FOREST COVER AND DEFORESTATION IN BELIZE: 1980-2010

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Abstract: Making use of a thirty year archive of satellite imagery available through the Regional Visualization & Monitoring System (SERVIR), the forest cover of Belize was analyzed at the national level, providing information never before available on deforestation rates in the Central American nation with the highest relative forest cover. A multi-temporal maximum likelihood classification was conducted on satellite image mosaics for the years 1980, 1989, 1994, 2000, 2004, and 2010, putting to use part of the extensive archive of data collected by the Landsat series of satellites since July 1972. The results of this assessment adjust down previous estimates of Belize's deforestation rate, such as the UN Food & Agriculture Organization (FAO)'s estimate of ~89,000 acres / year (2.3%). This study assesses Belize's deforestation rate between 1980 and 2010 to be under 25,000 acres / year (0.6%). Additionally, where estimates of Belize's forest cover have ranged widely, from 79% (Fairweather & Gray 1994) to 61.6% (Meerman et al 2010), this study estimates that the country's forest cover declined from approximately 75.9% in 1980 to 62.7% as of February 2010. With a short turn-around time between image acquisition and the generation of forest cover data, this study demonstrates SERVIR's capacities for rapidly converting satellite data into information, and has synergies with the current Forest Carbon Tracking Task occurring in the context of the Group on Earth Observations. The information generated is intended to be of use as an input to processes ranging from Reducing Emissions from Deforestation & Forest Degradation (REDD+) to the UN Millennium Development Goals.

Key words: Belize, forest, deforestation, land cover, remote sensing, SERVIR, GEO, TROPICARMS, REDD+

The Mesoamerican *Regional Visualization & Monitoring System (SERVIR* in Spanish, see www.servir.net*)* was formally launched in February 2005 at the Water Center for the Humid Tropics of Latin America & the Caribbean (CATHALAC) in Panama, in direct response to the expanded CONCAUSA agreement between the Governments of Central America and the USA. The system is jointly implemented by CATHALAC, NASA, the U.S. Agency for International Development (USAID), and various other partner institutions (Stokes 2007). As a platform for monitoring and forecasting Mesoamerica's land surface, oceans, and atmosphere, the system has provided the region with free and open access to a large archive of satellite imagery previously inaccessible because of cost. In providing products and datasets on the region's changing landscape, SERVIR has also supported monitoring of the land cover at the regional, national, and sub-national scale since its inception. This study – in supporting Belize's Ministry of Natural Resources and the Environment (MNRE) – examines national forest cover dynamics for the years 1980, 1989, 1994, 2000, 2004, and 2010, and the periods in between.

I. BACKGROUND

Various documents, ranging from the 1984 *Belize Country Environmental Profile* to the more recent 2010 United Nations Environment Programme (UNEP)-funded *GEO Belize* national report, have recognized Belize – a Central American nation with an area of ~22,966 km^2 and part of the globally-significant Mesoamerican Biological Corridor – as a highly forested nation. Since

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as early as 1996, with the publication of the USAID-funded *Deforestation in Belize: 1989/92 – 1994/96* study, it has likewise been recognized that Belize's forest cover has not remained static, but has been declining (White et al 1996). White et al (1996) and its predecessor Fairweather & Gray (1994) both made recommendations for establishing a baseline of forest cover and for monitoring from that baseline. Belize is likewise a signatory to a number of multilateral environmental agreements (MEAs)[1] which in some form or another require the monitoring and reporting of land cover, including the extent of the nation's forests. Goal 7 of the UN's Millennium Development Goals (MDGs), to which Belize is also a signatory, specifically addresses land cover change and deforestation. The various thematic assessment reports undertaken in Belize's 2005 *National Capacity Self-Assessment* also highlighted the need to monitor Belize's forest cover and overall land use (Boles 2005, Green 2005a, Green 2005b, IDEAS 2005). Institutionalized, regular monitoring of Belize's forests would thus address the constant need for updated forest cover data. To date, however, collection of such data has not been systematic, although the *National Environmental & Geomatics Information System* (NEGIS) proposed by the Land Information Centre (LIC) of the Lands & Surveys Department of the MNRE would likely address this (Edgar Ek, personal communication; Ek 2006).

Previous National Forest Cover Estimates

While Belize is required to report regularly on its forest cover, the various national reports reveal outdated and at times conflicting information, based on varying definitions of what constitutes 'forest.' National estimates of forest cover – derived from a variety of sources, with a variety of objectives, methodologies, and uses – have also been wide-ranging. For instance, Belize's forest cover for the period 1989-92 is often stated as 79% of the mainland, citing Fairweather & Gray (1994), even though the heading used by those authors was not exclusively "forest" but rather "forest and other wooded areas." Hence, classes that should not be considered as forest[2], and which were not considered forest in the follow up 1996 *Deforestation in Belize* study – namely 'herbaceous and scrub, secondary regrowth,' 'coastal strand vegetation,' 'saline swamp,' and 'marsh' – were included in the forest cover figure. If those classes are removed from the analysis, mainland forest cover is reduced to 74.5% (see **Table 1**).

The FAO's 2000 *Forest Resource Assessment* annotated bibliography report on forest cover change in Belize cites Rosado (1999) who in turn references the 1984 *Belize Country Environmental Profile* in stating that Belize's forest cover in 1971 was 97% (FAO 2000: 24). Rosado states that the supposed decline in forest cover from 97% in 1971 to the previously cited 79% in 1989-92 as a cause for concern. However, the 97% forested claim needs to be examined, as the source of Hartshorn et al (1984)'s estimate is unknown. For instance, the 2002 final report of World Bank and Government of the Netherlands-funded *Central America Ecosystems Mapping Project* shed light on the nature of the region's savannas, namely that these areas have

[1] The three main MEAs Belize is a signatory to are the United Nations Convention on Biological Diversity (CBD), which requires countries to report on their vegetation cover, the UN Convention to Combat Desertification (UNCCD) which requires reporting on deforestation and land degradation, and the UN Framework Convention on Climate Change (UNFCCC), which requires the reporting of forest cover and land cover change.

[2] Of the "forest and other wooded areas" class used by Fairweather & Gray (1994), only five sub-classes – broadleaf forest, pine forest, mangrove, bamboo and riparian vegetation, and thicket – were considered as "forest" in the joint University of Texas / Ministry of Natural Resources *Deforestation in Belize: 1989/92 – 1994/96* study (White et al 1996). The other classes bear little semblance to forest, regardless of forest definition.

existed as such for an untold period of time because of natural climatic factors (Vreugdenhil et al 2002: 30). If one extrapolates from that conclusion, then even in a pre-human state, non-forest land cover types would have covered 13.3% of Belize's mainland. Thus, Belize's forest cover in 1971 would at most have been 86.7% – *assuming that in 1971 there were no urban areas, roads or agricultural land* – which was certainly not the case. In fact, Charles Wright et al (1959)'s map of Belize's 'natural vegetation,' (i.e. vegetation prior to human settlement of the territory) puts forest cover at 88.8%, close to the 86.7% figure (see **Figure 1** below).

Figure 1: Belize's 'natural vegetation,' as mapped by Wright et al 1959[3]

As reviewed in Meerman & Sabido (2001), prior to Independence from Great Britain in 1981, a number of studies of Belize's land cover / vegetation had been conducted (e.g. Surveyor General of British Honduras 1933, Stephenson 1938, Wright et al 1959), and these produced maps indicating the general extent of Belize's vegetation, including forest types. According to Zisman (1998), one of the first such studies was the *National Land Cover Survey* carried out from 1931-1933 by the nascent Forest Department, with much of that work summarized by Stephenson (1935). This was followed up almost thirty years later by Wright et al (1959) who used aerial photography and field surveys to map Belize's 'natural vegetation' (i.e. in lieu of mapping existing vegetation) in order to assess the colony's agricultural potential. As Wright and his colleagues did not map cultivated land and settlements at the time, it is not possible to determine how much of Belize was actually covered by forest in the late 1950s. Post-independence, field surveys by Bruce King et al (1986-1992) paid specific attention to the agricultural capacity of the various 'land systems,' "area[s] with recurring pattern[s] of topography, soils, and vegetation"

[3] An electronic version of Wright et al (1959)'s data exists; its original classes were aggregated into: forest, non-forest, and water.

(King et al 1993: 8). King et al (1992) were the first to have their data stored in a geographic information system (GIS), so that their digital data exist to this day, unlike earlier efforts. However, as they did not focus on mapping land cover or vegetation types, the extent of Belize's forests between 1986 and 1992 is likewise unknown.

Mapping Forest in the Modern Era

Unlike King et al's studies, it was the specific objective of Fairweather & Gray (1994) to map the extent of Belize's land cover types and land use. Their work was based on delineating land cover (including forest extent) utilizing satellite imagery from France's SPOT-1 and SPOT-2.[4] Following Fairweather & Gray, there have been other, substantive efforts to map Belize's land cover. A few of these have been at the national level (i.e. Iremonger & Brokaw 1995, White et al 1996, Meerman & Sabido 2001, Meerman 2005, Meerman et al 2010)[5], but a greater number have been at sub-national or local scales (e.g. Pope et al 1994, Matus et al 1997, Vasquez 1997, Brokaw & Sabido 1998, Zisman 1998, White et al 1998, White et al 2002, DiFiore 2002, Ek 2004, Penn et al 2004, Emch et al 2005, Binford 2007, Meerman 2008, Wyman & Stein 2010).[6]

With Fairweather & Gray (1994) as their baseline, White el al's *Deforestation in Belize: 1989/92 – 1994/96* which followed two years later, examined the dynamics of forest cover change in Belize. Where the former study was based on visual interpretation[7] of 3-channel false color infrared 20m-resolution SPOT imagery, the latter study utilized the automated computer-assisted image classification technique known as 'supervised classification,' utilizing as its input 7-channel 30m-resolution Landat-5 imagery. At about the same time when White et al (1996) was being developed, another USAID-funded project also developed a map of Belize's vegetation types. That study, Iremonger & Brokaw (1995), mapped Belize's vegetation for the year 1993, identifying various forest types.

In 2001, Iremonger & Brokaw's work was built upon by Meerman & Sabido, who under the World Bank & Government of the Netherlands-funded *Central America Ecosystems Mapping Project* developed a map of Belize's ecosystems for 1993-1996-1998. Meerman & Sabido (2001) was eventually updated – via Meerman (2005) – under the monumental *National Protected Areas Policy & System Plan* (NPAPSP) project. In contrast to the automated supervised classification technique employed by White et al (1996), the studies conducted by Iremonger & Brokaw (1995), Meerman & Sabido (2001), and Meerman (2005) all utilized the visual interpretation technique to identify land cover / vegetation types. In contrast, Meerman et al (2010) utilized an automated 'supervised classification' technique for mapping forests for 3 periods (mean years 1990, 2000, and 2005). Of significance is that land cover /forest cover data available since Fairweather & Gray (1994) have largely been accessible to researchers wishing to further analyze the raw data. The availability of those datasets in GIS format has also allowed specialized analyses such as extracting and analyzing land cover for particular sites, as compared

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[4] Fairweather & Gray (1994) did not map most of Belize's offshore cayes, which make up ~2% of Belize's land territory, so forest cover data extracted from their study applies only to the mainland.

[5] **Table 1** presents details of the national-level studies, mapped at scales ranging from 1:50,000 to 1:250,000.

[6] There are also global and regional land cover datasets from which forest cover for Belize can be extracted (e.g. data from the USGS 1993, PROARCA/CAPAS 1998, JRC 2002, EarthSat 2005, Giri & Jenkins 2005, CAST/SERVIR 2006, University of Maryland 2008, ESA 2008, and GeoVille/DIVERSITY 2008).

[7] GOFC-GOLD (2009: 2-25) presents a list of avail. techniques for extracting land cover data from satellite imagery.

to previously having access only to tabular statistics.

Table 1 below thus compares the different forest cover estimates derived by the various studies. One sees that – perhaps due to the "interpreter dependent" nature of visual interpretation – the estimates can be conflicting (GOFC-GOLD 2009). For instance, examining the forest cover statistics generated by the different studies, it is unclear if around 1990 forest cover was 74.5% as reported by Fairweather & Gray (1994), or 66.8% as reported by Meerman et al (2010). Another challenge to utilizing the various datasets is that of the eight land cover / forest cover estimates, only the three published by Meerman et al (2010) possess accuracy assessments, even though conducting accuracy assessments is a commonly-cited principle of land cover / forest cover assessment (Aranoff 2004, Jensen 2006, Lillesand et al 2007). That makes it difficult to assess the ultimate quality of five of the eight data sources.

Table 1: National forest cover / land cover maps

No.	Study Authors	Pub. year	Ground condition	Source imagery	Classes mapped	Interp. method	Mainland forest cover	
							Acres	%
1	Fairweather & Gray	1994	1989-90-92	SPOT-1, SPOT-2	80	visual interp.	4,012,023	74.5%
2	Iremonger & Brokaw	1995	1993	Landsat-5	52	visual interp.	3,611,850	67.2%
3	White et al	1996	1994[8]	Landsat-5	16	supervised classification	3,546,061	65.9%
4	Meerman & Sabido	2001	1993-96-98	Landsat-5	85	visual interp.	3,374,612	62.7%
5	Meerman	2005	2004	Landsat-7	82	visual interp.	3,327,066	61.9%
6	Meerman et al	2010	1989-90-94	Landsat-5	6	supervised classification	3,275,703[9]	66.8%[10]
7	Meerman et al	2010	2000-03	Landsat-5 Landsat-7	6	supervised classification	3,072,138[9]	62.6%[10]
8	Meerman et al	2010	2004-05-06	Landsat-7	6	supervised classification	2,984,588[9]	61.6%[10]

It is also worth pointing out that over the sixteen years since the first *modern* land cover study of Belize was published in 1994, a number of technological and policy advancements have also occurred that now make possible what would not have previously been feasible in terms of land cover assessment. One has been the provision of open access to the satellite data used in land cover assessments. In February 2005, the respective governments of Central America joined CATHALAC, NASA, USAID, and other partners in establishing the *Regional Visualization & Monitoring System* (SERVIR) for Mesoamerica, based out of CATHALAC's regional headquarters in Panama. At SERVIR's inauguration, tens of thousands of dollars of satellite imagery were made available to the public via the system's online portal (www.servir.net). Specific satellite images for Belize (e.g. imagery from the Landsat series, and from the Aqua, Terra, and EO-1 satellites) have been acquired periodically and provided on CD and DVD media

[8] White et al (1996) also mapped parts of northern Belize for 1993, and parts of southern Belize for 1996, but the only complete country coverage they did was using an image mosaic for March 28, 1994.
[9] Meerman et al (2010) also includes the forest cover on the island of Ambergris Caye; lack of access to the raw data prevented removal of that island's data from the overall analysis.
[10] These estimates discount for cloud cover, estimating forest cover as the % of forest on land not obscured by cloud.

to the Government of Belize, and online to anyone with an Internet connection. SERVIR was and continues to be the region's largest public (i.e. open access) archive of satellite and geospatial data on the environment. Additionally, a number of training workshops organized in the context of SERVIR, and held at the regional- and the national level (the latter in Belize) have also supported the development of a cadre of technical specialists capable of processing satellite data and generating land cover datasets.

Four years after SERVIR's establishment, in February 2009, the U.S. Geological Survey (USGS) opened its entire Landsat archive to the world, making available imagery that was previously not available even via SERVIR. In addition to changes in policy that have liberated satellite data (at least from select US Govt. satellites), since the 1990s, computing capabilities have increased exponentially, and desktop and laptop personal computers can now rapidly implement processing algorithms which previously required significant amounts of time. A variety of software tools, both open source and commercial off the shelf packages, are also available for processing satellite data. Tied into this, since 2003, the Government of Belize has been a member of the intergovernmental Group on Earth Observations (GEO), with membership in GEO facilitating access to a range of benefits including access to satellite data, algorithms and capacity-building opportunities. Regarding forest cover mapping, in the context of the Global Earth Observation System of Systems (GEOSS)[11] whose implementation GEO is leading, GEO has also coordinated leading a Forest Carbon Tracking Task to assist countries in using satellite data for forest monitoring (GEO 2010).

II. OBJECTIVES

Considering (i) the necessity of forest cover data, (ii) the difficulty in comparing data sources generated through different methods by different studies, (iii) that the data stretch back only to 1989 and only as close to present as 2006, and (iv) that satellite data for a larger time frame is available through SERVIR and the USGS, a study of Belize's forest cover was conducted, utilizing readily available data resources. This was also based on a request from the LIC of the Lands & Surveys Department of the MNRE, which sought updated information on Belize's land cover. Specifically, the main objectives of this study were:

> (i) to apply automated image classification algorithms to map Belize's forest cover at a scale of 1:100,000 for the years 1980, 1989, 1994, 2000, 2004, and 2010[12], using the extensive archive of imagery available from the Landsat series of satellites,
>
> (ii) to estimate – and validate through the use of accuracy assessments – national and sub-national deforestation rates for the periods in between the aforementioned years, and
>
> (iii) to make this information and the methodology available for both national-level decision-making and international reporting requirements.[13]

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[11] SERVIR has been recognized both as a regional model for the implementation of GEOSS and as one of "the first 100 steps toward GEOSS" (GEO 2007).

[12] It was the intention of the authors to have time-steps of precisely five years (i.e. 1980, 1985, 1990, 1995, 2000, 2005, 2010), but the absence of cloud-free images prevented analyzing those specific years. While imagery for 1987 was available (to fill in a time-step between 1980 and 1989), it was decided against using this imagery due to its temporal proximity to the 1989 imagery used in this analysis.

[13] These include, but are not limited to the CBD, the UNCCD, and the UNFCCC.

Hence, in order to provide the MNRE[14] / Government of Belize, and other stakeholders with *current*[15] information on Belize's forest cover, it was also the aim of this study to produce a map for 2010 *during* the year 2010. (2010 is also, coincidentally, the UN's *International Year of Biodiversity*; 2011 is the UN's *International Year of Forests*). The present study was conducted over a four-month period, from March to June 2010.

III. METHODOLOGY

The study's objectives focused on being able to map forest, notwithstanding the technical limitations to what earth observation satellites can reliably identify (GOFC-GOLD 2009, Strand et al 2007). While White et al (1996) used remote sensing to identify five different types of forests in Belize, for the purpose of merely assessing forest cover and deforestation (i.e. the removal of forest), a simple forest / non-forest classification scheme was deemed appropriate. Even though a computer-aided identification of forests was conducted, the algorithm chosen (described later) required definition of the target to be identified by the software.

Defining the 'forest' target also required consideration of the technical limitations encountered in previous land cover studies of Belize. For instance, Fairweather & Gray 1994, White et al 1996, and White et al 1998 all noted difficulty in distinguishing broadleaf forests from secondary forest regrowth. This was taken into consideration both in the classification's training phase (described later), as well as in explicitly stating what constituted the 'forest' that would be mapped. While the Government of Belize has no national definition of forest (Marcelo Windsor, personal communication), through its participation in the UNFCCC's Clean Development Mechanism (CDM), it has ascribed to defining certain physical variables of forest (e.g. minimum height, percent land cover and parcel size).[16] In contrast, in the FAO's 2005 *Forest Resource Assessment* national report for Belize, the FAO defined 'forest' as follows:

> *Land spanning more than 0.5 hectares [1.24 acres] with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.* (FAO 2000: 7)

From the perspective of remote sensing, in practical terms the FAO's definition had to be adjusted in its application. For instance, this study does not include secondary forest regrowth as 'forest.' **Figure 2** thus illustrates how closed canopied forest could be distinguished from secondary forest regrowth during the classification's training stage which is described later.

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[14] The Forest Department within the MNRE, via the Forest Act of 1927 (revised in 2000), has the mandate for managing Belize's national forest estate and forest resources, while the objective of the Land Information Centre of the Lands & Surveys Department of the MNRE is to provide the Government of Belize with information about the current state of Belize's land resources.

[15] There is usually a time lag of *at least* a year in the development and publication of such satellite-based land cover assessments.

[16] As defined by Belize's Designated National Authority to the CDM, forests in Belize are defined as having a minimum height of 5m, at least 30% crown cover, and minimum parcel sizes of 0.3 hectares (UNFCCC 2010). From a remote sensing perspective, the practical definition of forest from Emch et al (2005: 260) was "formed by trees at least 5m tall with interlocking crowns and a canopy cover of 65 percent or greater."

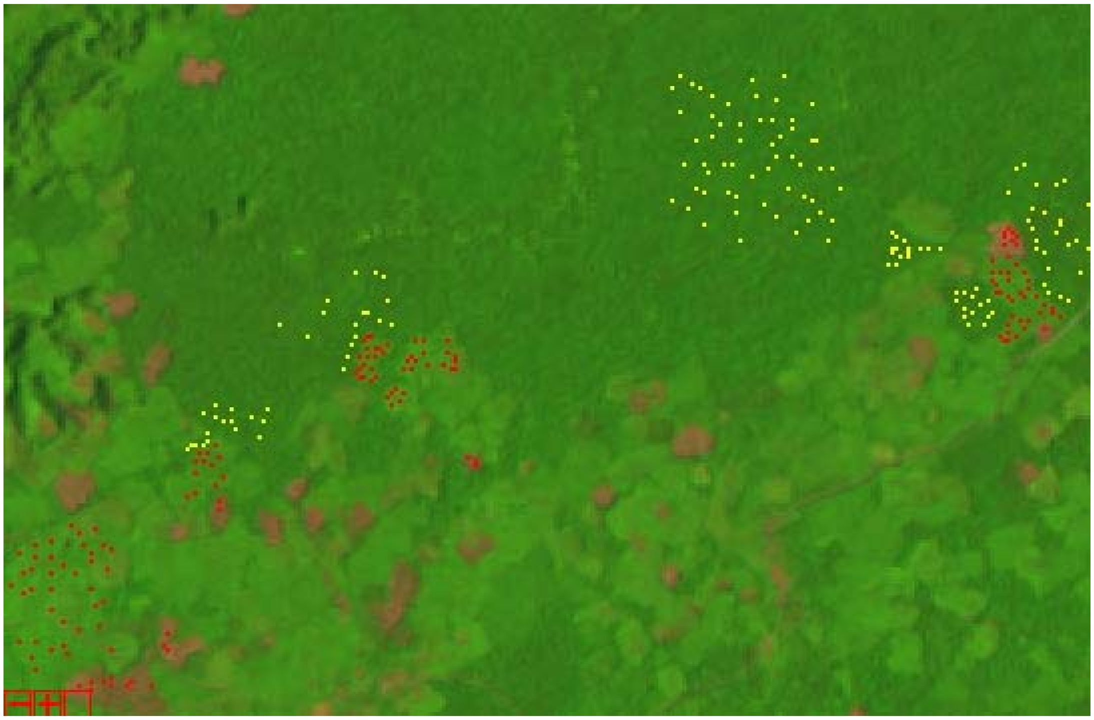

Figure 2: Training data (red, yellow dots) used to distinguish forest (dark green) from secondary regrowth (lighter green), utilizing a false color 5-4-3 band combination in the Landsat-5 image for March 28, 2000

The overall processing work flow utilized in developing the forest cover datasets for 1980, 1989, 1994, 2000, 2004, and 2010 was comprised of the following activities:

(i) pre-processing,
(ii) training,
(iii) image classification,
(iv) post-processing, and
(v) validation / accuracy assessment.

The pre-processing activities focused on acquiring and preparing Landsat satellite imagery for processing. The training stage was comprised of selecting the samples (i.e. training sites, such as shown in **Figure 2**) of the land cover classes to be mapped. The image classification phase focused on performing an automated, computer-assisted 'supervised' image classification using the 'training data' that had been selected. Post-processing activities consisted of filtering the output from the classification routine to make it more easily understandable. These activities were also followed by validation / accuracy assessment of the results by generating 'error matrices' (also known as 'confusion matrices') to assess the levels of accuracy and uncertainties in the forest cover datasets generated. (The validation activities elaborated under this project are treated in the subsequent section of this report.)

Pre-Processing

Landsat satellite images, which were available in SERVIR and the USGS' global archive, were acquired to develop largely cloud-free mosaics that covered all of mainland and offshore Belize. The acquired scenes corresponded to the following 'path rows' in the Landsat World Reference System:

- Path 19, Row 47 (northern Belize),
- Path 19, Row 48 (central Belize), and
- Path 19, Row 49 (southern Belize).

The specific Landsat scenes used in this analysis are presented in **Table 2** below. Mosaics for 1989, 1994, and 2000 could be developed using scenes for single dates, which largely eliminated difficulties matching brightness between scenes. For 1980, the data drop issue experienced by the Landsat-3 satellite which eliminated roughly the western third of each scene required that about 10% of the mosaic in the mid-western border of the Orange Walk district (near the Aguas Turbias National Park) be filled in with the clearest available imagery, which was from February 14, 1979. The 1980 mosaic (originally at 60m spatial resolution) was also resampled using cubic convolution to 30m to be comparable to the other five 30m-resolution mosaics which had been developed.

The 2004 mosaic was developed by stitching together four previously 'gap-filled' scenes[17] captured on January 27, February 12, and February 28, 2004. A combination of cloudiness and the unavailability of gap-filled Landsat-7 data required that the 2010 mosaic was developed using an algorithm developed by CATHALAC to choose the least cloudy pixel, from among 9 scenes taken on January 11, February 12, and February 28, 2010. Mosaicking was done in ERDAS Imagine 9.2 ®, followed by spatial subsetting (clipping) in the same software application using a polygon of the country's borders. This reduced 26 scenes to 6 mosaics for 1980, 1989, 1994, 2000, 2004, and 2010.

Table 2: Landsat scenes used in the analysis, and their characteristics

Mosaic	Satellite	Sensor	Spatial res.	Spectral res. (µm)	Reference		Location	Date
					Path	Row		
1: 1980	Landsat-3	MSS	60m	0.5 - 0.8	19	47	north	November 14, 1980
	Landsat-3	MSS	60m	0.5 - 0.8	19	48	central	February 14, 1979
	Landsat-3	MSS	60m	0.5 - 0.8	19	48	central	November 14, 1980*
	Landsat-3	MSS	60m	0.5 - 0.8	19	49	south	November 14, 1980
2: 1989	Landsat-5	TM	30m	0.45 - 2.35	19	47	north	December 27, 1989
	Landsat-5	TM	30m	0.45 - 2.35	19	48	central	December 28, 1989
	Landsat-5	TM	30m	0.45 - 2.35	19	49	south	December 29, 1989
3: 1994	Landsat-5	TM	30m	0.45 - 2.35	19	47	north	March 28, 1994
	Landsat-5	TM	30m	0.45 - 2.35	19	48	central	March 28, 1994
	Landsat-5	TM	30m	0.45 - 2.35	19	49	south	March 28, 1994

[17] Since a May 2003 instrument malfunction, all Landsat-7 data have significant data gaps in the eastern and western portions of each scene. This requiring filling with data from other scenes of similar dates (Lillesand et al 2007).

Mosaic	Satellite	Sensor	Spatial res.	Spectral res. (µm)	Reference		Location	Date
					Path	Row		
4: 2000	Landsat-5	TM	30m	0.45 - 2.35	19	47	north	March 28, 2000
	Landsat-5	TM	30m	0.45 - 2.35	19	48	central	March 28, 2000
	Landsat-5	TM	30m	0.45 - 2.35	19	49	south	March 28, 2000
5: 2004	Landsat-7	ETM+	30m	0.45 - 2.35	19	47	north	February 28, 2004
	Landsat-7	ETM+	30m	0.45 - 2.35	19	48	central	January 27, 2004
	Landsat-7	ETM+	30m	0.45 - 2.35	19	48	central	February 12, 2004
	Landsat-7	ETM+	30m	0.45 - 2.35	19	49	south	January 27, 2004
6: 2010	Landsat-7	ETM+	30m	0.45 - 2.35	19	47	north	January 11, 2010
	Landsat-7	ETM+	30m	0.45 - 2.35	19	47	north	February 12, 2010
	Landsat-7	ETM+	30m	0.45 - 2.35	19	47	north	February 28, 2010
	Landsat-7	ETM+	30m	0.45 - 2.35	19	48	central	January 11, 2010
	Landsat-7	ETM+	30m	0.45 - 2.35	19	48	central	February 12, 2010
	Landsat-7	ETM+	30m	0.45 - 2.35	19	48	central	February 28, 2010
	Landsat-7	ETM+	30m	0.45 - 2.35	19	49	south	January 11, 2010
	Landsat-7	ETM+	30m	0.45 - 2.35	19	49	south	February 12, 2010
	Landsat-7	ETM+	30m	0.45 - 2.35	19	49	south	February 28, 2010

** Primary scene utilized*

To maximize comparability and replicability within the study, it was decided at the outset that the six image mosaics would be radiometrically registered to each other (insofar as it was possible). For instance, the five images taken by the Thematic Mapper (TM) and Enhanced Thematic Mapper+ (ETM+) sensors were all spectrally subset to six bands[18], by having their thermal bands removed. This allowed for smaller file sizes and faster processing. The second near-infrared band was removed from the 4-channel Landsat Multispectral Scanner (MSS) 1980 mosaic. Following that spectral subsetting, the six mosaics were converted from radiance to top-of-atmosphere (TOA) reflectance by applying the gains and offsets factors supplied in Chander et al (2009).

In theory, merely converting all images to TOA reflectance should have made them all standardized, compensating for instance for differences in illumination resulting in the images being captured during different phenological stages. Nevertheless, two other pre-processing routines were conducted to better ensure image matching. To bring the images closer to representing bottom-of-atmosphere (BOA) reflectance, an automated haze reduction routine was also applied on the Landsat-5 mosaics, using ERDAS Imagine 9.2 ®. Of the five TM / ETM+ images, four were standardized to the March 28, 2000 image mosaic using histogram matching in the ERDAS Imagine platform, while the 1980 Landsat MSS mosaic was matched to a spectral subset of that March 28, 2000 mosaic which possessed three bands corresponding to the 1980 mosaic (i.e. green, red, and NIR). For public access, the image mosaics for each study year (with their corresponding metadata) have been published in the SERVIR Data Portal (http://www.servir.net/) and are available from the following URLs:

[18] The six bands used were the three visible bands, the near-infrared band, and the two mid-infrared bands.

- 1980: http://maps.cathalac.org/downloads/data/landsat/landsat3_reflectance_bz_1980-11-14_wgs84.zip
- 1989: http://maps.cathalac.org/downloads/data/landsat/landsat5_reflectance_bz_1989-12-27_wgs84.zip
- 1994: http://maps.cathalac.org/downloads/data/landsat/landsat5_reflectance_bz_1994-03-28_wgs84.zip
- 2000: http://maps.cathalac.org/downloads/data/landsat/landsat5_reflectance_bz_2000-03-28_wgs84.zip
- 2004: http://maps.cathalac.org/downloads/data/landsat/landsat7_reflectance_bz_2004-jan-feb_wgs84.zip
- 2010: http://maps.cathalac.org/downloads/data/landsat/landsat7_reflectance_bz_2010-jan-feb_wgs84.zip

Training & Image Classification

There are a variety of methods that could have been used to map forest using the satellite imagery which was prepared, with some methods being more effort-intensive than others[19] (Jensen 2007, Lillesand et al 2007, GOFC-GOLD 2009). At the outset of this study, it had been decided that employing an automated (i.e. computer-assisted) classification technique would be beneficial to this process for a variety of reasons. One, employing an automated technique would require less time and also be less interpreter-dependent than attempting a visual interpretation of the imagery, which would require an excessive number of hours digitizing (i.e. tracing the outlines of) land cover features. The time that would have been required to digitize 6 images, each spanning 22,000 km^2, would have been impractical. Furthermore, performing an automated classification such as supervised classification – in which the interpreter selects samples of the classes to be mapped and then lets the software map those features in the entire scene – was deemed desirable because the spectral signatures to be collected during the training phase could then be re-used in future land cover assessments, as well as refined, if necessary as new information became available. The RSI ENVI 4.5 ® platform was chosen for the classification analysis for its variety of features and algorithms.

Regarding selection of training data for image classification, in theory, training data for six image mosaics (i.e. 1980, 1989, 1994, 2000, 2004, and 2010) would have had to have been selected. However, because of how the images had been radiometrically registered to each other, the training data selected from only one mosaic was sufficient to classify all six mosaics. While the overall objective was to map forested areas versus areas without forest, it was decided to map forest, non-forest land areas, as well as water bodies and cloud, the last of which was present in each of the image mosaics even as these had been selected for being generally cloud-free. Using expert knowledge, existing land cover data, the 1:50,000 topographic maps, and the Landsat image mosaics themselves, 718 pixels from the March 28, 2000 image were carefully chosen for the forest class, supplemented by 1,594 pixels for the non-forest class, 275 pixels for the water class, and 53 pixels for the cloud class. These training samples were arrived at using an iterative process which included employing ENVI's *n-D Visualizer®* function to refine training samples. As demonstrated in **Figure 3**, this ensured that in general there was not significant 'spectral overlap' between the land cover classes.

[19] GOFC-GOLD 2009 (p. 2-25) presents a comprehensive overview of the different methodologies available.

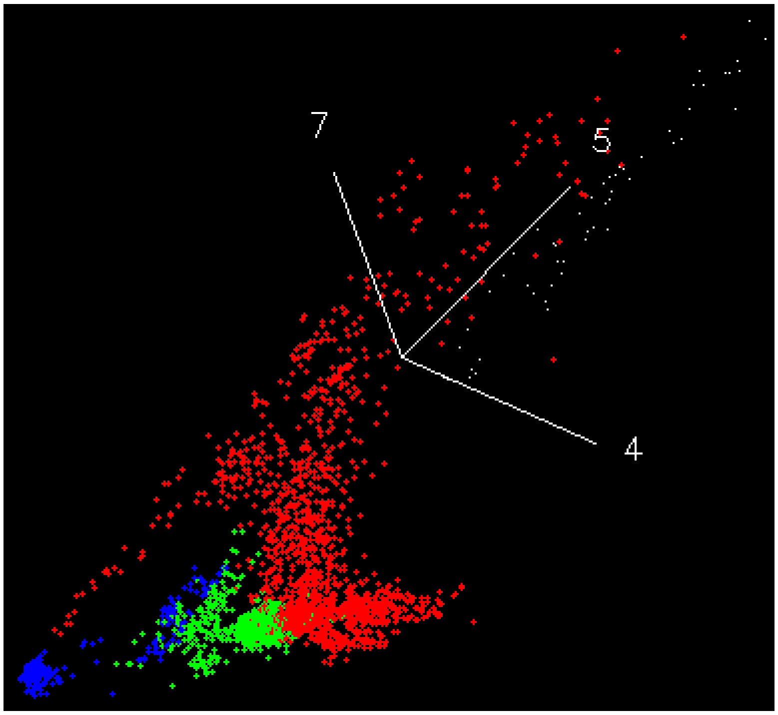

Figure 3: Visualization in three dimensions of the separability of the spectral signatures for cloud (white), forest (green), non-forest areas (red), and water (blue), in Landsat's near-infrared to mid-infrared bands (bands 4, 5, and 7)

One cannot overemphasize the significance of training data. As replicability is a key principle of land cover assessment, should one have access to the source data and the training data used in classification-based land cover assessments, one can replicate such assessments or expand them in time (Anderson 1976, Lillesand et al 2007). However, of the various classification-based land cover assessments done for Belize[20], the training data is not available for any of these[21]. Were these available – perhaps in the form of a publicly accessible library of spectral signatures for land cover types, as is the case with *NASA's ASTER Spectral Library* (http://speclib.jpl.nasa.gov/) – this would allow researchers to more easily follow-up such land cover work. Thus, in order for the current study to be followed up in the future, in addition to the source satellite image mosaics whose URLs are provided in this document, the corresponding training datasets used in generating this assessment are being made publicly available through SERVIR at the following URL: http://maps.cathalac.org/downloads/data/landsat/bz_endmembers_rois_1980-2010.zip.[22] The significance is that current and future remote sensing researchers and students will be able to

[20] These include White et al 1996, EarthSat 2005, and Meerman et al 2010 at the national level and Zisman 1992, White et al 1998, White et al 2002, DiFiore 2002, Ek 2004, Penn et al 2004, Emch et al 2005, Binford 2007, Meerman 2008, and Wyman & Stein 2010 at the sub-national level.

[21] Of various – but not all - of the authors contacted between 2005 and 2010, Emch et al was the only example who provided complete source data and training datasets. In other cases, some authors indicated that their source and training data had been lost.

[22] These consist of spectral signature files (i.e. 'endmember collection files') and polygon 'regions of interest' (ROIs), readable in the RSI ENVI ® remote sensing software package.

utilize and update the spectral signatures derived for Belize's forests to conduct follow-up assessments at other spatial scales, for other time periods, and even using data from satellites other than Landsat (provided those satellites have similar spectral channels). The spectral response 'curves' generated are presented in **Figure 4** below, and can be compared to the generalized spectral response curves shown in **Figure 5**.

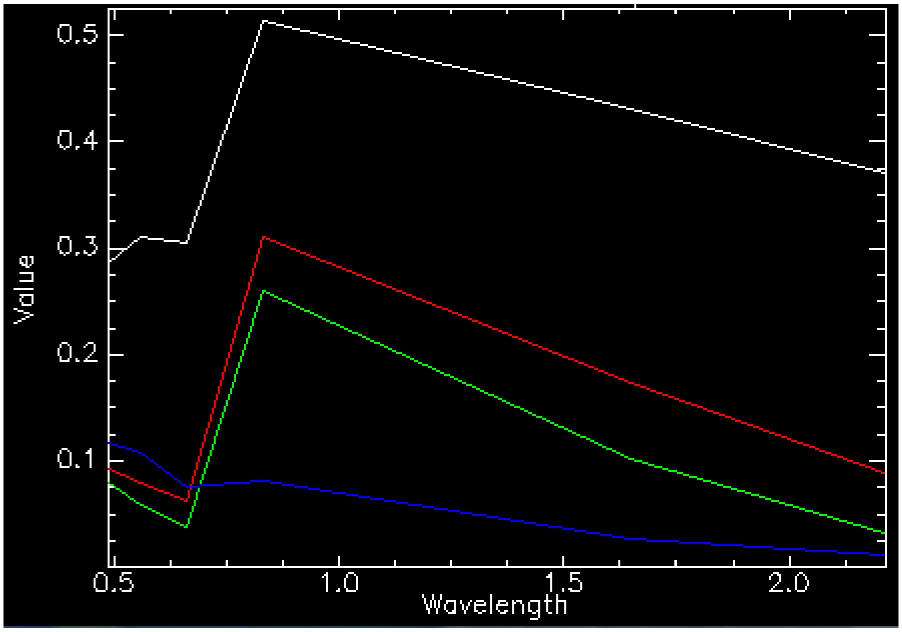

Figure 4: Spectral signatures (in μm) derived during this study for Belize, for: cloud (white), forest (green), non-forest areas (red), and water (blue)

With further regard to the classification, the single set of derived spectral signatures was used to classify cloud, forest, non-forest, and water in the six image mosaics. Based on an initial set of trial runs, it was determined that only the infrared bands (bands 4, 5 and 7) of the five Landsat-5 and Landsat-7 image mosaics would be used for the classification because, as seen in **Figure 4**, the four land cover types are more distinguishable in the infrared range than in the visible range. Since the 1980 Landsat-3 mosaic did not possess the same spectral range, only three bands (green, red and near IR) of that image mosaic were used for the classification. Specifically, the images and the signatures were utilized in a Maximum Likelihood Classification (MLC) algorithm in the RSI ENVI 4.5® platform and thereby classified. The MLC algorithm was selected from a variety of algorithms available for automated, 'supervised classification.' Supervised classification had likewise been selected for assessing forest cover from among a list of available interpretation techniques (e.g. unsupervised classification, visual interpretation, etc.) for its ease of implementation and replicability (GOFC-GOLD 2009: 2-25).

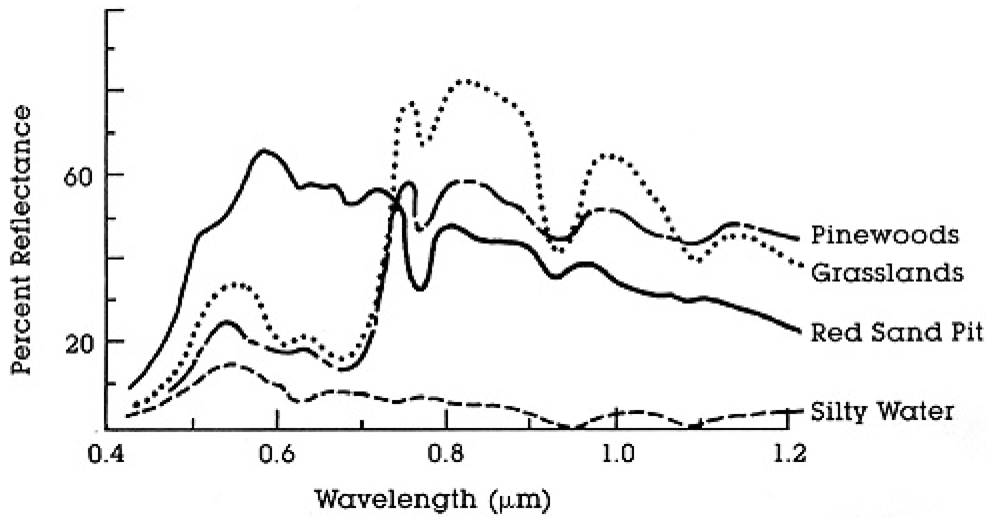

Figure 5: Common spectral response curves (*source: NASA Goddard Space Flight Center* / http://rst.gsfc.nasa.gov/Intro/Part2_5.html)

Post-Processing

Following the classification, as is standard practice, post-processing was also performed on the outputs of the image classifications (Lillesand et al 2007). From examining the appearance of the six map outputs, a 5x5 majority filter was applied to smooth the results; this resulted in removal of patches smaller than 2.89 acres. The data was also subset to the extent of Belize's mainland and offshore boundaries, removing the marine extent of Belize's territory from the analysis.

Whereas the original data outputs contained four classes (cloud, forest, non-forest and water), the cloud class was removed by assessing how those pixels were mapped in the periods before and after the image was captured. Thus, if an area was mapped as forest in 1980, but as cloud in 1989, but as forest anew in 1994, that pixel was re-mapped as forest. In the case of the 2010 data, while the cloud cover was minimized to about 2-3% using the algorithm employed, the pixels were mapped to the values they possessed in the previous period (i.e. 2004). This re-mapping of the 2010 data was also supported by visual comparison of the output with the source satellite imagery. With regard to the water class (which could have been lumped in with the non-forest class), since the mapping flood extent was not the focus, and noting overall land cover change, a single water class of the extent of water bodies across the thirty year (1980-2010) span was generated. Water was subsequently combined with the non-forest class, and each dataset was numerically re-classified each dataset into the following classes:

0: Forest
1: Non-forest

The various datasets were thereafter summed into a single gridded dataset. After reclassification, the resulting combined dataset possessed the values indicated in **Table 3**.

Table 3: Codes used in reclassification of the six forest cover datasets

Code	Land cover						Description
	1980	1989	1994	2000	2004	2010	
000000	Forest	Forest	Forest	Forest	Forest	Forest	Forested throughout period 1980-2010
100000	Forest	Forest	Forest	Forest	Forest	Non-forest	Forested 1980-2004; non-forest in 2010[23]
110000	Forest	Forest	Forest	Forest	Non-forest	Non-forest	Forested 1980-2000; non-forest in 2004-2010
111000	Forest	Forest	Forest	Non-forest	Non-forest	Non-forest	Forested 1980-1994; non-forest in 2000-2010
111100	Forest	Forest	Non-forest	Non-forest	Non-forest	Non-forest	Forested 1980-1989; non-forest in 1994-2010
111110	Forest	Non-forest	Non-forest	Non-forest	Non-forest	Non-forest	Forested 1980; non-forest in 1989-2010
111111	Non-forest	Non-forest	Non-forest	Non-forest	Non-forest	Non-forest	Non-forested throughout period 1980-2010

As can be deduced from examination of **Table 3**, this dataset was filtered thoroughly to remove values such as '000100' which would have indicated that a parcel of land was deforested between 1989 and 1994, and six years later appeared forested, or values such as '110111' which would indicate that a parcel was not forested during the period 1980-1994, but was forested between 1994 and 2000, and then deforested again between 2000 and 2004. This does rule out the possibility of showing forest regrowth (and afforestation) within the final dataset, but there are various reasons why, in terms of forest dynamics areas deforested continue to be treated as non-forest even when satellite imagery indicates that forest *may* have regrown.

Meerman et al (2010) for instance argue that in southern Belize, prevailing land use practices such as *milpa* (shifting cultivation) agriculture dictate that farmland which is reforested during fallow cycles is later re-cut. Additionally, various parcels that seemed to be afforested or reforested actually represented the cultivation of tree crops and canopied crops such as citrus and bananas which appear spectrally similar to forest. In other cases, anomalies between dates represented cloud cover. That is to say, even though an attempt was made to map clouds, varying cloud densities prevented identification all of a scene's clouds, and hence these areas appeared spectrally similar to deforested lands. In other cases, 'deforestation' between periods was merely the result of phenological effects of deciduous forests. These were largely located in the northwestern portion of the Maya Mountains, in the Cayo District near the Guatemalan border (see **Figure 6**). A mask was developed to identify forests undergoing phenological changes in the various images. The images showing the most phenological change are the 1994 and 2000 images, both captured on March 28, at the height of the dry season. In any event, the data prior to being processed into the final scheme shown in **Table 3** has been maintained, and can thus be used at a later date to speculate about potential reforestation / afforestation activities.

The dataset was also combined with a further layer showing exposed soils and generated from spectral mixture analysis (SMA) of the very same six Landsat image mosaics. (Of note, the SMA

[23] The deforestation detected in 2010, for instance, could have occurred anytime between 2004 and 2010.

outputs provide data on forest degradation as they allow assessment, over time, of how the density of Belize's forests have changed; that data is not reported here but may be published separately.) The refinement of the deforested areas using the SMA outputs was followed-up with some manual editing (combined with visual inspection) of the outputs. For instance, although the 2010 data was corrected for errors due to the Landsat-7 ETM+ Scan Line Corrector malfunction, which originally left data drop 'stripes' across the scene, a relatively small quantity of the filled data was replaced with cloud in the few areas where cloud was prevalent in all three image dates. Hence, manual editing was needed to correct for this, with those 2010 pixels being assigned the same values they had in 2004. Likely because of similar reflectance, some wetlands (e.g. Booth's River wetland in the Orange Walk district) were also classified as forest, and these were also manually adjusted. Some corrections were also made with regard to hill-shaded areas which had spectral reflectance values similar to water. The current data represents the authors' best effort in terms of the land cover assessment, having passed through rigorous post-processing, although errors are inevitably present. The data is likewise available online for download from the SERVIR Data Portal, and specifically from the following URL:

http://maps.cathalac.org/downloads/data/bz/bz_forest_cover_servir_v1_1980-2010.zip.

IV. VALIDATION

Errors in the data are inevitable; there are no perfect land cover assessments (Lillesand et al 2007). While reporting on the accuracy of land cover datasets is one of the principles of land cover assessment, very few[24] of the land cover studies available for Belize include accuracy assessments, inevitably calling into question their utility (Anderson 1976, Lillesand et al 2007). As indicated by Lillesand et al (2007: 585), "a classification is not complete until its accuracy is assessed." Assessing the accuracy of land cover (and forest cover) data generated allows one (i) to determine whether the data generated reaches a predetermined minimum acceptable level of accuracy, and also (ii) to gauge the uncertainty in the product (Aranoff 2005, GOFC-GOLD 2009, Jensen 2007, Lillesand et al 2007).

To assess accuracy of the six datasets generated, a dataset was compiled of some 784 field sites surveyed between 1990 and 2008 by the following sources:

1. Belize Audubon Society
2. The Conservation Management Institute of Virginia Technical University
3. David Buck, Sean Downey, and Miriam Wyman of the University of Florida
4. The Forest Department of the MNRE
5. The Geology & Petroleum Department of the MNRE
6. Jan Meerman (Belize Tropical Forest Studies)
7. The Missouri Botanical Garden
8. The Programme for Belize
9. Sonia DiFiore of Columbia University
10. The University of Texas-Austin

[24] Ek (2004)'s land cover assessment of central Belize for 2003 had an overall accuracy of 92% and a KHAT (explained later) of 90%. Emch et al (2005)'s assessments for Toledo for 1975 and 1999 had overall accuracies ranging from 84.4% to 95.2%, and KHAT's ranging from 71.84% to 88.88%. DiFiore (2002) did not report KHAT but did report an overall accuracy of 97.29%. Accuracies for the other land cover studies are unknown / unreported.

Subsets of these were extracted and used for conducting the accuracy assessment. For example, as there were not sufficient sites surveyed specifically in the year 2000 to correspond to the dataset generated from the March 2000 Landsat TM mosaic, field sites surveyed between 1998 and 2002 were utilized (i.e. 2000 ± 2 years). For the 1989 map however, as there were not sufficient field surveys for that timeframe, a random stratified sample of 150 points digitized from the 1993 series of Belize's E755 1:50,000 scale topographic sheets, based on guidance from GOFC-GOLD (2009). The topographic sheets are based on aerial photographs from 1988 and 1991 (i.e. a comparable period). The error matrices for five of the six datasets generated are hence presented below. In addition to reporting on overall classification accuracies, the user and producer accuracies are also presented, as well as class accuracies.

In addition to assessing the various classification accuracies, as Lillesand et al (2007: 590) indicate that "a random assignment could result in a surprisingly good classification result," estimates of $\hat{k}$ (also known as KHAT or the Cohen's Kappa statistic) were also derived. KHAT "serves as an indicator of the extent to which the percentage correct values of an error matrix are due to "true agreement" versus "chance" agreement" (Lillesand et al 2007: 590). The equation for calculating KHAT (Lillesand et al 2007: 590) is:

$$\hat{k} = \frac{\text{observed accuracy} - \text{chance agreement}}{1 - \text{chance agreement}}$$

1980 forest cover map accuracy

It was not possible to assess the accuracy of the 1980 land cover map because few sites had been surveyed during that period, nor were topographic maps corresponding to that period available. The permanent forest plots maintained by Belize's Forest Department since the ~1970s were too few to be used, and also did not correspond to non-forested areas.

1989 forest cover map accuracy

Table 4: Error matrix for the 1989 forest cover map

	User validation dataset (topographic sheets)					
Producer Classification Dataset (1989 forest cover map)	**Class**	**Forest**	**Non-forest**	**Total**	**User accuracy**	**Total class accuracy**
	Forest	72	3	75	96.00%	92.3%
	Non-forest	3	72	75	96.00%	92.3%
	Total	75	75	150	-	
	Producer accuracy	96.00%	96.00%	-		**96.00%**

$\hat{k}$ = 92.00%

1994 forest cover map accuracy

Table 5: Error matrix for the 1994 forest cover map

	User validation dataset (ground survey sites)					
Producer Classification Dataset (1994 forest cover map)	**Class**	**Forest**	**Non-forest**	**Total**	**User accuracy**	**Total class accuracy**
	Forest	85	9	94	90.43%	79.4%
	Non-forest	13	56	69	81.16%	71.8%
	Total	98	65	163	-	
	Producer accuracy	86.73%	86.15%	-		**86.50%**

$\hat{k}$ = 73.01%

2000 forest cover map accuracy

Table 6: Error matrix for the 2000 forest cover map

	User validation dataset (ground survey sites)					
Producer Classification Dataset (2000 forest cover map)	**Class**	**Forest**	**Non-forest**	**Total**	**User accuracy**	**Total class accuracy**
	Forest	53	2	55	96.36%	88.3%
	Non-forest	5	48	53	90.57%	87.3%
	Total	58	50	108	-	
	Producer accuracy	91.38%	96.00%	-		**93.52%**

$\hat{k}$ = 87.04%

2004 forest cover map accuracy

Table 7: Error matrix for the 2004 forest cover map

	User validation dataset (ground survey sites)					
Producer Classification Dataset (2004 forest cover map)	**Class**	**Forest**	**Non-forest**	**Total**	**User accuracy**	**Total class accuracy**
	Forest	81	13	94	86.17%	78.6%
	Non-forest	9	81	90	90.00%	78.6%
	Total	90	94	184	-	
	Producer accuracy	90.00%	86.17%	-		**88.04%**

$\hat{k}$ = 76.09%

2010 forest cover map accuracy

Table 8: Error matrix for the 2010 forest cover map

	User validation dataset (ground survey sites)					
Producer Classification Dataset (2010 forest cover map)	**Class***	**Forest**	**Non-forest**	**Total**	**User accuracy**	**Total class accuracy**
	Forest	91	12	103	88.35%	84.3%
	Non-forest	5	54	59	91.53%	76.1%
	Total	96	66	162	-	
	Producer accuracy	94.79%	81.82%	-		**89.51%**

$\hat{k}$ = 79.01%

With regard to interpreting the overall accuracies, class accuracies, producer and user accuracies, the overall accuracies presented exceed both the USGS' suggested threshold of 85% (Anderson 1976), as well the 80% threshold cited by Aranoff 2005 as "commonly considered acceptable." In all cases, one likewise sees that class accuracies – whether forest or non-forest – exceed 70%. The class accuracies for forests are a little better than the accuracies for the non-forest class. One can also see that in general, the error of commission for the forests are in the range of 3.64% to 13.83% across the various datasets (as measured by the user accuracies), while the error of omission for forests (as measured by the producer accuracies) are in the range of 4.0% to 13.27%. This helps to establish the domains of the certainty about the land cover data generated, and which are presented in the following section of this report.

In addition to examining the accuracies, the KHAT statistics generated likewise indicate the quality of the forest cover outputs developed (Lillesand et al 2007). The KHAT statistic is often used in place of overall accuracy as it "serves as an indicator of the extent to which the percentage correct values of an error matrix are due to 'true' agreement versus 'chance' agreement" (Lillesand et al 2007: 590). Like the class accuracies, the KHAT statistics for this study's data likewise all exceed 70% and indicate the high accuracy of the forest cover outputs. In terms of qualitative interpretations of those KHAT statistics, Fleiss et al (2003) indicates that KHAT statistics exceeding 75% are "excellent," and that threshold has been exceeded in all but one of the cases. Landis & Koch (1977) also indicate that KHAT statistics exceeding 60% show "substantial agreement," while those exceeding 80% show "almost perfect agreement." All of this study's outputs fit into either of those categories. The KHAT statistics show that for the datasets assessed (excluding the 1980 dataset for which an accuracy assessment could not be performed), all are 70%+ better than would have achieved by pure chance.

Hence, as (i) the overall accuracies meet commonly accepted standards, and (ii) the KHAT statistics likewise exceed the thresholds of what is considered acceptable, one can be confident in the accuracy of the forest cover datasets. Unfortunately, the lack of data for 1980 prevents evaluation of the accuracy of the 1980 forest cover dataset, although one can anticipate that it is possesses a similar level of accuracy to the other five outputs.

V. RESULTS

The following series of graphs, tables, and figures presents the results of this study. There are various ways that the results of this study can be dissected, hence the results are presented and analyzed in terms of:

(i) overall forest cover,
(ii) forest cover by geographic region,
(iii) forest cover by watershed, and
(iv) forest cover within and without protected areas

It is recognized that those are not the only types of analyses possible, so it is the hope of this study's authors that other researchers / students / resource managers will take it upon themselves to apply this data to other types of analysis. The data are available free of charge, through SERVIR, for public access and use.

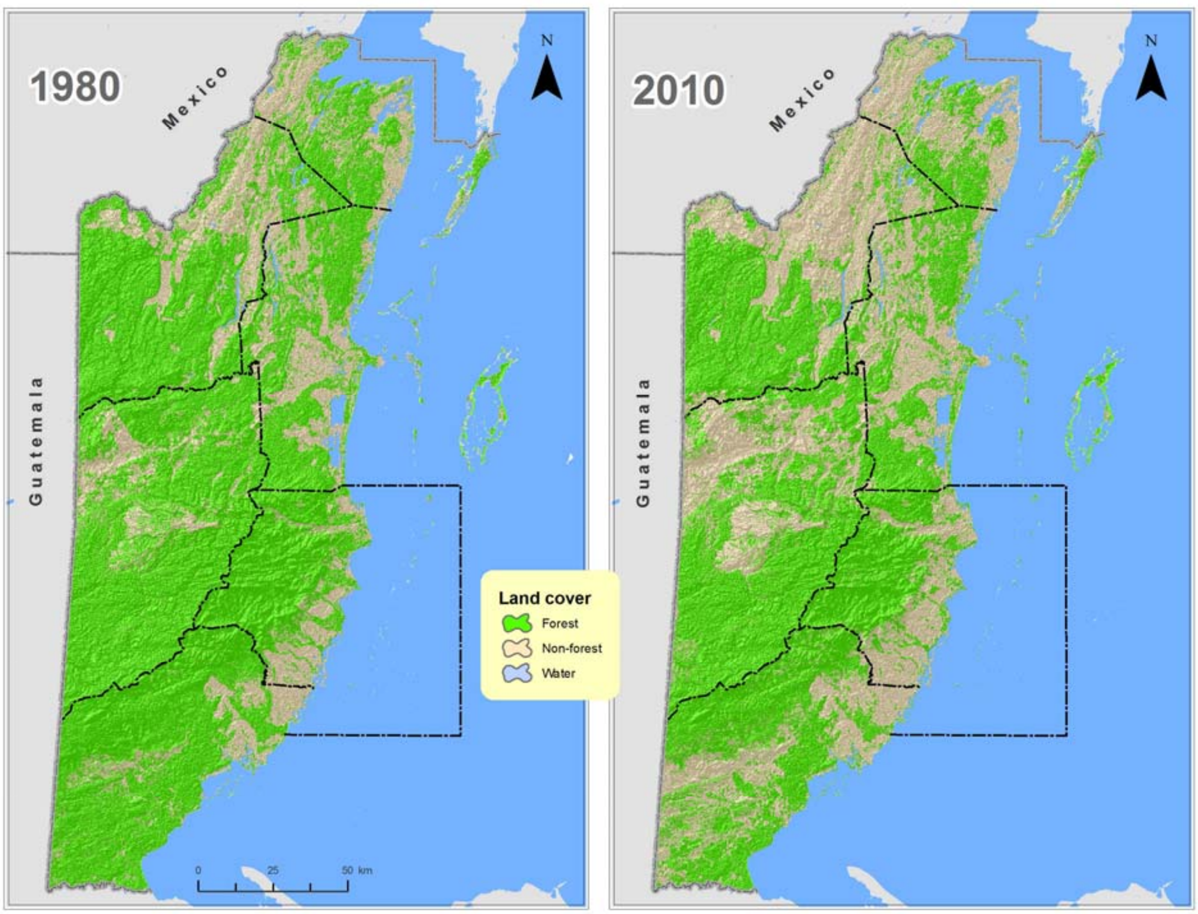

Figure 6: Forest cover, 1980 and 2010

Overall Trends

Figure 6 illustrates the drastic difference in forest cover between 1980 and 2010. This is substantiated by **Figures 7-8** and **Tables 9-10** which in turn show that that, as estimated by this study, Belize had some 4.2 million acres of forest in mid-November 1980, but which had declined to 3.4 million acres by late February 2010. In 1980, forests covered 75.9% of Belize's land territory[25], but this had declined to 62.7% by 2010. While the forest cover decline merely represented an absolute loss of 13.2%, the relative forest cover change over the thirty year period was a 17.4% decline. In other words, nearly a fifth of the forest which had covered Belize's territory in 1980 had been lost by 2010.

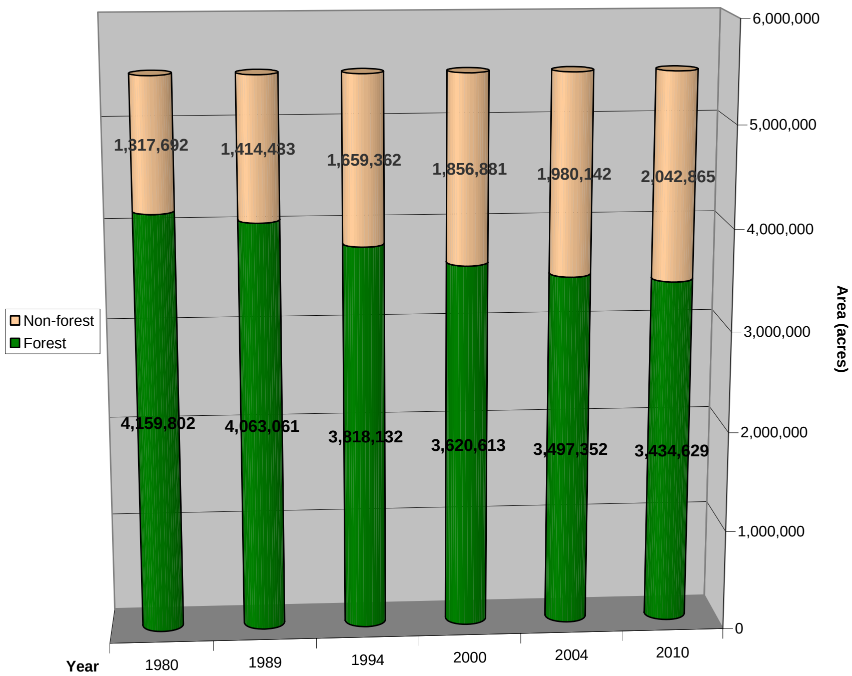

Figure 7: Land cover of Belize, 1980-2010

For direct comparison with **Table 1**'s compilation of the forest cover statistics derived by previous studies, **Table 9** likewise elaborates this study's forest cover data in terms of both national forest cover and forest cover solely on the mainland. (Comparison of the data is discussed later.) Trends in offshore forest cover are explored under the subheading of the 'cayes' in **Tables 12-13**. **Table 10** examines overall forest cover dynamics with respect to absolute changes in forest cover, while **Table 11** looks at annual rates of change.

Table 9: Forest cover, 1980-2010

Year	Mainland Cover		National Cover	
	Area (acres)	%	Area (acres)	%
1980	4,108,515	75.0%	4,159,802	75.9%
1989	4,011,963	73.2%	4,063,061	74.2%
1994	3,767,443	68.8%	3,818,132	69.7%
2000	3,571,246	65.2%	3,620,613	66.1%
2004	3,450,913	63.0%	3,497,352	63.9%
2010	3,389,026	61.9%	3,434,629	62.7%

[25] Percent cover was determined by dividing by 5,477,494 acres, Belize's land territory according to GIS analysis.

Table 10: Forest cover dynamics, 1980-2010 (*modified from* **Table 3**)

Area (acres)	Land cover						Description
	1980	1989	1994	2000	2004	2010	
3,434,629	Forest	Forest	Forest	Forest	Forest	Forest	Forested throughout period 1980-2010
62,723	Forest	Forest	Forest	Forest	Forest	Non-forest	Forested 1980-2004; non-forest in 2010
123,261	Forest	Forest	Forest	Forest	Non-forest	Non-forest	Forested 1980-2000; non-forest in 2004-2010
197,519	Forest	Forest	Forest	Non-forest	Non-forest	Non-forest	Forested 1980-1994; non-forest in 2000-2010
244,929	Forest	Forest	Non-forest	Non-forest	Non-forest	Non-forest	Forested 1980-1989; non-forest in 1994-2010
96,741	Forest	Non-forest	Non-forest	Non-forest	Non-forest	Non-forest	Forested 1980; non-forest in 1989-2010
1,313,730	Non-forest	Non-forest	Non-forest	Non-forest	Non-forest	Non-forest	Non-forested throughout period 1980-2010

The loss of 17.4% of Belize's forest area over a thirty-year span represents an average annual deforestation rate of 0.6%. In terms of absolute numbers, this translates to a total loss of 725,173 acres of forest over the ~30-year span, at an average national loss of 24,835 acres of forest per year, although **Table 11** also shows that forest loss ranged from as low as 3,002 acres per year in the 1980s to as high as 71,960 acres per year between 2000 and 2004.

Table 11: Deforestation, 1980-2010

Period	Area deforested / year (acres)	Change / year
1980 - 1989 (9.11 yrs)	3,002	-0.3%
1989 - 1994 (4.25 yrs)	51,260	-1.4%
1994 - 2000 (6 yrs)	17,426	-0.9%
2000 - 2004 (3.92 yrs)	71,960	-0.9%
2004 - 2010 (6 yrs)	15,101	-0.3%
Average / year	**24,835**	-0.6%

Deforestation by District

Figure 8 and **Tables 12-13** examine deforestation across Belize's administrative units (i.e. the Districts comprising the country). Beyond the fact that earlier studies like White et al (1996) have described the process of land cover change in terms of Belize's geographic zones, it is likewise quite useful to examine deforestation from that perspective when one acknowledges that agriculture – a key driver of deforestation in Belize – occurs differentially among the Districts. For instance, students of Belize's geography know well that in terms of Belize's principal agricultural exports, sugarcane is cultivated in Corozal and Orange Walk, while bananas and oranges are farmed in Stann Creek and Toledo.

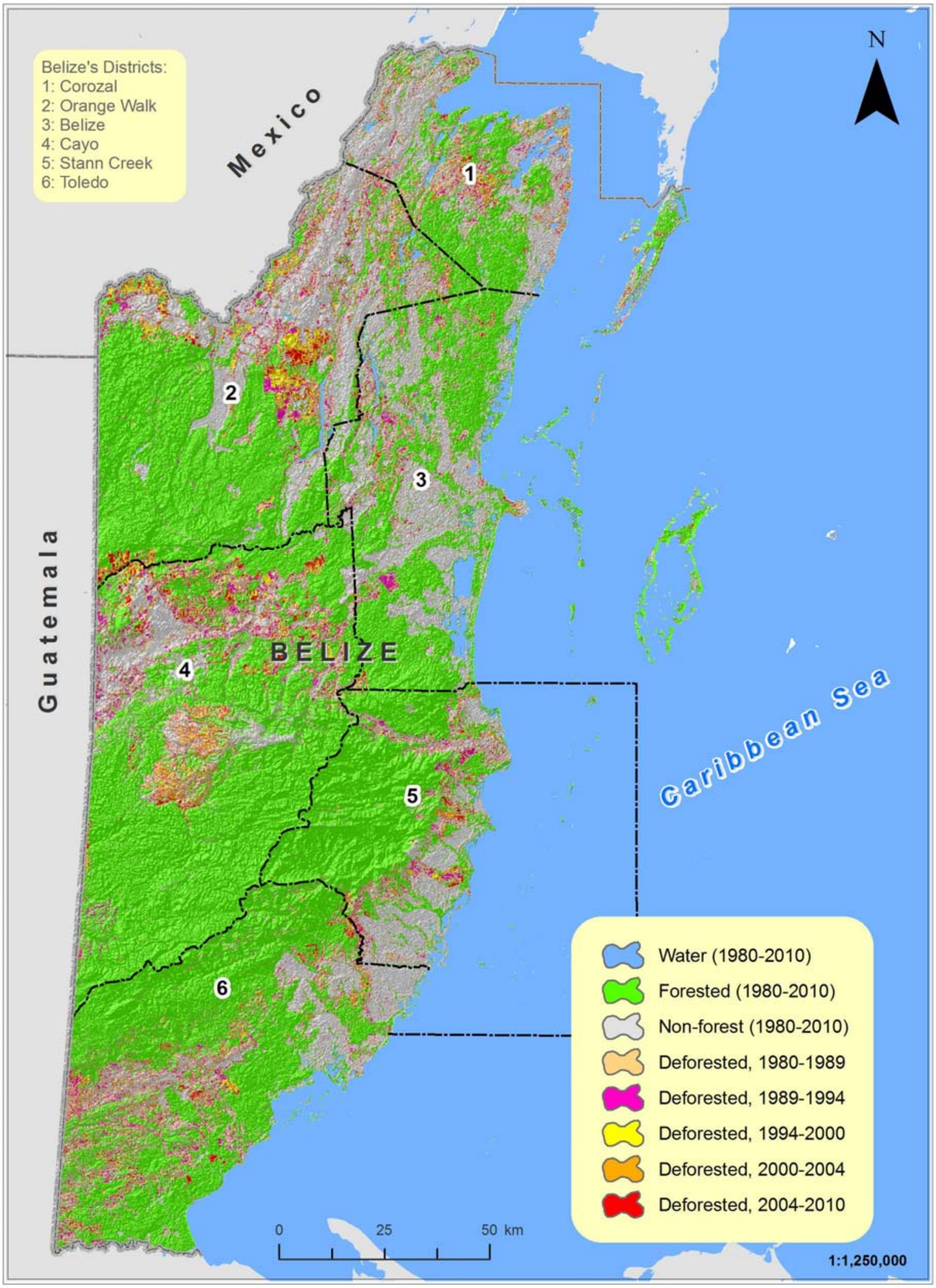

Figure 8: Forest cover change in the Districts, 1980-2010

In terms of highlights, the data indicate that the Cayo district was the most forested district both relatively and in absolute terms in 1980, remaining so through 2010. This is likely because of the extensive system of protected areas in the Maya Mountain massif which have shielded Cayo's forests from 'development.' Along with the Toledo district, Cayo was one of only two districts possessing higher than 70% forest cover in 2010. In absolute terms, however, having lost almost 190,000 acres of forest in 30 years, Cayo had also lost more forest than another other district.

Table 12: Forest cover extent (in acres) by District, 1980-2010

Year	Corozal	Orange Walk	Belize	Cayo	Stann Creek	Toledo	Cayes[26]	National
1980	264,588	853,186	493,526	1,129,640	461,798	905,152	51,299	4,159,802
1989	249,636	842,029	483,168	1,101,962	450,495	884,057	51,111	4,063,061
1994	235,528	784,167	451,879	1,037,509	424,011	833,763	50,701	3,818,132
2000	206,642	706,163	435,096	1,000,888	412,634	809,282	49,379	3,620,613
2004	196,286	689,669	429,783	961,796	403,696	769,172	46,451	3,497,352
2010	192,671	674,390	425,911	940,439	398,361	756,750	45,616	3,434,629
Decline	**71,918**	**178,793**	**67,615**	**189,201**	**63,437**	**148,402**	**5,683**	**725,173**
Avg. annual decline	2,463	6,123	2,316	6,479	2,173	5,082	195	24,835

The offshore islands – representing less than 2% of Belize's land territory – possess the smallest absolute share of Belize's forests, and were assessed to be less than 50% forested in 2010, but saw the least overall relative deforestation in the thirty-year period, having lost only 11.1% of its 1980 forest cover by 2010. The Corozal district, in contrast with the cayes, experienced the highest deforestation relative to its 1980 forest cover. Nearly a third of the forest which existed in Corozal in 1980 was cleared by 2010 due to agricultural expansion. Corozal was also the only district which had less than 50% forest cover in 2010, although the Belize district was only slightly more than half-forested in 2010.

Table 13: Percent forest cover by District, 1980-2010

Year	Corozal	Orange Walk	Belize	Cayo	Stann Creek	Toledo	Cayes	National
1980	56.0%	74.2%	61.9%	86.8%	78.%	85.2%	54.2%	**75.9%**
1989	52.8%	73.2%	60.6%	84.7%	76.0%	83.2%	54.0%	**74.2%**
1994	49.8%	68.2%	56.7%	79.7%	71.6%	78.5%	53.5%	**69.7%**
2000	43.7%	61.4%	54.6%	76.9%	69.7%	76.2%	52.1%	**66.1%**
2004	41.5%	60.0%	53.9%	73.9%	68.1%	72.4%	49.1%	**63.9%**
2010	40.8%	58.6%	53.4%	72.3%	67.2%	71.2%	48.2%	**62.7%**
Relative decline	**27.2%**	**21.0%**	**13.7%**	**16.8%**	**13.7%**	**16.4%**	**11.1%**	**17.4%**
Avg. annual decline	**0.9%**	**0.7%**	**0.5%**	**0.6%**	**0.5%**	**0.6%**	**0.4%**	**0.6%**

[26] The offshore cayes are administered under various District jurisdictions (e.g. Swallow Caye is within the Belize district), but they are examined them separately in this analysis to assess the trend of offshore land cover change.

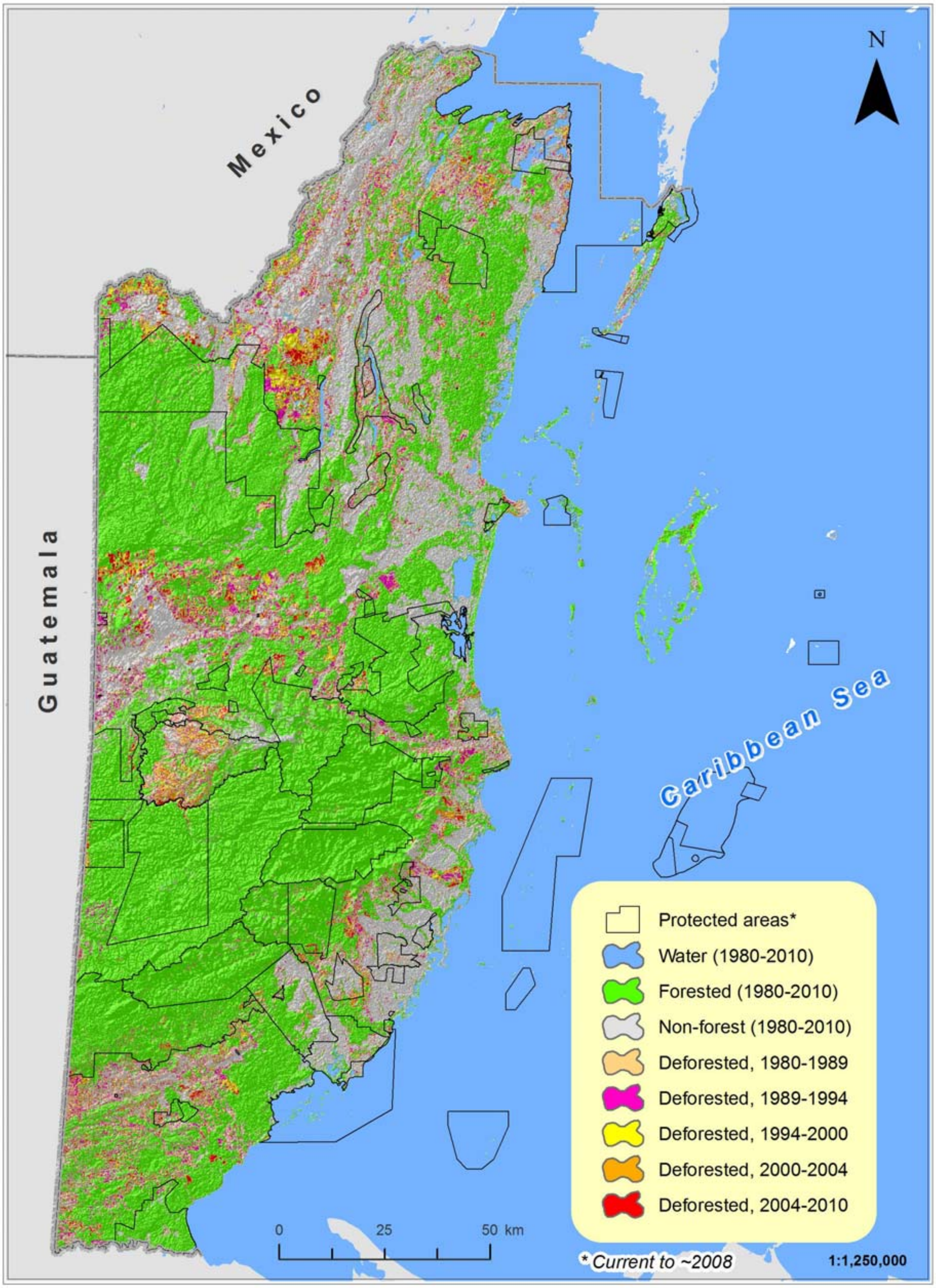

Figure 9: Forest cover change and protected areas

Forest Cover in and outside of Protected Areas

Protected areas cover some 36% of Belize's land surface (MNRE 2010). This study does not present a breakdown of forest cover per individual protected area or per category but the overall figures do speak for themselves. One compelling finding is that protected areas (PAs) in Belize have indeed protected the nation's forests.[27] **Table 14** illustrates the efficacy of protected areas in conserving forest, relative to land not under protected area status. Relatively speaking, over the past thirty years, only 6.4% of the forests within protected areas were cleared[28], compared to the quarter of the forests on unprotected land which were lost between 1980 and 2010. Put another way, 15.2% of the deforestation from 1980-2010 occurred in protected areas, while 84.8% occurred outside of protected areas.

The above findings in turn support and update the conclusion by a 2001 assessment of deforestation in the Mesoamerican Biological Corridor which showed that for Belize and the rest of Mesoamerica, most deforestation in the 1990s occurred outside of the region's protected areas (Sader et al 2001). This also corroborates with a satellite-based analysis of fires in Belize which showed that for the period 2003-2009, the vast majority of fires (four-fifths) occurred outside of Belize's protected areas (Cherrington 2010).

Table 14: Protected area status and forest cover

Year	Forest Cover					
	Inside PAs		Outside PAs		National	
	Acreage	%	Acreage	%	Acreage	%
1980	1,718,514	88.3%	2,441,288	69.1%	4,159,802	75.9%
1989	1,708,165	87.8%	2,354,896	66.7%	4,063,061	74.2%
1994	1,676,059	86.1%	2,142,073	60.7%	3,818,132	69.7%
2000	1,656,016	85.1%	1,964,597	55.6%	3,620,613	66.1%
2004	1,615,696	83.0%	1,881,656	53.3%	3,497,352	63.9%
2010	1,608,404	82.6%	1,826,225	51.7%	3,434,629	62.7%
Relative decline	6.4%		25.2%		17.4%	

Where protected areas contained only 41.3% of Belize's forest in 1980, widespread destruction of forests outside of protected areas resulted in the proportion of Belize's forest cover within protected areas rising to 46.8% by 2010. Consequently, where forests outside of protected areas represented 58.7% of total forest cover in 1980, this had declined to 53.2% in 2010. In extrapolating those figures, one might easily envision a future not too far off when the majority of Belize's forests exist mainly in protected areas. **Figure 9** likewise shows the relative sparseness of forests outside of protected areas. With ecosystem connectivity an important aspect of the gap analysis performed under the comprehensive 2004-05 NPAPSP, the figures presented here also have strong implications for successor projects and initiatives.

[27] It should be noted that the boundaries of the protected areas have changed over time as some areas have been added, others removed, and others have had boundaries modified. Many areas existing in 2010 did not exist in 1980.

[28] Not all deforestation in protected areas was manmade. The largest change detected within the protected areas system occurred in the Mountain Pine Ridge Forest Reserve and was caused by an infestation of the southern pine beetle (*Dendroctonus frontalis*) which greatly reduced the density of the once robust pine forest ecosystems there (Ek 2004). The sharp change in density of trees is thus registered as deforestation.

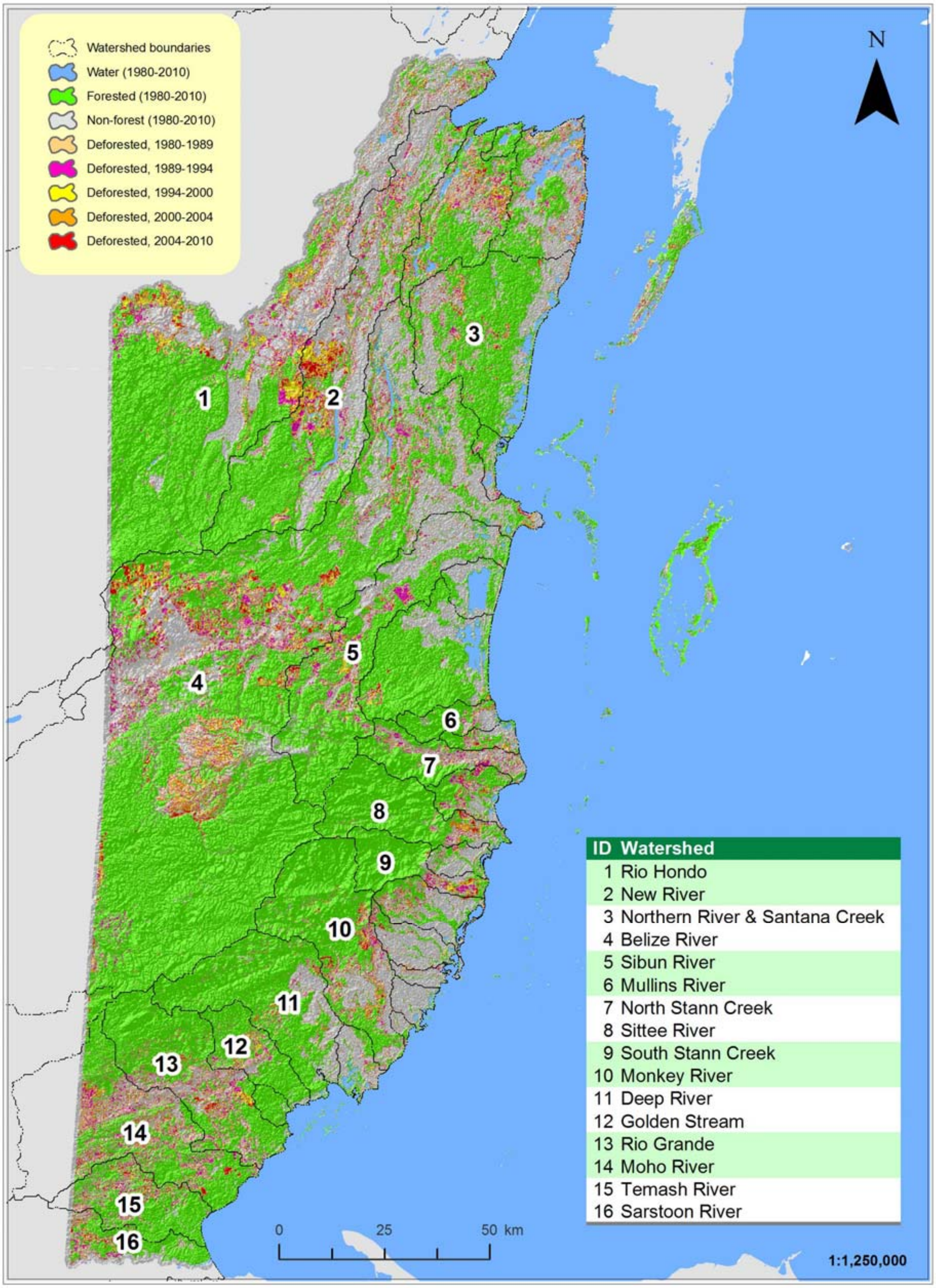

Figure 10: Forest cover change and major watersheds

Forest Cover in Watersheds

Belize's recent (2008) *National Plan of Action for the Control of Land-Based Sources of Marine Pollution in Belize* report notes that deforestation is a key contributing factor to the pollution of the country's marine environment, which is home to the second largest barrier reef system in the world. As noted in that national plan, deforestation contributes to erosion, which in turn send coral-smothering sediments out to sea. While the 2004-07 USAID-funded ICRAN-MAR project noted well that erosion is dependent not only on land cover and deforestation but also on an area's topography, soil types and the rainfall received, forest cover within a watershed nonetheless serves as a general indicator of environmental quality (Burke & Sugg 2006). The results of this study are thus examined through the prism of spatial hydrology. **Tables 15-16**, along with **Figure 10**, illustrates how forest cover has varied over the past thirty years across Belize's sixteen defined major watersheds.

Table 15: Percent forest cover by major watersheds[29] in northern and central Belize, 1980-2010

Year	Northern Watersheds			Central Watersheds					
	Rio Hondo	New R.	Northern River	Belize	Sibun	Mullins	North SC	Sittee	South SC
1980	72.0%	63.0%	70.4%	80.6%	75.3%	82.3%	80.9%	94.6%	91.2%
1989	71.2%	61.1%	69.6%	78.5%	73.9%	81.6%	76.7%	93.7%	90.2%
1994	66.8%	55.3%	66.7%	73.6%	68.1%	78.5%	67.8%	91.6%	85.9%
2000	60.2%	48.1%	64.2%	70.6%	65.0%	77.4%	65.4%	90.6%	82.5%
2004	59.2%	46.3%	63.5%	67.8%	64.0%	76.1%	64.0%	88.9%	81.3%
2010	58.4%	**44.9%**	62.8%	66.2%	63.2%	75.5%	63.7%	88.0%	80.4%
Relative decline	**19.0%**	**28.7%**	**10.9%**	**17.8%**	**16.1%**	**8.2%**	**21.3%**	**7.0%**	**11.8%**

Table 16: Percent forest cover by major watersheds in southern Belize, 1980-2010

Year	Southern Watersheds						
	Monkey R.	Deep R.	Golden Stream	Rio Grande	Moho	Temash	Sarstoon
1980	85.4%	85.1%	94.7%	90.7%	89.4%	96.2%	93.4%
1989	83.2%	84.8%	94.1%	89.4%	84.1%	94.9%	90.7%
1994	80.5%	83.5%	90.6%	84.1%	75.4%	87.7%	84.3%
2000	79.2%	83.1%	88.2%	81.4%	71.2%	84.0%	81.7%
2004	76.0%	80.8%	83.9%	76.8%	65.2%	81.1%	79.8%
2010	74.3%	80.6%	83.7%	75.8%	63.9%	78.8%	76.9%
Relative decline	**13.0%**	**5.3%**	**11.6%**	**16.4%**	**28.5%**	**18.0%**	**17.6%**

[29] Where a number of Belize's major watersheds are shared with either Mexico or Guatemala, this study only reports on the land cover within the Belizean portions of these watersheds. Transboundary watersheds include: the Rio Hondo, the Belize, Moho, Sarstoon, and Temash Rivers.

Only one of Belize's major watersheds – the New River watershed – was less than 50% forested in 2010. The New River watershed is located in Belize's developed northern region where sugarcane is cultivated; the other northern watersheds were generally less forested than the southern ones. The New River watershed also underwent the largest relative deforestation, although the watersheds for the Moho River and the North Stann Creek also lost more than 20% of their forests over the past 30 years. In contrast, the Deep River, Sittee River, and Mullins River watersheds all exhibited deforestation rates below 10% over thirty years. Overall, fourteen of the sixteen watersheds maintained forest cover exceeding 60%, while half of the sixteen were more than 75% forested, although the Mexican and Guatemalan segments of the five transboundary watersheds are not considered. The overall high state of forest cover of a significant number of the watersheds should be considered positive.

With regard to expanding on this hydrology-related analysis, DiFiore (2002) who studied riparian deforestation along the Belize River, noted the importance of riparian forest cover in preventing sediments as well as pesticides from entering rivers, thus protecting water quality. Riparian deforestation is not specifically addressed here, but it could easily be assessed based on the data provided through this study; it is the hope of this study's authors that the data will be utilized for various applications, as well as scrutinized.

VI. DISCUSSION

Having, in the previous section, presented the results of the 1980-2010 forest cover study of Belize, in this section this study's results are reviewed in terms of:

(i) earlier studies,
(ii) Belize's international commitments,
(iii) long-term monitoring, and
(iv) the regional context.

Comparison to Previous Studies

Prior to this study, assessing land cover change in Belize has involved comparison of studies realized under different conditions. For instance, in reporting on land cover change across Belize, the 2005 national Thematic Assessment Report for its implementation of the United Nations Convention to Combat Desertification, could only cite data compiled by Cherrington from existing sources, developed through different methods (MNRE 2005). The current study has sought to present consistent statistics on Belize's forest cover, utilizing the largest possible data archive available, shedding light on Belize's land cover at the outset of the 1980s, prior even to Belize's oldest existing satellite-based land cover assessment. In having consistently defined 'forests' in Belize from the remote sensing perspective, it is hoped that this study can also serve as a yardstick from which to monitor further changes in Belize's forest cover.

Those familiar with the previous national forest cover estimates from studies such as Fairweather & Gray (1994), Iremonger & Brokaw (1995), White et al (1996), Meerman & Sabido (2001), Meerman (2005), and Meerman et al (2010) will inevitably want to know why this study has resulted in somewhat different results and conclusions. The results of this study differ from, but do not necessarily contradict most of the earlier national-level studies of Belize's land cover and forest cover. As can be seen by comparison of **Table 1** with **Table 9**, in general the forest cover estimates generated by this study differ from previous studies by only a few percentage points. For instance, Fairweather & Gray (1994) estimate that for the period spanning 1989 to 1992, Belize's mainland forest cover was 74.5%. This 74.5% is less than 2% different than the 73.2% estimated by this study for 1989, even as the periods (1989 vs. 1989-92) are slightly different. This study's mainland forest cover estimate for 1994 (68.7%) is also less than 3% different than the estimate from the White et al (1996) estimate of 65.9%. This study's estimate for 2000 (65.2%) is likewise different from the Meerman et al (2010) estimate of 62.6% for the period circa 2000, although their data actually spans from 2000 to 2003. This study's estimate for mainland forest cover for 2004 (63%) is also less than 2% different from both Meerman (2005)'s estimate of 61.9% for 2004, and the Meerman et al (2010) estimate of 61.6% for the period 2004-2006.

Regarding deforestation rates, interestingly enough, this study has arrived at the same deforestation rate of 0.6% estimated by Meerman et al (2010) even though the period for their study was circa 1990 to circa 2005, compared to the 1980-2010 study period for the present assessment. Aside from Meerman et al (2010), there are not many other national-level deforestation-specific statistics to which to compare the present study. White et al (1996), for instance, quantified the deforestation rate in terms of annual area lost but did not specify the deforestation rate in percentage format. They estimate that between 1989-92 and 1994, the annual deforestation was approximately 61,729 acres / year. **Table 11** shows that for a similar period (1989-1994), deforestation is estimated at 51,260 acres / year. The 2010 *GEO Belize* report points out that the World Resources Institute (1987) had estimated that between 1980 and 1987, Belize's deforestation rate was 22,239 acres / year. While this differs significantly from the 3,002 acres / year estimated by the present study for the period 1980-1989, the *GEO Belize* report also aptly points out that the reliability of that figure cannot be known as there is no accompanying accuracy assessment for WRI's estimate.

Further regarding other estimates of Belize's deforestation rate, the UN Food & Agriculture Organization (FAO) has in one instance estimated Belize's annual deforestation rate to be 2.3% or ~89,000 acres / year (FAO 2005a) while in their FAOSTAT database and in their 2005 *Forest Resource Assessment* maintained that Belize's forest cover is a constant 4,084,738 acres (1.653 million ha), i.e. no deforestation (FAO 2005b, FAO 2008). In light of this study, and that even the source of the 2.3% annual deforestation rate reported by FAO could not be traced, it is the conclusion of this study that FAO's estimates of forest cover and deforestation (whether 0% or 2.3%) require substantial revision.

Considering, in general, how the present study compares to previous assessments, it should also be pointed out that the **previous national-level studies have generally lacked accuracy assessments**, unlike the present, *validated* (i.e. accuracy-assessed) study. The only exception to that rule has been Meerman at al (2010). This study's 30m Landsat-based 2010 forest cover data is also extremely similar to the 250m MODIS-based forest cover data recently developed and validated by CATHALAC under a separate project. **Figure 11** shows the high level of similarity between the two datasets, even as the MODIS-based map was developed using an automated, non classification-based methodology. Although the MODIS-based data estimates a 66.8% forest cover for Belize for 2010, compared to the 62.7% from the present study's Landsat-based data - a difference of 4.1% - that difference is partly due to varying spatial resolutions between the two source datasets. The other reason for the difference between the two datasets is that the MODIS-based data in large part depicts as "forest" areas which are tree crops or canopied crops. Through the high overall accuracies and KHAT statistics, this study's results have been *validated* the study's authors are therefore confident in the overall quality of the assessment.

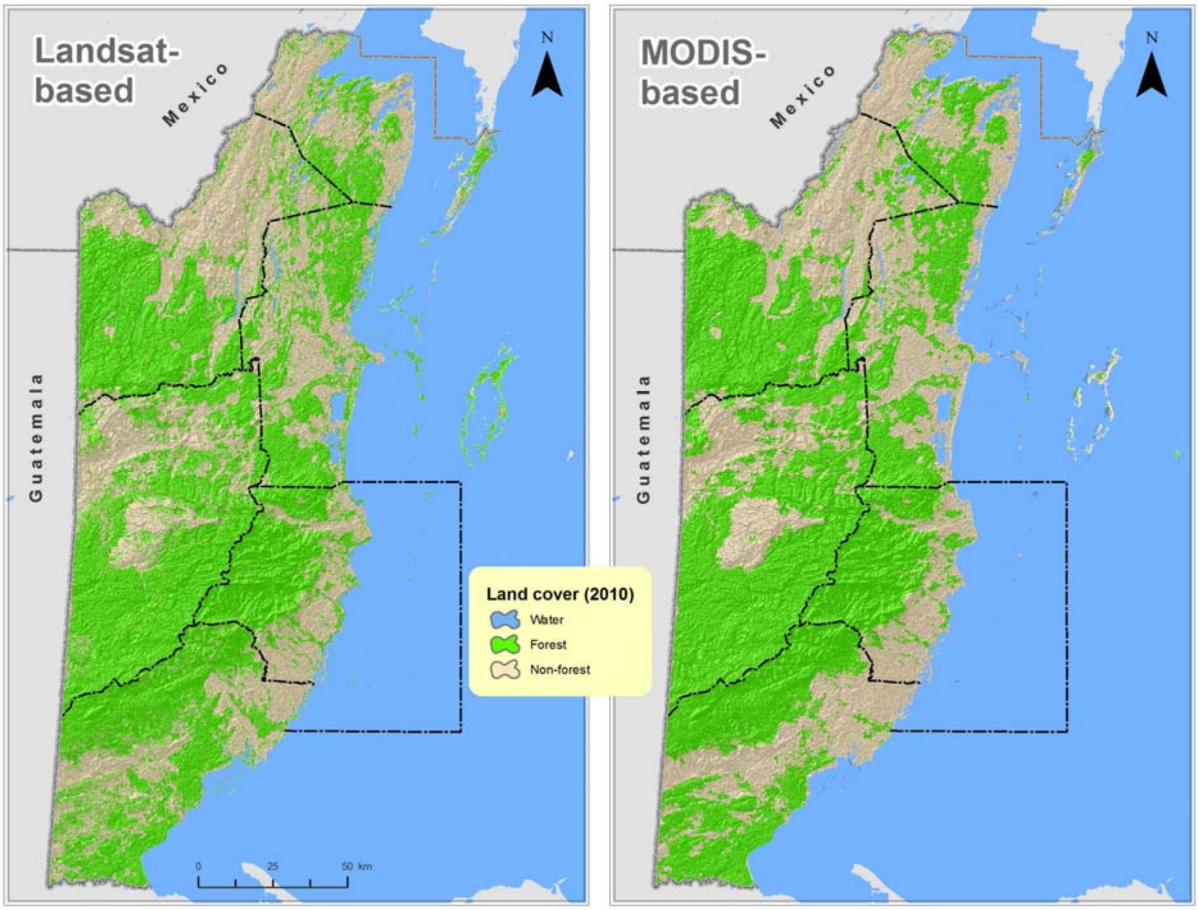

Figure 11: Comparison of Landsat-derived 30m forest cover data (left) with MODIS 250m canopy cover-derived forest cover data (right), both for 2010

Implications for International Commitments

The information provided can feed into Belize's reporting to its various international commitments. The country is a signatory to a number of multilateral environmental agreements whose reporting requirements request data on forest cover and deforestation. These include the CBD, the UNCCD and the UNFCCC. The need to monitor deforestation has even factored into Belize's implementation of the Global Program of Action to Protect the Marine Environment from Land-based Activities (GPA), and the Millennium Development Goals (the MDGs). In the framework of the UNFCCC, the emerging Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiative is likewise putting a spotlight on forest cover data and will require countries to regularly report on forest cover and the carbon content of those forests.

Belize's reporting of its forest cover and deforestation has been limited by the lack of such data, which have only come from studies implemented intermittently.

Regarding that carbon content, through the *Tropical Carbon Monitoring System 2.0* (TROPICARMS 2.0) platform, CATHALAC has likewise developed detailed Tier 2 analyses of Belize's forest carbon stocks, including projections through 2025. Those analyses indicate that Belize's forest carbon stock in 2010 is on the order of *over* 300 million tonnes of carbon. While Belize comprises slightly more than 4% of Central America's area, Belize's forest carbon stock comprises ~10% of the region's forest carbon stock (CATHALAC / TROPICARMS 2.0 unpublished data, 2009). With 300 million tonnes of carbon in its forests, Belize *may* indeed have potential for REDD+. However, where discussions of REDD+ schemes have focused on funding being provided proportional to the deforestation that is avoided, it is worth pointing out that – at least based on the historical trend of a low deforestation rate of 0.6% per year – Belize may not have a great deal of deforestation to avoid.

The present study indicates that some 25,000 acres of Belizean forest are cleared each year, equivalent to ~9,000 football fields. It would seem that meaningful participation in REDD+ would either mean that (i) Belize would have to reduce its deforestation to under 25,000 acres a year, or (ii) evidence would have to be presented that Belize's future deforestation rate would be much higher than at present. That all remains to be seen; this study has likewise not examined the degradation of Belize's forests, with degradation being the other pillar of REDD+ (GOFC-GOLD 2009). TROPICARMS also provides assessments of how Belize's forest carbon stocks are likely to be affected by potential future climatic change explored in Anderson et al (2008).

Beyond the MEAs, deforestation is also relevant to at least one bilateral agreement Belize has signed. In 2001, the Government of Belize signed a Debt-for-Nature Swap (DNS) agreement with the Government of the United States of America. The overall objective of the 26-year DNS is to stem deforestation in selected areas managed by the Belize Audubon Society, the Programme for Belize, and the Toledo Institute for Development and Environment (Cherrington 2004, US State Dept. 2001a, US State Dept. 2001b). Although the DNS' stated goal is combating deforestation, the program has not provided for actual monitoring of deforestation, which would demonstrate whether or not the program is effective. Cherrington (2004) argued that remote sensing should be used to regularly assess forest cover and deforestation in the areas funded by the DNS. The data generated by the present study can be subset to the areas funded by the DNS to assess the program's effectiveness. While this study has not assessed forest cover dynamics solely in the DNS-funded parks, it does indicate that Belize's protected areas have been effective in protecting forests.

Implications for Long-Term Forest Monitoring

It is also a logical conclusion that in order to provide information on forest cover and deforestation to a number of initiatives, it would make sense for Belize to establish a long-term plan for monitoring its forest cover, and likely look into the development of a full-fledged monitoring system for forests. One option at the country's disposal is utilizing SERVIR for such purposes as the current study was carried out by CATHALAC and NASA, with local collaboration. It goes without saying that Belize needs *sustained monitoring of forest cover*, as compared to the one-shot nature of the previous assessments that have been conducted. As previously noted, the Government of Belize is a member of the intergovernmental Group on Earth Observations (GEO) which facilitates access to imagery, algorithms and capacity-building among its members. In the context of the Global Earth Observation System of Systems (GEOSS) whose development GEO is leading, since late 2008, GEO has also been coordinating a "Forest Carbon Tracking Task" (GEO FCT) to support countries in monitoring their forests (GEO 2010). Emerging from the FCT is a proposal for establishment of a Global Forest Monitoring Network, a development which would also be relevant to Belize.

Currently, the GEO FCT has a demonstration site (http://www.geo-fct.org/national-demonstrators/browser) and might be useful to include Belize as a demonstration country under the GEO FCT, making use of the data large time-series of data developed under the present study. Further regarding the issue of sustained monitoring of Belize's forest cover, it is also anticipated that SERVIR will continue to support such activities. Linking SERVIR's work in Belize to the GEO FCT could provide additional data resources for monitoring.

With respect to the currently widely discussed subject of REDD+, should a workable situation emerge with respect to Belize and REDD+, it should be noted that the nation certainly possesses the requisite informational infrastructure to enable REDD+ -related activities. In addition to the archive of available historical satellite imagery and the thirty-year archive of forest cover data developed under this study, Belize even possesses land cover change scenario data through to the year 2025 (Agudelo 2007), and the drivers of deforestation in Belize are fairly well understood (FAO 2000, Cherrington 2005) in terms of:

(i) inland land clearing for agricultural expansion,
(ii) land clearing for urban expansion, and
(iii) coastal land clearing for development of tourism-related infrastructure.

Even as questions are raised about countries' capacities to effectively combat deforestation, the data seem to indicate that in Belize that process is *manageable*. The present study demonstrates how the national system of protected areas managed by the Government of Belize and partners, and which cover 36% of Belize's land has worked effectively in protecting Belize's forests.

An important theme not treated in this study has been the drivers of deforestation. Since this study has not comprehensively mapped Belize's various land cover types, unlike some earlier studies, the data cannot be used to examine whether the lands deforested have gone into agricultural use, for urban expansion, or for tourism development, and so on. Nonetheless, this study could be expanded with some effort to map Belize's other land cover types, especially as the spectral signature libraries employed in the present study have been made publicly accessible, which should facilitate future updates to this study. Additionally, where the REDD+ and REDD+ initiatives treat forest degradation in addition to deforestation, it should be noted that as a companion to this study, an analysis of forest degradation was conducted but is not included in this report. That analysis may be published separately at a later date.

Belize's Forests in the Regional Context

It is likewise illustrative to consider Belize in the broader regional context. The final report of the 1999-2002 *Central America Ecosystems Mapping Project* (Vreugdenhil et al 2002) recognized Belize as the country in Central America with the highest percent forest cover, while UNEP's 2008 publication, *Climate Change in the Caribbean and the Challenge of Adaptation* (Dubrie et al 2008) likewise cited Belize as one of the most forested nations in the wider Caribbean region, alongside highly-forested Guyana and Suriname. While this study reflects higher forest cover and lower deforestation rates for Belize, they certainly do not negate Belize's role as a part of the broader, globally-significant Mesoamerican Biological Corridor. This study's results shows that the large tracts of forest in the Maya Mountains and around Rio Bravo which interface with neighboring countries remain, for the most part, large intact forest blocks. Fragmentation of these blocks, however, remains a possibility, and some of the areas on the western edge of the Maya Mountain forest block have been cleared. The block of forest around Rio Bravo, for instance, forms a part of the 'Selva Maya' (Maya Forest) and is connected to the forests of neighboring Mexico and Guatemala.

In the context of the broader region, Belize's forest clearance rates (0.6% per year) are nonetheless low. Without considering the drivers of deforestation in detail, it should be noted that there are reasons – explored in other studies – as to why Belize remains largely forested (Cherrington 2004, FAO 2000, Young 2008). Belize is, in fact, the third least densely populated nation in all of Latin America and the Caribbean according to the most recent revision of the UN's world population database (UNPD 2009). The low population density is accompanied by the smallest population in Central America (the only population below a million inhabitants, in fact). The population is also concentrated, which has limited overall deforestation. As shown in **Figure 6**, most of the areas cleared in the past thirty years are within a narrow buffer of the four major highways. Twenty years ago, the relatively virgin state of Belize's environment, combined with the lack of developed infrastructure, inspired the then-Minister of the Environment to opine:

> *We are so far behind, we are ahead in ecotourism.* (Hon. Glenn Godfrey, 1990)

The information provided here also contributes to regional knowledge of what is occurring in the Mesoamerican Biological Corridor. Almost ten years ago, a NASA-supported study, Sader et al (2001), utilized Landsat imagery for select sites across the region to assess land cover change and deforestation between ~1990 and ~2000. Whereas Sader et al (2001) provided merely a snapshot, the present study provides a more detailed picture for the Belizean situation. Though generally not on as large a time scale, similar national-level studies on land cover change and forest cover change have been conducted in neighboring Mesoamerican countries. The most similar work to the present study was a 2004 assessment of Guatemala's forest cover (UVG-INAB-CONAP 2006). Utilizing Landsat imagery, that study examined forest cover dynamics for three periods (1991/93, 1996, 2001), and is now being updated to include 2006. Further south, Panama possesses its own time-series of national land cover studies, including satellite-based maps for 1992, 2000, and 2008, the last of was developed by CATHALAC (ANAM 2003). As in the case of Guatemala, the Government of Panama has also indicated plans to update its national land cover information every five years. Mexico possesses land cover data stretching further back in time than even the present study. Mexico's aerial photography-based 1976 land cover /

land use map has been complemented by Landsat-based land cover maps for 1993 and 2000 (Mas et al 2004). The current assessment thus assumes its place within the collection of Mesoamerica's national-level land cover studies.

VII. CONCLUSIONS

The study presented here has demonstrated some of the capacities of the *Regional Visualization & Monitoring System* (SERVIR) in serving as an observatory of environmental change in Mesoamerica, through mining a mere fraction of the imagery available through SERVIR. While errors in the data are inevitable, it has been demonstrated that it is possible perform wall-to-wall mapping of national forest cover at a scale of 1:100,000, with an acceptable level of accuracy and using standard techniques and publicly available moderate resolution satellite data. Based on multi-temporal, automated classification of satellite imagery of Belize, it was determined that Belize's forest cover has declined over the thirty years between 1980 and 2010. Forest cover in mid-November 1980 was estimated at 4.2 million acres, or 75.9% of Belize's land territory, while that cover had fallen to 3.4 million acres in late February 2010, or 62.7% of the country's land territory. While the highest rate of deforestation registered was the over 70,000 acres cut annually in the period 2000-2004, between 1980 and 2010, on average almost 25,000 acres of forest have been cut annually. This amounted to a loss of 0.6% of Belize's forest cover annually, or a loss of 17.4% of Belize's 1980 forest cover in the past thirty years. The present study has likewise revised estimates provided by previous studies of Belize's forest cover and deforestation. In general, those previous studies have assigned Belize a higher deforestation rate, and lower percent forest cover.

The northern districts of Corozal and Orange Walk showed the highest relative rates of deforestation, while the Belize and Stann Creek districts had the lowest deforestation rates of the nation's six districts. The Cayo and Toledo districts, by contrast, had the highest percent forest cover overall, with both having forest cover in 2010 exceeding 70%. Examining forest cover from the perspective of protected areas, it was likewise concluded that relative forest cover in protected areas was higher than outside of protected areas. Where forests had covered 69.1% of unprotected land in 1980, this had declined drastically to 51.7% forest cover in 2010; relatively speaking, 25.2% of unprotected forests had been cleared in thirty years. By contrast, where forests covered 88.3% of the land in protected areas in 1980, this had merely declined to 82.6% in 2010; the relative decline was only 6.4%. Likewise, where 58.7% of forests were found outside of protected areas in 1980 (compared to 41.3% in protected areas in 1980), by 2010 46.8% of the forest cover was inside of protected areas, compared to 53.2% outside of protected areas. That makes a strong case for the effectiveness of Belize's national protected areas system. In 2010, eight of Belize's sixteen defined major watersheds likewise possessed forest cover exceeding 70%, while fourteen of sixteen had forest cover exceeding 60%, and only one watershed (the New River watershed in northern Belize) was less than half forested. The northern watersheds were also less forested in general than the southern watersheds, the latter which were almost all more than 70% forested in 2010.

Whereas Belize's consistent rate of deforestation over the past thirty years leads one to anticipate that forest cover will continue to decline, it is noted that Belize's still relatively high forest cover provides it with significant opportunities in terms of emerging international initiatives such as

REDD+. By requiring countries to implement national monitoring, reporting and verification systems for forest cover, REDD+ will likewise necessitate continued monitoring of Belize's forest cover. Via SERVIR, a standardized series of validated and highly accurate maps of forest cover for a larger time-series than earlier efforts has been developed, translating into strong baseline for *sustained* monitoring & assessment of Belize's forest cover.

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