Regrowth
91	17	15	25.6	88	39	38.3	Broadleaf, Regrowth

GPS Site No.	Latitude			Longitude			Land Use/Cover Classes at or near GPS site
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	
92	17	14	37.1	88	39	40.1	Thicket, Regrowth
93	17	16	38.9	88	38	49.9	Residential/Commercial, Farmland, Regrowth
94	17	16	29.7	88	38	2.6	Residential/Commercial, Regrowth
95	17	14	41.2	88	37	56.9	Farmland (orchard), Regrowth
96	17	13	15.8	88	37	58.0	Farmland, Broadleaf
97	17	13	12.4	88	38	1.3	Riparian/Bamboo, Broadleaf
98	17	13	23.6	88	38	38.0	Farmland (citrus orchard)
99	17	14	15.9	88	38	30.1	Farmland (pastureland)
100	17	18	19.8	88	33	37.6	Riparian/Bamboo
101	17	18	1.2	88	33	13.6	Riparian/Bamboo
102	17	18	51.5	88	33	59.6	Pine, Thicket
103	17	20	41.9	88	33	39.0	Farmland (pastureland)
104	17	18	41.1	88	32	40.6	Farmland (orchard), Thicket, Broadleaf
105	17	19	7.1	88	33	28.0	Pine, Thicket
106	17	12	1.7	88	20	5.2	Residential/Commercial
107	17	10	37.4	88	20	12.1	Mangroves, Dwarf
108	17	10	49.4	88	20	24.5	Coastal Broadleaf, Mangrove fringe
109	17	10	53.1	88	20	37.6	Savannah
110	17	11	41.5	88	20	52.4	Coastal Broadleaf
111	17	12	39.8	88	20	53.2	Mangroves, Dwarf, Medium to Tall
112	17	13	12.5	88	21	29.9	Mangroves, Tall
113	17	13	32.9	88	21	9.0	Mangroves, Tall
114	17	13	28.0	88	20	29.6	Mangroves, Dwarf
115	17	14	9.8	88	21	24.1	Mangroves, Dwarf
116	17	14	37.4	88	22	2.9	Marsh
117	17	15	9.7	88	19	23.0	Barren area (saltpan)
118	17	14	24.1	88	19	18.2	Mangroves, Tall and Dwarf
119	17	13	45.4	88	19	27.5	Mangroves, Tall and Dwarf
120	17	13	55.7	88	18	22.7	Savannah and Marsh
121	17	13	34.4	88	18	23.8	Strand Vegetation
122	17	12	31.9	88	19	22.1	Savannah and Pines
123	17	20	15.7	88	32	23.0	Thicket, Pines

GPS Site No.	Latitude			Longitude			Land Use/Cover Classes at or near GPS site
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	
124	17	20	10.3	88	31	57.6	Thicket, Broadleaf
125	17	20	19.7	88	30	49.2	Farmland (citrus orchard), Thicket contact
126	17	19	4.2	88	29	41.4	Farmland (orchard), Regrowth contact
127	17	18	44.8	88	29	14.8	Broadleaf, Thicket
128	17	17	57.0	88	28	35.2	Savannah with Pine stands, Thicket
129	17	17	29.6	88	28	8.6	Marsh (fresh water)
130	17	14	34.2	88	25	10.8	Savannah, Broadleaf to Thicket
131	17	13	37.4	88	24	37.9	Broadleaf, Thicket, Savannah
132	17	11	30.1	88	23	54.0	Savannah, Thicket, Broadleaf
133	17	14	8.9	88	46	49.2	Regrowth, Farmland (Pastureland)
134	17	13	23.7	88	46	40.3	Farmland (cleared land), Regrowth, Broadleaf
135	17	12	54.4	88	46	35.6	Grassland (cleared, included in Savannah), Broadleaf adjacent
136	17	11	39.0	88	46	19.4	Regrowth, Farmland (cleared land), Surrounded by Broadleaf
137	17	10	26.7	88	45	31.0	Regrowth, Savannah (cleared land), Broadleaf
138	17	9	40.4	88	45	19.8	Farmland (cleared), Broadleaf
139	17	9	33.7	88	45	11.0	Regrowth
140	17	9	7.5	88	44	27.8	Cleared (Farmland) and Regrowth
141	17	8	52.2	88	41	46.8	Farmland (orchard) and Broadleaf
142	17	9	12.9	88	40	37.3	Regrowth and Thicket
143	17	8	8.2	88	38	59.4	Farmland (orchard), Regrowth
144	17	6	35.5	88	39	33.9	Farmland (orchard)
145	17	5	28.6	88	38	59.5	Broadleaf, Farmland (orchard), Regrowth
146	17	5	17.6	88	36	50.1	Regrowth, Farmland (orchard)
147	17	6	24.8	88	36	34.5	Farmland (orchard), Broadleaf
148	17	7	53.6	88	36	25.0	Broadleaf, Riparian/Bamboo
149	17	8	6.7	88	36	15.3	Farmland (orchard), Regrowth
150	17	7	55.3	88	36	18.2	Broadleaf, Riparian/Bamboo
151	17	6	27.1	88	36	0.2	Broadleaf, Farmland (orchard)
152	17	6	39.2	88	35	29.7	Regrowth, Farmland (cleared)
153	17	3	42.0	88	35	20.2	Broadleaf
154	17	1	7.1	88	30	49.7	Farmland (citrus orchard)
155	17	0	40.2	88	29	27.0	Broadleaf, Thicket, Regrowth, Riparian/Bamboo, orchards nearby

GPS Site No.	Latitude			Longitude			Land Use/Cover Classes at or near GPS site
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	
156	17	15	57.5	88	47	5.9	Thicket
157	17	21	26.9	88	33	2.9	Thicket, Pines
158	17	21	3.2	88	33	12.7	Pines, Thicket
159	17	20	32.1	88	33	29.6	Thicket, Pines
160	17	20	28.0	88	33	25.5	Pines, Grassland
161	17	20	21.3	88	33	27.0	Pines, Grassland
162	17	18	55.0	88	34	1.8	Thicket, scattered pines
163	17	18	44.0	88	33	58.2	Pines, Thicket
164	17	17	37.0	88	34	10.9	Riparian/Bamboo, Farmland (orchard)
165	17	17	22.5	88	34	4.7	Riparian/Bamboo, Broadleaf
166	17	18	18.7	88	34	15.4	Broadleaf, Riparian/Bamboo, Farmland (orchard)
167	17	19	9.7	88	34	19.2	Regrowth
168	17	17	37.0	88	35	48.6	Regrowth, Residential/Commercial
169	17	16	37.9	88	37	20.4	Thicket, Regrowth, Residential/Commercial
170	17	16	34.4	88	39	45.4	Barren area (cleared), Regrowth
171	17	16	21.8	88	46	50.5	Regrowth
172	17	16	44.4	88	46	56.8	Regrowth
173	17	17	15.4	88	46	37.2	Thicket
174	17	17	3.6	88	45	39.3	Savannah, Boadleaf
175	17	17	47.0	88	46	16.5	Grasslands, Regrowth
176	17	18	3.0	88	46	23.7	Riparian/Bamboo, Farmland (corn)
177	17	18	49.0	88	46	36.2	Broadleaf, Farmland (corn)
178	17	16	37.2	88	43	51.4	Regrowth
179	17	16	57.4	88	44	14.6	Broadleaf, Regrowth
180	17	17	34.1	88	44	39.0	Broadleaf
181	17	18	59.3	88	45	17.4	Farmland (cleared)
182	17	17	12.2	88	42	52.5	Thicket, Farmland (orchard)