The impact of forest degradation on carbon stocks of forests in the Matiwane area of the Transkei, South Africa

A thesis submitted in fulfillment of the requirements for the degree

MASTER OF SCIENCE

At

RHODES UNIVERSITY

By

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2010

Abstract

This study focused on assessing the condition and creating a carbon inventory of forests in the Matiwane area of the Transkei. This entailed the use of aerial photography in tracing forest cover change from 1942 to 2007 coupled with ground-truthing to assess whether the forests have in any way endured degradation over the years with a potential reduction in carbon stocks as a result. This study revealed both the loss and gain of biomass in the area with a general trend of forests being continuously converted to agricultural fields resulting in reduced forest area, stem density, tree density and carbon loss in different pools of the forests, reflecting that these forests are degraded. The conversion has resulted in the reduction in the number of species from a mean of 11±0.57 species/200m^2 in intact forests to 1±0.23species/200m^2 plot in degraded forests. It was also revealed that approximately 5.2 % (791 hectares) of 15 352 hectares of forest area was lost as a result of the conversion of forest land to agricultural fields from 1942 to 2007 with 99 % of the clearing occurring in the last 33 years (1974-2007) and of which 60 % (477 hectares) occurred from 1995 to 2007, indicating that forest degradation in these forests is on the increase. The assessment also revealed some areas that were non-forest in 1942 that have accumulated woody biomass (BAA), composed mainly of *Acacia sp* accounting for 51.18 MgC.ha^{-1} (Megagrams of carbon per hectare) and total carbon stocks of 0.02 TgC (Teragrams of carbon). The degradation of these forests induced a reduction in carbon stocks from 311.68±23.69 MgC.ha^{-1} (to a soil depth 0-50 cm) in intact forest to 73.46±12.34 MgC.ha^{-1} in degraded forests. The total carbon stocks in the degraded forests were approximated at 0.06 TgC and the BAA areas 0.02 TgC with 4.7 TgC in intact forests. The degradation of these forests has resulted in the net carbon loss of 0.19 TgC between 1942 and 2007 but 4.76 TgC is still locked in these forests. The large difference in carbon stocks between intact and degraded forests indicated the need to reduce the degradation of these forests to prevent further carbon loss and reduction of the carbon sequestration potential of these forests.

Acknowledgements

I would like to extend my gratitude to the following people:

My supervisors Professor Charlie Shackleton & Dr Ayanda Sigwela, who gave direction to this research, provided the necessary inputs, support and guidance throughout this research. It was not easy but through your motivations the work came to a successful completion.

Mike Powell, who provided the guidance on methodological matters during this research. Mike you went out of your way to help out and I couldn't have managed without your help.

The Department of Water Affairs through the Working for Woodlands program, for the funding. I would like to thank again the forest managers Mr Mgqudlwa and Mr Mkibi for all their help.

Rirhandzu Mkhari & Malibongwe Makafe who went out of their way to help with data collection and field work. You guys sacrificed your bodies and time, to help out in this research. Makafe, I am indebted to you my bra, you were the cornerstone of this research, ndiyabulela mhlobo wam.

The family at the Environmental Science department, for all their help. To my friends, thank you guys for the support and the crazy moments that kept me going during this last two years.

The people at S22 chemistry department, I became part of your family and thanks a lot. Nicole Sibuyi, you made this happen, thank you.

To my family, Ke Lebogile. Mma Rebecca, mma Lucy, mma Sarah le Nape-tsohle ke ka lebaka la lena **BAKGADITSI, DI TAU. KE BUSETSA DITEBOGO GO LENA KA MOKA.** Ke fihlise ditebogo gape go Maureen, Florence, Mary le lelapa ka moka- ka thekgo le lerato la lena ke kgonne, ka tielela go fihla ga bjale. Ke a le rata ka moka.

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List of abbreviations

AGB	Aboveground biomass
BAA	Biomass accumulating areas
BGD	Belowground biomass
C	Carbon
CCS	Carbon capture and storage
CDM	Clean Development Mechanism
DWAF	Department of water and forestry
DEAT	Department of Environmental Affairs and Tourism
DBH	Diameter at breast height, tree diameter taken at 1.3 m from the ground
FAO	Food and Agriculture Organization
GHG	Greenhouse gas (e.g. CO_2, N2O)
GIS	Geographic Information System
GPS	Geographic Positioning System
IDP	Integrated development plan
IPCC	Intergovernmental Panel on Climate Change
R3G	Restoration research group
RD	Relative difference
REDD	Reducing Emissions from Deforestation and Degradation
SE	Standard error
UNFCCC	United Nations Framework Convention on Climate Change

Units

Gt	gigatonnes
ha	hectare = 10,000 m^2
kg	kilogram

Mt	megaton or Million tons = 1 000 000 tons
Mg	megagrams=1 000 000 grams
Mha	megahectares = 1 000 000 hectares
ppm	parts per million
Pg	picograms
t	ton = 1,000 kg
Tg	teragrams

CHAPTER 1

Introduction and study site

1. Introduction

1.1 Overview

The general view is that forests over the world are continuously being degraded and deforested leading to a substantial loss of carbon from this biome to the atmosphere thus contributing to climate change (Mansourian *et al.*, 2005; DeFries *et al.*, 2007). This brought about a need to assess the condition of forests and the impact that forest degradation and deforestation have on forest carbon stocks to construct better measures of mitigating against forest carbon loss/reduction. Also, forest assessments are necessary to reflect on forests that need interventions such as restoration, afforestation, reforestation in an effort to replenish the lost carbon stocks in these forests (Mansourian *et al.*, 2005). These forest assessments are necessary, especially in former homelands of South Africa, which are regarded to have endured heavy forest degradation over the years (King, 1941; Cawe, 1986; von Maltitz and Shackleton, 2004).

These former homelands were associated with natural resource depletion or environmental degradation which is reported to be as a result of large populations residing in a small area (King, 1941; Cawe, 1986; von Maltitz and Shackleton, 2004). One of these homelands is an area formerly known as the Transkei on the eastern site of the Eastern Cape (Cawe, 1986). Forests in this area have been identified to be heavily fragmented over the years by natural causes which were further aggravated by human activities (King, 1941; Cawe, 1986; von Maltitz and Shackleton, 2004). Also within the Transkei area, the coastal forests of the Matiwane were identified to be degraded and due to the decline in forest area in the Matiwane, there came a need for the restoration of these forests (R3G, 2010), an initiative funded by the Working for Woodlands program of the Department of Water Affairs and Forestry (DWAF) and this study makes part of a collaborative research funded by the Working for Woodlands program of DWAF in collaboration with a group of restoration scientists (R3G) concerned with the restoration of the Matiwane forests. The study seeks to assess the condition of these forests and the role of forest degradation in carbon dynamics in these forests.

1.2 Motivation for the research

This research was induced by the following:

- Many researchers have pointed out that the forests in the Transkei are degraded (Robertson, 1924; King, 1941; Cawe, 1986, von Maltitz, 2003; von Maltitz and Shackleton, 2004) but the supplementary information on which forests in particular are regarded as degraded and the extent at which these forests are degraded is insufficient, including the forests of the Matiwane in the coastal regions of the Transkei.
- Data on carbon stocks of these forests and the carbon lost due to degradation has not been well documented for these forests. To better understand the role that the forests in the Matiwane area have played in carbon sequestration it is essential to come up with an inventory of the carbon stocks. Creating an inventory will allow other researchers to assess the carbon sequestration rate of the forests as it is difficult to determine the sequestration rate without the prior inventory data.
- South Africa as a signatory to the UNFCCC (United Nations Framework Convention on Climate Change), is required to report and update on its national carbon inventory and on its carbon sinks (DEAT, 2004). However, on the national scale data is insufficient on carbon stocks in forests and other biomes. The data made available by this study will contribute to the available data to aid in the construction of a regional and national carbon inventory, particularly for forests. As such the importance of this type of studies cannot be overlooked.

1.3 Objective and Research questions

The main objective of this study was to determine and characterise the current condition of forests in the Matiwane area and how this affects the carbon stocks of the forests. To achieve this, the following key questions were addressed:

(1) What is the current condition of the forests in the Matiwane area?

(2) What are typical woody plant species assemblages in different forest classes?

(3) What are the current carbon stocks of different forest classes?

(4) What has been the loss of carbon stocks subsequent to forest degradation?

1.4 Literature review

1.4.1 Global warming and forests

In the past two decades there have been concerns on the issue of global warming, which is understood to be caused by the accumulation of greenhouse gases (GHG) such as carbon dioxide CO_2, nitrogen oxide (N_2O), carbon monoxide (CO) and methane (CH_4) in the atmosphere (Khasnis and Nettleman, 2005). These gases form a layer in the atmosphere preventing the re-radiation or reflection of solar radiation back to space causing an increase in temperature of the globe, referred to as global warming (Perez *et al.*, 2005; Khasnis and Nettleman, 2005; Glenday, 2007). The average global surface temperature is estimated to have increased by $0.6 \pm 0.2°$ C over the 20^{th} century and is projected to rise by 0.3–2.5° C in the next fifty years and 1.4–5.8° C in the next century (Tett *et al.*, 1999; IPCC, 2001; Mitchell *et al.*, 2002; Perez *et al.*, 2005).

Global warming has received scientific, economic and political attention based on the negative impacts that it is predicted to have at the global scale such as the melting of polar ice, which is hypothesised to lead to increased sea levels (Khasnis and Nettleman, 2005; Glenday, 2007). High global temperatures are also hypothesized to lead to diseases outbreaks and extreme climatic conditions (Khasnis and Nettleman, 2005). Of all the greenhouse gases, carbon dioxide is one of the primary or the most abundant gas in the atmosphere which is as a result of fossil fuel burning (petroleum, coal), biomass burning (wood, vegetation) and land cover changes (e.g. deforestation and forest degradation) (Glenday, 2007). The largest carbon source is said to be from fossil fuel burning which is responsible for 6.3 Gigatons of carbon (C) per year (Prentice *et al.*, 2001; Wauters *et al.*, 2008).

It is estimated that the atmospheric carbon dioxide concentration has risen from 280 to 365 parts per million (ppm) since the industrial revolution and it is predicted that it may escalate to 700 ppm by the second half of the 21^{st} century (Houghton *et al.*, 1990; Lamlom and Savidge, 2003). At a global scale carbon dioxide emissions are estimated to be rising by 3.2 Pg C (picograms carbon) per year (Prentice *et al.*, 2001; Gurney *et al.*, 2002; Woodbury *et al.*, 2006). With the increase in scientific and public concern about global warming, political intervention has been advocated through the Kyoto protocol whereby the industrialised countries (as listed in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC)) are to reduce their collective greenhouse gas emissions to at least 5.2 % below their 1990 emission levels during the first commitment period between 2008–2012 (Wauters *et al.*, 2008). Most of the carbon dioxide sources or activities that are responsible for carbon emissions are important to our daily lives such as the use of petrol which is the major source of energy for motor vehicles (Fang *et al.*, 2006). In rural communities where electricity is unavailable the use of forest components for making fire for cooking and the use of timber for buildings leading to the deforestation of surrounding forests is part of their daily livelihoods which subsequently contributes to carbon emissions (Fang *et al*, 2006).

However, there is a close relationship between global warming and forests (FAO newsroom, 2006). Global warming induces climate change which alters precipitation patterns and extreme weather conditions consequently disturbing forests (FAO newsroom, 2006). At the same time forests store/sequester CO_2, the main gas that is associated with global warming. Also when disturbed, forests can be the source of this gas thus contributing to global warming (FAO newsroom, 2006). Thus, there is a need to manage this complex relationship for the future of this planet (FAO newsroom, 2006).

1.4.2 Carbon sequestration by forests

Carbon sequestration is described as the removal of carbon from the atmosphere into a reservoir where it will be captured or stored for some time (Lal *et al.*, 2003 as cited by Niu and Dieker, 2005). During photosynthesis, plants assimilate CO_2 from the atmosphere which is then locked in carbon containing molecules within plant cells resulting in an accumulation of carbon during the lifespan of a plant (Taiz and Zeiger, 2006). Roughly 50 % of the plant dry biomass is carbon, therefore plants can play an important role in carbon sequestration from the atmosphere (Redendo-Brenes and Montagnini 2006). The forest ecosystem harbours large volumes of biomass and as a result sequesters more carbon than other terrestrial ecosystems (Backéus *et al.*, 2005). Forest ecosystems occupy about one-third of Earth's land area with 80 % of the total aboveground terrestrial carbon and 40 % of below-ground carbon stored within this ecosystem (Dixon *et al.*, 1994; Song and Woodcock, 2003).

It is estimated that about two-thirds of the terrestrial carbon (excluding the carbon sequestered in rocks and sediments) is in standing forests, forest understory plants, leaves, forest debris and in forest soils (Sedjo *et al.*, 1998). According to FAO (2005) the world's forests store 283 Gigatonnes (Gt) of carbon in their biomass and it is estimated that carbon in forests is roughly 50 percent more than the amount of carbon in the atmosphere (FAO, 2005). However, carbon stored in forests can be lost subsequent to disturbances such as forest degradation and deforestation, which are the two important processes that greatly reduce forest carbon as forest biomass is lost subsequent to these processes (De Jong *et al.*, 2000).

1.4.3 Forest degradation and deforestation

In the last few decades more than ever, forest dynamics have been given attention on the economic, scientific and political grounds based on the positive and negative impacts that forest dynamics may hold for the future of humankind (De Jong *et al.*, 2000; Khasnis and Nettleman, 2005; Perez *et al.*, 2005). Coupled with the role that forests play in the carbon cycle, the interest in forest dynamics boomed further (Perez *et al.*, 2005). Forest degradation and deforestation are two sectors that are of interest as they are known to reduce forest biomass and ultimately result in the reduction of carbon stocks in forests (Naughton-Treves, 2004; Perez *et al.*, 2005). Deforestation is known as the complete conversion of forest area to non-forest and forest degradation (in terms of carbon dynamics) as the partial reduction in forest area induced by human activities thus reducing the carbon stocks in the forest (DeFries *et al.*, 2007). The two processes differ in a sense that degradation is the decline while deforestation is the complete loss of forest biomass (DeFries *et al.*, 2007). It is estimated that globally about 7.3 Mha per year of forest was lost during 2000-2005 subject to the growing demand for land for crop production and commercial cattle farming, etc. (FAO, 2007; Ravindranath and Ostwald, 2008). It estimated that annually approximately 1.6 and 2.4 Pg of carbon emissions result from tropical forest clearing alone (De Jong *et al.*, 2000: Fearnside, 2000 cited in Naughton-Treves, 2004). During the period 2000-2005 approximately four million hectares of forest area was lost annually in Africa with the conversion of forests to agricultural lands being the main contributor (approximately 59 %) to forest loss (FAO, 2009b). Forest loss during this period has resulted in 0.29 $PgCyr^{-1}$ of carbon emissions in Africa alone (Shvidenko, 2008).

Rodgers (1997) discusses deforestation and forest degradation in developing countries as influenced by an assortment of structural problems related to the international economic system, as well as the underlying socio-economic status of the country itself. Rodgers (1997) further introduces two levels of underlying causes of forest loss in developing countries which the author categorised as ultimate and proximate factors. The ultimate factors are described as those factors about which relatively little can be done to resolve them in the medium term and these include:

- Increasing population growth and forest resource demand;
- Economic dependence on natural resources by communities;
- Widespread poverty levels in most countries.

The proximate factors are discussed as those which can be addressed in the medium term (FAO, 2009b; Rodgers, 1997):

- Inadequate policy systems;
- Insufficient participation by stakeholders;
- Uncertainties in land tenure and access rights;
- Insufficient investment in the forest sector;
- Inapt valuation systems;
- Poor land-use planning capacity and systems.

Forest loss is driven by an amalgamation of different drivers which are classified as direct and indirect drivers of different nature; including social, ecological, economic, environmental and biophysical drivers (Rodgers, 1997; Shvidenko, 2008). In most cases the drivers intermingle with one another; these combinations of drivers vary within a region of the globe, by countries, and across different locations within a country. Direct drivers are human activities at the local level and they directly induce changes in the surrounding forest, these drivers can be broadly classified under those related to agricultural expansion, wood extraction, and infrastructure extension (Allen and Barnes, 1985; Shvidenko, 2008). Amongst all the drivers, agricultural expansion is the most important direct driver of forest loss in many regions of the world and includes shifting cultivation, permanent agriculture, pasture creation, and resettlement programs subsequently resulting in forest conversion to other land uses (Shvidenko, 2008; FAO, 2009b). Wood extraction incorporates activities such as commercial logging, fuelwood harvesting, and charcoal production from forest trees. Commercial logging is regarded as an important direct driver in Asia and Latin America while fuelwood gathering is one of the most important drivers in Africa responsible for forest fragmentation (Allen and Barnes, 1985; Shvidenko, 2008, FAO, 2009b). Infrastructure extension incorporates activities such as construction of transport routes; development of new industrial enterprises; settlement expansion; and a variety of other activities (such as oil exploration and extraction, mining, construction of hydropower stations, pipeline and electric grids) (Tole, 1998; Shvidenko, 2008, FAO, 2009b).

Indirect drivers may or may not occur at local levels which include economic, institutional, cultural and socio-political factors (Shvidenko, 2008). Economic factors such as rapid market growth and incorporation into the global economy, commercialization, urbanization and industrialization, growth of demand for forest-related consumer goods, poverty, etc. are some of the indirect factors that induce forest exploitation in many regions of the world (Shvidenko, 2008). Institutional factors include taxation, subsidies, corruption, property rights, etc. which usually intertwines with economic factors and may indirectly contribute to forest exploitation (Shvidenko, 2008; FAO, 2009b). Cultural and socio-political drivers includes factors such as lack of public support for forest protection and sustainable use, low educational levels and low perception of public responsibilities also play a substantial role (von Maltitz & Shackleton 2004; Shvidenko, 2008; Shackleton, 2009). Population growth, density, and spatial distribution are usually not classified as primary drivers of forest loss as they are always combined with other factors (Shvidenko, 2008). Although deforestation and forest degradation reduce forest carbon, the reverse process of forest restoration can recapture the lost carbon from the forest (Mansourian *et al.*, 2005).

1.4.4 Forest restoration and the carbon market

Forest restoration is described as a planned process of planting trees in previously degraded or deforested landscapes with the aim of regaining ecological functions (Mansourian *et al.*, 2005). The exerted pressure on forests has raised the need to restore forests with an effort to replenish the ecosystem services (such as CO_2 sequestration) initially provided by forests (Mansourian *et al.*, 2005). Also, the realisation that forests can aid in sequestering atmospheric carbon resulted in efforts to encourage initiatives such as forest restoration to sequester the lost carbon in this ecosystem in the medium term (Lecocq, 2004; Lubowski *et al.*, 2005; Mansourian *et al.*, 2005).

To encourage the capture of CO_2 an allowance is made under the Clean Development Mechanism (CDM) where the amount of carbon captured can be traded for a particular fee known to most as carbon credits (Lecocq, 2004; Lubowski *et al.*, 2005; Powell, 2009). Under the Kyoto protocol industrialised or developed countries are allowed to purchase CO_2 offsets from countries that emit less CO_2 (Perez *et al.*, 2005) or from an entity that captures carbon from the environment (Mills *et al.*, 2003).

The carbon market, which allows carbon dioxide emitters to pay for the creation of carbon sinks, has resulted in an increased interest in the carbon sequestration and trading for both environmental protection and poverty alleviation in developing countries (Mills *et al.*, 2003). This market is one of the few markets for environmental services in operation (Lecocq, 2004). Under carbon trading arrangements, an organization that introduces land management practices (such as restoration) that would elevate the storage of carbon would receive payments for the amount of carbon sequestered by that particular organization in that way encouraging initiatives that elevate carbon capture (Lubowski *et al.*, 2005).

The payments made available under the carbon market can be used to uplift the socio-economic status of the communities in which the project operates (Mills *et al.* 2003; Jindal, 2006). Restoration requires labour and payments received through the carbon market may be used to pay for the labour provided by the community and in that way contributing to the socio-economic improvement of the poor communities of the country (Mills *et al.* 2003; Lubowski *et al.*, 2005; Jindal, 2006). Millions of dollars are invested in carbon sequestration projects and the funds are mostly shared with the communities, an example of such projects is the Green belt movement project in Kenya in which farmers were allocated \$150 million for carbon sequestration and to carry out conservation activities to enhance carbon sequestration (Jindal, 2006). Some examples of other carbon sequestration projects in the African continent are reviewed in Appendix 1. The benefit sharing column of Appendix 1 also indicates the possibility of socio-economic impacts of these types of projects. However, the number of carbon sequestration projects on the whole continent of Africa is low considering the available forests within the continent. South African forests are also not immune to disturbance (von Maltitz and Shackleton, 2004) as such it is important to have background assessment of the state of the forests and whether they can be used for obtaining carbon credits through carbon mitigation.

For a carbon sequestration initiative using natural resources such as forest vegetation to participate in the carbon market and also to test the effect of reforestation/restoration as well as land management strategies on forest carbon storage, it is necessary to examine carbon pools and their changes (Zheng *et al.*, 2007). Thus, information regarding how much carbon is sequestered in a proposed restoration area is also necessary if the restored land is to be used for carbon credits.

1.4.5 The need for South Africa to engage in carbon studies in forests

It is predicted that of all regions of the world, Sub-Saharan Africa will be the most severely affected with the highest predicted human mortality rates linked to climate change impacts such as crop failures, increased disease ranges, and heat waves (Patz *et al.*, 2005; Glenday, 2007). South Africa is one of those countries that will be severely affected and it is predicted that South Africa will also be faced with significant challenges from increased temperatures, decreased water availability, and sea level rise expected to result from climate change (Glenday, 2007). As a country, South Africa is vulnerable to climate change, it is a contributor to climate change, a signatory to the Kyoto protocol and faced with diminishing forests (Glenday, 2007). Also, the restoration of lost forests for carbon credits and participation in REDD can also boast the socio-economic status of poor communities of the country (Ghazoul *et al.*, 2010). Thus, the need for South Africa to participate in carbon studies is beyond question, particularly in the forest biome which is an important sequestration site for carbon.

1.4.5.1 South Africa and its vulnerability to climate change

South Africa has three primary geographical regions: a large central plateau occurring in inland areas with altitudes ranging between 1 220 m to 1 830 m; a nearly continuous escarpment of mountain ranges that encompasses the plateau on the west, south and east, with altitudes exceeding 3 050 metres; and a narrow strip of low-lying land along the coastal regions of the country (Benhin, 2006).

South Africa is highly vulnerable to various climate change impacts because it is largely semi-arid and currently negatively affected by freshwater scarcity (Glenday, 2007). The mean annual rainfall experienced by South Africa as a whole is 500 mm per year which is below the world's average of 860 mm (Blignaut *et al.*, 2006). Only 10 % of the country receives an annual precipitation of more than 750 mm (Schulze, 1997; Benhin, 2006). Evaporation rates are also relatively high, estimated at 1 500 $mm.year^{-1}$ subsequently leading to only 8.5 % runoff (Schulze, 1997; Benhin, 2006). South Africa is characterised by six climatic zones with the arid and semi-arid covering most of the surface area of the country (Schulze, 1997). The desert covers 22.8 % of the surface area; arid (24.6 %); semi-arid (24.6 %); sub-humid (18.5 %); humid (6.7 %) and super-humid (2.8 %) (Schulze, 1997; Benhin, 2006). The country is further classified under three main rainfall regions (Benhin, 2006):

- The winter rainfall region in the south-western Cape receiving less than 500 mm mean rainfall per year.
- The area with rainfall throughout the year along the southern coastal region receiving more than 700 mm per year; and
- The summer rainfall areas receiving rainfall estimated at 700 mm per year.

Temperatures in South Africa are variable with summer temperatures varying from 20° C to 38°C, with high temperatures occurring in the far north section of the country (Schulze, 1997; Benhin, 2006). Winter temperatures vary from 6^0 C to 20° C (Benhin, 2006). However, the temperatures in South Africa are predicted to may increase greatly in the northern regions of the country, between 1° C and 3° C in the mid 21st century with the highest rises in the most arid regions of the country (DEAT, 2004). Also, the reduction in precipitation (rainfall) in the range of 10 % and 20 % is predicted for summer rainfall zones coupled with droughts and prolonged dry seasons for the upcoming decades in South Africa (DEAT, 2004).

Due to the change in the rainfall, water availability will be negatively affected and biomes will suffer maximally (Rutherford *et al.*, 1999; Turpie *et al.*, 2002; DEAT, 2004; Glenday, 2007). Vegetation growth and survival is limited by water availability as such substantial decline in plant growth and increase in mortality of forest trees subsequent to droughts induced by warm temperatures would surely be problematic to South Africa (Turpie *et al.*, 2002; Glenday, 2007; Allen *et al.*, 2010). Warmer temperatures independently induce mortality in trees through irreversible disruption of water columns within stems and leaves of trees thus affecting water transportation which subsequently lead to plant death (Allen *et al.*, 2010).

Some examples of drought induced mortalities of forest trees in South Africa include *inter alia Dichrostachys cinerea*, *Pterocarpus angolensis* and *Strychnos madagascariensis* species in the Limpopo province that occurred during a drought period between 1991 and 1993 (Allen *et al.*, 2010). Further, Allen *et al.* (2010) reported also on tree mortalities in the savanna ecosystem subject to drought and high temperatures within the same province with *Colophospermum mopane*, *Combretum apiculatum*, *Grewia* spp., *Ximenia americana* as the affected trees. These mortalities induced by drought and high temperatures raise a possibility of further escalated forest mortalities as temperatures increase following GHG induced global warming (Allen *et al.*, 2010). Also, in an effort to reflect on future projections of the impact of climate change on South African biomes Turpie *et al.* 2002 revealed a potential reduction of the South African biomes subject to climate change over the next 50 years (see Table1 and Figure 2). As estimated by Turpie *et al.* (2002) the area occupied by the seven biomes in South Africa is estimated to may reduce to between 38 % and 55 % of their current combined area with the 'vacated' areas inhabited by more arid-adapted vegetation. Although the authors make no mention of the total forest area remaining in 2050, the percentage value provided reflects that probably the forest area in 2050 would be close to zero (Turpie *et al.*, 2002).

Table 1: Current and projected climate change effects on indigenous biomes of South Africa Source: (Turpie *et al.*, 2002).

Biome	Current area(ha)	Area remaining in 2050 (ha)	% remaining 2050
Forest	721 154	-	0
Fynbos	7 720 960	2 915 069	38
Grassland	33 340 446	14 320 700	43
Nama Karoo	29 768 902	8 211 192	28
Savanna	42 525 186	30 608 402	72
Succulent Karoo	8 257 625	1 557 116	19
Thicket	4 156 647	-	0

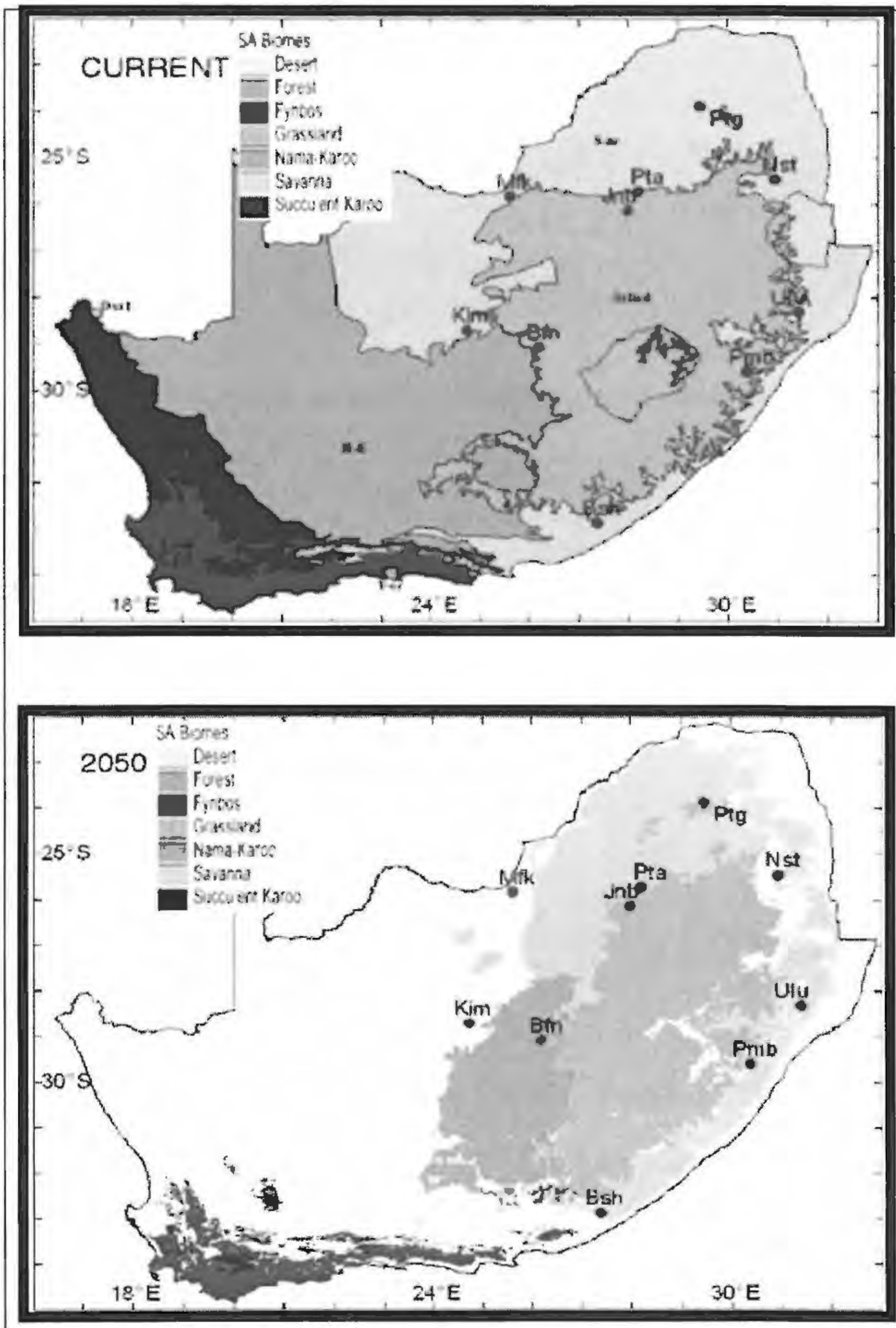


Figure 1: Current and predicted future distribution of biomes in South Africa. The future scenario is based on climate changes brought on by an increase in the concentration of atmospheric carbon dioxide to 550 ppm (Turpie *et al*, 2002).

1.4.5.2 South Africa as a GHG contributor and a signatory of the Kyoto protocol

South Africa is a significant contributor to global greenhouse gases (GHG) production due to the fact that it is a developing country with its primary energy sector that is mostly coal based (NER, 2002; DME, 2003; Mwakasonda and Winkler, 2005). It is estimated that about three-quarters of the primary energy supply and 93% of the electricity is derived from coal (NER, 2002; DME, 2003; Mwakasonda and Winkler, 2005). Further, South Africa has a power utility company, Electricity Supply Commission (namely Eskom) for the provision of electricity which supplies approximately 95 % of the country's electricity and of which 90 % is generated by coal-fired power stations, and it accounts for half of the country's emissions (NER, 2002; DME, 2003; Glenday, 2007; Mwakasonda and Winkler, 2005).

It is estimated that Eskom`s emissions will double in the next twenty years subject to the growing population and the growing demand which is escalating at 4.4 % per annum if the energy would still be coal based (NER, 2002; DME, 2003; Mwakasonda and Winkler, 2005; Taylor, 2009). Another point source emitter is an oil company (Sasol) that is responsible for emitting 72 million tons of carbon dioxide per year and its Secunda plant is the largest single point emitter in the world (Taylor, 2009).

To foster sustainable development in South Africa, both the causes and effects of climate change must be addressed as it may greatly impact development (Glenday, 2007). South Africa as a signatory to the UNFCCC (United Nations Framework on Climate Change Convention) has certain obligations in relation to climate change which include *inter alia* the following (DEAT, 2004):

- Construct and intermittently update a national inventory of greenhouse gas emissions and sinks.
- Encourage sustainable management, conservation and enhancement of sinks and reservoirs of all greenhouse gases.

- Encourage and cooperate in scientific, technological, technical, socio-economic systematic observation and development of data archives related to the climate system placed to better understand and to reduce or eliminate uncertainties related to climate change.
- Encourage and take part in open exchange of relevant scientific, technological and technical information related to climate change.
- Engage in preparing for adaptation to the impacts of climate change.

Despite the fact that South Africa is a country that will be adversely affected by climate change, South Africa makes a significant contribution to the problem: it is ranked fourteenth in the world for annual per capita carbon emissions, the primary GHG emitted globally (World Resources Institute, 2006). Due to this fact South Africa needs to take an active part in carbon capture.

1.4.6 The need for the assessment of the condition and carbon stocks of South African forests

The lack of knowledge on the status and trends of forest resources remains a limiting factor for decision-making in most countries, especially in developing countries (FAO, 2009b) like South Africa. Without proper or periodic assessment of forests, problems such as deforestation and degradation cannot be addressed properly, which may have dire consequences. Forest management policies require that information on the status and condition of forests (Noss, 1999) be made available so as to evaluate which forests require immediate attention and the type of intervention required.

Forest assessments are required to assess if forests cannot be considered for incentive based mechanisms under the CDM. The incentive based mechanisms can uplift the socio-economic status of poor communities surrounding forests (Jindal, 2006), also helping in conserving and restoring the forest status which can come as a huge benefit to South Africa which is trying to balance development and nature conservation. This includes payments made under reduced emissions from deforestation and degradation (REDD+); and payments made under the clean development mechanism (CDM) for restoration as discussed above. The need for assessment of indigenous forests is necessary when forests are to be included in REDD+ and CDM restoration projects.

1.4.6.1 Reduced emissions from deforestation and degradation (REDD)

The Intergovernmental Panel on Climate Change (IPCC) has noted that deforestation and degradation contributes to the overall greenhouse gases entering the atmosphere. Therefore, there is a need to make significant progress in reducing deforestation and forest degradation (FAO, 2009a). This led to governments of Papua New Guinea and Costa Rica proposing that "Reduced Emissions from Deforestation and Degradation" (REDD now called REDD+) be included as one of the emission reduction methods under the UNFCCC in December 2005 at the Conference of the Parties (COP11). This mechanism was the main area of discussion at the COP meeting in Copenhagen in December 2009, where the 'Copenhagen Accord' was signed by the United States, China, India, Brazil and South Africa which recognised the need for natural forest protection to avoid emissions from deforestation and degradation (Ghazoul *et al.*, 2010).

REDD+, recognises reforestation and sustainable forest management as important in an effort to reduce global carbon emissions (Ghazoul *et al.*, 2010). Under REDD+ economic incentives are to be provided to reduce emissions from deforestation and forest degradation in developing countries by giving a monetary value to carbon stored in forest trees, in that way creating a financial incentive that promotes forest protection (Ghazoul *et al.*, 2010). REDD+ is described to be a cost effective mechanism, which can greatly aid in retaining the carbon stocks available in forests and greatly improve the economic levels of poor communities (Ghazoul *et al.*, 2010; Oslo climate and forest conference, 2010). Approximately 4,0 billion US dollars has been pledged for the period 2010–2012 to finance measures to reduce greenhouse gas emissions from deforestation and forest degradation in developing countries (Oslo climate and forest conference, 2010). South Africa can greatly benefit from this incentive based mechanism, which can greatly aid in reducing forest loss in this country and also alleviate poverty levels of the communities that reside close to these forests.

1.4.7 South African forests

South Africa has a total surface area of 1.2 million square kilometres and it is regarded as the third most biodiverse country in the world (World Conservation Monitoring Centre, 1992; Glenday, 2007). South Africa boasts seven biomes; forest, thicket, savanna, grassland, nama-karoo, succulent karoo and the fynbos biome (Rutherford and Westfall, 1986; Glenday, 2007). Out of all these biomes the forest biome is the smallest covering about 350 000 ha with grassland and savanna as the dominant vegetation types (Rutherford and Westfall, 1986; Glenday, 2007; Shackleton *et al.*, 2007). These forests are limited to regions with high water availability and rainfall, mostly found in areas with mean annual rainfall of > 525 mm with strong winter rainfall and > 725 mm with strong summer rainfall (Rutherford and Westfall, 1986; Geldenhuys, 1991; Mucina and Rutherford, 2006). The distribution of South African forests has been greatly influenced by climate and fires with the wetter climates of the eastern and southern coast of the country (Fig. 2) promoting forest growth (von Maltitz *et al.*, 2003; Mucina and Rutherford, 2006; Glenday, 2007).

South African forests have a higher biodiversity than any warm-temperate forests in the world; they are between three to seven times richer in tree species compared to other forests in the southern hemisphere (Silander 2001; Cowling, 2002; DWAF, 2005). They exist as patches and are reported to have been fragmented due to repeated and severe climate changes in the Quaternary (DWAF, 2005). They occur as chains of 'habit islands' within a range of vegetation types including grasslands, fynbos woodlands, bushveld and succulent thicket occurring in between these patches (Eeley *et al.*, 1999; DWAF, 2005).

Most of these forests occur near rural communities of the country who rely on them (Lawes *et al.*, 2004). Poverty and unemployment are two issues that affect the rural communities of South Africa as such these forests play a vital role in the livelihoods of rural communities, providing about 35% of rural households' income (Lawes *et al.*, 2004). Due to poverty, the rural communities rely on subsistence farming, supplemented by harvesting of natural resources thus exerting pressure on natural ecosystems (Cooper *et al.*, 2004). The forest biome of South Africa is one of the biomes that is heavily exploited by rural communities that live around them (DWAF, 2005) thus resulting in forest degradation and deforestation.

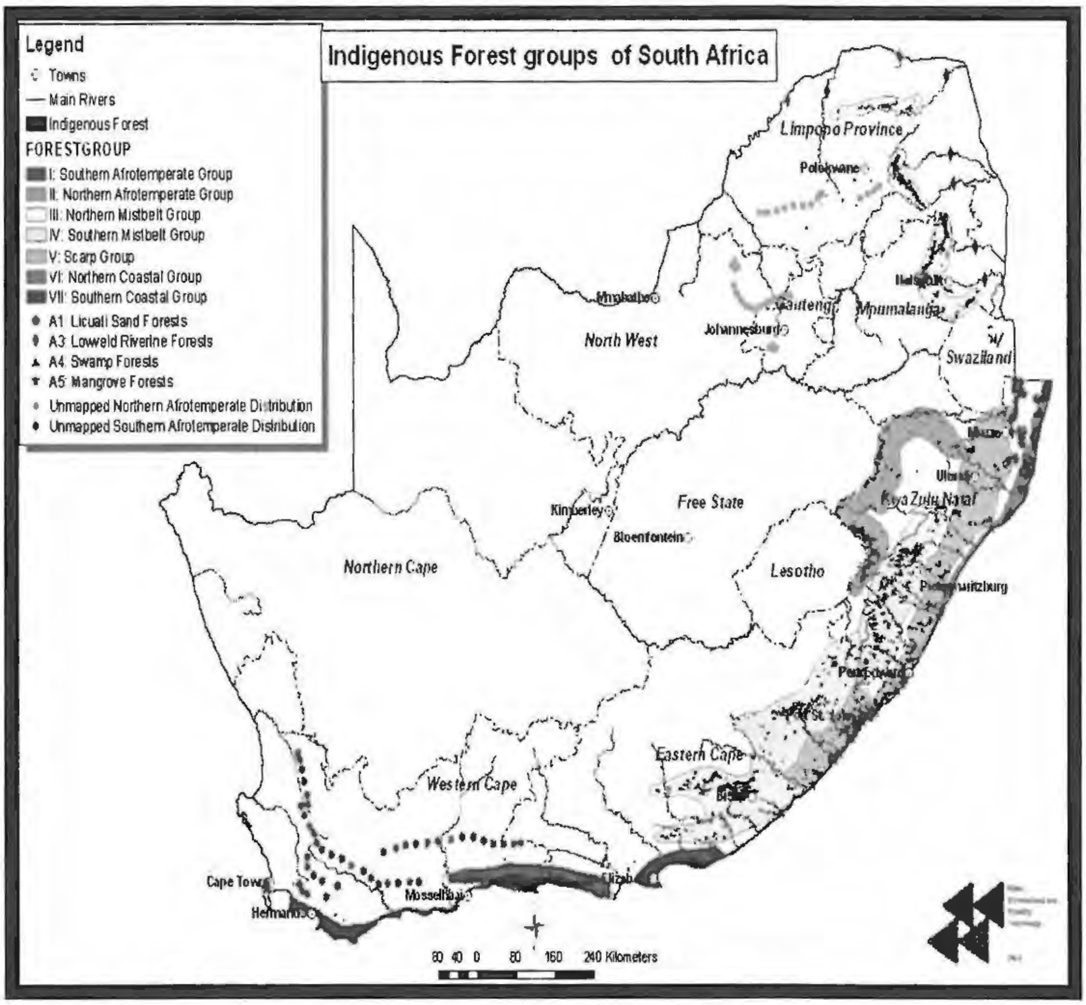


Figure 2: Forest groups of South Africa and the distribution of the forest biome in South Africa along the eastern and southern coast of the country (von Maltitz *et al.*, 2003).

1.4.8 Degradation and deforestation of South African forests

Anthropological activities, wild fires along with the spread of agriculture and commercial plantation forestry have contributed to the fragmentation of South African forests over the years (Rutherford and Westfall, 1986; Lawes *et al.*, 2000; DWAF, 2005). Further, the heavy utilization of forest products by many rural communities of the country has also led to the destruction of these forests in some rural areas (DWAF, 2005). Products obtained from forests include: fuel wood (over 90 % of households in certain rural villages obtain fuelwood from forests); poles used for hut construction and fencing; edible plants; and grazing (forests are vital in sourveld areas where surrounding areas provide poor winter fodder) (DWAF, 2005).

Cutting down trees for construction poles and firewood is regarded as a secondary cause of forest degradation in South Africa (Mucina and Rutherford, 2006). Firewood serves as one of the most important sources of energy for heating and cooking for the majority of households across the country (von Maltitz and Shackleton, 2004) and the use of wood for domestic purposes is an imperative source of income as it substitutes for formal energy and construction resources (DWAF, 2005). The consumption of firewood gathered from forests, woodlands and exotic plantations was estimated to be at 12 million tons per year accounting for about 51 percent of domestic energy use in South Africa in 1989 (Cunningham, 1989).

The direct annual consumption value of products obtained from forests was estimated at R396 million, R1 529 million and R842 million for the Eastern Cape, KwaZulu-Natal and the Limpopo provinces respectively (South Africa's National Biodiversity Strategy and Action plan, 2005). It was estimated that almost 10 million tons (dry biomass) of timber is harvested from forests and woodlands annually to provide fuel and construction timber for rural households (South Africa's National Biodiversity Strategy and Action plan, 2005). The use of these forest products is poverty-driven because people lack alternative income-generating activities resulting in the degradation of forests but some regard the use of forest products as a traditional practice (von Maltitz and Shackleton, 2004; Mucina and Rutherford, 2006; Cawe and Geldenhuys, 2007). In some areas of South Africa, forests have been cleared primarily for crop cultivation to provide the daily food needs of rural communities living close to forests (Mucina and Rutherford, 2006).

Historical evidence on the over-exploitation of forests and woodlands in South Africa dates back to the 1800s (Hutchins, 1903; Sim, 1907; Philliphs, 1931; 1963; King, 1941; Lückhoff, 1973 as cited in von Maltitz and Shackleton, 2004). The over-exploitation in the 1800s urged for an intervention by the government through the development of institutional structures and legislation to regulate the use and management of forests in South Africa and in 1888 the government appointed the first conservator to facilitate the formation of some form of management structure for indigenous forests (von Maltitz and Shackleton, 2004).

The South African government has committed itself to sustainable use, conservation and management of forests with the introduction of legal documents that will ensure that the goals set are achieved. As specified by the National Forest Act (ACT 84 of 1998) the South African government is obliged to monitor and report on the state of the forests (von Maltitz *et al.*, 2003) but the indigenous forests have not been extensively assessed particularly in regards to deforestation and degradation. The potential exists for securing funds for the restoration projects for these forests, only if they would be identified and assessed.

1.4.9 Transkei forests

Transkei is a former homeland that was incorporated into the Eastern Cape Province of South Africa, which stretches 250 kilometres (km) from the Great Kei river in the south to the Mtamvuna River in the north (White *et al.*, 1999). It is within a province that has a topography consisting of slopes and mountains comprising 31.3 % of the total area of the province with the rest belonging to plateaus, plains and river valley systems (Marcus *et al.*, 1996). It is situated between latitudes 30°S and 33°S and longitudes 26°45' E and 30°15' E and it covers an area of approximately 4 379 812 hectares (Wood and van Schoor, 1976; Cawe, 1986).

The coastal regions experience mild windy conditions throughout the year (Lubke, 2001). During spring and autumn months heavy rains are experienced in this region as a result of the south-easterly winds that are variable from year to year (Lubke, 2001). Winds along with cold and warm fronts are responsible for the varying climates of the region with cold winds from the west dropping the maximum temperatures to as low as 10-15° C and the hot berg winds from the north or north-west raise the temperatures to 20-25° C in the winter and over 35° C in summer (Lubke, 2001). In summer the winds have a cooling or drying effect to diminish extreme humidity spells during occasional hot rainy spells along the coast and the rainfall is between 600-1 200 mm per year (Lubke, 2001) thus promoting the development of forests in these areas.

The Transkei forests include some of the largest patches of indigenous forests remaining in South Africa and along with KwaZulu-Natal forests harbour the greatest diversity of forest types in the country (Cooper and Swart 1992; White, 2004). Indigenous Transkei forests cover 100 000 ha, of which 70 000 ha are demarcated and under the control of the Department of Water and Forestry (DWAF) (White, 2004). The smaller patches among the more than 1 300 indigenous forests of Transkei have not been surveyed or proclaimed and are termed Headman's forests controlled by the tribal local authorities (White, 2004).

Exploitation of Transkei forests for timber began in the 19th century when the voortrekkers settled in the area (King, 1941; Cawe, 1986; von Maltitz and Shackleton, 2004). In the initial stages excessive and uncontrolled exploitation took place subsequent to the forests being sold to private individuals and as a result the majority of the forests in the Transkei were destroyed (Robertson, 1924; Cawe, 1986; von Maltitz and Shackleton, 2004). However, Feely (1986) discusses the fact that heavy exploitation of these forests took place during the Iron Age in this area. The heavy-exploitation of these forests during the colonial era resulted in a reduction in forest size and some patches being clear-felled (Laughton, 1937; Cawe, 1986; von Maltitz and Shackleton, 2004). Other forest patches were cleared for agricultural purposes by surrounding poor communities and sawyers assisted by removing the large trees from these forests thus allowing the communities to further clear the area for agriculture (King, 1941; Cawe, 1986).

Cawe (1986) discussed the removal of firewood and saplings for domestic use as an important feature of the utilization of indigenous forests and the collection of firewood has been an important source of energy for poor local communities in the Transkei for centuries. Natural disasters have had their part in the destruction of forests that includes cyclones and heavy snowfalls particularly those that occurred after the heavy exploitation of forests were more catastrophic (Cawe, 1986; von Maltitz and Shackleton, 2004). With the realization of the decline in forest area in the region, the apartheid government surveyed, demarcated and gazetted some of the remaining forest patches thus preventing the local communities from accessing these forests (von Maltitz and Shackleton, 2004).

Only 30% of the forests in this area were not demarcated under the control of chiefs or headsmen commonly referred to as headman's forests. However, data is insufficient on the quantifiable impact of over-exploitation in this region. Of the forests that are experiencing exploitation in this area, coastal forests are one of the forests that are also experiencing pressure from uncontrolled utilization (Mucina and Rutherford, 2006; R3G, 2010).

1.5 The coastal forests of the Matiwane

This study was conducted in the Matiwane area of the Transkei, on the eastern part of the Eastern Cape Province of South Africa. The area runs from the Mbhashe River (32°35'94" S; 28°81'39" E) in the south to Umzimvubu River (31°57'51" S; 29°53'28" E) in the north, covering 90 km from north to south (aerial measurement) and running 10 km from the coast line to inland. It comprises the central portion of an area known as the Wild Coast.

The Wild Coast is characterised by its natural beauty and it is regarded as the only true coastal wilderness left in the Indian Ocean coastal region of South Africa (Simukonda and Kraai, 2008). It's an area of high biodiversity on the local and international scale (Simukonda and Kraai, 2008). The vegetation of the area falls under the Maputaland-Pondoland centre of endemism which is one of the world's biodiversity hotspots. The forested valleys and grasslands harbour more than 200 endemic plant species which makes it an attraction for conservationists and ecologists (Simukonda and Kraai, 2008). The area is underdeveloped and it is regarded as the poorest region in South Africa, with more than 72 % of the population living under extreme poverty (Simukonda and Kraai, 2008; OR Tambo IDP, 2009/10).

1.5.1 Administrative structures

The study area falls under two district municipalities, OR Thambo and Amathole. Within the OR Thambo the study area spans across three local municipalities i.e. Port St Johns, Nyandeni and King Sabatha Dalindyebo, while in Amathole it only includes Mbhashe local municipality. The study site makes part of the coastal section of all these local municipalities, covering only ten kilometers from the coastline.

These municipalities are regarded as the most underdeveloped municipalities in the Eastern Cape with the majority of the population not having access to water, sanitation and electricity (Sabata Dalinyebo local municipality, 2002; Port St Johns IDP, 2009/2010; Nyandeni local municipality IDP, 2009). The majority of the population depend on welfare and grants in the form of pensions for their survival as a result of poverty and high rates of unemployment (King Sabata Dalinyebo local municipality, 2002; Port St Johns IDP, 2009/2010; Nyandeni local municipality IDP, 2009). Some communities combine agriculture, fishing and basketry with external sources of income such as pensions and welfare grants to sustain their livelihoods (Kepe, 2001).

Due to the economic situation of the area the rural communities rely predominantly on subsistence agriculture and natural vegetation components for their livelihoods. Some of the villages have no access to electricity (about 23%) with fuelwood collected from forests as the only source of energy (King Sabata Dalinyebo local municipality, 2002; Port St Johns IDP, 2009/2010; Nyandeni local municipality IDP, 2009). As such the forestry sector plays a major role in the local economy in these municipalities with thousands of Rands generated from this sector alone (Table 2).

Table 2: The forest area of each municipality and the revenue generated from the forestry sector.

Municipality	Forest area (ha)	Number of people employed in forestry sector	Revenue per year	Source
Port St Johns	18 714	Not specified	R100 000	Port St Johns IDP, 2009/2010.
Nyandeni	13 199	117	R700 000	Nyandeni IDP, 2009
King Sabata Dalinyebo	5 727	667	R35 million	King Sabata Dalinyebo IDP, 200
Mbhashe	14 281	133	R600 000	Mbhashe municipality IDP, 2006

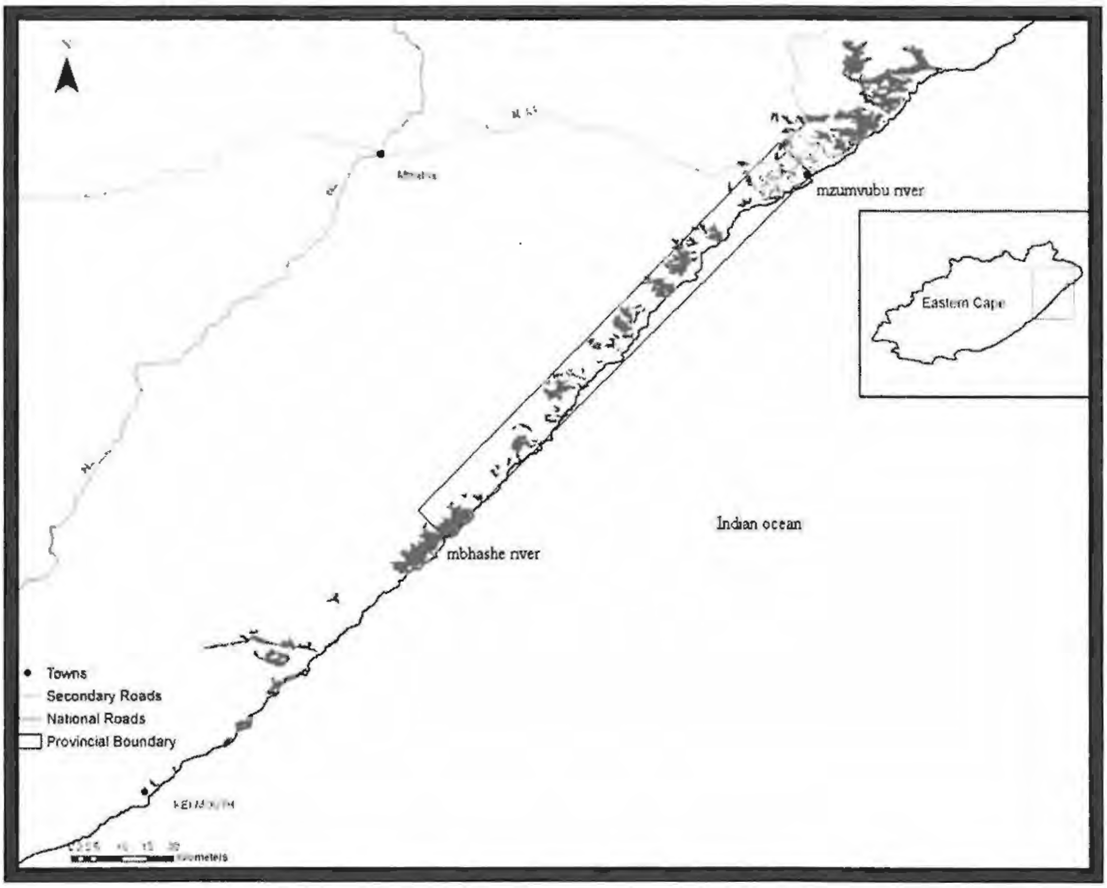


Figure 3: The forests of the Matiwane. Source: SANBI and DEAT (2009).

1.5.2 Climate and Geology

The area is classified as humid receiving rainfall of 1 000-1 400 mm per year in the northern section and 950 mm per year in the southern region with ≤ 1 400 mm per area evaporation rate (AGIS, 2007; Port St Johns, IDP, 2009/2010). About 70 % of rainfall occurs between October and March with mean summer temperatures ranging from 21^0C to 25^0C and winter temperatures ranging from 8^0C to 21^0C (AGIS, 2007). The upper northern section towards the Port St Johns area is made up of Table Mountain sandstone with rocky coastal strip of Ecca sediments, mainly shales with intrusions in the form of sheets of varying thickness of Karoo dolerite AGIS, 2007; Ackermann *et al.*, 2006; Yazini *et al.*, 2006. The area is characterized by its mountainous orientation with hills, cliffs, beaches and sandy dunes. The area is composed of sandy loam soils with shallow clay soils occurring in eroded, rounded hills and spurs. (AGIS, 2007; Ackermann *et al.*, 2006; Yazini *et al.*, 2006).

The southern section is made up of horizontally orientated Ecca Group (shales, mudstones and sandstones) and the Beaufort Group (bluish-grey fine-grained sandstone and bluish grey, greenish grey or reddish mudstone) forming part of the Karoo sequence. Dolerite sheets and aquifers also occur in this area (AGIS, 2007; Mbete *et al.*, 2006). Deep sandy loam and loamy clay soils predominate with less than 3% of the area having potential for cultivation (AGIS, 2007; Mbete *et al.*, 2006).

1.5.3 Forests in the area and forest degradation

The area is composed of grassland, thicket and forest biomes. The forests exist as patches and in between the forest patches the grassland is predominant. The Transkei Coastal belt grassland covers a significant area in this region with the Transkei Coastal Scarp Forests as the main forest type in the area (von Maltitz *et al.*, 2003; Mucina and Rutherford, 2006; AGIS, 2007).

1.5.3.1 Transkei coastal scarp forests

The forests in the Matiwane area belong to the Transkei Coastal Scarp Forests type (previously called Transkei Coastal Platform Forests) which comprises of two subtypes namely: the Transkei Coastal Platform Forests and Transkei Lower Scarp Forests (von Maltitz *et al.*, 2003). Only the Transkei Coastal Platform Forests subtype is found in the study area with famous Transkei forest localities such as Hluleka, Cwebe, Mpame and Pagela belonging to this forest subtype (von Maltitz *et al.*, 2003). Transkei Coastal Scarp Forests comprises of low-grown (up to 9 m) and middle-grown (15-25 m) species-rich forests with *Milettia grandis, M. sutherlandii, Buxus macowanii, B. natalensis* and *Umtiza listeriana* as the common constituents of the canopy layer and it also has a poorly developed ground layer (von Maltitz *et al.*, 2003). Beneath the canopy the forest is relatively open with mostly single stemmed trees and a poorly developed herb layer (von Maltitz *et al.*, 2003; SANBI and DEAT. 2009). These forests are found on sloping coastal platforms and steep scarps in deep incised valleys at altitudes ranging from 0 to 600-800 m (von Maltitz *et al.*, 2003; SANBI and DEAT, 2009).

Subsistence agriculture is a common practice in this area to sustain the livelihoods of the poor local communities and subsequently some forest patches in this area have been cleared for agricultural purposes (King, 1941; Cawe, 1986). Fire is another forest disturbing factor in this area, mismanagement of fires used to promote new and palatable grass growth greatly affects the indigenous forests in this area but natural wild fires occasionally occur in these forests (Sim 1907; Phillips, 1963; von Maltitz *et al.*, 2003; McCracken, 2004; Mucina and Rutherford, 2006; Cawe and Geldenhuys, 2007) thus affecting the forest cover and size. However, forests are reported to may regenerate after fires through the establishment of *Acacia* sp and invasive aliens but the time frame of the total forest establishment is unknown (Geldenhuys, 1994 & 2007; von Maltitz *et al.*, 2003). Also, windthrow resulting from strong coastal winds and shallow soils also contributes to the structural fragmentation of these forests (von Maltitz *et al.*, 2003).

Forest trees are removed for several functions in this area including: rafters and fence-droppers (cut from saplings and small trees <10 cm); poles and posts (cut from mostly understory trees of 10–20 cm), and sawn timber (from trees >20 cm) (Obiri *et al.*, 2002). The collection of firewood is another factor that is the cause of forest fragmentation in this area (King, 1941; Cawe, 1986; Cawe and Geldenhuys, 2007) as most households have no access to electricity and the collection of poles for construction also elevates the impact. DWAF, as the responsible party in forest management, initiated a project in which damage to forests is quantified but had failed due to insufficient data available for most of the areas in the country (Mucina and Rutherford, 2006) including the forests in the Matiwane area.

1.5.4 Conservation activities

It became apparent in the late 1800s that the heavy exploitation of forest resources should be reduced so as to prevent total clearing of these forests (von Maltitz and Shackleton, 2004). As a result many forests patches in the Matiwane area were demarcated by the state to address this problem (von Maltitz and Shackleton, 2004; Simukonda and Kraai, 2008). Conservation in the Wild Coast was rendered in the form of fences and fines, where forests are fenced off from local people in the form of nature reserves and if found in collecting forest resources, people would be prosecuted or fined for such activities

(Simukonda and Kraai, 2008). Three nature reserves were put in place to conserve forests of the Matiwane from further transformation by the local communities. The Silaka, Hluleka and Cwebe nature reserves are the main reserves under the Eastern Cape parks that are mandated to carry out conservation activities within this area (Simukonda and Kraai, 2008). The Department of Water and Forestry (DWAF) has also demarcated (but not fenced) most of the forest patches, these forests are patrolled by forest guards whose task is to restrict locals from cutting down the indigenous trees of the forest without permits (Simukonda and Kraai, 2008). There three forest estates within the study area namely: the Bomvane Forest Estate in the south, Ngqeleni and Port St Johns Estates towards the north. To further alleviate the impact of forest fragmentation, several gum plantations were made available primarily for use by the communities for building houses and fencing their yards (Port St Johns IDP, 2009/2010).

CHAPTER 2

Assessing the change in forest cover between 1942 and 2007

2.1 Introduction

It is well known that terrestrial ecosystems are under pressure from human activities. The need to detect and predict changes in natural environments has increased in order to understand and measure these changes that occur due to anthropological activities (Kerr and Ostrovsky, 2003; Horning, 2008; Palmer, 2009). The Transkei is regarded as one of the homelands that have experienced marked land cover change over the years, with the forest biome particularly heavily impacted (King, 1941; Cawe, 1986; Obiri *et al.*, 2002; Obiri and Lawes, 2004). Transkei, along with the Ciskei and KwaZulu-Natal former homelands, were regarded as the most degraded areas of South Africa by Hoffman and Todd (2000) in their degradation assessment of South Africa. von Maltitz and Shackleton (2004) and also Mucina and Rutherford (2006) attributed the over-exploitation of the Transkei forests, formerly protected under headmen and chiefs, to the collapse of traditional authorities in the apartheid era but Feely (1986) dates the exploitation back to the Iron age when forests were exploited for smelting of iron.

Other researchers, however, argued that the forest cover has changed particularly due to the indirect impacts of poverty experienced in this former homeland (Obiri and Lawes, 2004; Simukonda and Kraai, 2008). The occurrence of wild fires, agriculture, development of roads, subsistence harvesting of firewood (King, 1941; Cawe, 1986; von Maltitz *et al.*, 2003) are some of the perceived causes associated with forest cover change in this area. However, other than the early work of McKenzie (1984) little is known on the extent at which these forests have changed over the years, including the coastal forests such as the forests of the Matiwane area.

The conventional way of assessing ecological parameters is to travel to the area of interest and sample, which is practically difficult if the area is large, which means that traditional field ecological data could not be translated readily to regional, national or even the global extent (Kerr and Ostrovsky, 2003; Horning, 2008). As a result ecologists and conservation scientists are shifting from conventional methods to remote sensing which provides the techniques and data sources necessary to determine environmental change (Kerr and Ostrovsky, 2003). Remote sensing as defined by Horning (2008) is the acquisition of data about an object without being in contact with it and includes techniques such as aerial photography and satellite imagery. Remote sensing has proved to be effective in assessing deforestation, which is relatively easy to detect from aerial and satellite images as it involves merely recording forest cover (Tanser and Palmer, 1999; Kerr and Ostrovsky, 2003; Horning, 2008; Goetz, 2009). However, opposed to deforestation, forest degradation requires ground data as it is a gradual process and it is regarded to be qualitative (such as reduction in biomass/carbon) or qualitative (e.g. species loss), thus monitoring this forest degradation may require ground data (Sankhayan *et al.*, 2002). As such forest degradation can be assessed in terms of the reduction in crown cover, tree density, biomass density and also species loss (Sankhayan *et al.*, 2002).

The use of aerial photographs has been applied for many years by ecologists and conservationists to assess the change in vegetation cover over a particular time interval (Horning, 2008). Aerial photography is an important tool in assessing land use and land cover changes based on their availability and provide a broader view of a large area under study (Horning, 2008; Palmer, 2009). Aerial photographs date back to the early 1900s, which serves as an advantage allowing for cover assessment over the years and in South Africa aerial photography dates back to the late 1930s and as such can be invaluable in assessing forest cover change in the Matiwane area from the 1930s until recently.

With the introduction of geographic information systems (GIS), rectified aerial or orthophotos and satellite images can be easily manipulated to assess the changes in forest cover overtime with the help of the GIS software (Kalogirou, 2002; Ordóñez *et al.*, 2007). Quantifiable parameters such as forest area can be easily obtained from GIS assessment of these images. As such this technology offers a less time consuming and less laborious method of assessment than conventional field methods (Horning, 2008).

As mentioned before the Matiwane forests of the Transkei coast are marked for restoration, to restore the forest sections lost as a result of overexploitation over the years (R3G, 2010). As much as the forests are marked for restoration, there is no data on the extent at which these forests have been damaged, the overall forest area lost and the main cause of the forest cover change. This chapter sets out to assess the change in forest area over the years, and quantify the rate of change.

To achieve this objective, this chapter seeks to answer the following questions:

- How much of the forest area was lost and/gained from 1942 to 2007?
- Is there a significant difference between intact and degraded forests?
- What is the main cause of the forest cover change?
- Are there any areas that have accumulated cover since 1942?

2.2 Materials and Methods

2.2.1 Assessing forest cover change

The general approach was to compare the extent of forest cover from aerial photographs and satellite images of the forest from 1942 to 2007. Aerial photographs dated 1942, 1974 and 1995 obtained from National Geo-spatial Information, (NGI-previously Chief Directorate: Surveys and Mapping) were geo-referenced using ARGIS 9.2 (ESRI, 2006) and rectified images (also obtained from NGI) for the year 2003 were used as reference images for the geo-referencing of these old images (1942-1995). Images referred to as 1942 were a combination of images obtained for 1938 and 1942 as the process of image photography was started in 1938 but finished in 1942 for this area. After geo-referencing, the images were overlaid on one another to assess any change in forest cover over the years. Due to the fact that the old aerial images were geo-referenced, all the area estimates were made on the 2007 Spot images to avoid errors.

2.2.2 Assessing the cause and the impact of forest cover change

The ground-truth assessment involved sampling of randomly distributed survey plots in the areas of the forest that were judgmentally classified as intact, degraded and those that accumulated cover (BAA) over the years from aerial photograph analysis. The intact were regarded as those that showed no reduction in size over the years, degraded as those that showed a reduction in size over the years and BAA as those that have shown an increase in size over the years as result of biomass accumulation. Plots of 40 m × 5 m (200 m^2) were randomly delineated in different locations within each forest class, comprising 32 in intact areas, 24 in degraded sites and 12 in areas that had accumulated biomass. For 32 plots for the intact forests, 12 plots were established in the three reserves found in the area and 20 plots were established outside the reserves. Each plot was demarcated using a rope to prevent sampling of trees beyond the boundaries of the plot. Woody plants that were on the line, were deemed to be within the plot if more than 50 % of its trunk was within the plot and for those other plants with < 50 % of their trunk in the plot were disregarded. The following parameters were recorded for each plot: diameter at breast height (DBH) of each stem by species, number of cut stems and canopy cover. Stems below the breast height (1.3 m) were not included in the assessment. The basal area and size class profiles were also determined for the intact, degraded and BAA. Canopy cover was estimated visually as a percentage canopy cover (Jennings *et al.*, 1999).

2.2.3 Data analysis

A Kruskal-Wallis ANOVA was performed to compare species richness, stem density, tree density and basal area in intact and degraded forests and BAA. Further the intact forests within the three reserves were compared to the intact forests off the reserve to assess if there is any significant difference between the two.

2.3 Results

2.3.1 Forest cover change

Aerial imagery analysis reveals a forest area decline of 791 hectares (ha) between 1942 and 2007 which equates to 5.15 % of 15 352 ha of the forest area. A considerable impact on the forest occurred between 1974 and 2007 with 786 ha of the 791 ha cleared during this period. Within the three intervals forest clearing occurred at different rates with the highest rate of 39.75 ha per year recorded for 1995-2007 (Table 3).

The clearing was concentrated in the area between the Mthatha river and Mgazana river in the Ngqeleni and Port St Johns Forest Estates (Fig. 4). On the southern side in the Bomvane forest estate no clearing was observed from the aerial photographs. The canopy cover was reduced from > 70% in intact forest to between 0- 20% cover in degraded patches, while the canopy cover of BAA was between 10-20%.

Table 3: Comparing the cover change from 1942 to 2007.

Period	Years	Forest area loss		BAA	
		Total area (ha)	Rate (area.year^{-1})	Area (ha)	Rate (area.year^{-1})
1942- 1974	32	5.1	0.16	0	0
1974-1995	21	309	14.71	138	6.5
1995-2007	12	477	39.75	333	27.8

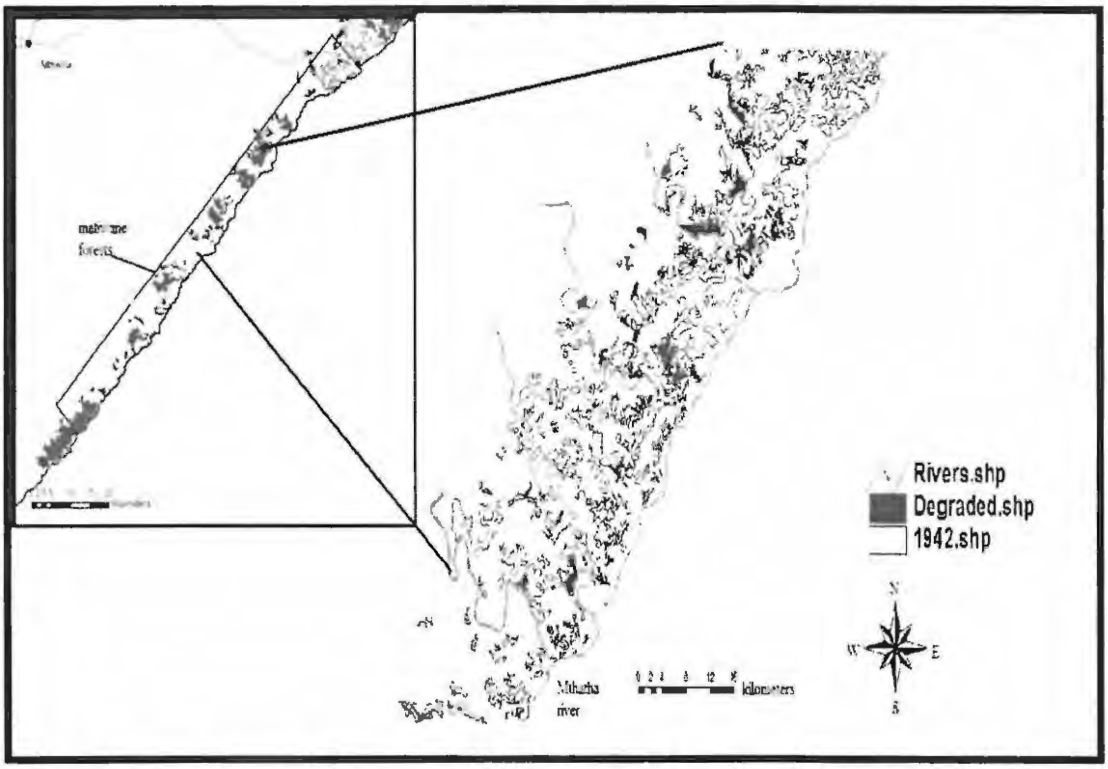


Figure 4: The distribution of cleared patches as from 1942 to 2007 between the Mthatha river and Mgazana. Legends: 1942.shp is a shapefile of the patches as they were in 1942 and the degraded.shp being the one for degraded areas. Viewed under ARGIS 9.2 (ESRI, 2006).

2.3.2 The main cause of forest degradation

The 24 plots placed in degraded patches fell in agricultural fields. The clearing occurred as the forest was converted to agricultural fields with the clearing occurring in gentle slopes and the bottom of valleys. About 87.5 % of the sampled degraded patches were still being used for agricultural purposes by the locals and 12.5 % of the sampled degraded patches were deserted old fields. The collection of firewood and timber has had a minimal impact on the forest degradation as compared to the conversion of the forests to agricultural fields with 14±6.82 cut stems per hectare in intact forests. Figure 5 shows an example of how the forest patches look on the 1942 (Figure 5a) and 2007 (Figure 5b) images showing a degraded patch of forest in Mankosi village with the agricultural fields clearly visible from the image.

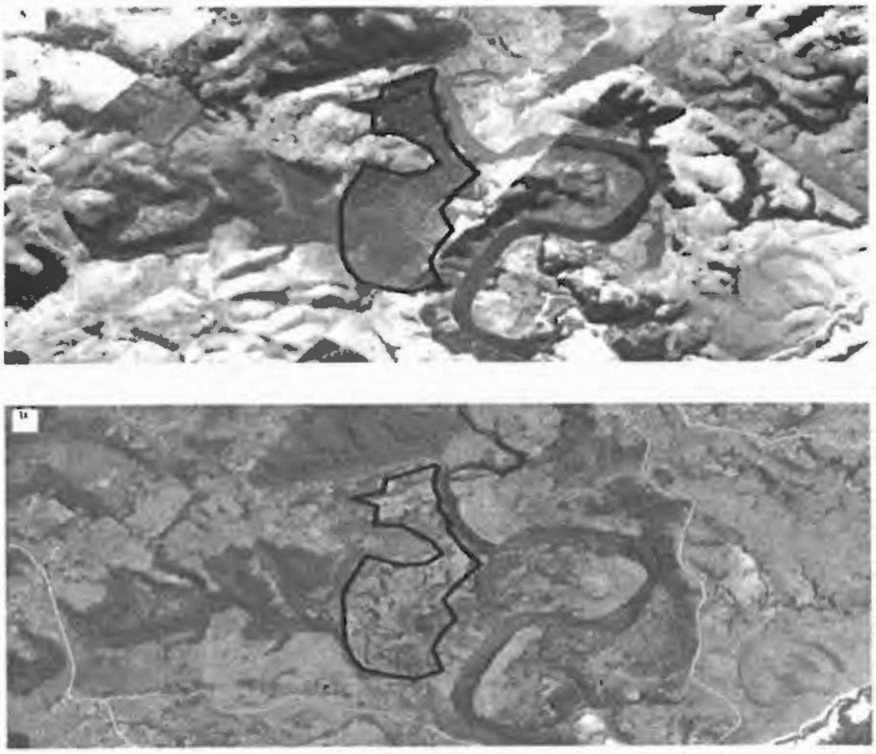


Figure 5: An example of how a degraded patch as observed from aerial and Spot 5 images. Image A shows the Mankosi forest patch as in 1942 (aerial photograph) and image B the same patch in 2007 (Spot 5).

2.3.3 Biomass accumulated areas (BAA)

The image analysis reveals that close to 471 ha of the area that was grassland in 1942 now have isolated trees, although not a continuous canopy cover forest (Fig. 6). These patches are covered mostly by grass, with a mean of 900±172.42 trees/ha of *Acacia karoo*. Table 4 and Figure 6 show the attributes and distribution of these patches.

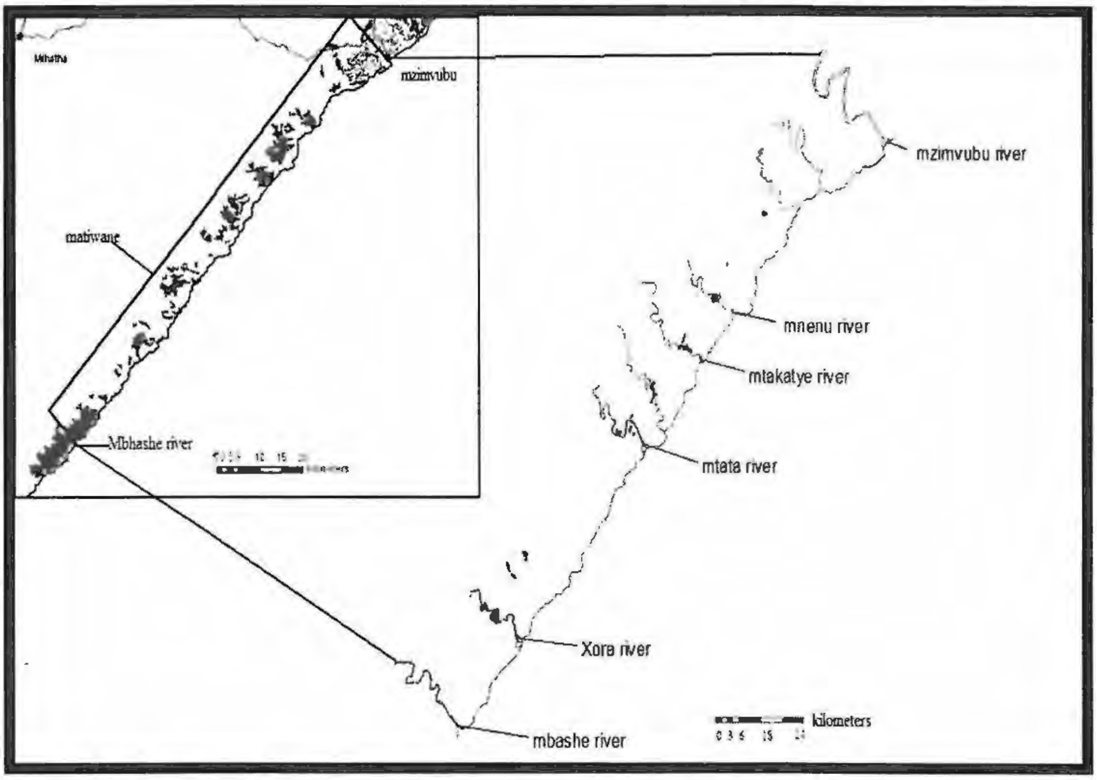


Figure 6: The distribution of patches that have accumulated biomass between 1942 and 2007 (Viewed under ARCGIS 9.2)

2.3.4 Forest composition of the two forest states and BAA patches

2.3.4.1 Woody species richness and stem density

The conversion of the forest to agricultural fields has resulted in the decline in the number of woody species present as depicted in Table 4. The species number reduced from 11 $\pm$ 0.57 species per plot in intact forests to 1 $\pm$ 0.23 woody species per plot in degraded areas of the forest. The total number of recorded plant species in intact forest was 82 (Appendix 2 gives the list of all species encountered) compared to only two for the degraded patches and the BAA of only one species recorded. The most frequent species found in the cleared or degraded patches was *Heywoodia lucens,* occurring in between the fields. The intact forest patches harboured 1 840±143.38 stems.ha^{-1} and degraded patches harboured only 223 $\pm$ 51.60 stems.ha^{-1}. The Kruskal-Wallis ANOVA (Table 4) indicated that there is a significant difference ($p<0.05$) between the number of stems, species in the two forest states and the BAA patches.

Table 4: Density, basal area and species richness of the three states

	Intact	Degraded	BAA	p-value
	mean± SE	mean± SE	mean± SE	
Number of species per 200m^2	11±0.57	1±0.23	1±0.08	<0.05
Number of stems.ha^{-1}	1819±140.56	223±51.60	1,550±361.05	<0.05
Number of trees.ha^{-1}	1435±78.84	162±39.38	900±172.42	<0.05
Basal area(m^2.ha^{-1})	43.29±4.77	10.7±4.75	5.46±0.82	<0.05

The stem density of the forests varied among the intact and the degraded forest as it can be observed from the Figure 7. The numbers of stems per hectare in degraded forests were well below the intact forests. The stem density decreased with the increase in the DBH of the stems, a higher stem density observed for lower DBH classes than in larger DBH classes (Figure 7).

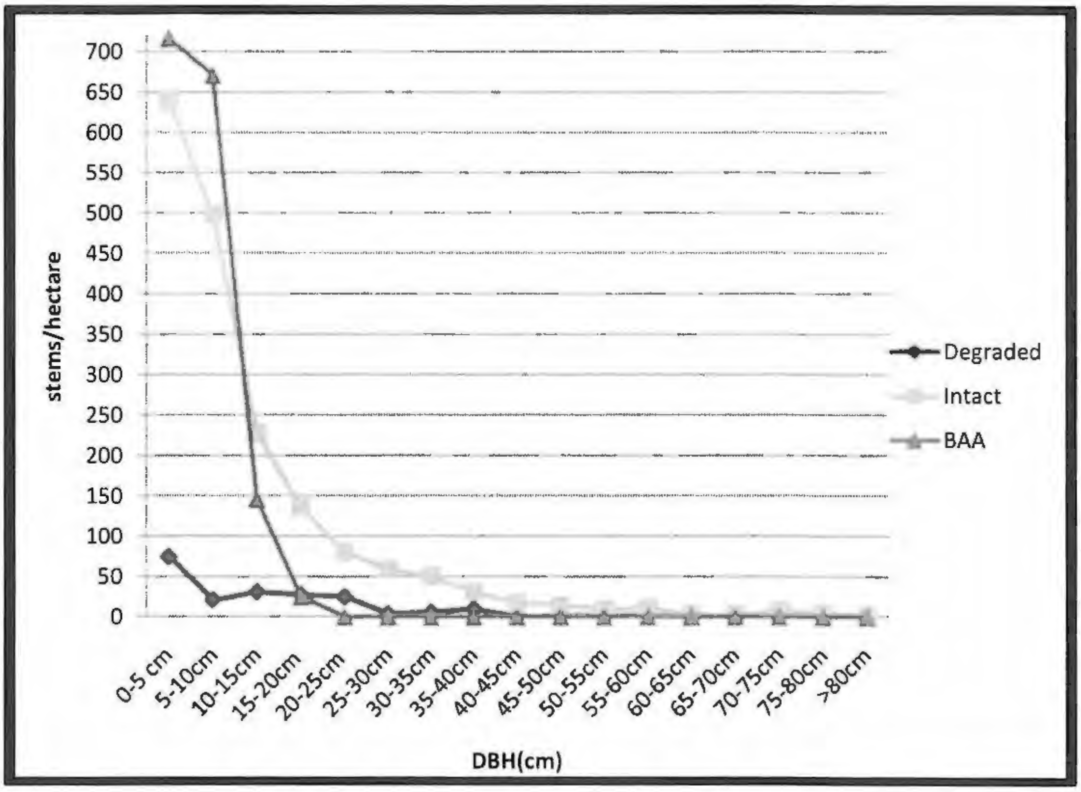


Figure 7: Diameter-size class of intact, degraded and BAA patches.

2.3.5 Comparing the intact forests in reserves with the ones off the reserve

The comparison of the intact forests within reserves with intact forests outside of the reserves revealed no significant difference in stem density, tree density and basal area. However, the variation in the two was observed for number of cut stems per hectare with the off-reserve intact forests having a mean of 23±10.56 cut stems.ha^{-1} as compared to 0 cut stems.ha^{-1}1 of the intact forests within the reserves (Table 5).

Table 5. Comparing the intact forests within reserves and outside the reserves (mean ± SE).

	Reserve	Off-reserve	P value
Number of species/200m^2	8±0.6	11.45 ± 0.81	<0.05
Stem density (stems.ha^{-1})	1 871 ± 252.8	1 823 ± 177.24	<0.05
Number of trees.ha^{-1}	1 550 ±143.28	1 368 ± 91.86	<0.05
Number of cut stems.ha^{-1}	0	23 ± 10.56	<0.05
Basal area(m^2.ha^{-1})	0.66 ± 0.11	0.99 ± 0.13	<0.05

2.4. Discussion

Aerial photography and Spot 5 imagery assessment revealed that there is continuous forest clearing that is occurring which is concentrated at the area between Mthatha river and Mgazana river. The area south of Mthatha river in the Bomvane Forest Estate and the area north of Mgazi river towards Port St Johns displayed no noticeable forest cover change over the years. The concentration of the clearing in between the Mthatha and Mgazana river may be due to the difference in agricultural practices, where in the southern side in the Bomvane forests estate the locals adopted the practices of having gardens within their homesteads as opposed to the area between Mthatha river and Mgazana river where the locals seem to prefer having ploughing fields away from the homesteads. This phenomenon was also reported by Andrew (1992) as cited by Fay (2009), who observed that in the southern region of the Transkei, locals followed the trend of having gardens adjacent to the homesteads as opposed to having fields away from the homestead. This trend is reported to have been facilitated by local magistrates, who occasionally warned headmen about allowing locals to extend their gardens beyond their homesteads (Fay, 2003 & 2009).

It further showed that from 1942 to 2007 about 791 hectares of forests were cleared with the clearing occurring in varying rates between the three periods (1942-1974, 1974-1995, and 1995-2007). About 0.03 % of 15 352 ha forest area was lost from 1942 to 1974, with 2.01 % lost during the period 1974 to 1995 and a further loss of 3.11% occurring between 1995 and 2007 which accounts for a total of 5.15 % of 15 352 ha forest area reduction from 1942 to 2007. The clearing became more noticeable after 1974 with 5.1 ha lost from 1942 to 1974 but after 1974 the clearing escalated to 309 ha (1974-1995) and a further loss of 477 ha occurred between 1995 and 2007. The rate almost tripled between the last two periods. The findings of this study reverberates the statement made by Cawe (1986) that forest clearing in this homeland was elevated during the 1970's. Cawe (1986) made note that the forests in the Transkei were degraded subject to the independence of this homeland or the declaration of it as a Bantustan, as of the 1970's the process of forest clearing became more visible which is the same era when the Transkei was declared an independent homeland. Contrary to the statement discussed by Obiri and Lawes (2004) that the forests in the Port St Johns area have declined in size in the past 25 years, the data from this study failed to come to the same conclusion, based on the observation on aerial photography which revealed no clearing or at least no noticeable clearing in the area north of Mgazana river during the past 65 years.

Aerial photography also revealed certain areas that have been accumulating biomass (BAA) since 1942, these areas previously covered by grassland developed scattered *Acacia karoo* trees along the years, a phenomenon observed by most authors for different regions within South Africa (O'Connor, 1995 as cited in Fay, 2009). This is regarded as the precursor for forest development (Cawe and Geldenhuys, 2007). These areas are estimated at 471 ha and are possibly as a result of grass burning by the communities to increase grass palatability for livestock, thus providing conducive conditions for *Acacia* seed germination and the abandoning of grass burning subsequently leads to dense regrowth of the *Acacia* over time (O'Connor, 1995 as cited in Fay, 2009; Cawe and Geldenhuys, 2007). Invasion of grasslands by *Acacia* sp is also reported for many localities in the world, Brown and Carter (1998) showed this phenomenon for Australia whereby *Acacia nilotica* was invading grasslands reflecting also on the observed increase in area invaded by these species between 1974 and 1994. Also reported for the Israeli

Mediterranean coastal dunes by Bar *et al.* (2004) who reflected that from 1965 to 1999 an area covered by *Acacia* increased by 166 % in this area and as could be observed from studies an invasion of grasslands is not a unique phenomenon to the Matiwane alone.

Ground-truthing revealed that the main cause of forest cover change in these forests is conversion of forest land to agricultural fields. The area is largely dependent on subsistence agriculture for livelihoods (King, 1941; Cawe, 1986). Timmermans (2004) showed that subsistence agriculture contributes to the socio-economic status of the locals in the Dwesa-Cwebe area on the southern tip of the study area. All the areas that were identified from aerial photography to be cleared were all agricultural fields both old and new. Ground-truthing also revealed that the cleared forests are communal forests, this was observed as all these cleared forests had no DWAF markings which are placed to separate state forests from communal forests. This can be attributed to the fact that state forests are under constant patrol by forest guards thus are less prone to clearing by locals.

Collection of firewood and poles for building are some of the other factors that previous authors report that may induce forest cover reduction which cannot be quantified by normal aerial photography. As sueh the numbers of cut stems in the intact forest were assessed and this revealed a mean of 14±6.82 cut stems.ha^{-1} in intact forests. In assessing if there is any difference between the intact forest within reserves with the ones off the reserve, the findings of this study indicated that there was no significant difference between these forests in terms of stem density, tree density and basal area. However, the off-reserve intact forests had a higher mean number of cut stems (23±10.56) than intact forests within the reserve (0 stems.ha^{-1}). The higher mean numbers of cut stems off-reserve compared to within reserve forests may be attributed to the impact of fencing and anti-poaching activities. Fencing prevents the access of people who could potentially access the trees while anti-poaching activities act as a deterrent to illegal access to the reserve. The conversion of the forests greatly affected the forest canopy cover from >70 % to less than 20 % cover in the degraded patches.

The clearing of these forests has resulted in the reduction of stem density, basal area and species richness with the number of species reduced from 11 per 200m^2 to 1 per 200 m^2. The stem density was reduced from 1 819±140.56 in intact forests to a mean stem density of 223±51.60 stems.ha^{-1} in degraded forests with tree density being reduced from 1 435±78.84 trees.ha^{-1} to 162±39.38 trees.ha^{-1} subsequently resulting in the reduction in the total basal area of the forest.

In comparison to values from Adie (unpub.data) as cited in Lawes (2004) for Scarp forests in the same area in the northern section of the study site (Port St Johns), the basal area value (43.29±4.77 m^2.ha^{-1}) from this study was slightly lower than the 56.3 m^2.ha^{-1} value for the Scarp forest in Port St Johns. Comparing the value again with Scarp forests that exist in the same coastline in the north revealed that the Scarp forests in Umtamvuna also had a higher value (50.5 m^2.ha^{-1}) than the one reported by this study but in comparison to values reported by Glenday (2007), the basal area value reported in this study was higher than the ones reported by Glenday (2007) for the scarp, lowland, dune and swamp forests for eThekwini in Kwazulu-Natal. However, the value for the basal area (43.29±4.77 m^2.ha^{-1}) was within the range (35-57 m^2.ha^{-1}) reported by Lawes *et al.* (2004) as cited by Glenday (2007) for scarp forests elsewhere in Kwazulu-Natal and also the value was within acceptable limits of published basal area values of other forests around the world (Table 6). The variation in the reported values from this study and the published values may be related to possibly variation in terrain, rainfall and stage of development since earlier disturbance.

The stem density values from this study were significantly higher with the stem density accounting for close to two to three times the values reported by Glenday (2007) for the scarp, lowland, dune and swamp forests for eThekwini in Kwazulu-Natal. Also in relation to other forests from different part of the world the values were still significantly higher (Table 6), this may be attributed to the difference in reporting. Most authors report on stem density for trees with DBH> 10 cm, of which in this study the trees with DBH<10 cm contributed significantly to stem density.

Table 6: Comparing the Matiwane stem density and basal area data with published ones.

Source	Forest type	Location	Basal area ($m^2.ha^{-1}$)	Stem density ($stems.ha^{-1}$)
This study	Scarp	Matiwane	43.29	1 819
Adie (unpub.data) in Lawes *et al.*, 2004	Scarp	Port St Johns	56.3	586
	Scarp	Umtamvuna	50.5	613
Lawes *et al.*, 2004 as cited in Glenday, 2007	Scarp	Kwazulu Natal	35-57	515
Van Wyk (unpub.data) in Lawes *et al.*, 2004	Scarp	Dlinza	53.6	385
Geldenhuys & Rathogwa, 1997 in Lawes *et al.*, 2004	Afromontane	Pirie, Eastern cape	43.1	1 980
	Afromontane	Sandile Kop	58.1	1398
Glenday, 2007	Dune	Kwazulu Natal	21.5	686
Glenday, 2007	Swamp	Kwazulu Natal	33.6	590
Glenday, 2007	Lowland	Kwazulu Natal	29.0	482
Lawes *et al.*, 2004	Lowland	Kwazulu Natal	17.4-37.4	254-510
Seydack, 2000	Afromantane	Knysna	30-45	793
Lowe & Clarke, 2000 in *Lawes et al.*, 2004	Dry	Tanzania	6.4-72.3	138-1 000
Lefsky, 1999	unspecified	Maryland	36.1	n/a
Maltamo *et al.*, 2007	Boreal	Finland	24.7	1 507

2.5. Conclusion

This study has revealed that the forests in the Matiwane area have endured a reduction in forest cover from 1942 to 2007, with about 791 ha of forests lost. This constitutes 5.15% of 15 352 ha of the forest, which is equivalent to 0.08 % per year or 12.2 ha per year. The main cause of forest cover reduction is the clearing of forests for agricultural purposes by the communities that reside close to the forests. It showed that the clearing of these forests to agricultural fields has resulted in a significant reduction in forest area, forest cover, stem density, tree density, species density and basal area. It further showed areas that were previously not vegetated with forest that have accumulated biomass over the years with these areas covering 477 ha. Thus there is a dynamic loss biomass loss and gain in this area.

The reduction in the forest area, forest cover, tree density and number of species clearly reflected the fact that this forests are being degraded, which may require an intervention to reduce further degradation. Significant effort will need to be made to construct better forest management strategies in these forests that integrate and consider both forest degradation and livelihoods of the locals to reach a more sustainable relationship between the two. However, the post-1994 government has made a significant effort around policies governing forests, the issue may then be just a mere implementation of these policies to effectively manage these forests sustainably (Willis, 2004).

This chapter has contributed significantly on the issues surrounding the impact of forest conversion on the overall composition of the forests and it further contributes to the greater understanding of the forest cover change dynamics emerging from the pre-democratic (pre-1994 era) times in this area.

CHAPTER 3

Allometry for aboveground biomass

3.1. Introduction

Estimating carbon stocks in forests has become one of the important ecological assessments today owed to climate change and the need to comply with the Kyoto protocol. In attempts to estimate carbon stocks researchers have identified the two most valuable parameters in the determination of carbon stocks in vegetation, which are the oven-dried biomass and also the carbon content of the dry biomass (Brown, 1997; Ketterings *et al.*, 2001; Zianis and Mencuccini, 2004; Pilli *et al.*, 2006).

The direct method of determining the oven-dried biomass involves the direct cutting of trees *in situ* and oven-drying the tree components, which are then weighed (Ketterings *et al.*, 2001). Although this method is undoubtedly the most accurate method for estimating the tree biomass, it is restricted to small areas and small sample sizes (Ketterings *et al.*, 2001) as it is extremely time consuming, destructive and labour intensive (Zianis and Mencuccini, 2004; Pilli *et al.*, 2006). Thus, the need to construct rapid, easily implementable and cost effective methods of estimating oven-dry biomass has become apparent (Zianis and Mencuccini, 2004). Many researchers have embarked on constructing allometric equations from easily measurable independent variables such as diameter at breast height or height to determine or estimate oven-dried biomass (Ketterings *et al.*, 2001; Zianis and Mencuccini, 2004; Niklas and Spatz, 2006; Powell, 2009), thereby negating more destructive and laborious sampling. The equation generally assumes the following form (Niklas, 1994; Ketterings *et al.*, 2000; Kaitaniemi, 2004; Pilli *et al.*, 2006):

$$\text{ABG} = aD^b$$

with ABG denoting aboveground biomass, D diameter at breast height, a and b are the scaling coefficient and the scaling exponent respectively. The scaling exponent is proposed to be between 2 and 3 (Zianis and Mencuecini, 2004; Pilli *et al.*, 2006). The scaling coefficient and scaling exponent are both noted to vary between species, site and age (Pilli *et al.*, 2006). However, a model by West *et al.* (1999) suggests that evolution by natural selection has induced a fractal-like vascular network in organisms as such organisms have a quarter-power scaling relationship with body mass. According to this model the aboveground biomass should scale against stem diameter with b= 8/7 ($\approx$2.67) independent of species, age and site (West *et al.*, 1999). The practicality of this model has been questioned for its general applicability (Pilli *et al.*, 2006) which will also be shown in this study.

Most allometric equations use diameter at breast height (1.3 m) and wood density as predictive variables for estimating aboveground tree biomass (Zianis and Mencuccini, 2004; Pilli *et al.*, 2006). Several researchers have developed generalised allometric equations which are constructed as an average across several empirically developed ones (Zianis and Mencuccini, 2004; Zianis *et al.*, 2005). Once again, this is aimed at reducing the destructive nature of determining oven-dry biomass. These include, *inter alia* Brown (1996), West *et al.* (1999) and Zianis and Mencuccini (2004), who proposed models for estimating oven-dry biomass of forests.

The approach of using generalised international equations has received criticism based on the fact that the equations fail to recognize the large variation in growth form within species as well as between vegetation types resulting from different climates and other environmental conditions (Chambers *et al.*, 2001; Pilli *et al.*, 2006). Thus, more site specific equations are required for precise measures, especially if a site is to be financed for its carbon sequestration capabilities (Pilli *et al.*, 2006).

To date no generalised equation is available for determining aboveground biomass of the forests in the Matiwane area. Thus, to estimate carbon stocks in these forests required the development of allometric equations for determining aboveground biomass. This chapter presents allometric equations for estimating the aboveground biomass in living vegetation of the forests in the Matiwane area with the following objectives:

(a) To test for a function that provides for the best fit for allometric relation of DBH to total aboveground biomass for hardwoods and softwoods.

(b) To construct allometric equations that relates DBH to different aboveground plant components.

(c) To compare the Matiwane hardwood equation with generalised international allometric equations.

3.2 Materials and methods

3.2.1 Developing the hardwood and softwood allometric equation

Allometric equations for hardwoods and softwoods were developed for the Matiwane site based on the destructive felling and drying of 28 trees across a range of size classes chosen from the ten species that contributed most to the basal area of the intact forest for hardwoods and seven trees for softwoods. Each tree was felled at ground level after the DBH (in cm) had been recorded. After felling the fresh plant components were separated into main stem, branches (branches+twigs/branchlets) and leaves as per FAO (1997) recommendations for biomass estimation. The fresh mass of each of the components was determined separately. A subsample of each was then taken, weighed, then dried at 60 ° C and re-weighed to get the fresh mass: dry mass ratio to extrapolate it to the whole component from which it was obtained. Summation of the different components gave the total oven-dried biomass of each plant. The oven-dry biomasses of all the trees were regressed against the DBH to obtain an allometric equation for the determination of aboveground dry biomass.

3.2.2 Selecting the best form of the equation

The selection of the best form of the equation, involved plotting scatter plots of different forms namely: power, linear, exponential and logarithmic functions of the actual dry-biomass of the sampled trees against DBH. The performance of each form of the equation was tested using the concept of the mean relative difference (RD) between the actual and the predicted dry-biomass values (Zianis and Mencuccini, 2004; Pilli *et al.*, 2006). The RD is given by:

Relative difference = $| B_p - B_a | / B_a$

where B_p and B_a denotes the predicted dry-biomass and actual biomass respectively (Zianis and Mencuccini, 2004; Pilli *et al.*, 2006).

3.2.3 Comparing the Matiwane hardwood equation with other equations

The mean relative difference (RD) of the Matiwane equation was compared to the mean relative differences of three internationally used generalised equations and one local equation developed for woodlands, to test if any of the generalised equations produces results close to those results produced from the Matiwane equation. The following are the generalised equations that were compared to the Matiwane equation:

- $AGB=0.1464(D)^{2.3679}$ ....(Zianis, 2004)

The 'global model' developed by Zianis (2004) using meta-data from different authors around the world. AGB and D refer to aboveground biomass and diameter at breast height, respectively.

- $AGB=0.1(D)^{2.67}$................................(West *et al.*, 1999)

The equation reported in Zianis (2008) based on the WBE model developed by West *et al.* (1999).

- $AGB = \exp\{-1.996 + 2.32 * \ln(D)\}$..........(Brown, 1997)

A UNFCCC (2009) recommended equation for forests in regions receiving mean annual rainfall of 900 mm – 1 500 mm per year, developed by Brown (1997).

- $AGB=0.035(D)^{2.5}$..............................(Netshiluvi & Scholes, 2001)

An allometric equation developed for South African woodlands using meta-analysis of all available allometric equations from various authors within the country, proposed by Netshiluvi and Scholes (2001).

3.3 Results

The ten species that contributed greatly to the total basal area are provided in Table 7. *Heywoodia lucens* (common name Umnebelele) was the top contributor, accounting for 36.4 % to the overall basal area of the 32 plots in intact forest. Combined, the top ten species contributed approximately 73.8 % to the total basal area of the intact plots. Nine species were used to develop the allometric equation for the hardwoods and the *Cussonia* species used for the development of a separate allometric equation. The percentage contribution of each of the plant species encountered in the forest is further reflected in Appendix 2.

Table 7: The average basal area contribution (%) of the top ten species in intact forests.

Species	Percentage contribution (%)	Number of trees used for Allometry
Heywoodia lucens	36.4	5
Vepris lanceolata	6.9	2
Cussonia sp.	6.0	7*
Strychnos henningsii	4.8	2
Milletia grandis	4.7	6
Ficus natalensis	4.4	1
Celtis africana	3.1	2
Millletia sutherlandii	2.7	5
Cassipourea gerrardii	2.6	1
Englerophytum natalense	2.3	4

3.3.1 Hardwoods allometry

3.3.1.1 Allometric equation relating DBH to total tree aboveground dry biomass

The power function gave the best results compared to the other three functions with r^2= 0.962, it also gave a lower mean relative difference value compared to the other three forms of the equation (Figure 7&Table 8) with a mean relative difference of 0.34 followed by the exponential function (1.33 mean RD).

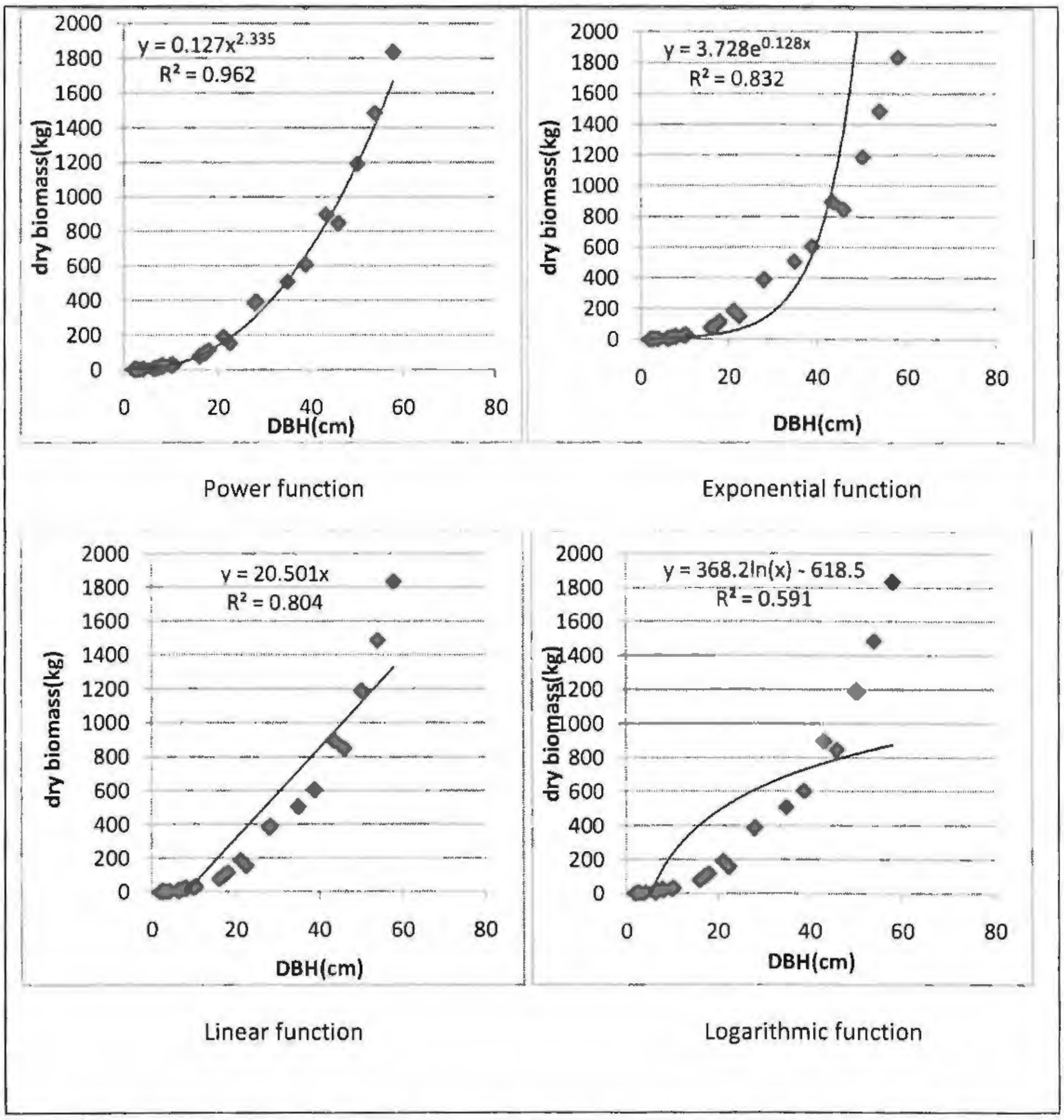


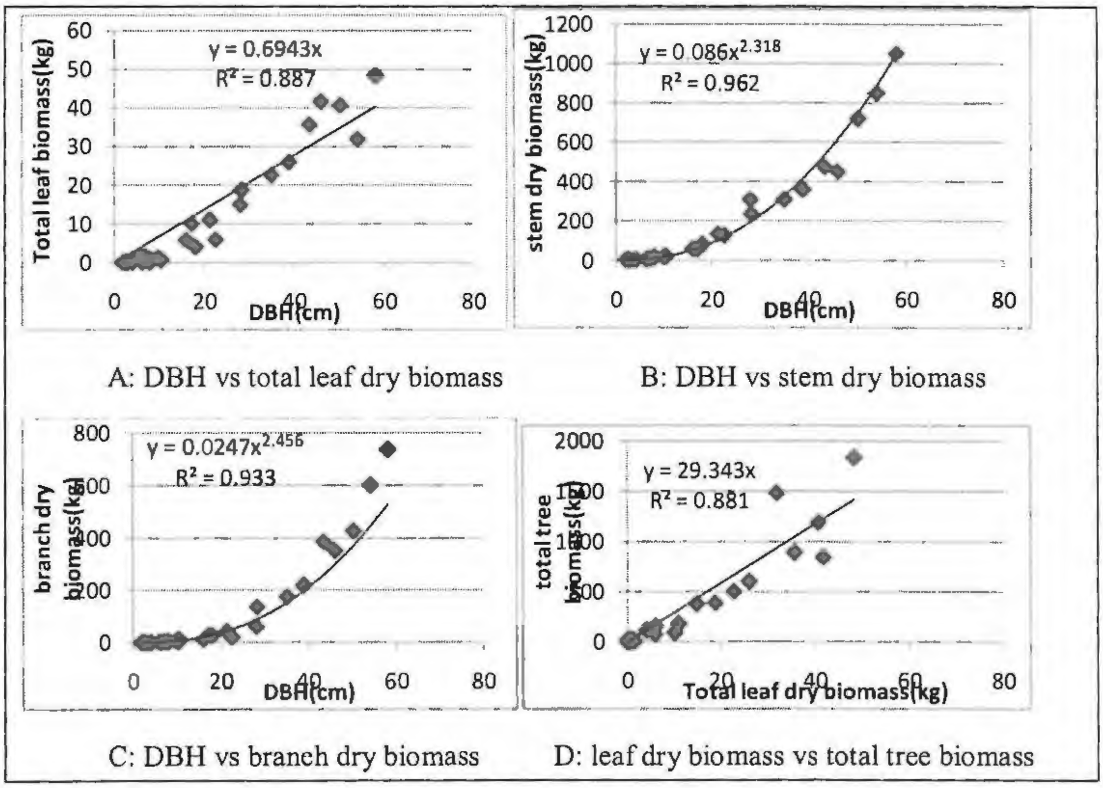
Figure 7: The comparison of the four forms of the Matiwane equation for the hardwoods.

Table 8: The mean relative difference of each of the four forms of the equation. *Note SEM (standard error of mean).*

	Power	Exponential	Linear	Logarithmic
Mean relative difference	0.34	1.33	14.59	50.40
Standard deviation	0.73	2.18	27.36	150.62
SEM	0.14	0.41	5.17	28.47

3.3.1.2 Allometric equations relating DBH to different tree components

The best functions for the hardwoods for the relationship between DBH and total leaf biomass, stem dry biomass or branch dry biomass, and between leaf dry biomass and total tree biomass are shown in Figure 8. Two functions namely the linear and power functions, gave better predictions, with the linear function effective in relating DBH to total leaf biomass (r^2=0.887) and relating total leaf dry biomass to total tree biomass (r^2=0.881). The power function was effective in relating DBH to total stem dry biomass (r^2=0.962) and also relating branch dry biomass (r^2=0.933) (Fig.8 & Table 9).



A: DBH vs total leaf dry biomass

B: DBH vs stem dry biomass

C: DBH vs branch dry biomass

D: leaf dry biomass vs total tree biomass

Figure 8: Allometric equations relating DBH to different tree components for hardwoods.

Table 9: The relative difference of the four equations relating DBH to different tree components.

	DBH vs total leaf dry biomass	DBH vs stem dry biomass	DBH vs branch dry biomass	Leaf dry biomass vs total tree biomass
Mean relative difference	20.91	0.35	0.67	1.07
Standard deviation	62.11	0.60	1.13	1.39
SEM	11.74	0.11	0.21	0.26

3.3.1.3 Comparing the equation with generalised equations

The five equations differed in their predictions of the total tree biomass (Table 10) in relation to the actual recorded data (Figure 9) as shown in the RD values (Table 10). The Matiwane equation gave better results with a lower mean relative difference of 0.14 ± 0.15 (± standard error of mean) compared to the other four generalised equations. Brown's (1997) equation also gave acceptable results with a 0.17 ± 0.16 relative difference value which was not far from the relative difference value of the Matiwane equation. The WBE equation gave the worst results with the mean RD of 1.12 ± 1.11, i.e, greatly overestimating the dry-biomass with the N & S equation underestimating the dry biomass.

Table 10: The mean relative difference of each of the five allometric equations. *Note SEM (standard error of mean).*

	Equation				
	Matiwane	Brown	Zianis	N&S	WBE
Relative difference	0.14	0.17	0.42	0.53	1.12
Standard dev.	0.80	0.84	0.84	0.28	1.11
SEM	0.15	0.16	0.18	0.05	0.21

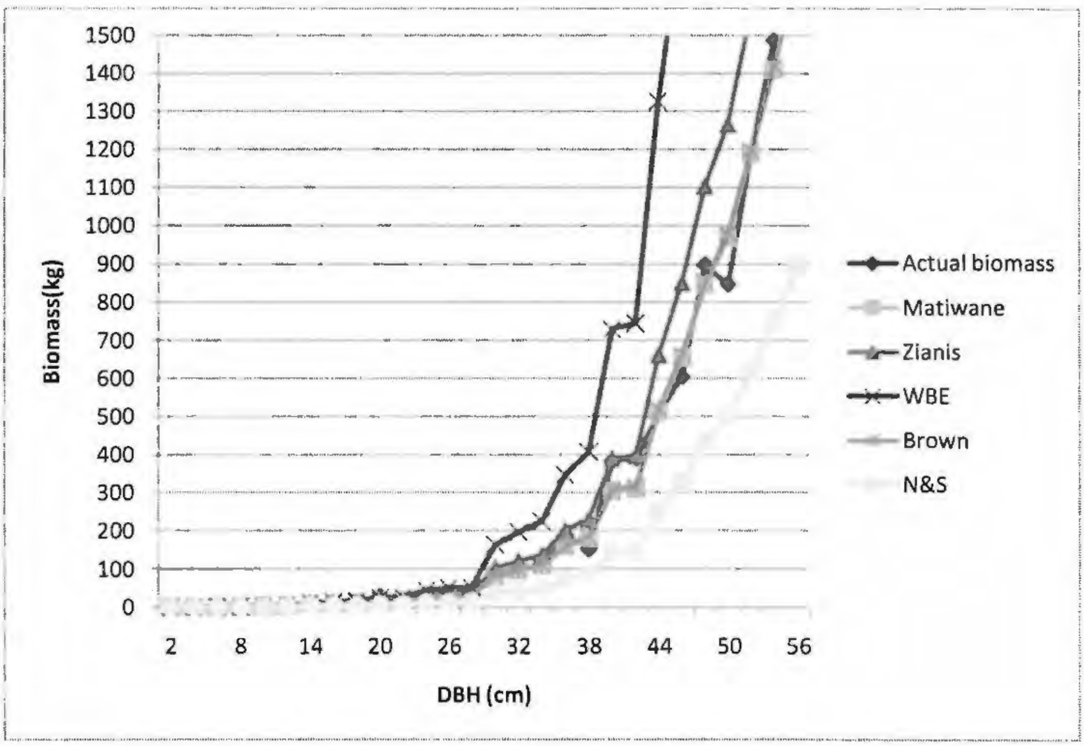


Figure 9: A comparison of the aboveground biomass predictions of the three international equations and a locally developed equation in relation to the Matiwane equation.

3.3.2 Softwood allometry

3.3.2.1 An allometric equation for relating biomass to total aboveground tree dry biomass for softwoods.

The four functions of the softwood equation gave strong correlations with $r^2 > 0.8$ for all the functions. The power function provided a better fit than the other three functions with an R^2 of over 0.95 (Fig. 10 & Table 11).

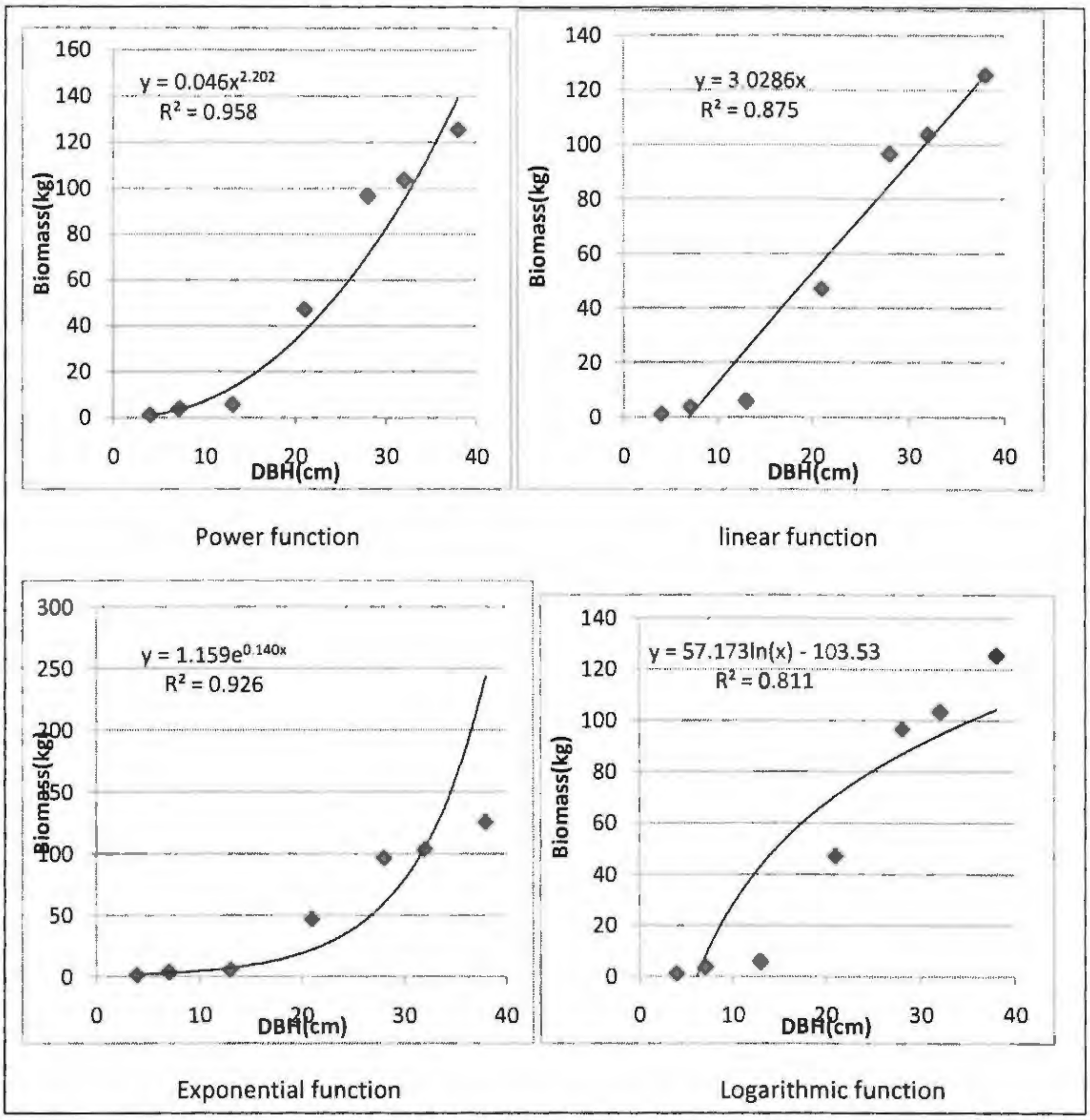


Figure 10: Comparing the four forms of the softwood allometric equation for *Cussonia* sp.

Table 11: The mean relative difference of the four functions for softwood.

	Power	Exponential	Linear	Logarithmic
Mean relative difference	0.32	0.42	2.87	4.23
standard deviation	0.43	0.32	3.63	7.74
SEM	0.16	0.12	1.37	2.92

3.3.2.2 Allometry for relating DBH to different tree components in softwoods

The evaluation of the different functions for relating DBH to the different tree components (total stem and leaf biomass) revealed that the power function gave better predictions than the other three functions with $r^2 > 0.95$. Also it proved to be effective even for relating total tree dry biomass to total leaf dry biomass ($r^2=0.995$) (Figure 11 & Table 12). Due to the physiognomic structure of *Cussonia* sp. which the main stem is attached directly to the leaf via their thick petioles, the branch allometry for softwoods could not be constructed.

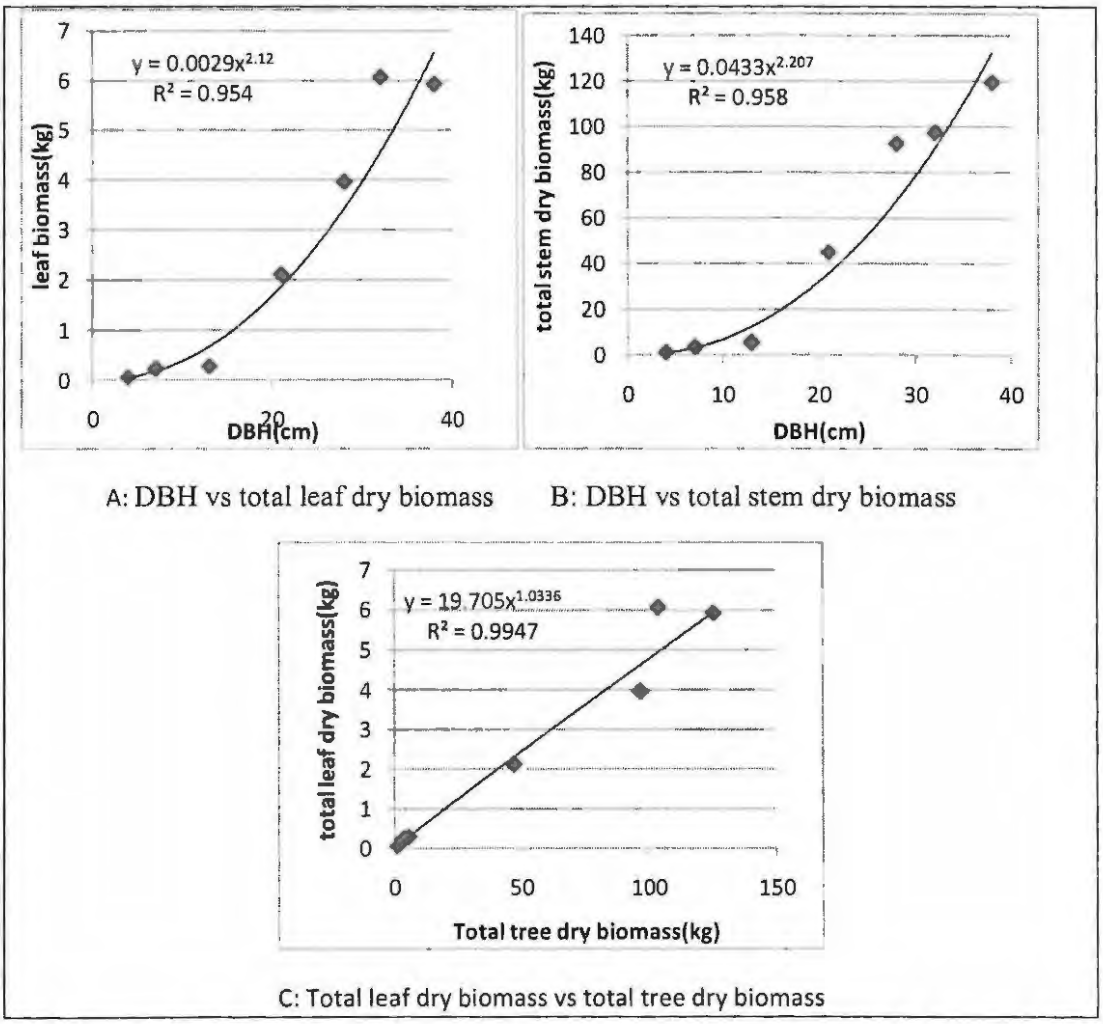


Figure 11: Allometric equations relating DBH to different tree components for softwoods.

Table 12: The mean relative difference of the three equations relating DBH to different tree components.

	DBH vs total leaf dry biomass	DBH vs total stem dry biomass	Total leaf dry biomass vs total tree dry biomass
Mean relative difference	0.33	0.32	0.11
Standard deviation	0.43	0.43	0.08
SEM	0.16	0.16	0.03

3.4 Discussion

Numerous forms (or functions) of allometric equations for determining the aboveground biomass of forest trees are available in the literature, including the power, linear, logarithmic and exponential functions. As such this study managed to reveal that the power function is best in predicting the aboveground biomass of the forests compared to the other forms of the equation. This may explain why the power function is a commonly used function in literature to relate diameter at breast height to aboveground biomass. Pilli *et al.* (2006) discussed the fact that allometric equations are generally expressed as a power form because it has long been observed that growing plants maintain proportions between different parts during their lifespan. For hardwoods the power function gave better results (r^2= 0.962), followed by the exponential function (r^2=0.832) and linear function (r^2= 0.804), with the logarithmic function giving the worst fit (r^2= 0.591). The same trend was observed for the softwood equation.

However, the power function was not effective in relating DBH to total leaf biomass and relating total leaf biomass to the total aboveground biomass in hardwoods as compared to the linear function which gave the best fit. This may need to be further investigated on why the power function better predicts total biomass but reduced predictive power when relating DBH to total leaf biomass.

Most authors give no insight on whether different functions of the allometric equation have been tested for a particular relationship, which gives the perception that most authors don't consider the possibility of increasing or decreasing predictive power subject to the chosen function as it is reflected in this study. The comparison of the different functions in this research clearly indicated that the choice of a function for a particular dataset for the construction of an allometric equation can affect the predictive power for that particular equation. As reflected by this study the four forms of the equation derived from one dataset give variable estimates.

The scaling exponent as discussed by Zianis and Mencuccini (2004) to be a value between 2 and 3 holds true for the forests in the Matiwane area as the scaling exponent for the Matiwane hardwood equation was 2.335 for hardwoods (r^2= 0.962), which is found to be very close to the one proposed by Zianis and Mencuccini (2004) of 2.3679. The developed equation for softwoods also had the scaling exponent of similar magnitude, but slightly lower (2.202; r^2= 0.958). The data from this study also proved that West *et al.* (1999) (herein referred to as WBE equation) fractal model does not apply for the Matiwane, which proposed that the scaling exponent should equal 2.67 independent of species, site, structural and morphological characteristics of the trees (Zianis and Mencuccini, 2004; Pilli *et al.*, 2006). The scaling exponent of the Matiwane equation (2.335) is well below the value proposed by West *et al.* (1999) as such the universality of the proposed model cannot hold true if not applicable to all areas of the world. The WBE equation has been heavily criticized with authors arguing that the general use of a universal scaling exponent is unacceptable, which would imply that the ratio of biomass and DBH for trees growing in different environments is constant and this is far from valid, as plant growth is affected by environmental conditions and as such the ratio should differ for different environments (Zianis and Mencuccini, 2004: Pilli *et al.*, 2006).

The scaling coefficient of the Matiwane equation (0.127) was slightly different from the ones proposed by the WBE (0.1) and the global model (0.1464), however the Netshiluvi and Scholes (2001) model had a much lower scaling coefficient (0.035) than all of the models. The comparison of the scaling coefficients is not taken in a strict way as it is expected that the values will vary as the scaling coefficient is specific to a particular system or region (Kaitaniemi, 2004). This is done only to reflect on the closeness of the estimated scaling coefficient to the published ones.

Although some authors encourage the inclusion of forest height in allometric equations, the non inclusion of this parameter in the Matiwane equation is justified as literature argues that the inclusion of tree height in a power equation only improves the estimates slightly (Ketterings *et al.*, 2000; Montagu *et al.*, 2005) and an equation with r^2= 0.962 the improvement might be negligible. Montagu *et al.* (2005) managed to show that an allometric equation of *Eucalyptus pilularis* with DBH alone was more stable across contrasting sites and the performance decreased with the inclusion of height into the equation. Additionally Ketterings *et al.* (2001) explained the omission of height in many data sets as based on the fact that DBH and height tend to be highly related. But Montagu *et al.* (2005) related this to the fact that DBH is a parameter with the least measurement error. DBH measurement errors are estimated to be less than three percent while the ones associated with height measurements in mature stands are reported to be between 10% and 15% (Gregoire *et al.*, 1989; Brown *et al.*, 1995 as cited in Montagu *et al.*, 2005). Also, tree height is a difficult parameter to attain in the field especially in multilayered canopies rendering allometric relationships that require tree height measurements limited in their application (Montagu *et al.*, 2005).

It was expected that the equation developed by Netshiluvi and Scholes (2001) would give a better estimate of the dry biomass as it was locally developed using meta data from local woodlands but unfortunately it greatly underestimated the dry aboveground biomass of forests of the Matiwane. This may be purely on the fact that it was constructed using equations developed for woodlands and not for forest ecosystems as the growth form of trees in woodlands and forests may vary.

Compared to the other equations, the Matiwane and Brown (1997) equations gave the best estimates for the aboveground biomass with only 13 % and 17 % relative difference to the actual biomass, implying that either one of the equations can be used in these forests. This revealed the possibility of the applicability of Brown (1997) equation in forests of South Africa. Apart from the fact that the Brown (1997) equation was developed outside of South Africa, it gave a good estimate of the dry aboveground biomass of the Matiwane. The lower average relative difference value of the predicted value to actual value of the Matiwane equation renders this equation a better estimator of the aboveground biomass of these forests.

Authors have shown that indices such as spectral vegetation index (SVI), simple ratio (SR), normalized difference vegetation index (NDVI), and corrected normalized difference vegetation index (NDVIc) obtained from satellite data are useful predictors of forest biomass at a landscape level (Zheng *et al.*, 2004). However, models derived from remote sensing for estimating forest aboveground biomass need further calibration with ground data prior to their application for a given area. Allometric equations generated from this study can be powerful tools in the calibration process for future researchers undertaking modeling remote sensing options for these forests. Allometric equations derived for predicting different aboveground components from DBH can also be useful for future researchers undertaking studies on biomass change over time.

3.5 Conclusion

Measuring tree aboveground biomass in the field is extremely time consuming and potentially limited to a small tree sample size as was noted in this study. This study has successfully developed allometric equations that can be used to estimate aboveground biomass in these forests. These equations relating DBH to total aboveground biomass can be applied with confidence by researchers, forest managers and are easy to apply. The application of these equations requires only two steps: the measurement of DBH and the insertion of the DBH into the equation to estimate the aboveground biomass. The proposed Matiwane equations provide for satisfactory estimates than internationally used generalised equations of the above ground biomass and can be used for this purpose to avoid destructive sampling for trees of DBH range >2cm <56cm. Further the developed allometric equations for relating DBH to other forest components can be strong tools for other researchers undertaking studies of forest growth rate dynamics, the relation of plant growth on plant components growth, biomass change overtime and carbon sequestration rates by different tree components in the forest.

CHAPTER 4

Estimating carbon stocks

4.1 Introduction

In South Africa carbon studies are significantly few in respect to terrestrial ecosystems, although few quantified carbon stocks in certain ecosystems and localities within the country. Scholes (2004) has made a signifieant contribution on reflecting the role of savannas and woodlands in carbon sequestration, with more recent work from Shackleton and Scholes (in press). Mills and Cowling (2006) and Powell (2009) have made a significant contribution in understanding carbon dynamics in the thicket biome of the Eastern Cape. Ntshotsho (2006) has assessed the carbon sequestration of sub-tropical dunes of South Africa and Glenday (2007) greatly contributed on the role of eThekwini forests in carbon sequestration but the list is not limited to the above mentioned publications. With little that these researchers have brought on the overall understanding of carbon dynamics in South African ecosystems, much remains to be done as some of these studies only covered small areas in relation to the total area covered by the seven biomes of South Africa.

To report and add to the greater understanding of carbon stocks in terrestrial ecosystems within the country great effort needs to be invested in assessing or quantifying carbon stocks within various ecosystems. Because terrestrial ecosystems contribute varyingly to carbon sequestration (Ntshotsho, 2006, Glenday, 2007; Powell, 2009), it becomes necessary to assess the role of degradation on the overall carbon stocks in these ecosystems.

Forest ecosystems are known to store large amounts of carbon (Glenday, 2007). But in many localities, the carbon stocks in forests are continuously reduced subject to the degradation processes, in particular clearing for agricultural purposes (Ordonez *et al.*, 2007). As forests are cleared the carbon pools are reduced and these pools include living vegetation, soil, litter and deadwood (Ordonez *et al.*, 2007). In order to address the impacts of forest degradation on forest carbon stocks it is necessary to quantify carbon loss resulting from forest degradation and a critical step in assessing carbon loss subject to forest degradation is the estimation of carbon stocks in non-disturbed forests compared to disturbed ones (Ordonez *et al.*, 2007). This study followed on this pathway to try and understand the impact of forest degradation on the overall carbon stocks in the Matiwane area.

Chapter 2 of this work revealed that the forests in the Matiwane area have experienced a reduction in the forest area subsequent to the conversion of the forest area into agricultural lands. To date no data has been reported for the carbon stocks of the Matiwane area of the Transkei. The main objective of this Chapter is to assess the carbon stocks of the forests in the Matiwane and quantify the lost carbon stocks subject to forest degradation. This will be attained by addressing the following key questions:

- What are the carbon stocks in forests of different states?
- How much carbon was lost in forest stands subject to degradation?

4.2 Materials and Methods

To estimate the carbon stocks in the forest, 68 plots of 40 m × 5 m were randomly established across all the three forest states namely: intact forest, degraded forest and areas that have accumulated biomass or biomass accumulated areas (BAA) since 1942. In the intact forests 32 plots were established of which 12 of them were in the three nature reserves within the study area. In degraded forests 24 plots were sampled and the remaining 12 plots were set out in patches that were accumulating biomass (BAA). Further, within the 40 m × 5 m plots, four 1 m×1 m subplots were delineated on the corners for the estimation of carbon in litter, grass, herbaceous layer and soil as is described below.

4.2.1 Carbon in trees

4.2.1.1 Carbon in aboveground components

The diameter at breast height (DBH at 1.3 m) of each tree in the 40 m × 5 m plots was measured and the allometric equations (below) constructed in Chapter 3 were used to determine the oven-dried aboveground biomass in trees. For *Acacia* species an allometric equation determined by Netshiluvi and Scholes (2001) was used for determining the aboveground biomass.

For hardwoods: AGB= $0.127DBH^{2.33}$ .... (Chapter 3)

For softwoods: AGB= $0.462DBH^{2.202}$......................... (Chapter 3)

For *Acacia*: AGB= $0.04DBH^{2.6}$ .... (Netshiluvi and Scholes, 2001)

where AGB and DBH refer to above-ground biomass and diameter at breast height respectively. The results of the oven-dried biomass were converted to carbon by multiplying by 0.5 to give the aboveground carbon content of each tree as it is known that 50% of plant dry weight is carbon (IPCC, 1996). This was then summed across all trees in the plot to provide carbon mass per 200 m^2 plot.

4.2.1.2 Determination of belowground dry biomass

To determine the belowground biomass density (BGD), or root biomass a UNFCCC recommended regression equation developed by Cairns *et al.* (1997) which relates the aboveground biomass density (ABD) to root biomass density was used. The equation takes the following form:

$$BGD= \exp\{ -1{,}085 + 0.926 \ln(ABD)\}$$

The belowground biomass density values where converted to carbon by multiplying by 0.5 to give the carbon content in belowground components.

4.2.3 Carbon in the soil

The soil surface was firstly cleared of litter within the four 1 m × 1 m subplots. The soil samples were taken at depths of 0-3 cm, 3–5 cm, 5–10 cm, 10–20 cm, and 20-50 cm at each of the four 1 m×1 m subplots. Due to rocks and large roots at deeper levels it was not possible to sample below 50 cm depth. . The soil samples from each soil depth were air-dried for 14 days and then thoroughly mixed between the four 1 m × 1 m subplots. The roots were removed and the soil samples sieved using a 2 mm sieve, then packaged in envelopes and then sent to Dohne labs for analysis. Separate cores were taken using a steel rod of known volume for the determination of soil bulk density. The soil carbon stocks were determined as the product of carbon concentration, bulk density, depth and area, extrapolated to per hectare basis.

4.2.4 Carbon stocks in forest litter, grass and deadwood

The carbon content in litter was determined by collecting all the litter present in the four 1 m×1 m subplots of each 40 m × 5 m plot. The collected materials were oven-dried at 70° C for seven days until constant weight. Litter was regarded as any detached dead organic material that was less than 10 cm thick which also included leaves, fruits, twigs and small branches. Carbon in grass was determined by clipping all the grass in the four 1 m × 1 m subplots, the samples oven-dried also at 70° C until constant weight. The weight of the four samples averaged for each of the subplots and carbon content estimated by multiplying the dry-biomass by 0.5 to get the carbon content (Ordonez *et al.*, 2007). Deadwood components were counted and their diameter at 1.3 m from the part that was uprooted was measured, with the dry-biomass determined as in live trees but the reading reduced by 10 % to account for the loss of leaves, twigs and small branches (Delaney *et al.*, 1998; Kirby and Potvin, 2007). The smaller deadwoods that were within the 1 m × 1 m subplots were collected, then dried at 70° C for 14 days until constant weight, the carbon in each sample was determined by multiplying by 0.5.

4.2.5 Determining carbon lost through logging

To determine carbon lost as a result of logging, in each of the 40 m × 5 m plots the diameter of each of the cut stems were recorded, with the diameter taken at the point where the cut was made if below 1.3 m high. The equation used to determine carbon in hardwoods was used to estimate the potential carbon removed from the cutting of these trees.

4.2.6 Data analysis

The carbon content of each pool per plot was extrapolated to a per hectare basis. The total carbon density (total carbon per hectare) of each state was determined by the summation of all the carbon stocks of each forest state using the following equation:

$C_d = C_t + C_s + C_l + C_{dw} + C_g$ (Mg C.ha^{-1})......................(Ordonez *et al*, 2007)

where C_d : carbon density, C_t carbon in live trees, C_s carbon in soil, C_l carbon in litter, C_{dw} carbon in deadwood and C_g carbon in grass. The total carbon in each forest state was attained by multiplying the carbon density of the forest state by the total area of the forest state as in the following equation:

Total carbon = $C_d \times A$, where C_d and A represent total carbon density and area of each forest state, respectively. The difference in the carbon pools were tested using Kruskal-Wallis ANOVA using Origin pro 8 (Originlab, 2007) and the differences are reported at the significance level of 0.05.

4.3 Results

4.3.1 Carbon in live standing trees

The quantification of carbon in belowground and aboveground biomass revealed that the intact forest patches had higher carbon content (113.7 ±14.9 $MgC.ha^{-1}$) than the degraded (15.6±8.0 $MgC.ha^{-1}$) and BAA (14.4±5.7) state (Table 13). The Kruskal-Wallis ANOVA analysis revealed a significant difference ($p< 0.05$) between the three states.

Table 13: Tree carbon content of the three forest states.

		Biomass ($Mg.ha^{-1}$) ±S.E	Carbon ($Mg.ha^{-1}$) ±S.E
Intact	Aboveground	227.4±29.8	113.7±14.9
	Belowground	30.3±3.7	15.2±1.9
	Total	257.7±33.6	128.9±16.7
Degraded	Aboveground	27.2±14.1	13.6±7.1
	Belowground	3.9±1.9	1.9±0.9
	Total	31.1±14.9	15.6±8.0
BAA	Aboveground	24.9±10	12.4±5
	Belowground	3.8±1.4	1.9±0.7
	Total	28.7±11.3	14.4±5.7
P value		<0.05	<0.05

4.3.2 Carbon in grass, litter and deadwood

The assessment revealed that the Matiwane intact forests contained no grass cover under the canopy, with grass occurring only in the degraded and BAA state (Table 14). In addition no herbaceous cover was recorded in any of the plots in the three states. There was no significant difference between grass carbon in degraded (0.76 ± 0.079 $MgC.ha^{-1}$) and BAA states (0.54 ± 0.029 Mg $C.ha^{-1}$). The intact forest state had significantly higher carbon content in litter and deadwood than in degraded and BAA states (Table 14).

Table 14: Carbon content in grass, litter and deadwood.

		Range ($MgC.ha^{1}$)	Mean ±SE ($MgC.ha^{1}$)
Intact ($MgC.ha^{-1}$)	Grass	0	0
	Deadwood	0.36-32.0	9.70 ± 1.45
	Litter	1.15-13.2	6.38 ± 0.64
Degraded ($MgC.ha^{-1}$)	Grass	0-1.3	0.76 ± 0.08
	Deadwood	0-2.5	0.59 ± 0.16
	Litter	0-2.8	0.51 ± 0.15
BAA ($MgC.ha^{-1}$)	Grass	0.39-0.69	0.54 ± 0.03
	Deadwood	0-4.5.0	0.06 ± 0.43
	Litter	0-0.21	0.08 ± 0.02
P value of different forest states	Grass		>0.05
	Deadwood		<0.05*
	Litter		<0.05*

*≈significantly different

4.3.3 Carbon in the soil

The upper depths of the soil revealed a higher carbon content than the lower depths per centimeter depth but there was no significant difference between the carbon content of the different soil depths with the highest percentage in the first layer or depth (3 cm) followed by the 3-5 cm depth. The intact forest accounted for 167.1±4.9 $MgC.ha^{-1}$, the BAA accounting for 57.2±4.1 $MgC.ha^{-1}$ and the degraded patches accounting for about 34.9±7.1 Mg $C.ha^{-1}$ (Table 15).

Table 15: The soil carbon density of the intact, degraded and BAA state.

Soil depth (cm)							
State		0-3	3-5	5-10	10-20	20-50	Total
Intact ($MgC.ha^{-1}$)	Mean±SE	24.1±0.6	18.1±0.5	31.9± 0.9	45.0±3.1	48.0±19.5	167.1±4.9
	Range	18.3-34.0	10.3-24.8	21.6-42.8	17.6-96.4	23.4±82.3	
Degraded ($MgC.ha^{-1}$)	mean±SE	11.4±1.4	7.8±0.43	15.9±0.9	22.1±1.4	28.6±1.0	57.2±4.1
	Range	4.7-18.4	3.5-11.2	9.8-23.5	7.38-32.4	23.1-42.4	
BAA ($MgC.ha^{-1}$)	mean±SE	7.8±0.6	4.3±0.4	10±1.2	12.9±4.9	26±1.8	34.9±7.1
	Range	5.6-13.0	2.1-6.7	5.16-19.4	7.5-20.0	21.5-34.8	
P value of different states		>0.05	>0.05	>0.05	>0.05	>0.05	<0.05

4.3.4 Total carbon density

The total carbon density varied amongst the three forest states (Table 16) with the intact having significantly higher total carbon density (311.68±23.69 $MgC.ha^{-1}$) than the degraded (73.46±12.34 $MgC.ha^{-1}$) and BAA forest patches (51.18±6.18 $MgC.ha^{-1}$). The soil carbon pool contributed between 55% (intact) to almost 80 % (degraded) of the total carbon density and in BAA it was 73 % (Table 16). Grass contributed the least to the total carbon density, contributing less than one percentage to the total carbon per hectare. In comparing the degraded with the intact, it is evident that the degraded areas have lost approximately 75 % of their original carbon pools.

Table 16: The total carbon density estimate of each forest state and the relative percentage contribution of each pool to the total carbon density.

Forest state		Carbon pool					Total carbon density
		Trees	Deadwood	Litter	Soil	Grass	
Intact	Mean ($MgC.ha^{-1}$)	128.9±16.7	9.70 ± 1.45	6.38 ±0.64	167.1±4.9	0	311.68±23.69
	Relative %	41.2	3.1	2.1	53.6	0	
Degraded	Mean ($MgC.ha^{-1}$)	15.6±8.0	0.59 ± 0.16	0.51 ±0.15	57.2±4.1	0.76 ±0.08	73.46±12.34
	Relative %	19.6	0.8	0.7	77.9	1.0	
BAA	Mean ($MgC.ha^{-1}$)	14.4±5.7	0.06 ± 0.43	0.08 ±0.02	34.9±7.1	0.54 ± 0.03	51.18±6.18
	Relative %	30.5	0.1	0.2	68.2	1.1	

4.3.5 Total carbon in each forest state and total carbon lost

With respect to total carbon in each forest state which is given by the carbon density multiplied by the total area of each forest state, 4.7 Teragrams (TgC), 0.06 TgC and 0.02 TgC were obtained for intact, degraded and BAA states, respectively (Table 17). The total calculated carbon loss in the forests as a result of the conversion of the forest area to agricultural fields was 0.19 TgC and approximately 0.0003 TgC was lost from logging. Approximately 0.024 TgC was accumulated from the BAA (Table 17).

Table 17: The total carbon content of the intact, degraded and BAA states..

	Carbon density (Mg C/ha)	Total area (ha)	Total carbon (Tg C)
Intact	311.68±23.69	15,352	4.70
Degraded	73.46±12.34	791	0.06
BAA	51.18±6.18	471	0.02
Carbon loss from degraded forests			0.19
Carbon lost through logging			0.0003
Net loss			0.19

4.4 Discussion

The quantification of carbon stocks in the three states indicated that the forests have lost carbon in all pools subject to the conversion of the forests to agricultural fields and also logging. As discussed in Chapter 2 the forests have been reduced in size and this part of the study has managed to construct a comprehensive carbon inventory of these forests and reflected on the quantifiable impact of degradation on the carbon stocks.

4.4.1 Carbon in tree biomass

The conversion of the forest to agricultural fields has reduced the total tree carbon density from 128.9±16.7 $MgC.ha^{-1}$ in intact forest to 15.6±8.0 $MgC.ha^{-1}$ in degraded forests revealing a significant reduction in the carbon content subject to degradation. The conversion has resulted in about 87.9 % reduction in the total tree carbon density, this is as a result of tree felling for the sole purpose of utilising the forest land for the production of crops in these rural communities who depend on subsistence agriculture (DEAT, 2000 as cited in Hadju, 2009). Trees store large carbon contents as such their removal greatly affects the carbon content in the components as reflected by other studies (e.g. Powell, 2009; Hughes *et al.*, 2000). This echoes the findings of Hughes *et al.*, 2000 who showed a 95% reduction in Los Tuxtlas Biological Station in Mexico subject to forest clearance and also Kauffman *et al.* (1995) who showed a 58–112 $Mg.ha^{-1}$ reduction in aboveground carbon pools in Amazon forests. This clearly reflects on the susceptibility of this carbon pool to the conversion of forests.

Although conversion has greatly reduced the carbon content in aboveground tree components of the degraded state, the remaining tree carbon is harboured in *Heywoodia lucens* trees that are left to stand by the communities to possibly provide for shade during planting times and the size of these trees renders the task of felling them extremely difficult thus leaving them to stand. Apart from the conversion of forests to agricultural lands some areas that were not previously vegetated in 1942 accumulated biomass (BAA) accounting for the accumulation of 14.4 ± 5.7 $MgC.ha^{-1}$ and as discussed in chapter 2 the carbon in these areas is as a result of growth of *Acacia* trees on these areas.

The tree aboveground carbon content in the scarp forests of the Matiwane area (113.7 ± 14.9 $MgC.ha^{-1}$) differed greatly with the one reported by Glenday (2007) for the scarp forests of eThekwini Municipal Area (66 ± 9 $MgC.ha^{-1}$) which lies on the same coastline towards the north in the Kwazulu-Natal province. Glenday (2007) used diameter and height data from different authors contributing to the DWAF forest classification report and managed to also estimate the mean above-ground carbon density of the Eastern Cape and Kwazulu-Natal provinces (173 ± 13 $MgC.ha^{-1}$) which also varied from the carbon density reported by this study. The main variation between the reported carbon density in this study and the mean carbon density reported by Glenday (2007) for the Eastern Cape and Kwazulu-Natal lies in the fact that Glenday (2007) estimated the mean carbon density used an allometric equation that was developed elsewhere in the world. This may have been the source of error thus inducing variation between the two estimates, coupled with climatic and altitude variations. Tree allometry is greatly affected by variation in site precipitation and other environmental factors, thus using allometric equations developed elsewhere needs to be done with caution as there can be significant differences to locally derived allometric relationships as in the case of Cairns *et al.* (2003) who observed a relative variation in the biomass estimates compared to earlier work (Cairns *et al.*, 2000) which used allometric equations developed elsewhere for the Yucatan Peninsula forests in Mexico. However, the belowground carbon density estimates of the intact forests of the Matiwane (15.2 ± 1.8 MgC.ha^{-1}) was not significantly different from the one reported for eThekwini Municipal area (18 ± 2 MgC.ha^{-1}) scarp forests (Glenday, 2007). The reported value for the tree carbon density was within acceptable limits of published estimates from around the world as reflected by Table 18, which range from 60 to 200 MgC.ha^{-1}.

4.4.2 Soil carbon (to 50 cm depth)

The soil pool had higher carbon content than any other pool in the forest, followed by living standing trees including both aboveground and belowground pools. The soil carbon pool contributed more than 50 % towards the total carbon density of the three states, with 54 % contribution in intact forest, 78 % in degraded and 68 % in BAA state. There was a significant difference between soil carbon stocks in different states. Also the carbon content of different depths in the same horizon had no significant difference with the upper depths having slightly higher carbon content per centimeter depth than the lower depths, which is attributed to the decomposition of litter on the upper depths of the soil. As a result the soil carbon content declined as the depth increased. The carbon percentage decreased from 10.8 % (0-3 cm) to 1.6 % (20-50 cm) in the intact state, 5.4 % (0-3cm) to 1.1% (20-50cm) in the degraded state and 3.3 % to 0.9 % in the BAA state. This is a typical finding as shown by Ordonez *et al.* (2007).

The conversion of forest lands to agricultural lands lowers the soil carbon (Guo and Gifford, 2002) and Table 13 showed that the soil carbon was reduced from 167.1 ± 4.9 MgC.ha^{-1} in intact forests to 57.2 ± 4.1 MgC.ha^{-1} in degraded states. The conversion of these intact forests to degraded forests has induced a 65.8 % reduction in soil carbon and this is a typical finding also shown by Guo and Gifford (2002) who revealed a 42% reduction in soil carbon stocks subject to the conversion of forest to crop land from their metadata analysis of 74 publications. Almendros *et al.* (2005) also reflected on the decline in soil carbon associated with clearing in the savanna ecosystem in Kwazulu-Natal and Eastern Cape, although his study was within the savanna this shows the general trend of the decline in soil carbon in different ecosystems subject to the clearing of trees within that particular ecosystem. This is attributed to the removal of vegetation and subsequent litter input which are the main inputs of carbon in the soil (Lal, 2005).

The soil carbon in the degraded site will continue to decline through time as pools established under a non-vegetated state decompose. Allen (1985) discusses the fact that forest clearing disturbs the deposition of organic matter into the soil, increases the soil temperature and interception of rainfall thus creating conducive conditions for fungal, bacterial and soil fauna which increases decomposition in these soils. The BAA contributed about 34.9±7.1 MgC.ha^{-1}, this is hypothesised to also be as a result of litter deposition from the newly developing vegetation cover on the grass cover, which increases the organic carbon in this areas.

4.4.3 Carbon in litter, deadwood and grass

The carbon content in litter also declined with the conversion of intact forest to more degraded forest patches. The intact forest contained a mean of 6.38 ± 0.64 MgC.ha^{-1} in litter and the degraded forest 0.51 ± 0.15 MgC.ha^{-1}. The overall decline in litter carbon was estimated at 87.3 % per hectare, but the area has managed to accumulate about 0.08 ± 0.02 MgC.ha^{-1} in litter in the BAA state. The decline is as result of the removal of the forest vegetation thus impacting on the litter production and also the burning process removes the available litter (Lasco, 2002) and deadwood. The litter carbon density value reported by this study (6.38 ± 0.64 MgC.ha^{-1}) was slightly almost double than reported by Glenday (2007) for KwaZulu-Natal scarp forests (3.7±0.3 MgC.ha^{-1}). Carbon in deadwood also revealed a decline from 9.70 ± 1.45 MgC.ha^{-1} in intact forests to 0.59 ± 0.16 MgC.ha^{-1} in degraded forest patches, but there was an accumulation of 0.063 ± 0.43 MgC.ha^{-1} from the BAA. Although it may be expected that the degraded forests may have a higher deadwood than the intact as a result of felling, this was not the case as the deadwood in degraded forests are usually burned to create space for ploughing and removed for fuelwood thus higher carbon content in intact than degraded state. There was no significant difference between the grass carbon density in degraded (0.76 ± 0.079 MgC.ha^{-1}) and BAA (0.54 ± 0.029 MgC.ha^{-1}) forest patches. Grass was limited to these two forest states as no grass layer was observed for the intact forests. The absence of the grass layer in intact forests and presence in the degraded state suggests that the clearing of the top canopy allows for the development of the grass layer. However, the absence of the grass layer in intact forests of the scarp forests was also noted by von Maltitz *et al.* (2003) for the Transkei forests.

Table 18: Comparing the total tree carbon density and soil carbon density with published values.

Source	Location	Forest type	Total tree Carbon ($Mg.ha^{-1}$)	Soil ($Mg.ha^{-1}$)
This study	Matiwane, Eastern Cape, South Africa	Scarp (subtropical)	128.9	167.1(50cm)
Glenday, 2007	eThekwini, Kwazulu Natal, south Africa	Scarp (subtropical)	66	100 (30cm)
Brown and Gaston (1995)	Congo, Equatorial Guinea, Gabon, and Liberia	Tropical	153-172	-
Brown (1997)/Achard *et al* (2004) in Gibbs *et al.*(2007)	Sub-Saharan Africa	Tropical	143	-
IPCC (2006) in Gibbs *et al.*, 2007	Sub-Saharan Africa	Equatorial forests (tropical)	200	-
Brown *et al.* (1993)	Mean for Asian countries	Tropical	144	148*
Prentice (2001) in Lal (2005)	Global mean	Temperate forests	60-130	122*
	Global mean	Tropical forests	120-194	122*

**=depth not specified*

4.4.4 Total carbon density

The comparison of the mean total carbon density (vegetation+soil+litter+deadwood) revealed a significant difference in the total carbon density in intact, degraded and accumulating areas of the forest. The intact forest state (311.68±23.69 $MgC.ha^{-1}$) had a greater carbon content than the degraded forest (73.46±12.34 $MgC.ha^{-1}$) and BAA (51.18±6.18 $MgC.ha^{-1}$), demonstrating that the conversion of the forest to agricultural fields has significantly reduced the total carbon content in these forests by 238.22 $MgC.ha^{-1}$. This significant (>200 $MgC.ha^{-1}$) reduction in carbon in forests subject to conversion of forest to agricultural fields was also observed by Kotto-samme *et al.* (1997) in Cameroon, who reported a reduction from 308 $MgC.ha^{-1}$ to 88 $MgC.ha^{-1}$ resulting in a total loss of 220 $MgC.ha^{-1}$ indicating a substantial contribution of forest degradation and/ clearance to the decline in carbon stocks in forests. There was no significant difference between the carbon density in degraded forest (73.46±12.34 $MgC.ha^{-1}$) and BAA (51.18±6.18 $MgC.ha^{-1}$) which is solely due to the fact that in degraded state, in-between the fields as discussed before trees of *Heywoodia lucens* are still present thus contributing to the carbon stocks in these degraded patches. The greatest differences in carbon pools among the three states were carbon content in vegetation and in the soil indicating the vulnerability of these two pools to the conversion of forest to agricultural lands.

Compared to the total carbon density of the KwaZulu-Natal scarp forests of 199±16 $MgC.ha^{-1}$ (Glenday, 2007), the values from this study were markedly higher (311.68±23.69 $MgC.ha^{-1}$). The variation in the two is probable due to the fact that Glenday (2007) reported on the total carbon density to a depth of 30 cm and in this study to a depth of 50 cm and also the possible underestimate of biomass carbon resulting from using allometric equations from outside the country as commented before. In creating the carbon inventory of the forests in the Matiwane area, that is, the total carbon stocks in each of the forests states, the degraded forests accounted for 0.06 TgC, and the BAA 0.02 TgC with 4.7 TgC in intact forests. The degradation of these forests has resulted in the net carbon loss of 0.19 TgC from 1942 to 2007 and a total of 4.7 TgC is still remaining in these forests.

4.4.5 Comparing carbon lost from conversion and selective logging

Selective logging in these forests proved to contribute minimally to the reduction of the carbon stocks, with 0.14 % (0.0003 TgC) of the carbon lost resulting from selective logging and 99.86 % (0.19 TgC) of the carbon lost resulting from the conversion of these forests to agricultural fields. These reflected that the process that is of concern in terms of carbon loss is the conversion of these forests, as most of the carbon was lost as a result of the conversion. Thus to significantly halt carbon loss in these forests the conversion of these forests will need to be addressed.

4.5 Conclusion

This study has successfully created a carbon inventory of forests in the Matiwane area in the coastal region of the Transkei and also successfully quantified the impact of forest degradation on the carbon stocks of these forests. The carbon loss is as a result of degradation subsequent to the conversion of forest land to agricultural fields. The two major pools in these forests, which were the live vegetation and the soil pool, experienced the greatest carbon reduction over the years suggesting the vulnerability of these pools to degradation. This study has shown that 4.7 TgC is still remaining in these forests and a net carbon loss of 0.19 of TgC was endured through forest degradation. This is estimated to be only 3.8 % of the initial total carbon in these forests and this small value is a reflection of the small proportion of the forests affected by clearing. But within a cleared site, carbon losses are extensive. This large difference in carbon content between the intact forests and the degraded may reflect on the need for an intervention to reduce the carbon loss and also to replenish the lost carbon stocks in these forests.

This study has provided the first step towards understanding the carbon dynamics in these forests and also to the general understanding of the carbon dynamics subsequent to degradation. The results of this study are valuable particularly for regional and national carbon estimates of the impact that forest degradation has on the overall forest biome and on the whole scope of biomes at the regional and national level.

CHAPTER 5

Concluding discussion and future research

5.1 Introduction

Updated and reliable data on the state of forest resources has become important in supporting decision-marking for policies that promote the integration of sustainable development and environmental conservation (FAO, 2009a). South Africa is one of many countries that have adopted policies that promote the conservation of forest resources (DEAT, 1997) but forest cover continues to decrease even under such policies (FAO, 2007). Globally, research has shown that forests are being lost at an increasing rate resulting in the loss of biomass and tangible resources of important value along with the reduction of biodiversity (Rodgers, 1997; FAO, 2009a). The need to mitigate these loss becomes apparent, however the quantity and quality of the available data to quantify these loss is inadequate in many regions of the world (Rodgers, 1997). The loss of biomass in forests greatly affects the carbon cycle in these ecosystems and forest degradation has resulted in a significant loss in carbon stocks in many forests around the world thus contributing to global warming and eventually climate change (FAO, 2009a). South Africa has been rather slow in trying to assess the role of degradation in ecosystems on carbon stocks, as can be judged based on the low number of published studies on this topic. This study successfully addressed this topic for the forests in the Matiwane area of the Transkei, which is marked for restoration (Restoration Research Group, 2010).

To better understand the role that forest degradation has had on the overall carbon stocks of the Matiwane forests, it became apparent that the assessments of forest degradation and carbon inventories for these forests were a necessity. This thesis successfully looked into these issues:

- The assessment of forest degradation in the Matiwane area
- Identification of degraded areas of the forests
- Creation of a carbon inventory for these forests
- The impact of forest degradation on the overall carbon stocks of the forests

5.2 Cover change of forests in the Matiwane area

Faced with insufficient historical data on forest cover change and also the extent of the area under study (90 km×10 km), remote sensing proved to be efficient for assessing historical forest cover change in these forests. This study utilized aerial photographs and Spot 5 satellite images for the assessment of forest cover change in these forests from 1942 to 2007. The aerial photography analysis with the aid of ArcGIS 9.2 (ESRI, 2006) revealed several areas within the Ngqeleni and Port St Johns Forest Estates that were cleared over the years. There was no noticeable clearing occurring in the Bomvane Estate and also the area between Mgazi river and Port St Johns however, it is important to note that clearing of small areas may occur which may not be visible under aerial photography.

The ground-truthing of these areas revealed that the forests were and are continuously being cleared (Ngqeleni and Port St Johns forest estates) for subsistence agriculture, a common practice in these poverty stricken communities (DEAT, 2000; Timmermans, 2002; Hadju, 2009). However, degradation resulting from the clearing of forests to agricultural fields is not a unique phenomenon for Matiwane area alone, as can be seen in numerous reports from all over the world (Murty *et al.*, 2002; Grünzweig *et al.*, 2003; Shearman *et al.*, 2009). The White Paper for Sustainable Coastal Development in South Africa describes the economy of this region of the Transkei to be largely based on subsistence agriculture, state pension and migrant labourer income (DEAT, 2000; Hadju, 2009). The clearing of forest for various reasons can therefore be translated to the community's needs for resources such as fuel and agricultural land. Without clear poverty alleviation programs, the potential for forest degradation will increase as communities use the forests to mitigate against their plight.

As revealed in Chapter 2, the clearing has resulted in the reduction in forest cover, tree density, number of species, basal area and carbon stocks implying that these forests are being degraded. It also revealed that only 5.2 % (791 ha) of the forest was degraded over a period of 65 years, equating to an average annual rate of 0.08 % or 12.2 ha per year inciting that the degradation process was rather slow and gradual as compared to other studies, for example the work by Ite and Williams (1998) who observed that in the

Okwangwo Division of the Cross River National Park in Nigeria, approximately 150 km^2 (15 000 ha) were lost over a period of 26 years (which is equivalent to 15 % of the total forest). Also just in the same coastline, Mozambique lost 50 000 hectares which is equivalent to 0.3 % of forests area within a period of 10 years between 1990 and 2000 (FAO, 2009b).

Many narratives have been forwarded to explain the degradation in the Transkei. Some authors have blamed the apartheid regime for the environmental collapse in the Transkei, arguing that apartheid polices induced overcrowding in small congested areas resulting in the overutilization of natural resources and subsequently leading to degradation (Carruthers, 2002; McCann, 1999 as cited by Hadju, 2009). Aerial photographic analysis revealed that immediately after the independence of the Transkei as a Bantustan, forest degradation escalated. The aerial photographs obtained for 1942 and 1974 (pre-independence) indicate that for the 33 years since 1942 only 5.1 hectares (0.15 ha.$year^{-1}$) cleared but from 1974 to 1995 (after independence) about 309 hectares were cleared at 14.7 ha.$year^{-1}$. Although, this is a common narrative for most of the former homelands in South Africa (Hadju, 2009), forest degradation still continues (and increasing) even after 16 years into democracy, the study revealed that from 1995 to 2007 about 477 hectares were cleared (39.8 ha.$year^{-1}$) which raises questions on whether or not the true causative factors for forest degradation were the apartheid policies.

However, politics is frequently implicated in forest fragmentation, as was the case in Madagascar where forest area was reduced following political turmoil (Vagen, 2006). It should be noted that the data from the aerial photography is not proof or negation of the validity of the narrative but rather showing the trend of forest degradation over the years. The convergence of the narrative to the data reported in this study gives an insight about the elevation of forest clearing after the 1970's. However the narratives is less effective in giving insight on the actual drivers of forest clearing as forest clearing dates back as early as the pre-colonial times as reported by von Maltitz & Shackleton (2004).

The other possibility that might have induced the degradation of forests after the independence of Transkei might be locals feeling free to utilise what was restricted to them for many years by the apartheid government, as has been reported for bushmeat

(White, 2004) and shellfish resources for the region in 1993-1994 (Palmer, 2003; Shackleton *et al.*, 2007), as well as other resources such as fuelwood, medicinal plants, fish reported by studies in other homelands (Twine *et al.*, 2003). This is illustrated further by the invasion of protected areas by local communities in the same region immediately after the democratic transition (Dwesa-Cwebe SMP, 2006). This sense of entitlement is probably also allied to the perceived decline of traditional authorities to govern natural resource use, as well as inadequate assumption of that responsibility by national, provincial or local government (von Maltitz and Shackleton, 2004, Shackleton, 2009).

According to the perception expressed by Masiso. *pers. comm.* (2008), the main reason locals invade and clear the forest is because the only fertile soils are underneath the forest canopy thus clearing the forest for agricultural purposes. Over time the cleared land becomes less productive and subsequently a new plot is cleared further into the forest (Masiso. *pers. comm.*, 2008). In a study south of the study area, Andrew and Fox (2004), as cited by Matose (2009), observed that the arable lands in the area have experienced a decline in soil fertility, substantiating the Masiso *pers. comm.* (2008), and driving the continual clearance of forests in the area. This is in common with dynamics on dystrophic soils elsewhere in the world, which promotes slash and burn agriculture in savannas and tropical forests (Desanker *et al.*, 1995; Tiessen, 1998; Tschakert *et al.*, 2007). The burning is reported to induce increase soil nutrients subject to transfer of nutrients contained within the burned biomass into the soil in the form of nutrient rich ash (Nye and Greenland, 1960, as cited in Giardina *et al.*, 2000).

The time and labour invested in felling and clearing of forests for subsistence agriculture might be an indicator that truly the locals have no alternative but to turn to the forest soils, since if soils on the periphery of the forests were fertile for cultivation a less labour intensive choice would be taken. A study by Benhin (2006) revealed and predicted that subsistence agriculture within the whole of South Africa will be highly disrupted by climate change. This might possibly escalate the forest clearing with locals in pursuit of more arable land under the forest canopy, due to the perception that soils under the canopy are fertile. Thus, it is necessary to properly identify and address the main driver of forest clearing in these forests to reduce the further degradation of these forests and to assure that the restored patches are not degraded once again.

Although this study has reflected upon the degradation of forests, some areas that were accumulating biomass (BAA) were observed from aerial photography. These areas were initially thought to be forest but upon ground-truthing it was discovered that these areas which were once grasslands were invaded by *Acacia karoo* (locally known as umnga). Although not part of the main objective of this study, it was shown that the area in-between forest patches in this area are starting to show signs of 'bush encroachment', a typical observation also reported by (Fay, 2009) for the Cwebe area which makes part of the southern tip of the study area. In some respects this may be regarded as a pioneer stage of forest invasion, but the time span required for true forest elements is unknown.

5.3 Allometry

Key to the estimation of carbon stocks in forest biomass is the development of allometric equations or models. Generalised global allometric equations are available in the literature (Brown, 1997; Zianis and Mencuccini, 2004; Pilli *et al.*, 2006; and others) but many authors argue that region-specific equations are required especially for carbon studies as varying precipitation and other environmental factors influence tree allometry (Ketterings *et al.*, 2001). Prior to this study no mixed species allometric equation existed for the Matiwane forests, and consequently allometric equations were developed for these forests to estimate the tree above-ground biomass (AGB) for hardwoods and softwoods. These allometric equations, based on a mixture of plant species available in the forest proved to be effective in predicting the aboveground biomass in this study, and in combination with satellite remote sensing techniques it can be invaluable for other researchers interested in biomass and carbon studies in the Matiwane area.

Although most researchers agree that species specific equations are key, the Matiwane equation is justified as only plant species that contributed most to the total carbon pools were used to construct the equation. Plant species used in the equation contributed about 73 % to the total carbon in the sampled plots. This study follows others such as Brown (1997) and Mukkonen (2007), to construct and apply mixed species allometric equations.

Forests contain a number of plant species and constructing species specific equations would be expensive, time consuming and very destructive (Brown, 2002; Zianis and Mencuccini 2004). Mixed-species allometric equations do provide good estimates as discussed by Brown (2002), particularly when used for area estimates. It should also be noted that there is a danger in using this mixed-species equations for a single tree biomass estimates as underestimates or overestimates can result (Brown, 2002; Zianis and Mencuccini 2004; Mukkonen, 2007). For a wide area or for a mix of species the underestimates and overestimates resulting from the equations cancel out (Zianis and Mencuccini 2004; Mukkonen, 2007) thus becoming effective in estimating the overall biomass.

5.4 Carbon stocks in forests

This study has also reflected that degradation of these forests has greatly reduced the carbon stocks (Chapter 4) in these forests revealed by the significant difference between the carbon stocks in intact forests and degraded forests. The degradation of these forests has resulted in a decline in carbon density from 311.68 MgC.ha^{-1} in intact forests to 73.5 MgC.ha^{-1} in degraded forests. The soil and vegetation pool were the mostly reduced, with a 65.8 % and 87.9 % lost respectively, which is as a result of biomass removal in this forests inducing a reduction in biomass carbon content and affecting the forest litter fall subsequently leading to a reduced carbon input in the soil (Guo and Gifford, 2002; Lal, 2005).

However, studies have indicated the possibility of regaining the lost carbon through reforestation/restoration and agroforestry practices for carbon sequestration initiatives (Fang *et al.*, 2001; Albrecht and Kandji, 2003). Fang *et al.* (2001) managed to reveal that afforestation and reforestation of forests can induce accumulation of carbon. They have shown that in China about 0.45 pentagram of carbon was accumulated from afforestation and reforestation from mid-1970s to 1998 (Fang *et al.*, 2001). This reflects upon the possibility of recapturing the lost carbon through these initiatives (restoration, reforestation and afforestation) in the degraded areas of the Matiwane. While substantial data have been provided by this study on the carbon stocks of the Matiwane forests, much work still needs to be done on the carbon sequestration rate and annual emissions subsequent to forest degradation in these forests.

5.5 Relevance to restoration

According to Article 12 of the Kyoto Protocol an allowance is made for developed countries who cannot meet their carbon emission targets to purchase carbon credits from developing countries through funding of afforestation, reforestation and forest restoration projects that sequester CO_2 (Jindal, 2006). Funds from carbon sequestration projects are mostly shared with communities that reside close to the forests being restored (Jindal, 2006) and this can greatly alleviate the poverty in this area of the Eastern Cape.

Jindal, (2006) reported on a number of carbon sequestration projects within Africa in which the benefits are shared with the locals. One such project is the Humbo Assisted Regeneration in Ethiopia where 2,728 hectares of natural forest are to be restored which is expected to sequester about 880,000 metric tonnes of CO_2 emissions over 30 years, which by 2017 would have accumulated 338,000 tonnes worth of carbon credits resulting in an income stream of more than US$ 700,000 to the local communities (www. wbcarbonfinance.org; Jindal, 2006). Another project is the Ugandian, Nile Basin Reforestation project which is set to develop timber plantations on a 2,137 ha area, which will result in 0.11 Mt CO_2 emissions sequestered by 2012 and employing approximately 700 individuals from the communities thus contributing to the socio-economy of the area (www.wbcarbonfinance.org). Funding received for carbon credits can greatly aid in alleviating poverty in communities that reside close to the forests of the Matiwane.

One of the fundamental starting points of any restoration initiative is to adequately and efficiently identify potential sites for re-vegetation (Lawson *et al.*, 2006). This study has identified degraded patches in the Matiwane that can be included in the current restoration initiative. The degraded forests have the potential to sequester carbon following the carbon lost through the process of forest clearing. Shapefiles generated in this study can be valuable for the location and quantification of these degraded patches. According to the UNFCCC (2008) quantification of available carbon stocks prior to the execution of a restoration project is a requirement for the project to be considered under the CDM, and as such the data on carbon stocks from this study can be invaluable particularly if the project is to be used to obtain carbon credits.

However this study notes the following: degraded patches (mostly) in these forests are currently used for cultivation which may require the provision of alternative arable lands for the local people before the initiation of the restoration process. I hypothesise that failure to provide alternative land for cultivation would lead to degradation of other forest patches, that is leakage, as locals seek for an alternative ploughing area and it might also lead to restored areas suffering a relapse after a few years. Although quantifiable data were not available to support this argument, the possibility cannot be overlooked. Mansourian *et al.* (2005) reiterates this issue, elaborating that the reason most of the restoration efforts fail is based on the fact that the causative factors of forest loss are usually not addressed beforehand, subsequently the restored forest suffers the same fate as the original forest. However, the understanding of causative factors of forest loss and co-operative planning of restoration initiatives with locals increases the chances of any restoration initiative succeeding (Mansourian *et al.*, 2005).

5.6 Carbon sequestration through agroforestry

In an attempt to recover the lost carbon from these forests agroforestry might be another alternative to recover some of the carbon lost through degradation. "Agroforestry is defined as any land-use system that involves the deliberate retention, introduction or mixture of trees or other woody perennials with agricultural crops, pastures and/or livestock to exploit the ecological and economic interactions of the different components" (Albrecht and Kandji, 2003). Agricultural lands have the potential to be major potential carbon sinks and could store large quantities of carbon if trees are reintroduced to these lands and tentatively managed together with crops (Albrecht and Kandji, 2003). In a situation where agroforestry is established immediately after slash and burn agriculture, about 35% of the original forest carbon stock can be recovered (Sánchez, 2000 as cited in Oelbermann *et al.*, 2004).

This has gained attraction following its recognition as a potential mitigation strategy under the Kyoto protocol (Takimoto *et al.*, 2008). A review by Albrecht and Kandji

(2003) showed estimates on the potential that agroforestry systems have in terms of storing carbon for different ecoregions of the world as reflected on Table 19 on page 92. This reflects that agroforestry can to some degree greatly sequester carbon from the atmosphere. Pandey (2002) described carbon sequestration through agroforestry as a better solution than oceanic and other terrestrial carbon sequestration options as it has secondary benefits such as helping in attaining food security, improving arable soils and mitigating the demand for wood thus alleviating pressure on natural forests.

Research has shown that soil in croplands can be induced to increase its carbon content by adopting carbon-conserving practices on arable lands (Antle and Diagana, 2003; Oelbermann *et al.*, 2004). A study in Costa Rica by Oelbermann *et al.* (2004) has shown that a 10-year-old system with *E. poeppigiana* managed to sequester carbon at a rate of 0.4 Mg C ha^{-1} $year^{-1}$ and 0.3 Mg C ha^{-1} $year^{-1}$ in coarse roots and tree trunks respectively, with the systems resulting in an annual increase in soil carbon pool by 0.6 Mg ha^{-1} $year^{-1}$. Takkimoto *et al.* (2008) discussed the fact that the sale of carbon sequestered through agroforestry initiatives to the industrialized countries could potentially be an attractive economic opportunity for subsistence farmers in developing countries, who are the major practitioners of agroforestry. The financial cost of sequestration carbon through agroforestry is estimated to be much lower (approximately \$1–69 per Mg C, median \$13 per Mg C) as compared to carbon sequestration through other mitigating options and the costs could be offset by monetary benefits from agricultural products and trading carbon credits (Albrecht and Kandji, 2003)

Since carbon capture through agroforestry allows for agriculture to continue on the respective land as opposed to restoration which requires that agriculture be totally stopped on the area to be restored, could have benefits in Matiwane where most of the degraded forests are still in use by the locals. However, research needs to be done on the potential of the areas to sequester carbon through agroforestry and since agroforestry for carbon sequestration can be complex to manage, expertise may be required as such the locals may need to be trained which can be a milestone.

Table 19: Reported potential of agroforestry systems (Table obtained from Albrecht and Kandji, 2003)

Region	Ecoregion	System	$MgC.ha^{-1}$
Africa	Humid tropical high	Agrosilviculture	29-53
South America	Humid tropical low	Agrosilviculture	39-102
	Dry lowlands	Agrosilviculture	39-195
Southern Asia	Humid tropical	Agrosilviculture	12-228
	Dry lowlands	Agrosilviculture	68-81
Australia	Australia	Silvopastoral	28-51
North America	Humid tropical high	Silvopastoral	133-154
	Humid tropical low	Silvopastoral	104-198
	Dry lowlands	Silvopastoral	90-175
Northern Asia	Humid tropical low	Silvopastoral	15-18

5.7 Possible participation in REDD+ mechanism

REDD+ (Reducing Emissions from Deforestation and Forest Degradation and the plus sign indicating the enhancement of carbon stocks in forests) is a mechanism that is set to provide incentives for avoided or reduction in emissions from deforestation and forest degradation, in that way making payments available to forest owners and users to fell forest trees less and manage forests effectively (Angelsen *et al.*, 2009). The main focus of REDD+ is the reduction of carbon emissions resulting from the removal of biomass in forests (Gibbs *et al.*, 2007; Angelsen *et al.*, 2009). REDD+ requires scientific information for its implementation and political acceptance for the respective region (Gibbs *et al.*, 2007). The first one being the reliable methodologies of measuring carbon in forests, such as allometric equations for measuring aboveground biomass and carbon content. This study has covered most of the information needs for the Matiwane area. A reliable area specific allometric equation was developed for these forests which can be invaluable for future quantification of carbon stocks for incentive based mechanisms.

Carbon inventory data and area estimates on cleared forest are baselines that will need to be also covered. Other information that is essential is the data on carbon emissions resulting from deforestation and degradation for the region or area of interest (Gibbs *et al.*, 2007). This study further quantified, located and reported on cleared forest area and the carbon loss subject to degradation of these forests. A carbon inventory was also created for these forests as such data from this research could potentially be invaluable if the Matiwane forests can be in line for REDD+. Although REDD+ is still in its initial phase (Angelsen, 2009), it can greatly alleviate poverty levels of communities residing near this forests.

5.8 Future projections

From the data generated from this study future projections were made to reflect on the possible future scenarios of the Matiwane forests. Using the current value for the degradation rate of the forests (obtained for the period 1995-2007: 39.8 hectares per year) it is predicted that from 2007 to 2050 a further 1 711 ha would be lost, which is equivalent to 11.5 % of these forests. The data also reveals that it would take close to three and half centuries (374 years) for these forests to be fully cleared at this rate. This prediction is based on the assumption that the rate does not change over the years, but since forest dynamics are never constant or even consistent the projections are constructed solely to create a scenario of the future of these forests based on current estimates, thus no restrictions are held for this projections as they may change with time. In terms of the carbon stocks approximately 0.5 Tg C would be lost during this period (2007-2050). Thus, to trace the change in the rate of clearing constant studies are a necessity in this area.

5.9 Future research

As discussed, the fundamental area that will need most attention is the question on the main causative drivers of forest clearance in this area, as it may determine the success of any restoration initiative, as relapse should be avoided. The carbon sequestration rate of the forests is another aspect that future research may look at and the data from this study can serve as baselines for the studies on carbon sequestration rate. Understanding the carbon sequestration rate (carbon sequestered per year) of these forests may be highly beneficial particularly if the carbon market is the target.

This study has also reflected on the reduction of the number of plant species in these forests, but the loss in forest area also may influence the fauna biodiversity loss as the habitat is converted or destroyed. Castley and Kerley (1996) in discussing the paradox of forest conservation in South Africa also highlighted that forest fragmentation has negative impacts of forest vertebrate population size. As such future research may look into the effect of forest degradation on fauna in order to formulate a proper overall impact of forest degradation on the whole scope of biodiversity loss.

Methodologies employed in this study were time-consuming, labour intensive and expensive. Better methodologies need to be employed for this kind of study such as the application of methods that incorporate the field of remote sensing for the quantification of forest biomass. Although with limited success remote sensing promises to be a better alternative for measuring forest biomass than conventional methods (Namayanga, 2002). Data from this study can provide as ground-truthing opportunity for the development of methods or models incorporating remote sensing for the estimation of aboveground biomass in these forests.

5.10 Recommendations

The South African forest biome is the smallest compared to other biomes (Bredenkamp *et al.*, 1996; von Maltitz *et al.*, 2003). Thus, the loss of any piece of this biome should be avoided. From the results of this study it can be observed that the forests in the Matiwane area are reduced every year in area through clearing by the local communities. Forest protection initiatives in this area in the form of nature reserves and patrolled state forests has managed to reduce the clearing of some of these forests but this has left the communal forests at risk of clearance. Without proper management strategies this communal forests will continue to reduce in size. Thus, effective management strategies will need to be in place to reduce this process of forest clearing which also contributes to net carbon emission of the country. A variety of community based models exist for natural resource management, but they will require time, dedication and financial resources to establish in the region. However, given the forests are cleared for local food security and livelihoods a community-based approach is recommended above fences and fines approach.

As also shown in this study, forests are cleared for agricultural activities. Therefore, to reduce this process, assistance should be considered to help the locals to deal with the low productive soils which are hypothesised to induce clearing. Restoration as pre-outlined above requires agriculture to stop in the respective land while agroforestry allows for agriculture to continue but at the same time allowing for carbon sequestration. As such, it is recommended for other projects that are aimed at regaining carbon in cleared forests that are still in use to adopt a more trade-off prone approach of agro-forestry which may have greater benefits than the restoration initiatives.

5.11 Conclusion

This study becomes the first to report on the impact of forest degradation on the carbon stocks of the Matiwane forests in the coastal area of the Transkei. This study successfully revealed that these forests have suffered some degradation over the years and that they are continuously being degraded resulting in a loss of carbon stocks. Further, about 791 hectares of forest area were cleared from 1942 to 2007. Findings showed that the clearing of these forests is on the increase (currently estimated at 39.8 hectares per year) with the potential to escalate further with the changing climates. Only 5.2% of the forest area was cleared from 1942 to 2007.

This study also created a carbon inventory of these forests, and revealed that forest degradation has reduced carbon stocks in forest pools which included the soil, litter, deadwood, grass and living vegetation pools. Forest degradation from 1942 to 2007 has resulted in the net carbon loss of 0.19 TgC. The current carbon in the forest is estimated at 4.76 TgC, with 4.7 TgC in the intact forests, 0.06 TgC in degraded forests. Approximately 0.02 TgC has been accumulated from the invasion of *Acacia* into the grasslands in the BAA (biomass accumulating areas). As shown in this study, locally forests are being degraded thus there is a need to increase the number of studies that investigate the impact of degradation on the carbon stocks in the Transkei and also the need for interventions to reduce the carbon loss in these areas. This work has taken a step in trying to understand forest degradation and also the carbon dynamics in these forests. Carbon data generated by this study will greatly add to the available carbon data to allow for regional and national carbon estimates for South African forests.

References

Achard, F., Eva, H.D., Mayaux, P., Stibig, H.J. & Belward, A. 2004. Improved estimates of net carbon emissions from land cover change in the tropics for the 1990s. Global Biogeochemical Cycles 18: 1-12.

Ackermann, J., Tshuta, L., Noqobo, D., Nogwina, J., Gaxela, N., Fielding, P. & Jounis, J. 2006. Silaka Nature Reserve: Integrated Reserve Management Plan – Strategic Management Plan. Eastern Cape Parks Board: 1-77.

Addie, H. (unpub.data). Data on forest structure measures of scarp forests in Port St Johns. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M. & Geach, B.G.S. (eds). 2004. Indigenous Forests and Woodlands in South Africa: policy, people and practice. University of KwaZulu-Natal press, South Africa: 41.

AGIS. 2007. Agricultural Geo-Referenced Information System. [Online] Available: www.agis.agric.za. Accessed 15 November 2009.

Albrecht, A. & Kandji, S.T. 2003. Carbon sequestration in tropical agroforestry systems. Agriculture, Ecosystems and Environment 99: 15-27.

Allen, C.D., Macalady, A.K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kizberger, T., Rigling, A., Breshears, D.D., Hogg, E.H., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J.H., Allard, G., Running, S.W., Semerci, A. & Cobb, N. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259 (4): 660-684.

Allen, J.C. 1985. Soil responses to forest clearing in the United States and the Tropics: Geological and Biological factors. Biotropica 17 (1): 15-27.

Allen, J.C. & Barnes, D.F. 1985. The Causes of Deforestation in Developing Countries. Annals of the Association of American Geographers 75 (2): 163-184.

Almendros, G., Zancada, M.C. & Pardo, M.T. 2005. Land use and soil carbon accumulation patterns in South African savanna ecosystems. Biology and Fertility of Soils 41: 173–181.

Andrew, M. 1992. A geographical study of agricultural change since the 1930s in Shixini location, Gatyana District, Transkei. Masters Thesis, Rhodes University, Grahamstown.

Andrew, M. & Fox, R.C. 2004. 'Undercultivation' and intensification in the Transkei: a case study of historical changes in the use of arable land in Nompa, Shixini. Development Southern Africa 21 (4): 687–706.

Angelsen, A., Brockhaus, M., Kanninen, M., Sills, E., Sunderlin, W.D. & Wertz-Kanounnikoff, S. (eds). 2009. Realising REDD+: National strategy and policy options. CIFOR, Bogor, Indonesia.

Antle, J.M. & Diagana, B. 2003. Creating incentives for the adoption of sustainable agricultural practices in developing countries: the role of soil carbon sequestration. American Journal of Agricultural Economics 85: 1178-1184.

Backéus, S., Wikström, P. & Lämås, T. 2005. A model for regional analysis of carbon sequestration and timber production. Forest Ecology and Management 216: 28-40.

Bar, P., Cohen, O. & Shoshany, M. 2004. Invasion rate of the alien species *Acacia saligna* within coastal sand dune habitats in Israel. Israel Journal of Plant Sciences 52 (2): 115-124.

Benhin, J.K.A. 2006. Climate change and South African agriculture: Impacts and Adaptation options. CEEPA Discussion Paper No. 21. Pretoria: 1-114.

Blignaut, J.N., Marais, C. & Turpie, J.K. 2006. Determining a charge for the clearing of invasive alien plant species (IAPs) to augment water supply in South Africa. Water SA 33: 27-34. [Online] Available: http://www.wrc.org.za. Accessed 15 January 2010.

Bredenkamp, G., Granger, J.E. & van Rooyen, N. 1996. Forest Biome. In: Low, A.B. & Rebelo, A.G. (eds). Vegetation of South Africa, Lesotho and Swaziland. Department of. Environmental Affairs and Tourism, Pretoria. [Online] Available:

http://www.ngo.grida.no/soesa/nsoer/Data/vegrsa/vegstart.htm. Accessed 21 October 2008.

Brown, I.F., Martinelli, L.A., Thomas, W.W., Moreira, M.Z., Ferreira, C.A.C. & Victoria, R.A. 1995. Uncertainty in the biomass of Amazonian forests - an example from Rondonia, Brazil. Forest Ecology and Management 75: 175-189.

Brown, J.R. & Carter, J. 1998. Spatial and temporal patterns of exotic shrub invasion in an Australian tropical grassland. Landscape Ecology 13: 93-102.

Brown, S. 1997. Estimating biomass and biomass change of tropical forests. A primer, FAO, Forestry Paper 134. A Forest Resources Assessment Publication, Rome.

Brown, S. 2002. Measuring carbon in forests: current status and future challenges. Environmental Pollution 116 (3): 363-372.

Brown, S. & Gaston, G. 1995. Use of forest inventories and geographic information systems to estimate biomass density of tropical forests: Application to tropical Africa. Environmental Monitoring and Assessment 38 (2-3): 157-168.

Brown, S., Iverson, L.R., Prasad, A. & Liu, D. 1993. Geographic distribution of carbon in biomass and soils of tropical Asian forests. Geocarto International. 8: 45-59.

Brown, S., Sathaye, J., Cannell, M. & Kauppi, P. 1996. Mitigation of carbon emission to the atmosphere by forest management. Commonwealth Forestry Review 75 (1): 80-91.

Brown, S. & Schroeder, P.E. 1999. Spatial patterns of aboveground production and mortality of woody biomass for eastern US forests. Ecological Applications 9: 968-980.

Brown, S.L., Schroeder, P. & Kern, J.S. 1999. Spatial distribution of biomass in forests of the eastern USA. Forest Ecology and Management 123: 81-90.

Cairns, M.A., Haggerty, P.K., Alvarez, R., de Jong, B.H.J. & Olmsted, I. 2000. Tropical Mexico's recent land-use change: a region's contribution to the global carbon cycle. Ecological Applications 10: 1426-1441.

Cairns, M.A., Olmsted, I., Granados, J. & Argaez, J. 2003. Composition and aboveground tree biomass of a dry evergreen forest on Mexico's Yucatan Peninsula. Forest Ecology and Management 186: 125-132.

Carruthers, J. 2002. Environmental History in Southern Africa: An Overview. In: Dowers S., Edgecombe, R. & Guest, B. (eds.) South Africa's Environmental History: Cases and Comparisons. David Philip, Cape Town: 3-15.

Castley, J.D. & Kerly, G.I.H. 1996. The paradox of forest conservation in South Africa. Forest Ecology and Management 85: 35-46.

Cawe, S.G. 1986. A quantitative and qualitative survey of the inland forests of Transkei. Masters thesis. University of Transkei, Umtata.

Cawe, S.G. & Geldenhuys, C.J. 2007. Resource status and Population dynamics of target species in Natural forests of the Port St Johns Forest Estate: A basis for sustainable resource use. Report for Project 2006-397, Directorate: Forestry Technical Services, Department of Water Affairs and Forestry, Pretoria: 102.

Chambers, J.Q., Santos, J., Ribeiro, R.J. & Higuchi, N. 2001. Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest. Forest Ecology and Management 152: 73-84.

Cooper, J.J., Fleming, G.J., Malungani, T.P. & Missehorn. 2004. Ecosystem services in Southern Africa: A regional assessment. Scholes, R.J & Biggs, R. (eds). Council for Scientific and Industrial research, Pretoria: 18.

Cooper, K.H. & Swart, W. 1992. Transkei forest survey. Wildlife Society of southern Africa, Durban: 96.

Cowling, R.M. 2002. Perspectives on the tree richness of South Africa's forests. Veld and Flora 88: 48-49.

Cunningham, A.B. 1989. Indigenous plant use: Balancing human needs and resources. In: Huntley, B.J. (ed). Biotic Diversity in Southern Africa: concepts and conservation. Oxford University press, Cape Town: 93-106.

DEAT. 1997. White paper on the conservation and sustainable use of South Africa's biological diversity. Department of Environmental Affairs and Tourism, Pretoria.

DEAT. 2000. White Paper for Sustainable Coastal Development in South Africa. Chief Directorate: Marine and Coastal Management, Department of Environmental Affairs and Tourism, Pretoria.

DEAT. 2004. A national climate change response strategy for South Africa. Department of Environmental Affairs and Tourism, Pretoria.

DeFries, R., Achard, F., Brown, S., Herold, M., Murdiyarso, D., Schlamandiger, B. & de Souza Jr, C. 2007. Earth observations for estimating greenhouse gas emissions from deforestation in developing countries. Environmental Science and Policy 10 (4): 385-394.

De Jong, B., Ochoa-Gaona, S., Castillo-Santiago, M., Ramirez-Marcial, N. & Carins, A. 2000. Carbon flux and patterns of land-use/land-cover change in the Selva Lacandona, Mexico. Ambio 29 (8): 504-511.

DME. 2003. South Africa National Energy Balance 2001. Department of Minerals and Energy, Pretoria.

Desanker, P.V., Frost, P.G.H., Justice, C.O. & Scholes, R.J. (eds). 1995. The Miombo Network: Framework for a Terrestrial Transect Study of Land-Use and Land-Cover Change in the Miombo Ecosystems of Central Africa. IGBP REPORT 41. Stockholm, Sweden.

DWAF. 2005. Systematic conservation planning for the forest biome of South Africa. Department of Water Affairs and Forestry, Pretoria.

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C. & Wisniewski, J. 1994. Carbon pools and flux of global forest ecosystems. Science 263: 185-190.

Eeley, H.A.C., Lawes, M.J. & Piper, S.E. 1999. The influence of climate change on the distribution of indigenous forest in KwaZulu-Natal, South Africa. Journal of Biogeography 26: 595-617.

ESRI. 2006. Desktop GIS for mapping, data integration and analysis. Redlands, California.

Fang, J., Chen, A., Peng, C., Zhao, S. & Ci, L. 2001. Changes in forest biomass carbon storage in China between 1949 and 1998. Science 22: 2320-2322.

Fang, S., Tang, L. & Xue, J. 2006. Biomass production and carbon sequestration potential in poplar plantations with different management patterns. Journal of Environmental Management 85: 672-679.

FAO. 1997. Estimating biomass and biomass change in tropical forests. FAO Forestry Paper 134: 55.

FAO. 2004. Carbon sequestration in dryland soils. World soil resources report 102.

FAO. 2005. State of the World's Forests. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2006. Global Forest Resources Assessment 2005: Progress towards sustainable forest management. FAO Forestry Paper: 320.

FAO. 2007. State of the World's Forests 2007. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2009a. Case studies on measuring and assessing forest degradation, Addressing forest degradation in the context of joint forest management in Udaipur India. Forest Resources Assessment Working Paper 157, Italy.

FAO. 2009b. State of the World's Forests 2009. Food and Agriculture Organization of the United Nations, Rome.

FAO newsroom. 2006. Forests and climate change, Better forest management has key role to play in dealing with climate change. [Online] Available: http://www.fao.org/newsroom/en/focus/2006/1000247/index.html: Accessed 15 May 2010.

Fay, D. 2003. "The Trust Is Over! We Want to Plough!": Land, livelihoods and reverse resettlement in South Africa's Transkei. Phd thesis, Boston University, Massachusetts.

Fay, D. 2009. Land Tenure, Land Use and Land Reform at Dwesa-Cwebe, South Africa: Local Transformations and the Limits of the State. World Development 37 (8): 1424-1433.

Fearnside, P.M. 2000. Global warming and tropical land-use change: Greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. Climatic Change 46: 115-158.

Feely, J.M. 1986. The distribution of Iron Age farming settlement in Transkei: 470 to 1870. Masters thesis, University of Natal, Pietermaritzburg.

Geldenhuys, C.J. 1991. Distribution, size, and ownership of forests in the southern Cape. South African Forestry Journal 158: 51-66.

Geldenhuys, C.J. 1994. Bergwind fires and the location pattern of forest patches in the southern Cape landscape, South Africa. Journal of Biogeography 21: 49-62.

Geldenhuys, C.J. 2007. Growth, ingrowth and mortality patterns over stands and species in the Manubi forest growth study site, Eastern Cape Province: Report on 2006 measurements. Report FW-01/07, FORESTWOOD cc, Pretoria: 22.

Geldenhuys, C.J. & Rathokgwa, N.R. 1995. Growth and mortality patterns over stands and species in the Manubi forest growth study site: Report on 1995 measurements. Report FOR-DEA 943. CSIR, Division of Forest Science and Technology, Pretoria.

Giardina, C.P., Sanford, R.L. & Døckersmith, I.C. 2000. Changes in Soil phosphorus and nitrogen during slash and burn clearing of a dry tropical forest. Soil Science Society of America Journal 64: 399-405.

Gibbs, H.K., Brown, S., Niles, J.O. & Foley, J.A. 2007. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environmental research letters 2: 1-13.

Ghazoul, J., Butler, R.A., Mateo-Vega, J. & Pin Koh, L. 2010. REDD: A reckoning of environment and development implications. Trends in Ecology and Evolution 25 (7): 396-402.

Glenday, J. 2007. Carbon Storage and Sequestration Analysis for the eThekwini Environmental Services Management Plan Open Space System. Report for the eThekwini Municipality Environmental Management Department, South Africa.

Goetz, A.F.H. 2009. Three decades of hyperspectral remote sensing of the Earth: A personal view. Remote Sensing of Environment 113 (1): S5-S16.

Gregoire, T.G., Zedaker, S.M. & Nicholas, N.S. 1989. Modeling relative error in stem basal area estimates. Canadian Journal of Forest Research 20: 496-502.

Grünzweig, J.M., Sparrow, S.T. & Chapin, F.S. 2003. Impact of forest conversion to agriculture on carbon and nitrogen mineralization in subarctic Alaska. Biogeochemistry 64: 271-296.

Guo, L.B & Gifford, R.M. 2002. Soil carbon stocks and land use change: meta analysis. Global Biology 8 (4): 345-360.

Gurney, K.R., Law, R.M., Denning, A.S., Rayner, P.J., Baker, D., Bousquet, P., Bruhwiler, L., Chen, Y.H., Ciais, P., Fan, S., Fung, I.Y., Gloor, M., Heimann, M., Higuchi, K., John, J., Maki, T., Maksyutov, S., Masarie, K., Peylin, P., Prather, M., Pak, B.C., Randerson, J., Sarmiento, J., Taguchi, S., Takahashi, T. & Yuen, C.W. 2002. Towards robust regional estimates of CO_2 sources and sinks using atmospheric transport models. Nature 415: 626-630.

Hadju, F. 2009. Questioning homogenous degradation narratives in Transkei: Livelihoods and natural resource use in two Pondoland villages. In: Guyot, S. & Dellier, J. (eds). Rethinking the Wild coast, South Africa: Eco-frontiers vs livelihoods in Pondoland. VDM Verlag: 129-161.

Hoffman, M.T. & Todd, S. 2000. A National Review of Land Degradation in South Africa: the Influence of Biophysical and Socio-economic Factors. Journal of Southern African Studies 26 (4): 754-758.

Horning, N. 2008. Remote sensing. Encyclopedia of ecology: 2986-2994.

Houghton, R. A. & Skole, D.L. 1990. Carbon in the earth as transformed by human action. Cambridge University Press, Cambridge: 393-408.

http://wbcarbonfinance.org/Router.cfm?Page=Projport&ProjID=9644. Accessed: 02 August 2010.

Hughes, R.F., Kauffman, J.B. & Victor, J.J. 2000. Ecosystem-scale impacts of deforestation and land use in a humid tropical region of Mexico. Ecological Applications 10 (2): 515-527.

Hutchins, D.E. 1903. Transvaal forest report. Government Printer. Pretoria.

IPCC. 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, vol. 3. Cambridge University Press, Cambridge: 1-74.

IPCC. 2000. Land use, land-use change, and forestry. A Special Report of the IPCC. Cambridge University Press, Cambridge: 377.

IPCC. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H.S., Buendia, L., Miwa, K., Ngara,T & Tanabe, K. (eds). Institute For Global Environmental Strategies, Japan.

Ite, U.E. & Williams, W.M. 1998. Forest conversion, conservation and forestry in Cross River State, Nigeria. Applied Geography 18 (4): 301-314.

Jindal, R. 2006. Carbon sequestration in Africa: Potential benefits and challenges to scaling up. Featured in Earthtrends. [Online] Available: http://earthtrends.wri.org/pdf_library/feature/cli_fea_csequest.pdf.

Kaitaniemi, P. 2004. Testing allometric scaling laws. Journal of Theoretical Biology 228: 149-153.

Kajimoto, T., Matsuura, Y., Osawa, A., Abaimov, A.P., Zyryanova, O.A., Isaev, P., Yefremov, P.D., Mori, S. & Koike, T. 2005. Size–mass allometry and biomass allocation of two larch species growing on the continuous permafrost region in Siberia. Forest Ecology and Management 222 (1-3): 314-325.

Kalogirou, S. 2002. Expert systems and GIS: An application of land suitability evaluation computers. Environment and Urban Systems 26 (2002): 89-112.

Kauffman, B.J., Cummings, D.L., Ward, D.E. & Babbitt, R. 1995. Fire in the Brazilian Amazon: Biomass, nutrient pools, and losses in slashed primary forests. Oecologia 104: 397-408.

Kepe, T. 2001. Clearing the ground in the Spatial Development Initiatives (SDIs): analysing 'process' on South Africa's Wild Coast. Development Southern Africa 18 (3): 279-293.

Kerr, J.T. & Ostrovsky, M. 2003. From space to species: ecological applications for remote sensing. Trends in Ecology and Evolution 18 (6): 299-304.

Kettering, M.Q., Coe, R., van Noordwijk, M., Ambagau, Y. & Palm, C.A. 2001. Reducing uncertainty in the use of allometric equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and Management 146: 199-209.

Khasnis, A.A. & Nettleman, M.D. 2005. Global Warming and Infectious Disease. Archives of Medical Research 36 (6): 689-696.

King, N.L. 1941. The exploitation of the indigenous forests of South Africa. Journal of the South African Forestry Association 6: 26-48.

King Sabata Dalinyebo Local Municipality. 2002. Intergrated Development Plan.

Kirby, K.R. & Potvin, C. 2007. Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. Forest Ecology and Management 246: 208-221.

Kotto-samme, J., Woomer, P.L., Appolinaire, M. & Louis, Z. 1997. Carbon dynamics in slash and burn agriculture and land use alternatives of the humid forest zone in Cameroon. Agriculture, Ecosystems and Environment 65 (3): 245-256.

Lal, R. 2005. Forest soils and carbon sequestration. Forest Ecology and Management 220: 242-258.

Lal, R., Kimble, L.M. & Follett, R.F. 2003. Achieving soil carbon sequestration in the United States: challenges to the policy markers. Soil Science 168: 827-845.

Lal, R., Kimble, L.M., Follett, R.F. & Cole, C.V. 1998. The Potential of US Cropland to Sequester C and Mitigate the Greenhouse Effect. Annual Arbor Press, Chelsea: 108.

Lamlom, S.H. & Savidge, R.A. 2003. A reassessment of carbon content in wood: variation within and between 41 North American species. Biomass and Bioenergy 25: 381-388.

Lasco, R.D. 2002. Forest carbon budgets in Southeast Asia following harvesting and land cover change. Science in China Series C (45): 55-64.

Laughton, F.S. 1937. The silviculture of the indigenous forests of the Union of South Africa with special reference to the forests of the Knysna Region. In: Science Bulletin 57, Forestry Series No. 7. Department of Agriculture and Forestry. Government Printer, Pretoria: 169.

Lawes, M.J, Mealin, P.E. & Piper, S.E. 2000. Patch occupancy and potential metapopulation dynamics of three forest mammals in fragmented Afromontane forest in South Africa. Conservation Biology 14: 1088-1098.

Lawes, M.J., Obiri, J.A.F. & Eeley, H.A.C. 2004. The use of indigenous forest resources in South Africa. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M. & Geach, B.G.S. (eds). Indigenous Forests and Woodlands in South Africa: policy, people and practice. University of KwaZulu-Natal press, South Africa: 227-273.

Lawson, T., Gillieson, D. & Goosem, M. 2006. Assessment of Riparian Rainforest Vegetation Change in Tropical North Queensland for Management and Restoration Purposes. Geographical Research 45 (4): 387-397.

Lecocq, F. 2004. State and Trends of the Carbon Market 2004. Development Economics Research Group, World Bank, Washington, DC. [Online] Available: http://carbonfinance.org/docs/CarbonMarketStudy2004.pdf. Accessed: 30 Septermber 2009.

Lefsky, M.A., Harding, D., Cohen, W.B., Parker, G. & Shugart, H.H. 1999. Surface Lidar Remote Sensing of basal area and biomass in deciduous forests of Eastern Maryland, USA. Remote Sensing of Environment 67: 83-98.

Lowe, A.J. & Clarke, G.P. 2000. Vegetation structure. In: Burgess, N.D. & Clarke, G.P. (eds). Biogeography and ecology of the rain forests of Eastern Africa. Cambridge: IUCN/The World Conservation Union: 103-114.

Lubke, R. 2001. Landscape and vegetation. In: Batten, A. & Bokelmann, H. Eastern Cape: South African wild flower guide 11. Botanical Society of South Africa: 13-28.

Lubowski, R.N., Plantinga, A.J. & Stavins, R.N. 2006. Land-use change and carbon sinks: Econometric estimation of the carbon sequestration supply function. Journal of Environmental Economics and Management 51: 135-152.

Lückhoff, H.A. 1973. The story of forestry and its people . In: Immelman, W.F.E., Wicht, C.L. & Ackerman, D.P. (eds). Our Green Heritage. Tafelberg, Cape Town: 20-32.

Maltamo, M., Suvanto, A. & Packalén, P. 2007. Comparison of basal area and stem frequency diameter distribution modelling using airborne laser scanner data and calibration estimate. Forest Ecology and Management 247 (1-3): 26-34.

Mansourian, S., Vallauri, D. & Dudley, N. (eds). (in co-operation with WWF International). 2005. Forest restoration in landscapes: Beyond planting trees. Springer, New York: 1-45.

Marcus, T., Eales, K. & Wildchut, A. 1996. Down to earth; land demand in the new South Africa. Indicator press. Johannesburg, South Africa: 150.

Masiso, S. 2008. Personal communication. Resident of Mankosi village.

Matose, F. 2009. Knowledge, power, livelihoods and commons practices in Dwesa-Cwebe, South Africa. Development Southern Africa 26: 627-637.

Mbhashe Local Municipality. 2006. Intergraded Development Plan.

Mbete, M., Mbandezi, S.W., Ncisana, K.A., Khumalo, C.S., Maggutia, Z.E., Mapukata, R.S., Geya, J., Ntisana, L., Mqiugwana, C.B., Nomlona, M., Masimini, N., Ntsuntswana, V., Jali, K., Venter, J., Fielding, P. & Begbie, R. 2006. Dwesa-Cwebe Nature Reserve: Integrated Reserve Management Plan - Strategic Management Plan. Eastern Cape Parks Board.

McCann, J. 1999. Green land, brown land, black land. An Environmental History of Africa, 1800-1990. James Currey, London.

McCracken, D.D. 2004. Dependence, destruction and development: A history of indigenous timber use in South Africa. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M. & Geach, B.G.S. (eds). Indigenous Forests and Woodlands in South Africa: policy, people and practice. University of KwaZulu-Natal press, South Africa: 277-281.

McKenzie, B. 1984. Ecological considerations of some past and present land practices in Transkei. Phd thesis, University of Cape Town, Cape Town.

Mills, A.J. & Cowling, R.M. 2006. Rate of carbon sequestration at two thicket restoration sites in the Eastern Cape, South Africa. Restoration Ecology 14 (1): 38-49.

Mills, A., O'Connor, T., Skowno, A., De Wet B., Donaldson, J., Lechmere-Oertel, A. & Sigwela, A. 2003. Farming for carbon credits: implications for land use decisions in

South African rangelands. Proceedings of the VIIth International Rangelands Congress: 1548-1554.

Mitchell, J.F.B., Johns, T.C., Gregory, J.M. & Tett, S.F.B. 2002. Climate response to increasing levels of greenhouse gases and sulphate aerosols. Nature 376: 501–504.

Montagu, K.D., Düttmer, K., Barton, C.M.V. & Cowie, A.L. 2005. Developing general allometric relationships for regional estimates of carbon sequestration - an example using *Eucalyptus pilularis* from seven contrasting sites. Forest Ecology and Management 204: 113–127.

Mucina, L., & Rutherford, M.C. (eds). 2006. The vegetation of South Africa, Lesotho and Swaziland. South African National Biodiversity Institute, Pretoria. Strelitzia 19: 586-610.

Mukkonen, P. 2007. Generalized allometric volume and biomass equations for some tree species in Europe. European Journal of Forest Research 126:157–166.

Murty, D., Kirschbaum, U.F., Mcmurtrie, E. & Mcgilvray, H. 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Global Change Biology 8 (2): 105-123.

Mwakasonda, S. & Winkler, H. 2005. Carbon capture and storage in South Africa. In: Bradley, R., Baumert, K. & Pershing, J. (eds). Growing in the greenhouse: Protecting the climate by putting development first. World Resources Institute, Washington DC: 94-109.

Namayanga, N. 2002. Estimating terrestrial carbon sequestered in aboveground woody biomass from remotely sensed data: the use of SEBAL and CASA algorithms in a semi arid area of Serowe Botswana. Masters thesis, International Institute for Geo-Information Science and Earth Observation (ITC), Enschede, Netherlands.

Naughton-Treves, L. 2004. Deforestation and Carbon Emissions at Tropical Frontiers: A Case Study from the Peruvian Amazon. World Development 32 (1): 173-190.

NER. 2002. Electricity Supply Statistics for South Africa 2002. National Electricity Regulator, Pretoria. [Online] Available: www.ner.org.za/publs.htm. Accessed: 15 January 2010.

Netshiluvhi, T. & Scholes, R.J. 2001. Allometry of South African woodland trees. Report ENV-P-I 2001-007, CSIR, Pretoria.

Niklas K. 1994. Plant allometry. The scaling of form and process. University of Chicago Press, Chicago.

Niklas, K.J. & Spatz, H. 2006. Allometric theory and the mechanical stability of large trees: proof and conjecture. American Journal of Botany 93 (6): 824-828.

Niu, X. & Dieker, S.W. 2005. Carbon sequestration potential by afforestation of marginal agriculture in the Midwestern U.S. Forest Ecology and Management 223 (1-3): 415-427.

Noss, R.F. 1999. Assessing and monitoring forest biodiversity: A suggested framework and indicators. Forest Ecology and Management 115: 135-146.

Ntshotsho, P. 2006. Carbon sequestration on the subtropical dunes of South Africa: a comparison between native regenerating ecosystems and exotic plantations. Masters thesis, University of Pretoria, Pretoria.

Nyandeni Local Municipality. 2006. Intergrated Development Plan.

Nye, P. & Greenland, D. 1960. The soil under shifting cultivation. Commonwealth Bureau of Soils, Harpenden, Commonwealth Agricultural Bureaux, England. Technical Communication 51. In: Giardina, C.P., Sanford, R.L. & Døckersmith, I.C. Changes in Soil Phosphorus and Nitrogen During Slash and Burn Clearing of a Dry Tropical Forest. Soil Science Society of America Journal 64: 399-405.

Obiri, J. & Lawes, M. 2004. Chance versus determinism in canopy gap regeneration in coastal scarp forest in South Africa. Journal of Vegetation Science 15 (4): 539-547.

Obiri, J., Lawes, M. & Mukolwe, M. 2002. The dynamics and sustainable use of high-value tree species of the coastal Pondoland forests of the Eastern Cape Province, South Africa. Forest Ecology and Management 166 (1-3): 131-148.

O'Connor, T.G. 1995. *Acacia karroo* invasion of grassland: Environmental and biotic effects influencing seedling emergence and establishment. Oecologia 103 (2): 214-223.

Oelbermann, M., Voroney, R.P. & Gordon, A.M. 2004. Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada. Agriculture, Ecosystems & Environment 104 (3): 359-377.

Ordónez, J.A.B., de Jong, B.H.J., Garcia-Olvia, F., Avina, F.L., Perez, J.V., Guerrero, G. & Masera, O. 2008. Carbon content in vegetation, litter, and soil under 10 different land-use and land-cover classes in the Central Highlands of Michoacan, Mexico. Forest Ecology and Management 255: 2074-2084.

OR Tambo District Municipality. 2009. Intergrated Development Plan.

Oslo Climate and Forestry Conference. 2010. Agreement on financing and quick-start measures to protect rainforest. [Online] Available: www.oslocfc2010.no. Accessed: 15 May 2010.

Palmer, R. 2003. From title to entitlement: the struggle continues at Dwesa-Cwebe. The Eastern Cape historical legacies and challenges conference 2003. Fort Hare Institute of Social and Economic Research, Working Paper 46: 1-22.

Palmer, B. 2009. A GIS assessment of development and land use change in the coastal zone of the Ndlambe and Ngqushwa local municipalities, Eastern Cape, South Africa. Masters thesis, Rhodes University, Grahamstown.

Pandey, D.N. 2002. Carbon sequestration in agroforestry systems. Climate policy 2 (4): 367-377.

Patz, J.A., Campbell-Lendrum, D., Holloway, T. & Foley, J.A. 2005. Impact of regional climate change on human health. Nature 438: 310-317.

Perez, C., Roncoli, C., Neely, C. & Steiner, J.L. 2005. Can carbon sequestration markets benefit low-income producers in semi-arid Africa? Potentials and challenges. Agricultural Systems 94: 2-12.

Phillips, J. 1963. The forest of George, Knysna, Zitzikama. A brief history of their management. Government printer. Pretoria: 1778-1939.

Pilli, P., Anfodillo, T., Carrer, M. 2006. Towards a functional and simplified allometry for estimating forest biomass. Forest Ecology and Management 237: 583-593.

Port St. Johns Local Municipality. 2009. Intergraded development plan.

Powell, M.J. 2009. Restoration of degraded subtropical thickets in the Baviaanskloof Megareserve, South Africa: The role of carbon stocks and *Portulacaria afra* survivorship. Masters Thesis, Rhodes University, Grahamstown.

Powell, M.J., Mills, A.J. & Marais, C.M. 2006. Carbon sequestration and restoration: challenges and opportunities in subtropical thicket. Proceedings of Natural Forests and Woodlands Savanna Symposium IV. Port Elizabeth: 214-223.

Prentice, I.C., Farquhar, G.D., Fasham, M.J.R., Goulden, M.L., Heimann, M., Jaramillo, V.J., Kheshgi, H.S., Le Que're', C., Scholes, R.J. & Wallace, D.W.R. 2001. The carbon cycle and atmospheric carbon dioxide. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. & Johnson, C.A. (eds.).The Scientific Basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK: 183-237.

Ravindranath, N.H. & Ostwald, M. 2008. Carbon inventory methods: Handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects. Springer, London. Advances in global change research 29.

Redondo-Brenes, A. & Montagnini, F. 2006. Growth, productivity, aboveground biomass, and carbon sequestration of pure and mixed native tree plantations in the Caribbean lowlands of Costa Rica. Forest Ecology and Management 232: 168-178.

Restoration Research Group (R3G). 2010. Matiwane Forest Restoration Programme. [Online] Available: http://www.r3g.co.za/index.php?p=coreprojects&pr=matiwane.

Robertson, S.S. 1924. The forests of South Africa. Empire Forestry Review 3: 99-121.

Rodgers, W.A. 1997. Patterns of loss of forestry biodiversity - a global perspective. Antalya, Turkey. XI World Forestry Congress 2 (7): 21-170.

Rutherford. M. C., Midgley, G. F., Bond, W.J., Powrie, L.W., Roberts, R. & Allsopp, L. 1999. Plant Biodiversity: Vulnerability and adaptation assessment. South African Country Study on Climate Change. Cape Town, South Africa: 1-34.

Rutherford, M.C. & Westfall, R.H. 1986. Biomes of southern Africa - an objective categorization. . Memoirs of the Botanical Survey of South Africa 54: 1-98.

SANBI & DEAT. 2009. Threatened Ecosystems in South Africa: Descriptions and Maps. DRAFT for Comment. South African National Biodiversity Institute. Pretoria, South Africa.

Sánchez, P.A. 2000. Linking climate change research with food security and poverty reduction in the tropics. Agriculture, Ecosystems & Environment 82: 371-383.

Sankhayan, P.L., Gurung, N., Sitaula, B.K. & Hofstad, O. 2002. Bio-economic modeling of land use and forest degradation at watershed level in Nepal. Agriculture, Ecosystems & Environment 94 (1): 105-116.

Scholes, R.J. 2004. Carbon storage on South African woodlands. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M. & Geach, B.G.S. (eds). Indigenous Forests and Woodlands in South Africa. University of KwaZulu-Natal press, South Africa: 797-813.

Scholes, R.J. & Netshiluvhi, T. 2000. New approaches to estimating the biomass of woodlands. In: Seydack, A.H.W., Vermeulen W.J., & Vermeulen, C. Towards sustainable management based on scientific understanding of natural forests and woodlands. Natural forests and Savanna woodlands symposium 11. Knysna, South Africa: 139-141.

Schulze, R.E. 1997. South African atlas of agrohydrology and climatology. Water Resources Commission, Report TT82/96. Pretoria, South Africa.

Sedjo, A.R., Sohngen, B. & Jagger, P. 1998. Carbon Sinks in the Post-Kyoto World. Internet edition. RFF Climate Issue Brief 12.

Seydack, A.H.W. 2000. Theory and practice of yield regulation systems for sustainable management of tropical and subtropical moist natural forests. In: von Gadow, K, Pakkala,

T. & Rome, M. (eds). Sustainable forest Management. Dordrecht: Kluwer Academic publishers: 257-317.

Shackleton, C.M. 2009. Will the real custodian of natural resource management please stand up?. South African Journal of Science 105: 91-93.

Shackleton, C.M. & Scholes, R.J. (in press). Aboveground woody community attributes and carbon stocks along a rainfall gradient in the savannas of the central lowveld, South Africa. South African Journal of Botany.

Shackleton, C.M., Shackleton, S.E., Buiten, E. & Bird, N. 2007a. The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. Forest Policy and Economics 9 (5): 558-577.

Shackleton, C.M., Timmermans, H.G., Nongwe, N., Hamer, N. & Palmer, R. 2007b. Direct-use values of non-timber forest products from two areas on the Transkei Wild Coast. Agrekon 46: 135-156.

Shearman, P.L., Ash, J., Mackey, B., Bryan, J.E & Lokes, B. 2009. Forest Conversion and Degradation in Papua New Guinea 1972-2002. Biotropica 41 (3): 379-390.

Shvidenko, A. 2008. Deforestation. Encyclopedia of Ecology: 853-859.

Silander, J.A Jr. 2001. Temperate forests: Plant species biodiversity and conservation. In: Levin, S.A. (ed). Academic Press. San Diego. Encyclopedia of Biodiversity 5: 607–626.

Sim, T.R. 1907. The forests and forest flora of the Cape of Good Hope. Taylor and Henderson , Aberdeen.

Simukonda, N. & Kraai, M. 2009. The Wild Coast: the Contested Territory. In: Guyot, S & Dellier, J. (eds). Rethinking the Wild coast South Africa: Eco-frontiers vs livelihoods in Pondoland. VDM Verlag: 129-161.

Song, C. & Woodcock, C.E. 2003. Regional forest ecosystem carbon budget model: impacts of forest age structure and landuse history. Ecological Modelling 164: 33-47.

South Africa's National Biodiversity Strategy and Action Plan. 2005. Department of Environmental Affairs and Tourism, Pretoria.

Taiz, L. & Zeiger, E. 2006. Plant physiology. 4th ed. Sinauer Associates, Inc. Sunderland.

Takimoto, A., Ramachandran, P.K. & Nair, V. 2008. Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel. Agriculture, Ecosystems and Environment 125 (4): 159-166.

Tanser, F. & Palmer, A.R. 1999. Vegetation mapping of the Great Fish River basin, South Africa: Integrating spatial and multi-spectral remote sensing techniques. Applied Vegetation Science 3: 197-204.

Taylor, T. 2009. Climate change, development and energy problems in South Africa: another world is possible. Earthlife Africa and Oxfarm International, Johannesburg, South Africa.

Tett, S.F.B., Stott, P.A., Allen, M.R., Ingram, W.J. & Mitchell, J.F.B. 1999. Causes of twentieth-century temperature change near the earth's surface. Nature 399: 569-572.

Tiessen, H. 1998. Resilience of phosphorus transformations in tropical forest and derived ecosystems. In: Schulte, A & Ruhiyat, D. (eds). Soils of tropical forest ecosystems: characteristics, ecology and management. Springer-Verlag, Berlin Heidelberg. Germany: 92-98.

Timmermans, H.G. 2004. Rural livelihoods at Dwesa/Cwebe: poverty, development and natural resource use on the Wild Coast, South Africa. Masters thesis, Rhodes University, Grahamstown.

Tole, L. 1998. Sources of Deforestation in Tropical Developing Countries. Environmental Management 22 (1): 19-33.

Tschakert, P., Oliver, T.C. & Potvin, C. 2007. Indigenous livelihoods, slash and burn agriculture, and carbon stocks in Eastern Panama. Ecological Economics 60: 807-820.

Turpie, J., Winkler, H., Spalding-Fecher, R. & Midgley, G. 2002. Economic impacts of climate change in South Africa: a preliminary analysis of unmitigated damage costs. Energy and Development Research Centre, University of Cape Town, Cape Town: 1-58.

Twine, W., Siphugu, V. & Moshe, D. 2003. Harvesting of communal resources by 'outsiders' in rural South Africa: a case study of xenophobia or a real threat to sustainability? International Journal of Sustainable Development and World ecology 10: 263-274.

UNFCCC. 2008. Report of the Conference of the Parties on its thirteenth session. Addendum, Part 2. Document FCCC/CP/2007/6/Add.1. UNFCCC, Bonn, Germany.

UNFCCC. 2009. Approved simplified baseline and monitoring methodology for small-scale agroforestry - afforestation and reforestation project activities under the clean development mechanism. AR-AMS0004 / Version 02, Sectoral Scope 14.

Vagen, T. 2006. Remote sensing of complex land use change trajectories - a case study from the highlands of Madagascar. Agriculture, Ecosystems and Environment 115: 219-228.

van Wyk, V. (unpub.data). Data on forest structure measures of scarp forests in Dlinza. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M & Geach, B.G.S. (eds). 2004. Indigenous Forests and Woodlands in South Africa: policy, people and practice. University of KwaZulu-Natal press, South Africa: 41.

von Maltitz, G., Mucina, L., Geldenhuys, C.K., Lawes, M.J., Eeley, H. & Adie, H. 2003. Classification system for South African indigenous forest: An objective classification for the Department of Water Affairs and Forestry. Council for Scientific and Industrial Research, Environmentek. Pretoria.

von Maltitz, G. & Shackleton, S.E. 2004. Use and management of forests and woodlands in South Africa: stakeholders, institutions and processes from past to present. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M. & Geach, B.G.S. (eds). Indigenous Forests and Woodlands in South Africa: policy, people and practice. University of KwaZulu-Natal press, South Africa: 109-135.

Wauters, J.B., Coudert, S., Grallien, E., Jonard, M. & Ponette, Q. 2008. Carbon stock in rubber tree plantations in Western Ghana and Mato Grosso, Brazil. Forest Ecology and Management 225 (7): 2347-2361.

West, G.B., Brown, J.H. & Enquist, B.J. 1999. A general model for the structure and allometry of plant vascular systems. Nature 400: 664-667.

White, R.H. 2004. People and forest fauna: A case study from the dune forest in the Transkei region of the Eastern Cape. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M & Geach, B.G.S. (eds). Indigenous Forests and Woodlands in South Africa: policy, people and practice. University of KwaZulu-Natal press, South Africa: 553-573.

Willis, C.B. 2004. Policy Frameworks Pertaining to the Conservation and Sustainable use of Forests and Woodlands in South Africa. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M. & Geach, B.G.S. (eds). Indigenous Forests and Woodlands in South Africa: policy, people and practice. University of KwaZulu-Natal press, South Africa: 77-105.

Wood, P.C. & van Schoor, N.M. 1976. The agricultural potential of Transkei. Department of Bantu Administration. Pretoria.

Woodbury, B.P., Smith, J.E. & Heath, L.S. 2006. Carbon sequestration in the US forest sector from 1990 to 2010. Forest Ecology and Management 241: 14-27.

World Conservation Monitoring Centre. 1992. "Development of a National Biodiversity Index." Global Biodiversity: Status of the Earth's Living Resources. Chapman & Hall, London.

World Resources Institute. 2006. Climate and Atmosphere - CO2: Total emissions. Climate and Atmosphere - CO2: Emissions per capita. [Online] Available: http://earthtrends.wri.org. Accessed: 30 November 2009.

Yazini, V., Nompe, B., Peter, P., Landule, N., Yolwa, B., Ngwevu, M., Gwadiso, L., Fielding, P. & Jounis, J. 2006. Hluleka Nature Reserve: Integrated Reserve Management Plan – Strategic Management Plan. Eastern Cape Parks Board.

Zianis, D. 2008. Predicting mean aboveground forest biomass and its associated variance. Forest Ecology and Management 256 (6): 1400-1407.

Zianis, D. & Mencuccini, M. 2004. On simplifying allometric analysis of forest biomass. Forest Ecology and Management 187: 311-332.

Zianis, D., Muukkonen, P., Mäkipää, R. & Mencuccini, M. 2005. Biomass and stem volume equations for tree species in Europe. Silva Fennica Monographs (4): 1-63.

Zheng, D., Rademacher, J., Chen, J., Crow, T., Bresee, M., Le Moine, J. & Ryu, S. 2004. Estimating aboveground biomass using Landsat 7 ETM+ data across a managed landscape in northern Wisconsin, USA. Remote Sensing of Environment 93: 402-411.

Zheng, H., Ouyang, Z., Xu, W., Wang, X., Miao, H., Li, X. & Tian, Y. 2007. Variation of carbon storage by different reforestation types in the hilly red soil region of southern China. Forest Ecology and Management 255: 1113-1121.

APPENDIX

Appendix 1: Examples of funded land cover based carbon emissions offset projects (Jindal, 2006).

Project title	Host country	Investor	Funds invested	Project years	Nature of benefit sharing
Participatory rehabilitation of degraded lands	Mauritania And senegal	GEF,AfricanDev. Bank, UNDP, National Govt.	GEF=$7.996 million;co-finance-$4.370 million	2000-present	All benefits belong to community. Carbon credits not claimed.
Community-based rangeland rehabilitation for carbon sequestration	Sudan	GEF	GEF $1.5 million;co-finance-$0.085 million	n.a	All benefits including timber and NTFPs belong to local community.
Village-based management of woody savanna and establishment of woodlots for carbon sequestration	Benin	GEF	$2.5 million	n.a	Woodlots with all products belong to local community. Information on carbon offsets n.a.
Sustainable energy management project	Burkina Faso	World bank, Govt. of Norway,DANIDA	n.a	1997-2003	Carbon offsets with World Bank. All other benefits with local community.
Forest rehabilitation in Mt.Elgon and kibale national parks	Uganda	FACE foundation	n.a	1994-present	Carbon offsets with World Bank. All other benefits with local community.
Nhambita community carbon project	Mozambique	European Union	n.a	2003-present	Carbon rights with implementing organizations. All others with local community
Western Kenya	Kenya	GEF,Co-financed by	GEF-$4.1	2005-	Local community to get

integrated ecosystem management projects		national Govt, Japan PHRD	million; Co-finance-$2.7 million	present	all timber and NTFP benefits. Carbon rights yet to be worked out.
Sequestration of carbon in soil organic matter	Senegal	USAID	n.a	1999-?	All benefits with local community. Carbon rights not traded.
Carbon from communities	Mali	NASA	$0.14 million	2002-2005	All benefits with local communities
Bateke fuel wood and timber plantation	Dem. Of Congo	World bank Biocarbon fund	n.a	2006-present	Timber and other benefits will be with villagers. Carbon credits may belong to World Bank and Novacel
Nile basin reforestation	Uganda	World bank Biocarbon fund	n.a	2006-present	Timber benefits shared with locals. Carbon credits with World Bank
Acacia community plantations	Niger	World bank Biocarbon fund	n.a	2006-present	Gum, firewood and timber to be shared with locals. ASI will sell carbon credits.
Andasibe-Mantadia biodiversity corridor	Madaga scar	World bank Biocarbon fund, GEF	n.a	2006-present	Mainly a biodiversity conservation project. Some benefits including carbon payments will be shared with locals.

Note: n.a= data not available

Appendix 2: The names of species encountered and percentage basal area contribution of each.

Species	Avg. percentage contribution
Heywoodia lucens	36.4
Vepris lanceolata	6.9
Cussonia sp.	6.0
Strychnos henningsii	4.8
Milletia grandis	4.7
Ficus natalensis	4.4
Celtis africana	3.1
Millletia sutherlandii	2.7
Cassipourea gerrardii	2.6
Englerophytum natalense	2.3
Maytenus acuminata	1.7
Dalbergia multijuga	1.7
Rothmania capensis	1.7
Chaetachme aristata	1.6
Combretum sp.	1.6
Lantana camara	1.6
sabhokwe	1.3
Umbotyane	1.0
Pavetta lanceolata	1.5
Trichilia dregeana	1.0
umnethe	0.7
Cola greenwayi	0.7
Homalium dentatum	0.7
Allophys dregeanus	0.7
Ptaeroxylon obliqum	0.5
Ekerbegia capensis	0.4
Celtis durandii	0.4
umduli	0.4
Zanthoxylum capense	0.4
Commelina benghalensis	0.4
Apodytes dimidiate	0.3
Calodendron capense	0.3
Xylamos monospora	0.3
umyingi	0.3
Maytenus heterophyla	0.3
Iqane	0.2

Dalbergia zeyheri	0.4
Cryptocarys latifolia	0.2
Buxus natalensis	0.2
Cassine sp.	0.2
Syzygium cordata	0.2
isixwathi	0.2
Mimusops cafra	0.2
Canthium ciliatum	0.1
Acalypha glabrata	0.1
Buxus macowanii	0.1
Cordia caffra	0.2
khomanzi	0.1
imbizo	0.1
Cryptocarya myrtifolia	0.1
Canthium sp.	0.1
Ficus ingens	0.1
Caffea racemosa	0.1
Caesalpinia decapitala	0.1
Cordial caffra	0.1
Cnetis polyphylla	0.1
Clausena aristata	0.1
Rhoicissus digitata	0.0
Croton gratissimus	0.1
Ochna arborea	0.0
Grewia lasiocarpa	0.0
Podocarpus latifolius	0.0
Oxyathus latifolius	0.0
Cola greenwayi	0.0
Ubobo	0.0
Dracaena aletriformis	0.0
Brachylaena discolor	0.0
Dalbergia armata	0.0
Ughodo	0.0
Harpephyllum caffrum	0.0
Drypetes arguta	0.0
Rhoicissus rhomboidea	0.0
umthozane	0.0
Imbambho zenja	0.0
Pachystigma venosum	0.0
Protorhus longifolia	0.0
Phytolacca dodecandra	0.0

Trichocladus crinitus	0.0
Scutia myrtina	0.0
Malepora sp.	0.0
Diospyros whyteana	0.0
Clerodendrum glabum	0.0