Deforestation in Belize
1989/92 - 1994/96

Final Report

by

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INTRODUCTION

Belize has extensive forest and associated woodland resources characterized primarily by tall, highly diverse broadleaf forests, and secondarily by pine forests, low scrubby woodland areas, and abundant mangroves, (King and others, 1986, 1989, 1992; Zisman, 1992; Forest Department, 1993; and LIC, 1994). Among the environmental issues facing Belize are deforestation and the management of forest resources. Thousands of hectares of broadleaf forest have been cleared for agriculture and other purposes (Forest Department, 1993). Nevertheless, it is generally believed that the amount of deforestation that has occurred in Belize is much less than that has occurred in other rain forest countries.

The Ministry of Natural Resources of Belize, and its various components including the Land Information Centre (LIC), Forestry Department, and Lands and Survey Department recognized the importance of assessing the current distribution of forest cover and determining the extent of deforestation in order to document the magnitude of the problem and to provide quantitative information to assist in managing these valuable natural resources.

The main objective of this project, sponsored by the U. S. Agency for International Development (USAID), was to determine the extent of deforestation that has occurred in mainland Belize (fig. 1) between 1989/92 and 1994/96. Baseline data on forest cover in Belize in 1989/92 is from a preliminary report (LIC, 1994) and corresponding digital map data of land use available through the Land Information Centre (LIC), Ministry of Natural Resources. This earlier land use mapping project was completed by the Aerial Survey Section of the Lands and Survey Department of the Ministry of Natural Resources, and represents the most comprehensive analysis of land use that has been completed for Belize. Among the stated purposes of the land use inventory is to serve as baseline data for various types of environmental monitoring including deforestation.

Forest cover mapped as part of this investigation, and to which the 1989/92 land use maps were compared, is based on 1993, 1994, and 1996 Landsat imagery acquired by the LIC. The short duration of this project, March to mid-July 1996, limited it to being a reconnaissance study in

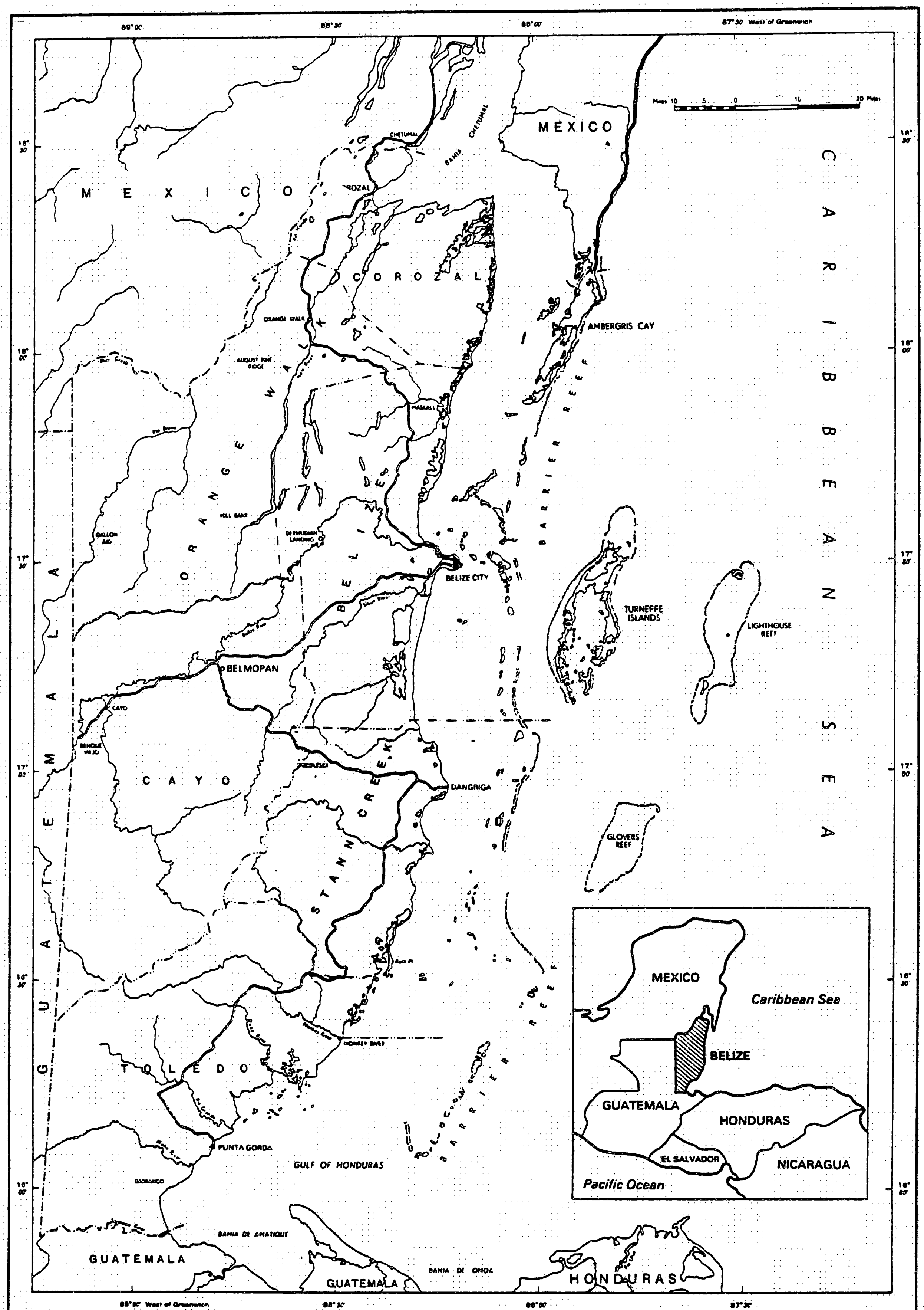

Figure 1. Map showing location of the six districts of Belize. From King and others (1989).

which the focus was primarily on mapping a single, all inclusive forest cover for comparison with the 1989/92 baseline data. Generalized forest classes, such as broadleaf forest, pine forest, mangrove and thicket, as well other land use classes were provisionally mapped. The analysis establishes a sound base for a more comprehensive investigation of specific forest classes as well as other land use classes throughout Belize.

METHODOLOGY

The methodology used in this investigation of deforestation was in large part determined by the stated reconnaissance objectives, and the type of data and time available. Forest cover was mapped by computer-assisted analysis (image classification) of recently acquired Landsat Thematic Mapper (TM) satellite imagery, and the results were compared to forest cover defined and mapped as part of the 1989/92 land use project based on visually interpreted SPOT satellite imagery. Forest cover classified from Landsat imagery was verified through limited field surveys and overflights in a fixed-wing aircraft, and from comparison with existing land use maps.

Although the approaches used in mapping land use and forested areas varied between the two projects, there had to be agreement in classification of forest cover for the determination of the rates of deforestation to be meaningful. The earlier land use inventory served as the baseline against which to measure change, and thus it set standards for forest cover classification.

Definition of Deforestation

Deforestation as defined in this study is the "permanent" removal of most of the natural tree cover of an area, and is more or less synonymous with land clearing (Ledec, 1992). According to Ledec (1992) logging is not considered to be outright deforestation but rather a type of forest modification or degradation. In Belize, types of deforestation range from large scale mechanized clearing of forest for agricultural purposes to smaller, slash-and-burn type clearings for temporarily shifting cultivation known as milpas. Although individual milpas are small in area, collectively they can form patchworks that cover large areas. Furthermore, these areas are typically reoccupied and cleared on a cyclical basis so that regrowth of natural vegetation is only temporary and recolonization by diverse species incomplete (Oswaldo Sabido, Belize Forest Department, personal communication, 1996).

It was decided early in this study by officers of the Forest Department in the Ministry of Natural Resources, that evaluation of areas undergoing logging should not be a separate topic of study, and the primary focus should be on overall evaluation of forest cover loss.

Analysis of Forest Cover Changes Using GIS

The 1989/92 land use information is stored in a digital Geographic Information System (GIS), in which the data can be spatially-referenced and compared to more recent forest distribution patterns. Forest cover mapped as part of the current investigation is based on more recent Landsat Thematic Mapper (TM) imagery provided by the LIC and analyzed and classified by the Center for Space Research (CSR) at The University of Texas at Austin. All computer-based data, including that from the 1989/92 land use and that generated during the current mapping effort, were incorporated into a GIS, ARC/INFO, for analysis of deforestation by the Bureau of Economic Geology (BEG), The University of Texas at Austin.

The digital information generated in this study is stored in the LIC GIS, where it can be used in environmental planning, management, and monitoring of forest resources. In addition, sets of 1:100,000 scale forest cover maps and imagery that covers all of Belize are on file at LIC and the Forest Department. The forest cover maps are based on processing of 1994 Landsat TM imagery, which provided the best overall coverage of the entire country. The other set of data consists of true color plots of the most recent cloud-free imagery (1994 for northern Belize and 1996 for southern Belize) that was obtained by the LIC.

LAND USE OF BELIZE 1989/92

The 1989/92 land use inventory (LIC, 1994) is the baseline data against which change in forest cover was measured in this project. Hence, the methods used in delineating forested areas in the previous study are briefly described for comparison with methods used during this study.

General Methodology of 1989/92 Study

The methodology used to map land use in Belize in 1989/92 is described in detail in the Land Information Centre report (LIC, 1994). In general, the land use information is presented in a series of thematic maps covering the mainland of Belize. It was derived from the interpretation of remotely-sensed SPOT XS (multi-spectral) data printed at a scale of 1:50,000. SPOT XS sensor bands 1, 2, and 3 were assigned to red, green, and blue, respectively, to produce a false color composite image from which prints were made for interpretation of various land use types, such as Broadleaf forest (LIC, 1994). The ground resolution of SPOT imagery is 20 m, which is a higher resolution than the 30 m Landsat TM data, but the spectral range of TM exceeds that of SPOT allowing a more refined discrimination of land use classes.

Because of the difficulty in obtaining cloud-free SPOT images of the entire country, the baseline study produced a mosaic of Belize from images acquired at different times. The dates of SPOT imagery acquisition vary from 1989 to 1992, with most of the 1989/90 imagery covering central and southern Belize, and 1992 imagery covering northern and portions of central Belize (fig. 2).

Land use classes were interpreted by project staff and delineated on acetate overlays on the SPOT false color composite prints, with a minimum mapping unit of 0.25 cm x 0.25 cm at a 1:50,000 scale. Interpretation of land use types were supported by other data sources such as aerial photographs, and maps of forests, mangroves, and land use of the Belize River Valley (LIC, 1994). Field work was an integral part of the interpretative work, although field verification was not comprehensive.

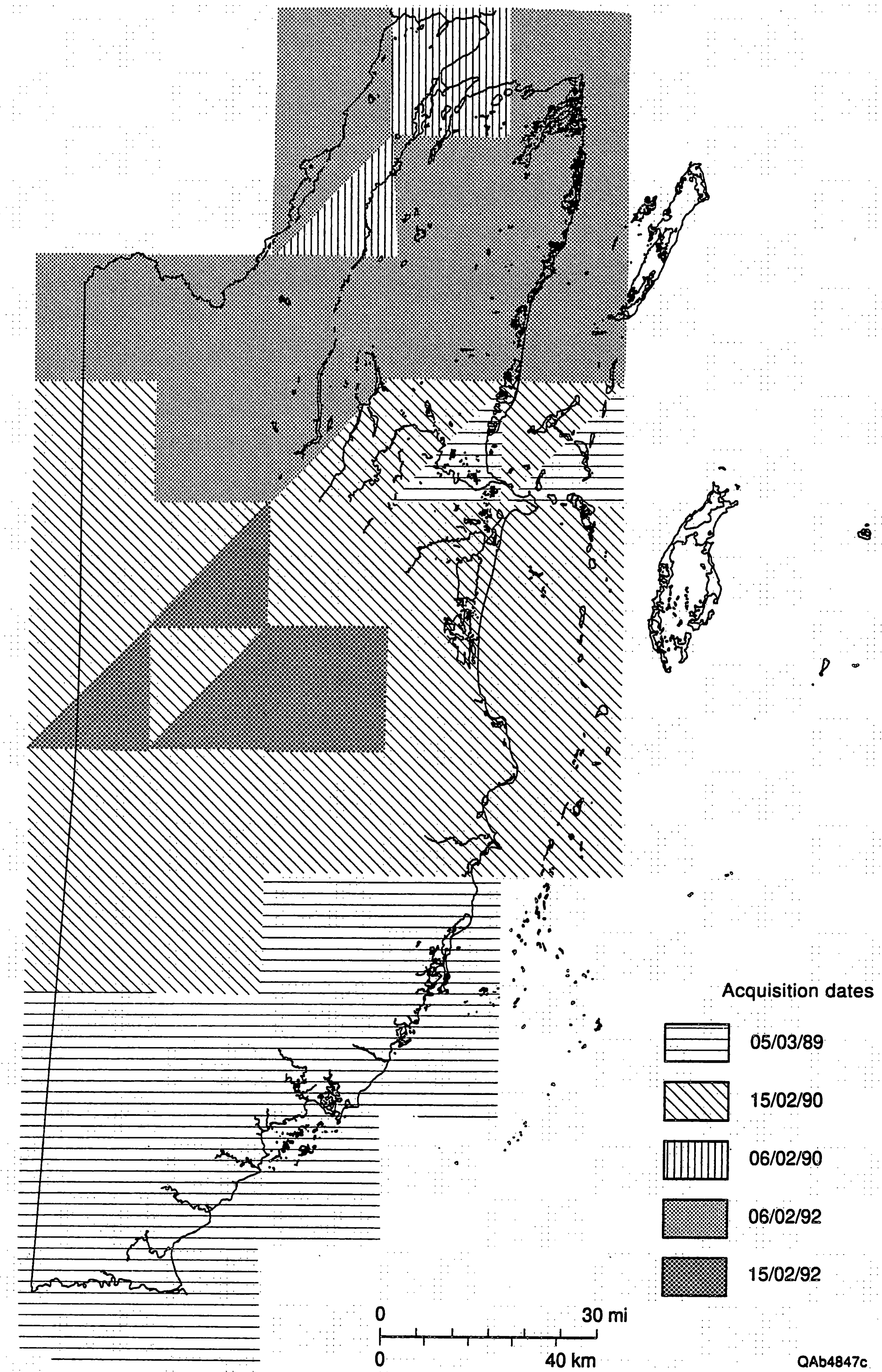

Figure 2. Coverage of 1989-1992 SPOT imagery. From LIC (1994).

Delineated areas were digitized into a GIS from which a series of 8 color maps (fig. 3) were printed at a scale of 1:200,000 and included in the preliminary report on land use (LIC, 1994). Also included in the report is a composite full-color land use map of Belize at a scale of 1:1,000,000.

Land Use Classification 1989/1992

The land use classification developed for the 1989/1992 land use report (LIC, 1994) contained five main classes: Urban, Agricultural, Range Land, Forest and other Wooded Areas, and Unproductive Land. Each was subdivided into sub classes. Twelve principal forest and wooded classes were defined (table 1). Together the forest classes cover 17,214 km^2, or 79 percent of the land area (table 1).

Among the problem areas cited in the baseline study (LIC, 1994) in distinguishing classes on the Spot imagery were (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, and (5) classes covering small isolated areas, such as shifting cultivation. Specific problems in delineation of classes included separating broadleaf forest from thicket, and separating certain types of clearing such as shifting cultivation, clearing for farming, and herbaceous and scrub, secondary regrowth after farming or clearing. Many of these problems were also encountered in this study as noted in a following section.

The earlier mapping project included various mixed classes, for example Broadleaf/Pine forest. A total of 80 classes were included in the final legend. The digital (GIS) data includes all 80 classes, but only 40 are listed in the printed report, and 28 are shown on the full-color maps (LIC, 1994).

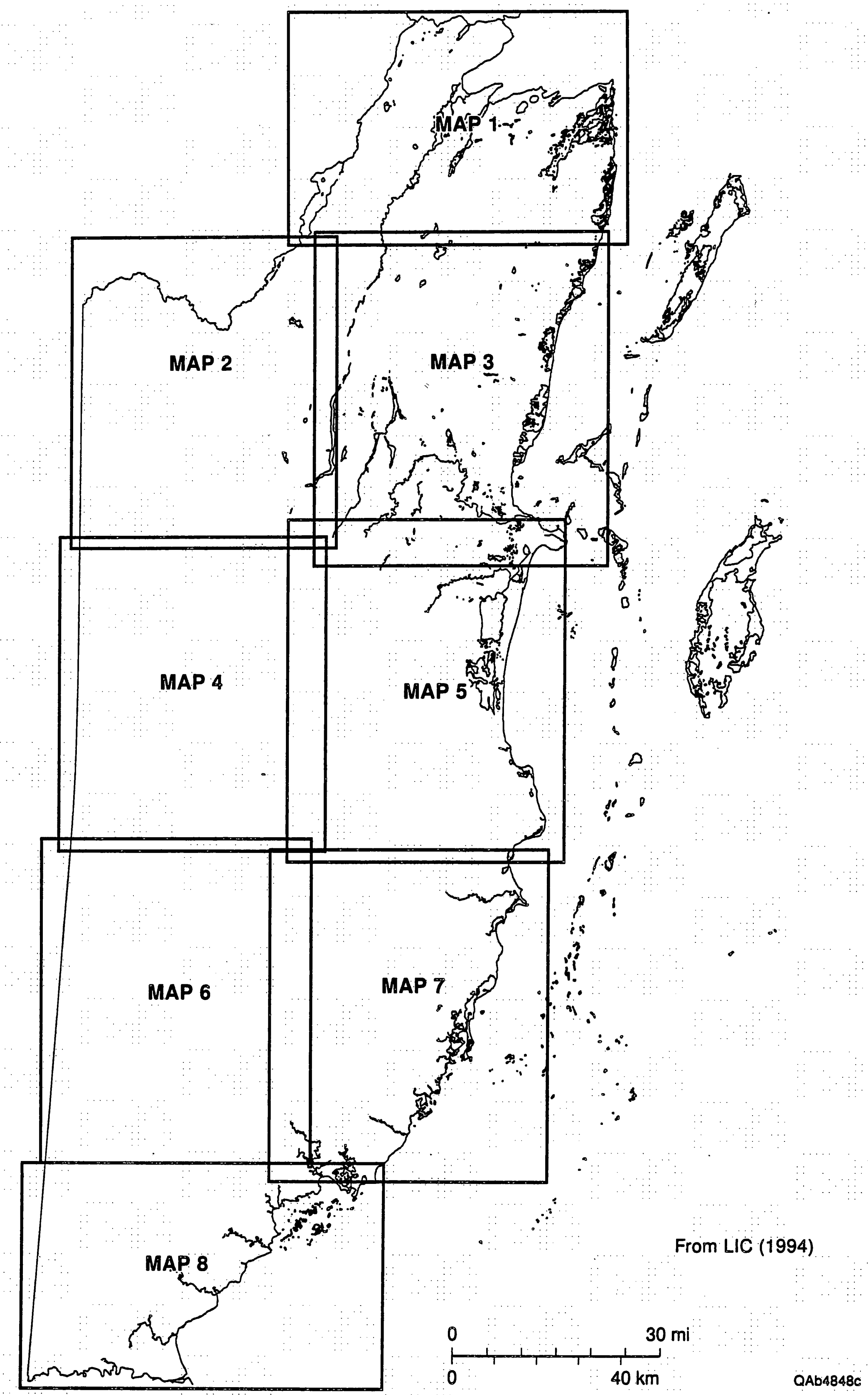

Figure 3. Index map showing number and location of map sheets covering mainland Belize. From LIC (1994).

Table 1. Forest classes, areas, and percentages for Belize mainland. From LIC (1994)

Forest Class	Area (hectares)	Area (acres)	Area (Sq. Km)	Percentage of land area
Broadleaf Forest	1,419,000	3,503,704	14,190.00	65.12
Open Broadleaf forest	12,031	29,705	120.31	0.55
Pine Forest	57,625	142,283	576.25	2.64
Open Pine Forest	7,307	18,041	73.07	0.34
Thicket and other degenerated Broadleaf Forest	84,838	209,477	848.38	3.89
Herbaceous and Scrub, secondary growth after clearing	18,859	46,564	188.59	0.87
Bamboo and Riparian Vegetation	11,527	28,462	115.27	0.53
Coastal Strand Vegetation	2,483	6,131	24.83	0.11
Mangrove, Medium and Tall	7,820	19,308	78.20	0.36
Mangrove, Dwarf	23,460	57,925	234.60	1.08
Saline swamp vegetation, with palmetto and mangrove	34,487	85,152	344.87	1.58
Marsh swamp	41,963	103,613	419.63	1.93
Total of forested areas	1,721,398	4,250,366	17,213.98	79.00

FOREST COVER OF BELIZE 1993/94/96

General Methodology

The methodology used in the present reconnaissance study to map forest cover for more recent periods, 1993/94/96, differs significantly from the previous land use mapping project (LIC, 1994). The earlier project was a long-term investigation in which a total of 80 separate land use classes were visually interpreted, delineated, and manually digitized. The current investigation of deforestation was one of short duration, in which primarily forested areas were classified through digital statistical methods applied to Landsat Thematic Mapper (TM) data. When time is a constraint, classification of large geographic areas can only be accomplished through computer-assisted methods.

Landsat Imagery

Landsat images were acquired for the years 1993, 1994, and 1996 by LIC. The original plans of the project were to process and classify forested areas on 1993 and 1995 imagery. However, two different sets of 1995 Landsat imagery proved unacceptable because of clouds and striping, and the LIC opted to obtain 1996 imagery instead. With this more recent imagery in mind, and because the 1994 imagery was more cloud free than that acquired in 1993, we decided to use the 1994 imagery throughout the country for comparison with that acquired in 1996, and to use the 1993 imagery for supplementary purposes.

Problems in obtaining the 1996 imagery from the supplier, however, delayed the project and postponed the period of field work and field verification. The imagery was still not available by mid May and the field work had to be accomplished using the 1994 classified imagery. The 1996 imagery arrived and was on hand when the field team was in Belize, but prints were not available for use in the field. In addition, the 1996 imagery for northern Belize was not usable because of cloud cover. Of the 1996 imagery, only the scene covering the southern half of Belize was analyzed. Landsat coverage and acquisition dates are shown in figure 4 and table 2.

Landsat Thematic Mapper

Background

The Landsat Earth Resources Satellite System has been operational since 1972 providing near global coverage on a continuous, regular basis. The first three Landsat satellites had an 18 day repeat orbit and carried a 5 channel multispectral scanner (MSS) system which could acquire data at ~80 m spatial resolution. In addition to MSS, Landsats 4 and 5 (launched in 1982 and 1984) carry the 7 channel Thematic Mapper (TM) multispectral scanner which acquires data in 6 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 (2 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 3 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, particularly when there are water bodies in a scene. While Landsats 4 and 5 continue to be operational, the follow-on series which includes TM and additional sensors has long been planned. The launch of Landsat 6 in 1995 was unsuccessful. Landsat 7 is scheduled for launch in 1998.

Landsat imagery is provided both in hard copy, where any combination of 3 bands can be displayed simultaneously, and in 8 bit digital format. All six bands of 30 m digital data were used to map land cover in this study. Two or three scenes are required to cover Belize. A total of eight scenes were used for mapping in 1993, 1994, 1996. Dates of acquisition of these scenes are shown in table 2.

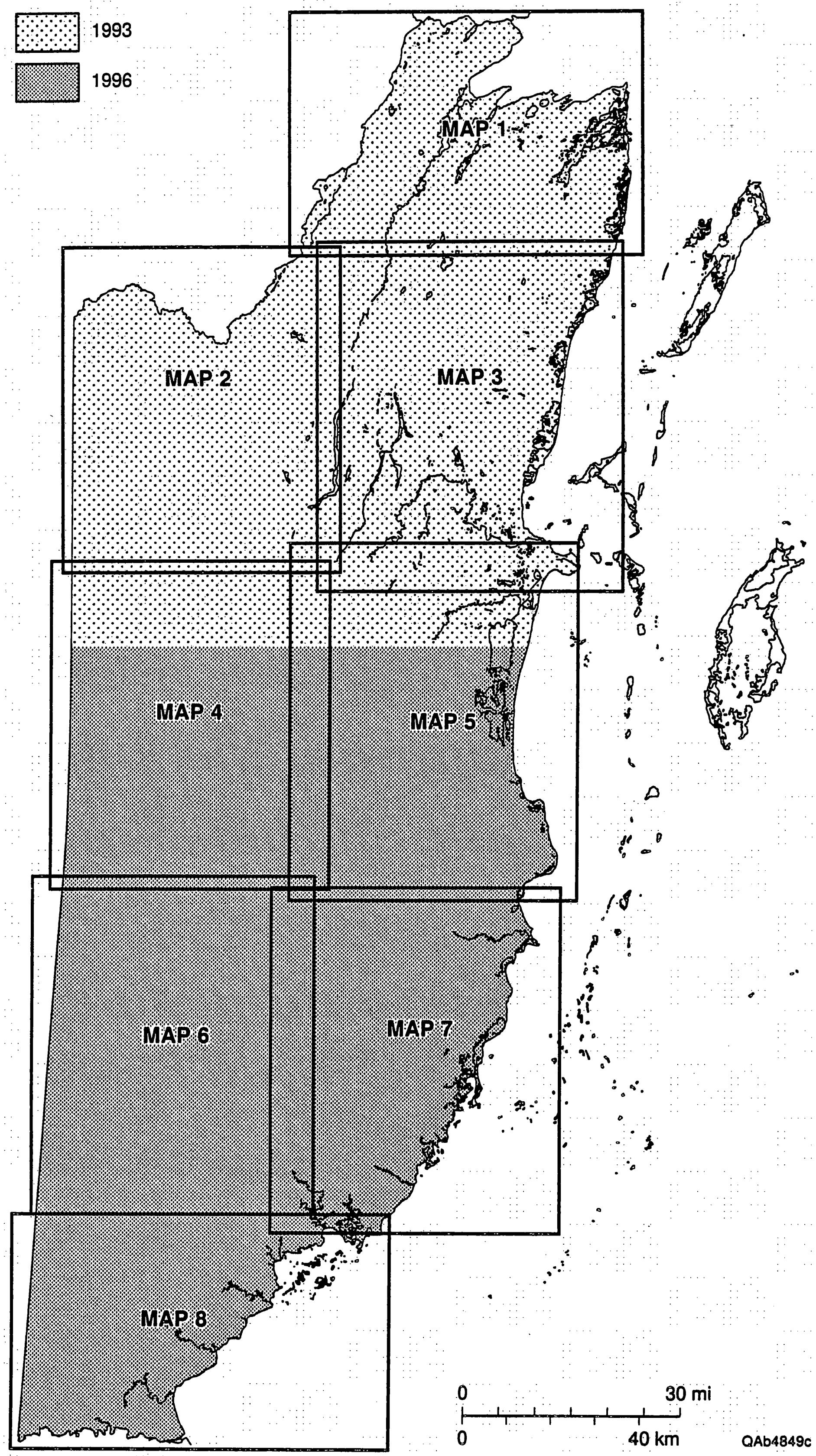

Figure 4. Landsat coverage for 1993 and 1996 imagery used in this study. The 1994 imagery was classified for the entire country.

Table 2. Dates of acquisition of Landsat TM scenes.

North	Central	South
93/4/10	93/4/10	93/3/17
94/3/28	94/3/28	94/3/28
96/3/17		96/3/17

Cloud Cover and Atmospheric Attenuation of Signal

As with the SPOT, Landsat TM data can be contaminated by cloud cover. This problem is usually dealt with by either using individual cloud free scenes from different dates or via mosaicing of imagery whereby clouds are detected, then multiple images are combined into a single scene to obtain as nearly cloud free coverage as possible. Only one scene was provided for each year of this study, so it was not possible to use this technique. Although the spectral signature of clouds is distinct enough that the clouds can usually be detected in the imagery, data under the clouds in these imagery is lost to analysis.

Cloud shadows also distort imagery values. Detection of cloud shadows is often possible by using the sun angle at the time of the overflight in conjunction with the shape of the clouds associated with shadows. Algorithms for such detection perform best when utilized with raw data which has not been transformed to a coordinate system utilized for mapping. The data analyzed in this project were already projected prior to delivery. Automated detection of cloud shadows was beyond the scope of this project.

Atmospheric haze and thin clouds are a problem for Landsat as well as SPOT imagery. While features on the ground are not occluded as with thick clouds, their spectral values are modified. Atmospheric correction codes can often be employed to normalize the data using local meteorological data, including information from radiosondes concurrent with the satellite pass. This information was not available for this study. Alternatively, simple normalization techniques can often be used to provide minimal "correction" for the imagery. These techniques typically involve either applying simple offsets or piecewise linear trends to the image based on the values in each of a constant target channel or matching histograms of multiple targets. Histogram matching was investigated for this project, but was not effective.

Instead, an unsupervised atmospheric correction algorithm based on a darkest pixel method was employed to normalize the data. The darkest pixel in the visible blue or green band was used as an indicator of the amount of "haze" present in the atmosphere. After a haze determination was made, a scattering coefficient was applied to each of the bands, and the result was subtracted from the top of the atmosphere radiance.

The actual amount of radiance at the top of the atmosphere was computed by first applying a sensor offset and gain to the digital counts. The value of the surface reflectance was then calculated using the determined radiance and haze terms, as well as the Earth-Sun distance and solar zenith angle. Finally, the resulting data was converted to common range of values prior to geometric correction.

While this method was reasonably effective in normalizing the imagery collected in different years, training data for each class of landcover were selected from each year of imagery for the classification stage in order to minimize any classification error from inadequate atmospheric correction. Training sites for classification were chosen from stable, homogeneous areas, and the same geographic locations were used for each image in order to maintain consistency through the multitemporal analysis.

Geometric Correction

Multitemporal studies based on imagery require registration (mapping) to a common coordinate system whereby all data at a given location on the ground are mapped to the same x,y location. Image-to-image registration involves selection of one scene as the master scene and then computing the transformation required to map other scenes to the same geometric coordinates. For the TM data analyzed in this study, ground control points (GCP's) were manually selected from each image, and a polynomial transformation was computed to perform the image-to-image registration via least squares warping.

Ideally, all data in the multitemporal spatial data base would be coregistered to accurately known surveyed points, typically acquired via differentially corrected satellite-based Global Positioning System (GPS) data. The classification map contained in the 1989-92 report as a vector file, as well as road and hydrologic maps should overlay the imagery. Unfortunately, the maps are not currently well registered, and limited GPS data are available for correcting the entire data set. This should be a focus of future work on the national Geographic Information System (GIS). 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, as additional GPS data are acquired, the master image can be registered to these points, then the common transformation for the remaining images can be computed readily.

Striping

In addition, the TM imagery also exhibited a striping effect in many scenes. Striping appeared to be an artifact of calibration, not a simple sensor dependent effect as is often observed in Landsat MSS data. The state of processing of 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.

Classification Approach

Limited budget and the short contract period for this project necessitated use of automated image classification techniques wherever possible. Only limited reconnaissance was performed to obtain field data, so a combination of the results from 1989-92, field data, and manual interpretation of imagery were utilized to select training sites for classification of the imagery. The classification phase of the analysis involved computation of principal components, classification of a subset of principal components, and post processing to remove local anomalously classified pixels. Each stage is described in the following subsections.

Principal Component Analysis

Preprocessing of data for classification included apriori selection of input bands and features for training and output classes. The selection of inputs and outputs was synergistic. Knowledge of the output classes provided information as to which bands, or combinations of bands, should be selected for the input feature vector based upon that band's class discrimination capabilities. Likewise, knowledge of the input bands provided a basis for choosing the range of output classes from general to specific.

The channels of Landsat data often contain redundant information for different landcover types. In addition, computation increases substantially as the number of bands increases. We computed the sample correlations between bands to identify the most appropriate combinations and eliminate redundancy. This assessment then allowed the number of inputs to the classifier to be reduced through either band selection or band transformation. Band selection is the process whereby the classifier inputs are selected from an input vector of the available bands. Band transformation involves mapping of the input vector to an alternative set of bands, typically of lower dimensionality. Based on preliminary classification results, we decided to use band transformation called Principal Component Analysis (PCA) for this study. This transformation provides a means of not only reducing the dimensionality of a vector of multispectral input data, but also of providing better estimates of parameters when multiple channels are highly correlated and enhancing contrast between features. The technique can sometimes enhance variation in change detection studies of multi-temporal data.

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. The technique is often successful in change detection studies of multitemporal data.

Mathematically, PCA involves performing a rotational transformation (i.e. linear) of the data whereby the new axes are aligned along the directions of decreasing variability in the original data and are orthogonal to each other. 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.

Maximum Likelihood Classification

Classification can be performed on the selected principal components via either unsupervised or supervised techniques. Trial clustering is typically performed to determine the separation between clusters associated with the various components and selection of relevant PCA's. Training data are selected for use by subsequent supervised techniques.

Maximum Likelihood Classification (ML) is the most common supervised classification technique. Pixels are assigned to preselected classes based on a decision rule which maximizes the likelihood of having obtained the observed values given the overall assignment of classes to the image. The goal is to assign each pixel to the class that has greatest probability of occurrence given the observed data. Although it is possible to use ML classification with data drawn from any population with any parametric or nonparametric distribution, virtually all commercial packages assume that the data are normally distributed. This assumption should be checked for each application. 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.

Post Processing of Classification Map

Because ML classification assumes that each pixel is statistically 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 this study, two post processing 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. This operation successfully reduced the noise in the classification map.

Selection of Training Sets

Training sets were based on (1) the 1989/92 land use maps, (2) 1996 field surveys, and (3) visual interpretation of Landsat images. Because the 1989/92 land use maps were the baseline data, selecting training sets from these maps was important in order to standardize classified units for comparison. Areas that appeared to be misclassified in the 1989/92 data sets, based on visual examination of recent images, were avoided.

Field Surveys

Field surveys were conducted during the weeks of March 18-21 and May 20-24. The Forest Department provided transportation and a forest officer accompanied the team to all field sites (see acknowledgments). Ground locations were determined by GPS (fig. 5). Three low altitude overflights were made in a fixed-wing aircraft and hundreds of slides were taken for reference and comparison with imagery and classified units. Representative sets of the slides are on file at the LIC. Flights were made over northern, central, and southern Belize (fig. 6). GPS locations were taken during two overflights (northern and southern Belize), but most areas photographed were located by comparing landscapes with plots of the 1994 Landsat imagery.

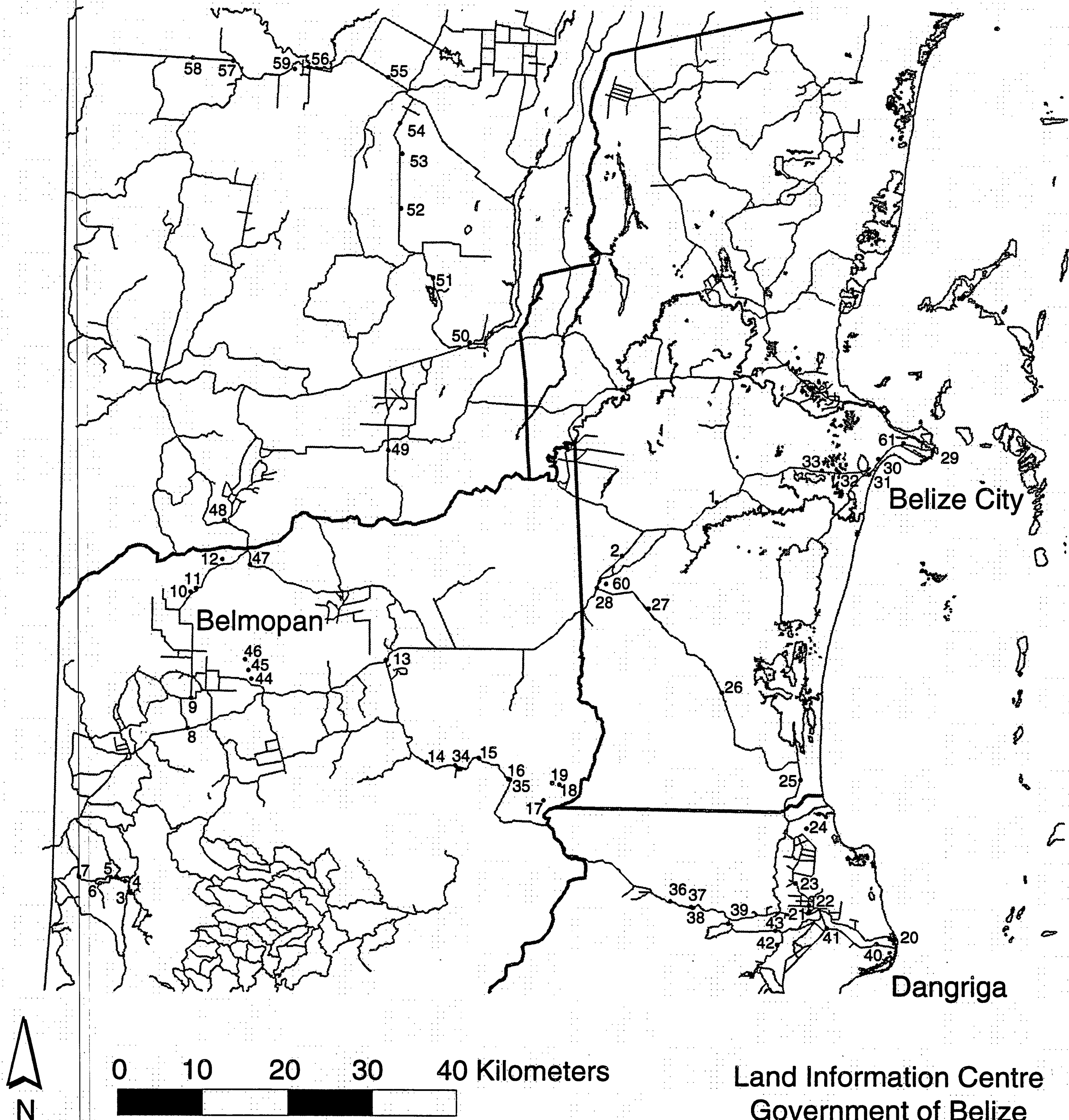

Figure 5. Field survey sites located with GPS.

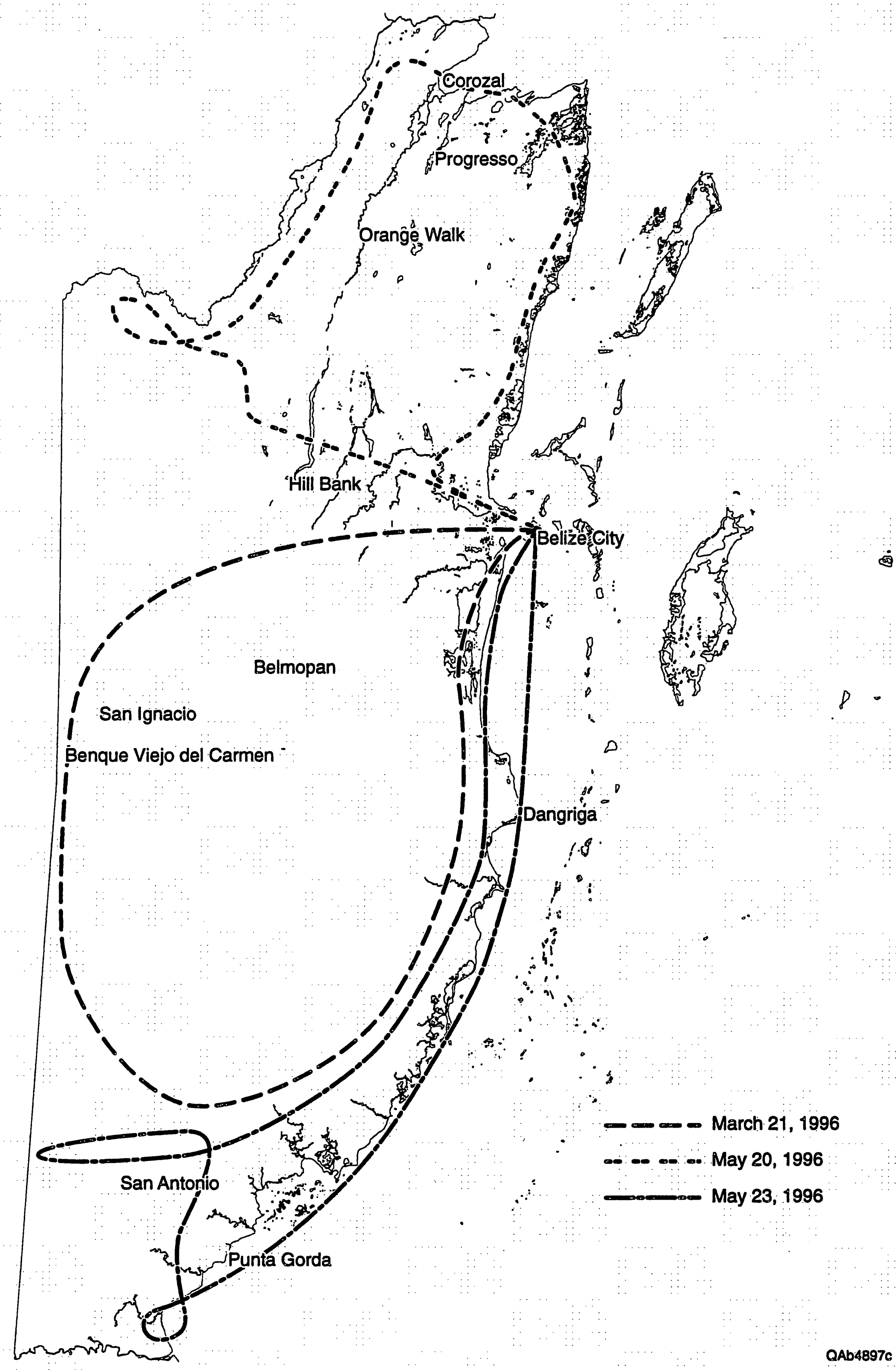

Figure 6. Approximate location of flight lines along which observations and photographs were made of land use in March and May, 1996.

Forest Cover Classification

Both forested and non forested areas on the Landsat imagery were classified on a provisional basis, resulting in a total of 17 classes for most scenes (table 3). The main emphasis of the classification was on total forest cover, however, and specific classes should be regarded as preliminary because time constraints prevented evaluation of the accuracy of classified areas except to verify whether or not they depicted forested areas. Plots of the classified imagery are on file at the LIC as working copies that may be of value in future projects, but they should be used with the understanding that refinements are needed that were beyond the scope of this project.

Table 3. Forested and non forested classes delineated through analysis of the digital Landsat TM imagery.

0	Unclassified
1	Urban
2	Barren
3	Road
4	Regrowth
5	Thicket
6	Broadleaf forest
7	Pine Forest
8	Mangrove
9	Swamp
10	Marsh
11	Savannah
12	Pasture
13	Agriculture
14	Orchards
15	Riparian
16	Rivers

Based on visual and computer assisted interpretation of imagery supported by field observations, we simplified the types of forests into five major classes, which when combined represent forest cover (table 4).

Table 4. Five major forest classes mapped using Landsat imagery.

Broadleaf Forest
Pine Forest
Thicket
Riparian
Mangrove

Comparison of 1989/92 with 1994/96 Forest Cover

Comparison of forest classes defined in this study (table 4) with those in the land use study (table 1), shows that open and closed broadleaf forests were combined into a single broadleaf forest class, and open and closed pine forests were combined into a single pine forest class. In addition, several of the forest or woodland classes listed in table 1 were not included as a forest cover class, e.g., herbaceous and scrub, secondary growth after clearing; coastal strand vegetation; saline swamp vegetation; and marsh swamp. Examination of Landsat imagery indicated that these classes, in general, did not correspond with interpreted and classified forested areas.

The major forest classes listed in table 4 were the most easily defined through image processing of the Landsat TM scenes, and had the best correlation with the modified forest classes (see previous paragraph) defined on the 1989/92 land use map series. Still, there were many locations on the two forest inventories where forest boundaries did not coincide because of interpretative differences. These "apparent" changes (not real) are the result of differences between the manual interpretation of the SPOT and interpretation of the spectral responses in the TM data. Specific problems were similar to those outlined in the 1989/92 land use report (LIC, 1994):

Separating Broadleaf Forest from Thicket
Separating secondary regrowth areas from Broadleaf Forest and Thicket
Maintaining consistency in classifying areas of varying density of cover, i.e., Open Broadleaf and Open Pine Forest

In conducting the supervised classification of the Landsat TM imagery, most training areas (representative sites that define a particular forest or land use class based on spectral properties) were derived from the 1989/92 land use maps. Overall, the 1989/92 maps serve as an excellent data base and were essential in selecting training areas for digital image classification of the Landsat TM scenes. There were obvious classification inconsistencies, however, that had to be reconciled. These areas, if unrecognized, would affect the supervised classification of the recent imagery, as well as present misleading information on changes in forest cover. For example, a large savanna southwest of Belize City was classified as thicket on the land use maps. Because this area was classified as a savanna on the 1994 imagery, there appeared to be a loss in forest cover (thicket) from 1992 to 1994. Another example is in northwestern Belize along the Rio Hondo River. Broad forested areas along the river were classified on the land use maps as sugarcane. Accordingly, comparisons of the 1989/92 land use maps with the 1994 maps show an apparent (not real) gain in forest cover.

The 1994 Landsat imagery and classified maps were incorporated into the GIS and prints of each were made at a scale of 1:100,000 with coverage as indexed in figure 3. These preliminary maps were for (1) use in field surveys, (2) for comparison with the 1989/92 baseline maps, and (3) for verifying the accuracy of training sets and classified areas. Plotted maps of the imagery, forest and nonforest classes, and overlays composed a suite of maps totaling 24 (three sets for the 8 map areas in fig. 3) of the entire country. The maps in conjunction with the field surveys were essential in modifying inputs to the classification, adding or deleting training sets to improve the accuracy of the classification. Several iterations of analysis were required to achieve satisfactory results. A composite map of forest cover of Belize, based on 1994 imagery, is shown in figure 7.

Maps in which GIS information layers depicting forest cover for the 1989/92 baseline maps and the 1994 Landsat maps were superimposed proved particularly useful in analyzing trends. This allowed areas in which there were losses or gains in forest cover to be visually examined and compared to the baseline maps, Landsat TM imagery maps, and field sites to assess the nature of the changes and to verify whether they were the result of actual changes in land use or problems in classification, cloud cover, registration, or cartography (eg. differences in the position of class boundaries resulting from digitization and map preparation). For example, clouds and shadows over forested areas produced an apparent loss in forest cover when compared to the baseline data. These and similar losses that were not real were deleted from the maps showing forest cover loss and eliminated from the analysis. This process greatly reduced the cumulative apparent loss by eliminating many areas in which the losses were the result of factors, such as differences in classification or cloud cover, noted previously. Although the "non real" losses were deleted from the forest loss GIS files, the reconnaissance nature and time limitations of this project prevented us from systematically correcting either the baseline data or the image processed data.

FOREST RESERVES AND OTHER PROTECTED AREAS

Differentiation of forest cover changes on national and private lands was an objective of this investigation. Available digital files include boundaries for national and private lands within protected areas (fig. 8), but do not distinguish between national and private lands outside of the protected areas. Accordingly, losses in the protected areas, such as national forest reserves and private reserves, are spatially defined and tabulated; losses outside these protected areas are not differentiated as having occurred on national or private lands, but are described as having occurred in non-protected areas.

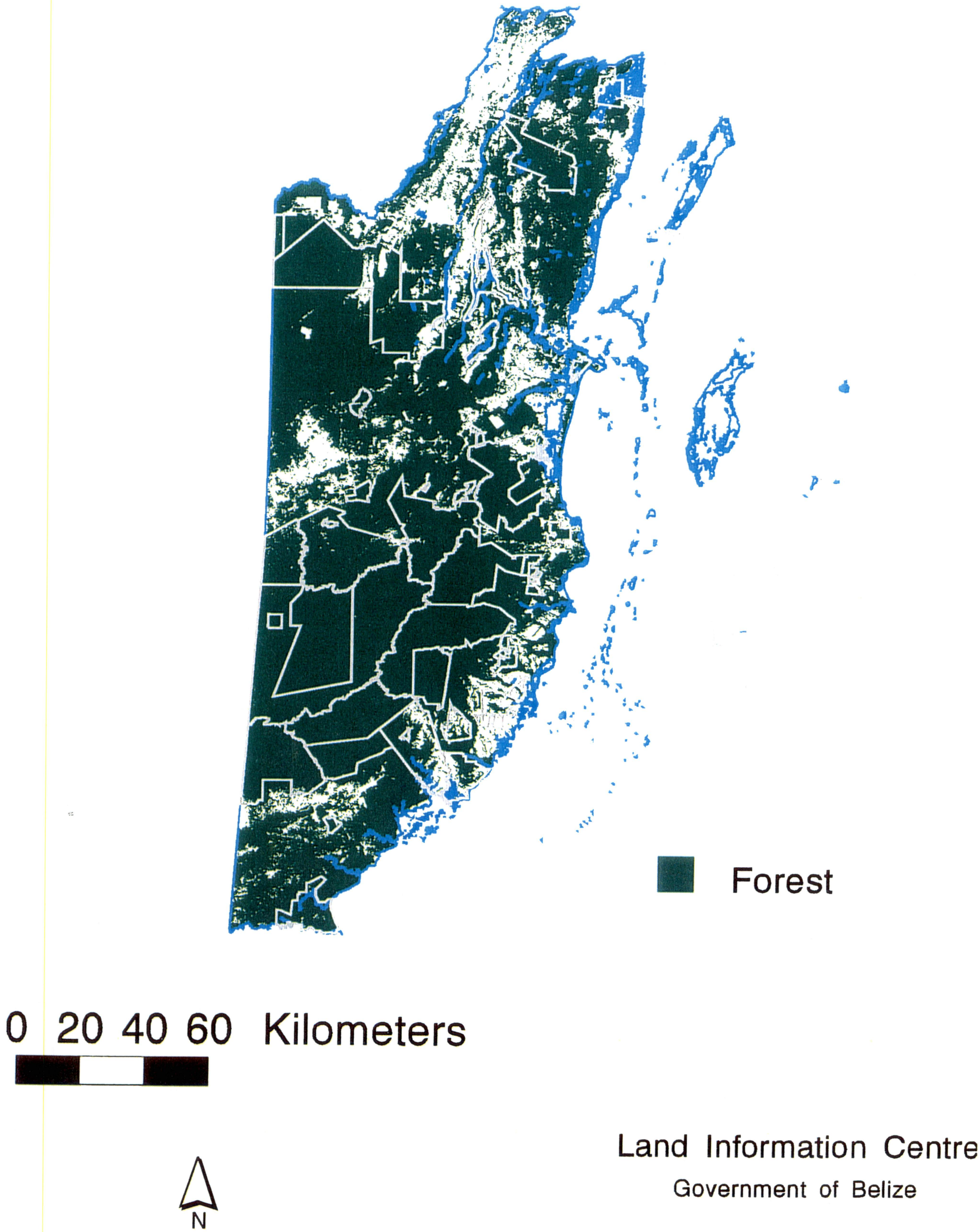

Figure 7. Distribution of forests and associated woodlands based on digital interpretation of Landsat TM imagery acquired in 1994.

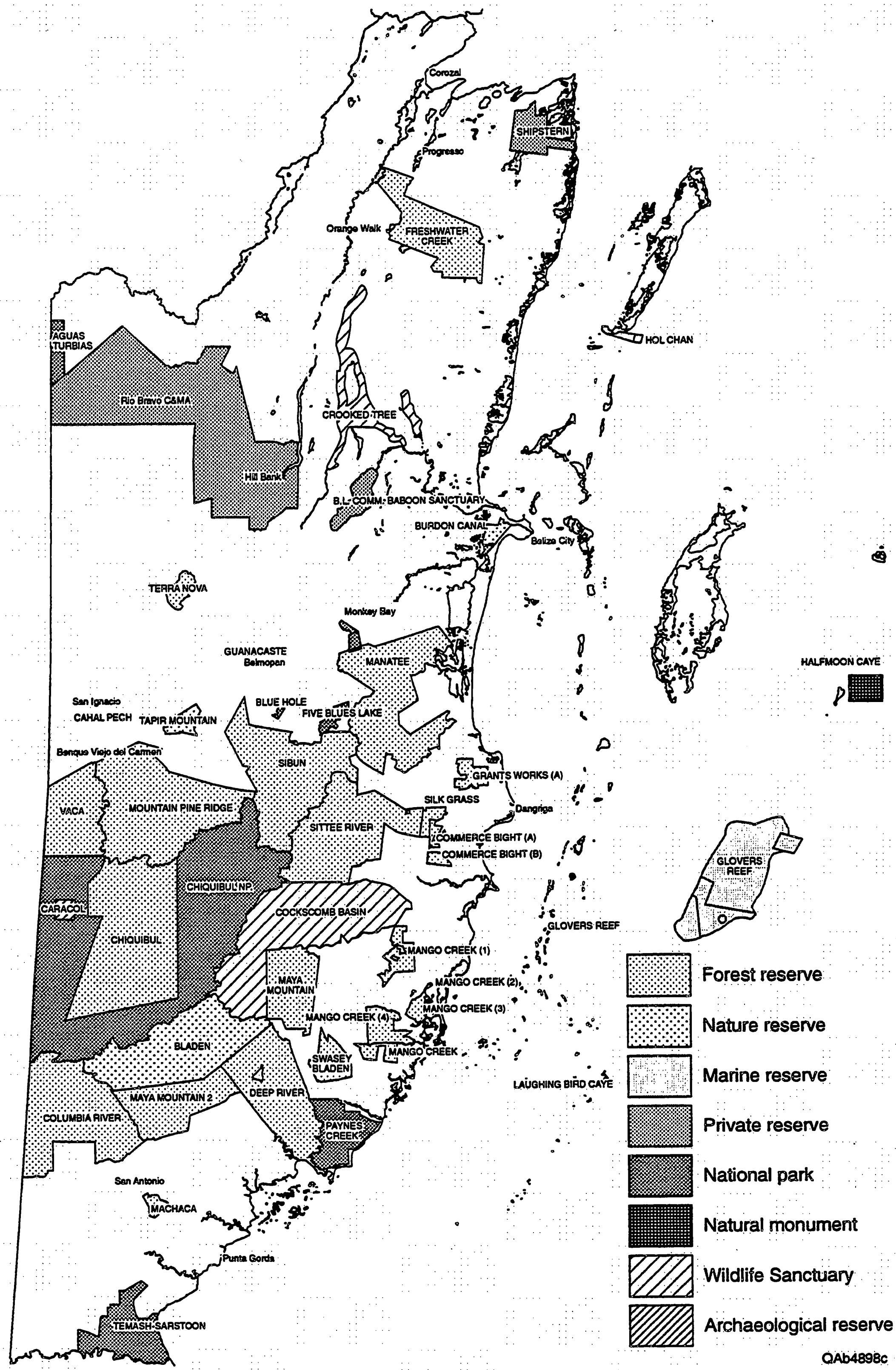

Figure 8. Map of protected areas in Belize. From LIC (1994).

National forest and nature reserves, parks, and sanctuaries and private reserves cover approximately 36 percent of mainland Belize. Forest reserves encompass the largest area at approximately 421,000 ha, or 53 percent of all protected areas. All but one of the forest reserves are in southern Belize (fig. 8). A list of national and private protected areas is presented in table 5.

Table 5. National and private reserves, sanctuaries, and parks. From LIC (1994).

Forest Reserves
- Chiquibul
- Columbia River
- Commerce Bight (3 areas)
- Deep River
- Freshwater Creek
- Grants Works
- Machaca
- Manatee (5 areas)
- Mango Creek (5 areas)
- Maya Mountain (2 areas)
- Mountain Pine Ridge
- Sibun
- Silk Grass
- Sittee River
- Swasey Bladen
- Terra Nova
- Vaca

Nature Reserves
- Bladen
- Burdon Canal
- Tapir Mountain

National Parks
- Aguas Turbias
- Blue Hole
- Chiquibul
- Five Blues Lake
- Guanacaste
- Monkey Bay
- Paynes Creek
- Temash-Sarstoon

Wildlife Sanctuaries
- Cockscomb Basin
- Crooked Tree

Conservation and Management Area
- Rio Blanco

Archaeological Reserves
- Cahal Pech
- Caracol

Private Reserves
- Bermudian Landing Community Baboon Sanctuary
- Monkey Bay
- Rio Bravo Conservation and Management Area
- Shipstern

RESULTS

The 1994 Landsat TM data provided the best cloud-free coverage of Belize, and it was used for the entire country to determine the forest cover losses that have occurred since the baseline period of 1989/92 (LIC, 1994). Forest cover change between 1994 and 1996 based on Landsat imagery acquired in those years was determined in selective areas in southern Belize where cloud cover did not prevent change analysis. The 1996 Landsat imagery was not used in northern Belize because of extensive cloud cover. The 1993 Landsat imagery was digitally interpreted throughout the country, but was used only selectively to examine forest cover changes in northern Belize.

As previously mentioned, both the 1989/92 land use project and this project had difficulty in distinguishing and classifying certain forest classes, e.g., areas of regrowth and open pine forest, for example. Accordingly, some apparent changes in forest cover are the result of differences in methodology and classification and of class boundary offsets due to map-to-map registration, and slight misalignments of land use boundaries that were artifacts of the different methods used in mapping and digitizing. While the overall results are believed to represent good approximations of total change in forest cover, the cumulative effect of the above suggests that the estimates of probable forest cover loss should be viewed as maxima.

All areas of apparent loss in forest cover between 1989/92 and 1994, as delineated by analysis of the digital data, were visually compared to plots of the 1994 imagery. Losses in forest cover that were visually verified were retained in the GIS digital files, and those losses that were considered not real were deleted. A corrected digital file of all losses was created. Using these data, losses in forest and associated woodland cover were calculated for all of mainland Belize and for national and private lands within protected areas.

Forest Cover Losses 1989/92-1994

From 1989/92 to 1994, there was a loss in forest cover of approximately 78,100 ha throughout mainland Belize. More than 90 percent occurred on private and national land outside of protected

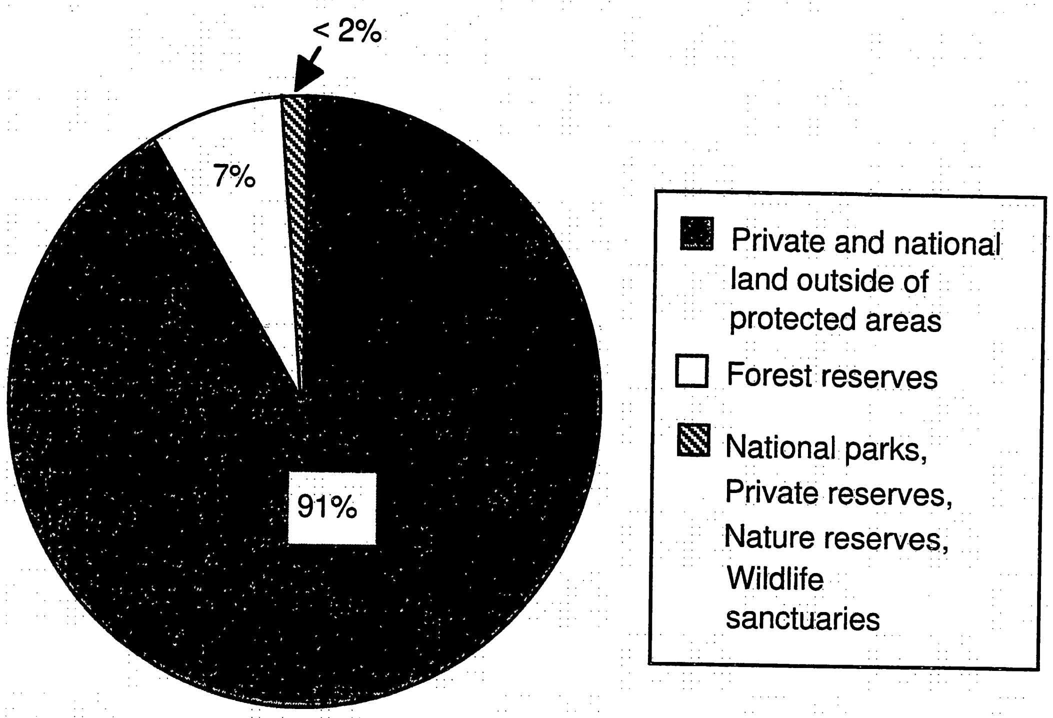

Figure 9. Percentage of total forest cover loss that occurred inside and outside of protected areas.

areas (fig. 9). Forest cover loss in protected areas, consisting primarily of National forest reserves, accounted for about 6,680 ha, or 8.8 percent of the total loss (fig. 9). A look at the mainland as a whole shows that the most extensive losses occurred in the west central, and southern and northern parts of the country (fig. 10). Additional losses occurred along the coastal plain from Dangriga southward.

The spatial and temporal trends of forest cover loss were determined using the analysis capability of the GIS. Relative rates of forest cover loss were estimated by comparing forest cover determined on SPOT imagery (fig. 2) for the baseline years (1989 to 1992) and forest cover determined on the 1994 Landsat imagery (fig. 7). In general, south Belize was covered with SPOT imagery acquired in 1989, central Belize in 1990, and north Belize in 1992. The amount of change to 1994 varied from north to south (table 6). Although the actual magnitudes of the losses in the north, central and south were similar, ranging from about 24,500 to 26,800 ha, the rates varied substantially because the periods over which the losses occurred ranged from 2 to 5 years (table 6). Highest rates of

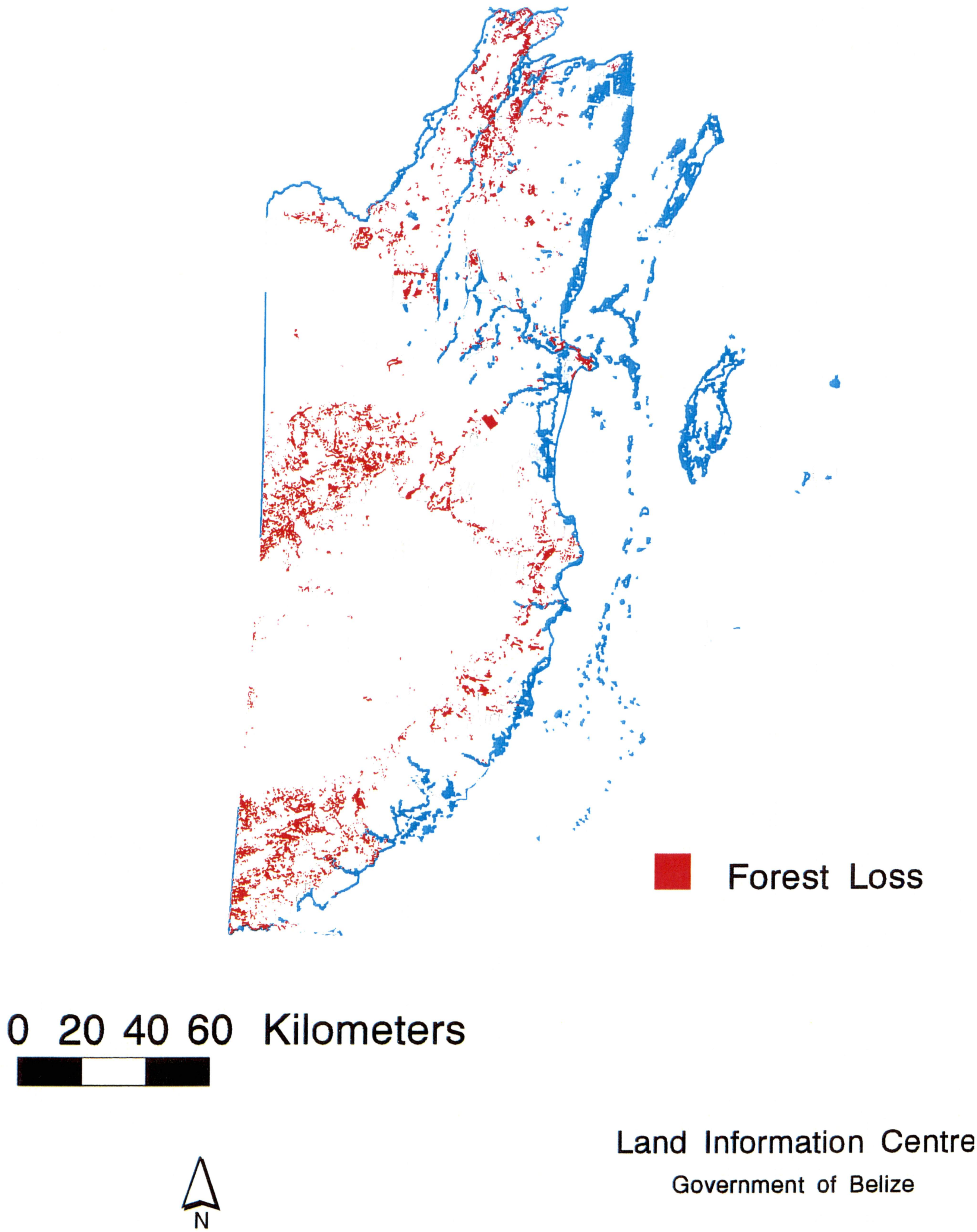

Figure 10. Location of forest and associated woodland cover losses on mainland Belize from 1989/92 to 1994.

about 13,400 ha/yr occurred in the north where approximately 26,750 ha were lost over a 2 year period. Lowest rates occurred in the south, less than 5,000 ha/yr, where the losses were spread over a 5 year period. Based on these data, the average annual rate of loss throughout Belize was almost 25,000 ha/yr. This rate is substantially higher than previous estimated rates (table 6), although the reliability of the previous rates is in question (FAO, 1994; Ledec, 1992). The estimates determined by the present study are believed to be maximum rates for reasons previously discussed. The present study also shows that losses were concentrated in areas not protected or managed by the Forest Department or lands managed as private reserves or sanctuaries (see fig. 9). Some areas of loss outside of protected areas occurred in areas previously used for cultivation so the loss was not of pristine forest.

Table 6. Rates of forest cover loss on mainland Belize, 1989/92 to 1994.

Period	**Loss (ha)**	**Annual rate (ha/yr)**	**Approximate location in Belize**
1989-94	24,495	4,899	South
1990-94	26,832	6,708	Central
1992-94	26,749	13,374	North
Total	78,076	24,981	
1981-90*		5,000	
1980-87?**		9,000	

*Food and Agriculture (FAO) Organization of the UN (1994) Forest Resources Assessment 1990, Country Briefs

** World Resources Institute (1987) cited in Ledec (1992)

Forest Cover Loss in Protected Areas

Forest Reserves

From 1989/92 to 1994 the largest change in forest cover in protected areas occurred in national forest reserves (fig. 9, table 7). The forest reserve with the largest loss was Vaca, where losses accounted for almost 40 percent of the total forest cover loss in all the reserves (table 8, fig. 11). Most of the change in forest cover in the Vaca Reserve occurred from 1990 (date of SPOT imagery) to 1994 (date of Landsat imagery). Deforestation was most extensive in the northern part of the reserve which is closer to population centers and road networks. This reserve borders Guatemala and is on the northern margin of the Maya Mountains where the terrain is relatively steep. Losses appear to be mostly the result of milpas. Part of the apparent forest cover loss, however, appears to be due to naturally sparse stands of trees (Oswaldo Sabido, personal communication, 1996), especially on ridge crests, that previously were classified as forest. Thus, the apparent loss or forest change in this area may be in part due to differences in classification between the earlier baseline study (LIC, 1994) and this project. The exact amount of forest cover loss resulting from naturally sparse areas and possible classification differences could not be determined because the original SPOT imagery from which baseline maps were prepared was not available for comparison with Landsat imagery. Thus, the total loss of 2,227 ha in the Vaca Forest Reserve is a high estimate, and the losses due solely to anthropogenic causes could not be adequately determined. However, it should also be noted that the Vaca Forest Reserve is a relatively new reserve (1991) and legal leases within the reserve may be a contributing factor to the high amount of forest cover loss (Noreen Fairweather and Oswaldo Sabido, Ministry of Natural Resources, personal communications, 1996).

Table 7. Forest cover loss between 1989/92 and 1994 in National and private reserves, parks, and sanctuaries.

Protected Area	**Forest cover loss (ha)**
Forest Reserves	5,640
National Parks	525
Private Reserves	238
Nature Reserves	199
Wildlife Sanctuaries	72
Archaeological Reserves	8
Total	6,682

Table 8. Amount of forest cover loss in those forest reserves in which losses were documented between 1989/92 and 1994.

Forest Reserve	Size of Reserve (ha)	Loss (ha)	Period of loss	Approximate annual rate of loss (ha/yr)
Vaca	21,114	2,227	1990-1994	557
Mango Creek 4	5,286	580	1989-1994	116
Columbia River	41,514	579	1989-1994	116
Mountain Pine Ridge	51,149	562	1990/92-1994	187
Freshwater Creek	24,269	446	1992-1994	223
Sibun	42,908	327	1990/92-1994	109
Swasey Bladen	5,960	274	1989-1994	55
Commerce Bight (B)	2,199	164	1990-1994	41
Mango Creek 1	4,357	107	1989-1994	21
Deep River	31,279	107	1989-1994	21
Grants Works (A)	3,189	63	1990-1994	16
Chiquibul	59,640	49	1990-1994	12
Terra Nova	2,735	41	1990-1994	10
Manatee (5 areas)	41,897	27	1990/92-1994	9
Maya Mountain 2	20,740	23	1989-1994	5
Sittee River	37,973	22	1990-1999	6
Machaca	1,515	19	1989-1994	4
Maya Mountain	16,834	11	1989-1994	2
Mango Creek 3	1,945	8	1989-1994	2
Silk Grass	1,938	3	1990-1994	1
Total	418,440	5,640		

In other reserves, losses in forest cover were significantly lower than in the Vaca Reserve. Losses in four reserves, Mango Creek 4, Columbia River, Mountain Pine Ridge, and Freshwater Creek, ranged between 400 and 600 ha for the period 1989/92 to 1994 (fig. 11; table 8). Of these four reserves, the highest annual rate of loss, 223 ha/yr, occurred in Freshwater Creek (table 8). Losses were predominantly in the northwestern corner of the reserve and resulted in large part from expansion of cropland, probably sugar cane (King and others, 1992).

Losses in forest cover in Mango Creek 4 are less well defined. Most of the losses occurred in areas mapped as pine forest on the 1989 land use maps. There is probably some margin of error in

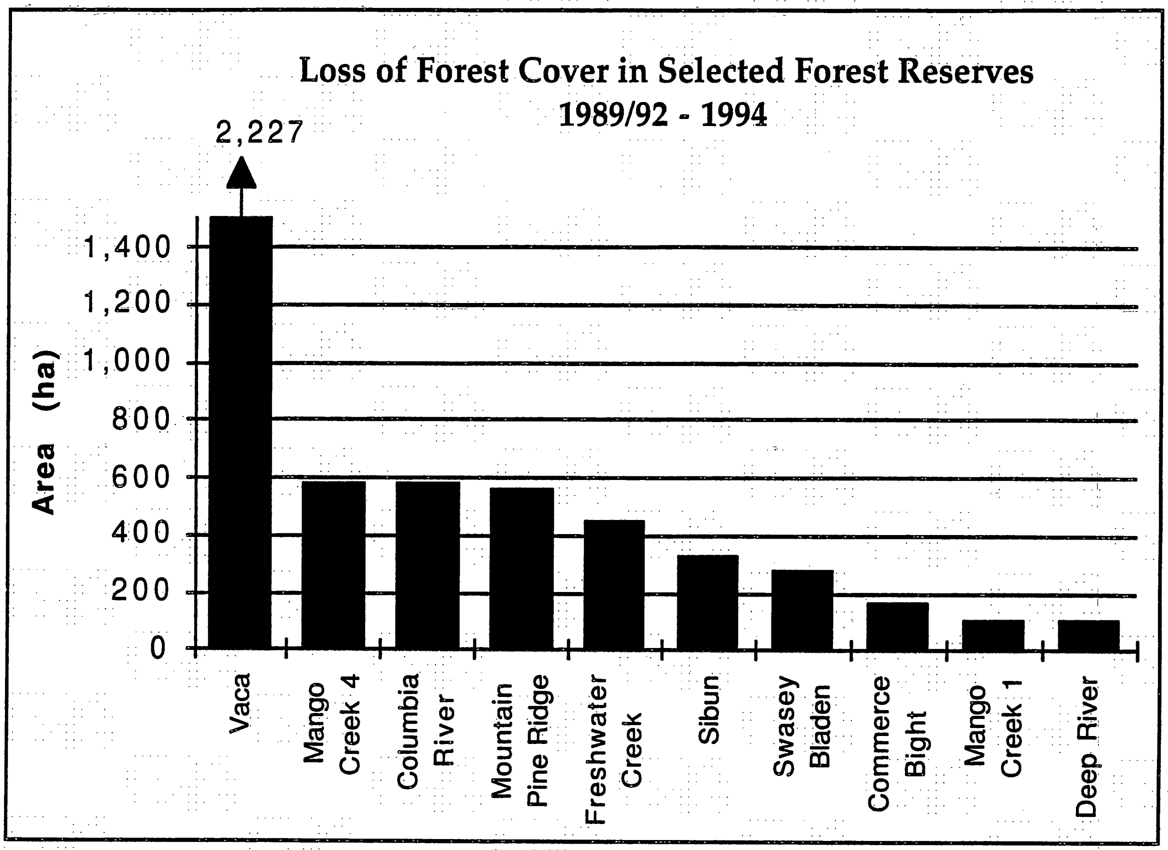

Figure 11. Loss of forest cover in the 10 forest reserves where losses were greatest.

the true magnitude of loss because of differences in classification with respect to the density of forest cover that existed in 1989 and in 1994. In other words, if areas with relatively sparse tree cover were mapped as pine forest on the 1989 SPOT imagery and these same areas were classified as non forested on the 1994 Landsat imagery, an apparent loss in forest cover would be determined. Without having access to the SPOT imagery for comparison, we had to assume the changes were real. A similar situation existed in the Swasey Bladen Forest Reserve. Although the total loss of forest cover amounted to only 274 ha from 1989 to 1994 (an average annual rate of 55 ha/yr), much of the loss occurred in an area mapped as pine forest on the SPOT imagery, and part of the loss may be due to classification differences.

Total losses in forest cover in Columbia River were about 580 ha and occurred primarily in the southwest corner of the reserve adjacent to the Guatemalan border. Primary cause of the loss appears to have been milpa farming.

Losses of forest cover in the Sibun Forest Reserve amounted to 327 ha, with an annual average rate of 109 ha/yr (table 8). The majority of the loss in the Sibun reserve was along the Hummingbird Highway and was the result of agricultural development consisting of citrus orchards and mixed farming.

Forest cover losses in other forest reserves ranged from 165 ha to 3 ha (table 8). Causes for losses varied but most are probably due to agricultural development, ranging from orchards and mixed farming to milpas. Loss of forest cover in the Silk Grass Forest Reserve may be more extensive since 1994, but cloud cover in the 1996 Landsat image prevented an accurate assessment of losses in this reserve from 1994 to 1996.

Nature Reserves

Approximately 200 ha of forest cover loss occurred in the three Nature Reserves (table 9). The largest loss of 102 ha occurred in Burdon Canal, but only a small portion of this area of loss, which is in mangroves, may be real. Thinner mangrove cover may have produced the non-forested classification in the classification of the digital imagery.

Table 9. Loss of forest cover in Nature Reserves, 1989/92 to 1994.

Nature Reserve	Total area of reserve (ha)	Total Loss (ha)
Burdon Canal (3 areas)	2,119	102
Bladen	40,198	83
Tapir Mountain	2,720	14
Total	45,037	199

Although the 1994 Landsat imagery shows that many of the areas in the Bladen Nature Reserve are not forested, most were mapped as a forest class, thicket or pine on the 1989/92 land use maps. It is possible that some of the 83 ha loss in forest cover is due to classification differences between the baseline maps and the digitally classified 1994 Landsat imagery.

In the Tapir Mountain Nature Reserve losses of forest cover amounting to 14 ha occurred along the northern and eastern border of the reserve and apparently are the result of agricultural expansion from adjacent lands.

National Parks

Total forest cover loss in National Parks for the period 1989/92 to 1994 is 525 ha. Losses ranged from 319 ha in Chiquibul to less than 2 ha in Monkey Bay (table 10; fig. 12). Chiquibul National Park is very large, covering more than 115,000 ha. The loss of 319 ha of forest cover represents less than 0.3 percent of the total area encompassed by the park. The majority of the loss, which occurred between 1990 and 1994, is near the western boundary of the park along the Guatemalan border and is the result of milpa farming along the border.

Table 10. Forest cover loss in National Parks.

National Park	Total area of reserve (ha)	Total loss (ha)
Chiquibul	115,454	319
Temash-Sarstoon	16,897	151
Five Blues Lake	1,638	28
Paynes Creek	12,775	22
Guanacaste	23	4
Monkey Bay	725	2
Aguas Turbias	3,546	
Blue Hole	268	
Total	151,327	525

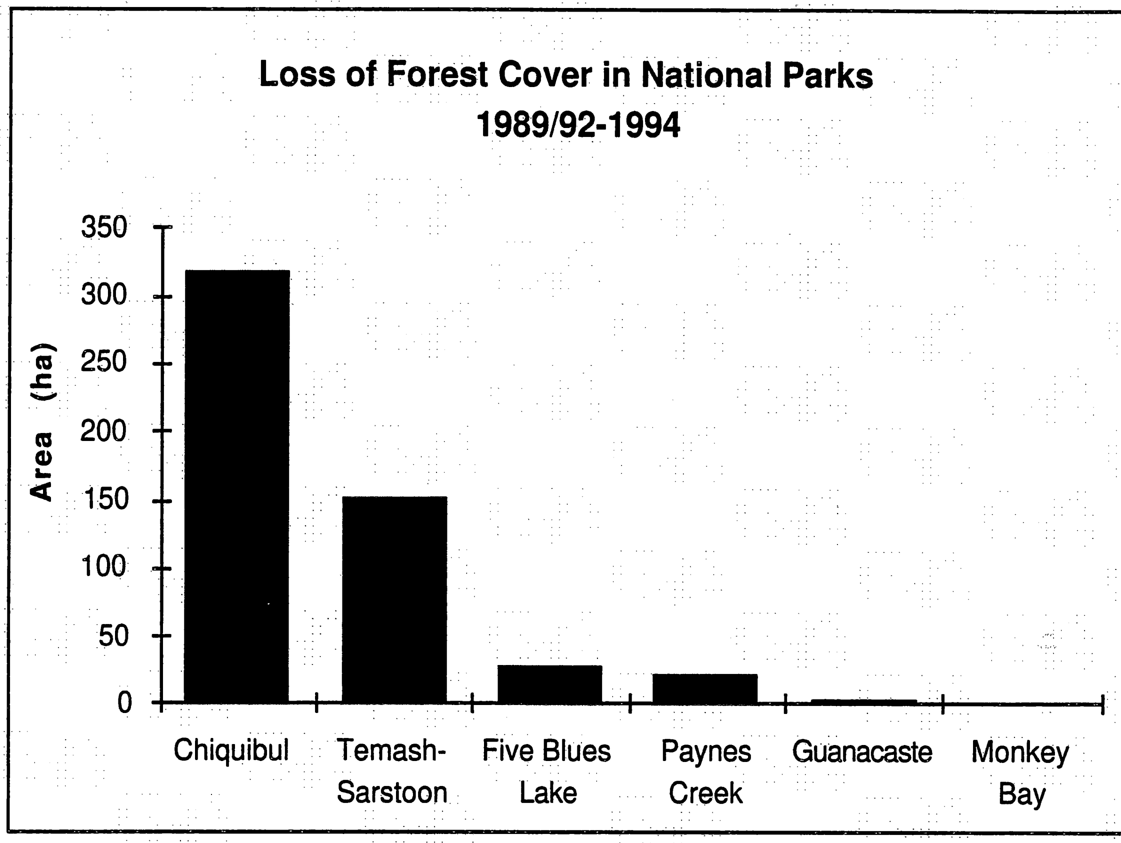

Figure 12. Loss of forest cover in National Parks.

Approximately 150 ha of apparent forest cover loss occurred between 1989 and 1994 in Temash-Sarstoon National Park, but only about half of the loss appears to be related to human deforestation. These losses were the result of milpas in the northern part of the park. Apparent losses in forest cover along the Sarstoon River seem to be due to forest cover classification differences rather than to human activities. It appears that areas of naturally sparse vegetation (open broadleaf forest) mapped as forest on base line maps, were mapped as nonforested on Landsat TM imagery.

Almost 30 ha of forest cover was cleared in Five Blues Lake National Park. The losses occurred along boundaries at the southern end of the park, and are the result of the expansion of adjacent agricultural areas. In Paynes Creek National Park, 22 ha of forest cover was lost in the central part of the park on the margins of larger areas previously cleared.

Wildlife Sanctuaries

Forest cover losses in wildlife sanctuaries from 1989/92 to 1994 were 59 ha and 14 ha in Crooked Tree and Cockscomb Basin sanctuaries, respectively. Losses in Crooked Tree appear to be predominantly due to milpa farming in the central part of the sanctuary along the boundaries. Some of the losses may have occurred outside the sanctuary, but may have been attributed to it because of boundary registration problems. Estimates of losses in both of these sanctuaries are probably high.

Archaeological Reserves

Only two archaeological reserves are listed and mapped as part of the baseline data (LIC, 1994), Cahal Pech and Caracol. For the period 1989/92 to 1994, losses amounted to about 7 ha in these two reserves with most (5 ha) occurring in Cahal Pech.

Private Reserves

Losses in private reserves were approximately 130 ha and 105 ha in the Bermudian Landing Community Baboon Sanctuary and Rio Bravo Conservation and Management Area, respectively. No losses were documented in Shipstern or Monkey Bay private reserves.

Forest Cover Losses on National and Private Lands Outside of Protected Areas

Approximately 92 percent of the total losses in forest cover between 1989/92 and 1994 occurred on land outside of protected areas (fig. 9). These lands represent between 60 and 65 percent of the total area of mainland Belize. The majority of the losses throughout mainland Belize as shown in figure 9 occurred on lands outside of protected areas.

The most extensive losses in forest cover occurred in the Cayo and Toledo Districts (fig. 1), where 20,090 ha and 19,035 ha, respectively, were lost from 1989/92 to 1994 (fig. 13). In the Cayo District, losses were concentrated in the northern half of the district where large areas were cleared for agriculture. The losses were spread throughout areas north and south of the Western Highway between Belmopan and San Ignacio. Most of the losses in this district occurred on map sheet 4 (figs. 3 and 14), which includes the Mennonite settlements north of the Western Highway.

Losses in private and national lands outside of protected areas in the Toledo District in southern Belize occurred primarily on map sheet 8 (fig. 3), and appear to be principally the result of clearing for agricultural purposes including citrus orchards and small milpas that cumulatively encompass large areas.

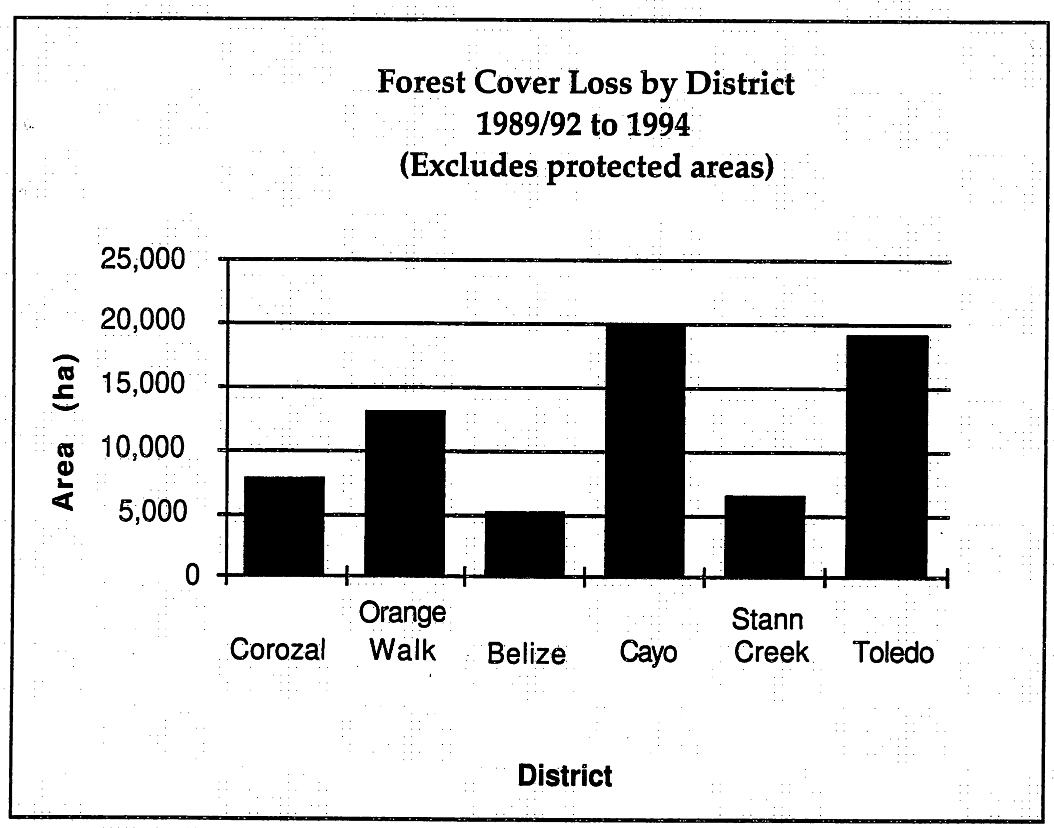

Figure 13. Loss of forest cover on national and private lands outside of protected areas in the six districts of Belize. See figure 1 for district locations.

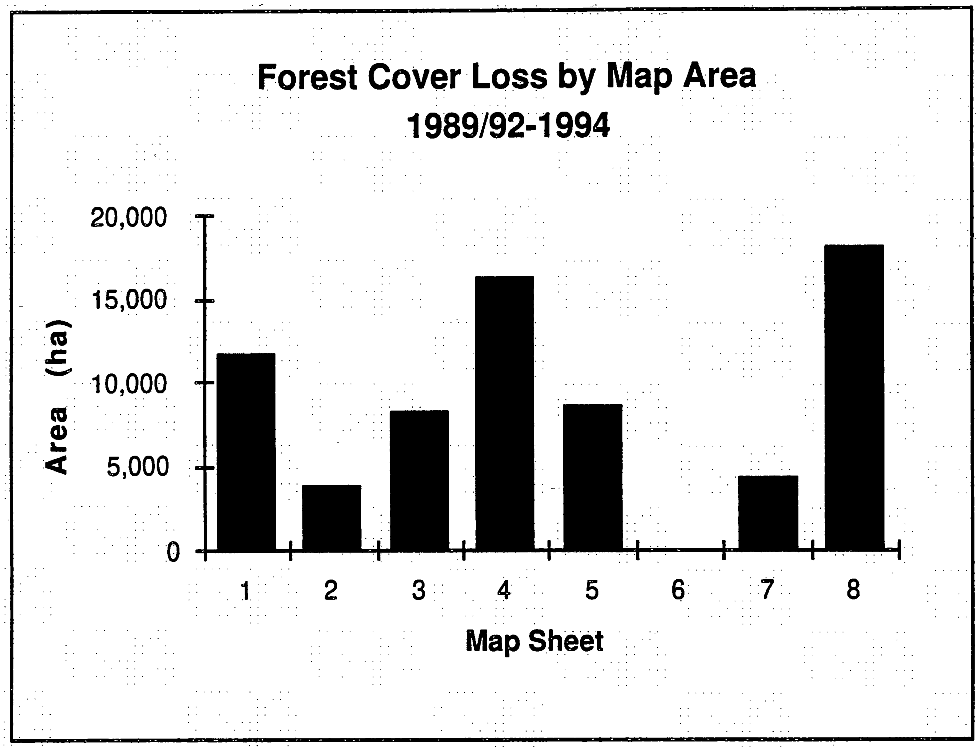

Figure 14. Losses in forest cover on national and private lands outside of protected areas within areas defined by 1:100,000 scale map sheets. See figure 3 for location of map sheets.

Approximately 13,000 ha of forest cover were cleared on lands outside of protected areas in the Orange Walk district between 1992 and 1994 (fig. 13). Most of the losses occurred in map area 2 (figs. 3 and 10) north and east of the Rio Bravo Conservation and Management Area, extending to north of Orangewalk. This area includes Mennonite settlements south and west of San Felipe. Forest cover was cleared primarily for cropland on the coastal plain east of the Rio Bravo Escarpment, and for pasture land in the rolling and undulating plains west of the escarpment.

Forest cover losses outside of protected areas in the Corozal and Stann Creek Districts were approximately 7,700 ha and 6,500 ha, respectively (fig. 13). However, more than 10,000 ha of loss occurred in map sheet 1 (fig. 14), which includes most of the Corozal District and the northern tip of Orange Walk District including Orange Walk (town). To the northwest of Orange Walk town there were extensive losses in forest cover in areas primarily used for sugar-cane fields (King and others, 1992).

The Belize District had the least amount of forest cover loss, approximately 5,000 ha from 1989/92 to 1994 (fig. 13). Most of the loss occurred in the vicinity of Belize City where mangroves were cleared for urban development, and in an area between Belize City and Belmopan where a large area of thicket and broadleaf forest (LIC, 1994) was cleared to plant a citrus orchard covering an area of more than 1,000 ha north of the Coastal Highway (see large rectangular area southwest of Belize City on figure 10).

Type of Forest Cover Lost, 1989/92-1994

Approximately 80 percent of the 78,100 ha loss in forest cover was in broadleaf forests (fig. 15), which amounted to about 62,000 ha. The remaining 20 percent of the total loss was primarily in thickets at about 10,000 ha, followed by pine forest (3,400 ha), bamboo and riparian

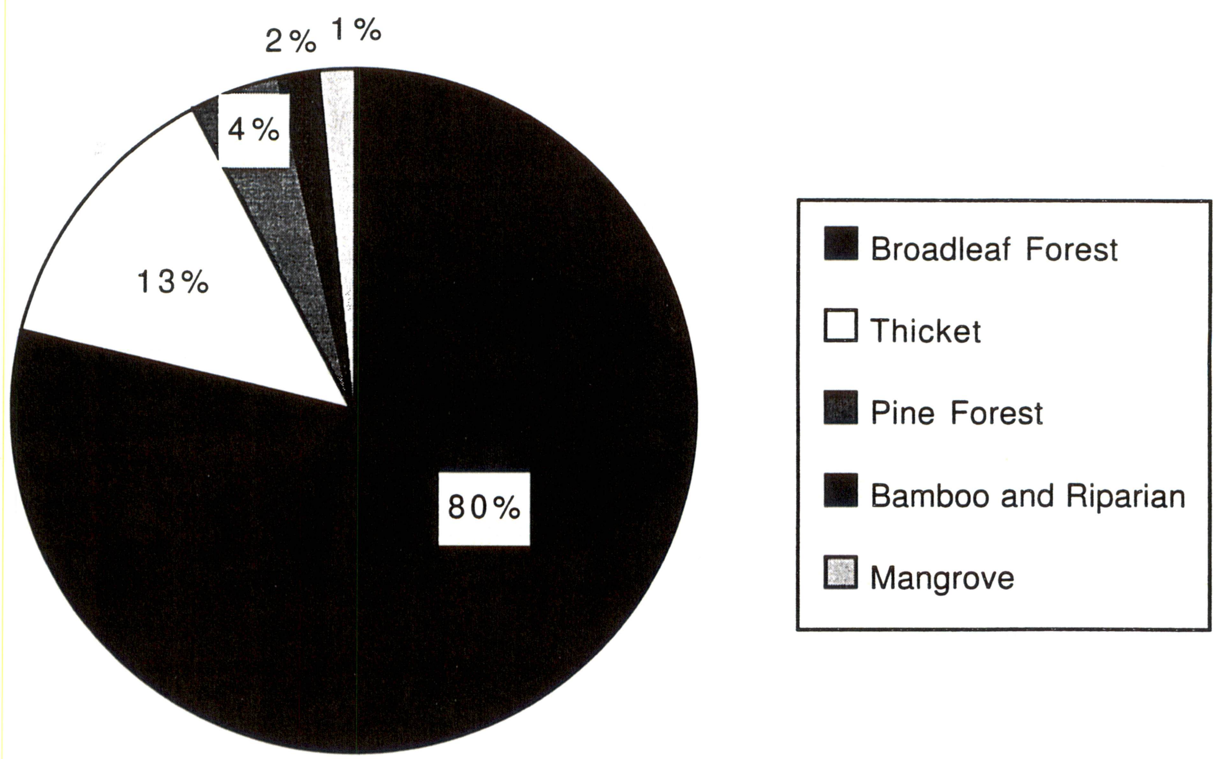

Figure 15. Percentage of the total forest cover lost by principal forest types.

vegetation (1,600 ha), and mangroves (1,100 ha). A perusal of table 1 of forest classes shows that the percentage loss generally corresponds to the size of the forest resource. Broadleaf forest makes up approximately 66 percent of the land area in Belize, thicket almost 4 percent, and pine forest 3 percent. Mangrove (dwarf and tall) makes up about 1.4 percent, however, which is larger than the 0.5 percent made up of bamboo and riparian vegetation.

Considering the total forest cover in Belize as shown by the 1989/92 baseline data, by 1994, 4 percent of broadleaf forest was lost, 5 percent of pine forest, 12 percent of thicket, 14 percent of bamboo and riparian vegetation, and 4 percent of mangrove habitat.

Forest Cover Losses 1994-1996

Forest cover loss from 1994 to 1996 was determined by GIS analysis of forests and associated woodlands digitally classified from the 1994 and 1996 Landsat TM scenes (fig. 16). Cloud cover in the 1996 imagery over northern Belize and along the coast in southern Belize, restricted forest cover loss analysis to areas in southwestern Belize. Analysis of forest cover change for the 1994-1996 period, even excluding areas with clouds, was not without complications. A direct comparison of the 1994 and 1996 digitally classified data revealed spurious losses and gains along the boundaries of many classified units. To eliminate most of these false changes from the analysis, only those losses of greater than 5 ha were considered. A detailed examination and verification of the losses with reference to plots of the imagery as was done for the 1989/92 to 1994 data could not be accomplished because of time limitations. Thus, the 1994 to 1996 forest cover losses should be viewed as preliminary. Among the real losses are ones that occurred along the Guatemalan border in Columbia River reserve and Chiquibul National Park (fig. 16; see fig. 8 for location of protected areas).

In protected areas, the most extensive apparent losses occurred in Mountain Pine Ridge, Sibun, Columbia River, Chiquibul, and Manatee Forest Reserves, and Chiquibul National Park, where losses ranged from approximately 400 to 720 ha and rates of loss ranged from about 195 to

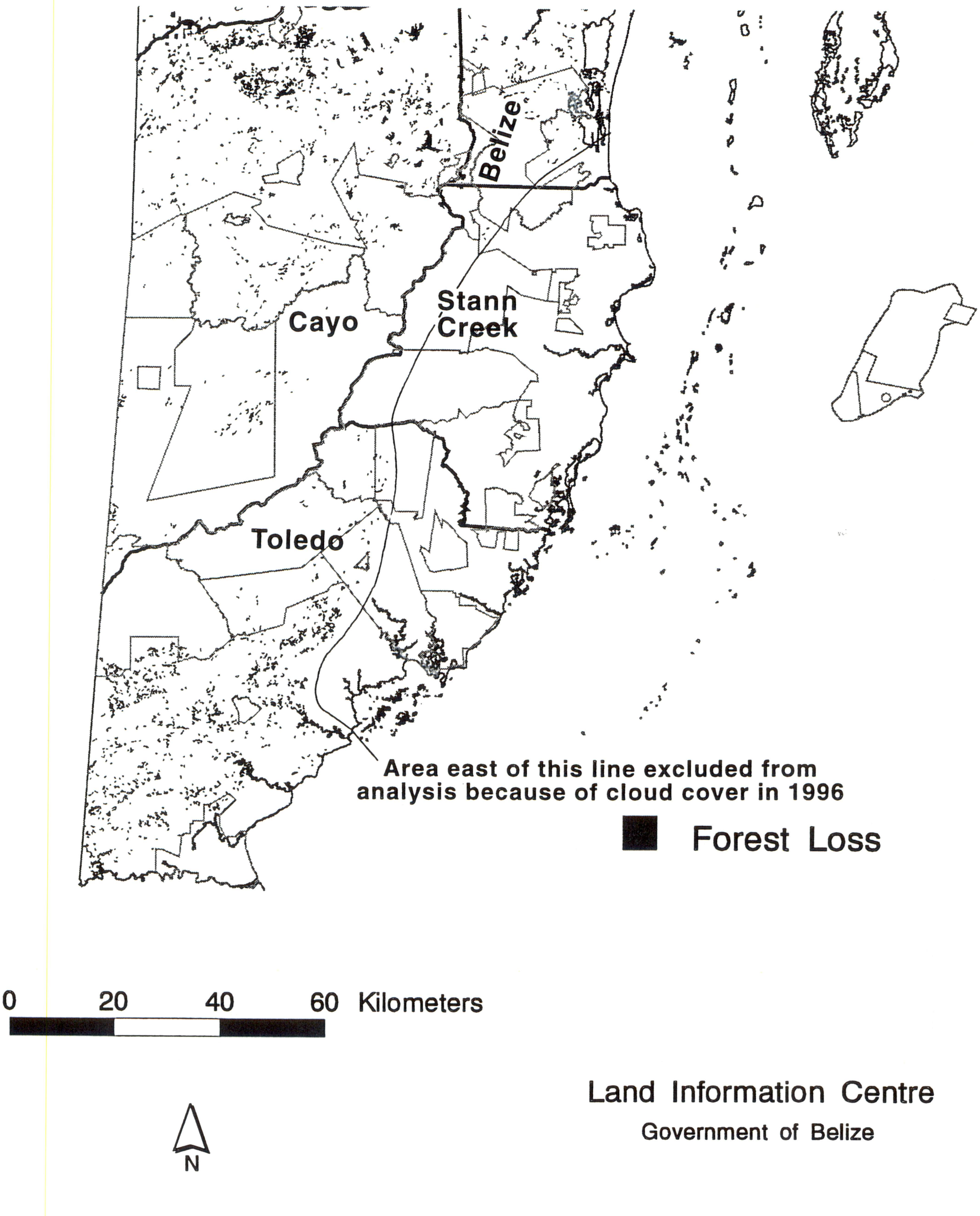

Figure 16. Loss of forest cover in southern Belize from 1994-1996.

360 ha/yr (table 11). It is believed that losses are both real and artificial, the latter the result of classification differences in areas of naturally sparse vegetation.

Total losses between 1994 and 1996 within the districts of Belize could only be tabulated for two, Cayo and Toledo, where 1996 coverage was sufficiently cloud free for analysis. The northeastern portion of Toledo had to be omitted because of clouds. Losses were 13,667 and 10,163 ha in Cayo and Toledo Districts, respectively. The total loss in these two districts translates into an annual rate of approximately 12,000 ha/yr.

In the geographic area investigated to define losses between 1994-1996, a total of 25,650 ha was loss over this two year period. This loss only includes those greater than 5 ha, and excludes the area affected by clouds (fig. 16). Of this total, about 15 percent occurred in protected areas.

Table 11. Forest cover loss, 1994-1996, in protected areas in southwestern Belize. See text for a more specific explanation of where and how forest cover loss was determined.

Protected Area	Forest Cover Loss 1994-1996 (ha)	Rate of Loss (ha/yr)
Forest Reserves		
Mountain Pine Ridge	720	360
Sibun	582	291
Columbia River	432	216
Chiquibul	392	196
Manatee	264	132
Deep River	177	89
Terra Nova	175	88
Maya Mountain 2	173	87
Vaca	106	53
Maya Mountain	89	45
Tapir Mountain	1.3	1
National Parks		
Chiquibul	464	232
Temash-Sarstoon	128	64
Blue Hole	4	2
Monkey Bay	0.05	
Wildlife Sanctuaries		
Cockscomb Basin	115	58
Nature Reserves		
Bladen	108	54

CONCLUSIONS

From the 1989/92 baseline period to 1994, approximately 78,100 ha of forest and associated woodland cover was cleared. This magnitude of loss should be viewed as a maximum because it includes some losses which are not real, but resulted from classification and methodology differences between the baseline mapping project and this reconnaissance project.

More than 90 percent of the total losses in forest cover (> 70,000 ha) occurred outside of protected areas.

The success of national and private protected areas including forest reserves, nature reserves, wildlife sanctuaries, and national parks in protecting forest resources is manifested in the observation that less than 9 percent of the total losses in forest cover occurred in protected areas. Of the total calculated loss (6,682 ha), as much as 15 to 20 percent may be due to discrepancies in classification.

Most losses in forest cover were due to agricultural development ranging from large citrus orchards, to mixed farming and cropland, to small individually but cumulatively large areas of milpa farming.

Average rates of forest cover loss ranged from less than 5,000 ha/yr in southern Belize to more than 13,000 ha/yr in northern Belize, but the rate of loss throughout the country was almost 25,000 ha/yr from the baseline period of 1989/92 to 1994.

There has been a substantial increase in the rate of clearing of forest and associated woodlands over the past 2 to 5 years (25,000 ha/yr) relative to previously published estimates (5,000 to 9,000 ha/yr) over the past decade (1981-1990). Even if the estimates in the current reconnaissance study are as much as 20 percent too high, the rate of deforestation is still very significant.

RECOMMENDATIONS

This reconnaissance investigation was one of limited scope and duration. The main objective was to delineate total forest cover through analysis of digital Landsat TM imagery for comparison with total forest cover on baseline maps that were visually interpreted from SPOT imagery. Very extensive visual verification of forest cover changes on Landsat imagery and subsequent GIS editing of digital forest-cover loss files added a large measure of confidence to the results reported in this investigation. Nevertheless, a more detailed evaluation of forest cover losses should be performed, with reference to correcting classification problems in the baseline data and the provisionally classified land use types defined in this project. Although the GIS files showing losses between the baseline maps and more recent Landsat maps were extensively checked, edited, and corrected, the original land use classifications were not changed.

Because the emphasis of the study was on total forest cover, other land use types were only provisionally classified. There is a need for a more detailed and rigorous digital analysis of Landsat TM imagery to refine the classification of both forested and nonforested areas to provide more up-to-date and complete digital data and maps of current land use in Belize. A more complete classification of land use would allow a quantitative analysis of specific causes for loss in forest cover by documenting types of land use responsible for deforestation. In addition, remotely sensed imagery can be used to address more specific land use and forest management issues and assist in environmental oversight.

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