# Abstract

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| Title of Dissertation: | IMPACTS OF CONFLICT ON LAND USE AND LAND COVER IN THE IMATONG MOUNTAIN REGION OF SOUTH SUDAN AND NORTHERN UGANDA |
| | Virginia B. Gorsevski, Doctor of Philosophy, 2012 |
| Dissertation directed by: | Professor Eric S. Kasischke<br>The University of Maryland, College Park<br>Department of Geographical Sciences |

The Imatong Mountain region of South Sudan makes up the northern most part of the Afromontane conservation 'biodiversity hotspot' due to the numerous species of plants and animals found here, some of which are endemic. At the same time, this area (including the nearby Dongotana Hills and the Agoro-Agu region of northern Uganda) has witnessed decades of armed conflict resulting from the Sudan Civil War and the presence of the Ugandan Lord's Resistance Army (LRA). The objective of my research was to investigate the impact of war on land use and land cover using a combination of satellite remote sensing data and semi-structured interviews with local informants. Specifically, I sought to 1) assess and compare changes in forest cover and location during both war and peace; 2) compare trends in fire activity with human population patterns; and 3) investigate the underlying causes influencing land use patterns related to war. I did this by using a Disturbance Index (DI), which isolates un-vegetated spectral signatures associated with deforestation, on Landsat TM and ETM+ data in order to compare changes in forest cover during conflict and post-conflict years, mapping the location and frequency of fires in subsets of the greater study area using MODIS active fire data, and by analyzing and summarizing information derived from interviews with key informants. I found that the rate of forest recovery was significantly higher than the

rate of disturbance both during and after wartime in and around the Imatong Central Forest Reserve (ICFR) and that change in net forest cover remained largely unchanged for the two time periods. In contrast, the nearby Dongotana Hills experienced relatively high rates of disturbance during both periods; however, post war period losses were largely offset by gains in forest cover, potentially indicating opposing patterns in human population movements and land use activities within these two areas. For the Agoro-Agu Forest Reserve (AFR) region northern Uganda, the rate of forest recovery was much higher during the second period, coinciding with the time people began leaving overcrowded Internally Displaced Persons (IDP) camps. I also found that fire activity largely corresponded to coarse-scale human population trends on the South Sudan and northern Uganda side of the border in that post-war fire activity decreased for all areas in South Sudan and northern Uganda except for areas near the larger towns and villages of South Sudan, where people have begun to resettle. Fires occurred most frequently in woodlands on the South Sudan side, while the greatest increase in post-war, northern Ugandan fires occurred in croplands and the forested area around the Agoro-Agu reserve, Interviews with key informants revealed that while some people fled the area during the war, many others remained in the forest to hide; however, their impact on the forests during and after the conflict has been minimal; in contrast, those interviewed believed that wildlife has been largely depleted due to the widespread access to firearms and lack of regulations and enforcement. This study demonstrates the utility of using a multi-disciplinary approach to examine aspects of forest dynamics and fire activity related to human activities and conflict and as such contributes to the nascent but growing body of research on armed conflict and the environment.

# IMPACTS OF CONFLICT ON LAND USE AND LAND COVER IN THE IMATONG MOUNTAIN REGION OF SOUTH SUDAN AND NORTHERN UGANDA

by

Virginia B. Gorsevski

Dissertation submitted to the Faculty of the Graduate School of the University of Maryland, College Park, in partial fulfillment of the requirements for the degree of Doctor of Philosophy

2012

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## Foreword

The research presented in this dissertation has been submitted to peer-reviewed journals, with myself as first author and others (including some members of my dissertation committee) as co-authors. The research presented in Chapter 2 has been published in ***Remote Sensing of Environment*** (Gorsevski et al. 2012c). The research in Chapter 3 has been submitted to International Journal of Remote Sensing (Gorsevski et al. 2012b). The research presented in Chapter 4 has been submitted to Journal of Human Ecology (Gorsevski et al. 2012a).

## Dedication

I dedicate this work to my children, Milo, Brice and Theo Parrott, and to all the people of The Republic of South Sudan – may they experience lasting peace and prosperity.

# Acknowledgements

This research would not have been possible without the help and support of many people. First and foremost, I would like to thank Dr. Simon Trigg who was an early advocate of my research and helped me shape my ideas on the subject. I am equally indebted to my advisor – Dr. Eric Kasischke – for his steadfast support of my doctoral work in general, and more specifically for the countless hours he spent reviewing my results and draft papers. I would also like to thank Jan Dempewolf, who provided me with the technical guidance I needed to undertake many aspects of my research. I would also like to thank the other members of my advisory committee for their support and instructive comments along the way – Dr. Martha Geores, Dr. David Inouye, and Dr. Steve Prince. Many other people at the University of Maryland were invaluable in dispensing their advice and direction including Elizabeth Hoy, Tatiana Loboda, and Louis Giglio. I also want to thank the staff of the Wildlife Conservation Society (WCS) Southern Sudan Programme – especially Paul and Sarah Elkan and Falk Grossmann for their logistics support and friendship during my trips to Juba and the Imatong Mountains. Gary Alex and Brian d'Silva of the United States Agency for International Development (USAID) provided me with invaluable sources of information and contacts in South Sudan, beginning with my volunteer work in 2006 until my last trip in 2011 and without their help my research never would have taken place and I thank them wholeheartedly for their support. There are many other people in South Sudan that have helped me along the way and though I cannot mention them all, I want to thank them, particularly Leek Thon and Musa Buyinza from the Catholic Relief Services (CRS) for their help and friendship during my latest stay in South Sudan. And finally I want to thank my family. First my parents, Boris and Violet Gorsevski, and my brother, Alex Gorsevski, for encouraging me to pursue my education and for their invaluable help caring for our children – especially during my field work to South Sudan. And lastly, a thousand thanks to my husband Ned for his unwavering love and support and to my children for their patience and inspiration.

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## 1.1 Introduction

During the period 1946 to 2001, there were 225 armed conflicts globally (Gleditsch et al. 2002) accounting for approximately 20 million human casualties (Fearon & Laitin 2003). In 2010 alone, there were 30 active armed conflicts in 25 locations around the world (Themner & Wallensteen 2011)[1] . While the number of conflicts increased significantly during the second half of the 20$^{th}$ century, their primary causes remain largely unchanged; that is, differential access to critical resources and disagreements about ideology and/or the nature of collective identity (Pedersen 2002). On the other hand, the prevailing type of war in modern times tends to occur *within*, rather than *between* states (Fearon & Laitin 2003; Pedersen 2002).

Africa in particular has been deeply and disproportionately affected by conflict in recent years. During the last forty years of the 20$^{th}$ century, about 40 % of Sub-Saharan Africa experienced at least one period of civil war – mainly resulting from high levels of poverty, heavy dependence on resource-based primary exports and failed political institutions (Elbadawi & Sambanis 2000). The consequences for Africans have been devastating, partly as a result of the associated high levels of refugees and displaced persons, which continues the cycle of poverty and has disastrous implications for human health (Kalipeni & Oppong 1998; Sidel & Levy 2008).

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[1] According to the Department of Peace and Conflict Research at the University of Uppsala, armed conflict is defined as "a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25-battle related deaths (Strand et al. 2004)."

Armed conflict also frequently wreaks havoc on the environment. In Africa, where there is a high degree of dependency on natural resources (Shambaugh et al. 2001), this can be particularly harmful for civilians. In recent years, scholars have begun paying closer attention to the negative impacts of conflict on the environment. A recent study by Reuveny et al. (2010) examined the impact of war on several environmental indicators such as $CO_2$ and NOx emissions, deforestation and a composite environmental stress indicator with mixed results, including the finding that warfare increases deforestation in a country when fought at home, and promotes forest growth when fought abroad, particularly among Least Developed Countries (LDCs) (Reuveny et al. 2010). Hanson et al. (2009) similarly looked at the occurrence of war and its relationship to areas of high biodiversity globally and found that over 90% of the major armed conflicts between 1950 and 2000 occurred within countries containing biodiversity hotspots and more than 80% actually occurred within a hotspot (Hanson et al. 2009).

In general, however, research on war and the environment is presented on a case-study basis, focusing on several reoccurring themes such as habitat destruction, pollution, loss of wildlife, reduction in biodiversity and general over-exploitation and degradation of natural resources (Baral & Heinen 2005; Davalos et al. 2011; Draulans & Van Krunkelsven 2002; Dudley et al. 2002; Dudley & Woodford 2002; Eniang et al. 2007; Glew & Hudson 2007; Joksimovich 2000; Kalpers 2001; Kanyamibwa 1998; Loucks et al. 2009; McNeely 2003; Messina & Delamater 2006; Pearce 1995; Westing 1971). As these and other studies reveal, the negative impacts of war can be directly related to military activity such as defoliation from the use of herbicides, wildlife mortality from landmines and hunting, or air and water pollution from the bombing of industrial facilities. Damage can also occur when laws and regulations designed to protect the environment break down and natural resources are extracted and over utilized to support military efforts, such as widespread logging to fund the acquisition of weapons for soldiers. The negative effects of war can often occur both *prior* to the actual conflict due to pre-war build-up of weaponry and military exercises and *after* the war due to the long-lasting effects of a dramatically altered environment (Machlis & Hanson 2008). Indirect effects of war on the landscape can occur when large-scale displacements of people put added stress on the environment – often in the form of crowded refugee camps (Allan 1987; Biswas & Tortajada-Quiroz 1996; Ghimire 1994; Hugo 1996; Sato et al. 2000).

In some cases, however, researchers have noted that conflict can have a positive effect on some aspects of the environment. For example, Martin and Szuter found that there was an abundance of large animals such as bison in the early 1800s "Upper Missouri war zone" due to inter-tribal warfare that prevented people from entering the area (Martin & Szuter 1999). The modern-day equivalent often cited is the Korean demilitarized zone (DMZ)[2], where wildlife has seen a major resurgence since the end of the Korean War (Brady 2008; Kim 1997).

Understandably, it is often difficult to conduct field research in conflict environments (Cohen & Arieli 2011). One method for collecting information about the physical landscape in an otherwise inaccessible war-torn environment is through remote means such as the use of satellite imagery. This is occurring more frequently in recent years due to advancements in technology that allow for the collection and display of data at

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[2] A complete list of acronyms and their definitions can be found on pages 134 - 137.

relatively low cost. High profile examples include the Satellite Sentinel Project spearheaded by actor George Clooney that uses high resolution satellite imagery to showcase the burning of villages and troop movements, among other things, in Sudan (www.satsentinel.org). As with other studies focusing on war and the environment, the use of remote sensing for this purpose has generally been documented on a case-by-case study. For example, multi-date Landsat data were used to quantify environmental damage from the burning of oil wells in Kuwait (El-Gamily 2007). Other studies using spaceborne imagery to examine the effects of war and its effects have used satellite remote sensing data to measure and characterize land cover change over an extended time period (de Beurs & Henebry 2008; Kuemmerle et al. 2007; Suthakar & Bui 2008; Witmer 2008).

The Eastern Afromontane ecoregion has provided the backdrop to several conflicts, including the decades-long Sudan Civil War (1955 to 1972 and 1983 to 2005) and the terrorist activities of the Ugandan Lord's Resistance Army (LRA). This ecoregion, which spans portions of Tanzania, Uganda, Kenya and South Sudan, is considered a biodiversity hotspot by the nongovernmental organization (NGO) Conservation International (CI) because it contains nearly 7,600 species of plants, of which more than 2,350 are endemic. In addition, about 1,300 bird species occur in this hotspot, 110 of which are found nowhere else, as well as 500 mammal species, with more than 100 endemic to the region (see http://www.biodiversityhotspots.org/xp/hotspots/afromontane/Pages/default.aspx). Figure 1-1 shows armed conflicts occurring in or near the Eastern Afromontane Biodiversity Hotspot.

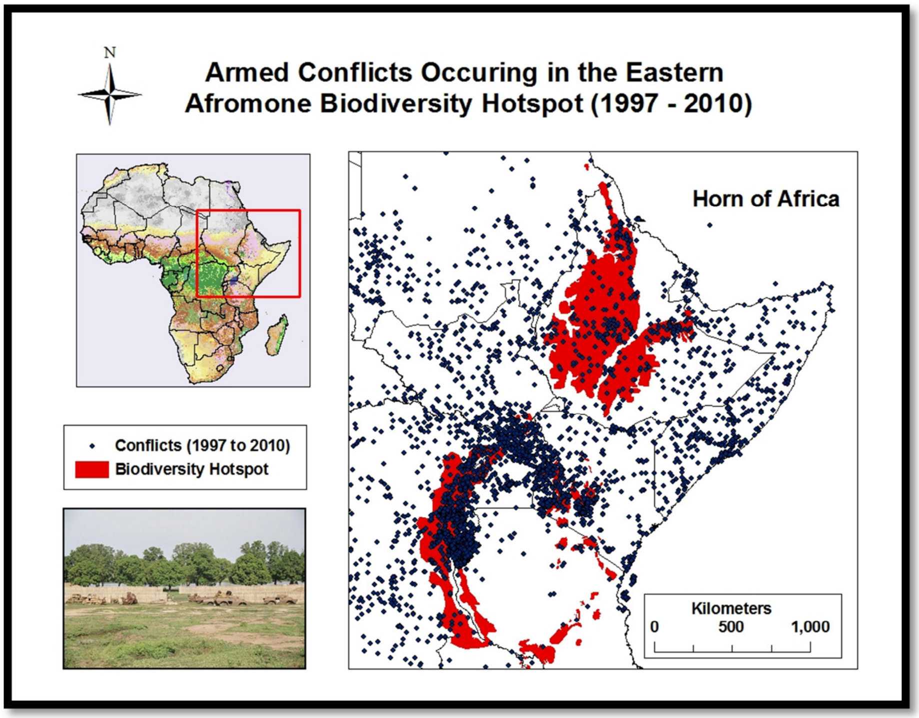


**Figure 1-1: Conflict data were obtained from the Armed Conflict Location and Event Data (ACLED) (http://www.acleddata.com/indix.php/data). The ACLED dataset collects reported information on internal political conflict disaggregated by date, location and actor. For more information on how data are collected and coded see (Raleigh et al. 2010). Biodiversity Hotspot spatial data were obtained from the Conservation International Foundation (Mittermeier et al. 2004). See (http://www.biodiversityhotspots.org/xp/Hotspots/resources/pages/maps.aspx). The background image used to make the Africa map is a 2000 land cover map for Africa developed by (Mayaux et al. 2004) using the SPOT Vegetation instrument as part of the EC Joint Research Centre Global Environment Monitoring Unit (http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php. The photo of tanks was taken by V. Gorsevski in 2006 in Juba, Southern Sudan.**

Across Africa, fire is an important factor in shaping ecosystem processes (Guyette et al. 2002) and this is also true of the Imatong Mountain region where fires are mainly ignited by people to clear land for farming, hunt wildlife, promote green flush for grazing, collect honey, provide security around settlements and huts and to clear trails through the forest and bush (Friis & Vollesen 2005). A significant amount of research on fire has been conducted for parts of Africa – often called the “fire continent” (Sheuyange et al. 2005), and some work has been done to determine the relative importance of various factors – both natural and human-caused – behind fire occurrence and spread (Archibald et al. 2009). With the widespread availability of time-series data from satellite sensors, much of the research on fire in Africa (and elsewhere) uses products derived from remote sensing technologies specifically designed to record fire activity and fire properties across time and space. However, very few studies have used fire data products to gain insight into the causes and consequences of armed conflict (Bromley 2010).The research conducted as part of this dissertation seeks to examine the impact of conflict on land cover and land use using satellite remote sensing data combined with qualitative data obtained through interviews with local participants. The Imatong mountain region of South Sudan and northern Uganda was specifically chosen as my area of study because of its high biodiversity and unique geographical position spanning two different, but war-affected regions in East Africa, where a recent cessation of hostilities has made it possible to examine the effects of war and peace on the landscape.

## 1.2 Research Objectives

Focusing on the Imatong Mountains and surrounding area, the primary goal of my research was to understand better how human activity influences land use and land cover, both during and immediately following prolonged armed conflict. In support of this primary goal, the specific objectives of the research presented in this dissertation were as follows:

1. To compare spatial and temporal trends in forest cover related to war and post-war periods in a biologically diverse region spanning two separate countries experiencing different types of conflict and resulting human land use patterns.

2. To characterize the spatial and temporal attributes of anthropogenic fire in these same two cross-border regions and compare results with broad-scale population trends across different land cover types.

3. To explore the underlying causes of different human land use patterns during and after war and to relate this information to observed changes in forest cover through integration of satellite remote sensing and qualitative research approaches.

## 1.3 Dissertation Organization

This dissertation is organized in three major sections – each corresponding to the specific objectives listed in Section 1.2. Chapters 2 through 4 have been written such that they can stand alone for publication in different journals corresponding to their topic area and for this reason some information contained in the Introduction and Study Area sections may be repetitive. Chapter 2 investigates changes in forest cover for two distinct periods representing conflict and post-conflict for three separate but proximate areas. This chapter was published by *Remote Sensing of Environment* (RSE) in March 2012 (Gorsevski et al. 2012c). Chapter 3 explores the relationship between fire activity and human population trends across the study area during the war and post war periods. This section is currently under review by the *International Journal of Remote Sensing* (Gorsevski et al. 2012b). Chapter 4 focuses only on the South Sudan portion of the study area, and uses qualitative research methods to understand better the human dimensions behind observed changes in forest cover. This section has been submitted to the *Journal of Human Ecology* and is also currently under review (Gorsevski et al. 2012a). Chapter 5 includes a brief summary of the dissertation research and results, future proposed research, and policy implications and next steps.

# 2 Analysis of the Impacts of Armed Conflict on the Eastern Afromontane Forest Region on the Sudan – Uganda Border Using Multitemporal Landsat Imagery[3]

## 2.1 Summary

*The impacts of armed conflict on ecosystems are complex and difficult to assess due to restricted access to affected areas during wartime, making satellite remote sensing a useful tool for studying direct and indirect effects of conflict on the landscape. The Imatong Central Forest Reserve (ICFR) in South Sudan together with the nearby Dongotana Hills and the Agoro-Agu Forest Reserve (AFR) in northern Uganda, share a boundary and encompass a biologically diverse montane ecosystem. This study used information derived from satellite data combined with broad-scale human population trends to examine the impact of armed conflict and its outcome on similar forest ecosystems both during and after hostilities have occurred. A Disturbance Index (DI) was developed to generate images that were used to investigate the location and extent of forest cover loss and gain in three areas for two key time periods from mid-1980s to 2001 and 2003 to 2010. Results indicate that the rate of forest recovery was significantly higher than the rate of disturbance both during and after wartime in and around the ICFR and the net rate of forest cover change remained largely unchanged for the two time periods. In contrast, the nearby Dongotana Hills experienced relatively high rates of disturbance during both periods; however, post war period losses were largely offset by some gains in forest cover. For the AFR in Uganda, the rate of forest recovery was much higher during the second period, coinciding with the time people began leaving overcrowded camps. The diversity and merging of floristic regions in a very narrow band around the Imatong Mountains makes this area biologically distinct and of outstanding conservation importance; therefore, any future loss in forest cover is important to monitor – particularly in South Sudan where large numbers of people continue to return following the 2005 peace agreement and the 2011 Referendum on Independence.*

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[3] Published in *Remote Sensing of Environment (Gorsevski et al. 2012).*

## 2.2 Introduction

The direct effects of war on civilians are generally well-understood and have been extensively documented (Clodfelter 2002; Ismael 2007; Keegan 1994; Sidel & Levy 2008; Tardanico 2008). The indirect effects of war due to the use of munitions on a nation's land, air and water can also have adverse, long-term and far-reaching effects on human populations and the surrounding environment (Joksimovich 2000). Often overlooked is the effect of war on land cover, which in turn impacts biodiversity (Dudley & Woodford 2002), despite the fact that ninety percent of the major armed conflicts between 1950 to 2000 occurred within countries containing biodiversity hotspots and more than eighty percent took place directly within the hotspots (Hanson et al. 2009). Several studies have concluded that armed conflict is generally deleterious to plants and animals due to habitat destruction and fragmentation, direct loss of animals from poaching or land mines, over-exploitation and degradation of natural resources, and increases in land and water pollution (Baral & Heinen 2005; Eniang et al. 2007; Gleditsch 1998; Jacobs & Schloeder 2001; Kalpers 2001; Kanyamibwa 1998; Messina & Delamater 2006; Pearce 1995; Shambaugh et al. 2001; Van Houven & Nimir 2004; Vanasselt 2003). In some cases, however, wars have been found to have a positive impact on biodiversity, through the formation of "no go zones" due to reduced security, resulting in a decrease in human pressure on the environment and wildlife (Kaimowitz & Faune 2003; Martin & Szuter 1999; McNeely 2003; Nietschmann 1990; Vogel 2000).

Difficulty of access to an area during war combined with no clear spatial or temporal definition for the extent of conflict makes an accurate and timely assessment of the impacts extremely challenging (Glew & Hudson 2007). Because of these limitations, information derived from satellite remote sensing data can provide insight into how conflict *directly* affects the physical landscape during wartime, and *indirectly* leads to changes in human populations and land use activity that drive the observed land cover modifications. For example, data from satellite remote sensing have been used to identify the effects and quantify environmental damages in Kuwait from military activity that occurred during the 1990-1991 Gulf War (El-Gamily 2007; Koch & El-Baz 1998). Satellite imagery was also used to show how the spraying of defoliants on coca crops in Columbia negatively affected native plant and food crop parcels (Messina & Delamater 2006) and to monitor the burning of fields, forests and villages by the Turkish army in Kurdistan (De Vos et al. 2008).

Because the impacts of war on the environment are often felt both prior to and following conflict (Machlis & Hanson 2008), time-series of satellite imagery can be used to monitor the landscape over a longer period to record changes resulting from the effects of war (Pearce 1995), including the abandonment of agricultural lands (Suthakar & Bui 2008; Witmer 2008). One of the more visible effects of war is the imprint left on the landscape due to mass migration and subsequent settlement of people in internally displaced person (IDP) or refugee camps. Much has been written and debated about the impact of IDPs and refugees on the environment, but it is generally agreed that emigration tends to reduce pressure at the origin and increase pressure at the destination (Hugo 1996), leading to deforestation and general land degradation at the latter (Allan 1987; Biswas & Tortajada-Quiroz 1996; Ghimire 1994; Hugo 1996; Sato et al. 2000). This has significant implications for the environment since the number of forcibly displaced people has risen in recent years, despite a reduction in the actual number of civil conflicts (Cohen & Deng 2008). Peace can be equally damaging to the environment if mass migration is reversed back to the point of origin, accompanied by resource exploitation necessary to rebuild communities and revive the local economy (Robinson & Sutherland 2002).

The objective of this study was to use information derived from remotely sensed satellite imagery to compare and contrast changes in forest cover in a cross-border conservation hotspot located on the border of South Sudan and Northern Uganda. It is expected that forest cover will remain constant or increase during the war periods on the South Sudan side of the study area as people leave the region and abandon farming and other activities that affect land cover, and that forest cover will decline with migration of people back to the area. In contrast, forest cover is expected to decrease during the war years in the northern Uganda study area as a result of the heavy concentration of IDP camps located in the study area and then rebound in recent years due to abandonment of the camps.

## 2.3 Sudan and Uganda Conflicts

In January 2005, the historic Comprehensive Peace Agreement (CPA) put an end to nearly fifty years of civil war in Sudan (excluding a period of peace from 1972 to 1983) that resulted in an estimated two million dead and over four million IDPs (Haynes 2007). The war largely pitted the Arab-dominated North against the Christian/animist South in a multifarious conflict that had wide-reaching impacts on neighboring countries, due in large part to the outpouring of some 600,000 Sudanese refugees, mainly into Uganda, Kenya, Ethiopia and the Democratic Republic of Congo (Burr & Collins 1995; UNHCR 2007a; USAID 2006). Nearly all Southern Sudanese who stayed in the country migrated north to IDP camps in and around Khartoum and the 'transition zone' border area between Northern and Southern Sudan (Duffield 2002). One of the few exceptions was the Labone IDP camp located in Southern Sudan's Eastern Equatoria State, where in 1992 thousands of people from the Bor Dinka tribe were relocated due to inter-ethnic fighting (Dowden, R. (1994, February 10). Attack Forces Sudan Refugees to Flee Camp. *The Independent*. Retrieved from http://www.independent.co.uk/) and who have since returned north to Jonglei State following the 2005 Peace Agreement.

Since 2005, an estimated two million refugees and IDPs have returned to Southern and now South Sudan (Hovil 2010). According to the official 2008 census for Southern Sudan, the total population was 8.26 million, compared with an estimated 6 million in 2005 (OCHA February 2006) and 5.3 million in 1983 (House 1989). And while no official population estimates are available since 2008, widespread returns in advance of the January 2011 Referendum on Independence – including more than 180,000 returnees over a period of just three months – have caused the population to surge to an estimated 9.5 million according to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) (IRIN February, 2011)

In neighboring Uganda, around ninety percent of the population in the north had similarly been uprooted as a result of conflict – in this case between the LRA and government forces (Miller 2006). The seeds of the war were planted in 1986 after Ugandan President Yoweri Museveni took power through an armed uprising, that resulted in the fleeing of soldiers loyal to the old regime, many of whom were of the Acholi and Lango tribes whose villages and towns were located on the northern border with Sudan (Ochan 2009). Opposition to the new regime gave rise to various resistance movements, most notably the LRA, led by the notorious Joseph Kony, whose terrorist tactics have resulted in decades of brutality against civilians in Uganda, Sudan and the Democratic Republic of Congo (Eichstaedt 2009). As with Sudan, the civil war in Uganda led to mass upheaval of the local population. While some people fled to neighboring countries, the majority of civilians were forced to relocate into overcrowded IDP camps in the north of Uganda as part of a 'protected villages' policy that began in 1996 in an effort to isolate LRA combatants (IDMC 2010). This policy was reversed in 2006 due to improvements in the security situation, such that only 73,239 IDPs (of the original 1.8 million) remain in northern Uganda as of March 2011(IDMC 2011) . According to the IDMC (Internal Displacement Monitoring Centre), this figure is down from 166,000 IDPs in November 2010, 295,000 IDPs in June 2010, 437,000 IDPs in December 2009, 710,000 IDPs in February 2009, 869,000 IDPs in November 2008 and 915,000 IDPs in October 2008. (IDMC fact sheet – http://www.internal-displacement.org/idmc/website/countries.nsf/(httpEnvelopes)/2439C2AC21E16365C125719C004177C7?OpenDocument. *Accessed February 1, 2012*).

## 2.4 Methods

### 2.4.1 Study area

The Imatong Mountains are located on the Sudan – Uganda border between 3°40’ and 4°20’ North latitude and 32°30’ and 33°10’ East longitude (Figure 2-1).

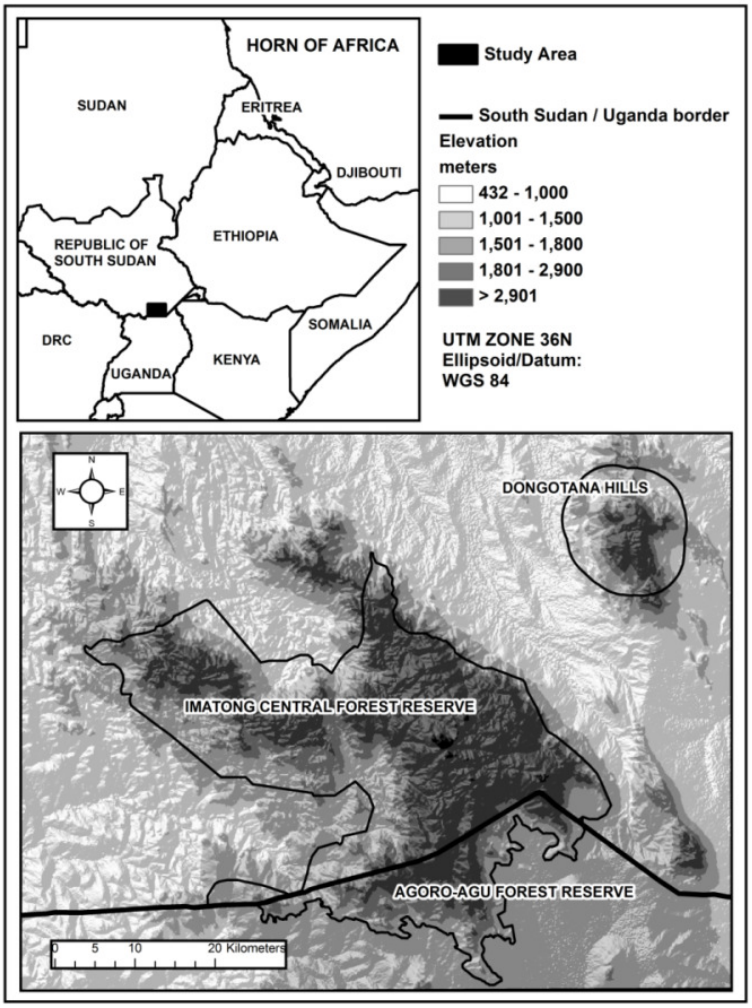


**Figure 2-1: Study area located in South Sudan and northern Uganda. Elevation data obtained from the Centre for Tropical Agriculture (CIAT), available from the International Centre for Tropical Agriculture (CGIAR) at http://srtm.csi.cgiar.org using data derived from USGS/NASA SRTM (Shuttle Radar Topography Mission). This map was created using version 4.1 data – see (Jarvis et al. 2008). ICFR and AFR outlines provided by the Wildlife Conservation Society Southern Sudan Programme. The outline of the Dongotana Hills was created by first digitizing the forest outlines from a pre-existing Africover data product (Di Gregorio & Jansen 2005) and adding a 5-km buffer.**

The mountains form a northern continuation of the upthrusts as part of the great East African mountain systems (Chipp 1929). The entire study area covers 8,375 km$^2$. The boundaries of the study region were selected to include the Imatong Central Forest Reserve (ICFR) and the Agoro-Agu Forest Reserve (AFR), as well as another region with significant forest cover, the Dongotana Hills located to the northeast of the Reserve (Figures 2-1 and 2-2).

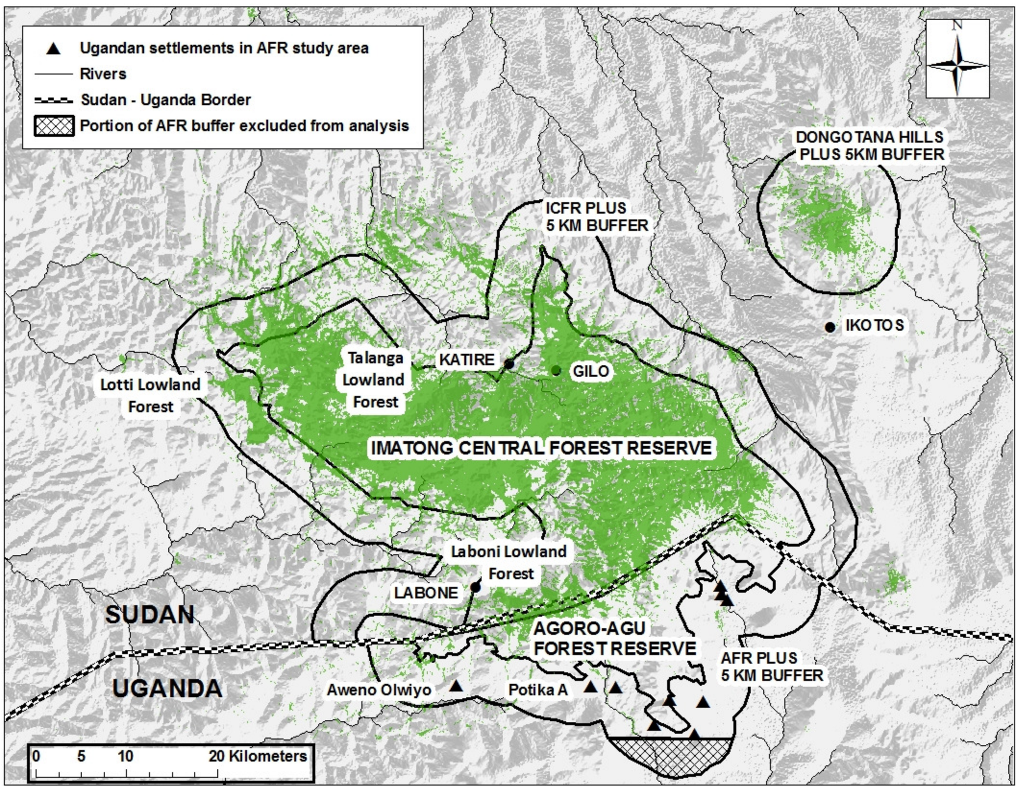


**Figure 2-2: Select areas of analysis in South Sudan and northern Uganda. Background images based on 1) hillshade created from hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org., and 2) Landsat MSS p157r84 (1973) with forest cover (shown in green) isolated using ISODATA unsupervised classification algorithm.**

The ICFR spans 1,032 km$^2$ (Sommerlatte & Sommerlatte 1990) and the Agoro-Agu Forest Reserve is 236 km$^2$ (Davenport & Howard 1996). The forested area of the

Dongotana Hills is approximately 21 $km^2$. The ICFR was named a forest reserve in 1952 (Sommerlatte & Sommerlatte 1990); however, actual management and law enforcement has been lacking as a consequence of the civil war. Altitudes in the study region vary from 568 m to 3172 m above sea level (A.S.L.). The mountains consist of granitic crystalline rocks, most of which are folded and foliated and soils largely fall within the following four categories: (1) dark cracking clays, (2) non-cracking clays, (3) red loam and ironstone soils, and (4) hill or mountains soils (Friis & Vollesen 2005).

Precipitation over the Imatong Mountains follows a gradient with a general decline from west to east, where a rain shadow has the effect of creating much drier environments along the escarpment and ridges. Precipitation increases with altitude, resulting in a transition of the montane forest zone to the alpine zone. Rainfall across the study region is seasonal with the rainy season beginning in late March and lasting until the end of October (Sommerlatte & Sommerlatte 1990) (Figure 2-3). This area of Sudan (and now South Sudan) receives the highest amount of rainfall in the country – precipitation steadily decreases towards the North-East with increasing distance from the Atlantic Ocean (Van Noordwijk 1984). The climate is temperate and fairly constant throughout the season with warm day time temperatures up to 35° C and cooling to 15° C at night (at Katire, 800 m A.S.L.) (Figure 2-4).

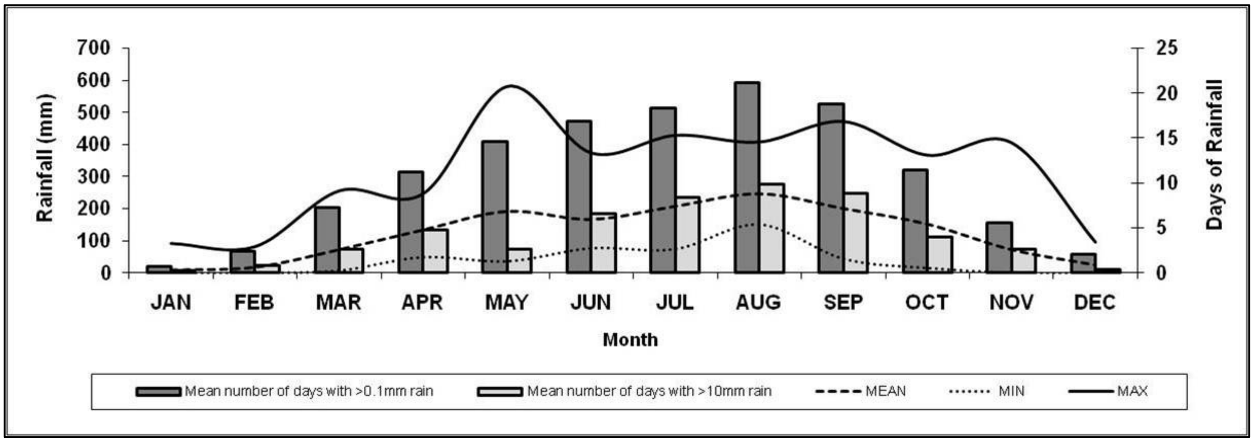


**Figure 2-3: Average rainfall for Katire, South Sudan located at approximately 4°2'North latitude and 32°47'East longitude at the base of the mountains at an altitude of approximately 1000 meters (Mt. Kinyeti – the highest point – is at 3187 m elevation) (see Figure 2-2). Rainfall data from Jackson, 1956, which were extracted from data supplied by the Sudan Meteorological Service.**

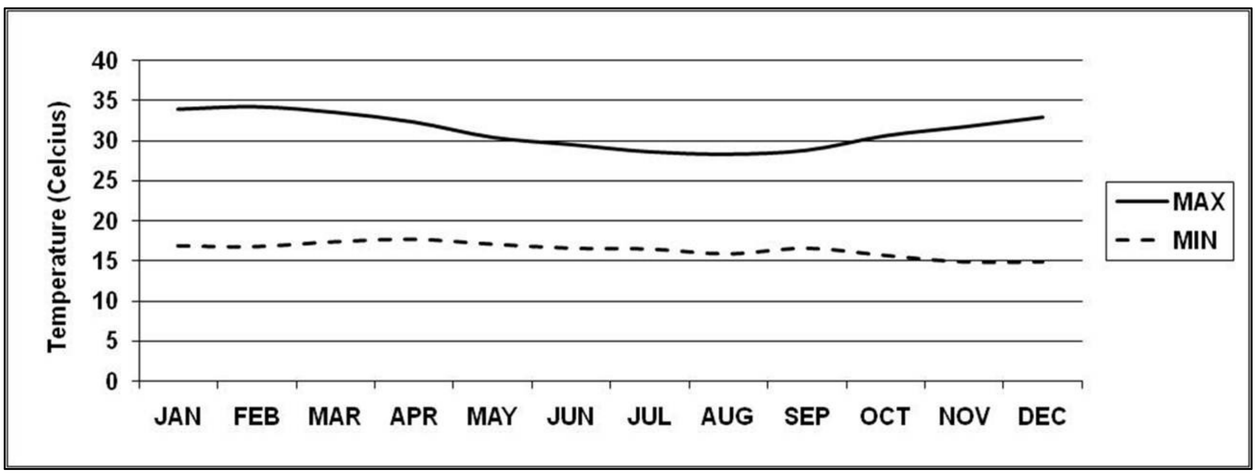


**Figure 2-4: Average temperature for Katire, South Sudan, the only station in the Imatongs from which temperature was recorded. (Jackson 1956).**

Major vegetation types range from *Albizia-Terminalia* woodland and savanna in the lowland zone to *Erica* thicket in the Ericaceous zone. The associated floristic affinities and location are summarized in Table 2-1.

**Table 2-1: Floristic affinities of various vegetation types found in the ICFR. Adapted from Sommerlatte and Sommerlatte, 1990.**

| Floristic Affinities | Altitude Zone | Elevation (m) | Vegetation Type |
|---|---|---|---|
| Sudanian | Lowland zone | 1,000 – 1,5000 | *Albizia-Terminalia* woodland and savanna woodland (on the wet western side) |
| Somalia-Masai | Lowland zone | | *Acacia-Combretum* wooded grassland and savanna woodland (on the dry eastern side) |
| Guineo-Congolian | Lowland to intermediate zone | 1,000 – 1,800 | *Khaya-Cola* forest<br>*Khaya-Syzgium* forest |
| | | 1,200 – 1,500 | *Entandrophragma-Manilkara* forest |
| Afromontane | Lower montane zone | 1,200 – 2,400 | *Loudetia* grassland<br>*Acacia abyssinica* woodland<br>*Croton-Macaranga-Albizia* forest<br>*Oxytenanthera* bamboo thicket<br>*Podocarpus-Olea-Syzygium* forest |
| | Upper montane zone | 2,400 – 2,900 | *Hagenia-Maesa* woodland<br>*Hagenia-Hypericum* woodland<br>*Podocarpus-Olea* forest<br>*Podocarpus-Dombeya* forest<br>*Exotheca* grassland<br>*Carex* sedge swamp |
| Afroalpine | Alpine or Ericaceous zone | >2,900 | Erica thicket |

There are three major areas of lowland rain forest at Lotti, Talanga and Labone and these are not or only partially included in the ICFR (Jackson 1953) (Figure 2-2). Aerial observations in 2009 indicate that of these forests, only the Lotti remains largely intact.

Precise population data for the ICFR and surrounding area are not available; however, discussions with local residents in early 2009 indicated that improvements in the security situation since 2005/2006 have led to a significant rise in the number of people returning to resettle in the area. In Eastern Equatoria, the State where the Imatong study area is located, total population increased from between 537,822 to 632,760[4] in 1998 to 906,126 in 2008 alone (SSCCSE 2010).

The adjacent Agoro-Agu Forest Reserve is located within Lamwo county in the extreme north of Kitgum district of Uganda between 3°40 - 3°53' N and 32°42' - 33°04 E. It has an altitudinal range of 1100 m to 2700 m A.S.L. (Davenport & Howard 1996) (Figure 2-1). A 1996 study commissioned by the Ugandan Forest Department – limited in its scope due to the security situation – recorded moderate to high levels of biodiversity and noted that the Reserve was extensively encroached throughout the lower and medium altitude areas, particularly in the southern and eastern sections (Davenport & Howard 1996). Results from this study (described below) confirm that the majority of observed forest loss during this time occurred at lower altitude areas, when the forest was being used by locals for harvesting trees for building poles, honey collection, bushmeat and medicinal plants. Though not specifically documented, it is likely that similar to the IDP camps in Pader district, the presence of these camps in and around the AFR had a negative impact on the surrounding land and forests (Owona 2008). Since 2006, the

[4] The lower estimate is provided by the Sudan Relief and Rehabilitation Association (SRRA) – the humanitarian agency of the Sudan People's Liberation Movement (SPLM). The higher estimate is derived from the World Health Organization (WHO) Sudan National Immunization Days (SNID) campaign to eradicate Polio.

number of people living in the IDP camps in northern Uganda has dwindled, as discussed in Section 2.3 of this paper.

Although the forests of the Dongotana Hills are similar in structure and composition to those of the ICFR and the AFR, the area has never formally been declared as a conservation reserve. The closest large town, Ikotos, is located due south of the Dongotana Hills (Figure 2-2), with an estimated population of 20,242 in 2007 including small villages surrounding the town (UNHCR 2007b).

### 2.4.2 Technical Approach

This study used data layers created from analysis of multi-scale remote sensing data in a geographic information system (GIS) to detect changes in forest cover occurring in the study area. Within the study area, three separate areas – all with similar vegetation – were compared in terms of change in forest cover over time. These areas include 1) the ICFR and a 5 km buffer on the South Sudan side only; 2) the AFR and a 5 km buffer on the Ugandan side only (with the exception of a small area not covered by the Landsat scenes representing approximately six percent of the entire area); and 3) the Dongotana Hills and a 5 km buffer (Figure 2-2). The outlines of the forest reserves were supplied by the Wildlife Conservation Society (WCS) and are currently used by the various non-governmental organizations (NGOs) working in the area and the Government of Southern Sudan (GoSS) and have been documented by prior studies of the area (Sommerlatte & Sommerlatte 1990); the extent of the Dongotana Hills was created by digitizing the forest outlines of a pre-existing Africover data product (Di Gregorio & Jansen 2005). A buffer area around each of the reserves was created for the ICFR and the AFR since previous research has shown that areas adjacent to established protected areas (PAs) are often subject to extensive forest loss due to human pressures (DeFries et al. 2005; Hansen & DeFries 2007). A distance of 5 km was specifically selected to be consistent with other similar studies related to African PAs (Bergl et al. 2007) and best practice guidelines (Morgan & Sanz 2007). And for Southern Sudan specifically, a USAID-commissioned report determined that IDP camp residents generally travelled from between 2 and 6 km in search of firewood, which is relevant to this study since we are examining the impact of people on the forest (USAID 2003).

Spatially explicit data were derived over the study area using moderate (30 m) spatial resolution satellite data (described in Section 2.4.3 below) acquired for two primary study periods roughly representing years of 'war' and 'peace'. The first period is from mid-1980s to 2001 during which time both Sudan and Uganda were heavily embroiled in their respective conflicts. The second period covers 2003 to 2010, when peace and stability slowly began to return to both countries – peace was formally declared in Sudan in 2005 with the signing of the Peace Agreement, and shortly thereafter the LRA moved its base further west creating a respite from attacks in the study area and allowing civilians in northern Uganda to leave the IDP camps.

### 2.4.3 Data

We acquired four pairs of Landsat TM and ETM+ images (Worldwide Reference System (WRS)) path / rows: 171/57 and 172/57), representing both the 'war' and 'post-war' periods described above. For Landsat p171r57, the acquisition dates were 01-13-1987, 01-27-2001, 01-17-2003, and 12-14-2010. For Landsat p172r57, the acquisition dates were 01-17-1986, 01-02-2001, 02-09-2003, and 12-21-2010 (Table 2). Eight scenes were necessary because the study area is situated at the edges of path/row 172/57 and 171/57. All of the Landsat scenes were acquired during the dry season and on near-anniversary dates, to reduce scene-to-scene variation and to minimize the introduction of spurious changes due to changes in topographic shadowing, sun angle and vegetation phenology (Hayes & Sader 2001; Singh 1989). To assess whether changes in seasonal plant phenology influenced the spectral signatures from the Landsat TM and ETM+ imagery used for this study, we analyzed data from the 16-day normalized difference vegetation index (NDVI) product (MOD13Q1) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the Terra (EOS AM) satellite for years 2000 to 2010. Other studies have shown that despite differences in spectral and spatial resolution, comparisons of NDVI values across satellite sensors - including MODIS and Landsat – show general agreement (Brown et al. 2006). Results confirmed that the NDVI values for the days when Landsat images were acquired were congruent with the long-term average NDVI for that month implying that the Landsat scenes were representative of the mean phenological condition occurring in this area during the middle of these dry season months.

Administrative boundaries, settlements including villages and IDP camps, and the reserve boundaries were obtained from a variety of organizations with in-depth knowledge of the area. High resolution imagery for 2010 over a significant portion of the study area was not available. Therefore, validation of the results was performed using the existing 2003 and 2010 Landsat imagery over the entire region combined with aerial photos for two select regions during the second time period (Table 2-2).

**Table 2-2: Datasets used for the analysis of land cover change in South Sudan and northern Uganda study regions including acquisition dates and other attributes.**

| Dataset | WRS: (P/R) | Spatial Res. | Acquisition Date | Producer | Attributes | Parameter of Interest | Data Source |
|---|---|---|---|---|---|---|---|
| Landsat 5 TM | 171/057 | 30 m | 1987-01-13 | USGS/ GLCF | Orthorectified, GLS 1990 | Forest cover | GLCF |
| Landsat 7 ETM+ | 171/057 | 30 m | 2001-01-27 | USGS/ GLCF | Orthorectified, GLS 2000 | Forest cover | GLCF |
| Landsat 5 TM | 172/057 | 30 m | 1986-01-17 | USGS/ GLCF | Orthorectified, GLS 1990 | Forest cover | GLCF |
| Landsat 7 ETM+ | 172/057 | 30 m | 2001-01-02 | USGS/ LP DAAC | L1T LPGS | Forest cover | GLOVIS |
| Landsat 7 ETM+ | 171/057 | 30 m | 2003-01-17 | USGS/ LP DAAC | L1T LPGS | Forest cover | GLOVIS |
| Landsat 5 TM | 171/057 | 30 m | 2010-12-14 | USGS/ LP DAAC | L1T LPGS | Forest cover | GLOVIS |
| Landsat 7 ETM+ | 172/057 | 30 m | 2003-02-09 | USGS/ LP DAAC | L1T LPGS | Forest cover | GLOVIS |
| Landsat 5 TM | 172/057 | 30 m | 2010-12-21 | USGS/ LP DAAC | L1T LPGS | Forest cover | GLOVIS |
| MODIS (MOD13Q1) | H21v08 | 250 m | 2000 – 2010 dry season months | USGS/LP DAAC | 16 day NIR reflectance | NDVI | WIST |
| Aerial photographs | Within 171/057 and 172/057 | varies | 2009- 01- 30 and 2009-01-31 | WCS | 500 – 700 feet above ground | Land cover and land use | WCS |
| Southern Sudan Settlements | N/A | 1: 1000000 | Updated on January 2007 | DEPHA | Reliability of Data = Primary Source | Human Settlements | SIM |
| Administrative Boundaries for Sudan | N/A | 1: 1000000 | 1996 | USAID/ FEWS/ ARD | Unknown attribute reliability | Sudan / Uganda border | DEPHA |
| Northern Uganda IDP camps and villages | N/A | 1: 1000000 | 2009 | OCHA | Unknown attribute reliability | IDP camps and villages in Kitgum District | GEO – IM Working Group www.ugandaclusters.ug |
| ICFR and AFR | N/A | 1: 1000000 | 2009 | WCS Southern Sudan and Uganda Programmes | Unknown attribute reliability | Forest Reserve Outlines | WCS Southern Sudan and Uganda Programmes |

### 2.4.4 Methods

To classify forest cover and forest cover change, we initially explored the efficacy of both post-classification comparison and direct change detection methods (Foody 2004;

Johnson & Kasischke 1998). Ultimately, the selected change detection procedure was based on the Disturbance Index (DI) methodology, which uses different combinations of indices generated by the Tasseled Cap transformation (defined below) to quantify changes in the forest canopy (Healey et al. 2005). The Tasseled Cap transformation reduces the Landsat reflectance bands to three orthogonal indices or features by creating weighted sums from all Landsat reflectance bands (Crist & Cicone 1984; Kauth & Thomas 1976) and has been widely used by researchers to monitor changes in land and forest cover (Franklin et al. 2001; Parmenter et al. 2003; Skakun et al. 2003). The first feature – 'brightness' – is defined in the direction of the principal variation in soil reflectance; the second feature – 'greenness' – represents a contrast between the near-infrared and visible bands and correlates closely with the amount of green vegetation in the image (Lillesand et al. 2003). The third feature – 'wetness' – was intended to be used to examine variations in soil and canopy moisture (Parmenter et al. 2003), but has also been shown to be sensitive to variations in forest stand structure (Franklin et al. 2001). The DI transformation was developed to isolate un-vegetated spectral signatures associated with stand-replacing disturbance and is based on the assumption that areas where forest cover has been reduced will have a higher Tasseled Cap brightness value and lower Tasseled Cap greenness and wetness values than undisturbed forest areas (Healey et al. 2005). The DI has been used in other studies to show the differentiated effects of socioeconomic changes on forest disturbance (Kuemmerle et al. 2007).

Precise geometric correction of images is critical when performing change detection analyses (Coppin et al. 2004; Kuemmerle et al. 2007). Therefore, all scenes acquired for this study were pre-processed by their producer (USGS or GLCF) as part of the Global

Land Survey (GLS) collection, which improves upon the previous GeoCover product by using more accurate elevation data (SRTM) for terrain correction. The GLS dataset is compatible with the L1T scenes acquired directly from USGS, which is similarly precision- and terrain- corrected. Both TM and ETM+ images were resampled to 30 meters pixel size using the Cubic Convolution (CC) method. All scenes used the Level 1 Product Generation System (LPGS), further minimizing any potential geometric, radiometric, and data format differences between scenes. An extensive visual inspection and comparison of all eight images indicated that no further geometric adjustments were necessary. Each of the eight Landsat TM and ETM+ images were then converted to at-satellite reflectance prior to analysis (Chander & Markham 2003).

The stacked images were then transformed to 'greenness' 'brightness' and 'wetness' using coefficients for the derived Tasseled Cap Transformation based on at-satellite reflectance (Huang et al. 2002). Next, for each Landsat image, a 'mature forest' unsupervised classification was performed using the Iterative Self-Organizing Data Analysis (ISODATA) classifier, with masks for clouds and shadows applied where necessary. A separate mask was then created for each 'mature forest' year and used to normalize the Tasseled Cap brightness, greenness, and wetness components to that of the mature forests using the following equations (Healey et al. 2005):

$$\mathbf{B_r = (B - B_\mu) / B_\sigma}$$

$$\mathbf{G_r = (G - G_\mu) / G_\sigma}$$

$$\mathbf{W_r = (W - W_\mu) / W_\sigma}$$

where $B_r$, $G_r$, $W_r$ is rescaled Brightness, Greenness and Wetness. $B_\mu$, $G_\mu$, and $W_\mu$ is mean Brightness, Greenness and Wetness of 'mature forest' and $B_\sigma$, $G_\sigma$, and $W_\sigma$ is the standard deviation of Brightness, Greenness and Wetness. Once the images were rescaled, the disturbance index (DI) was calculated following:

$$\mathbf{DI = B_r - (G_r + W_r)}$$

Forest cover change was then assessed for each multi-temporal stack for each side of the study area (Landsat scene p172r057: 1986-2001 and 2003-2010 and Landsat scene p171r057: 1987-2001 and 2003-2010) by creating a differenced image for each period of interest (war = 1986/87 to 2001 and peace = 2003 to 2010) so that positive numbers would indicate forest recovery and negative numbers would indicate forest disturbance.

The mean and standard deviation values were calculated for each differenced image, with a cloud and shadow masks applied where appropriate. Using a threshold value of mean +/- two standard deviations, pixels of forest loss and forest gain were identified and isolated for import to ArcGIS. Isolated classified pixels were removed by applying a post-classification filter. Finally, to ensure that observed reductions in forest cover between periods were in fact occurring in areas that had previously been vegetated, the Normalized Difference Vegetation Index (NDVI) – a commonly used surrogate measure representing the density of green vegetation on land - was calculated for the earlier image for both periods using the equation

$$\mathbf{NDVI = (NIR - Red) / (NIR + Red),}$$

and a mask applied to the initial results using a threshold value of 0.3 that was selected by comparing the computer-generated threshold ranges using the density slice function of ENVI 4.8 with the original Landsat image (bands R=4, G=3, B=2).

When using an image differencing approach like the one described here, the selection of a threshold to separate real and spurious change can be somewhat subjective and results are improved when the analyst has first-hand knowledge of the region (Hayes & Sader 2001). In this case, the threshold was based on our knowledge of the landscape from a 2009 field visit, combined with examination of publically available imagery visible on Google Earth which used 2.5 m resolution SPOT (Satellite pour l'Observation de la Terre) image dated 2011. During the 2009 visit, the use of a global positioning system (GPS) during aerial reconnaissance flights provided the locations of forested and deforested areas within the ICFR. Therefore, the forest loss and gain thresholds for each differenced image were selected by first using the initial automated results generated by the ENVI remote sensing software and by then examining these against the original composite images to visually corroborate where forest cover had been lost or gained for each side and for each period, and modifying the threshold accordingly. 'Forest loss' and 'forest gain' pixels were then masked and merged to create 'forest loss' and 'forest gain' masks for the entire study area.

The accuracy assessment was conducted using a 'nested approach' and followed standard validation protocol (Congalton & Green 1999; Thomas et al. 2011). First, we selected 100 points for each of the three classes - unchanged, forest gain, and forest loss – based on a stratified random sample technique. High resolution imagery over a significant portion of the study area is not available; therefore, we used the existing Landsat 2003 and 2010 moderate resolution images to visually compare each sample site and label it accordingly based on a careful comparison of the image pairs. This visual analysis approach has been successfully used by researchers to validate the accuracy of disturbance in other areas (Huang et al. 2009; Thomas et al. 2011). Overall accuracy using this method was 81.67% with a Kappa Coefficient of 0.722 (Table 2-3).

**Table 2-3: Accuracy assessment using original Landsat imagery for visual comparison against results from change detection analysis.**

| | | **Observed Class** | | | | |
|---|---|---|---|---|---|---|
| | | **No change** | **Forest loss** | **Forest gain** | **Total** | **Commission (percent)** |
| **Predicted Class** | **No change** | **102** | 31 | 17 | 150 | 32.00 |
| | **Forest loss** | 2 | **72** | 1 | 75 | 4.00 |
| | **Forest gain** | 4 | 0 | **71** | 75 | 5.33 |
| | **Total** | 108 | 103 | 89 | **300** | |
| | **Omission (percent)** | 5.56 | 30.1 | 20.22 | | |

**Overall Accuracy = 81.67%**

**Kappa Coefficient = 0.722**

Next, we related specific areas to field observations obtained during a January 2009 aerial survey, conducted using a small high wing aircraft (Cessna 206). This one-year discrepancy between the aerial photos (January 2009) and the most recent Landsat imagery (December 2010) was the best possible temporal matching given the general lack of data available for the area. At this time, a log of the flight track was recorded using a handheld GPS on a one-second time setting. Observations were recorded on both sides of the airplane along the flight path; however, for the validation only photos from the front-seat observer (FSO) were used as these photos were specifically taken vertically out of the open front window at pre-selected points as well as at frequent intervals along the flight path. The survey zone centered on the main massif and within 10 km of the massif and was restricted to Southern Sudan only. To achieve representative coverage, surveys were conducted along altitude bands and each quarter of a degree cell was visited. The reconnaissance flights were flown at various speeds and altitude due to the mountainous terrain with average speeds at approximately 145 km/hr. and at a height of 500-700 feet above ground. The aerial flight took place over a two-day time period for a total of ten hours. All photographs were then geo-referenced using the GPS track log.

We overlaid our 2009 aerial flight plan and points depicting where photos had been taken over the change map to identify two major areas where a) significant change had occurred during the 2003 – 2010 time period and b) aerial photos were available. These were the Labone IDP camp (recovery/gain) and the Dongotana Hills (disturbance/loss) (see Figures 2-7 and 2-8). The number of aerial photos was extremely limited, therefore, we manually selected a point roughly centered within each of these two geographical areas, and included it, along with nearly all of the remaining sample points on either side of the centered point, amounting to a total of 36 sample points for both areas. We then visually compared the photos with the change map results. Overall accuracy using this approach was 91.67% with a Kappa Coefficient of 0.762 (Table 2-4).

**Table 2-4: Accuracy assessment using aerial photographs taken during January 2009 overflights of Imatongs and Dongotana Hills.**

| Predicted Class | Observed Class: No change | Forest loss | Forest gain | Total | Commission (percent) |
|---|---|---|---|---|---|
| **No change** | **27** | 3 | 0 | 30 | 10.00 |
| **Forest loss** | 0 | **4** | 0 | 4 | 0.00 |
| **Forest gain** | 0 | 0 | **2** | 2 | 0.00 |
| **Total** | 27 | 7 | 2 | **36** | |
| **Omission (percent)** | 0.00 | 42.86 | 0.00 | | |

**Overall Accuracy = 91.67%**

**Kappa Coefficient = 0.762**

## 2.5 Results

For the ICFR, the rate of forest recovery was significantly higher than the rate of disturbance both during and after wartime, though the net gain in forest cover in the ICFR during and post-war were largely the same at 0.55% and 0.57%, respectively. In contrast, the nearby Dongotana Hills experienced high rates of disturbance during both periods, suffering a net loss of forest cover of -1.05% during war and -0.77% post-war; however, post war period losses were largely offset by some gains in forest cover. For the AFR in Uganda, the rate of forest disturbance was only slightly higher during the first period while the rate of forest recovery increased markedly during the second period (Figure 2-5).

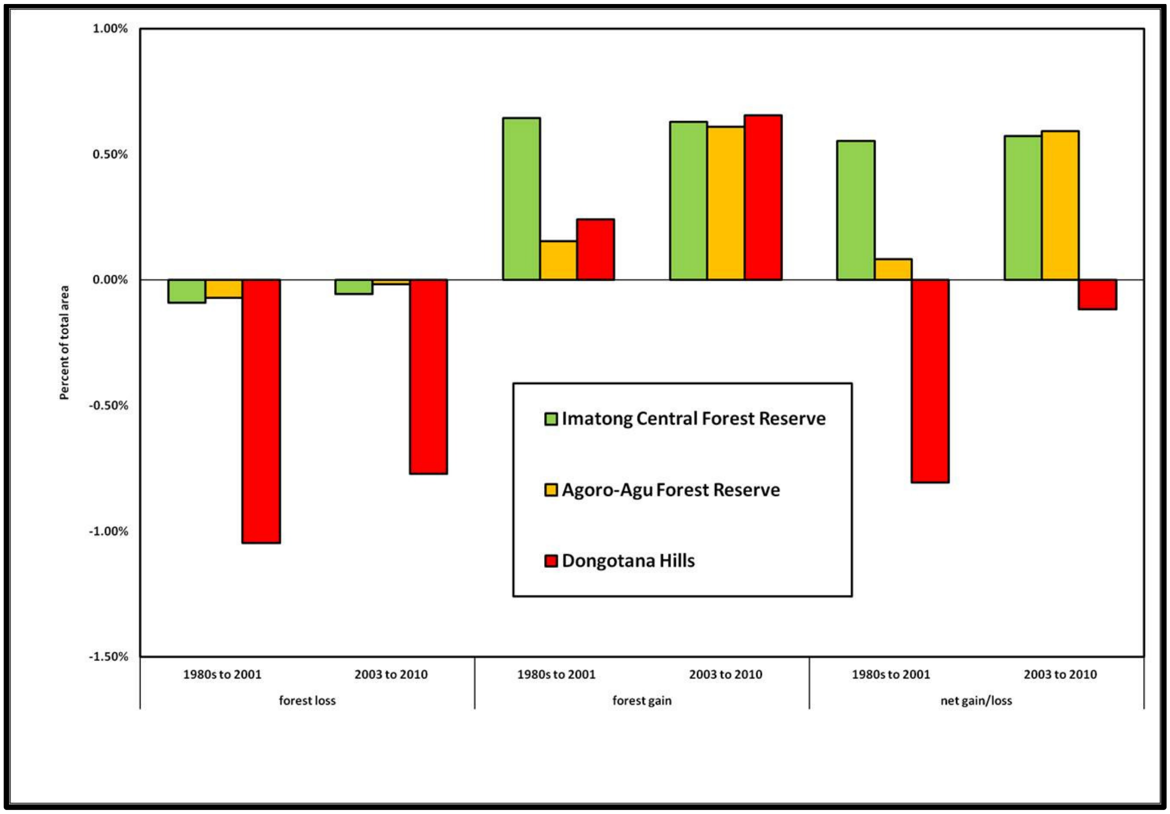


**Figure 2-5: Forest cover gain and loss for conflict and post-conflict periods in the ICFR, the AFR and the Dongotana Hills.**

The location of forest cover loss and gain for both periods is shown in Figures 2-6 and 2-7. For the ICFR and its buffer, most of the forest gain during the war period occurred in the forest interior, and within the Lotti Lowland Forest. The pronounced circular patch of renewed forest cover in Figure 2-6 is likely due to secondary growth in and around the former Talanga tea estate. Forest loss during this time occurred mainly near the Labone IDP camp, which saw a large influx of Bor Dinka peoples in the early 1990s. This same area shows a minor increase in forest cover during the post-war years, following the return of IDPs from Labone to their former villages further north (Figure 2-7). In the AFR and its buffer, forest cover loss occurred in the southwest portion of the 5 km buffer area, near the village of Aweno Olwiyo village and Potika A IDP camp, and increases in forest cover for the second period occurred near this same area (Figures 2-6 and 2-7).

In the Dongotana Hills, forest cover loss was pronounced around the perimeter of the montane forest during the conflict years, particularly on the southern side; post-conflict forest cover loss in the Dongotana Hills was concentrated on the northern tier (Figures 2-6, 2-7 and 2-8).

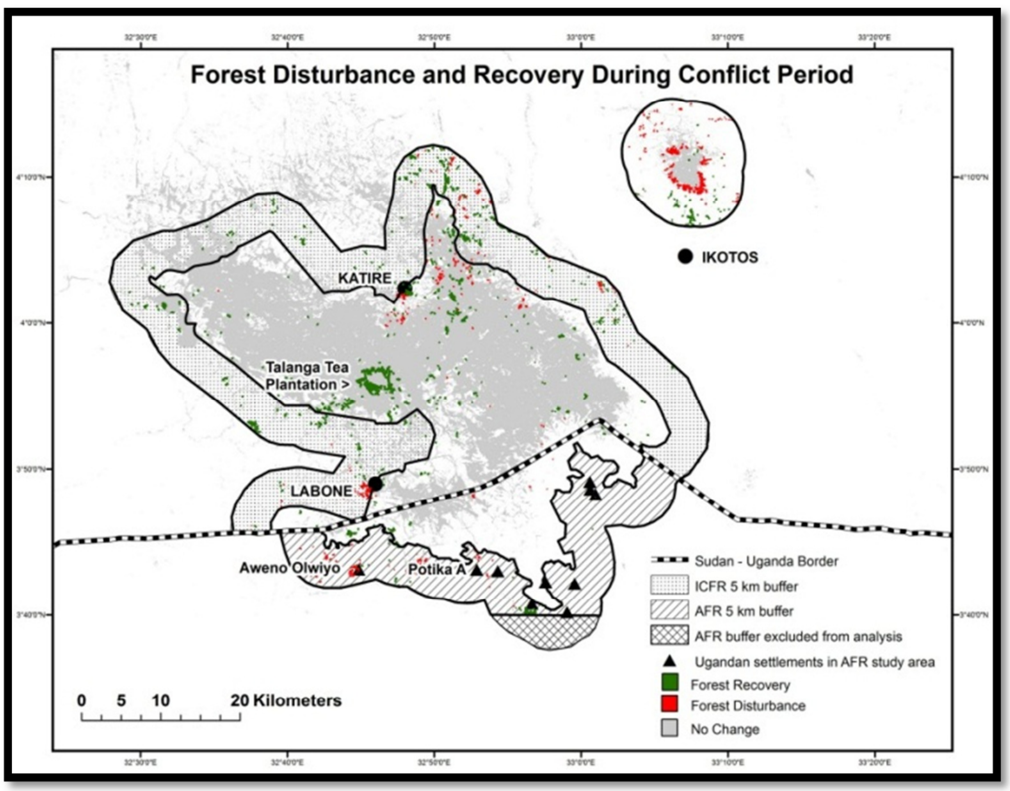


**Figure 2-6: Location of forest cover gain and loss during conflict period (mid-1980s to 2001) using the DI methodology. The round circular green patch likely represents forest regrowth near the abandoned former Talanga Tea Plantation. Forest disturbance around Labone is attributed to the presence of an IDP camp, populated primarily by Bor Dinka after fighting in the north led to mass migration southward. The red ring around the Dongotana Hills highlights the location of extensive forest loss shown in Figure 2-5 above.**

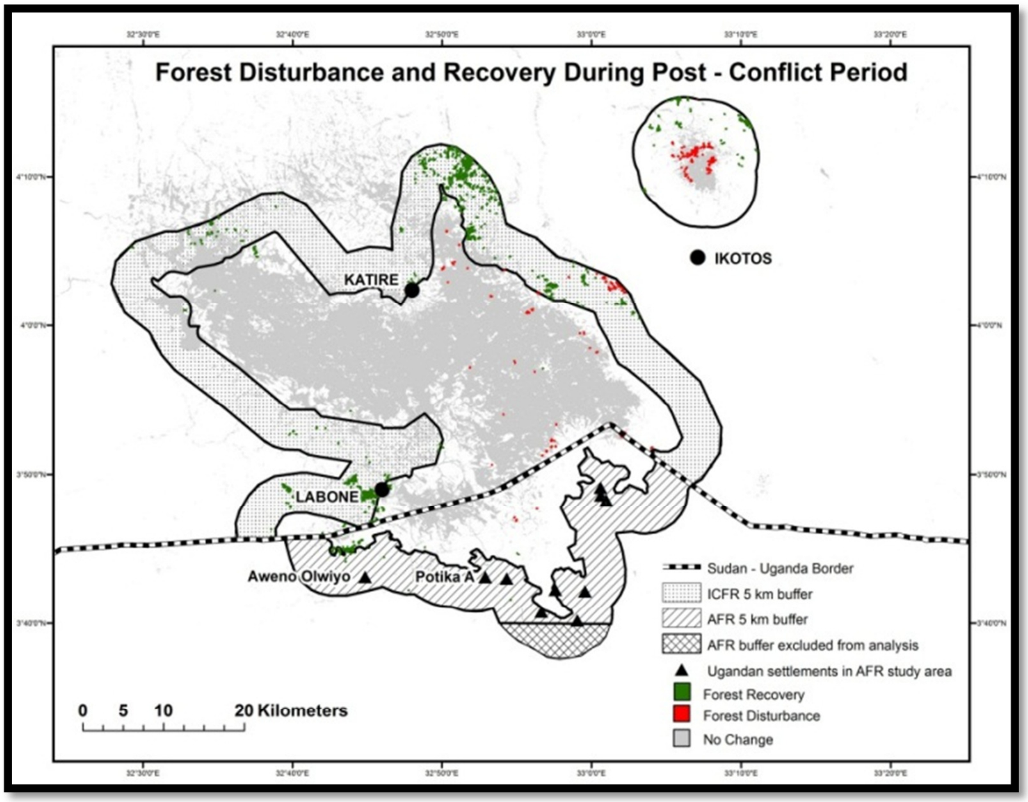


**Figure 2-7: Location of forest cover gain and loss during post-conflict period (2003 to 2010). Overall, both the ICFR and AFR show a minor net gain in forest cover in contrast to the Dongotana Hills, where encroachment has shifted to the north side of the forest. The AFR shows a minor net gain in forest cover which is concentrated on the western side of the reserve.**

**Figure 2-8: Photograph of northern side of the Dongotana Hills taken during the January 2009 overflight. The approximate location of this photo is 4°11'44.246" North latitude and 33°6'54.428" East longitude. Aerial photos were taken using a SLR Rebel XT camera (50-85mm lens). Average speed of aircraft was approximately 145 km/hr at a height of 500-700 feet above ground.**

## 2.6 Discussion

One possible explanation for the high rates of forest recovery within the ICFR interior is a reduction in human-induced fire activity leading to the spread of vegetation in previously open areas. The presence of the LRA and other factions in the ICFR seems to have had a negligible impact on forest cover during the earlier time period. This may be due to the fact that trees were used to ensure secrecy of troop whereabouts, and/or because villagers who under normal circumstances would promote conversion of forests to cropland, were forced to abandon their homes during this tumultuous time. However, if this is the case, one would expect an increase in the rate of disturbance during the second time period, but in fact the rate of forest cover loss actually declines slightly suggesting that precise, fine-scale demographic data are needed to fully understand where returnees are resettling and how their land use practices are affecting forest cover.

As expected in the AFR, forest cover rebounded slightly during the second period – likely due to the abandonment of IDP camps beginning in 2006 resulting in regrowth of previously destroyed and degraded forests. Interestingly, very little forest cover loss or gain occurs in the heavily forested area near the border with South Sudan - perhaps because this area was restricted and/or inaccessible to locals and if so, it is possible that this tract of forest is still largely intact. The location of forest recovery is concentrated approximately 5 kilometers from the Aweno Olwiyo IDP camp. While in general this is a reasonable distance to expect to see changes in forest cover resulting from demographic change near an IDP camp (USAID 2003), the lack of observed change in other areas indicates that additional fine-scale imagery combined with socio-economic surveys are necessary to fully understand the land cover and land use dynamics occurring here.

In the Dongotana Hills, forest cover loss during both periods is pronounced and is corroborated by aerial photos taken of the area in 2009 (Figure 2-8). One explanation is that unlike the ICFR, the montane forest ecosystem has never been under formal protection as a National Park or Reserve. More likely is the fact that as a relatively small patch of forest with numerous villages in the immediate vicinity, this area is easily accessible to people who depended on the forest and forest product during the war to survive and continue to use the forest to rebuild their communities. This ‘ease of access’ notion is supported by the fact that most of the clearing of forest in this area is for agriculture so that early forest removal occurred in the south where the slope is less pronounced than in the north.

The relatively long time interval for the ‘war period’ of nearly fifteen years was unavoidable due to the lack of available, cloud-free Landsat imagery in intervening years. As a result it is likely that all of the disturbance occurring during this period was not adequately captured (Masek et al. 2008).

## 2.7 Conclusion

Results from this study indicate that changes in forest cover are generally consistent with population and land use changes associated with civil war. In contrast to other forested regions of the world that have experienced extensive losses such as the Amazon Basin at roughly 0.45 percent per annum from 1990 to 2000 (Rojas-Briales & Ze Meka 2011), losses in the most heavily disturbed of the three study areas – the Dongotana Hills - are by comparison quite minimal. However, given the recent rise in population for all of South Sudan and the heavy dependence of people on the forests for food, fuel and construction materials, future planned development should consider how additional human pressure could impact long-term sustainability of the region. At the same time, the fact that the ICFR was largely left intact during and immediately following the war in Sudan is encouraging and these findings should be used to encourage the creation of a National Park to protect key vegetation types and their associated biodiversity. Finally, results for the Agoro-Agu Forest Reserve offer a hopeful sign that a reduction in population pressure is allowing for recovery of forests in this area, potentially paving the way for a trans-boundary park with South Sudan, as has been proposed by the Wildlife Conservation Society (Grossmann et al. 2009).

A major challenge highlighted by this paper is interpreting results in the absence of fine-scale population data or other information that could help validate results and/or provide in-depth explanation of observed changes. Yet it is precisely because of the conflict that this information is unavailable. The end of hostilities in both Southern Sudan and in northern Uganda provides an opportunity to corroborate findings and further investigate underlying causes of land use change and to use this newfound understanding as the basis for conservation and land use planning efforts for the region.

Rapid changes in human population migration due to conflict can leave a lasting impact on the natural landscape. As this study shows, whether the effects lead to an increase or decrease in forest cover depends on numerous underlying factors that cannot be explained through remote sensing technologies alone. Yet despite limitations stemming from an imprecise matching of spatial and temporal scales, remotely sensed satellite imagery is a useful tool for monitoring the longer-term impact of human activity on the landscape – particularly where precise, time-series population data are difficult to obtain or non-existent.

# 3 Mapping Anthropogenic Fires During Periods of Conflict and Peace in South Sudan and Northern Uganda Using MODIS Active Fire Data[5]

## 3.1 Summary

*The Afromontane forests located in the Imatong/Agoro Massif of South Sudan and Northern Uganda are a conservation 'hotspot' due to the convergence of several floristic regions which provide habitat for small mammals, birds and other wildlife. Fires in this area help shape the natural ecosystem and therefore influence biological communities therein. Changes in the fire regime due to human activity impact local inhabitants and may also ultimately affect the regional and global climate. On both sides of the border, there have been significant fluctuations in human migration as a result of separate but related armed conflicts. The objective of this study was to use information derived from remotely-sensed satellite imagery to compare fire number and location during times of war and peace with population trends across several key areas and land cover types. Using MODIS active fire data, I found that overall, fire activity corresponded with broad-scale human population trends on both sides of the border and that they tended to occur more frequently in areas dominated by the woody savanna land cover type in South Sudan, and in croplands and forests in northern Uganda. This study highlights the potential for using remotely sensed satellite data to gain insight into human activity and the impacts of different types of conflicts in inaccessible war zones where data are likely to be scarce and where the implications for conservation and human well-being are significant.*

## 3.2 Introduction

Fires have helped shape ecosystem processes for millennia (Guyette et al. 2002) and as a primary factor in determining biome distributions, have had a significant effect on

[5] Submitted to *International Journal of Remote Sensing* (Gorsevski et al. 2012b)

the extent of global forest cover (Bond et al. 2005). Fires also release considerable amounts of trace gases to the atmosphere with important implications for the Earth's climate (Crutzen & Andreae 1990; French et al. 2003; van der Werf et al. 2003). Much research on wildland fire and biomass burning has focused on Africa, often called the 'fire continent' because of the widespread and reoccurring anthropogenic savanna fires occurring there (Sheuyange et al. 2005). Fire—along with water and nutrient availability and herbivory—is critical for the maintenance and conservation of African savanna ecosystems (Govender et al. 2006; Sankaran et al. 2008); however there is also concern that annual biomass burning results in land degradation and biodiversity loss (Laris 2005). Other studies on biomass burning in Africa have focused on tropical forests (Eva & Lambin 1998, 2000); far fewer have concentrated on fires in Africa's montane forests (Bussmann 2001; Finch & Marchant 2011) despite the fact this ecosystem has been recognized as having exceptional biodiversity (Brooks et al. 2002; Myers 2003)

Fire behavior is largely influenced by environmental factors such as vegetation type, fuel load, seasonal weather, fuel moisture, wind and topography (Cochrane 2009; DeBano et al. 1998). While fires predate the appearance of humans (Scott 2000), there is little doubt that people have significantly influenced specific aspects of fire regimes across all continents except Antarctica, and that anthropogenic fires dominate over fires induced by lightning in many natural ecosystems (Yang et al. 2007), even in remote areas (Mollicone et al. 2006; Pausas & Keeley 2009; Venevsky et al. 2002) and particularly in Africa (Sheuyange et al. 2005; Verlinden & Laamanen 2006). Efforts to differentiate and rank the human and natural drivers of fire variation occurring within a particular landscape are conducted through extensive fieldwork (Angassa & Oba 2007; Sheuyange et al. 2005) and the use of various modeling techniques – often with data derived from satellite remote sensing systems (Aldersley et al. 2011; Archibald et al. 2009; Bucini & Hanan 2007; Forsyth & van Wilgen 2008; Serneels et al. 2007). A careful analysis of these studies makes it clear that the relative importance of various drivers is location-specific and scale-dependent (Aldersley et al. 2011; Laris 2005; Sheuyange et al. 2005).

Increasingly, anthropogenic fires occurring throughout a range of human-related activities and settings are modifying the natural landscape with important implications for societies (Guyette et al. 2002) and biodiversity (Barazesh 2009; Gregory et al. 2010). People influence fire directly through the frequency of ignitions (Senici et al. 2010) and indirectly through changes in land use (Saunders et al. 1991) and land management policies (Heyerdahl et al. 2001). Land cover type can be an important indicator of where fires are more likely to occur and spread, and the transition from one land cover type to another (e.g. grassland to wooded savanna) often coincides with changes in the fire regime (Finch & Marchant 2011; Gillson & Ekblom 2009). There is also an increased risk of accidental fires due to changes in land use and landscape fragmentation, which can expose forests and woodlands to fire (Cochrane et al. 1999; Csiszar et al. 2004). In developing countries, biomass burning is used for a variety of reasons including clearing land for agriculture, control of pests, insects and weeds, preservation of pastureland, game hunting, energy production for cooking and heating, charcoal production, and various religious and aesthetic purposes (Crutzen & Andreae 1990).

The interplay of human activity with fire and vegetation is complex, varying across time and space (Guyette et al. 2002) and involving numerous location – specific, interdependent variables. As such, there is no universally agreed up relationship between fire and human population. For example, population densities fewer than 10 people/km$^2$ were found to be positively related with active fire counts, whereas densities higher than 10 people/km$^2$ were associated with fewer fires (Archibald et al. 2009). Other studies show a variation in the relationship between fire and population density during different stages of human settlement and cultural development (Guyette et al. 2002). Research conducted in California similarly indicated that the link between population density and fire frequency is not linear (Syphard et al. 2007; Syphard et al. 2008) and studies in Mediterranean ecosystems revealed there is a consistent association between higher population densities and fire regardless of differences between land cover types, natural fire regimes or overall population up to an intermediate density, where fires tended to peak (Syphard et al. 2009). Exogenous human-related factors such as war and migration influence the stability of the fire regime (Guyette et al. 2002); yet we could find no studies that specifically examined how abrupt changes in population due to war impacted fire location and number of fires.

The objective of this study was to determine if shifts in human populations caused by the presence or absence of conflict influenced fire activity in the Imatong/Agoro Mountain region where conflict – followed by a period of peace – has been the primary cause of abrupt changes in human population dynamics on both the South Sudan and northern Uganda sides of the border. To address this objective, we compared multi-scale remote sensing data and population information to provide insights into the linkage between observed changes in fire counts and location and anthropogenic processes involving the migration of Internally Displaced People (IDPs) and refugees during two distinct periods. Although some fires in this area are likely ignited by lightning strikes, it is widely agreed that most fires are started by humans in Africa (Sheuyange et al. 2005; Verlinden & Laamanen 2006), especially during the dry season when storms producing lightning are absent. The same has been documented for the Imatong region (Friis & Vollesen 2005; Jackson 1956; Sommerlatte & Sommerlatte 1990). Based on this underlying assumption, we hypothesize that changes in the location and number of fire counts in this area will predominantly be a function of the population density, and that this relationship will be positive in areas of low population densities and negative in areas with high population densities (Archibald et al. 2009). The results of this study are important given current pressing conservation and development priorities for the region and this type of analysis could prove useful for monitoring change in other impoverished and war-torn regions lacking resources for 'on the ground' fire monitoring and management.

### 3.3 Background

The Imatong/Agoro Massif extends along both sides of a roughly 45 km border between South Sudan and Uganda (Figure 3-1). The three main ethnic groups inhabiting the South Sudan side of the border are the Acholi, the Lango, and the Latuka. While the Acholi are mainly farmers with few livestock, the Lango and Latuka practice some form of agro-pastoralism with varying degrees of livestock holdings ranging from 3-5 cattle and 6-19 goats for poor families to 21-40 cattle and 45-60 goats for better-off families (Muchomba & Sharp 2006). The Ugandan side of the border is part of what is known commonly as "Acholiland," named after the predominant ethnic group. Subsistence agriculture is the main economic activity here as well, and people keep livestock such as cattle, goats, sheep and chicken, though livestock numbers have been in decline throughout Kitgum District (where the study area is located) due in large part to disease and diminishing rangeland (NEMA 2007).

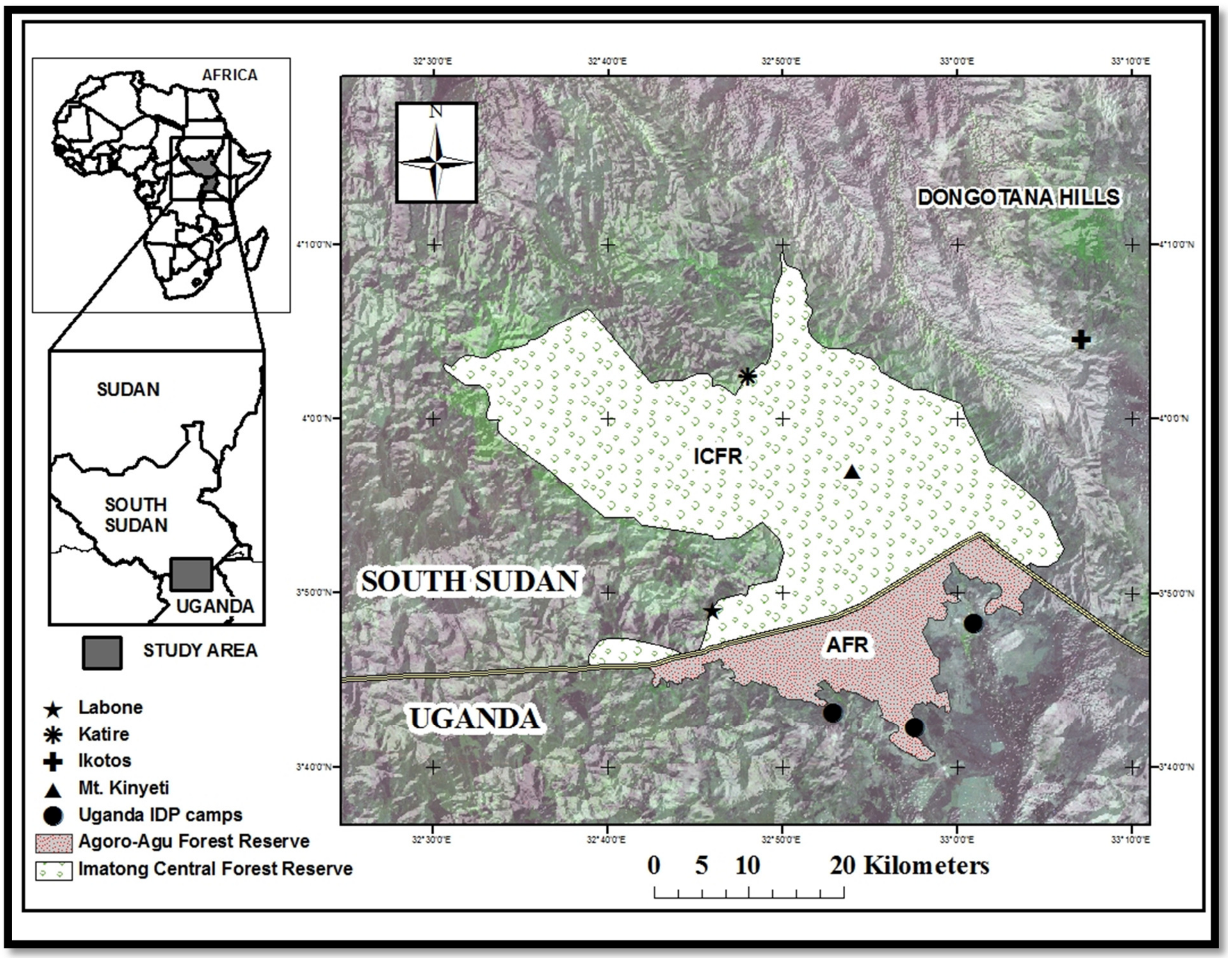


**Figure 3-1: Imatong Mountains and surrounding Area including the Dongotana Hills and the Agoro Ago Forest Reserve in Northern Uganda. ICFR is the Imatong Central Forest Reserve and AFR is the Agoro-Agu Forest Reserve. The background image used to make this map is a Landsat MSS p184r57 acquired 03 February, 1973 (band 1=R, band 3=G, band 2=B) draped over a hillshade image created using hole-filled SRTM data v. 4 downloaded from the CIAT-CSI website (http://srtm.csi.cgiar.org).**

Both of these areas experienced a period of conflict followed by peace, albeit owing to different causes and with opposite impacts on human migration patterns. In South Sudan, the conflict was related to the decades-long civil war between the North and South, that resulted in an estimated 4 million displaced people and 2 million killed (Haynes 2007). In addition to the North/South war, the Imatong Mountain area was impacted by the terrorist activities of the Lord's Resistance Army (LRA), who sought refuge in the montane forest until 2005 when they permanently left the area. (Schomerus 2008a). Since the January 2005 Comprehensive Peace Agreement (CPA) and departure of the LRA, many people have been returning to South Sudan including to the Imatong Mountain region (Kanani 2006).

Repatriation statistics vary depending on how the data are acquired and reported. In Southern Sudan, there was a roughly five-fold increase in returning population between 2006 and 2007 (Figures 3-2 and 3-3). This was due in part to the spontaneous return of some 60,000 refugees from the Adjumani area of Northern Uganda (not located in the study area) that same year (UNHCR Steps up Voluntary Repatriation to Southern Sudan (2008, March 16). *Sudan Vision*. Retrieved from http://news.sudanvisiondaily.com.) and may also have been driven by a desire to be counted in the 2008 census. Similarly, there was an increase in returns between 2008 and 2009 – likely the beginning of an inflow of Southern Sudanese in anticipation of the January 2011 Referendum on Independence.

In Uganda, the conflict was also due to the presence of the LRA; however, the effect on the IDP population was reversed. More than 90 percent of the northern Ugandan population was internally displaced as a result of the conflict between Ugandan government forces (Ugandan Peoples Defense Force or UPDF) and the LRA, which began in 1988 (Madden & Ross 2009). In 1996, the government forced people to move into camps as part of its "protected villages" policy. Many of these camps were located in Kitgum district, which encompasses the Agoro-Agu area on the Uganda side of the study area. This policy was later reversed in 2006 due to improvements in the security situation, so that by the end of 2009, about 1.4 of the 1.8 million IDPs had left the camps in northern Uganda (IDMC fact sheet – www.internal-displacement.org) (Figure 3-4). In terms of repatriations, Kitgum District in northern Uganda (where the Agoro-Agu Forest Reserve is located) has witnessed a steady decline in IDPs since 2006. The study area includes three IDP camps – Agoro, Potika A and Potika B – which similarly recorded a reduction in the number of individuals living there (Figure 3-5).

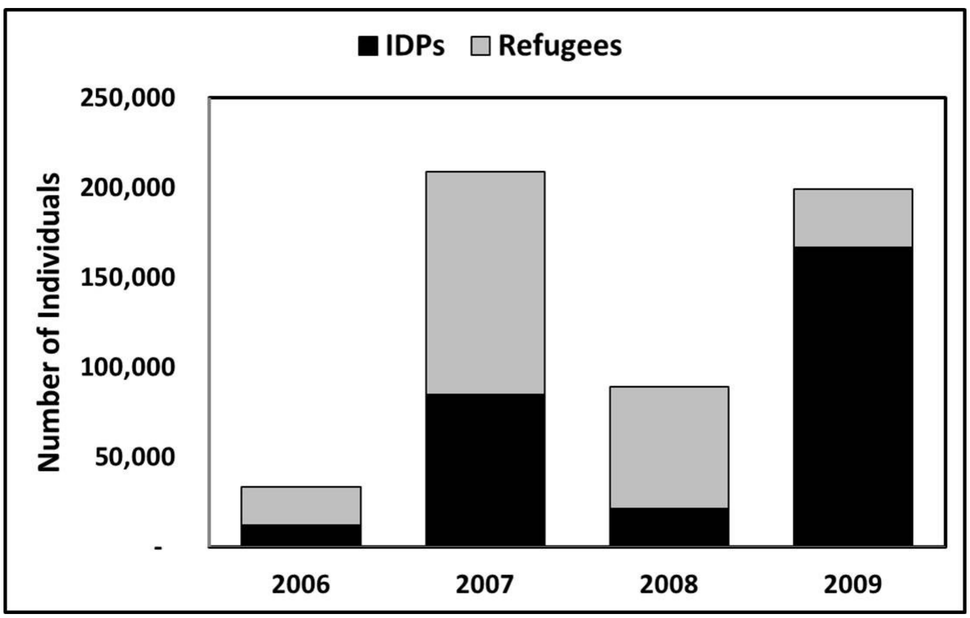


**Figure 3-2: Repatriations to Southern Sudan (Source: United Nations High Commissioner for Refugees (UNHCR) Statistical Database).**

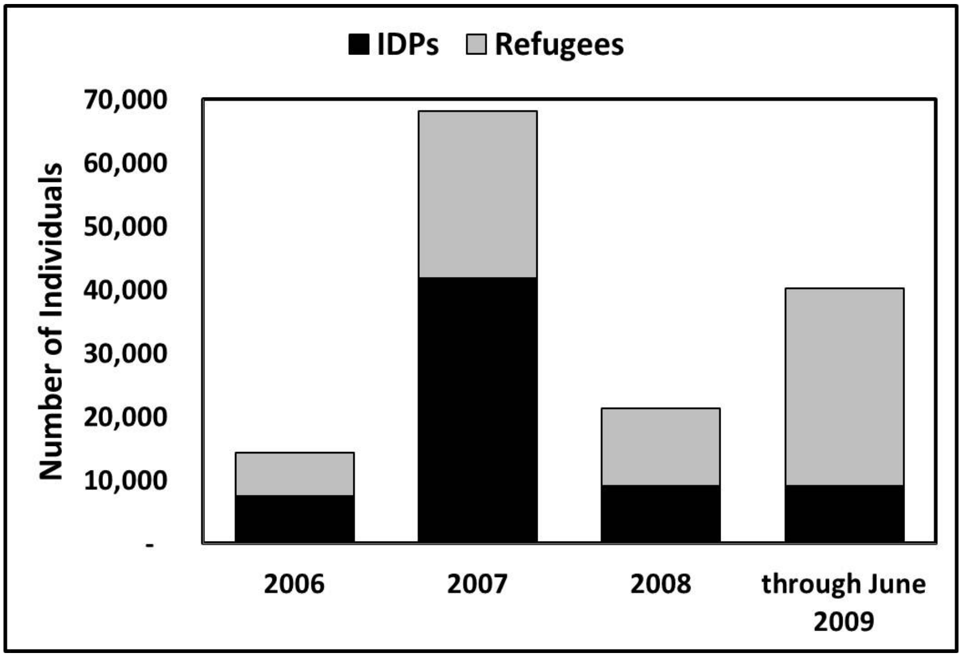


**Figure 3-3: Repatriations to Southern Sudan (Source: International Organization for Migration (IOM) Return Fact Sheet Summary and Internal Displacement Monitoring Centre (IDMC)).**

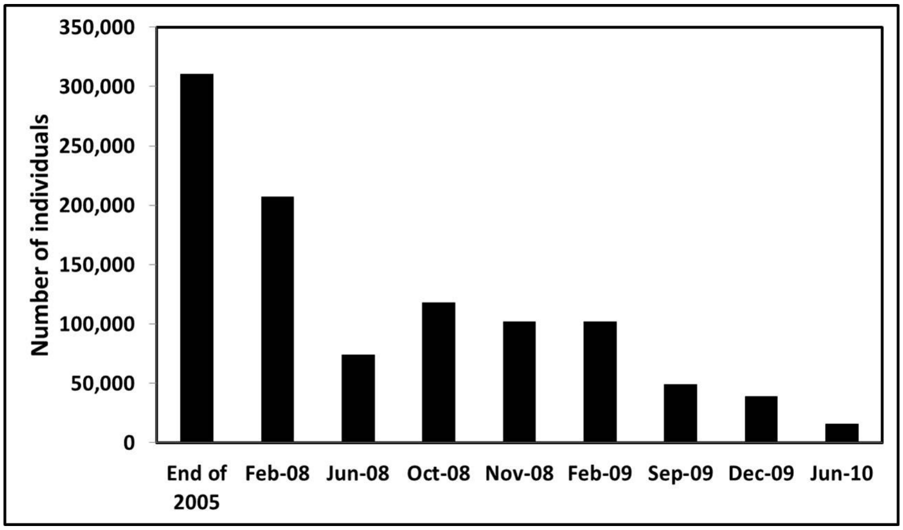


**Figure 3-4: Population of IDP camps in Kitgum District, northern Uganda, where the study area is located [Source: The World Food Programme (WFP)].**

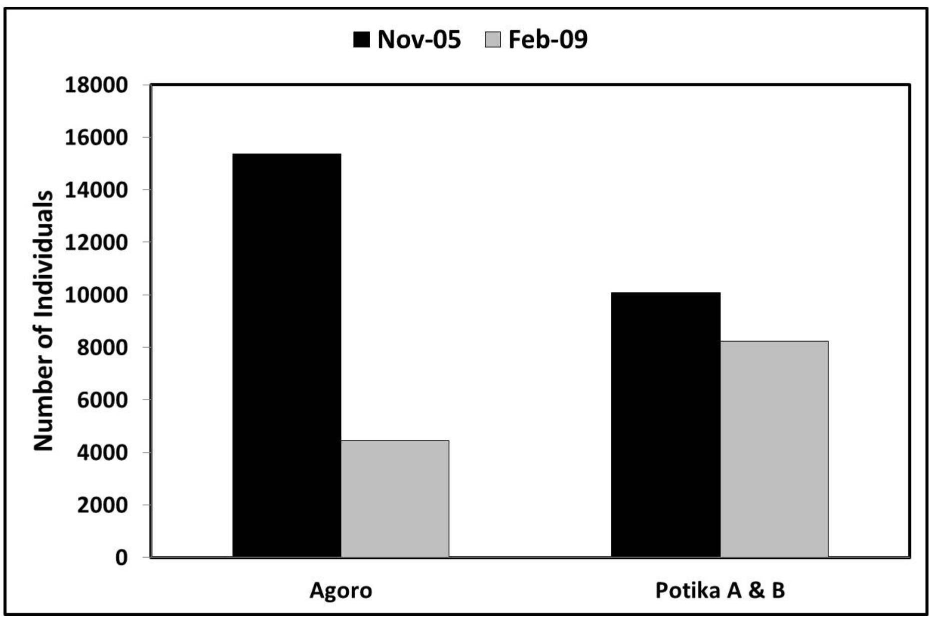


**Figure 3-5: Population of main IDP camps in northern Uganda study area [Source: The United Nations High Commissioner for Refugees (UNHCR)].**

## 3.4 Methods

### 3.4.1 Study area

The Imatong Mountains are located on the South Sudan – Uganda border between 3°40’ and 4°20’ North latitude and 32°30’ and 33°10’ East longitude (Figure 3-1). The mountains rise abruptly from the surrounding plain (600 m above sea level (a.s.l.) to the highest point in South Sudan – Mt. Kinyeti (3187 m a.s.l.). These mountains are comprised of crystalline basement rocks. The soils within the Imatong Central Forest Reserve (ICFR) – formally delineated in 1952 and covering an area of 1,032 $km^2$ – are somewhat acidic and range from shallow skeletal soils on the escarpment to deeply developed red brown loam soils in the valleys (Sommerlatte & Sommerlatte 1990). The vegetation is in large part a function of elevation, and has been described as consisting of several zones, including 1) the lowland and transition zone (1000 – 1800 meters) where *Khaya* and *Chlorophora* species are typical, 2) the lower montane zone (1800 – 2400 meters) with closed forests dominated by *Olea* and *Podocarpus* species interspersed with grassland on hill tops, 3) the higher montane zone (2400-2900 meters) with open forest dominated by *Podocarpus* and *Dombeya* species, and 4) the Ericaceous zone (over 2900 meters) with heather shrubs and open vegetation (Van Noordwijk 1984). The distribution of forest types is also controlled by precipitation, which increases with altitude and from east to west (Sommerlatte & Sommerlatte 1990). Various forestry projects in the Imatong Mountains over the years resulted in the elimination of some natural forest, which were replaced by pine and eucalyptus plantations (Jenkin et al. 1977). Though overgrown due to lack of management, these introduced species are still present, as are remnants of tea plantations. A small portion of the mountain area extends over the border with Uganda in what is known as Agoro-Agu Forest Reserve. With altitudinal ranges of 1100 to 2700 m a.s.l., this area covers 236 $km^2$ plus a small 18 $km^2$ enclave within the reserve itself. According to a 1993 survey by the Ugandan Forestry Department, the forest within the reserve is used for building poles (primarily bamboo), honey, bush meat and medicinal plants (Davenport & Howard 1996).

Two main settlements located in the study region in South Sudan are Labone and Katire (Figure 3-6). Labone was an IDP camp established in the mid-1990s for members of the Bor Dinka tribe that were relocated from further north following inter-tribal fighting (Dowden, R. (1994, February 10). Attack Forces Sudan Refugees to Flee Camp. *The Independent*. Retrieved from http://www.independent.co.uk/). Katire is a large village located at the end of a major road from nearby Torit that provides access to the ICFR. As such, Katire has served as an important entry point for timber and other development projects throughout the years. According to an unofficial local enumerator in April 2009, Katire is comprised of approximately 7000 people. Census data from 2008 obtained from the South Sudan National Bureau of Statistics (NBS) in November 2011 lists the populations of these settlements as 5,721 (Katire) and 12,832 (Labone).

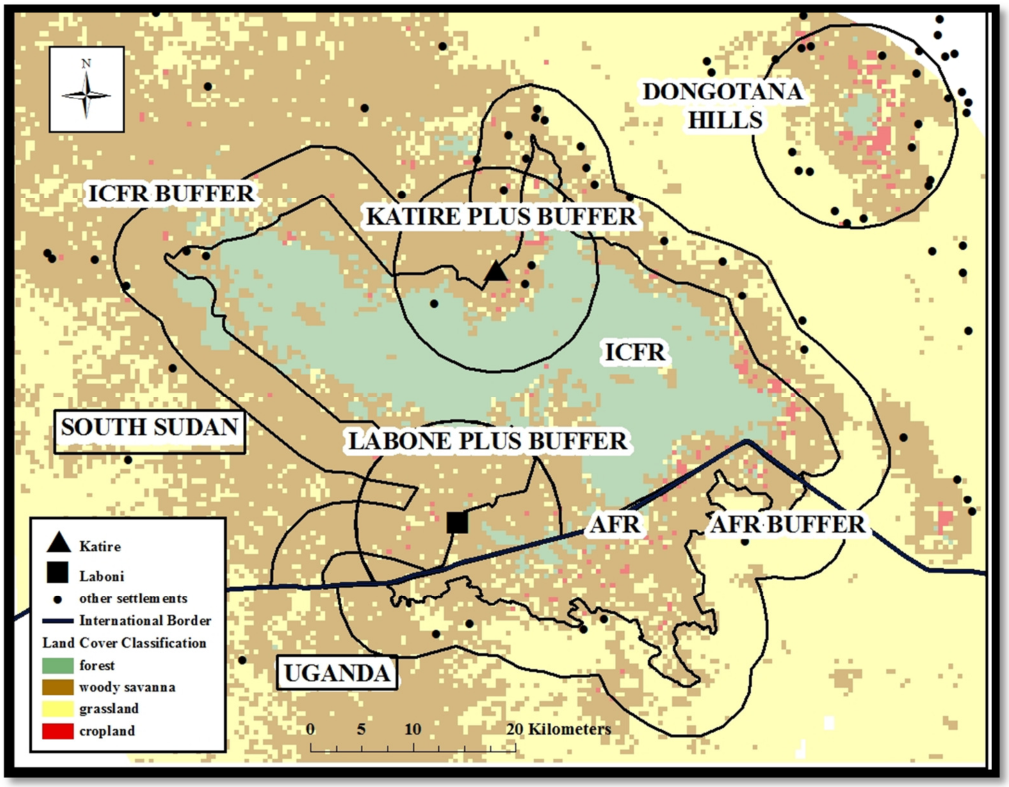


**Figure 3-6: Study area for fire analysis. The underlying land cover image was created using a pre-existing MODIS land cover data product (MCD12Q1) from 2008 (Friedl et al. 2002) at 500 meter resolution (UTM 36N Datum, WGS-84).**

The impact of fire on vegetation in the Imatongs is not fully understood due to the lack of recorded observations; however, it is clear that fire is the primary tool used by local villagers to clear land, hunt, promote green flush for grazing, collect honey, provide security around settlements and huts, and to clear trails through the forest and bush (Friis & Vollesen 2005; Sommerlatte & Sommerlatte 1990). In general, fires originate in and around settlement areas and spread outward, and they are also set by hunters and honey collectors along paths within the forested areas (Grossmann et al. 2009). Figure 3-7 shows a tree that was felled after it was burned to smoke out bees for honey collection. The photo was taken during a 2009 expedition to the region.

**Figure 3-7: Photo of a tree in the ICFR showing effects of using fire for honey collection. This photo was taken during a trip to the Konoro forest, located to the east of Katire at approximately 32°50’46” E longitude and 4°2’6.622” N latitude at an elevation of approximately 1,500 m (Photograph collected by V. Gorsevski).**

Because the fires are uncontrolled and occur in areas with few barriers and strong dry season winds, they have the potential to spread quickly and cover large areas. While other factors likely influence vegetation type in the plains area surrounding the mountain such as underlying environmental factors and herbivory, fire is believed to be a major factor in producing savannah woodland instead of closed forest (Friis & Vollesen 2005; Jackson 1956). Topography is an important factor in the spread of fires and those occurring within the forested areas of the reserve can burn quickly and fiercely uphill during the dry season, creating ‘bowls’ within closed forest (Jackson 1956). In addition, there are many ‘mountain meadows’ within the reserve that are maintained by fires which mainly occur during the dry season from November to April (Friis & Vollesen 2005). Fires occurring early in the season do relatively little damage, while late fires, involving dry biomass of up to 3m tall grasses, can burn several hundred square kilometers (Friis & Vollesen 2005).

### 3.4.2 Technical Approach

For this study, the region was divided into seven sub-regions, shown in Figure 3-6 and discussed in detail in Section 3.4.3 below. Fire activity was determined by analyzing satellite information products. Satellite remote sensing data were also used to map vegetation cover and to assess inter-annual variations in precipitation. These data products, as well as gridded population data derived from country-level population statistics, were imported into a Geographic Information System (GIS) for analysis. The study was carried out for periods of conflict in Sudan (2002 through early 2005) and non-conflict (late 2005 through April 2011), which coincides roughly with the departure of the LRA from Northern Uganda and the closure of IDP camps in Northern Uganda. The fire activity data used for this study corresponded to the beginning and end of the dry season for South Sudan and northern Uganda (November – April), when fires are most likely to occur. By focusing on the dry season months, we also minimize the possibility of including fires ignited by lightning strikes, since they tend to be associated with early wet-season thunderstorms (Frost 1999; Roy et al. 2008). Figure 3-8 shows all MODIS active fire detections occurring during the dry season for both war and post-war years.

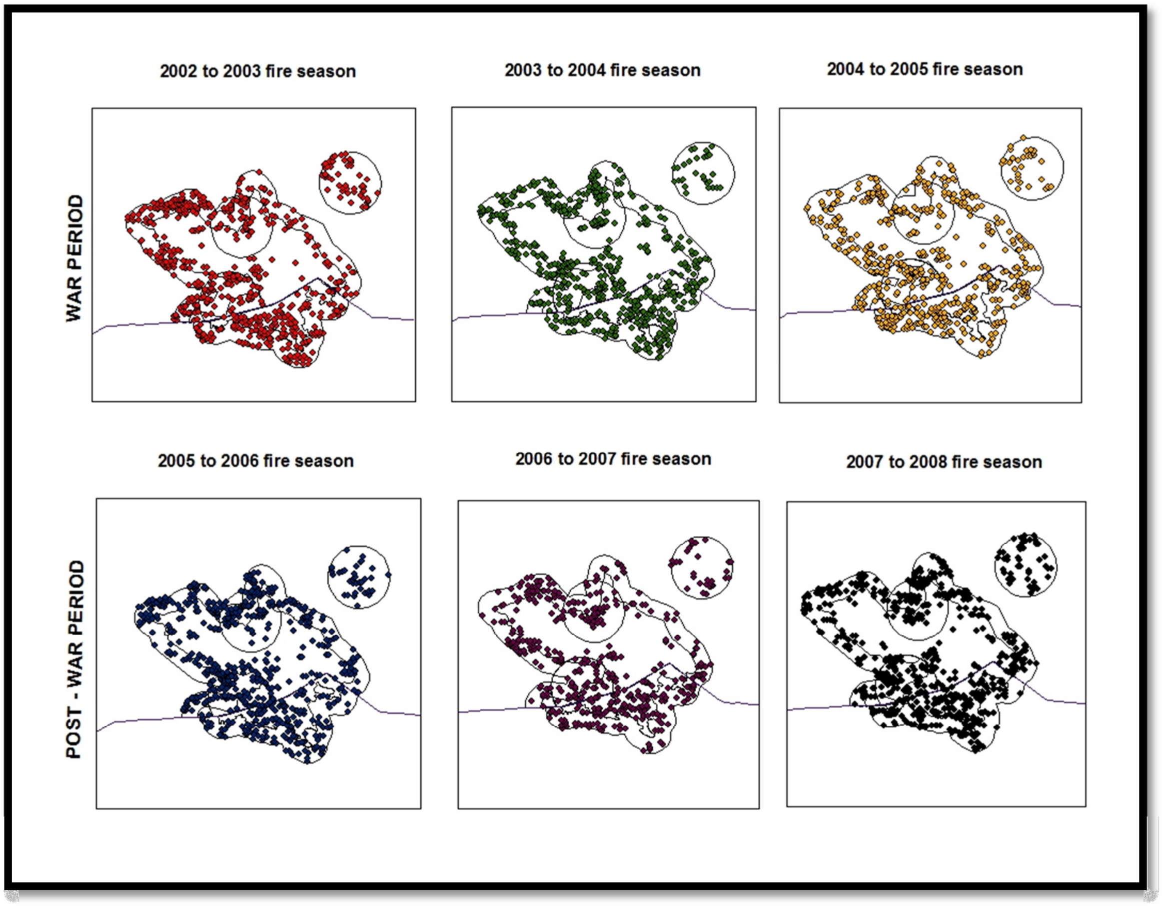


**Figure 3-8: Active fires for war and post-war years for 7 sub-regions in the study area. The MODIS dataset (MCD14ML) datasets were obtained from UMD researchers working for the Fire Information for Resource Management System (FIRMS) program. Figure 3-8 was created by separating active fires first by season and then by geographical region. For more information on the MCD14ML data product, see (Giglio 2010).**

### 3.4.3 Data

A variety of data sets were used for this study (Table 3-1). Active fire data were obtained from the MODIS sensor on board the NASA Earth Observing System (EOS) satellites, Terra and Aqua, which combined provide four active fire observations (two in the morning and two in the evening) for most land surfaces (Davies et al. 2009). The MODIS active fire algorithm uses multiple channels to detect thermal anomalies on a per-pixel basis (Justice et al. 2002b) so that a detected "hotspot" represents the center of a 1 km pixel containing one or more actively burning fires (Davies et al. 2009; Giglio et al. 2003). However, because Terra was launched in December 1999 and Aqua in May 2002, inter-annual comparison of fires must take into account a potential undercounting of fires during the years of Terra only. For this study, a complete dataset (MCD14ML) was obtained from the University of Maryland FIRMS (The Fire Information for Resource Management System) program (ftp://fuoco.geog.umd.edu). Specifically, we used datasets for South Sudan and northern Uganda beginning in November 2002 through April 2011 to avoid a "Terra only" data bias.

So far, there has been limited research comparing burned area and active fire products (Roy et al. 2008). In general, burned area products are most useful for studies focusing on changes in biomass and carbon emissions (Roy & Boschetti 2009). Previous analyses have indicated that the currently available burned area product (MCD45A1) is less likely to detect smaller-sized burns (Boschetti et al. 2008), such as those that occur in the Imatong study region, due in part to the low resolution bias – defined as bias resulting from the difference in spatial resolution between fine and coarse resolution data sets

(Boschetti et al. 2004). Studies have shown that this bias results in significant underestimation of the amount of burned area in areas with fine-scale seasonal-mosaic burning regimes (Laris 2005). Other studies comparing active fire products to the burned area approach also point out that the latter tends to undercount fires obscured by forest canopy including in woody savanna ecosystems (Schroeder et al. 2008). On the other hand, cloud cover is known to limit active fire detections (Hawbaker et al. 2008; Justice et al. 2002a; Roy et al. 2005), potentially resulting in an undercounting of fires in some cases. However, an analysis of numerous moderate resolution satellite images (Landsat TM and ETM+) for the study area for multiple years during the dry season months (mainly December – February) (Gorsevski et al. 2012c) indicates that clouds over the Imatong Mountains generally form over the montane forests in higher elevations where fires are least likely to occur due to the inaccessibility of the area to people; therefore, the potential undercounting of active fires would be minimal compared to the potential for low resolution bias.

Land cover data were acquired from the MODIS 500m land cover data product (MCD12Q1 v05), which incorporates five different land cover classification schemes using a supervised decision-tree classification method (Friedl et al. 2002). Of these schemes, the University of Maryland classification, was selected because the classes were most closely representative of those found in the study region. Each of the eight datasets representing years 2002 to 2008 (the latest year the product is available) was re-projected from sinusoidal to UTM 36N Datum WGS-84 for compatibility with other datasets. It was necessary to use the MODIS pre-existing land cover classification because although higher resolution satellite images are available including from SPOT (Satellite pour l'Observation de la Terre) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), none included the larger study area and some contained areas obscured by cloud cover.

Rainfall data were obtained from the NASA/JAXA (Japan Aerospace Exploration Agency) Tropical Rainfall Measuring Mission (TRMM), which monitors rain structure, rate and distribution in tropical and subtropical regions. These data were aggregated to monthly precipitation to further examine changes in climate patterns for the study region. The TRMM 3B43 data product used for this analysis provides gridded precipitation estimates on a calendar month temporal resolution and a 0.25 x 0.25 degree spatial resolution. The data were derived by combining the 3-hourly merged high-quality/IR (infrared) estimates with the monthly accumulated Climate Assessment and Monitoring System (CAMS) or Global Precipitation Climatology Centre (GPCC) rain gauge analysis (Huffman et al. 2007).

**Table 3-1: Datasets and their attributes used for fire analysis.**

| Data | Spatial Resolution | Temporal Resolution | Parameter of Interest | Data Source |
|---|---|---|---|---|
| **MODIS Aqua / Terra MCD12Q1** | 500 m | Yearly | Land cover | LP DAAC<br><br>WIST |
| **MODIS Aqua / Terra<br><br>MCD14ML** | 1 km | Daily (four overpasses) | Active fires | FIRMS / University of Maryland |
| **TRMM** | .25 degree x .25 degree | Monthly | Rainfall | NASA/JAXA |
| **SPOT** | 5 m | 02-05-2006 | Land cover (to validate MODIS LC classification) | SPOT Image Corporation |
| **CIESEN GPW v3** | 2.5 arc minutes | 2005 and 2010 | Population density | SEDAC |
| **GIS-compatible shapefiles** | N/A | N/A | Location of settlement and reserves | UNJLC, UNSIG |
| **Population data for Sudan and Uganda** | N/A | 2005 to 2010 | Repatriations to Southern Sudan and changes in IDP camp population in Northern Uganda | UNHCR, WFP, IOM |

The study area was then divided into seven geographic areas of interest for comparison (Figure 3-6). The ICFR and the Agoro-Agu Forest Reserve were selected because of their clear delineation as conservation reserves, indicating intent to provide these areas some degree of ecological protection (even if the boundaries have not been respected in practice due to war and pressing humanitarian needs). A 5 km buffer area around each of the reserves were used as a separate geographic region since many previous studies have shown that areas adjacent to established PAs are often subject to extensive land use activities from that are not allowed in the PAs (Curran et al. 2004;

DeFries et al. 2005; Hansen & DeFries 2007). The use of a 5 km buffer allowed me to examine whether fire activities were higher in the area immediately adjacent to the PAs compared to within the PAs. The Dongotana Hills were included in the analysis because this area shares a similar montane ecosystem and because recent aerial overflights indicated that areas of the forest were being utilized by people from nearby towns and villages. These overflights took place over a two-day period using a small high wing aircraft (Cessna 206). At this time, a log of the flight track was recorded using a handheld GPS on a one-second time setting. The survey zone centered on the main massif and within 10 km of the massif and was restricted to South Sudan only. To achieve representative coverage, surveys were conducted along latitudinal bands and each quarter of a degree cell was visited. The reconnaissance flights were flown at various speeds and altitude due to the mountainous terrain with average speeds at approximately 145 km/hr and at a height of 500 – 700 feet above ground. All photographs were then geo-referenced using the GPS track log. Finally, the areas surrounding Labone and Katire were selected to represent the larger human settlements in the study area. The extent of Labone and Katire were defined using GIS-based data points supplied by the United Nations Joint Logistics Commission (UNJLC) assumed to be the center of the town/village, with the 10-km buffer radiating out from this location.

### 3.4.4 Fire and Land Cover Type

To determine the relationship between fire and land cover type, the MODIS 1 km active fire data points were restricted to the dry season months (November to April) and separated by year and the geographic areas (Figure 3-8). I selected the dry season months because a review of several years of MODIS active fire data, conversations with experts during fieldwork that took place in April 2009, and a review of the literature specific to this area (Friis & Vollesen 2005; Sommerlatte & Sommerlatte 1990) indicated that these were the months when fires were most likely to occur in this area. An analysis of the MODIS hotspot data showed in fact that very few fires occur during the wet season months.

The following procedure was used to examine the influence of land cover type on fire activity. First, the MODIS land cover datasets were exported into a GIS (ArcMAP 9.3) and aggregated from 14 categories into the following five simplified land-cover classes: (1) forest (including the evergreen needleleaf and broadleaf and deciduous needleleaf and broadleaf and mixed forest categories); (2) woody savanna and closed and open shrubland, (3) savanna and grassland and barren or sparsely vegetated; (4) croplands, and (5) urban and built up. Ultimately, the urban and built up category was removed since it comprised a negligible amount of total land cover within the study region. The MODIS land cover classification was compared with a high resolution (5m) image acquired by the SPOT (Satellite pour l'Observation de la Terre) satellite sensor in 2006 for validation purposes. Next, the active fire data points were intersected with the corresponding year of the MODIS land cover classification in a GIS, using spatial analysis tools to determine the relationship between land cover type and fire activity. The results were normalized by area for comparison.

### 3.4.5 Precipitation

Inter-annual variations in precipitation could influence fire activities in several ways. First, as vegetation growth is controlled by precipitation, variations in fire activity can be controlled by variations in fuel availability, with lower levels of fire activity following low levels of precipitation in the period prior to fire activity. On the other hand, precipitation during the fire season controls fuel moisture, with higher levels of fire activity being expected during low levels of precipitation during the fire season.

To normalize for the possible effects of inter-annual variations in precipitation on fire activity, we created a precipitation mask for the study area for the entire period the data were available (1998 to 2011) and calculated average monthly precipitation from the TRMM data. These monthly values were separated into the following categories: the two, four, and six months of the wet season immediately prior to the dry season, the dry season itself, and the entire year, for a total of five separate groupings. The average TRMM rainfall amounts for these periods for each year were correlated to total fire counts for each of the major land cover types (grassland, woodland, forest and cropland) using statistical analysis tools in Microsoft Excel. Based on the results, a regression analysis was performed for each category using the precipitation data showing the strongest correlation with fire activity for each land cover type in order to develop a rainfall/fire count adjustment coefficient.

The only significant linear correlation that was found ($p < 0.01$) in this analysis was between burn counts in woodland areas for the average rainfall during the dry season. The linear relationship between rainfall and fire count was used to normalize annual fire counts only in woodland areas. The result of this normalization was an increase in fire counts during low fire years, and a decrease in fire counts in high fire years. The adjusted woodland fire activity counts were then combined with the unadjusted fire counts for the other land cover types to create war and post-war averages for the seven distinct geographic regions.

### 3.4.6 Fire and Population Density

I calculated mean population density for 2005 and 2010 using the CIESEN Gridded Population of the World (GPWv3) data (CIESEN 2005) for each of the 7 sub-regions in South Sudan and northern Uganda. These two dates coincide roughly with the end of the war (2005) and five years post war (2010), providing a controlled experiment to determine the effects of population density with fire activity. After confining the population data to the study area, we compared the mean population density value for each of the 7 sub-regions with the corresponding precipitation-adjusted active fire data.

## 3.5 Results

### 3.5.1 Precipitation Adjustments

The results from using TRMM data to adjust the fire counts are shown below. As an example, Figure 3-9 shows the comparison between active fire counts in woodland areas and precipitation during the dry season and Figure 3-10 shows the difference between actual vs. normalized fire counts in woodland areas where a correlation was found.

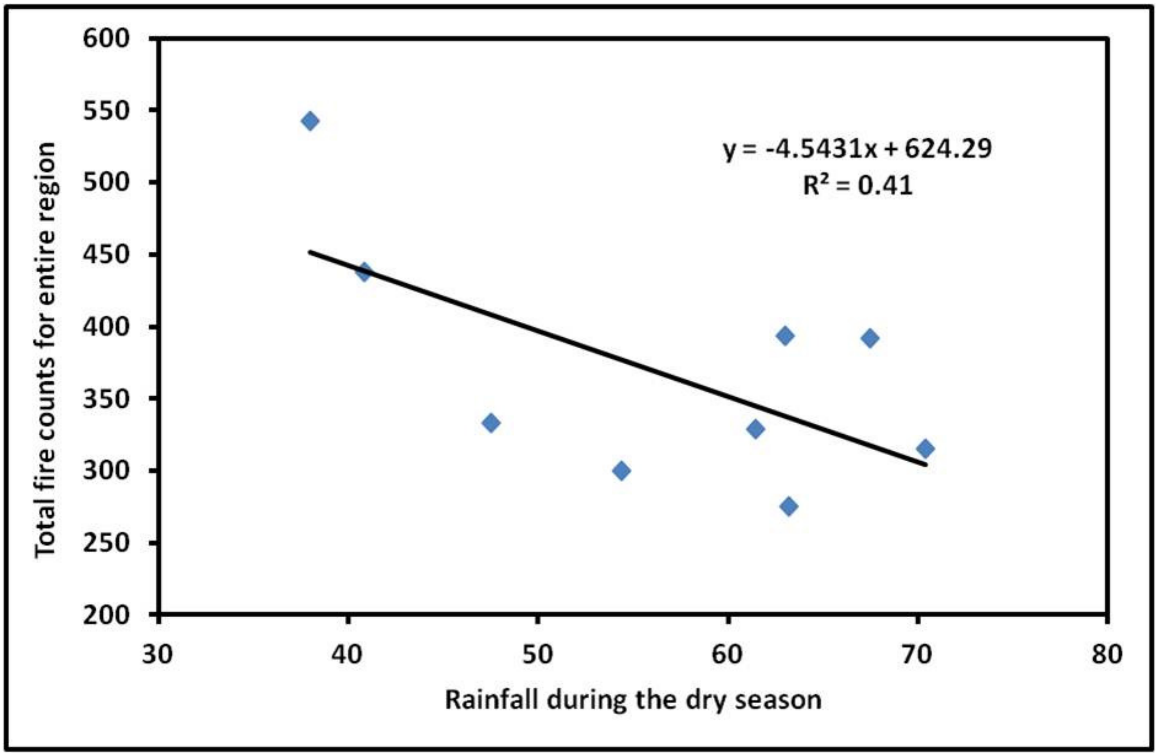


**Figure 3-9: Comparison between active fire counts in woodland areas and precipitation during the dry season. The $R^2$ value of 0.41 shows a negative relationship between rain and fire within this land cover type during the dry season months – that is, fewer fire counts with increased rainfall. No significant linear correlation was found between active fire counts and precipitation in other land cover types.**

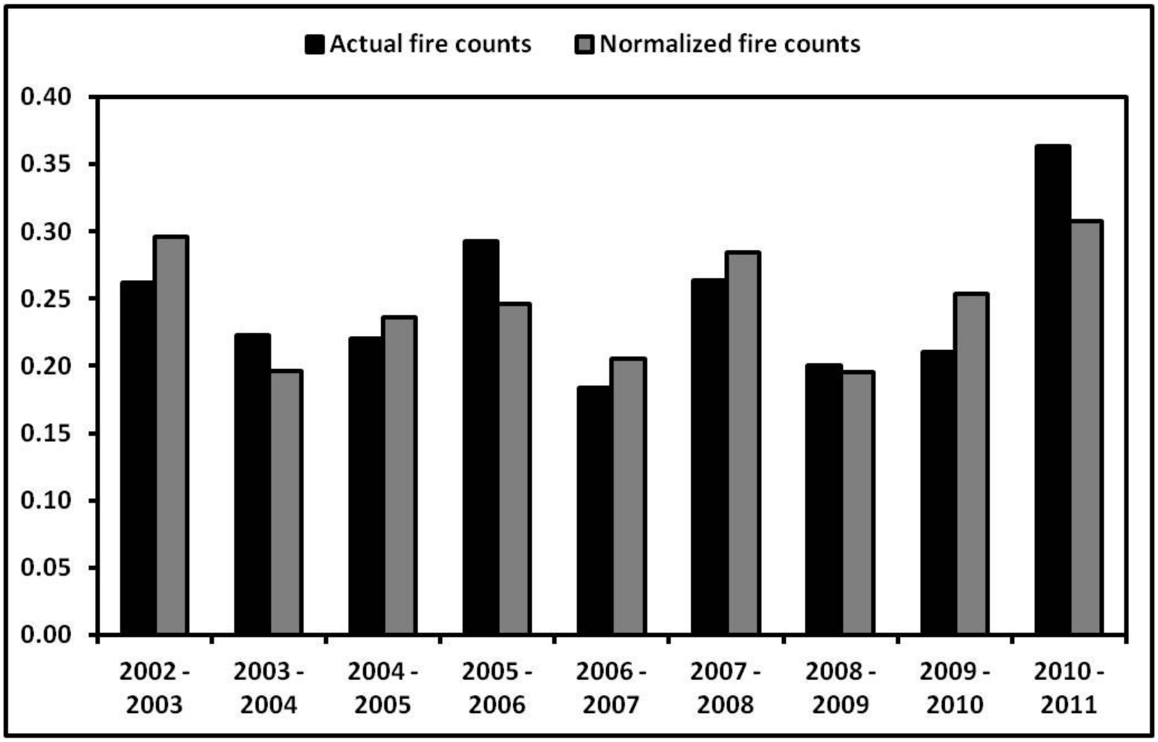


**Figure 3-10: Difference between actual vs. normalized fire counts in woodland areas where a significant correlation was found between active fires and precipitation. The result of this normalization was an increase in low fire years, and a decrease in fire counts in high fire years.**

### 3.5.2 General Fire Trends

Overall, fire activity on the northern Uganda side of the study area was greater than that on the South Sudan side both during and after conflict. In South Sudan, fire activity remained relatively constant with values ranging from 0.10 to 0.19 fires per km$^2$. The last year fire season on record (2010/2011) recorded the highest number of fires for the South Sudan series – other post-war increases in fire activity occurred during the 2005/2006 and 2007/2008 fire seasons (Figure 3-11). In Uganda, fire counts were highest during the 2002/2003 and 2007/2008 dry seasons, after which time they steadily decreased until the 2010/2011 fire season, which saw another spike in fire counts. (Figure 3-11).

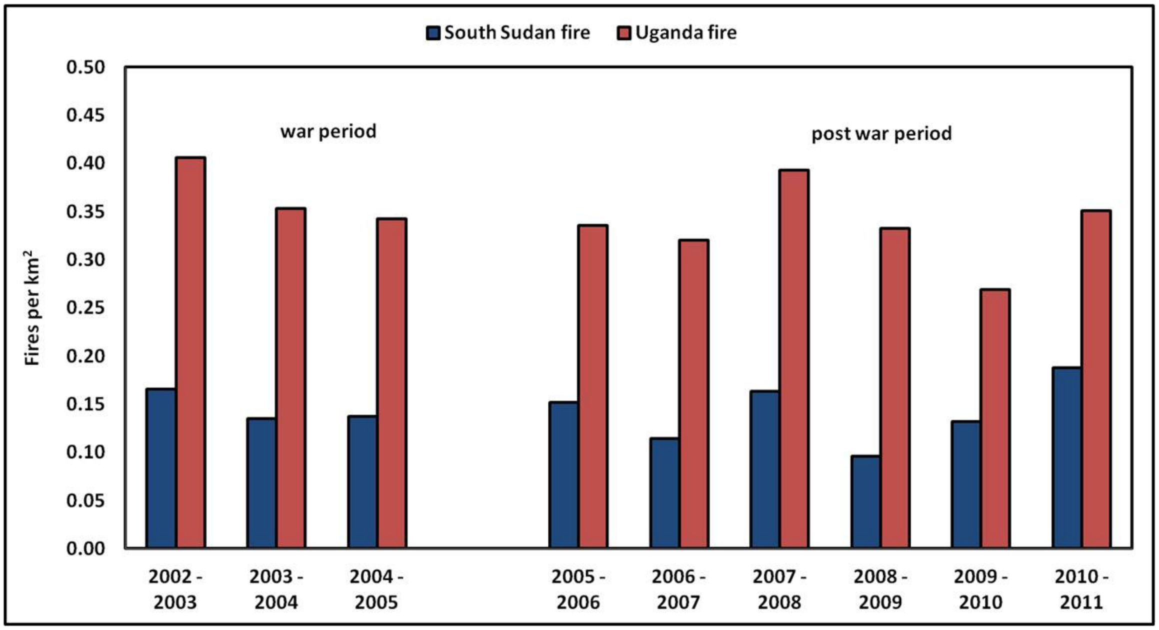


**Figure 3-11: Summary of fire counts in South Sudan and northern Uganda per km$^2$. Each year (e.g. 2002 – 2003) represents the dry season only (November to April) when fires are most prevalent.**

### 3.5.3 Fire and Land Cover Type

The land cover classification accuracy assessment showed the MODIS land cover classification has an overall accuracy of 77.5% and a Kappa Coefficient of 0.649 (Table 3- 2). The highest percent of error occurred between grassland and woodland.

**Table 3-2: Validation of MODIS land cover classification using 5m imagery acquired from SPOT satellite sensor. We used 50 points for each of the three classes – forest, grassland, and woodland – based on a stratified random sample technique.**

| | | Observed Class | | | | |
|---|---|---|---|---|---|---|
| | | **Forest** | **Grassland** | **Woodland** | **Total** | **Commission (percent)** |
| **Predicted Class** | **Forest** | 41 | 1 | 3 | 45 | 8.89 |
| | **Grassland** | 2 | 15 | 4 | 21 | 28.57 |
| | **Woodland** | 7 | 8 | 30 | 45 | 33.33 |
| | **Total** | 50 | 24 | 37 | 111 | |
| | **Omission (percent)** | 18.00 | 37.50 | 18.92 | | |

**Overall Accuracy = 77.5%**
**Kappa Coefficient = 0.649**

The average area of land cover type in the South Sudan study area as compared to the northern Uganda study area (using 2005 land cover data) indicates that the percentage of woodland vs. grassland is larger in the South Sudan study area than in the northern Uganda study area, and that forests in general make up a larger percentage of total area on the South Sudan side (Table 3-3).

**Table 3-3: Comparison of land cover types for South Sudan and northern Uganda study area for 2005 using MODIS land cover product (MCD12Q1) at 500 m resolution.**

| | **South Sudan** | | | **Uganda** | | |
|---|---|---|---|---|---|---|
| | **Surface area in km$^2$** | **% of S. Sudan study area** | **As a percentage of the total area** | **Surface area in km$^2$** | **% of N. Uganda study area** | **As a percentage of the total area** |
| **Forest** | 715 | 30% | 23% | 20 | 3% | 1% |
| **Woodland** | 1191 | 50% | 39% | 256 | 38% | 8% |
| **Grassland** | 430 | 18% | 14% | 395 | 58% | 12% |
| **Cropland** | 58 | 2% | 2% | 9 | 1% | 0% |
| **TOTAL** | 2394 | 100% | 78% | 680 | 100% | 21% |

Results comparing fire activity and land cover type indicate that on the South Sudan side of the border, there was generally limited fire activity in forested areas. In contrast, fires in woodlands were consistently high, particularly during the five most recent years when fire activity in this land cover type was greater than in any other type. Cropland fires in South Sudan were highest in 2002/2003 and also in 2005/2006, but otherwise fires in this land cover type tended to be minimal (Figure 3-12). In Northern Uganda, a significant spike in forest fires occurred during the 2005/2006 fire season compared with other years, particularly the preceding year when no fires occurred in this land cover type. (Figure 3-13). The number of grassland fires in northern Uganda was generally consistent across war and post-war years, averaging 0.27 fires per km$^2$ over the entire time series.

Fires in the cropland land cover type were much higher in the post-war years, particularly the 2009/2010 fire season.

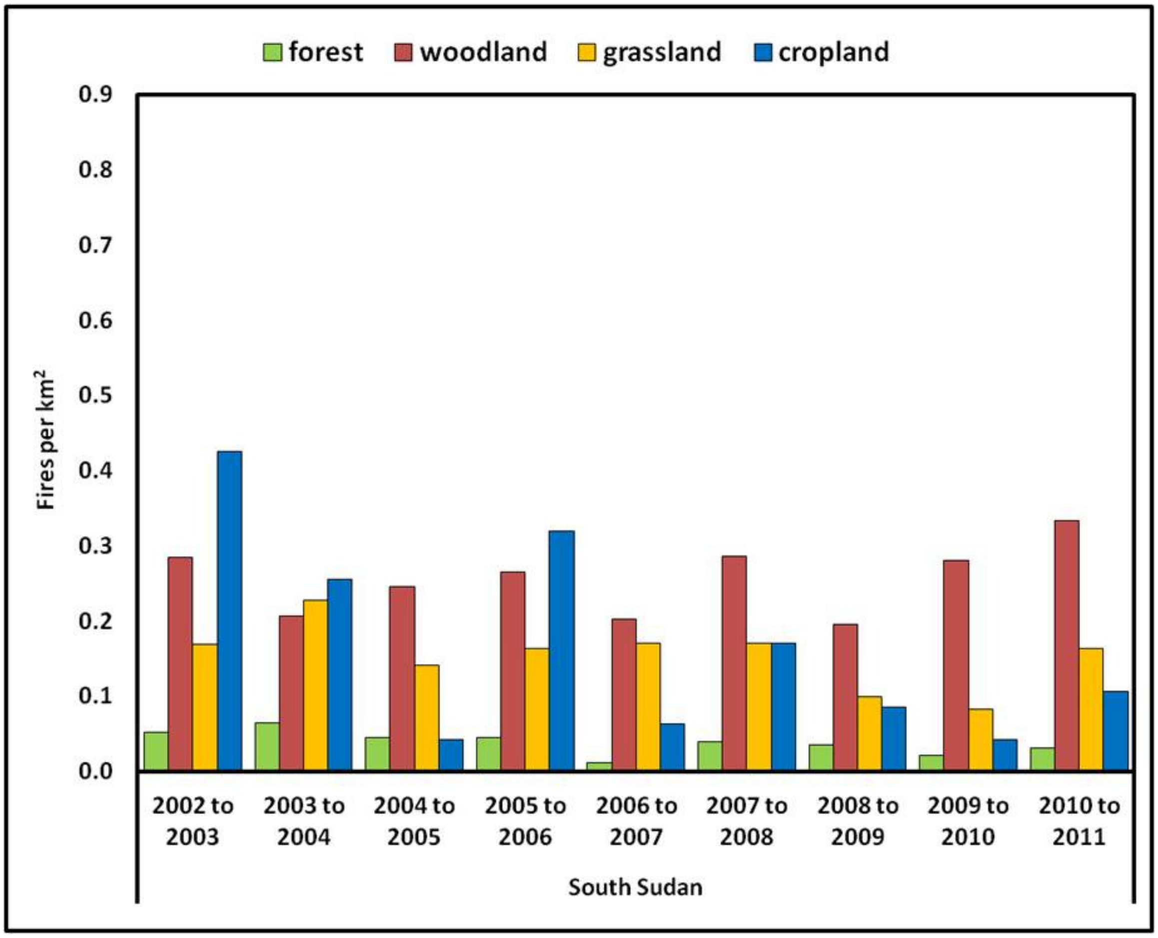


**Figure 3-12: Fire activity and land cover type in the South Sudan side of the study area. Forest fires are minimal, while fires in woodlands tend to remain relatively consistent each year.**

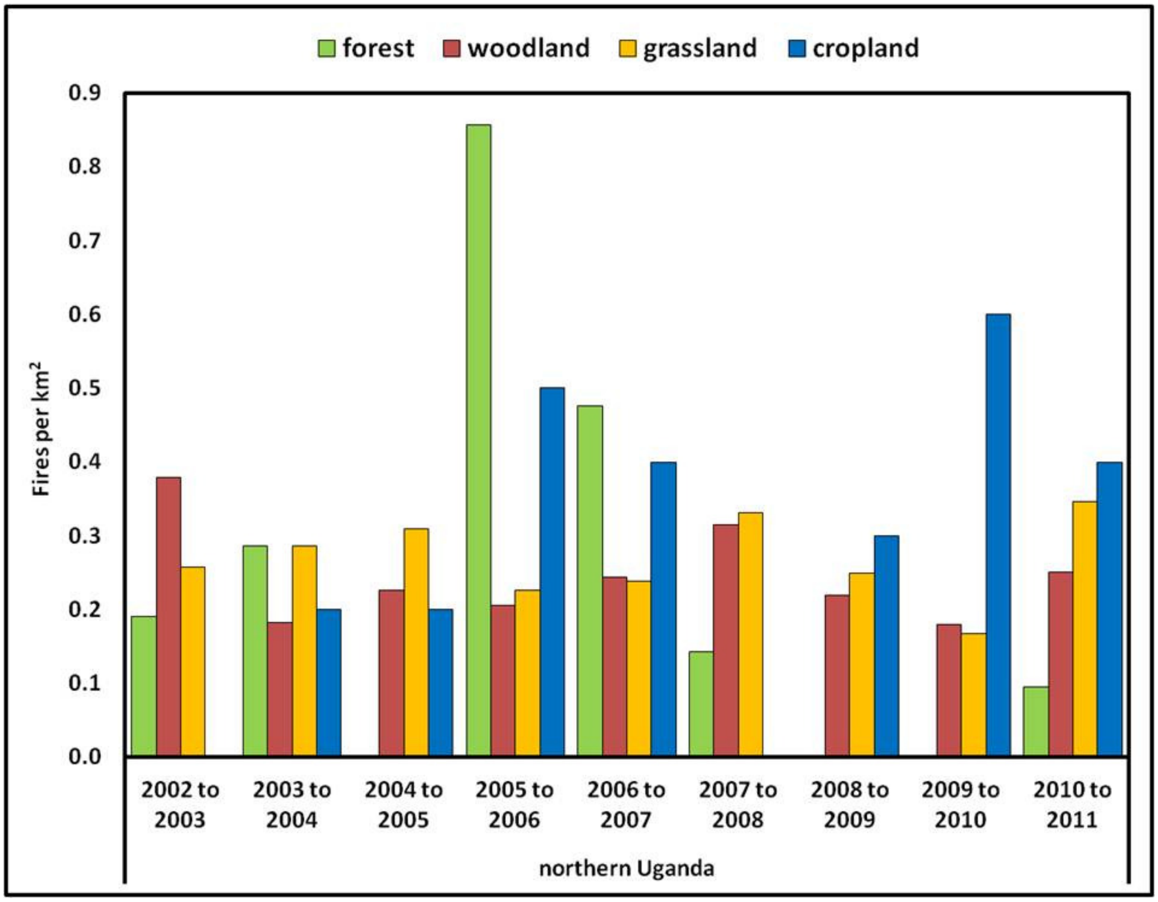


**Figure 3-13: Fire activity and land cover type in the northern Uganda side of the study area. While fires occurring in the grassland and woodland land cover types are generally constant, fires in cropland and forest vary from year to year, with the largest spike in forest fires occurring during the 2005/2006 fire season. .**

### 3.5.4 War vs. Post-War Fire Counts

A comparison of war and post-war fire activity in the different geographical areas shows that following the signing of the peace agreement in 2005, overall fire activity decreased for all areas except for the settlements of Katire and Labone, (Figure 3-14). The increase in Labone is likely due to population and land use shifts resulting from the departure of the Dinka IDPs and the resulting influx of native Acholi returning from

Uganda, though further research is needed to compare the effects of differing land use practices on fire patterns between these two tribal groups.

The ICFR and the Dongotana Hills had the lowest fire activity in South Sudan. The buffer areas surrounding both the ICFR and the AFR experienced higher fire activity than the ICFR and AFR themselves, which may reflect the tendency of people to settle around the forest edge in order to have access to timber and non-timber resources therein. This also shows that human activities are having less of an impact within the ICFR than outside its borders.

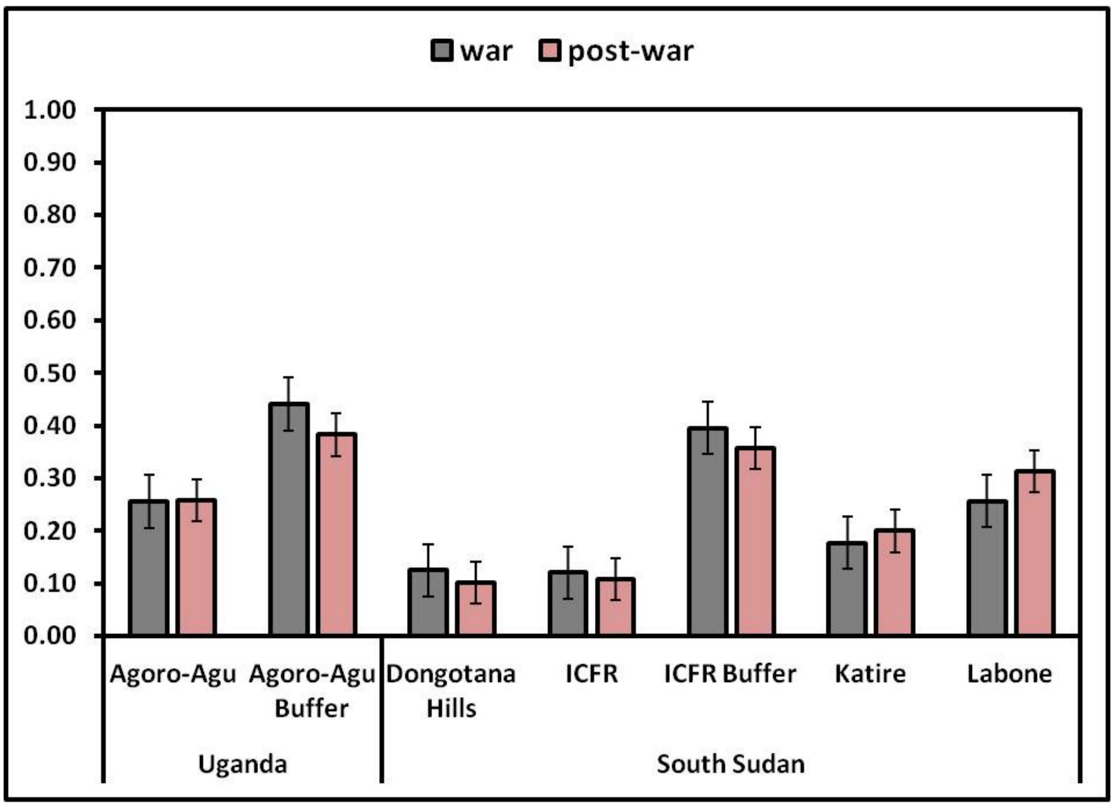


**Figure 3-14: War vs. post-war fire activity for all land cover types in each of the 7 sub-regions. Fire activity decreased in all areas post-war with the exception of Katire and Labone, each of which saw a slight uptick in fires. The error bars used in this and all subsequent graphs depict the standard error, calculated by dividing the standard deviation of the series by the square root of the sample size.**

When war and post-war fire activity is compared with the three main land cover types, the trends are somewhat different. For grasslands, all areas in both the South Sudan and northern Uganda study areas see a decrease in the number of fires occurring in this land cover type (Figure 3-15), with the exception of Agoro-Agu, where fire counts are roughly equal. Grassland fires drop precipitously in Katire following the war. The majority of the increase in post war fires in Katire and Labone occurred in woodland areas. There is also a small increase in fire counts in the ICFR for woodlands (Figure 3-16). Fire counts in forested areas are relatively low in number, with the exception of the Agoro-Agu buffer where war and post-war fires are much higher than in the AFR itself, perhaps reflecting the area's inaccessibility. In contrast to the AFR buffer, forest fires in the ICFR buffer decrease during the post-war years. (Figure 3-17). Cropland fires increase in Ago-Agu and its buffer following the war, possibly indicating that once the IDP camps were closed, people were allowed to settle in the area and cultivate freely without fear of being attacked by LRA soldiers.

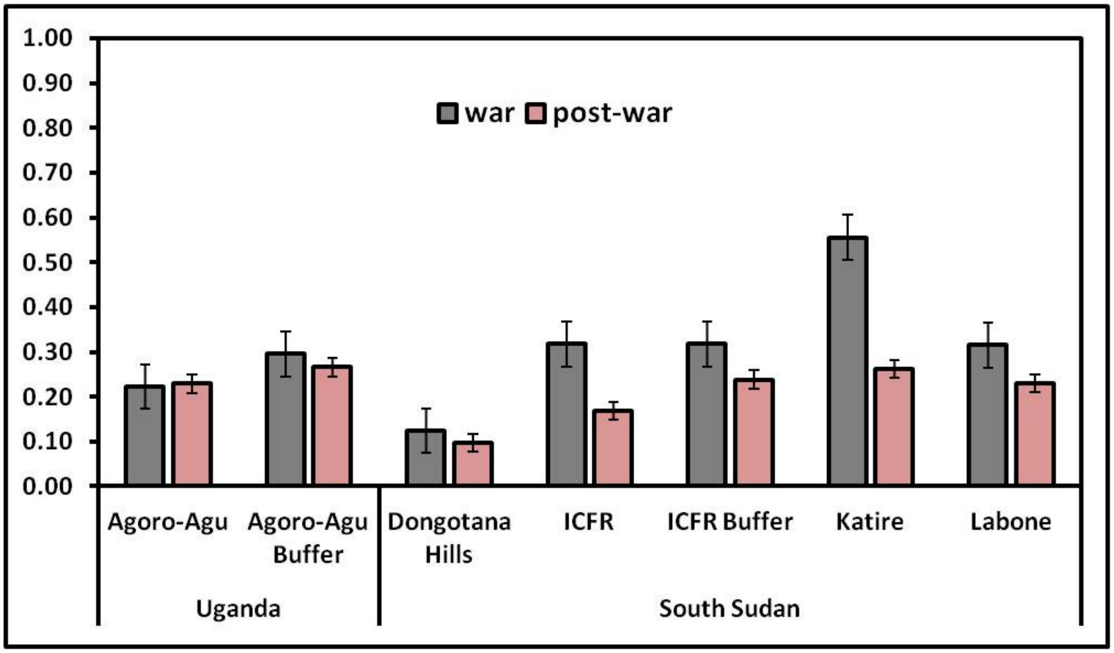


**Figure 3-15: War vs. post-war fire activity in the grassland land cover type. Fires in grasslands decrease post-war in all areas of analysis, except for in Agoro-Agu where they remain relatively constant.**

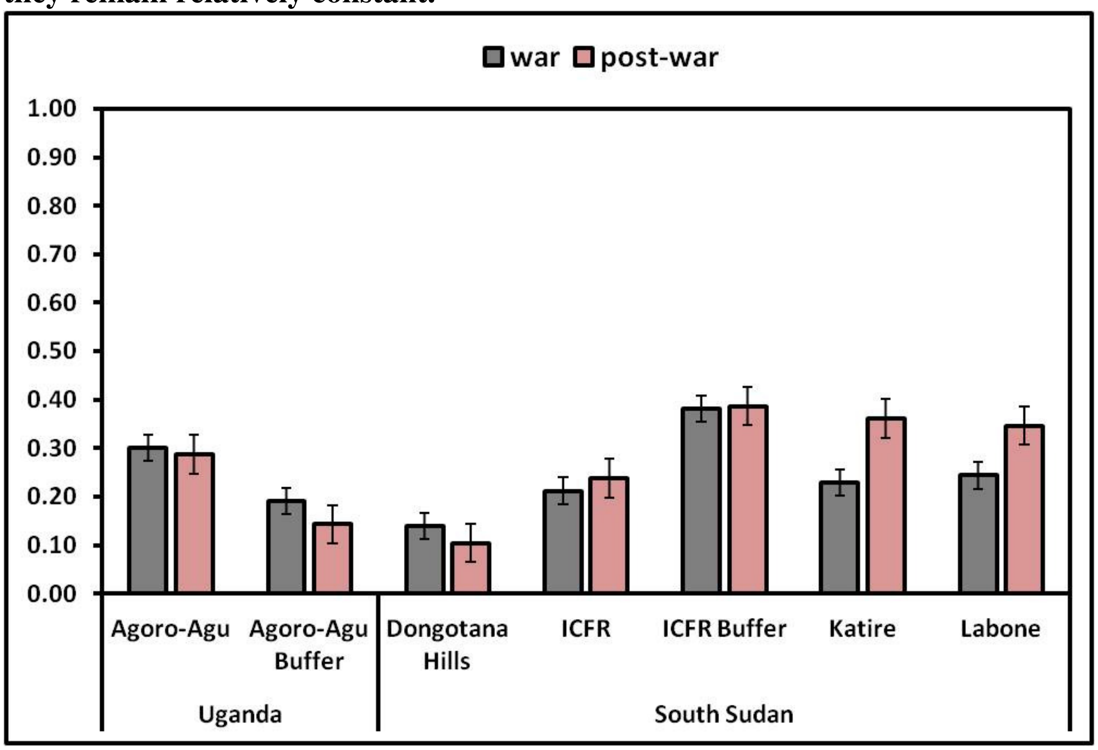


**Figure 3-16: War vs. post-war fire activity in the woodland land cover type. Fires in woodlands increased in Katire and Labone in South Sudan, as well as within the ICFR, post-war. In all other areas, woodland fires decreased or stayed the same following the end of the war.**

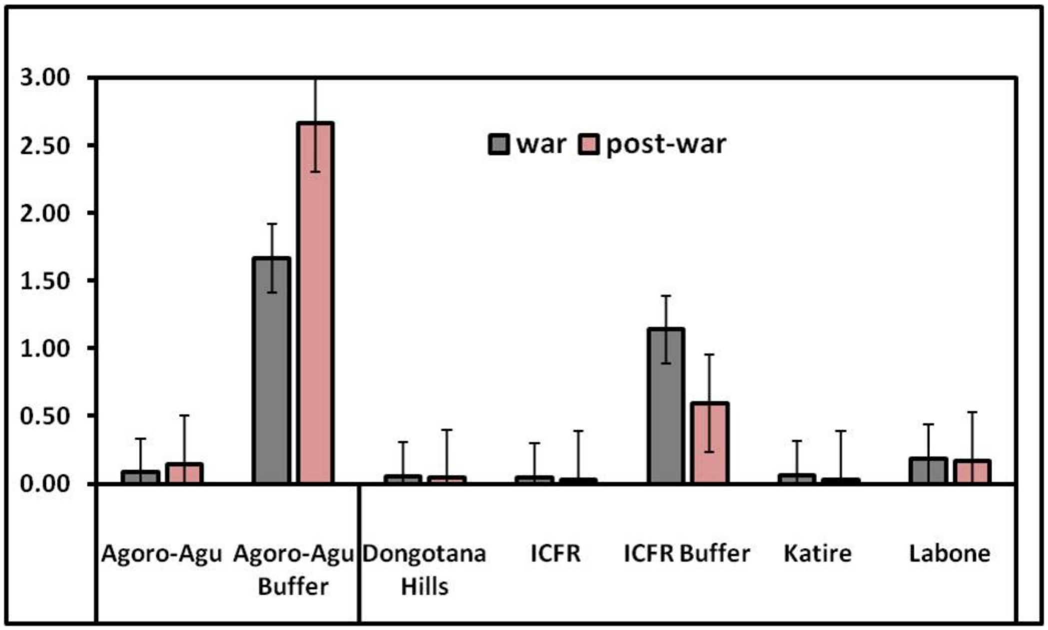


**Figure 3-17: War vs. post-war fire activity in the forest land cover type. Fires in forests made up a relatively small portion of overall fire activity except for within the two forest reserve buffer areas, where they showed opposite trends, increasing in Agoro-Agu buffer and decreasing in the ICFR buffer after the war.**

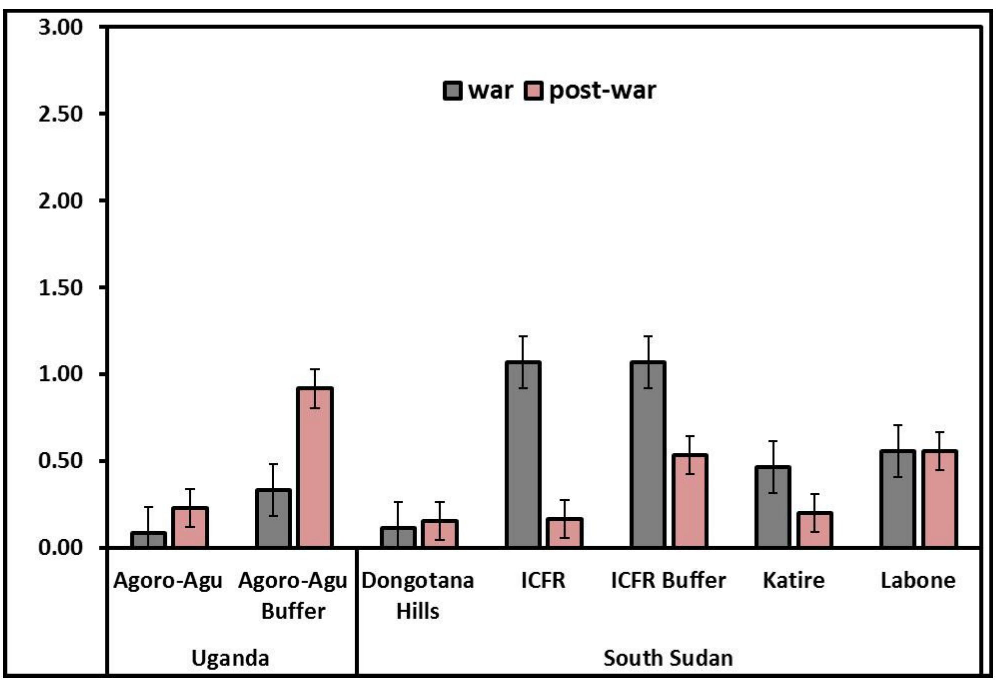


**Figure 3-18: War vs. post-war fire activity in cropland land cover type. Fires decrease precipitously in the ICFR, its buffer and Katire, and increase in all areas of northern Uganda following the war's end.**

### 3.5.5 Fire and Population Density

General population trends for the 7 sub-regions between 2005 and 2011 are shown below in Figure 3-18. According to results using CIESEN data, population density has increased in all of the 7 sub-regions of the study area. This would be expected in South Sudan, where people have been returning since the end of the war. In northern Uganda, the earlier figures (see Figs 3-4 and 3-5) clearly show that people are leaving the IDP camps; however, with population density increasing in both Agoro-Agu and its buffer according to the CIESEN data, it is possible that people are still living in the general area – perhaps in nearby villages – and without security concerns related to the LRA, are able to move more freely into the Agoro-Agu Forest Reserve. This conclusion cannot be corroborated, however, and requires additional fieldwork to verify that population densities are in fact increasing since the CIESEN data may not adequately reflect population changes in areas where significant population displacement has occurred since the last enumeration (Deichmann et al. 2001).

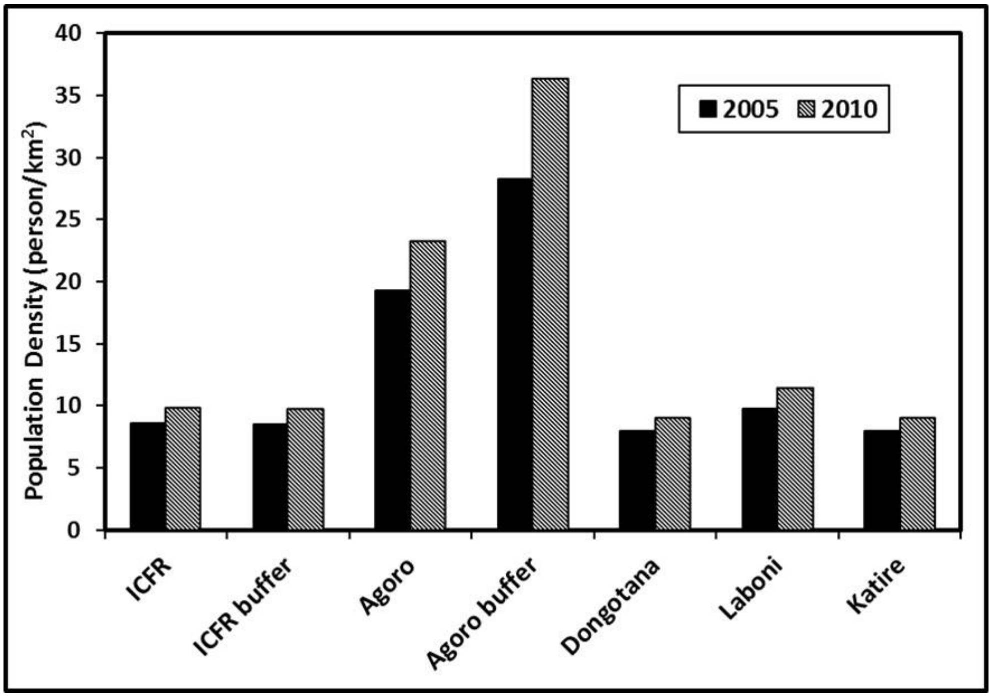


**Figure 3-19: Population density for each of the 7 sub-regions (2005 and 2010) using CIESEN gridded population of the world (GPW v3) database. CIESEN data are presented in raster grids at 2.5 arc minutes per side. Estimates are derived using country specific census data for two recent population estimates to compute an average annual population growth rate.**

There was no significant correlation between population density and total fire counts for all regions for both years, but a positive correlation between population and total fire counts for the savannah grasslands cover type ($R^2$= 0.71, $p < 0.004$). These correlations were higher when the two years were compared individually ($R^2$ = .75, $p < 0.001$ for 2005 and $R^2$ = 0.86, $p < 0.001$ for 2010) as shown in Figure 3-19 below.

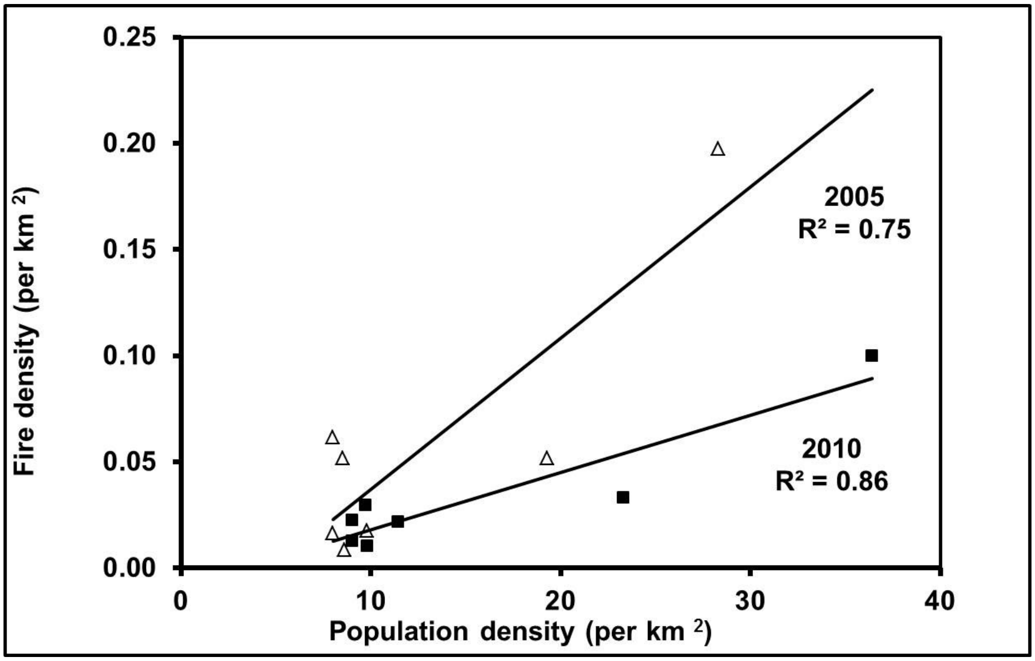


**Figure 3-20: Population density and fire counts for grassland savannas show a positive correlation for 2005 ($R^2$ = 0.75) and 2010 ($R^2$ = 0.86). No significant correlation was found between population density and fire counts in other land cover types.**

## 3.6 Discussion

The time-series plots in Figures 3-11, 3-12 and 3-13 present the evolution of fire activity over time in both the South Sudan and northern Uganda study. Several international organizations monitor the return (assisted and spontaneous) of refugees, IDPs, and migrants. While exact numbers for each category are unknown, in general the flow of returnees to South Sudan has been gradually accelerating since the signing of the CPA in 2005, with returns peaking in 2007 (Pantuliano et al. 2008). In northern Uganda, IDP populations in Kitgum District in Northern Uganda have been steadily decreasing over the last decade, however, overall population densities also appear to be rising in both Agoro-Agu and its buffer.

Differences in spatial scale along with temporal lags make it difficult to definitively link trends in fire activity to changes in human population patterns. However, two possible explanations for the slight rise in fire activity in 2005 and 2007 in the Imatong region of South Sudan are a) the expulsion of the LRA around this time causing some to return to their villages, and b) an increase in the number of people returning to the area in anticipation of the 5$^{th}$ Population and Housing Census in 2008. The slight rise in fire activity in the 2009/2010 dry season may be due to increased returnees in anticipation of the 2011 Referendum on Independence. In contrast, the steady decline in fire activity in the Agoro-Agu region of northern Uganda from 2007 to 2010 may be due to the gradual departure of IDPs from camps in this area following a cessation in attacks by the LRA. The recent upsurge in fires in northern Uganda in 2010/1011 and the fact that they mainly occurred in croplands may indicate that people who left the camp are resettling in nearby villages and using fire to clear land for crops, which they were unable to do during the 'protected villages' campaign. The CIESEN data shows that population density for Agoro-Agu and its buffer have substantially increased between 2005 and 2010 (roughly doubling from 20 to 40 people/km$^2$), possibly indicating an increase in fragmented fuel beds that comes with higher populations (Archibald et al. 2009; Guyette et al. 2002; Syphard et al. 2009) and/or perhaps reflecting changes in the use of fire – for example, the improved security situation may make burning around IDP camps to improve visibility no longer necessary.

Overall, the results of the population density/fire activity analysis indicate that for the entire South Sudan study area, population density and fire activity are inversely related – that is, as population density increases slightly from 9 – 10 people/km$^2$ between 2005 and

2010, fire activity goes down. The same relationship holds for the AFR and its buffer in northern Uganda, where densities are much higher (24 - 30 people/km$^2$). When taken separately, however, the larger settlements of Katire and Labone show an increase in both population density and fire during this time period. The positive relationship between fire and population density requires further investigation; however, one possible explanation is that population growth within these two areas is resulting in an outward expansion of settlements into woodland areas where fuel is plentiful. For Labone, a change in the predominant tribe occupying the area (from pastoralist Dinka to agro-pastoralist Acholi) might account for differing land use practices resulting in an increase in fire ignitions.

Comparing average fire activity during and post-war shows that fires have generally decreased for all areas except woodlands in the South Sudan study area. This is most likely because the higher population areas are located closer to woodlands than any other land cover type in general in South Sudan, versus northern Uganda where the proportion of woodland and grassland near camps and villages is roughly equal. In comparison, fires in forested areas and cropland are noticeably fewer – likely for the same reason. That is, while people set fires in forests for hunting and honey collection, this occurs on a limited basis due to the rugged terrain. It is also true that some of the smaller fires may not be picked up by the MODIS sensor – particularly if they occur underneath heavy tree canopy and/or are short-lived. During the war years in South Sudan, people who fled to the forests rather than leave the area may have limited their use of fire in order to remain hidden – this includes members of the LRA who were known to have their camp in the montane forests of the Imatong Mountains in the early 2000s, thus accounting for the low number of fires.

Notably, fire activity in the ICFR buffer area is greater than that of the larger village and town, perhaps indicating that people have settled around the forest area to make use of forest and non-forest resources during times of both war and peacetime. In the Agoro-Agu area, fire activity largely declines after 2005 in all land cover types except in the forest and cropland land cover types. This may be due to shifting population and land use practices away from camps and into villages located closer to the Agoro-Agu Reserve.

The underlying premise of this study is that Sudan was at war from 1983 to 2005 and has been at peace since the signing of the CPA in January 2005. However, this is clearly an oversimplification that assumes that the entire country (the largest in Africa) is either completely embroiled in conflict or entirely at peace. As with all conflicts, the actual battles are localized and occur at a specific time and place. Therefore, although Sudan was officially entangled in civil war, actual fighting and the resulting displacement occurred in certain areas at varying times with complex results in terms of the impact on populations and land use patterns. Similarly, the return of IDPs and refugees is not instantaneous, making the 2005 cut-off date somewhat unrealistic. Despite this, given the relatively short period of time within which such large shifts in population occurred in a continuous ecosystem, this area offered an ideal area to conduct such an analysis on anthropogenic fire.

## 3.7 Conclusion

As with other studies, this research has found evidence that people are associated with the frequency and spatial distribution of fire, despite variations in fire history, land-use history and socio-economic and political conditions (Prasad et al. 2008; Syphard et al. 2007; Verlinden & Laamanen 2006). Whether in a conflict or peace zone, this type of research can lend insight into the causes and consequences of anthropogenic fires with important implications for conservation and land use planning and management. In the Imatong Mountain region of South Sudan, creating and enforcing laws designed to manage fires, in concert with regulations pertaining to hunting, forestry and agriculture, are critical if the existing and highly-biodiverse lowland and montane forests are to be preserved. This is particularly urgent given the ongoing and expected increase in human populations during a time of welcome peace and stability in the region. Similarly, in northern Uganda, efforts should be taken to successfully reintegrate IDPs that encourage self-sufficiency based on agriculture that can sustain current and future generations in the foreseeable future.

In the absence of fine-scale, time-series data on population numbers, satellite-derived fire products - combined with land cover type and coarse population trends - can provide insight into land use patterns of human populations. Because of the decades-long conflict, reliable and complete household-level data were not available for this study. As an alternative, population density can allow for simple comparisons among and between geographical areas. However, it is important to note that population density alone does not give any reliable indication of the impact of people on the land since there are as many examples in mountainous regions where the relationship between population density and deforestation is positive, as there are examples where this relationship is negative (Templeton & Scherr 1997). In addition, the data used in this analysis was based on national census data, which is often questionable, and future projections that do not take into account abrupt population increases or decreases resulting from conflict (Deichmann et al. 2001). Despite these limitations, in the case of the Imatong Mountain region in South Sudan and the adjacent Agoro-Agu forest area of northern Uganda, results from this analysis indicate that general trends in fire activity were consistent with changes in populations impacted by conflict. Ideally, this analysis should be supplemented with qualitative analysis involving interviews/questionnaires focusing on history of population movements and land use changes over time to verify and expand upon the results. Future studies in this area might examine the relative importance of other non-anthropogenic factors such as topography and include the potential impacts of climate change and its impact on fire ignition and extent.

# 4 Human Dimensions of Land Use and Land Cover Change Related to Civil Unrest in the Imatong Mountains of South Sudan[6]

## 4.1 Summary

*Civil unrest disrupts not only the lives of people in the area, but also the environment in ways not well understood. Armed conflict generally has a negative impact on the immediate environment; however, the absence of people due to war can be beneficial to local ecosystems and wildlife. Lack of access to a war zone during conflict makes it difficult to gather primary data on the effects of conflict in real time. Satellite imagery has been used successfully to document changes on the landscape during and after war; however additional information is needed to explain the underlying drivers of these observed changes in land use and land cover. To understand how human decisions and actions during war and peace impact land use and subsistence practices, we combined results from key informant interviews with observations made from remotely-sensed satellite imagery and compared expected results with findings in seven major thematic areas. In the high biodiversity region of the Imatong Mountains in South Sudan, we discovered that while some people fled the area during the various conflicts, many others escaped to higher ground to live off the resources available from the forest. Earlier studies indicated that the impact on forest cover during and after the war were minimal in the Imatong Mountains, and extensive in the nearby Dongotana Hills. Discussions with local inhabitants confirmed these findings and provided further explanation for how migration and land use patterns impacted forest cover and wildlife in this volatile region.*

## 4.2 Introduction

The field of 'land change science' seeks to understand the human and environmental dynamics that give rise to changed land uses and covers in terms of type, magnitude and location (Rindfuss et al. 2004). Numerous advances have been made in this field using

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[6] Submitted to *Journal of Human Ecology* (Gorsevski et al. 2012a, in review).

and combining a variety of approaches across multiple disciplines in both the social and physical sciences. In addition to the socio-economic and biophysical drivers of change, it is important to account for the specific human-environment conditions within which these drivers operate (Lambin et al. 2001). War, for example, is recognized as one of many underlying causes behind tropical deforestation (Geist & Lambin 2002). Over 90% of the major armed conflicts between 1950 and 2000 occurred within countries containing biodiversity hotspots and more than 80% actually occurred within a hotspot (Hanson et al. 2009). The Imatong Mountain region in South Sudan is part of the Eastern Afromontane 'biodiversity hotspot' (as identified by Conservation International) due to the numerous species of plants found here, many of which are endemic to the region (see http://www.biodiversityhotspots.org and has also provided the backdrop to several ongoing armed conflicts over the past few decades.

Lack of reliable data and danger inherent in a warzone necessitates the use of various methods, including the use of spaceborne imagery. These data alone, however, cannot explain the individual decisions that ultimately drive changes in land use. Previous studies have used satellite remote sensing to monitor changes in forest in the Imatong Mountains and neighboring Agoro-Agu forest reserve in northern Uganda (Gorsevski et al. 2012c) and similarly to link changes in fire activity to coarse-scale population trends in this region (Gorsevski et al. 2012b). We build on these earlier efforts by recording local impressions of war and its effects, and by comparing various interpretations of satellite-derived land cover imagery in order to explore the nuances behind the overarching premise that the Sudan civil war caused mass out-migration of people, and that this trend was later reversed following the signing of the Comprehensive Peace Agreement (CPA) in 2005.

Information on human inhabitants is lacking for the Imatong Mountain region. While it is widely accepted that millions of people left Sudan during its two main civil wars (1956 to 1972 and 1983 to 2005), there is little record of current and historic human migration and land use patterns in this specific region, as the few humanitarian organizations working here were forced to evacuate during the conflicts. Because of the region's close proximity to northern Uganda as well as the shared ethnic identity of a portion of the population (the Acholi), a reasonable assumption would be that most people fled across the border to safety. If this were the case, one would expect to see the resulting impact on the natural landscape in the form of abandoned agricultural plots and regeneration of natural vegetation, as has been demonstrated in other war-torn regions (Witmer 2008). Conversely, if people remained in the area, the opposite might occur (e.g. increased deforestation in order to meet basic needs during wartime).

In this paper we present the results of a study that investigates issues related to war, land use and the environment by focusing on the Imatong Mountains and nearby Dongotana Hills – located in the State of Eastern Equatoria on the border with northern Uganda, where people living in and around the forests were deeply affected by several ongoing conflicts. Using information from interviews with local inhabitants and government officials who were shown a satellite image of the forest cover of the region, we explored how people were impacted by the Sudan civil war and other concurrent conflicts, and how decisions related to these conflicts have affected land use practices and forest cover over time.

### 4.3 Conflict and the Environment

Evidence from the current and previous centuries indicates that across the globe, armed conflicts have a negative impact on the natural environment to some degree, including adverse effects on wildlife habitat, which in turn causes changes to biodiversity (Hanson et al. 2009). Recent examples include the bombing of Kuwaiti oil wells in the early 1990s which resulted in extensive near-term air, water and land pollution (El-Gamily 2007) and changes in surface sediment and morphological features leading to land-surface degradation over the long term (Koch & El-Baz 1998; Pearce 1995). Intentional and widespread defoliation of forest vegetation using herbicidal chemical agents occurred during the Vietnam War to deny sanctuary to the National Liberation Front (FNL) (Westing 1971). More recently, chemical defoliants have been used in the so-called “war on drugs” in Columbia to eradicate cocoa production with the unintended consequence of destroying adjacent forestland (Messina & Delamater 2006). Wars often lead to a breakdown of law and order, allowing various factions to appropriate control of natural resources such as timber and wildlife to fund their war effort (Baral & Heinen 2005; McNeely 2003). In developing countries, where people tend to be more directly dependent on natural resources for their livelihoods and where democratic institutions are not always established (Kanyamibwa 1998), studies have shown that wars can greatly amplify existing threats to the environment that already existed during peacetime (Glew & Hudson 2007). Numerous examples of past and present conflicts demonstrate the negative impact of war on the environment and on biodiversity (Hanson et al. 2009) – such that a new term "warfare ecology" – has been coined to encompass this growing field of study (Machlis & Hanson 2008).

And yet there are cases where conflict has been found to have a negligible or even positive effect on the environment through the formation of a buffer or "no-go zone." Here, the absence of human activity allows for regrowth of vegetation as well as reduces hunting pressure on wildlife (Joshi 2006; Kaimowitz & Faune 2003; Kim 1997; Martin & Szuter 1999; Nietschmann 1990; Robinson & Sutherland 2002). The most frequently cited example of this phenomenon is the demilitarized zone (DMZ) between North and South Korea where the absence of humans resulted from the war's diplomatic solution. The 2.5 mile wide, 155 mile long stretch of land within the DMZ has provided a haven for wildlife, particularly migratory birds (Brady 2008; Kim 1997). Another example is the resurgence of leopards, bears and other wildlife in Jammu and Kashmir (India) due to local inhabitants' fear of being caught in exchanges between militants and security forces (Joshi 2006). As the above examples demonstrate, the impact of a conflict on a region's ecology is location-specific and depends on a multitude of inter-related factors. And finally, it must be noted that the impact of war and/or military activities on an area can be interpreted differently depending on perspective. For example, while many tout the pristine, natural landscape of the island of Vieques, Puerto Rico since much of it was converted into a wildlife refuge in 2003 when the United States Navy ended bombing and military exercises, others still view it as a deeply contaminated dumping ground (Davis et al. 2007).

One important consequence of conflict on the landscape that can be felt during and often long after the war ends involves abrupt and large scale movements of human populations. This produces either an absence of people in a formerly populated area due to their having fled the conflict or conversely, a concentration of people in 'safe havens' such as internally displaced persons (IDP) and refugee camps. There is general agreement that emigration reduces land-use pressure at the origin and increases pressure at the destination (Hugo 1996). The burden of additional people can result in deforestation, and land degradation (Allan 1987; Biswas & Tortajada-Quiroz 1996; Ghimire 1994; Hugo 1996; Sato et al. 2000) due to a dramatic increase in the demand for resources following the creation of settlements (Martin 2005). For example, the flood of refugees from Darfur to Chad in recent years put a severe strain on natural resources such as water and firewood, and competition between refugees and the local community led to violent attacks, particularly on women (Bauer 2006). Similarly, the end of the Rwandan civil war in 1994 caused 1.5 to 2 million people to move to the Democratic Republic of Congo (then Zaire) resulting in the destruction of over 150 $km^2$ of forest in the Virunga National Park by refugees (Draulans & Van Krunkelsven 2002). Conflicts over natural resource use between host and refugee communities always takes place within complex political-ecological landscapes of war (Martin 2005) and it is likewise important to note that the impact of refugees on the environment relies less on the sheer number of people involved than the political-economic processes which influence access to land which govern its use. (Black & Sessay 1997).

The return of refugees and IDPs following war's end can similarly lead to increases in intensive use and contestation of resources such as land and timber for the rebuilding of infrastructure, planting of crops, and use of pasture (Robinson & Sutherland 2002; Unruh 2002). Akagera National Park in Rwanda, for example, has been largely decimated by the influx of cattle following the return of refugees from Uganda and elsewhere (Hintjens 2006). When a conflict ends, environmental considerations are often a low priority compared with the need to rebuild infrastructure and the economy, although in some cases – such as in Uganda and Mozambique – improved policy making following war actually led to greater community participation in natural resource management (Vanasselt 2003). The lingering effects of war can also dictate where people settle. For example, the presence or absence of landmines can be a significant factor in where people choose to rebuild their communities and plant crops (Oppong & Kalipeni 2005).

Because of the inherent danger and inaccessibility of war zones, it is often difficult for researchers to gather primary information in real time. In response, some have used remotely-sensed satellite imagery to detect changes to the landscape or land use prior to, during, and after the war (Gorsevski et al. 2012c; Suthakar & Bui 2008; Witmer 2008). While results of remote sensing analysis are a useful and cost-effective means of identifying land cover types and change over time, it is only through direct interaction with the populace that one can begin to understand the complex ways in which people are influenced by conflict and how they in turn make decisions that impact land use, land cover, and subsistence resources during and after war. In this case, products derived from remotely-sensed satellite imagery can provide the spatial context within which people discuss their experiences and locate areas of interest as a springboard for discussion (Rindfuss & Stern 1998).

## 4.4 Study Area

The Imatong Mountains and nearby Dongotana Hills of South Sudan are located at the South Sudan – Uganda border between 3°40’ and 4°20’ North latitude and 32°30’ and 33°10’ East longitude. The boundaries of the study region were selected to include the Imatong Central Forest Reserve (ICFR) and the Dongotana Hills located to the northeast of the Reserve. The ICFR spans 1,032 $km^2$ (Sommerlatte & Sommerlatte 1990) and the forested area of the Dongotana Hills is approximately 21 $km^2$. The ICFR was named a forest reserve in 1952 (Sommerlatte & Sommerlatte 1990); however, actual management and law enforcement have been lacking as a consequence of the civil war (Figure 4-1).

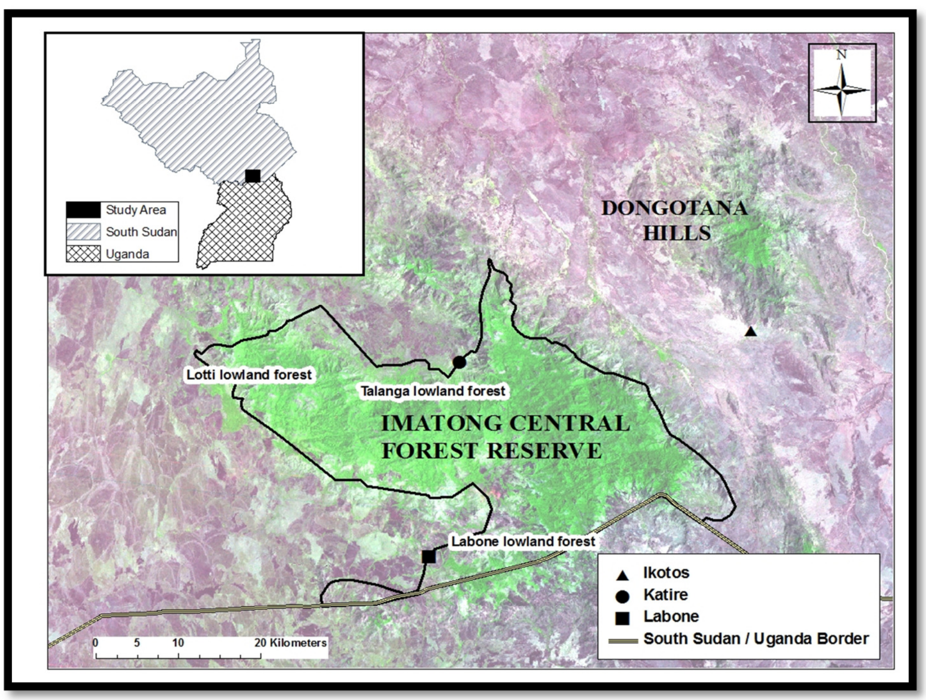


**Figure 4-1: Study Area including the Imatong Central Forest Reserve (ICFR) and nearby Dongotana Hills – both in South Sudan near the border with northern Uganda. The baseline satellite image is at 57 meters resolution in true color such that green represents vegetated areas. The image was taken in February, during the middle of the dry season.**

The mountains form a northern continuation of the upthrusts as part of the great East African mountain systems (Chipp 1929). Altitudes in the study region vary from 568 m to 3172 m above sea level (A.S.L.). The mountains consist of granitic crystalline rocks, most of which are folded and foliated and soils largely fall within the following four categories: (1) dark cracking clays, (2) non-cracking clays, (3) red loam and ironstone soils, and (4) hill or mountains soils. Major vegetation types range from *Albizia-Terminalia* woodlands and savannas in the lowland zone to *Erica* thickets in the Ericaceous zone. The forests, woodlands and grasslands tend to reflect differences in elevation, climate, soil conditions and past land use (Jackson 1956). The vegetation is divided into three major vegetation zones according to altitude and vegetation associations (Table 4-1).

**Table 4-1: Vegetation zones and associations in the ICFR (adapted from Sommerlatte and Sommerlatte, 1990).**

| Zone | Area (km.) | Vegetation Association | Phytogeographical Region |
|---|---|---|---|
| Lowland (<1,800 m.) | 234 | Lowland woodland | Sudano-Gambesian |
| | 90 | Lowland and Intermediate forest | Guineo-Congolian |
| | 14 | *Oxytenanthera* bamboo thicket | Sudano-Gambesian |
| Montane (1,800 m. – 2,900 m.) | 49 | Montane grasslands | Afromontane |
| | 85 | *Veronia* bush thicket | |
| | 29 | *Hagenia* woodland | |
| | 184 | Albizia forest | |
| | 298 | Mixed *Podocarpus* forest | |
| Alpine (>2,900 m.) | 2 | *Erica* shrub thicket | Afro-Alpine |

As indicated in Table 4-1, a large portion of the ICFR is comprised of lower and upper montane forests which are characterized by the occurrence of *Podocarpus milanjianus*, interspersed with a number of other tree and shrub species as well as montane grasslands and bare rock (Jackson 1956). There are also three major areas of lowland rain forest at Lotti, Talanga and Labone and these are not or only partially included in the ICFR (Jackson 1953). Of the lowland forests, only the Lotti forest remains largely intact (Figure 4-1). Most people live on the lower slopes and foothills (between 700 and 1,500 meters); between 1,500 and 2,000 meters, there are generally small clustered groupings of households with about 5-10 huts per settlement connected to each other through an extensive network of footpaths (Grossmann et al. 2009).

Although the forests of the Dongotana Hills are similar in structure and composition to those of the ICFR, the area has never formally been declared as a conservation reserve. The closest large town, Ikotos, is located roughly 10 km due south of the forested area of the Dongotana Hills (Figure 4-1), with an estimated population of 20,242 in 2007 including small villages surrounding the town (UNHCR 2007b). This area saw relatively little fighting during most of the Sudan civil war between the Sudan People's Liberation Army (SPLA) and the Government of Sudan (GoS) until the late 1980s when the SPLA entered the area and caused many of the primarily Lango people to flee to IDP camps in GoS-controlled areas such as Torit, Juba and Khartoum, or else to refugee camps in Uganda and Kenya (Ochan 2007). Though many people have returned, insecurity remains due to inter-tribal cattle raiding and banditry (Kanani 2006).

Administratively, the Imatong Mountains and Dongotana Hills are located in the State of Eastern Equatoria, whose capital city is Torit and which is comprised of 7 counties, of which the study area spans two (Magwe and Ikotos). The main tribes in the study region are the Acholi, the Lango, and the Latuka – each of which have their own distinct sub-tribes. While the Acholi are mainly farmers with few livestock, the Lango and Latuka practice some form of agro-pastoralism with varying degrees of livestock holdings ranging from 3-5 cattle and 6-19 goats for poor families to 21-40 cattle and 45-60 goats for better-off families (Muchomba & Sharp 2006). In addition, the town of Labone was an IDP camp beginning in the mid-1990s for some members of the Bor Dinka tribe that were relocated from further north following inter-tribal fighting (Dowden, R. (1994, February 10). Attack Forces Sudan Refugees to Flee Camp. *The Independent*. Retrieved from http://www.independent.co.uk/). (Figure 4-2).

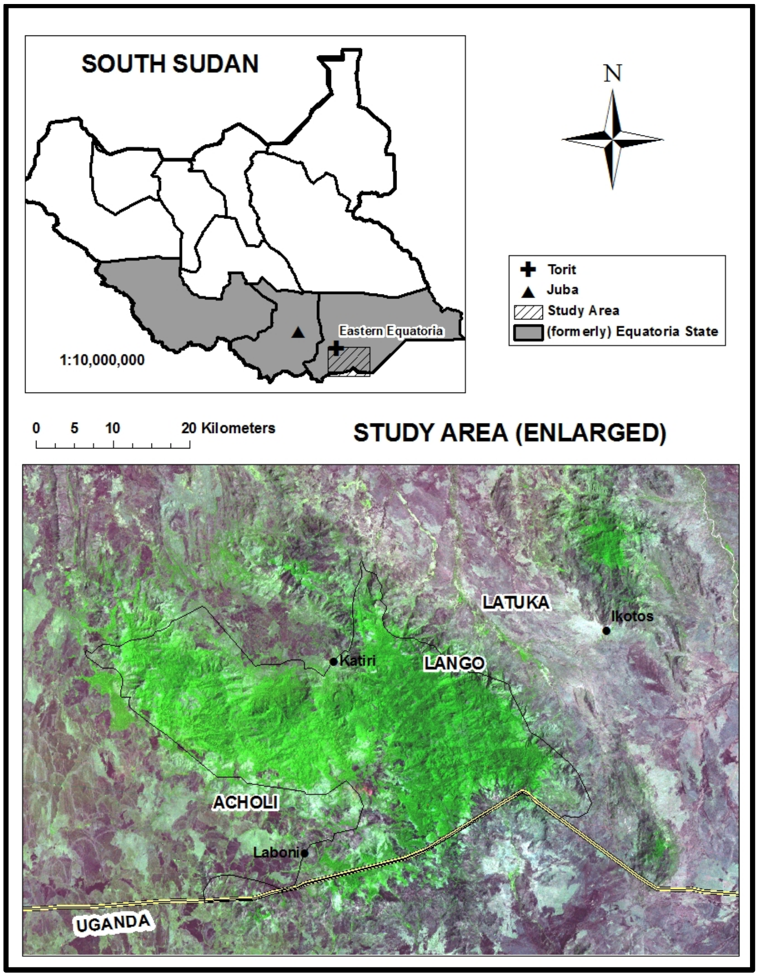


**Figure 4-2: Equatoria County and the main tribes found in the study area including the Acholi, Lango and Latuka. Background image is true color Landsat MSS image (57m resolution). Tribal groups based on a map provided by the United Nations Sudan Information Gateway (www.unsudanig.org).**

The Sudan civil war, which began in 1955 and ended in 2005 (with a 10 year period of peace between 1972 to 1983), resulted in an estimated 2 million dead and 4 million displaced people (Haynes 2007). Many of the displaced people fled north to the suburbs of Khartoum, and to the transition zone between north and south Sudan (Duffield 2002), or to refugee camps in neighboring Kenya, Uganda, and Ethiopia (UNHCR 2007a). Beginning around the time of the January 2005 Comprehensive Peace Agreement (CPA) until and following the July 2011 independence of South Sudan, former IDPs and refugees have been migrating back to Southern and now South Sudan. The International Displacement Monitoring Centre (IDMC) estimates that between January 2005 and December 2009, approximately 2 million people returned to Southern Sudan, Abyei and Southern Kordofan (IDMC 2011).

In the Imatong Mountains region, no publically available information exists on wartime migration numbers and patterns. Data obtained from the South Sudan National Bureau of Statistics (NBS) indicates that for the entire State of Eastern Equatoria, total population was 906,126 in 2008. This number was derived from the Fifth Population Census carried out from April 22nd to May 6th, though the results have been widely decried as having under-enumerated Southern Sudanese (Mangony 2011). The South Sudan Relief and Rehabilitation Commission (SSRRC) and the IOM (International Organization for Migration) estimate that since December 2010, approximately 5,560 people have returned to Eastern Equatoria and that an additional 24,000 are expected to return in the near future (personal communication with John Odongi Simon from the SSRRC in Torit, South Sudan on November 17, 2011). A comparison of population data for Equatoria State, which no longer exists but which includes today's Eastern, Central and Western Equatoria (Figure 4-2), using data from five population censuses shows that the number of people in this greater area has generally followed wartime patterns with increases during periods of peace (1973 to 1983) and reductions during wartime (1956 to 1973). The period 1993 to 2008 includes both war and peace since the CPA was signed in 2005; therefore, the increase likely reflects the spike in IDP and refugee returns during the period 2005 to 2008 (Table 4-2). It must be noted that these data have been called into question based under-enumeration in the South for a variety of reasons, not least of which was the ongoing conflict. For a complete overview of the Sudan censuses and a critique of each census's shortcomings, see Mangony 2011.

**Table 4-2: Population data for Equatoria State. Data are taken from censuses conducted for each of the years listed below; however, the accuracy of the data has been called into question as a result of either poor coverage or deliberate scaling down of population based on unrealistic assumptions (Mangony 2011).**

| | **Population** | | | | | **Rate of Growth (percent)** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Equatoria State** | **1956** | **1973** | **1983** | **1993** | **2008** | **1956-1973** | **1973-1983** | **1983-1993** | **1993-2008** |
| | 889,136 | 758,412 | 1,478,009 | 1,150,222 | 2,628,747 | -1.8 | 6.4 | -2.5 | 5.2 |

In addition to the official census data, humanitarian agencies and others record migration patterns – particularly those related to refugees and IDPs. While some of these showed trends in migration for the whole of Southern Sudan or even at the State and County level, no fine-scale, multi-temporal data were available for our study region. Data from the 2008 census obtained directly from the NBS indicated that approximately 73,549 people were living in the area at this time. Previous reports record 30,000 people living in villages scattered around the boundaries of the ICFR (Sommerlatte & Sommerlatte 1990); but this figure does not include the towns and villages located to the southeast closer to the Dongotana Hills. Clearly, population trends are difficult to substantiate and compare due to wide disparity of data that comes from variances in spatial boundaries and temporal scales.

## 4.5 Methods

In order to balance conservation and development priorities in the Imatong Mountains, where data and information required for resource planning are largely lacking, future land use planning will likely incorporate some form of participatory planning (including mapping), as these methods have become standard practice and are often required by donor organizations such as the Global Environment Facility (GEF) and World Bank (Diamond et al. 2004; Ericson 2006). The use of images generated by geographic information systems (GIS) in participatory mapping is becoming widespread. Many herald this technology as an effective way of combining disparate sources of information in an interactive setting that emphasizes human activity in addition to biological and physical processes (Bunch & Dudycha 2004) and promoting good governance (McCall 2003). Others, however, have noted some pitfalls associated with a participatory approach including the incompatibility with overarching conservation objectives (Ericson 2006). The main focus of this study was not to test the merits of a participatory approach to conservation, but rather to use spatial data and satellite images as a launching pad to initiate discussions of the historical movements within a war-torn region and to understand better how their present and future use of the forest and surrounding land relates to observed changes in land cover.

This study was conducted from 2009 to 2011 and information was compiled from literature sources, field observations and key informant interviews. Early interactions with guides and direct observations that took place during initial field work conducted in April 2009 to validate satellite imagery provided critical information regarding events that took place in the region during and after the war. A one-day focus group interview session with key informants from the Imatong Mountains took place in the town of Torit on November 16, 2011. Because of logistics and funding constraints, we used an availability sample approach to select key informants for the one-day session. As such, most of the key informants resided in Torit and were originally from a smaller geographical subset of the larger study area; however, their migration patterns during and after the war extended throughout the larger area including travel across the border into northern Uganda. Informants from the one-day interview sessions were largely from the Lango tribal group.

Each participants was shown a map (Figure 4-3) of the Imatong Mountain region that was created using a GIS with a SPOT (Satellite Pour l'Observation de la Terre) 5 meter image in false color composite as the basis of the map. The ICFR boundaries and the border with Uganda were included on the map, as were major settlements. The settlement data were obtained from publically-available GIS data files on the Internet, supplied by the United Nations groups working in South Sudan (http://www.unsudanig.org/new_gateway/maps/index.php). The ICFR and the Agoro-Agu Forest Reserve boundaries were obtained from the Wildlife Conservation Society (WCS) Southern Sudan Programme. These shapefiles were overlaid onto the satellite imagery using ArcGIS 9.3. (Figure 4-3).

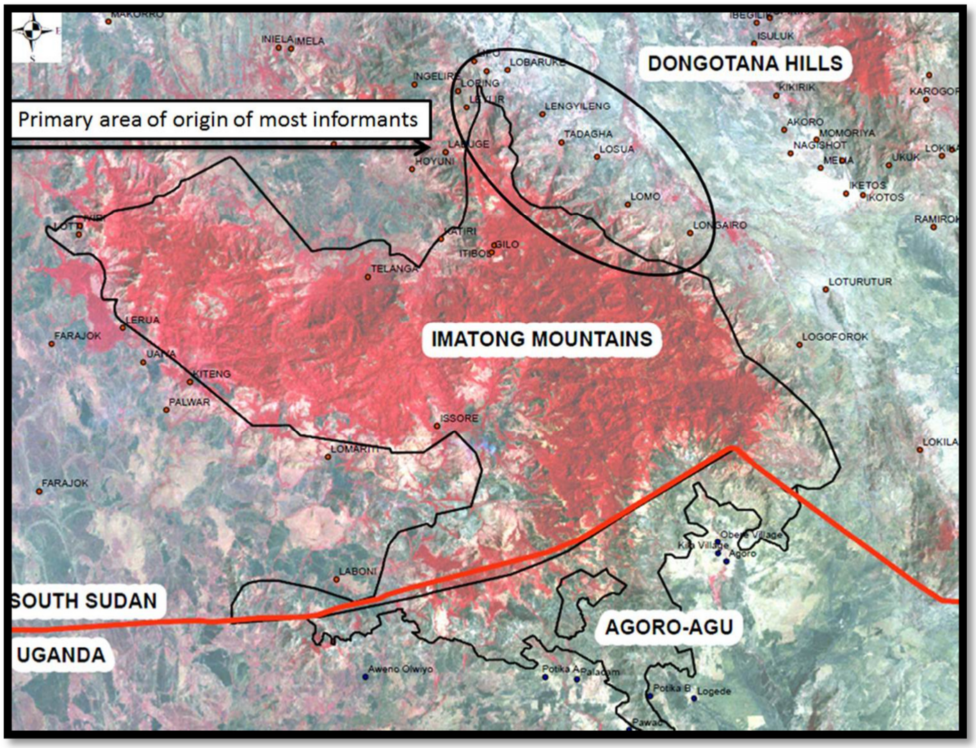


**Figure 4-3: Satellite image shown to interview group participants. Apart from the oval indicating the primary origin of most inhabitants, the image is the document shown to each participant (in paper form) [color display: red = channel 1, green = channel 2, blue = channel 3].**

The one-day focus group interview session was recorded using a portable digital audio recorder and later transcribed and supplemented with notes taken during the event. The interviews were recorded in the local dialect, with a translator present to convey information in English. Prior to and after the one-day session, government officials and other experts were interviewed independently. Information obtained through these informal interviews was recorded manually and without the assistance of a translator as English was the dominant language. These informants were selected using an availability sampling approach, which despite limitations related to wide generalizability, was effective in locating people with first-hand knowledge about this lesser-known region.

The information from each source was then coded according to a set of categories using the open source software WEFT QDA freely available on the Internet (http://www.pressure.to/qda/). The selected categories encapsulate the major themes and perceptions of the discussion and they are as follows (in alphabetical order):

- Boundaries
- Fire
- Forest use and wildlife
- Future challenges
- Ikotos
- Labone
- Land use and land cover change
- LRA and UPDF
- Pre-war happenings
- Post-war migration
- War-time migration

The results from the analyses of the data based on these categories were then condensed into the seven following major topics for in-depth analysis and further discussion: 1) the nature of conflict, 2) conflict and migration, 3) land use, 4) fire, 5) impacts on forests, 6) impacts on wildlife, and 7) concerns about the future. These results were compared with pre-interview expectations related to conflict and the environment.

## 4.6 Results

Based on our interactions with people with in-depth knowledge of the Imatong Mountain region, we discovered many nuances with respect to conflict, including how insecurity due to war forced people to change their land use practices. Table 4-3 compares our expectations based on previous studies to the results from the interviews and observations. Sections 4.6.1 – 4.6.4 provide greater detail for each major topic.

**Table 4-3: Summary of expectations vs. observations from interviews related to seven main categories related to conflict and land use in one sub-area of the greater Imatong Mountain study region.**

| Category | Expectations based on results from previous studies and other general perceptions | Observations based on interviews with key informants | Explanations / Notes |
|---|---|---|---|
| The Nature of Conflict | There were two major conflicts – the north/south Sudan civil war and the LRA insurgency. | There were conflicts within factions of the Southern army and complex allegiances. Tribal conflicts continued during the war and in the present day. | Tribal allegiances and ethnic identity play an important role in all of the conflicts described by participants. |
| Conflict and Migration | Most people fled the Imatong Mountains to go to camps in Uganda. | In fact many people stayed in the mountains and hid from the various military groups and insurgents. Some people remain there today because they don't believe the war has ended. | Mountains have historically offered refuge during times of conflict – both in Sudan and elsewhere (Babikir 1988). |
| Land Use | People ceased all forms of cultivation during the war because they either fled or were hiding. Now with peace, they have begun cultivation again. | This was generally true in the Imatongs, though they were able to grow beans on small plots. In nearby Dongotana Hills, people cultivated during the war since this area was held by the SPLA who allowed it. | Post-war issues related to land tenure are complex and require additional fieldwork. Despite reports to the contrary for other parts of the Imatongs (e.g. Labone), participants maintained that there were no conflicts related to land ownership. |
| Fire | People use fire primarily for honey collection, poaching, cooking, heating, clearing for agriculture. | This was confirmed by observations and discussions with local inhabitants. | The results also confirmed that few fires were ignited by lightning and that fire was an important aspect of community life. People wanted government help to control fires to prevent burning the forest. |

| | | | |
|---|---|---|---|
| Impacts on Forest | Post-2005 would result in significant forest loss as people returned to the region to rebuild communities. | Forest loss post 2005 is said to be minimal. This is confirmed by previous analysis using remotely sensed satellite imagery. | Return to the area has been minimal due to lack of schools and health facilities. Many people have moved to Torit and other large towns. Also, the people place a great value on the forest and don't wish to see large forestry projects resume. The forest must be "blessed" by a landlord in order to be cut down and so he decides what land can be cultivated. Those who stayed in the forest or returned to nearby villages are not doing extensive damage. |
| | Forest cover loss around the Dongotana Hills was due to the relative accessibility of the forests compared with the Imatongs.. | This was partially true; however, because this was held by the SPLA and there was an IDP camp, there were no restrictions on using the forests and surrounding land. | |
| Impact on Wildlife | Wildlife would largely be decimated due to the presence of fire arms and inability to cultivate freely in the mountains. | This was confirmed; however, there was widespread agreement that poaching was negative and therefore done in secret. | Many people wanted assistance from the government in stopping poaching. |
| Concerns about the Future | People were anxious to develop the land in order to bring in revenue and create jobs. | Informants wanted government assistance to build schools and hospitals and were wary of any plans to develop the forest without their consent. There was also a lot of support for organizing community members to educate them about the hazards of poaching and uncontrolled fire. | Plantations have been blamed for altering the flow of water and causing flooding, which may be a major reason for hesitation to start new development projects. |

### 4.6.1 The Nature of Conflict

Throughout the interview session, it became clear that the people of the Imatong Mountain region were victim to not just one but four separate conflicts – some of which are ongoing and others that have ended but are perceived to be ongoing. First, there was the North-South civil war, which contributed to a general feeling of fear and insecurity and which caused many to flee to neighboring countries. Second, the split that occurred within the main Southern faction – the SPLA or Sudanese Peoples Liberation Army – primarily between the predominant tribes, the Nuer and the Dinka, had consequences for the people of the Imatongs. Third was the presence of the Ugandan Lord's Resistance Army (LRA), a ragtag militia of men and boys with origins in northern Uganda that have kidnapped and killed thousands of people in the region (Eichstaedt 2009). The LRA first crossed into Southern Sudan in the early 1990s and formally established a presence in Sudan in 1993-1994 at the invitation of the government in Khartoum (Schomerus 2008a). In 2002, the governments of Uganda and Sudan agreed to allow the Uganda People's Defense Force (UPDF) to establish bases within Sudan to pursue the LRA as part of Operation Iron Fist (Ochan 2009). Despite their intended purpose, many believe the UPDF was largely ineffective and accuse the group of turning their guns on the civilian population and destroying the area including cutting trees in the forest (Ochan 2009). This was the same year (2002) of a vicious attack by the LRA against villagers in Katire (or Katiri) at the base of the Imatongs when an estimated 520 people were killed (Schomerus 2008a), causing many more to flee to places such as Ikotos. The LRA left Eastern Equatoria in 2007, leading to an increase in returnees – mainly to towns which are believed by many to be safer than villages since the LRA are still at large and no formal agreement has been signed to stop hostilities (Schomerus 2008a). Other armed groups active in the Imatong Mountains during this time include the Equatorian Defense Force (EDF), which was a militia group formed with the aim of defending the local inhabitants during the period 1995 to 2004, and which also had a base in Katire (Schomerus 2007). The EDF and the LRA often fought side by side in the 1990s though the relationship deteriorated as early as 1997 when the LRA attacked Equatorian civilians (Schomerus 2008b). Finally, inter-tribal rivalries continue post-2005 – mainly between the Lango people of the eastern slope and the Latuka people of the plains between the Imatongs and the Dongotana Hills. This conflict has resulted in cattle rustling and violence between communities – made worse as a result of the prevalence of small arms among the population.

### 4.6.2 Conflict and Migration

As a result of these different but related conflicts, many people fled from their homes and villages. However, discussions with the local informants revealed that the forest mountain landscape provided many with sanctuary where people were not only able to escape notice, but also supported themselves through hunting, gathering of forest products, and limited cultivation. In order to procure goods such as salt, oil, soap and clothes, some people travel to markets day in Uganda trade bushmeat and honey, and risk meeting the LRA along the paths that crossed the border. While the mountains provided a safe haven from the direct impacts of conflict, lack of healthcare during resulted in numerous deaths. In addition, children were unable to go to school as it was not safe to travel.

While many people have returned to their villages or to nearby towns, we discovered that some people remain in the forest at present since they do not believe that the conflict has ended or else they fear future violence from any number of sources, even if they don't understand the origin of the wars in the first place. Many of the key informants echoed the sentiment that people were severely traumatized by the violence they had witnessed and insisted on holding on to their weapons should war break out again.  At the same time, many people who fled to larger towns such as Torit and Ikotos as well as the Ugandan and Kenyan refugee camps began returning to their villages after the 2005 CPA and the subsequent departure of the LRA, and have begun farming. Although the respondents stressed that their communities were at peace with one another, reports on the Lango community in 2006 indicate that at least initially there was tension between and within communities related to land and property, including how to best reintegrate returnees. In the Lango tradition, for example, a person should live where his or her parents are buried (Kanani 2006) so that many people returning from Uganda and elsewhere have come into conflict with those who had taken up residence in their former homes.

### 4.6.3 Land Use

Interview participants reiterated the fact that during the war, many people living in and around the mountains did not want to be seen and therefore did not clear lands to practice extensive cultivation. During this time, they mostly grew beans on small plots, harvested honey, raised chickens and poached bushmeat. Now with peace, they can cultivate freely and rather than cross the border to go to Uganda along undeveloped paths, they can use the newly graded road from Katire to Torit to transport their items for sale or to buy necessary goods. Major crops currently cultivated include cassava, maize, sweet potatoes, bananas, sugar cane, paw paw, onions and cabbage. Observations during fieldwork in 2009 indicate that people practice shifting cultivation using so-called “slash and burn” agricultural techniques (Figure 4-4).

**Figure 4-4: Photo depicting typical "slash and burn" cultivation techniques used in and around the study area. This photo was taken near Lohotulo village, located at approximately 4°0’58’’ North latitude and 32°49’37’’ East longitude near the village of Katire (shown in Figures 4-1 and 4-2) Photograph by V. Gorsevski.**

A major challenge in South Sudan in general has to do with securing land and property since those who have come back want access to their former plots, which in many cases have since been occupied by IDPs. Land tenure issues are complex in South Sudan and beyond the scope of this paper; however, it is important to note the role of the landlord who was referred to on several occasions by interview participants as the person who must 'bless' the land before it can be cultivated. Each State in South Sudan is comprised of smaller administrative units including (from largest to smallest) county, Payam, Boma, and village. A Boma has one or more 'landlords' depending on its size. The landlord, along with the Boma Chief, addresses land allocation and conflicts at the Boma level (Shanmugaratnam 2010). Interview participants repeatedly stressed the lack of conflict among community members with respect to land tenure in their immediate area; however, reports from other parts of the study area such as Labone, where the Bor Dinka IDPs largely replaced the indigenous Acholi, indicate that this issue is still quite volatile (Shanmugaratnam 2010).

### 4.6.4 Fire

Previous studies used satellite remote sensing to examine frequency and patterns of fire activity in and around the Imatongs during and after the war and found that fire frequency and location generally matched coarse-scale human population trends in both South Sudan and the neighboring Agoro-Agu Forest Reserve in northern Uganda (Gorsevski et al. 2012b). Key informants corroborated the importance of land-management fire in the Imatongs and that fire is used extensively for cultivation, honey collection and by poachers. This last category of ignitions was thought to be responsible for fires that burn uncontrollably – often into the forests – causing extensive damage. There was no mention of the use of fire to promote green flush for grazing, as was observed by Sommerlatte and Sommerlatte (1990) in the late 1980s and which occurs extensively in other parts of South Sudan among mainly pastoral communities who own large numbers of cattle. During the colonial period, early burning was practiced to encourage tree regeneration and discourage grasses (Sommerlatte & Sommerlatte 1990) and perimeter areas were burnt around the forest reserve to prevent fires from entering (Grossmann et al. 2009); however, during the war all efforts to promote responsible fire management, including the creation of fire breaks, have ceased. Many informants stressed the need to mobilize people and the government to help prevent excessive use of fire – including an end to poaching, which occurs within the forest interior so that fires resulting from this practice have the unintended side effect of destroying much of the natural forest.

### 4.6.5 Impacts on Forests

Land use associated with conflict had several impacts on the forest cover in the study region. Different areas experienced abandonment of forest plantations, regrowth of forests, and increases in deforestation.

Before the re-ignition of the Sudan second civil war (1983 – 2005), several international aid agencies and investor groups came to the area to exploit the forestry potential and to undertake development projects. For example, forest plantations that had been planted during British colonial rule and shortly after Independence in 1955 were expanded so that by 1982 the total plantation area (comprised of pine, cypress and eucalyptus trees at the expense of natural forest) was between  750 to780 hectares (Grossmann et al. 2009). During this time, the British came to Katire and nearby Gilo to build huts and houses and improve the roads to help transport timber and materials. They installed a saw mill in Katire, where timber was cut and then transported to Juba by the Imatong Mountain Forestry Development Company, which used the timber to make houses and furniture. Finished goods were either sold in Juba or taken to Khartoum. At this time, many local people were employed by the British, and schooling was provided for children; therefore the population of the region expanded along with employment and education opportunities. However, at least one key informant worked on the forest plantation during this time and informed us that in hindsight, the British project was detrimental to the ecosystem as some of the trees that were cut were very big (they took 7 days to cut with a power saw) and the new species used too much water at the expense of the Kinyeti river. Research corroborates this general observation that both Eucalyptus and Cypress trees, which have been widely planted in other developing countries as a means of countering deforestation, are water and nutrient intensive (Fritzsche et al. 2006; Shiva & Bandyopadhyay 1989).

Results using a change detection analysis of remotely sensed satellite imagery previously showed forest recovery in parts of the Imatong Mountains during the war – particularly near the former Talanga Tea Plantation, and significant forest encroachment in the Dongotana Hills during the same period as well as after the war (Gorsevski et al. 2012c) (Figure 4-5).

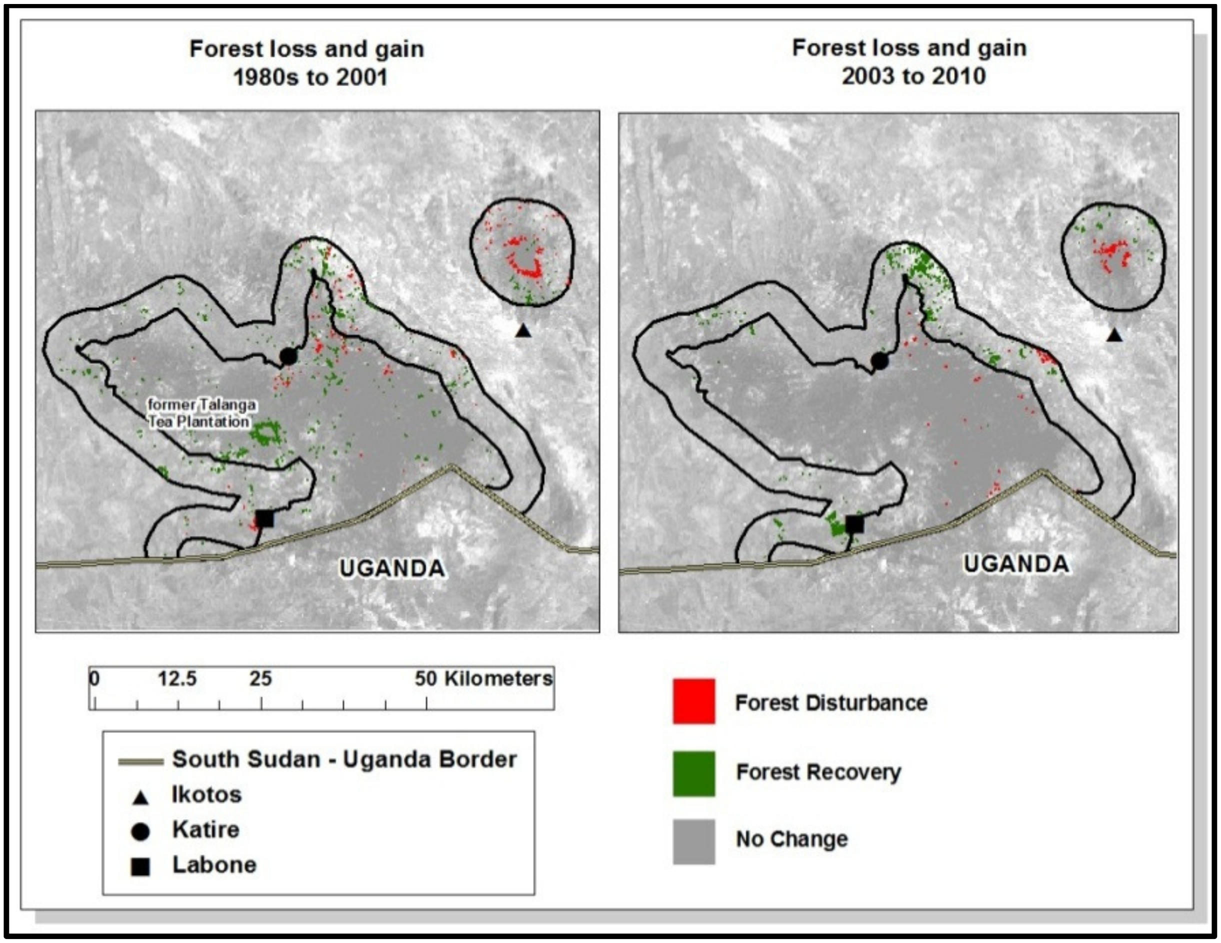


**Figure 4-5: Results from previous forest cover change analysis. Areas of green indicate forest regrowth while areas of red indicate forest disturbance. Overall, there is little change – particularly in the montane forests, with the exception of the Dongotana Hills, where extensive destruction of the forest has been verified with aerial photography. (The images in Figure 5 are modified from previously published research – see Gorsevski et al. 2012).**

The Dongotana Hills share a similar ecology to that of the Imatong Mountains; however, the area is substantially smaller at with only 21 $km^2$ of forested area and at lower elevations, the forests are generally more accessible. According to key informants, wartime realities were in large part responsible for the different effects of conflicts on forested areas. While people in and around the Imatongs had either fled or were hiding in the dense mountain forests, the areas around the Dongotana Hills were heavily populated due to the presence of IDPs in the Ikotos and Momoriya camps. Despite many security issues, the occupants of these camps were more able to freely cultivate land to grow food. The SPLA were in Ikotos and despite intense fighting at various times, the Sudan Armed Forces (SAF) never took control of Ikotos so that cultivation was possible. Post-war cultivation and encroachment of the forested area was observed near the Dongotana Hills during aerial overflights that took place in January 2009. In contrast, these same flights revealed large tracts of intact montane forests in the Imatong Mountains. (Figures 4-6a and 4-6b). In addition, an abandoned base camp – likely used by the LRA – is shown in Figure 4-6c, confirming local informant claims that they used the mountains as a hideout. Figure 4-6d shows a typical settlement pattern near the heavily populated area of Labone. Here, people from the Dinka tribe previously living in Bor (approximately 200 miles north) were displaced during the war due to heavy fighting between different factions of the SPLA – first to Ame camp and then to Labone camp in 1994 (Dowden, R. (1994, February 10). Attack Forces Sudan Refugees to Flee Camp. *The Independent*. Retrieved from http://www.independent.co.uk/). Formerly the Acholi people lived in Labone and while some of them stayed, others left the area and then returned after the Peace Agreement when many of the Dinka had also migrated north. Unlike the largely pastorial Acholi, the Dinka rely heavily on cattle for their livelihood, and much of the social and political system of the Dinka tribe is centered around cattle and their use (Lako 1985). While no first-hand information was available for Labone, it is likely that the implications for land use are great given the need extensive grazing area.

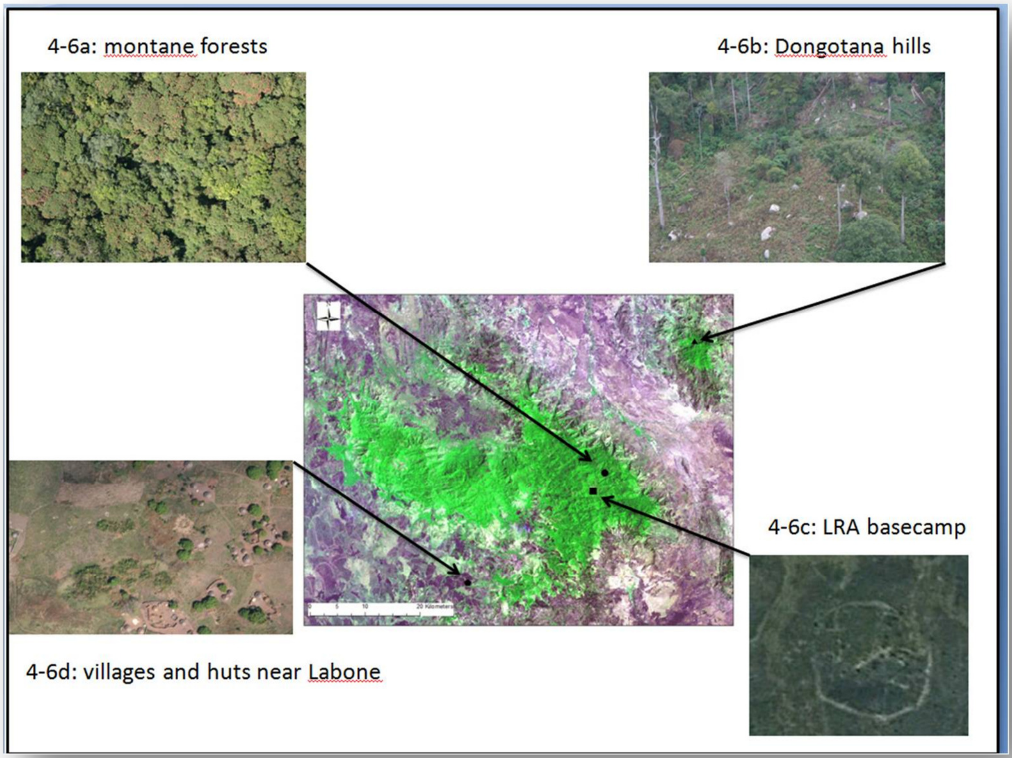


**Figure 4-6: Photographs from the study region illustrating: (a) intact montane forests from the Imatong Mountains – mainly consisting of the species Podocarpus latifolius occurring in the upper montane area; (b) area cleared in the Dongotana Hills – likely for fuelwood and/or construction material; (c) LRA basecamp in a clearing in the otherwise dense montane forest; and (d) huts scattered near the town of Labone, previously home to an IDP camp for members of the Bor Dinka tribe. (photos a, b and c are aerial photographs by V. Gorsevski; image d is a screenshot taken from Google Earth).**

As mentioned previously, of all the lowland forests in the Imatong Mountain region, only the Lotti forest remains largely intact. The interviews revealed that this was because the Labone lowland forest was located near the Labone IDP camp; therefore, much of the wood was harvested for fuelwood and construction. In contrast, the Lotti forest was discovered by WCS field staff to be largely intact during 2009 fieldwork (personal communication with Falk Grossmann, Wildlife Conservation Society, Southern Sudan Programme). Subsequent research revealed that early on, international agreements prevented interference with the natural vegetation or fauna in Lotti, whereas Talanga was allowed to be exploited for timber (Jackson 1953). Discussions with one expert informant revealed that a tse tse fly outbreak that caused the Acholi people to leave the area around the Lotti forests may be a plausible explanation for why it remained largely undamaged; further research verified that this occurred before 1929 but more up-to-date information could not be found (Chipp 1929). More recently, logging roads have been developed leading to the northern end of the forest raising fear that these lowland forests will also soon disappear (Grossmann et al. 2009).

### 4.6.6 Impacts on Wildlife

Conflict generally has two impacts on wildlife – there are indirect impacts via changes to forest cover and fire activities (as indicated in the previous two sections), and a direct impact through hunting. Previous studies have provided detailed accounts of various animals that have historically been found in the Imatong mountains including elephants, buffalos, bushbuck, greater kudu, bush pig, duiker, klipspringer, leopards, a wide variety of small mammals such as porcupine, and numerous birds including several endemic to the region (Jackson 1953; Jackson & Owen 1959). Interviews with informants including wildlife experts confirmed observations by the Wildlife Conservation Society (WCS) Southern Sudan programme that many of these animals are no longer present (such as elephants and leopards) and that others such as the blue monkey are still present, but rare since they were hunted by all parties during and after the war’s end. One expert said that hyrax, klipspringer, porcupines, bushbuck and duikers, and Greater Kudu were still present in the Dongotana Hills. Informants also confirmed that poaching is still widespread and uncontrolled and that the poachers use traps and largely work in small groups or individually without consent from the larger community. Figure 4-7 shows photos of snares and traps used to catch animals, as well as a poacher’s station. These photos were taken during fieldwork in January 2009.

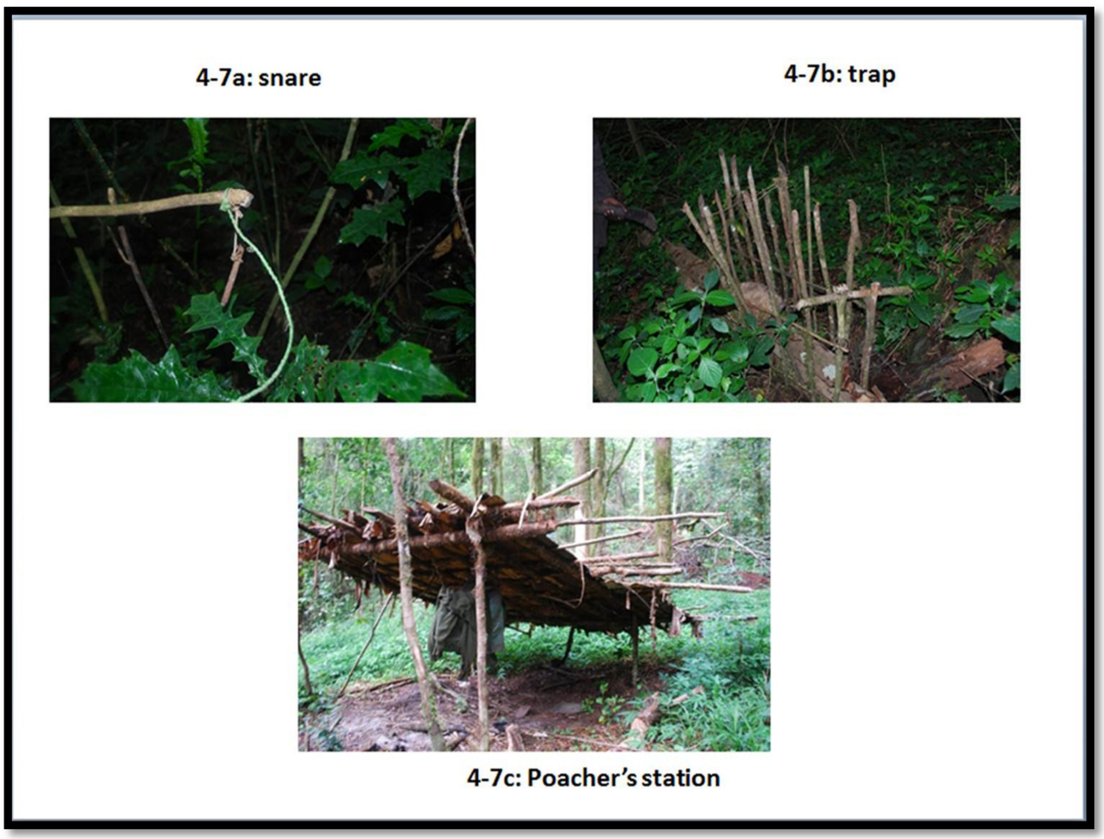


**Figure 4-7: Evidence of poaching in the Imatong Mountains including (a) a snare, generally made from wire, nylon or vine and often resulting in waste of animals who are left to decay upon being trapped; (b) a trap – smaller drop traps are used to catch rodents and birds, whereas larger pit traps are used to catch bushbuck and bushpig; and (c) a poacher’s station. (photos taken by V. Gorsevski during 2009 fieldwork. Information about hunting methods from Grossmann et al. 2009).**

Results from earlier studies using satellite imagery and from discussions with local inhabitants and government officials confirm that an unintended consequence of the conflict was reduced pressure on the forests – from villagers but also from planned expansion of large-scale forestry projects. On the other hand, the impact of war on wildlife appears to have been largely detrimental since many of the species previously reported as being present in this region, such as elephants, buffalo and leopards (to name a few), are believed to have been extirpated (Grossmann et al. 2009). According to key informants, the widespread availability of firearms and the lack of enforcement of wildlife protection laws have meant a continuation of illegal poaching. Other studies have found that the legacy of conflict continues after the war is over (Loucks et al. 2009) and it appears that this in the absence of government intervention, this may also be the case in the Imatong Mountains.

### 4.6.7 Concerns about the Future

During the one-day focus group interviews, nearly all the participants discussed the need for government assistance to build infrastructure – mainly schools and health care facilities – in order for people to resettle in towns and villages in and around the Imatong Mountains. Many people have decided to stay in Torit or Ikotos for this reason and are waiting for assistance from the government before they move back. There was also a general feeling that the people need to organize among themselves to make specific demands and prevent any attempts by outsiders to control the forest and its associated resources. Capacity building and outreach within the community was also mentioned as ways in which to prevent poaching and to train people to build fire lines. Because of the war, many people are traumatized and have turned to heavy drinking, which remains a problem.

Finally, a recurring outcome of the November 2011 interviews was the high value people place on the forest and associated forest resources such as wildlife and non-forest products. There was a plea by many informants that the forest be preserved in general, and specifically for government assistance in safeguarding it from use by outsiders. There was overwhelming agreement that the community knows best how to manage the forest and that people needed to mobilize to prevent outsiders from cutting trees without consent from the local inhabitants.

### 4.7 Discussion

As the results outlined in Section 5 illustrate, the outcome of the one-day information session led to several general observations about both the past and current state of the forests, people and wildlife in the Imatong region (summarized in Table 4-3). While some of these results confirmed existing expectations, others uncovered additional or even contradictory information. For example, prior reports and observations regarding the use of fire and problems controlling its spread were largely confirmed by key informants. On the other hand, the complexity of the conflicts occurring within the Imatongs in terms of the number and type and impact on people's decisions to stay or go was largely unexpected and offered intriguing new insights about how these decisions affected land use, including impacts on the forest. Discussions also confirmed the results of prior land cover mapping using remotely sensed satellite imagery by highlighting minimal loss of forest within the Imatong montane forest and extensive forest loss around the Dongotana

Hills. At the same time, the socio-political context within which these changes occurred (e.g. the existence of IDP camps around the Dongotana Hills and control by the SPLA) provided additional insight into the cause and effect of war on the environment. And finally, the discussions led to additional questions that can only be adequately addressed with further qualitative research. For example, research using satellite imagery shows a regrowth of forest near Labone following the war, as well as an increase in fire activity (Gorsevski et al. 2012c). A better understanding of Dinka-Acholi migration and land use patterns both during and after the war is needed to fully explain the dynamics behind these observations.

The interview session also highlighted issues related to the participatory process itself. One important observation had to do with boundaries – in particular, the boundary of the now-defunct ICFR, which was included on the map, as well as the international boundary between South Sudan and Uganda. While no one objected to the ICFR boundary, there was some confusion as to what the lines represented and some hesitation in placing one's village with respect to the protected area. Other researchers have found that unintended consequences can arise from participatory mapping exercises – particularly with respect to where boundaries are drawn – since it forces people to confront latent issues related to land tenure (Fox 2002). Related to this was the fact that informants repeatedly corrected the names and locations listed on the map, which was created using publically available United Nations supplied data, and clearly in need of revision.

While the interview participants repeatedly stressed the lack of conflict within their Lango community, they also differentiated themselves from the other primary ethnic groups – the Acholi and the Latuka – the latter of which they had accused of cattle rustling. In addition, other reports show that there is tension among some members of the Lango community related to where a person went during the war. For example, when the SPLA took over the Ikotos area in 1988, civilians either went to IDP camps in GOS-controlled areas including Torit, Juba and Khartoum, while others fled to refugee camps or hid in the nearby hills creating tension between those who left and those who stayed (Kanani 2006). People who stayed behind often accused those who left of being traitors.

I also noticed that the interview participants were largely comprised of men and that a few of the younger men refused to speak during their ‘turn,’ as did the sole woman in the group. Future efforts to engage the community should take care to  represent better both males and females, since women and men differ in their knowledge and use of forest resources (Agarwal 2000; Kalibo & Medley 2007).

The lack of women and members from the other two predominant tribes living in the area (the Acholi and Latuka) highlights one of the major shortcomings of using the availability sampling design discussed in the Section 4.5. As mentioned, this approach was employed due to logistics and funding constraints. In the absence of these constraints, a preferred method would be a stratified random sampling approach to ensure that members of each of three main ethnic groups are included in the discussion. Ideally, interview sessions would be held in each of the three main South Sudanese sub-regions of the study (e.g. Katire, Labone, Ikotos – near the Dongotana Hills) in order to learn more about land use practices specific to these areas.

### 4.8 Conclusion

Numerous studies have attempted to 'link people with pixels' by supplementing data derived from remotely sensed satellite imagery with qualitative information obtained through interviews, focus groups and other means (Dennis et al. 2005; Entwisle et al. 2005; Laris 2011; Moran & Brondizio 1998; Songer et al. 2009). While few would argue the benefits of using a multi-disciplinary approach, one major challenge inherent in relating geospatial technologies with qualitative data has to do with differences in temporal and spatial scales (McCusker & Weiner 2003) and specifically the exclusion of local studies when seeking to explain trends across regional scales (Turner 1999). Some even contend that the use of satellite imagery actually reinforces, rather than reduces, the contentiousness of landscape change claims due to divergent interpretations of the same data and imagery (Robbins 2003). This was evident during our interview session to a limited extent given the discrepancies in place name and location. The fact that our group came from one distinct area comprised of the same ethnic group likely minimized tension that might have materialized if all tribes from across the region were represented.

The impact of conflict on forest cover follows a complex path beset with many decisions along the way. That is, the presence or absence of conflict causes individuals and communities to make decisions relative to their well-being. These decisions in turn impact how resources are used and the overall imprint that human activities have on the landscape. Over time, changes in land use practices can leave a lasting imprint on land cover. These patterns can sometimes be observed using data derived from satellite remote sensing. In this respect, rather than be viewed as the 'end point,' satellite remote sensing can be extremely useful in providing the entry point for discussions with local inhabitants to understand better how their decisions are linked with coarse-scale observations. However, in order to effectively 'link people with pixels,' it is necessary to combine quantitative satellite data with qualitative research that effectively explains the decisions that they made as a result of war and how these decisions result in perceptible changes in the landscape.

This research was designed to gather and analyze data on human perceptions and activities related to conflict in the Imatong Mountain region of South Sudan as a means of building on previous results that relied almost exclusively on satellite remote sensing data. My work with collaborators in this region indicates that the impact of the various conflicts during the 1983 – 2005 timeframe had mixed results for the local ecology. On one hand, I found that much of the Imatong Mountain forests remain intact due to a reduction in population numbers and limited cultivation due to the war, with the exception of the Labone area and surrounding lowland forest which witnessed an influx of IDPs in the 1990s as discussed in Section 5.5. On the other hand, wildlife was diminished since local inhabitants who stayed in the forest, as well as militia groups that used the forest as a base from which to launch attacks relied on bushmeat for survival. In contrast, the results from the satellite remote sensing analysis indicate that the Dongotana Hills were heavily encroached upon both during and after the war and discussions with local inhabitants and experts help to explain the underlying political and military realities that allowed this area to be transformed through increased human settlement and cultivation.

My findings help to explain the processes underlying the time-series patterns observed with satellite imagery with regards to forest gain and forest loss through a more complete understanding of local decision-making processes in the face of several conflicts. It must be noted, however, that this study was conducted on a very minimal scale and did not include all groups residing in and around the mountain. In the future, a triangulated approach that incorporates additional methods and a more complete representation of ethnic groups, including both men and women, would avoid distortion by favoring one group over another and lead to more optimal policy recommendations (Ericson 2006).

# 5 Conclusions, Policy Implications and Next Steps

## 5.1 Summary

The three individual studies in this dissertation integrate remote sensing and interview data to address the research questions presented in Section 1.2 related to the impacts of war on land use and land cover in the Imatong Mountain region of South Sudan and northern Uganda.

Section 2 of this dissertation entitled "Analysis of the Impacts of Armed Conflict on the Eastern Afromontane Forest Region on the Sudan-Uganda Border Using Multitemporal Landsat Imagery" compared spatial and temporal trends in forest cover gain and loss across three specific areas – each of which are comprised of similar montane forest vegetation but which experienced different aspects of various inter-related armed conflicts. I used Landsat TM and ETM+ imagery to represent "war" and "post-war" periods and applied the Disturbance Index methodology to compare changes in forest cover change. I found that within the ICFR itself, there was very little change in the net rate of forest cover, in contrast to the nearby Dongotana Hills, which experienced relatively high rates of disturbance both during and after the war. Across the border in northern Uganda, the rate of forest recovery was higher in the second period, corresponding to the time during which people began leaving the IDP camps.

Section 3 of this dissertation entitled "Mapping Anthropogenic Fires During Periods of Conflict and Peace in South Sudan and Northern Uganda using MODIS Active Fire Data" characterized the spatial and temporal attributes of anthropogenic fire in the same cross-border region and compared results with coarse-scale population trends across different land cover types. I discovered that overall, fire activity corresponded to broad-scale human population trends on both sides of the border. On the South Sudan side, for example, year-to-year fluctuations in IDP and refugee returnees resemble the large annual variability in fire counts, whereas fire activity on the northern Uganda side steadily decreases over time, largely corresponding to the gradual reductions in IDP camp populations. I also found that there was a reduction in active fire counts in all of the sub-regions for both South Sudan and northern Uganda, with the exception of the woodland land cover type in two of the larger settlements – Labone and Katire – where returnees are more likely to resettle following war.

Section 4 of this dissertation entitled "Human Dimensions of Land Use and Land Cover Change Related to Civil Unrest in the Imatong Mountains of South Sudan" explored the underlying causes of different land use patterns during and after war and related this information to observed changes in forest cover by integrating satellite remote sensing data with information derived from interviews with local people. In doing so, I discovered many nuances to my previously held expectations about how variations in population associated with conflict affected land use in and around the Imatong Mountains and Dongotana Hills during and after the war. For example, the underlying expectation that most people fled the area during war was challenged by first-hand testimony that many people opted to stay in the forest and hide instead. Other previously-held beliefs were confirmed such as the widespread use of fire and the main reasons it is used by villagers. This portion of the research underlined the value of using a multi-disciplinary approach to examine changes in land use and land cover to either corroborate or contradict previously-held expectations.

## 5.2 Future Research

While tropical montane forests are priority areas for conservation, in many regions they also support high human population densities. The Government of Southern Sudan (GoSS) has recognized the importance of the Imatong Mountains and their conservation in the South Sudan Wildlife and Protected Area Policy (2003), which specifically underlines the importance of conserving the montane forest of the Imatong massif. At the same time, people who fled during the Sudan Civil War are returning to the area and depend heavily on the land and forest to meet their basic needs. As a result, great effort will be needed to balance conservation and development priorities effectively for this region. Research conducted as part of this dissertation and the methods developed can help inform the development of an integrated land use plan; however additional information is needed to improve our understanding of the complex landscape. There are several areas of research that are suggested for further analysis. Table 5-1 presents these recommended areas of current and future potential research.

**Table 5-1: Summary of current and potential future research in the Imatong Mountains and surrounding area.**

| | Issue/Question | Research |
|---|---|---|
| Current | In the absence of fine-scale, time series population data, there is potential to examine the existing fire data in different ways and in greater detail to gain new insight into trends across regions and land cover types to challenge or reinforce existing conclusions from initial fire research. | 1. Extend the fire season data (2000 to 2011) by using Terra only fire hotspots.<br>2. Revise existing analysis using Terra/Aqua data but with the following modifications:<br>• Only look at high confidence fires<br>• Adjust for cloudiness levels<br>• Count active fire detections in adjacent pixels in subsequent dates as 1 single fire<br>• Look only at daytime fires<br>• Examine spatial patterns of fires by doing an analysis for spatial proximity of fires with the idea that anthropogenic fires would be more clustered than natural fires<br>• Repeat analysis without the precipitation adjustment |
| | The qualitative interviews that form the basis of the 'human dimensions' paper submitted to HE are a good start; however, the paper could be strengthened by a more thorough investigation of household characteristics and location vis-à-vis arable land and the forest. | • Use 2008 census data to examine household composition for one year only within the S. Sudan study area. Combine this with digitized, high resolution satellite imagery of key areas to undertake spatial analysis showing the relationship between household size and location to different land cover types. |
| Ideally (with funding) | Conclusions from the forest cover change and fire sections of this dissertation raised additional questions regarding land use patterns in Labone during and post war but little information was available about population shifts that might influence satellite-derived observations. | Conduct additional analysis specific to this area:<br>• Acquire and analyze high resolution, time-series satellite imagery to map settlements, burned area, other possible indicators of human activities.<br>• Conduct additional fieldwork to interview past and present inhabitants of the area from both of the predominant tribal groups (Dinka and Acholi). |
| | The same is true for land cover and fire patterns in the Agoro-Agu region of northern Uganda where limited funding and institutional support made it impossible to fully investigate population trends and land use activities in this area. | Conduct additional analysis specific to this area:<br>• Acquire and analyze high resolution, time-series satellite imagery to map settlements, burned area, other possible indicators of human activities.<br>• Conduct additional fieldwork to interview past and present inhabitants of the area – both IDPs and non-IDPs. |
| Other (practical) | With the end of the war, there is a need to confront the conservation/development needs of the area vis-à-vis land use planning, policy development and implementation re wildlife, forestry, wildfires, etc. | Continue to work with WCS and the GOSS to use satellite remote sensing and GIS to inform the land use plans for the area. |

## 5.3 Policy Implications and Next Steps

In the absence of renewed conflict, it is likely that human activity will continue to increase in and around the Imatong Mountains in coming years as a result of improved security, as well as the favorable climate and soils found in the area. This assumption was confirmed by local aid agencies and government officials charged with addressing the current and anticipated future influx of returning IDPs and refugees. According to local inhabitants, whether or not people decide to settle in and around the forests or permanently reside in larger nearby towns depends largely on the extent to which the government delivers on promises to build and staff schools and health facilities, and specifically *where* these services are located.

Other areas of East Africa with similar ecosystems that have seen an increase in human settlements and have also experienced associated conversion of the forests for agriculture, as well as large-scale timber extraction in recent years. African tropical mountains in particular have among the highest population densities on the continent because they generally wetter and/or more reliable seasons allowing for the establishment of permanent agricultural systems (Burgess et al. 2007a). This high concentration of rural people has in many cases led to dire consequences for the environment itself and for those who depend heavily on natural resources for their everyday survival. For example, in the Kenyan Mau Forest – the largest block of montane forest in East Africa – deforestation, along with climate change, has altered the quantity, quality and time distribution of water from the Mara River with severe implications for people and animals living downstream (Blackie & Robinson 2011; Dybas 2011; Mango et al. 2010).

The Imatong Mountains are similarly an important water catchment area, supplying people and wildlife of Eastern Equatoria with critical water supplies throughout the year. Major modifications to the forests in the Imatongs would have repercussions for downstream communities as well as wildlife in nearby Bandingalo National Park (BNP).

Recent feasibility studies conducted by Italian and Chinese companies to develop a hydroelectric power station to harness energy from the Kinyeti River for nearby towns (Verhoeven 2011) raise the specter of large-scale modifications to the ecosystem and should be monitored carefully. Widespread changes in land use and land cover in the Imatongs would also likely be detrimental to the area's biodiversity. Globally, habitat loss is believed to be the greatest threat to biodiversity (Brooks et al. 2002; Chapin et al. 2000; Cincotta & Wisnewski 2000; Pimm et al. 1995; Sala et al. 2000). This is certainly the case in the nearby Eastern Arc Mountains of Tanzania, where high levels of endemism have been documented (Burgess et al. 2007b), and where forest loss has occurred at high rates – 80% total loss in historical forest area and 25% of forests have been lost since 1955 (Hall et al. 2009). As discussed throughout this dissertation, the Imatong Mountains are included in the Afromontane 'biodiversity hotspot' making them susceptible to high levels of loss resulting from deforestation. One method of curtailing deforestation to conserve biodiversity is through the establishment of protected areas, which despite only covering about 12.5% of the Earth's total land surface have been found to be effective in keeping land intact (DeFries et al. 2005), though other studies have found that the overall effectiveness of a protected area depends on a variety of factors such as the economic status of people living around the park (Wright et al. 2007).

In the Imatongs, there is a unique opportunity to create a protected area in the higher elevation montane forest, which is almost entirely intact due to low levels of human activity as a result of people either fleeing the area or hiding in the forest during the war. Evidence for this was revealed in the Results section of Chapters 2 and 3 on land cover change and anthropogenic fires, and visually confirmed during 2009 aerial overflights. Results and observations similarly reveal that of the three lowland forests, only the Lotti forest remains largely undamaged (Figs 2-2 and 4-1), though for how long is uncertain given its close proximity to towns and villages in the area. Steps should be taken to conserve this remaining lowland forest, which makes up the northernmost part of the Guineo – Congolian rainforest complex (Table 2-1) and has been shown in other areas to have high levels of biodiversity contained therein (Waltert et al. 2005).

Results from fieldwork in the area indicate that ideally, a protected area within the Imatongs would encompass biological communities rich in endemic species of restricted range, that contain community types under – represented in other protected areas, that support threatened species, and that contain resources of potential use to people such as valuable ecosystem services that are easily understood by the public (Primack 2006). Because of the decades-long war, however, species data to support this level of detailed analysis are lacking. Based on discussions with local informants and the results from the 2009 reconnaissance surveys within ten major forest blocks of larger mammals conducted by WCS, it is clear that excessive poaching during and after the war has led to a decline in previously present animals such as buffalo, leopards and elephants. This is not unique to the Imatongs and has occurred throughout South Sudan where experts maintain that a "faunal holocaust" occurred during the war due to widespread shooting of animals for meat, ivory, horns and skins (personal communication, Philip Winter, Rift Valley Institute). Fortunately, some species in the Imatongs such as duikers, bushbucks and bush pigs are still present and could conceivably recover and even thrive if protected from illegal hunting (Grossmann et al. 2009).

In addition to wildlife conservation, future plans for the Imatong region should consider whether or not currently defunct forestry projects will be revitalized. Field surveys in 2009 involved several employees from the GoSS Ministry of Agriculture and Forestry (MAF) who measured the current extent and state of existing Cypress, Pine and Eucalyptus plantations. Results from these surveys indicated that approximately 7.5 $km^2$ of plantation species still exist, although the trees are in poor shape after over twenty years of neglect and falling prey to fires, windblow and insect damage (Grossmann et al. 2009). Rehabilitation of these plantations would most certainly provide South Sudan with much needed timber for construction and give a boost to the local economy through employment and the development of secondary markets. At the same time, however, some within the local community have expressed concern for the ecological damage caused by the non-indigenous species (as discussed in Section 4.6.5), and the infrastructure needed to undertake these projects (e.g. new roads, housing for workers, etc.) could lead to additional, unplanned deforestation as has been the case in other parts of the world (Arima et al. 2005; De León 2009; Moran 1993). Clearly, future development of forestry projects must take great care to balance local and national development benefits with short and long-term ecological consequences.

As discussed in Section 4.6, many of the community members interviewed want to prevent destruction of the forests and are looking for assistance from local authorities to help them in this endeavor. While it is unclear how representative this sentiment is of the greater Imatong community, where people may have different viewpoints regarding the fate of the forests, it raises the question of the extent to which local people are included in conservation and development plans for the Imatong region. The integration of local knowledge for environmental management is a controversial issue that has practically seen mixed results (Oldekop et al. 2010). The use of traditional ecological knowledge (TEK) alongside scientific knowledge as part of a greater community-based conservation program (commonly known as CBNRM or community-based natural resource management, or CBC – community-based conservation, or ICDP – Integrated Conservation and Development Project) has been viewed by many as an effective, bottom-up method to conserve biodiversity (Berkes 2004; Berkes et al. 2000; Horwich & Lyon 2007). On the other hand, failure to show practical results (Chapin 2004) as well as the long and arduous process often necessary to achieve consensus among stakeholders (Sayer & Campbell 2004), has led to critiques of this participatory technique in recent years in favor of renewed use of protected areas that exclude local communities from them and their management (Sanderson & Redford 2004).

While an exclusionary approach may be appealing for its avoidance of a prolonged and potentially contentious process, the rapid and somewhat unpredictable influx of people to the area, the pressing development needs of the local community, and the uncertainty of the future with respect to overall stability of the country, the region, and the climate, suggests that the use of science – based considerations alone to create a protected area will not be sustainable in the long run. Future plans will require innovative conservation strategies that incorporate alternative perspectives as previous efforts have shown that there is often no single ‘best plan’ for a landscape and therefore multiple scenarios need to be assessed (Peterson et al. 2003). For this reason, the participatory planning process begun as part of Chapter 4 of this dissertation could be continued and expanded upon to include people from all ethnic groups present in the area that represent long-term residents, recent returnees, and current IDPs, as well as government and civic leaders to develop an integrated land use plan that seeks to strike a balance between conservation and development objectives.

In addition to resolving the location and extent of protected areas and plantations, the development of possible future scenarios for conservation planning should take into account the underlying processes driving land use and land cover change – such as the widespread use of fire and land conversion for cultivation. As seen in Sections 3 and 4 of this dissertation, anthropogenic fire is widespread and uncontrolled, and can quickly spread into the forest, damaging large areas of both natural and plantation forests. Observations during a 2009 field visit were confirmed by key informants in 2011 that in general, there is a lack of awareness by locals of the potential negative impacts of widespread burning.

**Figure 5-1: The burning of a mature *Podocarpus milanjianus* tree by local guides in April 2009 to clear the area, despite the fact that the trees were immediately adjacent to a field that was ideal for setting up camp. (Photograph by V. Gorsevski).**

In order to minimize the negative impact of fires in the Imatongs, laws should be developed and enforced that encourage early burning and the creation of fire breaks in certain areas to prevent the spread of fire into forested areas. These laws should be part of a greater effort to educate community members about the consequences of uncontrolled fire, as recommended by key informants during the November 2011 interviews.

As seen in Section 4 of this dissertation, many people support themselves by farming and often produce extra crops for sale in local markets. As security is no longer an issue and people can freely cultivate in and around the Imatongs, it is likely that farming will expand in future years with potentially deleterious consequences for nearby forests, unless steps are taken to encourage farming techniques that are less destructive to the natural landscape. As a result, conservation planning should assess different cultivation options, such crop diversification, which has been shown to increase resilience as well as providing economic benefits (Lin 2011). One type of diversification in agricultural systems is known as agroforestry, where trees or shrubs are used within agricultural systems, and which has seen various levels of success and failure depending on the specific circumstances (Frohlich 2011; Russell et al. 2010). This and other options might be explored for the Imatong region as a way to address the needs of a growing population without putting undue pressure of the forests.

The research presented in this dissertation demonstrates the value of combining remote sensing data with information obtained from interviews with local inhabitants to investigate questions about land use and land cover change during times of war and peace. This study is the first to examine changes in forest cover in this cross-border region experiencing different, but related conflicts. The results highlight how conflict impacts decisions related to land use and how this in turn affects the local ecology. From a practical perspective, research begun under this dissertation can be used in concert with other data to help develop an integrated land use plan that incorporates conservation and development priorities.

## List of Acronyms

| | |
|---|---|
| ACLED | Armed Conflict Location and Event Data |
| AFR | Agoro-Agu Forest Reserve |
| ARD | Associates in Rural Development |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| BNP | Bandingalo National Park |
| CAMS | Climate Assessment and Monitoring System |
| CBC | Community-based Conservation |
| CGIAR | Consultative Group on International Agricultural Research |
| CI | Conservation International |
| CIAT | Centro Internacional de Agricultura Tropical |
| CIESEN | Center for International Earth Science Information Network |
| CC | Cubic Convolution |
| CBNRM | Community-Based Natural Resource Management |
| CPA | Comprehensive Peace Agreement |
| CRS | Catholic Relief Services |
| CSI | Consortium for Spatial Information |
| DEPHA | Data Exchange Platform for the Horn of Africa |
| DRC | Democratic Republic of Congo |
| DI | Disturbance Index |
| EDF | Equatorian Defense Force |
| ENVI | Environment for Visualizing Images |
| EOS | Earth Observing System |
| ETM | Enhanced Thematic Mapper |
| FAO | Food and Agriculture Organization |

| | |
|---|---|
| FEWS | Famine Early Warning System |
| FIRMS | Fire Information for Resource Management System |
| FNL | National Liberation Front |
| FSO | Front-Seat Observer |
| GEF | Global Environment Facility |
| GIS | Geographic Information System |
| GLCF | Global Land Cover Facility |
| GPS | Global Positioning System |
| GLOVIS | Global Visualization Viewer |
| GLS | Global Land Survey |
| GoS | Government of Sudan |
| GoSS | Government of South Sudan |
| GPCC | Global Precipitation Climatology Centre |
| GPW | Gridded Population of the World |
| ICDP | Integrated Conservation and Development Project |
| ICFR | Imatong Central Forest Reserve |
| IDMC | Internal Displacement Monitoring Centre |
| IDP | Internally Displaced Person |
| IJRS | International Journal of Remote Sensing |
| IOM | International Organization for Migration |
| IR | Infrared |
| IRIN | Integrated Regional Information Networks |
| ISODATA | Iterative Self-Organizing Data Analysis |
| JAXA | Japan Aerospace Exploration Agency |
| JLC | Joint Logistics Commission |
| LDC | Least Developed Country |
| LPDAAC | Land Processes Distributed Active Archive Center |

| | |
|---|---|
| LPGS | Level 1 Product Generation System |
| LRA | Lord's Resistance Army |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NASA | National Aeronautics and Space Administration |
| NBS | National Bureau of Statistics |
| MAF | Ministry of Agriculture and Forestry |
| NEMA | National Environment Management Authority (in Uganda) |
| NESSF | NAS Earth and Space Science Fellowship |
| NDVI | Normalized Difference Vegetation Index |
| NGO | Nongovernmental Organization |
| OCHA | Office for the Coordination of Humanitarian Affairs |
| RSE | Remote Sensing of Environment |
| SAF | Sudan Armed Forces |
| SEDAC | Socioeconomic Data and Applications Center |
| SIM | Sudan Interagency Mapping |
| SNID | Sudan National Immunization Days |
| SPLA | Sudan People's Liberation Army |
| SPLM | Sudan People's Liberation Movement |
| SPOT | Satellite pour l'Observation de la Terre |
| SRRA | Sudan Relief and Rehabilitation Association |
| SRTM | Shuttle Radar Topography Mission |
| SSRRC | South Sudan Relief and Rehabilitation Commission |
| SSCCSE | Southern Sudan Center for Census, Statistics and Evaluation |
| TEK | Traditional Ecological Knowledge |
| TM | Thematic Mapper |
| TRMM | Tropical Rainfall Measuring Mission |
| UMD | University of Maryland |

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|---|---|
| UNHCR | United Nations High Commissioner for Refugees |
| UNJLC | United Nations Joint Logistics Centre |
| UNMIS | United Nations Mission in Sudan |
| UNSIG | United Nations Sudan Information Gateway |
| UPDF | Ugandan Peoples Defense Force |
| USGS | United States Geological Survey |
| USAID | United States Agency for International Development |
| WCS | Wildlife Conservation Society |
| WFP | World Food Programme |
| WIST | Warehouse Inventory Search Tool |
| WRS | Worldwide Reference System |

**PRAYER FOR THE REPUBLIC OF SOUTH SUDAN**

God of Mercies,
we thank you for your great love for us.
We ask you to guide all our leaders
in the process of nation building,
grant them your wisdom, compassion and fortitude.

Loving God,
give us courage to reject resentment
as well as ethnic conflicts.

Through the intercession of St. Josephine Bakhita[7],
help us to overcome hurt, hostility and bitterness in our hearts
so that we become reconciled citizens of our new nation.

Renew in us the will for honest and hard work
and bring us closer to you in the spirit of service,
unity and lasting peace.

Loving God, we pray for our heroes,
our martyrs and all innocent people
who died during the long years of war.

We pray in thanksgiving for all those
who stood with us in solidarity
To bring about peace.

Unite us from every tribe, tongue and people.
Send your Holy Spirit upon us
And may your Will be done in us.

God, bless our new nation;
bless the Republic of South Sudan,
bless also the Republic of Sudan.
In Jesus' name. Amen.

by Anonymous
(transcribed from a prayer card commonly found throughout offices in South Sudan following Independence in July 2011)

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[7] Josephine Bakhita (c. 1869 – 8 February 1947) was a Sudanese-born former slave who became a Roman Catholic Canossian nun in Italy, living and working there for 45 years. In 2000, she was declared a saint by the Roman Catholic Church (http://en.wikipedia.org/wiki/Josephine_Bakhita. Accessed on May 6, 2012).

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