2007

An examination of contributing factors to land use/land cover change in southern Belize and the use of satellite image analysis to track changes

Marissa Lenée Moore

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An examination of contributing factors to land use/land cover change in southern Belize

and the use of satellite image analysis to track changes

by

Marissa Lenée Moore

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF COMMUNITY AND REGIONAL PLANNING

Major: Community and Regional Planning

Program of Study Committee:
Francis Owusu, Major Professor
Tara Lynne Clapp
Amy Leigh Kaleita-Forbes

Iowa State University

Ames, Iowa

2007
This thesis is dedicated to my son, Joshua, whose patience and happiness brought relief and joy to me during this process; to my mom, dad, step-mom, brothers, and sisters for their help and support; to my great friends, Colleen and Nana, for their sense of humor, support, and friendship; and to Francis, who is a mentor, colleague, and good friend. I also want to thank all you tree-huggers who have actively pursued inconvenient methods of making this world a better place and not allowed yourselves to be diluted by the media or Mr. Bush and his money-hungry oil-monger cronies. Though Earth-friendly lifestyles are at best inconvenient and at worst, life-changing and expensive, without Earth, we would have no money and no life. When it is within their abilities, I appreciate those who place importance and priority on the consideration of others, future generations, and the world as a whole and singular unit. I cannot understand those who make conscious decisions to continue to pursue those things which are damaging to not just “their” Earth, but my Earth, my son’s Earth, my family’s Earth, your Earth - everyone’s Earth.
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ABSTRACT

Land use and land cover change analyses are important tools for planning and development decisions. Tropical deforestation has both local and global implications. One main reason for deforestation is the conversion of forest to agricultural land. This study explores influences and potential causes for agricultural expansion and deforestation within the Toledo District in southern Belize, Central America. Many factors play into the deforestation and degradation of tropical forests in this district, including social, cultural, political and economic issues, all of which need serious consideration if planners and politicians are to combat the problem. Understanding the reasons for deforestation goes hand in hand with knowing where the deforestation is occurring. Knowing where and why will aid in knowing how to focus policies to prevent or control the deforestation. Conversely, looking at historical deforestation trends can aid in discerning what socio-cultural, economic, and/or political influences may have occurred at the time changes in trends occurred. One way to determine where it occurs is through the use of remotely sensed data. Remote sensing provides a viable source of data from which LULC changes can be gathered efficiently and inexpensively in order to track these changes. Using Landsat satellite images from 1994 and 1999 to perform an analysis of the land cover change in the Toledo District, this study expands on a previous study of the same area by Emch, Quinn, Peterson, and Alexander (2005). This study explores the question, “Can an unsupervised classification of the Toledo District, which is less time consuming, requires less intensive data collection, and thus is less costly, produce statistically significant data?” If this can be done using unsupervised classification, it will provide an efficient tool for planners and policy makers to focus efforts to understand where and why deforestation is occurring and thus focus policies to control
and/or prevent deforestation, whether that be through the creation of new policies and development plans, implementing policies that have worked in the past, or detecting unforeseen or unwanted outcomes and changing policies to change the course of current trends. This study used the same 1999 Landsat satellite image also used in the Emch, et al. (2005) study, which served as a control for the current study. The 1999 image results from the Emch, et al. study with the results found in the current study. The images used in the current study were analyzed using unsupervised classification, whereas the images used in the Emch, et al. study used supervised classification. It was difficult to discern if an area was “agriculture” or “cleared” or “deforested/regrowth”. There are great differences between the 1999 image data results from the current study and those found by Emch, et al. The most drastic difference is seen in the difference between forest data, which differed by 59 percent. While the results of this analysis are determined to be insignificant, the implications relating to the method of performing this analysis will impact future studies.
CHAPTER 1: INTRODUCTION

Land Use/Land Cover Change, Tropical Deforestation, and Agriculture

Land-use, land-cover (LULC) changes may involve local, regional, and global concerns (Hayes, et al., 2002). Land use refers to how the land is being used, such as agriculture, forest reserve, residential, industrial, and so forth. Land cover refers to what is actually on the land, such as urban development, farms, forest, wetlands, savannah, and so forth. Large-scale changes in LULC, including developments in agriculture, industry, or harbor facilities modify the natural environment, with serious outcomes, depending on the extent of the changes (Ruiz-Luna and Berlanga-Robles, 2003). These effects often include altered hydrology and nutrient cycles, degraded soil, reduced productivity, loss of biotic diversity and ecosystem services, climatic changes such as global warming, and can influence sustainability and even the international economy (Geoghegan, et al., 2001; Nagendra et al., 2003). Soil erosion from runoff can cause sedimentation\(^1\) in nearby waters, affecting marine life by causing damage to estuaries and coral reefs, which in turn impacts local and international economies by affecting dependent activities like fishing and tourism (Caribbean Environmental Programme [CEP], 2005). Because these negative impacts occur on a variety of scales (local, regional, and global), they draw much attention at different political, environmental and economic levels (Allen and Barns, 1985; Chomitz and Gray, 1996; Barbier, 1997; Levasseur and Olivier, 2000; Hayes et al., 2002; Barbier, 2003; Batistella, 2003; Nagendra et al., 2003; Barbier, 2004, Emch Quinn, Peterson, and Alexander, 2005). Deforestation of tropical forests is of particular concern (Kreger, 2004).

\(^1\) Sedimentation from soil erosion occurs when the soil is a suspended solid in run-off and carried away in the water to streams, rivers, estuaries, and bays (CEP, 2005).
Of Earth’s ecosystems, tropical forests have the greatest concentration of biodiversity. Some disruption to the environment can be restored over time (though this may take thousands of years), but the extinction of species that play roles in ecosystem functions can permanently damage Earth’s biological performance. It is believed that at least half, and potentially up to 90 percent of all Earth’s species are found in tropical forests (Kreger, 2004). When expanses of tropical forests are cleared, the number of species affected, and possibly eradicated, can be enormous. Studying and developing an understanding of land use and land cover change can play a part in protection and supervision of tropical forest regions for the maintenance and management of environmental changes (Emch, 2003).

Aside from large scale impacts on climate, ecosystems and biodiversity, local impacts of deforestation can include the degradation of soil and water resources (which can influence crop yields), wood fuel supplies for household energy, and the overall quality of life in rural settings (Allen and Barnes, 1985). As the intensity of the land use increases, so does the degradation of the soil (Morrison and Pearce, 1997). Land clearing experiments have shown that deforestation causes degradation of the soil structure itself: the biochemical properties change, and heavy equipment used for industrial agricultural reduces soil porosity and increases compaction leading to decreased infiltration rates (Pierce and Barbier, 2001).

More than any other human activity, agriculture makes the greatest alterations to Earth’s landscape (Clay, 2004). The primary cause of forest conversion in the tropics is agriculture. For example, shifting cultivation practices in Africa account for 70 percent of the clearing of closed-canopy forests (Brown and Thomas, 1990). At a basic level, most environmental damage, such as erosion, loss of biodiversity, and so forth, done by agriculture occurs when natural landscapes are converted into agricultural landscapes (Achard, et al.,
Agricultural lands can be crop land that is permanent, such as orchards, or arable crops, such as corn, which is harvested and replanted. Agricultural lands can also be pastureland for cattle. Central America is no exception to increased deforestation and agricultural expansion trends typical throughout the world. While a 2002 study (Archard, et al.) found that, between Latin America, Southeast Asia and Africa, Latin America exhibited the lowest percentage deforestation rate, that rate translated to approximately the same amount of forest lost as that in Southeast Asia. And while there is no conclusive evidence that in Central America conversion of forest to crop land is more prevalent than the conversion of forest to cattle pastures, there is enough data to conclude that the creation of croplands is significant (Kaimowitz, 1996). Any form of cropping of the land increases exposure of the soil to water and wind erosion (Clay, 2004). This connection between agriculture and deforestation should be a primary concern for land use policy and planning to help determine appropriate land use legislation and regulation.

The problem of deforestation in the humid tropics is of global concern. Tropical deforestation is strongly linked with global warming and climate changes, to include decreased evapotranspiration\(^2\), increased surface wind speeds, decreased CO2 absorption, not to mention a loss of biodiversity, which is highly concentrated in tropical forest regions (Sud, Lau, Walker, Kim, Liston and Sellers, 2002). These regions are defined as having mean monthly temperatures above 64.5 degrees Fahrenheit (18 degrees Celsius), and where rainfall exceeds evapotranspiration for at least 270 days during the year (Lal, 1995). The humid tropics have a great amount of biodiversity and have an average annual rainfall of 59-94

\(^2\) Evapotranspiration is the sum of water movement via evaporation into the atmosphere and movement into plant materials.
inches each year. The humid tropics comprise approximately 10 percent of Earth’s land mass. A common farming method within the humid tropics in Latin America is slash and burn, where sections of forest area cleared, the cut vegetation is burned, and the product of the burnt material is cultivated into the soil to provide additional nutrients for the farm plot. Not only does this method of farming reduce carbon-dioxide absorbing trees, but the burning of these trees adds even more carbon-dioxide into the environment. Typically, no additional inputs, such as fertilizers or irrigation systems, are used, usually because the farmers are poor and impoverished and cannot afford the inputs or purchasing the land (which would in turn possibly provide a return on their time and financial investments). This leads to greatly reduced soil quality and eventually reduced crop output. This reduced output makes it more desirable for the farmer to move to another plot of land and repeat the cycle. Our knowledge concerning their distribution and rates of change of deforestation within the tropics remains surprisingly limited (Achard, et al., 2002).

Tropical regions (the area between the Tropic of Cancer and the Tropic of Capricorn) also have the greatest concentration of poverty in the world (Sachs, Mellinger, and Gallup, 2001). While factors such as politics, which affect economic and social policies, may contribute to regional and localized rates of deforestation, the widespread poverty of the region also plays a significant role. Those with little or no means of purchasing their land and/or providing inputs to improve their farming methods, such as fertilizers, are often left with little choice but to continue traditional farming methods that degrade the forest, the soil, and the environment. High poverty rates and the slash and burn method of farming are both prevalent in the region of Belize on which this study focuses.
It is important to track where deforestation occurs, so as to better understand why it occurs. In addition, understanding trends over time can potentially link policies, political change, economic growth or recession, or any other potential contributing factors with those changes. Knowing where the deforestation is occurring can aid in focusing research to understand contributing factors. One way to track LULC changes is through the use of remote sensing. A form of remote sensing commonly used is that of satellite imagery. This study attempts to contribute to determining rates of deforestation between 1994 and 1999, using satellite images of the southern-most district in Belize, the Toledo District, in Central America.

Objectives

Establishing how best to confront the problem of deforestation and its link with agricultural expansion, especially in developing countries in tropical areas, is invaluable in combating the negative impacts of these changes. Determining how to go about tracking the amount and location of deforestation and agricultural expansion can arguably be the first step in the process of determining how and why these trends are occurring. This knowledge would then assist in the process of deterring negative trends and promoting healthy, sustainable trends. This study hopes to take a step in the direction in discerning whether the methods used here are viable analysis options for future studies of this particular region.

This study explores a number of the influencing factors of deforestation and agriculture expansion in the Toledo District in southern Belize. It does so by investigating some of the historic, cultural, economic, and political influences on how the land is used in this District. Before one can know the “why” and “how” deforestation is occurring, one must
certainly determine the “where”. Determining this important factor will allow researches, planners, and policy-makers to understand the unique factors of that area that may be contributing to deforestation and associated agricultural expansion. Therefore, this study also explores a comparison of methods for determining LULC changes within a particular region. Specifically, the LULC changes within the Toledo District and the differences in the accuracy of two methods for classifying land covers in two separate satellite images are explored. These two methods are “supervised” and “unsupervised” classification of data.

Supervised classification is done by obtaining a significant amount of field data which is input into a computer program to defines what covers are represented at very specific locations within a satellite image. The program then determines what other pixels have the same data signature as those that were manually input. This is carried out until all pixels within an image are placed into one of the cover classes that were discerned by the user. Supervised classification is time-consuming and costly, as collection of extensive field data is required. In addition to whatever software is needed to perform the classification, the expense for paying an individual or people to accurately gather field data, which also requires GPS locators, must be considered as well. It is possible that locals could gather this data, which would save on travel and lodging costs, but it might not be an option. The terrain may make data collection difficult, making unsupervised an easier option.

Unsupervised classification requires no field data, and relies completely on the computer program used to analyze the data. All pixels are compared and placed into a user-specified number of classes, based on the similarity of their data. However, edge effects, meaning the interspersion of more than one cover class that may exist at the edge of two adjacent covers, may not be recognized and categorized appropriately. This would result in
data that are not an accurate portrayal of what actually occurs. While each method of classification has its benefits, it may make more sense to choose one over the other. For example, it may be too treacherous, due to weather, terrain, or even war, to perform a supervised classification, while in another instances, especially for small study areas, supervised classification may provide a higher level of accuracy than unsupervised, since data have been ground-truthed, or verified (Nagendra and Gadgil, 1999). This study uses unsupervised classification, because it is a financially and temporally less expensive form of classification of cover types than that used in a previous study of the same area. One of the two satellite images used in this study is the same image used in the previous study, conducted by Emch, et al. (2005). Images used in the current study are from two different years. This study uses images from 1994 and 1999. The previous study used an image from 1975 and the same 1999 image as was used in the current study. The logic behind keeping one image the same and one different is twofold. First, by comparing the data from the 1999 obtained in the current study with the data from the previous study, one may be able to determine if less expensive means of analysis are viable options for studying LULC change. If the results of this study are statistically comparable to the other study, then future studies of this area can possibly be carried out with unsupervised classification – a more cost-effective and less time-consuming approach. Second, if the data is comparable, one can begin to create a more dynamic trend, with three data points as opposed to two. If they are not statistically comparable, then it can be deduced that one method (either that used in the previous study or that used in the current study), or perhaps both, were not done accurately. Thus, the policy implications of this study’s results, whether they are comparable to the previous study or not, will be considered. If the data are not comparable, there is no way to
determine which method is actually correct (or even if a combination of the data found in the current and previous studies is correct). Therefore, the current study is limited in that one would not be able to determine which method should be used in future studies, and more information would be needed to make that determination. Regardless, this study will contribute to the determination of how countries with limited funding, such as Belize, can go about tracking and addressing deforestation trends.

**Belize as a study site**

This study focuses on the Toledo District in southern Belize. Belize is located in Central America, south of Mexico’s Yucatan Peninsula (see highlighted area in Figure 1.). It is bordered by Mexico to the north, Guatemala to the west and south, and the Caribbean Ocean to the east. Belize is slightly less than 23,000 square kilometers³ (2,297,000 ha) and is home to approximately 280,000 people, with a population growth rate of 2.33 percent (CIA, 2006; FAO, 2005). While any tropical area would be appropriate for the study of land use/land cover changes associated with deforestation and agricultural expansion, time and cost constraints as well as differing cultural, political, and economic situations in the various tropical areas make studying a particular region more practical. This study will focus on a district in southern Belize. Belize is an appropriate study site due to its large stretches of forest and the continuing expansion of agricultural land use occurring there.

Belize is located within the equatorial “humid tropics”. This country is an important study site because of its large tracts of contiguous forest that house a very high level of

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³ 1 square kilometer = 0.386 square mile
biodiversity, especially for its small size\(^4\) (Chomitz and Gray, 1996). Agriculture is the largest industry in Belize, comprising 71 percent of the country’s foreign exchange earnings.

Figure 1. Map of Central America


(Government of Belize, 1999). Only 4 percent of the land use is arable crops\(^5\) and 1.52 percent permanent crops\(^6\) (FAO, 2005). Belize also has the largest barrier reef in the Northern Hemisphere\(^7\), which draws a considerable amount of tourism\(^8\).

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\(^4\) For instance, Belize hosts approximately 528 bird species, while the entire United States houses 650 (Chomitz and Gray, 1996).

\(^5\) Arable crops are those that are replanted after harvest, such as corn, rice, and beans.

\(^6\) Permanent crops are those that remain in place after harvest, such as coffee, citrus, and bananas.

\(^7\) Globally, the largest barrier reef is Australia’s Great Barrier Reef.

\(^8\) As of 2001, the services industry, which is primarily tourism, was the third largest industry in Belize, contributing an average of 20.2% to the country’s GDP between 1997 and 2001 (Government of Belize website, available at: http://www.belize.gov.bz/belize/economy.html)
Deforestation is an important, if not the most important, environmental issue facing Belize (CIA, 2006; Forestry Department of the Food and Agriculture Organization [FDFAO], 2000, 1999). Deforestation not only affects the environment on various scales, but also directly impacts the citizens and economy of Belize. Belize’s tourism economy is highly reliant on ecotourism. In addition, soil run-off, caused by forest clearing, can pollute water and affect coastal fish breeding grounds, and even the barrier reef.

Even though deforestation is a serious issue for this small country, the relative amount of forest to all lands within the country is fairly large. A study done by the Forestry Department of the Food and Agriculture Organization (FDFAO) provided information on the dynamics of the change in forest cover, as depicted in Figure 2. This figure shows the amount of forested land within Belize as a percent of all land (to include other LULC types, such as savannah, urban, agriculture, and so forth). However, discrepancies in classification methods used to determine these changes pose problems with tracking actual deforestation rates, even within such a small country (FDFAO, 2000). The statistics on total forest cover ranged from 77.2 percent to 95.9 percent of total land in Belize (FDFAO, 2000).
The area of focus for this study is the Toledo District, the southern-most district in Belize (see highlighted area in Figure 3). It is 4,421 square km and is approximately 40 km from east to west and 95 km from north to south (Emch, et al., 2005). One of the largest forest regions in Central America – the Maya Mountains – is located in the northern portion of the Toledo District (Emch, et al., 2005). This region is primarily forest reserves, and there are very few people living here. Table 1 depicts the population totals for the Toledo district and the percent of these numbers that live in rural areas. It also shows the population growth rate within this district. The central area of the Toledo District has the highest population density, compared with the rest of the District. Toledo is home to about 27,600 people (see Table 1) (Government of Belize’s Central Statistics Office, 2005).

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9 This converts to 2,345 square miles – 25 miles from east to west and 55 miles from north to south.
Table 1. Population of Toledo District, Belize

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<td>POPULATION</td>
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<tr>
<td></td>
<td>Rural</td>
<td>*</td>
<td>*</td>
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<td>20,600</td>
<td>21,200</td>
<td>21,900</td>
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<tr>
<td></td>
<td>(total)</td>
<td></td>
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<td></td>
<td></td>
<td>(81.7)</td>
<td>(81.5)</td>
<td>(81.7)</td>
</tr>
<tr>
<td>Percent Growth</td>
<td>*</td>
<td>30</td>
<td>25.7</td>
<td>49</td>
<td>33</td>
<td>8</td>
<td>3</td>
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*Data not available
†From previous date in table
‡Note that from 2002-2005 there has been a consistent growth rate of 3 percent

As can be seen in Table 1, there was considerable growth between 1990 and 1991. Political unrest in neighboring countries created a number of refugees who moved to Belize (Collins, 1995). A number of these most likely settled in the Toledo district, accounting for the large population growth rate during this period. Eighty-two percent of the Toledo population lives in rural areas. Toledo has the highest unemployment rate (16 percent) and the lowest labor force participation rate (55.1 percent) in Belize (GOB, 2004)\(^\text{10}\). According to the “Poverty Assessment Report – Belize” (Kairi Consultants, Ltd., 2002), the Toledo district has the highest rate of poverty at both the household level and individual level in the country, at 47.2 percent and 57.6 percent respectively. Between 1991 and 2000, the number of foreign-born people living in the Toledo District increased from 2,491 to 3,885 (Emch, et al., 2005).

More than half of the rural population in this district lives below the poverty level\(^\text{11}\). The poor depend on agriculture and fishing for their livelihoods and “squatting and ‘other’ forms of tenancy” (as opposed to owning or renting) were the primary forms of land occupation in Toledo (Kairi Consultants, 2002, p. 3). The problems of unemployment, poverty, labor force participation, and land tenure have been exacerbated by the arrival of immigrants and refugees from neighboring countries, and this is especially true for the Toledo district (Emch, et al., 2005; Kairi Consultants, Ltd., 2002). Most of the immigrants in the Toledo District - 76.9 percent - are Maya from Guatemala (Emch, et al., 2005, Emch, 2003). This percent is calculated from census data, but there is a chance that this number is actually greater, as those families without legal residency may not have responded to census

\(^{10}\) The corresponding rates at the country level are 11.6% and 60.3% respectively (GOB, 2004).

\(^{11}\) The Poverty level in this study is defined by taking the average spent on non-food elements “by the poorest 40 percent of the population on these items. The sum of the values of the minimum food requirements and the non-food elements constitute the poverty line,” (Kairi Consultants, 2002, p. 2).
questionnaires. The Toledo district is 65 percent Mayan - the highest concentration of this ethnic group in the country (Levasseur and Olivier, 2000). Throughout the entire country, the Mayas make up only 10.6 percent of the total Belizean population, or approximately 29,600 people (CIA, 2006).

Two significant events in Belize, and specifically the Toledo District, add to the need to track LULC changes, and specifically deforestation. First, the Government of Belize has sold off logging rights of 75,000 ha of forest within the Toledo District to both domestic and international companies. Some of this forest is located on forest reserves. Second, the Southern Highway has been paved and additional roadways are being constructed by logging companies to aid in accessing forest and transporting their harvest. However, roadways increase access to virginal lands, which has been found to lead to increased forest harvesting and increased farming activities (Chomitz and Gray, 1996). Tracking the effects these activities have on deforestation, the amount of deforestation occurring in the region, and where the deforestation and agricultural expansion are taking place will aid policy-makers, planners, and scientists alike in determining how to address the issue.

Belize is an important study site because it presents many of the issues facing similar tropical regions – that of increased deforestation, increased agricultural expansion, increased population, and widespread poverty. Linking the areas experiencing deforestation with the reasons behind it is an important step for any region, regardless of the differences in the actual reasons. Establishing a trend of pinpointing, so to speak, where the deforestation is occurring and then investigating the factors that are contributing to the deforestation should be a goal for all regions experiencing this problem. Equally important is associating desirable, or undesirable, trends with the policies that were enacted, the socio-cultural
influences and the economic setting during that time.

In this chapter, Belize, and more specifically the Toledo District, was described to establish the setting for this study. Chapter 2 will discuss information about what are the known associated factors contributing to deforestation and agricultural expansion and their interconnections will be explored. As mentioned previously, knowing where the deforestation is occurring is just as important as understanding the reasons why it is occurring. Chapter 3 will provide the methodology behind an attempt to classify the LULC types in two satellite images. This was performed in an effort to explore possible means of tracking these LULC changes, which, as mentioned could aid in linking changes in the trend with political, economic and/or social policies. Chapter 4 provides the results and a discussion of the satellite image analysis. Finally, Chapter 5 will provide insight into the implications of the results of this study and their impact on future analysis of LULC changes.
CHAPTER 2: INFLUENCES ON DEFORESTATION

Deforestation in Latin America

Latin America has experienced high rates of deforestation (Achard, et al., 2002). In fact, between 1981-1990, the total area deforested in Latin America (7.4 million ha) was almost as much as Asia and Africa combined (Barbier, 2003). Most of the deforestation in Latin America occurred in South America. However, the rate of deforestation in Central America and Mexico was the fastest in the world during this time – approximately 1.5 percent of the forests in this region were cleared annually. And while deforestation has decreased in the years since, Central America and Mexico are still experiencing the fastest deforestation rates globally, at 1.4 percent.

Conversion of forest to agricultural land far is the primary reason for deforestation in Latin America (Barbier, 2001; Babrier, 2003). The relationship between deforestation, rural poverty, and agriculture is important in Latin America and has been well explored (Barbier, 1997; Morrison and Pearce, 1997; Pierce and Barbier, 2001; Barbier, 2001; Barbier, 2003). This relationship is quite complex and the associated cultural, legislative and socio-economic causes for deforestation need consideration. For example, rural poor households lack capital and resources for investing in more sustainable farming methods and are unable to obtain land tenure rights and/or credit. They are in competition with the wealthy for high quality land, and economic incentives provided by the government to reduce land use impacts are not created for them (Barbier, 1997; Nagendra, et al., 2003).

Agriculture (along with mining and the need for new roads and settlements) is currently responsible for the greatest amount of forest clearing in Latin America [United Nations Environmental Programme (UNEP), 1999]. Cropland provides a great portion of the
natural wealth of developing countries (Barbier, 2001; Barbier, 2003). Developing countries are often dependent on their natural resources and need to exploit these resources via land expansion. Commercial farming produces mostly primary resources, such as oranges, sugar, bananas, corn, and so forth. These products may or may not be further processed within a country before being exported. Economies of low-income and lower middle-income countries greatly rely on their primary resources (Barbier, 2003). Relying on primary industries (for example, forestry, agriculture, and fishing) for income and economic development, essentially involves the exploitation of the land\textsuperscript{12} for many countries. Most export earnings are often earned from primary industry products. Growing population and increases in incomes within the countries themselves also lead to increase demand for food, which is often met by increase in cropland, created by the conversion of forests and wetlands (Morrison and Pearce, 2997; Barbier, 2003).

The increase in cropland demand is often problematic for those whose income is small or relatively non-existent (e.g., the rural poor) and are reliant on subsistence farming. The demand for high quality farmland leaves the less desirable or marginal areas available for poor rural farmers. Poor rural farmers may be unable to, or for good reason choose not to, improve on their agricultural methods to more sustainable methods of farming that may prevent or slow down their conversion of forest to agricultural land.

A common method of subsistence farming by rural farmers in developing Latin American countries (including Belize) is the “slash and burn” or “swidden-fallow” system (Steinberg, 1998; Levasseur and Olivier, 2000). Though modern agriculture is responsible for

\textsuperscript{12} Exploitation of the land can be loosely defined as unfairly taking advantage of or abusing the resources the land provides for one’s own needs, without returning an equivalent of what was taken out in return.
the largest individual areas of cleared land in Latin America, slash and burn agriculture is the primary reason for the expansion of agricultural land (UNEP, 1999). Eighty percent of farmers in the Toledo District practice milpa farming, a traditional version of slash and burn agriculture (Emch, 2003). Milpa means “corn farm” in Mayan. Mayas make up the majority of farmers living and working in the Toledo District.

**Population**

Understanding the demographics of a population can help to explain reasons and patterns of LULC change. There are two predominant ethnic groups in the Toledo District, each with similar yet different farming styles. Mopan village populations most often include a number of Kekchis (Emch, 2003). From 1980-1990 Mopan areas experienced greater increases in population densities than in Kekchi areas, though the Kekchi experienced greater increases in absolute numbers than the Mopan (Emch, 2003).

One overriding issue for this area is the impact of immigrants on the land. There are conflicting reports regarding the impact that immigration has had in this area. Immigration into the Toledo District has been identified as a major component of the increases in deforestation within the District (Kairi Consultants, 2002). The immigrants generally do not have enough capital to purchase land and support themselves and their family and are not educated or have skills for obtaining employment. The lack of control and regulation of immigrants at border crossings coupled with the Government of Belize’s agreement\(^\text{13}\) to

\[^{13}\] This agreement is called the ‘Principles and Criteria for the Protection of and Assistance to Central American Refugees, Returnees and Displaced Persons in Latin America’ (CIREFCA) and was instituted under the United Nations High Commission for Refugees (UNHCR) in the 1980’s in response to civil wars in Nicaragua, Guatemala, and El Salvador during this time, and for the refugees these wars created. More information on this can be found at: [http://www.unhcr.org/cgi-bin/texis/vtx/home](http://www.unhcr.org/cgi-bin/texis/vtx/home).
allow Nicaraguans, Salvadorans, and Guatemalans refugee protection makes Belize a shelter from the social and economic unrest. Unfortunately, it has put a great stress on social services provided by Belize to its citizens, to include the refugees perpetuating poverty and unemployment. However, Emch (2003) states that, though there is in fact an influx in population, which are mostly Maya from Guatemala, the primary reason for population increases in this district are due to natural growth trends, not immigration.

Van Ausdal (2001) questions blaming population growth for deforestation altogether. He believes that the population has not grown enough to put serious pressure on the forest. The problem with Van Ausdal’s and Emch’s arguments is that, though the population may not be growing at a drastic rate due to immigrants, and maybe there is a significant amount of total forest cover within Belize, there is still population growth and there is still a finite amount of land with forest cover. Each year, the amount of forest cover lost might be relatively small, but over time this will add up and contribute to the overall level of deforestation. Downplaying the importance of small annual changes in forest cover is detrimental to the protection of forests. The same holds true for population growth – it might be small in any given year, but over time, it adds up. Yet the situation is more complex than just this – the land tenure, the farming methods themselves, and the economy in which these people live are each major components of the problem of deforestation.

**Land Tenure**

“Tenure” refers to the various forms of land ownership or land use, which includes legal ownership of the land, leasehold (which is essentially renting), and governmental and public rights for use of the land. There are three basic means of land rights in the Toledo
District: ministerfiat, leasefiat, and the conveyancing system (Emch, 2003). Ministerfiat, occurs when land rights are transferred from the government to a private owner. Leasefiat, occurs when land rights are leased from the government. Leasing the land provides an opportunity for a transfer of ownership from the government to a private owner after a period of time. In Belize, the leased land must be 50 percent developed over a five year period before the land can be purchased. Development of the land can include arable or permanent cropping. Both of the previous two land tenure require money to purchase the land. The other form of tenure is the conveyancing system, which is the transfer of private land from one individual to another. This type of land tenure does not necessarily require money, as land can be passed down within a family or given away.

Belize has four types of land ownership: national land (owned by government, includes lease-land); forest reserves (government administrated land); private land; and Indian Reserves. The different types of land ownership and land attainment, coupled with poor record-keeping, have created many disputes over ownership of specific holdings (Emch, 2003). Currently, about 50 percent of Maya live on reservations with essentially no official recognition of land ownership. There are reserves on which they farm and live, however, these lands are owned by the government, not the farmers, and no form of a lease contract is employed to ensure a level of security.

During colonial era, the government made land tenure very difficult for the Maya to obtain. This was so the government maintained ultimate control of the land and logging rights to traditional Mayan lands (Steinberg, 1998). In order to “subdue” the Mayas, a 77,000 acre reservation was created in the 1880’s by the British to allow the government to log other lands. The exact boundaries of the preservation lands or reservations were not well-defined,
and over time the Government of Belize has added “unofficial”, i.e., not officially documented, reserve land or has unofficially created new reservations altogether (Emch, 2003).

Property rights have not been defined in the country’s constitution, either (Nystrom, 1997). Many Mayas constructed villages outside of this reserve land without government approval. This represents lax land use and land tenure regulation. An important element of successful community and regional planning is citizen participation. Yet, the Mayas are not involved in land distribution issues, although it greatly affects them, given their lack of ability to secure land tenure (Emch, 2003). Therefore, historically, regulations regarding land use and regulations which determine land boundaries have had almost a complete lack of citizen participation, resulting in unsuccessful planning, as is evidenced by the continued deforestation by people who do not have true property rights or ownership of the land they are deforesting, but who have little, if any, other options for survival.

Land tenure in Belize is not only confusing, but has also been corrupted by politics (Emch, 2003; Toledo Maya Cultural Council, 1998). Usufruct rights to the land are implemented on reservation land, meaning the land is considered communal and rights to parcels are distributed via first-come - first-serve, or through a decision process implemented by community leaders. On reservations, tenure is determined through distribution of land by village alcalde (an elected village official or village major who works with the Government of Belize) who is paid a small sum for rights to use that land ($5 in 1990) (Emch, 2003). Under the usufruct rights system, land cannot be bought, sold, rented, or passed down through generations. This is a traditional method of land tenure for Maya.
If permanent crops, such as fruit or cacao trees, are planted on a piece of property, the land rights may be owned by that farmer and these trees can be bought, sold, rented, or inherited. However, planting of permanent crops reduces the amount available for *milpas* (Emch, 2003). Some permanent crops are not allowed to be held by one “owner”, and are considered to be property of the community (Steinberg, 1998).

Even though a usufruct rights system is implemented on reservations, the land is ultimately owned by the GOB. This means the GOB can take land away whenever it discerns it to be profitable or necessary for government purposes, without regard to the Mayas living on and using this land. As a result, most land is still owned and rights for use of the land are held by the GOB. This means the GOB has the right to refuse an “Indian” to occupy land and to “withdraw permission” which may have been given (Steinberg, 1998, p. 412). Today, in order to get a lease on a parcel of land, the plot has to be surveyed and an administrative fee must be paid, which, in 1998, was approximately $200 – an expense too high for most Mayas (Steinberg, 1998).

Since 1989, the Mayas, through the Toledo Maya Cultural Council (TMCC), have been working to acquire tenure of 500,000 acres of land to be called the “Maya Homeland”, which would guarantee equitable land distribution amongst the Mayas (Emch, 2003; Steinberg, 1998; Nystrom, 1997). The TMCC mapped the area that included the proposed “Maya Homeland” to determine the potential for sustainable development. This information was then presented to the GOB in an attempt to acquire tenure of this land and to ask for consideration of the traditional Mayan culture and farming methods (Nystrom, 1997). One of the TMCC’s main goals is to attain sustainability and to minimize disturbance to the natural environment.
In spite of the number of Mayas in this district and therefore the voice they should have as a collective group, violation of Mayan land rights has been an ongoing issue. The government has been known to lease land rights within reservations. In 1980’s, 12,000 acres were “de-reserved” (Emch, 2003, p. 123). Since 1995 international logging firms have received rights to log 65,000 ha (about 161,100 acres) of land in southern Toledo near Mayan communities and 10,000 ha (about 24,700 acres) in reserves in the northern area of the district (these reserves are in both Toledo and Cayo districts) (Emch, et al., 2005). At one point 202,300 ha (500,000 acres) of the Mayan forest was to be harvested, without consideration for those who use it for subsistence hunting and non-timber forest products (Indigenous Peoples Law and Policy Program, 2004). But if the land is cleared and used for farming, the government may be more inclined to consider it in use and therefore owned de facto (Emch, 2003). Allowing the Mayas to have a set area available to them, they argue, could both satisfy their right to continue their traditional farming methods, while at the same time it could help in preventing the milpas from taking over the whole District.

**Agricultural Practices**

To create a milpa, or corn farm, a plot of land (estimated to be between 1.2 and 5 ha\(^{14}\)) is developed and farmed for one or more years and typically left in a fallow state for a period of time (Emch, et al., 2005, Emch, 2003; Van Ausdal, 2001; Steinberg, 1998). Steinberg (1998) found that all of the Mopan Mayas he surveyed left their plots in the fallow state for no more than five years, and some plots were cleared yearly and never let go to the fallow state. However, Emch (2003) and Van Ausdal (2001) both found that fallow plots

\(^{14}\) 1 hectare = 10,000 meters squared = 2.471 acres
were left from 4-40 years, which has been the case from 1930 to the present. Studies in this area have found that a fallow state of 4-5 years on better soils (soils with higher nutrient content), such as those found in much of the Toledo District, is sufficient time for avoiding soil degradation (Wright, et al., 1959). The varying fallow times observed means there are a variety of farming methods and/or there are varying demands on the land within certain areas. If the farmers in a certain area are more settled, rather than transient, they may not allow the plot to remain in the fallow state as long as a more transient community might. In addition, as a community’s population grows, greater demands for farming plots may reduce fallow time.

In addition to the varying times a plot is left in a fallow state, there are varying uses, or disuse, reported as well. Understanding what happens during a fallow state is important to understanding deforestation-agricultural expansion and how it contributes to levels of biodiversity, the economy, and soil chemistry and physics. Emch (2003) and Van Ausdal (2001) report that some plots that are planted with fruit-bearing trees, after arable crops are harvested, are left in a fallow state (i.e., not annually cultivated) for 15-40 years, as it takes several years for the trees to even begin producing fruit and providing a return on the investment.

One woman interviewed by Van Ausdal (2001) said she had inherited a fruit-bearing tree plot that had been in existence for more than 100 years. On the other hand, Steinberg (1998) and Clark (2000) both state the only tree species that is left on the land after clearing is the cohune palm species (*Orbignya cohune*) which provides palm fronds and wooden posts used for housing construction, palm hearts for food, and nuts for charcoal. Additionally, Steinberg reports that the fallow plots are not utilized for crop production
during this state, e.g. by planting fruit-bearing trees or other forms of an orchard garden that would support multiple plant and animal species which would create better biodiversity and provide another source of food. He argues that maintaining only one species on a fallow plot (e.g., only cohune palms) greatly reduces plant and animal biodiversity, as animals choose not to frequent these fallow plots. Local Mayans comment on these plots being the least desirable for hunting due to the lack of animal diversity found there (Steinberg, 1998). Van Ausdal (2001) points out that some studies have found fallow states to have shortened over time, yet, he states, the Toledo Research and Development Project warned that those claiming fallow states had been shortened over time were also promoting modernization. In other words, the data was adjusted to favor results that would promote more modern forms of agriculture. This does not appear to be the reasoning behind Steinberg’s discrepant claims, as his paper attributes his findings to the negative impacts of cultural change, promoted by the government and missionaries (1998).

Therefore, taking available data into consideration, the range of fallow periods seems to range from zero to 40 years, with some fallow plots also supporting fruit-bearing trees. This is quite a broad range of time and land use. Explaining both the expansion of agricultural land and the continued degradation of forest during the fallow state on the milpa cycles does not appear to be a very strong argument. One possible reason for the discrepancies between Steinberg’s data and Emch and Van Ausdal’s data is that Steinberg interviewed 75 Mopan Mayas in the Toledo District, yet he does not elaborate on how these informants were chosen. If they all lived in the same area selected randomly, perhaps this is a small group whose practices differ from those practiced by the majority, and therefore the data is not statistically significant and cannot be applied to the Toledo District or even the
Country of Belize or other tropical regions, in general. Additionally, discrepancies between ethnic groups appear to exist, most likely based on variations in areas of habitation and specific practices between the two predominant ethnic groups - the Kekchi and Mopan Maya - in the District (more detailed information regarding these differences will be presented below).

Since the 1924 establishment of forest reserves in the Toledo District, the government has determinedly attempted to convince the Mayas to discontinue *milpa* farming and “become more integrated into the country’s economy” (Van Ausdal, 2001, p. 582). The Maya have resisted, obviously, since this method of farming is still practiced in great numbers within the Toledo District (Emch, et al., 2005).

The Kekchi Maya live and farm in lowland areas and crop for one year then let the plot go fallow for six years. The first season’s crop is maize; the second is maize and/or beans and root crops. Adult men form cooperative labor groups for farming tasks such as clearing, planting, harvesting, threshing of rice, and building pig pens. Maize provides most of the caloric intake for Kekchi, yet rice is their most important cash crop.

Mopan Maya, on the other hand, live and farm upland areas. Their plots are cropped for 1-2 years, and then left fallow for 5-6 years. Their first cropping season consists of maize and usually a small area of rice; the second season is maize, beans, and root crops. The amount of land cropped during the second year is greatly reduced from the first. Maize is the most important crop for Mopan, too.

The importance in knowing cultural differences within a study area is that they provide insight into the different farming practices. The cultural reasons for the differences can aid in policy focus. Policies that concentrate goals and objectives based on a certain type
of crop, such as rice, a certain location, such as upland forest, or for certain periods of time, such as 1-year versus 5-year programs, can affect different groups in different ways, thus resulting in different outcomes. Understanding the cultural dynamics of the issue will aid policy-makers in reaching desired outcomes.

**Crop economy**

Many factors need to be considered when addressing the economy of crop propagation within the Toledo District. These factors include the creation of roads and their effects on the distribution of farms, the creation of marketing boards, and the creation of policies that offer incentives for some.

Mayan farmers in the Toledo district produce crops for both subsistence and cash (Emch, 2003). Cash crops have ranged from bananas in the early 1900’s to rice in the 1930’s to the latest development of cacao farms, beginning in the 1980’s. Maya farms also produce beans, pigs and marijuana for cash. Rice is the most important cash crop of Kekchi, while the Mopan rely more on beans for cash crops. One of the reasons for the difference in the choice of cash crops between the two groups is access to roads.

Increased access for poor households to frontier land (i.e. forest) through the creation of roads has added to the issue of deforestation in Belize (Chomitz and Gray, 1996, Barbier, 1997, Nagendra, et al., 2003). Initially, the government will provide subsidies to develop roads for large-scale commercial agriculture, timber extraction or mining. Once the resources are extracted, the land is abandoned or sold off. These large-scale activities essentially open up the land, providing ease of access and relocation to areas that weren’t previously accessible. Small-scale farmers then have increased opportunities to clear and use frontier
land. They have no incentive to remain on a piece of land (due to lack of tenure, lack of funds, etc.). The roads provide access to markets where they can possibly sell their crops, as well.

Rice is difficult to transport, so most rice is produced along main roads, and not throughout the region. The Kekchi live primarily in lowlands along primary roads, whereas Mopan live in upland areas, closer to secondary roads than primary roads. The Mopan also rely more on cacao than the Kekchi as a cash crop, as well as honey and annatto.

The Belize Marketing Board buys and sells rice from producers in the Toledo district at a higher rate than the fair market value (GOB website, 1999). By paying higher prices, the government is supporting and encouraging rice production. Yet, as mentioned earlier, as the population in the Toledo area has increased, so, too, has the demand on the land. Therefore, there are essentially two economic options: decrease fallow period or move to new land (Emch, 2003). Cropping in this region experienced a 27 percent increase from 1970-1985. In recent years, the government has attempted to combat this issue by supporting permanent cropping, which involves a need for the farmers to attain land tenure.

International institutions have also become involved in the agricultural industry in Belize, promoting permanent cropping. In 1988, the Toledo Agriculture and Marketing Project (TAMP) was created which provided the benefits of education, agricultural supply, and loan disbursement for cacao farming (Emch, 2003). Once TAMP was created, it became apparent to those administering the project that small-scale farmers in Toledo District were unable to attain credit because of their lack of capital collateral, so loans were given in-kind.

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15 Chomitz and Gray (1996) found that even if the roads themselves don’t increase deforestation, they cause fragmentation of the forest and this access could also lead to increased animal poaching.
This project’s benefits were provided solely to the cacao farmers, and not to farmers of other crops, thus promoting the growth of the cacao production. It takes five years for cacao plants to bear fruit and produce income for the farmers (Powell, 2003). Unfortunately, in 2001 Hurricane Iris hit the area, destroying up to 85 percent of the cacao trees in the district (Emch, 2003, Powell, 2003).

In the Toledo District, the entire cacao crop grown by farmers who are members of the Toledo Cacao Growers’ Association (a group of 225 farms) is sold to one buyer: Green & Black’s (Emch, 2003). Though this gives them some security, knowing that all of their cacao will be purchased, it also leads to more risk, as this is a monopoly. If one buyer decides not to buy and there are several buyers, then the situation is more secure. If one buyer doesn’t want to buy and there is only one buyer, then the Toledo Mayas will be faced with a difficult and unfortunate situation.

In order to ensure continued purchases from Green & Black’s, the Mayas have learned how to process high-quality fermented cacao beans. The Maya maintain high quality standards so that they can protect their market (Powell, 2003). Cacao production has provided income that allows farmers to send their children to school, visit the doctor, and purchase clothing. Unfortunately, their inability to secure land tenure puts these farmers at risk, and in fact, some farmers in the region refuse to make the investment in cacao due to worries about having their farmland taken away. Though cacao farming was highly promoted by the government, it lacked the security needed to be a truly viable option for the poor rural farmers to whom the idea was marketed. The government attempted to implement more sustainable farming that provided income for the farmers, yet they did not provide the
security needed to truly make this a viable option – the government did not provide a mechanism for land tenure attainment for the rural poor.

Economic incentives can influence the behavior of the rural poor. According to Barbier and Pierce (2001), public policies and investments affect the market and institutions. For example, policies which offer tax incentives to larger farms, owned by wealthier households or corporations, while offering no subsidization to poor landless farmers will promote commercial, large-scale agricultural growth. These policies will not provide incentives for those rural farmers to discontinue the traditional farming which involves deforestation. Wealthy households are favored by institutional provisions, investments, and policies, which may support wealthier households’ land purchases because they can use their market and political power to acquire absolute rights to better quality land. Unfortunately, virgin lands are becoming more accessible to the Mayas and their creation of *milpas*.

Wealthier households are also able to use their access to capital (markets) and their political power to acquire scarce resources (e.g., higher quality land) and capture a larger portion of resource rents\(^{16}\). This leaves landless households to choose between less productive lands or to migrate to virgin, frontier lands (Barbier, 2003). Only when the wealthy households have degraded the land’s ability to support sufficient crop output will they leave it and thus allow poor households access to it (Pierce and Barbier, 2001). This situation limits poor households to poor quality land, limiting both their source of income and their ability to capture rents.

\(^{16}\) Resource rents are the profits collected from the exploitation of scarce resources.
Sustainability

The *milpa* farming practice could be converted to something more sustainable if more permanent agricultural methods are employed (Barbier, 1997). Though permanent cropping may involve the increased introduction of chemicals, the issues of deforestation, global warming, soil degradation, and so forth would be averted. Applications of conservation systems and improved methods of farming can reduce the degradation associated with agriculture (Morrison and Pearce, 1997). However, this idea would only be sustainable below a certain population threshold.

For example, Hobbs, Sayre and Gupta (2006) have demonstrated how methods of conservation agriculture, which include minimal disturbance to the soil (“no-till”), applying a permanent ground cover, such as mulch, and rotating crops, are more sustainable than other traditional farming methods. However, the issues of cost, inability to secure land tenure, lack of credit, and the wait time needed to see a return on an investment are all reasons why methods that reuse the same parcel, and not deforesting new land, are not implemented. Unfortunately, once the number of people increases to a point where the demand on the forest does not allow time for the forest to re-grow between cultivation periods (the “fallow state”), the slash and burn system will collapse.

Investing in sustainable farming systems and soil conservation includes equipment, fertilizers, irrigation, and other chemicals, which are expensive. These farmers do not have the financial means to purchase the needed materials, tools, and possibly even labor to implement these methods. They are primarily subsistence farmers and sell little of their crop at market, consuming much of it themselves (Emch, et al., 2005). They have limited access to lines of credit or loans, due to a lack of collateral – their only assets are the land, for which
they don’t officially have tenure rights and so as collateral is essentially of no value, and their labor abilities, which are considered “unskilled” (Morrison and Pearce, 1997).

Even for farmers who have access to lines of credit, loans for these purposes (improving farming systems) are often not available. Because they cannot invest in these improved and more sustainable farming themselves, they forego improvements that would reduce degradation. Immediate food needs may also trump an investment for which returns would not be acquired in the short-run, and instead have relatively long-range returns. Regardless of whether or not they invest in improved farming or conservation practices, the cost will be absorbed, either directly through the expense of an investment or indirectly through loss of productivity associated with other farming practices (Morrison and Pearce, 1997). This argument does not take into account the value of the biodiversity and old-growth forest lost by not investing in more sustainable agriculture. But the overriding issues of land tenure and investments are compounded by the ability of wealthier families to purchase the land and take it away from these farmers. Studies of the swidden-fallow method of farming employed in the Toledo district, and throughout Latin America, have found it to be sustainable if long (i.e. at least four years) fallow periods are permitted (Clark, 2000). The Maya are aware of this and have been promoting their traditional desires for environmental sustainability for years (Clark, 2000). Unfortunately, though they may desire sustainability, there is significant evidence that the cause for the fall of the Maya civilization was due to the exact same practices of milpa farming as are seen today (cited in Barry, 2004).

Employing archaeological data with satellite image analysis, the National Aeronautics and Space Administration’s (NASA’s) only archaeologist, Tom Sever, has determined through pollen samples in swamps that about pollen disappeared from the samples dating
about 1200 years ago - and only weed pollen was present at that time (Barry, 2004). He attributes this to severe deforestation. Sever explained that deforestation at this level would cause about a six degree rise in temperature in this area. This deforestation would also affect rainfall patterns. Both of these would lead to drier land that would be very difficult to cultivate. The lack of cover would lead to erosion of top soils. Erosion coupled with repeated cultivation of the same plots would lead to serious soil degradation, and thus farms would experience reduced crop output. After examining the bones of Mayan skeletons from this time period, it was determined for decades before the collapse of the Mayan civilization, the people experienced severe malnutrition. The lesson that can be learned is this: for a period of time milpa farming would be sustainable because the cropped land would have enough time to go fallow between cultivation periods; when the practicing population gets large enough to the point there is not enough land to go around and fallow periods need to be shortened, neither the forest or the soil will have time to replenish itself. This is the part of the practice of milpa farming that makes it unsustainable. Couple this with a large percent of the population in this area having an inability to secure land tenure, which prevents a desire to invest in other forms of agriculture, and there can certainly be a major problem at hand, even in today’s world. Basically, population growth coupled with lax immigration controls leads to increased land use. Based on historical data, the Mayan farming methods are not sustainable once the population gets too large to allow the land to regenerate soil nutrients. These methods are still being used today, and the Maya population is increasing. There is a possibility this area could experience the same outcomes it did in the past.
Conclusion

The plethora of contributing factors to the issues of agricultural land availability, land tenure, and land use and the changes these factors undergo fairly regularly make studying the process of deforestation and its link to the expansion of agricultural land difficult. At a very basic level of determining how this dynamic process evolves, the locality of deforestation and agricultural expansion trends need to be determined. While one area may go fallow for many, many years, another may experience developmental. Political situations, such as civil wars in neighboring countries, can contribute to population growth that leads to increases in deforestation trends, especially when those uprooted are poor rural farmers who would be inclined to relocate to an area that would allow for agricultural activities without land tenure. While the government of Belize provided a safe haven for refugees, they did not provide incentives for these new residents to enter the economy any other way than through milpa farming. Providing assistance to farmers growing a more permanent crop, such as was seen through the TAMP cacao-growing project, may aid in providing greater income for these farmers while reducing the amount of newly-cleared forest. Yet, because the farmers did not own their land, and because there is a monopoly on the part of the purchasing firm, there are disincentives for farmers to enter into this alternative to traditional milpa farming as well. And while the Maya leadership are attempting to find means for allowing milpa farming in specific areas and they attempt to prove the sustainability of this method of farming, historic evidence as well as current data linking population growth to increases in deforestation disprove the long-term sustainability of such practices. Without providing the educational and financial ability and incentives for those causing deforestation, one cannot expect these poor rural farmers to make any different choices than they have for thousands of years – to
continue their traditional swidden-fallow agricultural practices. Yet how is the government to determine what policies need to be implemented? Determining the cultural and economic situations of those deforesting a region is certainly important. Equally important is determining where the deforesting is occurring. Identifying a region experiencing great amounts, or even increasing amounts, of deforestation can help determine where one needs to begin investigating the cultural and economic setting of that area. Then the policies that would best aid that region can be better formulated.

Linking the locations of this agricultural expansion/deforestation over time with current or past policies, cultural practices, financial systems, and so forth can help determine what works, what doesn’t, and how to promote desired planning outcomes and avoid those which are unwanted. One beneficial tool in determining where deforestation is occurring is satellite images. Using satellite images over time can aid in determining the location and trends of LULC changes.

Determining how to go about analyzing the images is the first step in this process, for there are two general methods of determining LULC change: supervised and unsupervised classifications. As will be discussed in the next chapter, both of these methods have benefits and down-falls. What is important, and what is being investigated in this study, is how a poor, developing country can cost-effectively determine deforestation and agricultural expansion trends. Supervised classification is generally very costly, while unsupervised is relatively inexpensive. One of the major issues associated with supervised classification is the time and cost of developing training sites, which are typically collected in the field (Hepner, Logan, Ritter, and Bryant, 1990). Conversely, unsupervised classification requires little, if any, first-hand field data collection. However, unsupervised classification poses
issues as well. Areas containing multiple land cover types within small areas can be misclassified as one particular class (Thomas 1998). Areas containing regrowth, tree farms, managed growth, and so forth, may all appear the same in the satellite image, but may be classified as one particular class. In either of these incidences, cover classes not appropriately identified could lead to a misinterpretation of what is actually occurring in a particular area. If statistically significant data can be attained in a cost-efficient manner, i.e. through unsupervised classification, a county like Belize may realistically be able to employ the use of these images for tracking LULC changes – through their country and even throughout the region.
CHAPTER 3. METHODOLOGY

The wide range of human dimensions and factors that determine land use and land cover (LULC) in Belize are important to consider when evaluating the links between deforestation and agriculture. Nagendra, et al. (2003) state most land cover changes in tropical regions are the result of human influences, which occur at various spatial and temporal scales. Determining the overall land cover changes is an important component in the evaluation of the contributing components of deforestation. Understanding where and at what rate the changes are occurring can help to associate LULC changes to social, cultural, economic, and/or governmental changes that occurred in the study area. Thus, it is important to monitor the situation in southern Belize and associate dynamics of LULC changes with causes for these changes. Creating these associations can help determine proper land use planning and policies that will benefit both the environment and the people. One fairly cost-efficient method of tracking LULC changes is through the analysis of remotely sensed images.

Satellite Images

Remote sensing is an excellent source of information for assessing major LULC changes and trends in a region over time (Hayes, et al, 2002). Remote sensing, as compared to relying completely on data gathered by hand in the field, is practical, as well, in that it is relatively inexpensive and fast for analysis of landscape changes (Ruiz-Luna and Berlanga-Robles, 2003). The United States National Aeronautics and Space Administration (NASA) defines “remote sensing” as, “the detection and measurement of radiation of different wavelengths reflected or emitted from distant objects or materials…” (NASA, 2006). Aerial
photographs and satellite images are two of the most common methods of remote sensing for large-scale studies. Satellite images generally contain a greater extent of the land than aerial photographs because the images were taken from a higher altitude. However, because the resolution and scale amongst satellite images differs, analysis of satellite imagery should be considered a complementary tool to aerial photography, rather than a replacement of analysis of photographic images (Lillesand and Kiefer, 2000). However, satellite images use more detailed spectral signatures\(^{17}\) which can be easier for evaluating cover types. Aerial photographs leave a bit more to assumption and speculation if the actual cover types in an area are unknown, given that the spectral signature cannot be used to determine the cover type in this form of remotely-sensed data.

A common source for satellite images is from a Landsat satellite. “Landsat” is a program through the partnerships of the U.S. Department of the Interior, Department of Agriculture, Environmental Sciences Services Administration (predecessor of NOAA), and NASA. It was initiated in the mid-1960’s as a program for repetitive observation of Earth’s landmasses via satellite images (USGS, 2005). There have now been several satellites used throughout the program, which is still currently operational. The images from Landsat 1-3 have a 79-82m resolution and used a Multispectral Scanner, or MSS (See Table 2) (Lillesand and Kiefer, 2000; USGS, 2005). Even though the resolution is considered somewhat coarse as compared to that of later Landsat images, if a linear feature sharply contrasts a

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\(^{17}\) Satellite images used in this study contain wavelengths from visible blue-green through mid-infrared. Aerial photographs only capture, and thus can only be analyzed for, visible wavelengths [Comment: this is not true. You can take aerial infrared photographs, too. You can also take aerial images that are multispectral or hyperspectral. The real difference is that aerial photographs are recorded on film rather than digitally – but this distinction almost doesn’t matter anymore, since most aerial photos are digitized or imaged now anyway]. The specific combination, or signature, of wavelengths reflected from the land cover types are specific to the type; water has a different wavelength combination reflected than trees, which also differs from soil or prairie grasses and so on. These unique combinations are the cover types’ “spectral signature”.
neighboring land cover, features as narrow as a few meters can be discerned (such as roads) (Lillesand and Kiefer, 2000). Landsat 4 and 5 had the MSS but also utilized a Thematic Mapper, or TM, which has an improved resolution of 30 m (Lillesand and Kiefer, 2000; USGS, 2005). The TM records a greater range of spectral bands than the MSS (See Table 3). The last Landsat Satellite launched to date was Landsat 7 (Landsat 6 never made it into orbit). This satellite has the MSS and also includes an Enhanced Thematic Mapper Plus (ETM+) that has a resolution of up to 15 m on the panchromatic spectral band. Only Landsats 5 and 7 are still operational.

Table 2. Individual Satellite Information

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Launched</th>
<th>Decommissioned</th>
<th>Sensors</th>
<th>Bands†</th>
<th>Finest Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 1</td>
<td>July 23, 1972</td>
<td>January 6, 1978</td>
<td>MSS</td>
<td>4-7</td>
<td>78-82m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RBV*</td>
<td>1-3</td>
<td>78-82m</td>
</tr>
<tr>
<td>Landsat 2</td>
<td>January 22, 1975</td>
<td>February 25, 1982</td>
<td>MSS</td>
<td>4-7</td>
<td>78-82m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RBV*</td>
<td>1-3</td>
<td>78-82m</td>
</tr>
<tr>
<td>Landsat 3</td>
<td>March 5, 1978</td>
<td>March 31, 1983</td>
<td>MSS</td>
<td>4-8†</td>
<td>78-82m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RBV*‡</td>
<td>1-3</td>
<td>40m</td>
</tr>
<tr>
<td>Landsat 4</td>
<td>July 16, 1982</td>
<td>June 15, 2001</td>
<td>MSS</td>
<td>4-7</td>
<td>78-82m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TM</td>
<td>1-7</td>
<td>30m</td>
</tr>
<tr>
<td>Landsat 5</td>
<td>March 1, 1984</td>
<td>Operational</td>
<td>MSS</td>
<td>4-7</td>
<td>78-82m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TM</td>
<td>1-7</td>
<td>30m</td>
</tr>
<tr>
<td>Landsat 6</td>
<td>October 5, 1993</td>
<td>Did not achieve orbit</td>
<td>ETM**</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Landsat 7</td>
<td>April 15, 1999</td>
<td>Operational</td>
<td>ETM+***</td>
<td>1-8</td>
<td>30m (band 8 is 15m)</td>
</tr>
</tbody>
</table>

*The return beam vidicon (RBV) was essentially a television camera and did not achieve the popularity of the MultiSpectral Scanner (MSS) sensor.

**The sensor onboard Landsat 6 was the Enhanced Thematic Mapper (ETM). Landsat 7 carries the ETM+.

†See Table 3 for band explanations

Images collected from any of the Landsat Satellites would have a sufficiently high resolution for the purposes of this study. Return beam vidicon (RBV) images from Landsats 1-3 are similar to a television image. RBV images were not used for this study due to their unavailability.

Table 3. Band Names and Corresponding Information

<table>
<thead>
<tr>
<th>BAND</th>
<th>WAVELENGTH CAPTURED</th>
<th>INSTRUMENT USED</th>
<th>LANDSAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visible blue-green</td>
<td>RBV</td>
<td>Landsats 1-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TM</td>
<td>Landsats 4 &amp; 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETM+</td>
<td>Landsat 7</td>
</tr>
<tr>
<td>2</td>
<td>Visible orange-red</td>
<td>RBV</td>
<td>Landsats 1-3</td>
</tr>
<tr>
<td></td>
<td>Visible green</td>
<td>TM</td>
<td>Landsats 4 &amp; 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETM+</td>
<td>Landsat 7</td>
</tr>
<tr>
<td>3</td>
<td>Visible red to near infrared (NIR)</td>
<td>RBV</td>
<td>Landsats 1-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TM</td>
<td>Landsats 4 &amp; 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETM+</td>
<td>Landsat 7</td>
</tr>
<tr>
<td>4</td>
<td>Visible green</td>
<td>MSS</td>
<td>Landsats 1-3</td>
</tr>
<tr>
<td></td>
<td>NIR</td>
<td>TM</td>
<td>Landsats 4 &amp; 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETM+</td>
<td>Landsat 7</td>
</tr>
<tr>
<td>5</td>
<td>Visible red</td>
<td>MSS</td>
<td>Landsats 1-3</td>
</tr>
<tr>
<td></td>
<td>NIR</td>
<td>TM</td>
<td>Landsats 4 &amp; 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETM+</td>
<td>Landsat 7</td>
</tr>
<tr>
<td>6</td>
<td>NIR</td>
<td>MSS,</td>
<td>Landsats 1-3</td>
</tr>
<tr>
<td></td>
<td>Thermal</td>
<td>TM</td>
<td>Landsats 4 &amp; 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETM+</td>
<td>Landsat 7</td>
</tr>
<tr>
<td>7</td>
<td>NIR</td>
<td>MSS,</td>
<td>Landsats 1-3</td>
</tr>
<tr>
<td></td>
<td>Mid-infrared</td>
<td>TM</td>
<td>Landsats 4 &amp; 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETM+</td>
<td>Landsat 7</td>
</tr>
<tr>
<td>8</td>
<td>Thermal*</td>
<td>MSS*</td>
<td>Landsat 3</td>
</tr>
<tr>
<td></td>
<td>Panchromatic</td>
<td>ETM+</td>
<td>Landsat 7</td>
</tr>
</tbody>
</table>

*Also on Landsat 3, but failed shortly after launch, rendering Landsat 3’s abilities the same as Landsats 1 and 2

The spectral bands captured by the satellites expose various properties of the land cover being analyzed. Table 4 outlines the land cover characteristics each spectral band highlights.

Table 4. Band Designations for TM and ETM+

<table>
<thead>
<tr>
<th>Spectral Bands</th>
<th>Wavelengths (micrometers)</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETM+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Blue-green</td>
<td>0.45 - 0.52</td>
<td>0.45-0.52 Bathymetric mapping; distinguishes soil from vegetation; deciduous from coniferous vegetation</td>
</tr>
<tr>
<td>2 Green</td>
<td>0.52 - 0.60</td>
<td>0.53-0.61 Emphasizes peak vegetation, which is useful for assessing plant vigor</td>
</tr>
<tr>
<td>3 Red</td>
<td>0.63 - 0.69</td>
<td>0.63-0.69 Emphasizes vegetation slopes</td>
</tr>
<tr>
<td>4 Reflected Infrared</td>
<td>0.76 - 0.90</td>
<td>0.78-0.90 Emphasizes biomass content and shorelines</td>
</tr>
<tr>
<td>5 Reflected Infrared</td>
<td>1.55 - 1.75</td>
<td>1.55-1.75 Discriminates moisture content of soil and vegetation; penetrates thin clouds</td>
</tr>
<tr>
<td>6 Thermal Infrared</td>
<td>10.4 - 12.5</td>
<td>10.40-12.50 Useful for thermal mapping and estimated soil moisture</td>
</tr>
<tr>
<td>7 Reflected Infrared</td>
<td>2.08 - 2.35</td>
<td>2.09-2.35 Useful for mapping hydrothermally altered rocks associated with mineral deposits</td>
</tr>
<tr>
<td>8 Panchromatic</td>
<td>n/a</td>
<td>.52-.90 Landsat 7 carries a panchromatic band (visible through near infrared) with 15 m resolution for &quot;sharpening&quot; of multispectral images</td>
</tr>
</tbody>
</table>

**Emch, et al, and the Current Study**

This study builds on an earlier study by Emch, et al. (2005) on the same area. In an effort to establish the best approach to determine where LULC change is taking place and at what rate, this study expands on an evaluation of forest cover change in the Toledo district in Southern Belize by Emch, et al (2005). In order to establish the dynamics of the changes, an assessment of the forest cover change over time and with multiple data points is needed. However, determining if the method of analyzing data used in this study, which is less costly than the method used in the Emch, et al (2005) study, is important in determining how future studies of this kind should progress. Based on this information, the Government of Belize (GOB) can better determine the methodology needed to move forward with this form of LULC change analysis.

Emch, et al., (2005) studied forest cover change in the Toledo District using two satellite images. The first image was captured by Landsat-2’s MSS on 25 March 1975 (WRs-1 Path 020 Row 49). The second was collected by Landsat-7’s ETM+ on 29 November 1999 (WRS-2 Path 019 Row 049). Their study used both supervised and unsupervised classification methods, which will be explained in detail later. They first used unsupervised classification to assign the pixels in the images into 100 classes, which were then clustered into LULC types with the aid of aerial photographs and ecosystem maps. Table 5 provides a description of the six land cover types into which the pixels were placed: deforest/regrowth, forested, lowland savanna, open water, wetlands, and farmland/bare soils/towns\(^{18}\) (freshly tilled areas as well as newly burned milpas were included in farmland).

\(^{18}\) “Farmland” and “towns” are probably placed in the same category due to the relatively small plots of land farmed. In the U.S., farmland is placed in its own category, as more farms are relatively large and distinctly discernable from “urban” or “town” LULC’s.
Table 5. Cover Types and Descriptions

<table>
<thead>
<tr>
<th>Land Cover Type</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforested/Regrowth</td>
<td>Secondary forest in some stage of regrowth.</td>
</tr>
<tr>
<td>Forested</td>
<td>Dense forest formed by trees at least 5 m tall with interlocking crowns and a canopy cover of 65 percent or greater.</td>
</tr>
<tr>
<td>Lowland Savanna</td>
<td>Grasslands, which may be flat or hilly, with a predominantly herbaceous community.</td>
</tr>
<tr>
<td>Open Water</td>
<td>Rivers, lakes, and flooded areas.</td>
</tr>
<tr>
<td>Wetlands</td>
<td>Swamps, mixed vegetation composed of rooted and/or floating plants that endure or need water covering the soil constantly or at most times of the year.</td>
</tr>
<tr>
<td>Farmland/Bare Soil/Towns</td>
<td>New milpas, roads, and/or towns with bare soil</td>
</tr>
</tbody>
</table>

Table from Emch, et al, 2005, p. 260

The results from the unsupervised classification in conjunction with field data were then used to determine which pixels best exemplified a specific cover type. These field data and pixels were portrayed as a map which depicts the forested and non-forested areas for each image date (1975 and 1999). These are shown in Figure 4. Comparing the total area of each cover type in each image allows total change and percent change of each cover type to be calculated. Figure 4 shows the areas their study determined were either forest or non-forest. Table 6 shows the summary data for the LULC changes as calculated by Emch, et al.
Figure 4. Map of Toledo District depicting areas of forest and non-forest

![Map of Toledo District](image1)

Table 6. Land Use/Land Cover Change in Toledo district, 1975-1999

<table>
<thead>
<tr>
<th>Land Cover Type</th>
<th>1975</th>
<th>1999</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% area</td>
<td>Hectares</td>
<td>% area</td>
</tr>
<tr>
<td>Deforested/Regrowth</td>
<td>6.11</td>
<td>21925</td>
<td>18.61</td>
</tr>
<tr>
<td>Forested</td>
<td>74.74</td>
<td>268010</td>
<td>65.00</td>
</tr>
<tr>
<td>Lowland savanna</td>
<td>12.5</td>
<td>44828</td>
<td>12.28</td>
</tr>
<tr>
<td>Open water</td>
<td>0.56</td>
<td>2023</td>
<td>1.35</td>
</tr>
<tr>
<td>Wetlands</td>
<td>2.46</td>
<td>8816</td>
<td>1.86</td>
</tr>
<tr>
<td>Farmland/soil/towns</td>
<td>3.62</td>
<td>12977</td>
<td>2.9</td>
</tr>
<tr>
<td>TOTAL HECTARES</td>
<td>358579</td>
<td>358647</td>
<td></td>
</tr>
</tbody>
</table>

Data from Emch, et al, 2005, p. 261
The results of their study found that the areas that were most densely forested were in the northern area of the District where the Maya Mountains are located. Their data showed approximately 70 percent of the study area consisted of forest. Most of the areas their data showed evidence of deforestation were located in central Toledo District and along the Guatemalan border. As mentioned previously, the central Toledo District is where the highest population density occurs. In addition, Guatemalans, whether for lack of land availability in Guatemala or as refugees from Guatemala, generally relocate along this border, where they practice *milpa* farming.

It should be noted that much of the central area within the district was deforested prior to 1975, while most of the deforestation in the area of the District occurred adjacent to this populated area. Emch, et al, concluded that the increased deforestation in the central area was due, at least in part, to population growth. The areas that experienced the majority of the reforestation, surprisingly, were also located in the central area of the District. Emch, et al, associated this with the increases in cacao farming the Maya were practicing at this time19. The northern area of the district, where forest reserves are located, was found to have been forested during both years.

This study used the same 1999 image used in the 2005 Emch, et al study as a base for comparison between the method of image analysis used for this study and that used in the Emch, et al study (which involved more extensive, and more expensive, methods of image analysis)20. Also, this study adds one more image -199421 - to the data analysis to compare

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19 No information was found that indicates whether or not cacao farming is still practiced to the extent it was during the Emch, et al, study timeframe (1975-1999), nor if incidences of cacao farms have increased.
20 This image was obtained from Marc Peterson, who was an author of the Emch, et al, study.
with the 1999 image. Therefore, the two images used in this study are from March 1994 and
November 1999 and are from Landsat 5 and Landsat 7 respectively. Emch, et al (2005)
performed extensive accuracy testing on the 1999 image, with an overall accuracy of 90.8
percent in correctly classifying pixels into their respective LULC types (see Table 7).
Based on this information, the data from the Emch, et al 2005 study will be used to determine
accuracy of classification performed for this study.

This study differs from the Emch, et al. study in that it employs unsupervised
classification methods only. Unsupervised classification may leave some ambiguity in the
determination of what class pixels should be assigned, due to a lack of first-hand knowledge
about an area. However, it allows for a greater level of validity, in that all different cover
classes will be identified by the program (even though the user may be unable to assign it a
name). The Emch, et al. study acknowledges that a more multi-disciplinary approach is
required to understand why the spatiotemporal changes are occurring. This study differs in
that a more broad perspective of the reasons behind LULC changes within the Toledo
District has been explored. The Emch, et al. study is more exhaustive in the analysis of the
satellite image data, in that it incorporated subpixel analysis, which aided in determining the
density of the forest in forested regions. However, because the study used data collected first-
hand by the researches, it was greatly more expensive than this study.

21 The 1994 image was downloaded from MesoStor – an online data service which offers free downloads of
various data from Mesoamerica. MesoStor is supported by SERVIR, which is funded primarily by NASA. More
information about this site can be found at: http://servir.nsstc.nasa.gov/MesoStor/.
22 Emch, et al, commented on the accuracy values stating, “While the accuracy assessment revealed substantial
confusion between several nonforest classes, especially with the farmland/bare soils/towns class, the main
objective of this study is to distinguish between forest and nonforest for both years…” (p. 262).
Table 7. Accuracy Assessment

<table>
<thead>
<tr>
<th>Land Cover Class</th>
<th>Producer’s Accuracy*</th>
<th>User’s Accuracy*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforested/Regrowth</td>
<td>87.9%</td>
<td>76.60%</td>
</tr>
<tr>
<td>Farmland/soil/towns</td>
<td>43.75%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Forest</td>
<td>98.10%</td>
<td>95.68%</td>
</tr>
<tr>
<td>Lowland Savanna</td>
<td>85.71%</td>
<td>92.31%</td>
</tr>
<tr>
<td>Wetlands</td>
<td>75.00%</td>
<td>60.00%</td>
</tr>
</tbody>
</table>

*The “producer’s accuracy” relates to the probability that a reference sample (interpreted land cover class) will be correctly mapped and measures the errors of omission. In contrast, the user’s accuracy indicates the probability that a sample from the land cover map actually matches what it is from the reference data (interpreted land cover class) and measures the error of omission. Table recreated from Emch, et al, 2005, p. 263.

Image Selection

A number of differences in the final images can present themselves based on how and when the images were captured. Differences in the satellite instruments used can result in the center wavelength captured by a Band to be different. Differences in collections dates and/or times can result in the scene changes due to plant senescence. Some differences in atmospheric conditions can be corrected by doing radiance and reflectance pre-processing calibrations on the images. These calibrations ensure the images are in the same units and are thus comparable to one another. If images have different resolutions, comparisons between the two can be difficult, as the results will not be the same. The higher resolution will theoretically be more accurate if the land cover features are smaller than the resolution of the coarser image. As the number of pixels in a particular area will be greater, allowing them to be classified appropriately, whereas images with low resolution would show the same pixels as only one pixel. Preferably, the images would all be from the same time of year, the same

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23 For example, an image with a 30 m resolution will show four pixels in the same square as a 60m resolution will show one pixel.
area, and obtained by the same instrument to hold temporal, spatial, and spectral variables constant (Emch, et al, 2005).

A search was done to find images that present clear views of the Toledo District between 1975 and 2005. Given the lack of available satellite images of this area without extensive cloud cover (which prevents evaluation of the land cover underneath), without satellite anomalies\textsuperscript{24}, and without expending large sums of money, two images from the same time of year were unattainable. Therefore, there are a number of differences that exist between the images. The instruments used to collect the data as well as the differing times of year (one during the wet season, the other during the dry) make the results different and will make comparing data analysis results somewhat difficult in discerning exactly what cover types existed in both images. The two images utilized have a resolution of 30m. Pictures of the images are below (Figures 5 and Figure 6):

\textsuperscript{24} Two satellite images were available, from 2004 and 2005, but the satellite that took these later images had a malfunctioning mechanism needed for obtaining a complete image and resulted in “streaks” that caused areas devoid of data.
Image Preparation – Pre-processing Procedures

To be useful for the analysis, the images had to be put through a series of preprocessing procedures. Reducing the number of variables, such as camera shading – which is caused by non-uniform sensitivity across the satellite camera’s field-of-view, different areas and amounts of cloud cover, and so forth, make them as comparable to each other as possible. First, all of the bands were “stacked” so that they existed in one image/file (prior to stacking, the bands existed as individual files). Stacking makes image analysis easier because it allows the images to be analyzed as one file rather than having to analyze each individual band file. Stacking also makes selecting an area of interest easier.

Second, both of the images were then put through a standardization process using the satellite image processing and analysis program called Environment for Visualizing Images, or ENVI, created by Research Systems, Incorporated (RSI). This process calibrated the images so that radiance (brightness) variables that existed between the two were calibrated. Only bands 1-5 and band 7 were used. Reflectance calibration could not be performed on the 1999 image due to the lack of certain data components that are included in the file, and therefore was done on neither image. However, upon further investigation, it is fairly standard for only the radiance calibration to be performed.

Third, an area of interest, or AOI, was created based on the administrative boundaries within Belize, limited to the southern-most district of Toledo. This AOI was

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25 Band 6 and Band 8 differed between these two images – only those common bands between the two images were used.

26 When obtaining a satellite images, there are typically a number of files that comprise the image, which consist of a file for each band a “header” file. Specifically in this case the header file was missing, which contains data such as the number of rows and columns of pixels in the image, the location of the sun and of the satellite at the time the image was captured, the geographic boundaries of the image, and so forth.

27 This is also referred to as a “region of interest”, or ROI (Emch, et al, 2005).
determined by overlaying a vector map (sometimes called a line map\textsuperscript{28}) of the boundaries of the Toledo District onto the satellite image and cropping (sometimes called “clipping” or “subsetting”) the image to just the Toledo District. Again, this will ensured that the areas analyzed are as similar in size and shape as possible (see Figures 7 – before clipping and Figure 8 – after clipping). In Figure 7, the Toledo district is outlined in white and located within the red circle.

Figure 7. 1994 Image Before Clipping

\textsuperscript{28} This is similar to the shapefile described earlier.
The 1999 image had considerable amounts of cloud cover in the study area (see white areas in Figure 4). In order to ensure that only those areas that are visible and in the same location would be compared between the images, a “mask” was created. This process entailed viewing the graphs (called histograms), which depicted the number of pixels captured by a Landsat band. For example, looking at a graph of Band 1 shows the wavelength captured on the x-axis and the number of pixels within the image that correspond with that specific wavelength on the y-axis. When the bands are viewed alone (in other words, not layered on top of each other), Band 1 presented the most obvious cloud cover, while the other bands did not depict the cloud cover as well. Looking at the histogram of Band 1, there was a sharp spike in the number of pixels captured within a specific range of non-calibrated radiance values (see Figure 9).
The mask was created to remove all radiance values between 0-0.1018 nanometers. This mask did eliminate portions of the land, most likely due to moisture or fog close to the ground that reflected the same spectral signature as the clouds and thus had the same radiance values. An attempt was made to determine if this range was appropriate. By increasing the extent of radiance values included in the mask (e.g., 0-0.1061) eliminated even more of the land, while decreasing it (e.g. 0-0.0916) left a considerable amount of cloud cover in the image. Therefore, only those values between 0 and 0.1018 were eliminated. While there weren’t clouds in the 1994 image, to keep the area analyzed as similar in size and shape as possible between the two images, these portions were eliminated from both images. It should be noted that the shadows created by the clouds were not removed, but their possible misclassification contributes a small source of error (see Figure 10a and 10b). Once these processes were completed, the images are essentially ready for classification of the
pixels into their respective LULC classes. Figures 11 and 12 show the images after pre-processing and prior to classification.

Figures 10a and 10b. Images before and after Masking of Clouds.

Top - before mask is applied to remove clouds; bottom - after mask was applied, with reference points highlighted in red. Note the remaining cloud shadows.
Figure 11. 1994 false color composite image after pre-processing
Classification of the Image LULCs

The land cover needs to be classified to determine the extent of the cover types. Two types of classifications can be used to analyze land cover types: supervised and unsupervised. To perform a supervised classification, knowledge of the existing land cover classes of an area is needed to accurately classify those types within a satellite image. Different cover
classes give off different spectral signatures. Only specific knowledge of the actual land covers in that exact area can determine a specific cover class – e.g. forest, agriculture, urban, and so forth. The computer program is instructed to use the spectral signature of a specific pixel (or small group of pixels) whose class is positively identified from field observations as the “endmember” (i.e. “perfect example” and sometimes called a “training set”) of the land cover class and to assign all other pixels with that same spectral signature to the same land cover class. However, there may be unlabeled pixels within the image after a classification has been done, and in order to not label them erroneously, an understanding of the actual cover types in the area captured in the image is needed.

This problem can be resolved in several ways. First, a supervised classification can be performed, which entails visiting the study area and “ground-truthing” the cover types, that is, determine exactly what is on that specific area of land that is not assigned a classification. Unfortunately, this could be costly and time consuming. Another way to resolve this problem would be to use a map for which precise ground-truthing has already been done. While the first and second way are related (someone is collecting the field data at some point), collecting the data first hand can be much more costly than relying on published, and sometimes free, second-hand data. Finally, to improve the accuracy of pixel assignment to those unassigned pixels, an unsupervised classification (which will be further discussed later) can be performed. The statistical difference in the results of the unsupervised classification compared with those done by using the map can be determined. If the difference is too large, then only an unsupervised classification should be considered. If there has been no ground-truthing or access to a very recent map that expresses precise land cover classes, supervised classification can be very time consuming and can be inaccurate. Pixels previously left
Unclassified are then assigned to a class, which may be inaccurate to the point that the data are not valid or reliable (based on the number of pixels incorrectly assigned).

Another problem with using supervised classification is that an exhaustive classification scheme characterizing all features – even those irrelevant to the specific study question – must be created to minimize (or preferably prevent) mistakes in assigning those pixels that were initially left unclassified. A classification scheme, that is, a system of predetermined land cover types should already have been tried and tested successfully (Wilkie and Finn, 1996). Newly created schemes have generally only been used on one study and therefore their use precludes comparisons with other studies for reliability and validity. It is also extremely time consuming to create a classification scheme from scratch, as the collection of field data and geo-referencing of that data would need to be performed.

Unsupervised classification differs from supervised in its approach and accuracy. Unsupervised classification of the land cover types does not require additional or prior knowledge of existing cover types. If all of the existing cover classes in an area are unknown or if there is an unusual or rare land cover class (with an unusual spectral signature), using this method for identifying cover classes will be advantageous (Lillesand and Kiefer, 2000; Verbyla, 1995). All cover classes will be identified. Identifying every single cover class employing a supervised classification could be costly, time consuming and difficult (Hepner, Logan, Ritter, and Bryant, 1990). An unsupervised classification is almost completely done by the computer program, except for the initial instructions given by the user, to include instructions regarding the number of classes to divide the pixels into or what mathematical method of determining into which class a pixel should be placed. Pixels are grouped based on
the similarity of their spectral values (Verbyla, 1995). Wilkie and Finn (1996, p. 65) liken unsupervised classification to clothing manufacturing:

“Identification of landscape classes is more like attempting to determine an individual’s suit size based on height and weight, and less like clustering people into discrete categories such as sex, level of education, car ownership, and income. [If you plot] a hypothetical population of men according to height and weight…the swarm of data points is continuous, with no clear dividing lines. As clothes manufacturers cannot make custom tailored clothes for each man in the population, they must decide how many sizes to make and where they should draw the lines between sizes.”

Dividing spectral features into classes is often just as subjective as labeling suits as “small”, “medium”, “large”, “tall”, “short”, and so forth.

The user needs to determine the minimum and maximum number of classes (or groups) into which the program should sort the spectral signatures. One of the problems with using unsupervised classification is that in landscapes there are often areas on the edge of two (or more) different land cover types that are difficult to discern, without field knowledge of what land covers and land uses are actually present (Thomas, 1990). These areas may be an overlap of land cover types. This poses a dilemma about how many classes should be created. Should there be one for each “pure” cover type, with certain vegetation types, and one for each of the various mixed cover types be created, or should the mixed cover areas be included with one of the pure classes?

A component of the program called Environment for Visualizing Images, or ENVI, created by Research Systems, Incorporated (RSI) can perform subpixel classification that analyzes the various data layers to determine the most likely class to which the unclassified pixels should be assigned. Performing a sub-pixel classification would address the issue of mixed-class unassigned pixels. Once all pixels have been assigned to a class, the classes can
be named by using the most recent land use/land cover map of the area (e.g., forest, agriculture, water, etc.). However, for the purposes of this study, subpixel classification was not performed.

Studies have shown that unsupervised classification of tropical forests at the regional and sub-regional level, such as this study, provides sufficient information as compared to what actually exists (Stibig and Malingreau, 2003). The results of this study were compared with those found in the Emch, et al., study, which aided in determining differences between supervised and unsupervised classification for this region.

ENVI used an algorithmic process to assign pixels to classes called the k-means algorithm (also called “sequential clustering approach”)\(^{29}\) (Verbyla, 1995, p. 111). The k-means approach to unsupervised classification can produce very accurate results in identifying areas of forest clearing (Leckie, et al, 2002).\(^{30}\) A current land use/land cover map of Belize (created from data provided by Belize Tropical Forest Studies by Belize Biodiversity Mapping Service and published in 2004) in the format of a shapefile\(^{31}\) was overlayed on the satellite images. This assisted in the actual naming of the spectral classes. The map used for this study was created from extensive field work (ground-truthing) from 2001 to 2004 by Meerman and Sabido (2001) (see Figure 13; approximate location of Toledo District encircled in red). A 1995 1:250,000 scale vegetation map was used as a starting point, and their data was used to update this map.

\(^{29}\) For detailed information on the k-means algorithmic approach, see Verbyla, 1995, pp. 111-117.

\(^{30}\) This algorithm can even detect fine details in cover change. For example, in an image with a resolution of 30 meters, each pixel is then 30m square. If this area is forest in one image and agriculture in another, the k-means would detect the change and assign it accordingly. Thus, at the finest scale available, changes can be detected.

\(^{31}\) A “shapefile” is a map layer used in Geographic Image Analysis, of GIS. In this case, the shapefile is a map depicting the outlines of various land cover classes in the Toledo region.
The 1995 map was an update to a 1959 ecosystem map. Meerman and Sabido (2001) also used several Landsat images and quite an extensive collection of other maps done of the area (e.g. geological maps, maps of the Rio Bravo river area, etc.) This data was then analyzed and compiled to produce the final “Central America Ecosystem Map: Belize” in 2004. This map has 96 classes, though not all of these classes were present in the AOI of this study.
ENVI was programmed to divide the pixels in the picture into 150 classes. The maximum number of classes any image can be divided into is 256. For 8-bit data, such as those produced by Landsat, the sensor only allows for radiometric sensitivity in 256 levels. The basic unit of computing is the bit. Each bit has 2 possible values: 0 and 1. In an 8-bit system there are $2^8 = 256$ possible permutations of the data\footnote{A “permutation” is a sequential arrangement of data components or objects. E.g. the number 1, 2, 3, 4 can have a permutation of 1, 3, 2, 4 and 1, 4, 3, 2, and so forth. In an 8-bit system, there are 256 possible permutations, or sequential arrangements, of the data held in each pixel}. Therefore, each image band is already "classified" into 256 classes. When viewing three-bands of data on the screen, you have $256^3 = 16,777,216$ possible values. A typical Landsat scene has over 36 million pixels, so there is already some data "loss" or simplification, but only in regards to the screen display, which doesn't have much weight in the classification process – the pixels may visually look the same on the screen, but the data contained in the pixels can vary. A 6-band TM or ETM+ image would allow for $256^6$ or 281 trillion possible values. This is how individual bands of only 256 values are able to reasonably represent the vast variation in the real world and this is what unsupervised classification is ultimately sorting (Peterson, 2006). However, typically at some number (which probably varies depending on the size of the image) there will be a diminishing return on the number of pixels assigned to new groups. Put differently, the types of land uses/land covers in the images is most likely fewer than 256, so asking the computer to categorize the pixels into all possible classes will not result in 256 different classes (Peterson, 2006). Due to time constraints, the images were classified into 150 classes\footnote{The more classes into which the program is told to divide the pixels, the longer it takes. 150 classes for each image took approximately 8 hours.}. As mentioned previously, the pixels were placed in groups using the K-Means algorithm. ENVI ran through this process 5 times, allowing for more accurate classification.
of the pixels (by comparing where the pixel has been assigned in the previous iteration and then placing it in the most likely/common class). The program was set at a 5 percent threshold, which means that if the pixel varied less than 5 percent from other pixels placed in one class (based on the possible combinations of wavelength data contained within the pixel), it would be placed in that class. If it differed greater than 5 percent, a new class would be created into which that pixel would be placed and to which other pixels could be assigned should they meet the similarity threshold requirements. Figure 14 shows a visual representation of the pixels after being divided into 150 separate classes. Note that the colors are not yet programmed to coordinate with their respective LULC classes. This will be done in the next step in the process.

Emch, et al (2005) created six LULC classes (p. 261) as did this study. An attempt was made to use the same or as similar classes as possible to the Emch et al study based on the classes used in the Ecosystem Map, which was used as an overlay on the image to aid in naming the classes. Table 8 outlines the LULC classes used in this study. All pixels were turned off, that is, they were not visible or black. One by one, each class was turned “on”.

The location of the majority of pixels as compared to the overlay of the outlines of the ecosystems was determined. The classes were named based on the ecosystem in which the majority of pixels in each individual class lay. Once all the pixels were named, they were grouped together based on their ecosystem name. For example, class #78 and 120 were determined to be “Forest”. At the end, these two classes, and all others determined to be forest, were grouped together so all “Forest” classes were then only one class. Each class group was then colored, e.g. forest was green, savannah was yellow, and so forth, so that
spatial patterns could be examined (see Table 9 for colors associated with cover types).

Figures 15 and 16 show the 1994 and 1999 images, respectively, after classification.

Figure 14. 1994 image, after classification
Table 8. LULC change classes used in Emch, et al study and the current study

<table>
<thead>
<tr>
<th>Emch, et al Class Names</th>
<th>Class Names used in this study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforested/regrowth,</td>
<td>Disturbed/shrubland</td>
</tr>
<tr>
<td>Forested</td>
<td>Forested</td>
</tr>
<tr>
<td>Lowland savannah</td>
<td>Savannah</td>
</tr>
<tr>
<td>Open water</td>
<td>Water</td>
</tr>
<tr>
<td>Wetland</td>
<td>Wetlands</td>
</tr>
<tr>
<td>Farmlands/soil/towns</td>
<td>Cleared/urban; Agriculture</td>
</tr>
</tbody>
</table>

Table 9. LULC Classes and their color assignments for the two images used in this study

<table>
<thead>
<tr>
<th>LULC Class</th>
<th>COLOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>Red</td>
</tr>
<tr>
<td>Savanna</td>
<td>Yellow</td>
</tr>
<tr>
<td>Wetlands</td>
<td>Cyan</td>
</tr>
<tr>
<td>Water</td>
<td>Blue</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Green</td>
</tr>
<tr>
<td>Disturbed/Shrubland</td>
<td>Maroon</td>
</tr>
<tr>
<td>Cleared/Urban</td>
<td>Magenta</td>
</tr>
</tbody>
</table>
Figure 15. 1994 image after pixels assigned to one of the seven LULC classes
It became apparent at this time that the valleys between the mountains in the southwestern area of the image were misclassified as being savannah and presented a ripple effect (as can be seen in the magenta-colored pixels in Figure 17).
Figure 17. Notice magenta striping which coincides with the hills and valleys in the area and were re-classified to forest.

The classes that contained those pixels that were previously named “savanna” were reclassified to forest. After a visual examination, this affected few areas of the image and there appeared to be little impact on the other classes by changing these pixel classes from savanna to forest. It appeared that during the process of naming, these pixels were not definitively in one particular group, as they were dispersed between several different classes. However, once they were grouped together, it became evident that they were similar. Few pixels were present in other groups, therefore causing relatively insignificant changes in group totals.
Conclusion

Satellite image analysis can be a useful tool for evaluating LULC change on large scales. The technology in the area of capturing satellite images and the analysis of these images has expanded to be quite complex and involved. However, growth in this field is important, as it aids in tracking trends of growth and loss of various LULC types. While supervised and unsupervised classification methods both have their pros and cons, determining which method would best serve the purposes and intent of the researching bodies or individuals might aid in focusing advancements of that method, potentially aiding in making it more accurate and/or more cost- and time-efficient.

While every effort was made to make the images used in this study to be comparable, it should be noted that there will be discrepancies based simply on the differences in the time of year they were taken and differences in the instruments that captured the images. In addition, every effort was made to accurately classify the pixels into the respective LULC types. However, this process was extremely time-consuming for several reasons. First, even with a computer with a fast processing chip, analysis, especially classification of the images, too many hours (between 10-12 hours per image). Should any errors be made or changes be desired with the threshold criteria or any other pre-processing procedure, one would have to go back, re-do the pre-processing, and re-run the classification step. Second, the process used in this study for placing the pixels into the respective LULC types took approximately 40-50 hours per image. Each class was turned on, one by one, and the entire image was visually examining by zooming in on each area, with the ecosystem map overlay visible, to determine exactly which ecosystem type had the majority of the pixels. This was done manually, i.e., the computer did not calculate this. However, should the researcher be aptly trained to
perform such an analysis, the time involved would probably be less (than that of a novice), any user errors may be reduced or eliminated, and it would certainly be less time-consuming than traveling to the study site (from the United States) and collecting field data. If this method could be improved upon to ensure and increase a level of accuracy, it would be highly beneficial for those countries to possibly employ educated citizens or hire international consultant to perform this type of analysis from remote locations, require less of a financial investment. Additionally, as technology improves, programs may be able to perform aspects of the analysis with little assistance from the researcher, reducing time and perhaps consulting fees. Regardless of which method of classification is used, satellite image analysis is an excellent tool and should be considered a necessary tool for evaluating LULC changes for any level of government, throughout the world.
CHAPTER 4. RESULTS & DISCUSSION

After the images were analyzed, ENVI consolidated the data for each over class. Statistics on this data were generated and these results are presented here. Comparisons were also made between the Emch, et al, study results for the 1999 image and the corresponding results obtained in this study.

Table 10 shows the total areas in hectares for each cover type and compares the differences between the 1994 image and the 1999 image. Table 11 shows the results from the Emch, et al. (2005) study. Table 12 shows the comparison of the data from each class total from the 1999 image with the results from the Emch, et al. (2005) 1999 image analysis.

Discussion of Data Results

It was difficult to discern if an area was “agriculture” or “cleared” or “deforested/regrowth”. Some speculation, based on knowledge of the area, nearby pixel classes, and the ecosystem map, was used to place pixels into their respective classes. Other studies have shown that vegetation diversity and the diversity of land covers within small areas can make it difficult to discern between cover types and cause problems with classification (Mas, 1999). Mas (1999) even goes on to say that researchers have reported “spectral confusion” between disturbed and undisturbed forests, as well as between grasslands, such as savannah, and pasture land. Mas (1999) states this is a common problem in the tropical forests, given the nature of the vegetation and how plant communities in these regions of the world grow.

As can be seen in Table 10, no “disturbed/shrubland” was identified in the 1994 image, while 1.8 percent of the 1999 image was determined to be disturbed/shrubland. This
<table>
<thead>
<tr>
<th>Cover Name</th>
<th>1994 amount (m²)</th>
<th>1994 amount (hectares)</th>
<th>1994 percent*</th>
<th>1999 amount (m²)</th>
<th>1999 amount (hectares)</th>
<th>1999 percent*</th>
<th>Change (Hectares)</th>
<th>Change (Percent)</th>
<th>Growth/Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>12,019,500</td>
<td>1,202</td>
<td>0.289%</td>
<td>15,502,500</td>
<td>1,550</td>
<td>0.365%</td>
<td>348</td>
<td>0.076%</td>
<td>Growth</td>
</tr>
<tr>
<td>Wetlands</td>
<td>31,090,500</td>
<td>3,109</td>
<td>0.747%</td>
<td>41,909,400</td>
<td>4,191</td>
<td>0.987%</td>
<td>1082</td>
<td>0.240%</td>
<td>Growth</td>
</tr>
<tr>
<td>Forest</td>
<td>3,472,291,800</td>
<td>347,229</td>
<td>83.470%</td>
<td>3,679,584,300</td>
<td>367,958</td>
<td>86.698%</td>
<td>20729</td>
<td>3.229%</td>
<td>Growth</td>
</tr>
<tr>
<td>Savannah</td>
<td>261,430,200</td>
<td>26,143</td>
<td>6.284%</td>
<td>236,423,700</td>
<td>23,642</td>
<td>5.571%</td>
<td>-2501</td>
<td>-0.714%</td>
<td>Loss</td>
</tr>
<tr>
<td>Disturbed/Shrubland</td>
<td>0</td>
<td>0</td>
<td>0.000%</td>
<td>76,239,000</td>
<td>7,624</td>
<td>1.796%</td>
<td>7624</td>
<td>1.796%</td>
<td>Growth</td>
</tr>
<tr>
<td>Cleared/Urban/Pasture</td>
<td>47,607,300</td>
<td>4,761</td>
<td>1.144%</td>
<td>38,763,900</td>
<td>3,876</td>
<td>0.913%</td>
<td>-884</td>
<td>-0.231%</td>
<td>Loss</td>
</tr>
<tr>
<td>Agriculture</td>
<td>335,507,400</td>
<td>33,551</td>
<td>8.065%</td>
<td>155,706,300</td>
<td>15,571</td>
<td>3.669%</td>
<td>-17980</td>
<td>-4.396%</td>
<td>Loss</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>4,159,946,700</strong></td>
<td><strong>415,995</strong></td>
<td><strong>4,244,129,100</strong></td>
<td><strong>424,413</strong></td>
<td><strong>8418</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Percent of total land evaluated for the respective year
Table 11. Results from the Emch, et al. (2005) study.

<table>
<thead>
<tr>
<th>Land Cover Type</th>
<th>1975</th>
<th>1999</th>
<th>% Area</th>
<th>% Area</th>
<th>Gain</th>
<th>Loss</th>
<th>Net Gain/Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Area</td>
<td>Hectares</td>
<td>% Area</td>
<td>Hectares</td>
<td>Hectares</td>
<td>Gain</td>
<td>Loss</td>
</tr>
<tr>
<td>Deforested/Regrowth</td>
<td>6.11</td>
<td>21,925</td>
<td>18.61</td>
<td>66,743</td>
<td>15.16</td>
<td>2.66</td>
<td>12.5</td>
</tr>
<tr>
<td>Forested</td>
<td>74.74</td>
<td>268,010</td>
<td>65</td>
<td>233,126</td>
<td>4.63</td>
<td>14.37</td>
<td>-9.74</td>
</tr>
<tr>
<td>Lowland savanna</td>
<td>12.5</td>
<td>44,828</td>
<td>12.28</td>
<td>36,867</td>
<td>2.05</td>
<td>4.27</td>
<td>-2.22</td>
</tr>
<tr>
<td>Open water</td>
<td>0.56</td>
<td>2,023</td>
<td>1.35</td>
<td>4,836</td>
<td>0.86</td>
<td>0.07</td>
<td>0.79</td>
</tr>
<tr>
<td>Wetlands</td>
<td>2.46</td>
<td>8,816</td>
<td>1.86</td>
<td>6,656</td>
<td>0.77</td>
<td>1.37</td>
<td>-0.6</td>
</tr>
<tr>
<td>Farmland/soil/towns</td>
<td>3.62</td>
<td>12,977</td>
<td>2.9</td>
<td>10,419</td>
<td>2.42</td>
<td>3.13</td>
<td>-0.71</td>
</tr>
<tr>
<td>TOTAL HECTARES</td>
<td>358,579</td>
<td>358,647</td>
<td>358,579</td>
<td>358,647</td>
<td>358,579</td>
<td>358,647</td>
<td>358,579</td>
</tr>
</tbody>
</table>

Table 12. Comparison between current study results and Emch, et al. results for 1999 image*.

<table>
<thead>
<tr>
<th>Class compared</th>
<th>hectares difference</th>
<th>Difference as a percent of Emch totals (by category)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>-3,286</td>
<td>-68%</td>
</tr>
<tr>
<td>Wetlands</td>
<td>-2,465</td>
<td>-37%</td>
</tr>
<tr>
<td>Forest</td>
<td>134,832</td>
<td>58%</td>
</tr>
<tr>
<td>my cleared/urban/pasture + agriculture</td>
<td>9,028</td>
<td>87%</td>
</tr>
<tr>
<td>farmland/soil/towns (Emch, et al. study)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savannah</td>
<td>-13,225</td>
<td>-36%</td>
</tr>
<tr>
<td>Disturbed/shrubland (current study)</td>
<td>-59,119</td>
<td>-89%</td>
</tr>
<tr>
<td>deforested/regrowth (Emch, et al., study)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>65,766</td>
<td>18%</td>
</tr>
</tbody>
</table>

*Calculations done using Emch, et al. (2005) as the base, with the current study data being subtracted from their data to denote differences.

34 The method of supervised classification in the Emch, et al. (2005) article was determined through two different methods. In their published article, they explain that the results between the two methods were very similar, and therefore, only the results from one method are shown here, the “maximum likelihood”
is probably due to classification “confusion”, using Mas’ terminology. There was no way to affirm the true classification that was represented in the pixel spectral signature without ground-truthing. That being said, savannah, water, forest, wetlands, and agriculture did prove to be easier to identify. For example, those pixels placed in “savanna” were easily identified because they typically presented in large clusters within the area outlined on the ecosystem map as savanna. The same was true of the other LULC types. However, the changes in forest and agriculture pose a problem – that of accurately identifying agricultural land that appears to be forested as “agriculture”. In this study, the greatest growth was seen in the “forest” cover type, at 3.2 percent. This could be, as Emch, et al., suggested, due to an increase in cacao farming, which would make that land appear to have forest, because cacao grows on trees. The greatest loss was agriculture, which showed and almost 4.4 percent loss. There is an inherent difficulty in classifying forest and tree crop farms. This, too, could be related to the increase in cacao farming. Thus land that is being farmed (and all that entails, including depletion of soil nutrients, possible use of fertilizer, clearing of forest to meet the needs of a growing population, etc.) could be improperly classified, leading to inaccurate results. A section identified as farmland in the northeast area of the images showed a great amount of agricultural land. However, some of this land was identified as savanna, as well. As Mas (1999) noted, land used for pasture might appear as savanna in a satellite image, but might technically be used for livestock grazing. This, too, would then misidentify the land use, creating inaccurate results. Growth in wetlands (0.24 percent) and water (0.08 percent) could be due to the 1999 image being taken during wet season. This shows the importance, as
mentioned earlier, of images being taken at the same time of year to eliminate this type of discrepancy.

As can be seen in Table 12, there are great differences between the 1999 image data results from the current study and those found by Emch, et al.. The most drastic difference is seen in the difference between forest (134,832 ha, or approximately 520 square miles). This area of difference would constitute approximately 22 percent of the total area of the entire Toledo district. Additionally, the difference between the categories “cleared/urban/pasture and agriculture” (from the current study) and “farmland/soil/towns” (from the Emch, et al. study), LULC types that are a primary focus of this study, shows the expansion of these cover types to be 87 percent greater in the current study than Emch, et al. found in the field. Conversely, “disturbed/shrubland” in the current study is shown to have covered approximately 59,000 acres, or 89 percent, more than “deforested/regrowth” in the Emch, et al. study. One reason for the difference between these last two numbers could lie in the difference in the classification of the pixels. While in the field, it might be apparent that these”disturbed/shrubland” and “deforested/regrowth” are not truly comparable, that is, they are not truly the same or even similar. For example, comparing “disturbed” to “deforested” might actually result in two separate categories. Or, perhaps what is being categorized as “disturbed” might actually fit better under an entirely different category, or it may be better classified as a new and separate category, rather than either “disturbed” or “deforested”. Thus, in reality, those pixels may have been assigned to a category/classification incorrectly. Perhaps the differences between “disturbed” and “deforested” are not so different. Deforested could be looked at as land cover that has been cleared or certain types of vegetation have been removed, and in essence is on its way “out”. Disturbed could be looked at as land cover
that has been altered but is re-growing, and is in essence on its way “in”. But perhaps because the Emch, et al. study was more hands-on, as supervised classification is, the differences are due to their judgement calls in the field, rather than any true differences between the cover classification assigned in this study differing from the cover type assigned in the Emch, et al. study. It could possibly come down to a judgement call that would incorrectly place similar pixels, but with a lower threshold between differences, into the certain category that, in reality, would be different categories/classifications. Thus, these pixels would be classified incorrectly, or at least placed in different categories, creating differences in the end data and statistics. It is likely that there is some level of classification discrepancy or error between this study and the Emch, et al. study in determining the correct LULC type, or maybe just in determination of which class the pixels should be assigned.

As discussed earlier, supervised classification does not necessarily provide more accurate results than unsupervised. If all cover type are not accounted for, then a classification can be missed, causing pixels to be arbitrarily and/or mistakenly assigned to an incorrect LULC classification. Conversely, doing unsupervised classification, using second-hand data, can end with the same results: arbitrarily and/or mistakenly assigning a pixel, or pixels, to a class that is incorrect.

**Conclusion**

Based on the results of this study, as compared with the results of the Emch, et al. study, there can be great statistical differences in data. These differences may be based on the method of classification. A determination of which method of classification employed would need serious and robust investigation. Perhaps even a combination of methods, or even more
complex methods, would provide the best results to use for data tracking, and ultimately policy analysis.

While unsupervised classification can be a very robust and accurate tool for determining LULC types, the results here show the possibility of a great deal of variability in those results. Emch, et al.’s (2005) 1999 image was used to determine accuracy of the current study. And while their accuracy assessment proved their own difficulties in classifying non-forest LULC types, their accuracy in classifying forest cover was 95-98 percent accurate. This means that the total forest cover in this study and Emch, et al.’s study, which differ by 58 percent, is probably a strong basis for proving discrepancies between the data collected in this study and the data collected in the Emch, et al. study.
CHAPTER 5. CONCLUSION

This study focused on two aspects of LULC changes in the Toledo District in southern Belize. First, an examination of the cultural, political, economic, and legal setting in the Toledo district was performed. It was found that there are legal issues, relating to land tenure and ownership; cultural issues, relating to the Maya and their traditional farming methods; political issues, relating to the government's identification and use of reserve forest; policy issues, relating to incentives or disincentives to more sustainable methods of farming; and financial issues, which are influenced by policies, and also relate to the farmers' ability to change their methods of procuring food which is also their livelihood and means for procuring income. The second component of this study was determining if an unsupervised classification of the study area would provide sufficient data to implicate this method as a viable means of tracking LULC changes. By tracking these changes over time and by location, there is a possibility of linking what has been done in the past, who has done it, and why. Having the combination of knowledge and data will aid policy-makers and planners in determining how to control deforestation, how to support the rural poor in this region to allow them alternatives to continued and increasing deforestation, and how to do so with the environment’s, the economy’s, and the individual’s best interests in mind.

Determining the best method for attaining more accurate results will have significant implications on the tracking of LULC change in this area, which would be highly beneficial for future studies as well as influential in the determination of policies that would guide, prevent and/or protect various LULC classes. This may require significantly greater resources (to include financial and time investments), should methods such as ground-truthing be deemed necessary.
Future studies should be conducted to assess the land cover conversion from forest to agriculture using remote sensing images. Continuing to expand on previous studies of this particular area of interest (the Toledo District in southern Belize), such as the Emch, et al. study and the current study, and possibly adding more data, such as additional years or performing more ground-truthing, will help to illuminate the dynamics of the LULC change over time. By using the same classifications of land cover types as were used in the previous studies, some consistency in results can be developed. Studies showing different classifications for cover types lead to discrepancies in rates of LULC change between studies, as might be the case for the differences accounted for between the current study and the Emch, et al., study. This makes it difficult to establish general rates of change for different cover types. It also creates difficulties in connecting rates of LULC change and the causes of the changes.

It would be highly beneficial to be able to explore the differences in the impacts of deforestation between indigenous subsistence farming versus industrial commercial farming in the study area. Few studies of Belize actually look at the causes of forest cover change and are limited to basic evaluations of rates of change (Forestry Department of the Food and Agriculture Organization [FDFAO], 2000). The FDFAO (2000) states that indigenous farming is concentrated in southern Belize, while extensive banana and citrus cultivation is also present in the study area. Determining the extent of deforestation done by the different types of farms (industrial versus subsistence) can help the government determine appropriate policies to prevent unsustainable rates of deforestation by farm type.

Though culture itself is dynamic and changing, some aspects of culture are held on to for various reasons. Continuing to permit traditional methods of farming to be practiced,
while at the same time understanding and accepting their knowledge and care of the environment and desire to be sustainable, would do them justice. However, even better is providing them with freedom of choice and options to choose from, as is the democratic way. Expecting them to do milpa farming or permanent cropping is not providing them with options. It appears that there are two extremes. First, the government wants to create a more modern farming culture, which is more sedentary and profitable. Second, the traditionalists want all of the Mayas to have this vast area of land for them to continue practicing their long-established, semi-nomadic subsistence farming. Yet, as can be seen with the choices the Mayas have made, not every one of them fits into a particular category. At this point, citizen participation and compromise need to be introduced. If either side is going to gain anything over the long-run, they need to be willing to give a little, too.

Choosing between permanent and milpa farming is difficult. Indigenous cultural practices have intrinsic value, to both those within the culture and those who appreciate variety and choice in our world. Yet, sometimes traditional ways are not always the best. This is applicable to traditions that have withstanded centuries or only decades. Given the archaeological evidence, the very farming methods in question could be the culprit in the decline of a once powerful and extensive civilization. Unfortunately, the alternatives are not necessarily any better. Permanent farms require increased chemical inputs, which requires money and can, themselves, do environmental damage.

Perhaps the best way to attack this issue is to get the concerned parties involved in the decision- and policy-making processes while providing them with data and information that would educate them on their options, the pros and cons of each option, and provide them with an opportunity to make a rational and learned decision that sits best with each individual
or group. Perhaps, if the Mayas are as interested in the environment as they say they are, they would choose a different system. Perhaps if the government is interested in the environment, it will implement land reforms and distribution policies that would support different farming methods. And, perhaps, the lesser of two evils will be the ultimate outcome. Fortunately, technology is always providing opportunities for advancements and as the world’s population grows and at the same time becomes more aware of and educated in the issues it faces in the future – both near and soon, and distant and far off – research is conducted to attack these issues. One can only hope that we can all work together to do what is best, and implement what is best, for a sustainable, and perhaps even better world for us and for the future. One thing is certain: in the words of Albert Einstein, “We cannot solve our problems with the same thinking we used when we created them.” Change is guaranteed and thus the issues of LULC change in tropical regions that cause deforestation must be addressed before it is too late.
WORKS CITED


