ASSESSMENT OF INDIGENOUS FOREST DEGRADATION AND DEFORESTATION ALONG THE WILD COAST, NEAR PORT ST JOHN'S, EASTERN CAPE PROVINCE, SOUTH AFRICA

BY

KATENDE – LUKYAMUZI LUCKY FULGENTIUS

JULY, 2018

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ABSTRACT

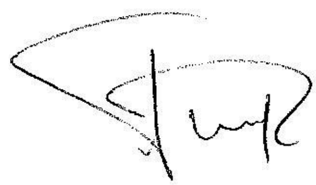
Indigenous forests along the Wild Coast of the Eastern Cape Province have experienced both degradation and deforestation over the past decades. In early 2000, steps were taken to rehabilitate some of the degraded areas. Nevertheless, there is no monitoring mechanism in place, so little is known about the extent of degradation and impact of the rehabilitation efforts. The present study assesses the extent to which deforestation and degradation of the indigenous forests have occurred, and evaluates rehabilitation efforts in the study area around Port Saint John's. Forest degradation was defined as the decrease in forest cover density while deforestation was defined as an increase in the trend of light forests and/ or a decrease in dense forests. The details for this study were obtained from multi – temporal remotely sensed data for a period between 1982 and 2013 (31 years). Multi-temporal Landsat satellite imagery for 1982, 1986, 1989, 2002, 2009 and 2013 was acquired and analysed. On the basis of prior knowledge of the area, the supervised classification approach was used. The Maximum likelihood supervised classification technique was used to extract information from satellite data. The classified images were filtered using a majority filtering procedure to reduce noise. Google Earth (Astrium) ancillary images were used to refine the classification based on expert rules. The derived changes in the degraded and rehabilitated areas were further validated through field visits.

The overall image classification accuracy generated from Landsat image data ranged from 80% to 90%. It was noted that the area of dense forest almost doubled between 1986 and 1989, coinciding with a 59% decrease in the light forest. Subsequently, dense forests increased by 14,820 ha while light forests decreased by 16,690 ha between 1989 and 2002. The subsequent reduction in light forest coverage is explained by the establishment of the Participatory Forest Management (PFMA) approach by Department of Water Affairs and Forestry (DWAF) which reversed the degradation trend. However, specific degradation hotspots were identified, particularly where new settlements have been established. The emergence of the non-vegetated area increased gradually from 7% in 1986 to 23.4% in 2013. Notably, dense forest was observed to have experienced higher rates of forest degradation and deforestation than the light forest. The highest number patches were recorded between 2002 and 1998, followed by between 2010 and 2013 and lastly 1986. Based on spatial connectedness of patches, the year 1986 had the highest landscape connectedness of forest vegetation (CONAT = 35.3) followed by 2002 and 1996 while the year 2010 and 2013 had the lowest landscape contiguity. Over the study period, the distribution of patches clearly shows that forest degradation and deforestation rates were lower in the years 1986, 1998 and tremendously increased in the later period of between 2010 and 2013. However, as a result of rehabilitation efforts, dense forest was seen to steadily gain more land than light forest. Finer details of degradation trends could not be easily picked from the images used in the study, given their spatial resolution limitations. That notwithstanding, the trends identified are good for overview decisions. The study has also established that de-agraianisation, forest restoration and rehabilitation greatly contributed to increased forest cover. Therefore, with more use of GIS by forest managers, and imagery of the high resolution being readily available, forests will in future be easily monitored using remote sensing.

Keywords: Indigenous Forests, Forest Degradation, Deforestation, Forest rehabilitation and Remote Sensing

DECLARATION

I, **Katende – Lukyamuzi Lucky Fulgentius** solemnly declare that this thesis was compiled and written by me. It has never been presented anywhere for any academic award or published in any peer reviewed journals. Therefore, all materials used from other sources are duly appreciated and properly acknowledged.



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LIST OF ABBREVIATIONS / ACRONYMS

CO_2 Carbon Dioxide
CO_2 Carbon Dioxide
DAAF Department of Agriculture, Forestry and Fisheries
DAAF Department of Agriculture, Forestry and Fisheries
DEAT Department of Environmental Affairs and Tourism
DEAT Department of Environmental Affairs and Tourism
DWAF Department of Water Affairs and Forestry
DWAF Department of Water Affairs and Forestry
EOI Environmental Offset Investment
EOI Environmental Offset Investment
ETM+ Enhanced Thematic Mapper Plus
ETM+ Enhanced Thematic Mapper Plus
FAO Food and Agricultural Organisation
FAO Food and Agricultural Organisation
GCPs Group Control Points
GCPs Group Control Points
GIS Geographical Information System
GIS Geographical Information System
GPS Global Positioning System
GPS Global Positioning System
GVI Greenness Vegetation Index
GVI Greenness Vegetation Index
IFM Indigenous Forest Management
IFM Indigenous Forest Management
IFOV Instantaneous Field of View
IFOV Instantaneous Field of View
IPF Intergovernmental Panel on Forests
IPF Intergovernmental Panel on Forests
LAI Leaf Area Index

LAI Leaf Area Index

MSS Multi-Spectral Scanner

MSS Multi-Spectral Scanner

NASA National Aeronautics and Space Administration

NASA National Aeronautics and Space Administration

NDVI Normalised Difference Vegetation Index

NDVI Normalised Difference Vegetation Index

NFA National Forest Act of 1998

NFA National Forest Act of 1998

NFAP National Forestry Action Programme

NFAP National Forestry Action Programme

NGO Non-Governmental Organisation

NGO Non-Governmental Organisation

NIR Near Infrared

NIR Near Infrared

PCI &S Principles, Criteria, Indicators and Standards

PCI &S Principles, Criteria, Indicators and Standards

PSJ Port Saint Johns

PSJ Port Saint Johns

PVI Perpendicular Vegetation Index

PVI Perpendicular Vegetation Index

RDP Rural Development Program

RDP Rural Development Program

REDD+ Reducing Emissions from Deforestation and forest Degradation

REDD+ Reducing Emissions from Deforestation and forest Degradation

RS Remote Sensing

RS Remote Sensing

SAVI Soil Adjusted Vegetation Index

SAVI Soil Adjusted Vegetation Index

TM Thematic Mapper

UN United Nations

UNCCD	UN Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

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Chapter 1 : INTRODUCTION

"*For large areas, satellite remote – sensing techniques have now become the single most effective method for land – cover and land – use data acquisition*". Mark Thomson, 1996.

1.1 Background

According to Food and Agriculture Organisation of the United Nations (FAO), sustainable forest management is defined as "*the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems*" (FAO, 2003). In South Africa, the Department of Agriculture Forestry and Fisheries (DAFF) holds the mandate to promote certification programmes that encourage Sustainable Indigenous Forest Management (National Forests Act, 1998).

South Africa's forest resources are primarily classified into three main forest types according to their use (DAFF, 2011). These include natural or indigenous forests which are valued for biodiversity, ecotourism, small-scale timber production and non-timber forest products; the wooded savannah woodlands, commonly referred to as woodlands, provide essential resources such as non-timber forest products, building materials, fuel for energy, household utensils, fencing material and a variety of food and medicinal products for sustaining the livelihoods of the rural people; and commercial timber plantations which are man-made forests that provide for industrial timber products such as sawlogs and mining timber. All forest types play an important environmental role in protecting soils and storing carbon, thereby mitigating the effects of the new global phenomenon, climate change that threatens sustainable development.

The country's forest resources are spread over some of the poorest areas in the country, covering a land surface area of over 40 million ha. Natural forests — this forest type is too fragmented and covers a smaller area of nearly half a million ha (492 700 ha), about 0.4% of South Africa's land surface area. Although the forest biome is the smallest and the most fragmented of all the biomes (Low & Rebelo, 1996), it has the highest plant diversity per hectare (0,418 species per ha). They predominantly occur in the provinces of the Eastern Cape and KwaZulu-Natal. All natural forests are protected under the National Forests Act, making it an offence for any person to tamper in any way or to transport an indigenous tree or the product thereof without an authorisation.

The extent of natural forests area remains fairly stable, at least according to the National Land Cover (NLC) data sets, though there is evidence of a decline in certain areas and expansion in others. The benefits derived from natural forests are difficult to express in monetary terms. However, the specialist furniture industry in Knysna, Western Cape Province, based on 25000 m^3 of indigenous timber per year, contributes an annual amount of R20 million to the Gross Domestic Product (GDP). The rate at which natural forests are declining or expanding is unknown but property development and land invasions, noticeably in some parts of the country, seem to be the major threats to our natural forests.

Indigenous forest ecosystems are fragile (Omoro, 2012). Thus, any significant change in forestry cover and species ought to be monitored and make necessary plans to curb the negative change in time, through sustainable forest management mechanisms. However, poverty, unemployment and low levels of literacy especially in undeveloped and developing countries present huge challenges due to indiscriminate use of forest produce and products (Bryan *et al.*, 2012). Indeed, forests are degraded and deforested through illegal forest activities such as pit sawing, charcoal burning, grazing, cultivation and settlement and over-harvesting for medicinal purposes (Waiswa, 2011; Namaalwa, 2008).

1.2 Status of forest monitoring in South Africa

1.2.1 Ground-based monitoring

Forest assessment and monitoring programmes are designed to provide information on natural changes occurring in the ecosystems, effects of management activities on the ecosystems, and effectiveness of management activities (SANPark, 2015). In a nutshell, forests are monitored to observe natural processes, such as long-term changes in the composition of the forest, growth rates, regeneration, mortality and condition of the forest.

Monitoring results are used to change or refine management systems to ensure that valuable natural resources are managed sustainably, based on reliable scientific data. Several of the projects in the country were established for long-term monitoring *viz*; to gather and provide information for several years, and in many cases, for several decades. This is important because of the slow rates of natural change in the forests, the long periods between management interventions for some activities (e.g., the 10-year felling cycle for timber in the Garden Route National Park) and the relatively light impacts of most of the management activities. Some low-impact changes may only be detected after several monitoring events, i.e. after several decades. The data emanating from these projects can provide valuable information on the impacts of climate change on the forests over the next few decades.

An array of methods has been employed in monitoring forest dynamics in South Africa including strip plots which are permanently marked 10m wide transects through the forest, divided into plots 20m long; permanent sample plots (PSPs) in which undisturbed areas are compared with similar areas where harvesting is carried out to assess the impacts of harvesting through post-harvesting audits; National system of forest plots established for long-term monitoring of growth and mortality in indigenous forests; and, photo-monitoring provide information on the recovery of burnt forest areas. Notably, all the methods require lots of resources in terms of funds, time and human capital, which limit their efficiency and out-scaling.

1.2.2 Satellite image-based monitoring

According to Bajracharya (2008), "forest degradation and its associated impacts have drawn the attention of the scientific, environmental and policy-making bodies. Spatial distribution of forest is large and hence some places are inaccessible". The inconsistency in the definition of forest degradation and deforestation coupled with the lack of quantitative, spatially explicit and statistically representative data has often resulted into uncertainties in the current estimates of forest degradation. Notably, implementation of incentives for Reducing Emissions from Deforestation and Degradation in developing countries (REDD) requires robust and reliable methods for estimating forest degradation (UNFCCC, 2007). Thus, the importance of satellite imagery to identify forest degradation, at both national and international levels is increasing. However, these means have not been entirely effective to identify or contribute to reducing forest degradation. The role of remote sensing as a tool for degradation monitoring is essential in natural resource management and is still in a testing phase, more so in South Africa. Remote sensing data can support inventory approaches by informing degradation patterns in forests in combination with ground-based monitoring of forest degradation. Identification of small scale and gradual degradation is often not easy using remote sensing data alone and contemporary in situ information is necessary (Rosenqvist *et al.*, 2003).

1.3 Research Problem

South Africa (SA) is a dry country with only 8% of the country receiving high enough rainfall to allow forest growth (Low & Rebelo, 1996). Thus, the distribution of *bona fide* indigenous forests in SA has been limited to a narrow strip between the Indian Ocean and the Quteniqua and Tsitsikamma mountains on the southern part, and the Drakensberg along the north (DEAT, 1997). The dismal spatial distribution of indigenous forests and increasing population pressures present a danger of these forests becoming extinct if proper measures are not put in place to protect them (DWAF, 2005). Nevertheless, most of the indigenous forests are inaccessible, making their routine monitoring rather difficult. In this context, remote sensing becomes a useful tool for monitoring indigenous forest conditions. Elsewhere, remote sensing has proved to be a reliable, cheap and timely method of monitoring changes in forests (Bajracharya, 2008). Small patches of indigenous forests are spread all over the former Transkei homeland including the mountainous Drakensberg, making feasibility of forest monitoring not only difficult but very expensive too. This renders remote sensing the only cost-effective and reliable tool for forest monitoring and assessment at local as well as national level.

The main threats to indigenous forests are related to social and economic problems, uncontrolled fires, invasive alien species and climatic changes. According to DWAF (2003 and 2005), currently, indigenous forests including those in Transkei area, Eastern Cape and Limpopo are under threat from a number of land-use pressures particularly mining, agriculture and over-harvesting for illegal commercial use and subsistence, particularly for medicinal plants. In South Africa, Coastal forests in particular, are under threat from coastal development. This is particularly alarming given that, of the various forest types, coastal forest tends to have the highest species diversity, as well as most of the forest-dependent endemic species (Lawes, 2002).

Although much research on deforestation scenarios has been carried out, not many environmental and spatial investigative studies have focused on coastal changes in indigenous forests related to forest degradation and degradation in South Africa. The present study aims to integrate remote sensing with ground forest monitoring and assessment data to monitor changes in forest cover related to forest degradation along the Wild Coast, near Port St John's in the Eastern Cape Province, South Africa for the period of 28 years, between 1986 and 2013.

1.4 Study objectives

1.4.1 Main objective

The main aim of the study is to assess changes in indigenous forest degradation and deforestation along the Wild Coast, near Port St John's (PSJ) in the Eastern Cape Province, South Africa

1.4.2 Specific objectives

1. To assess the extent of changes in indigenous forests around PSJ between 1986 and 2013.
2. To identify and distinguish between forest degradation and deforestation in PSJ over the past 3 decades.
3. To establish the effectiveness of indigenous forest rehabilitation efforts in the study area.

1.5 Research Questions

1. Is there significant changes in indigenous forest degradation and deforestation over the years around PSJ?
2. What is landscape differentiation between forest degradation and deforestation in the PSJ
3. How effective was the rehabilitation programme carried out by DAFF since 1998?

1.6 Significance of the study

The continuous deforestation and degradation of forest ecosystems is of major concern due to the negative impacts this has on many of the ecosystem services (IPCC, 2006). Despite the fact that indigenous forests are reasonably protected /or well-managed, PSJ forests which are characterised by a variety of tree species including some that are endemic to the area have lost over 0.5% of their cover during the last 30 years (DAFF, 2011) due to agricultural expansion. In addition, other forms of land use change, notably from the introduction of the exotic species have caused the fragmentation of these forests. Presenting the magnitude of changes in forest degradation and degradation is ultimately expected to inform decision makers in the forest sector and farmers if the rehabilitation efforts are fruitful and sustainable and if they could be duplicated elsewhere.

The apparent impacts of forest degradation on forest cover make it necessary to monitor and assess those ecosystem services that are affected and their impacts on people's livelihoods. Such assessments can provide information needed for the rehabilitation of the forests at the local scale, so as to sustain the flow of services and goods valued by the local communities. On a broader scale, such assessments are also necessary because they provide information about the status of the ecosystem for which management decisions related to rehabilitation or conservation can be made (Fisher and Turner, 2008).

1.7 Structure of the thesis

1.7.1 Chapter 1: Introduction

In this chapter, research background is provided, highlighting the importance of using RS in monitoring and managing indigenous forests and land degradation. The research problem, aim of the study and specific objectives are provided.

1.7.2 Chapter 2: Literature Review

The chapter provides definitions of concepts such as indigenous forests, forest degradation, deforestation and forest rehabilitation. It also provides detail on the role of remote sensing in indigenous forest monitoring

1.7.3 Chapter 3: Study Area

In this chapter, the background of the study area is given. The location, climate, topography, geology, soils, vegetation, relief, natural habitation, anthropology, economic activities and the encroachment of indigenous forests during the new dispensation are described.

1.7.4 Chapter 4: Methodology

A description of the methods used to achieve the aim and set of objectives is provided in this chapter. Changes in indigenous forest extent, forest degradation and deforestation were measured using medium-resolution and high-resolution satellite imagery interpreted by means of spatial analysis.

1.7.5 Chapter 5: Results

The study results obtained are presented and interpreted in this chapter. These results include, but not limited to, the magnitude and changes of indigenous forest, forest degradation and deforestation.

1.7.6 Chapter 6: Discussion,

The findings of this study are discussed in this chapter and compared with the other intriguing observations made by other scholars. Recommendations to minimise deforestation and forest degradation are also presented in this chapter and directions for further future research are provided. The overall study conclusions are also presented.

1.7.7 Chapter 7: Conclusion

The study conclusion is presented in this chapter – detailing the significance of the results

Chapter 2 : LITERATURE REVIEW

2.1 The extent and distribution of Indigenous forests in South Africa

South Africa, as a dry country, is covered by dry savannah woodlands and bushveld. Most indigenous evergreen forests are found in areas of higher rainfall, along with the southern and eastern coastline and in the country’s mountainous regions towards its eastern borders with Swaziland and Mozambique (Table 1). Estimates of the area covered by indigenous (closed canopy) forests vary between 0.25% (Low & Rebelo, 1996) and 0.59% of the land surface (DEAT, 1997), with woodlands between 35 and 40% and plantations at about 1.4% (Grundy & Wynberg, 2001).

Indigenous forests make up approximately 0.4% of the land surface in South Africa. However, this biome encompasses extensive areas and contains valuable resources. They are valued for biodiversity, ecotourism, timber production and non-timber forest products, particularly firewood, poles and medicine. They are predominantly located in the Eastern Cape and KwaZulu-Natal (KZN) provinces. According to National Land Cover (NLC) data sets, indigenous forests are stable but evidence on the ground shows that they are declining in some areas for various reasons, while in many other areas, they are expanding. However, there are no concrete data to back up these claims at national level, let alone quantifying losses and gains. This is so because there has been no comprehensive national forests assessment in the country; it is not possible to establish trends or rate of change in woodlands and indigenous forests (DAFF, 2011).

Table 2:1 Distribution of indigenous forests in South Africa

Indigenous forest type	Area (ha)
Albany	22 046.37
Amatole Mistbelt	64 221.09
Drakensberg Montane	1 926.39
Eastern Cape Dune	10 940.58
Eastern Mistbelt	41841.86
Eastern Scarp	33 750.17
KwaZulu-Natal Coastal	21 089.11
KwaZulu-Natal Dune	12 395.9
Licuati Sand	24 275.67
Lowveld Riverine	11 401.28
Mangrove	2 392.70
Mpumalanga Mistbelt	32 772.36
Northern KwaZulu-Natal Mistbelt	5 323.42
Northern Mistbelt	19 203.65
Pondoland Scarp	12 337.00
Southern Cape Afrotemperate	68 563.35
Swamp	3 021.77
Transkei Coastal Platform	61 484.01
Transkei Mistbelt	30 249.84
Western Cape Afrotemperate	4 731.06
Western Cape Milkwood	2 499.74
Total area	**492 699.76**

Source: DAFF (2011)

2.1.1 Forest protection in South Africa

According to the NFA, all indigenous forests are protected, with only five million ha of woodlands thought to have some form of protection status. The forests outside protected areas are usually overexploited by neighbouring communities for fuelwood consumption and for other community needs.

DAFF and the South African National Biodiversity Institute (SANBI) are involved in a process to identify threatened forest ecosystems. The list of threatened ecosystems published in 2009 in relation to the National Environmental Management Biodiversity Act (Act No. 10 of 2004) includes three forest types as endangered and six as vulnerable. Several individual threatened forest patches of high conservation value were also listed for protection under this Act, which gives such listed ecosystems enhanced status in the Integrated Development Plans of local and regional authorities.

To enhance forest protection, four strategies were developed by DAFF including:

1. Publication of a list of 47 tree species under the protected trees and the braai wood market initiative
2. The tree champion project aimed at identifying and protecting individual trees of national conservation importance under the NFA
3. Conservation of minimum area of each woodland type
4. Woodland rehabilitation framework that provides for the rehabilitation of woodlands

2.2 Conceptualisation of forest, forest degradation and deforestation

"Forest degradation is more difficult to measure using remotely sensed data compared to deforestation. Moderate spatial resolution images often do not provide detailed information about degraded forests. For example, forest structure and composition (e.g. crown size, liana density, tree species, etc) cannot be retrieved at these moderate spatial resolutions (i.e. 20 – 30m pixel size)" (Giri *et al*., 2007).

"The underlying causes of deforestation and forest degradation, and drivers of forest restoration,' include persistent high demand for wood; spiralling demand for land for plantations and other forms of agriculture; conflict over land tenure; industrialisation, urbanisation and infrastructure; poor central planning, lack of political will, and inadequate capacity; economic poverty and a lack of alternative livelihood options; neoliberal economic policies locking in unsustainable rates of consumption and poverty; and climate change". (REDD+ and the Underlying Causes of Deforestation and Forest Degradation, Global Forest Coalition, 13 January 2914 Report).

Deforestation and forest degradation are the second leading causes of anthropogenic greenhouse emissions following fossil fuel combustion, accounting for over 17% of global carbon dioxide emissions (IPCC, 2007). Forest degradation constitutes a significant proportion of greenhouse gas emissions (Meneses – Tovar, 2011).

According to Joshi *et al*. (2015), there is an international move and international agreement on the critical role of forests in mitigating climate change. The aim is to reduce emissions from deforestation and forest degradation, enhance conservation, sustainable management and improve forest carbon stocks in developing countries. This move is known as Reducing Emissions from Deforestation and forest Degradation (REDD+). The plus sign refers to the role of conservation and the sustainable management of forests. It is a collaborative initiative of the FAO, UNDP and UNEP. There has been intense negotiation since 2007, carried out by United Nations Framework on Climate Change (UNFCCC), (UNFCCC 2007, 2011). Deforestation and forest degradation have become an important issue concerning climate change. Most of the international attention has focused on deforestation (Gullison *et al*., 2007; Kindermann *et al*., 2008) and enhancement of carbon sinks through reforestation and afforestation (Thomas *et al*., 2010) either within or outside the framework of the Kyoto Protocol. Alongside REDD+ process, monitoring forests using satellites is gaining momentum, as studies progress in assessing carbon stocks and forest clearance across the globe (Houghton and Goetz, 2008; Hansen *et al*., 2013;

Joshi *et al*., 2015,). Despite the fact that most countries' direct intervention plans focus on reducing forest degradation (Salvini *et al*., 2014), the use of common remote sensing time – series imagery is not yet well established (De Sy *et al*., 2012; Joshi *et al*., 2015).

It is more difficult to identify forest degradation than deforestation using satellite images. According to Giri *et al*. (2007), it is said that old degraded forests (two years old and over), are difficult to distinguish from an intact forest by using both Landsat and SPOT images. However, there are techniques that can be applied to identify forest degradation, using these images, but according to Jukka, *et al*. (2014); several authors have achieved promising results in geographically limited areas, in Asia, using automated detection algorithms. This is done by using biophysical attributes that are indicative of forest degradation. This can be done by either using empirical approaches (using vegetation indices such as NDVI), or a physically – based approach (relying on model inversion and classifications). Regular monitoring of several biophysical variables over several years can lead to an accurate detection of forest degradation (FAO, 2007). According to Giri *et al*., 2007, the model inversion approach, is still in its initial stages, so it has not yet been applied routinely on large scale. According to Baccini *et al*. (2008) and Mitchard *et al*. (2011), significant forest cover changes such as rehabilitated areas can be easily detected using Landsat TM images which can be supported by other studies done in the past

Table 2 below shows various sources available for remote sensing data sources, their spatial, spectral and temporal resolutions. IKONOS images, which can be acquired with resolution as fine as one meter, were used in Amazon region to identify forest degradation (FAO, 2007). However, in the present study, Landsat imagery of spatial resolution of 30 were utilized because of.

Table 2:2 : Major satellite remote sensing data available (source: FAO, 2007)

Name	Spatial Resolution (m)	Spectral Resolution	Temporal resolution (Days)	Launched (Year)	Link/portal
Landsat	15 – 18	V/NIR, SWIR, TIR	16	1972	www.landsat.org
SPOT	2.5 – 20	V/NIR, SWIR	26	1986	www.spotimage.fr
IRS	6 – 188	V/NIR, SWIR	24	1995	www.isro.org
IKONOS	1 – 4	V/NIR, SWIR	3	1999	www.spaceimaging.com
QuickBird	0.61 – 2.44	V/NIR		2002	www.digitalglob.com
MODIS	250 – 1000	V/NIR, SWIR, TIR	1	1999	Modis.gsfc.nasa.gov
VEGETATION	1000	V/NIR, SWIR, TIR	1	1998	www.spot-vegetation.com
AVHRR	1000	V/NIR, SWIR	1	1978	www.noaa.gov
MERIS	300	V/NIR, SWIR	3	2002	www.envisat.esa.int
ASTER	15 – 90	V/NIR, SWIR, TIR	4 - 16	1999	Asterweb.jpl.nasa.gov
Hyperion	30	V/NIR, SWIR	16	2000	eo 1.usgs.gov
ALI	10 – 30	V/NIR, SWIR	16	2000	eo 1.usgs.gov
CBRES	20 – 260	V/NIR, SWIR	3 - 26	2003	www.dgi.inpe.br

JERS/SAR	18	L - band	44	1992	www.eorc.jaxa.jp
Radarsat	8 – 100	C - band	24	1995	www.rsi.ca

Degradation of forests is a complex process (Lambin, 1999). In order to be able to determine the rate of deforestation and forest degradation, one has first to define what a forest is, what forest degradation is and what deforestation is. There is no universal definition of those three terms. Due to the scale of variation in forest structure globally, countries often had different perceptions of forests. Some countries consider open woodland and thicket vegetation as forests while others do not (Sasaki & Putz, 2009). Furthermore, different parties have differing views of what constitutes deforestation and forest degradation.

Indeed, owing to the fact that most of the literature and experts do not give a clear-cut distinction between degradation and deforestation, the definition of forest degradation is quite confusing. Therefore, it is imperative to first understand the meaning of a forest in order to clearly distinguish between degradation and deforestation. According to FAO (2011), "forest is a land spanning more than 0.5 ha, with a tree canopy cover of more than 10%, which is not primarily under agricultural or other specific non-forest land use". The trees should have a potential of reaching a height of 5 m *insitu* and constitute about 10% crown cover in case of young forests (Bajracharya, 2008).

The UN Commission on Sustainable Development established an Intergovernmental Panel on Forests (IPF) which addressed "Underlying Causes of Deforestation and Forest Degradation". In the context of the IPF terms of reference, deforestation is defined as "changing forests into other land uses" and forest degradation as "deterioration of forest quality" (Verolme and Moussa, 1999). Indeed, "deforestation and degradation are both changes in forest landscapes, which can be both human-induced or natural phenomenon" (Bajracharya, 2008). It worth noting, however, that the way in which changes occur is not the same. Deforestation is a non-temporal change of land use from forest to other land use (e.g., forest land to settlement) or "the depletion of forest crown to less than 10 %" (Bajracharya, 2008). Degradation is a complex process (Lambin, 1999); and defines changes within a forest class, which negatively affect the stand or site, lowering the species composition, biological diversity and productivity.

2.2.1 The term Forest

To understand or to determine the rate of forest degradation or and deforestation depend on the definition of "Forest" (Lamb and Gilmour, 2003).

According to Lamb and Gilmour (2003), Originally FAO defined "forest" as non-agricultural land, which has a tree cover of at least 20 per cent. In 2000, this definition was changed to land with a tree cover of at least 10 per cent. By implication, land which was previously categorised as "woodland" was now considered 'forest'. After changes in definition in 2000, FAO recalculated the available data to make them comparable with the new definition. It concluded that the net rate of deforestation had probably decreased, although this was mainly due to regrowth and plantation establishment rather than a reduction in gross deforestation rates. For the purposes of clarifying forest degradation, this definition is adopted in full recognition of its limitations (Sasaki & Putz 2009, Hance 2010, Putz & Redford 2010), but it was done for the purposes of reversing forest degradation, in line with UNFCCC (Marrakesh Accord, Decision 11/CP.7). Mathews (2001) suggested that rates of natural forest loss had probably worsened in all tropical countries except in Latin America and that more forest was lost in the 1990s than the 1980s.

Just the change in the definition of the word 'forest' can create a different interpretation of the same data. The term forest also has many definitions. In this study, we shall embrace the FAO, (2000), definition, whereby a forest is defined as *a land spanning more than 0.5ha with a tree canopy cover of more than 10%, which is not primarily under agricultural or other specific non-forest land use*". Trees should have the potential of reaching a height of 5 m *in situ* and cover 10% crown cover in case of young forests.

2.2.2 Forest Degradation

The lack of a universal definition of forest and forest degradation cause complications when REDD+ projects are implemented (Sasaki and Putz, 2009). Identifying or determining forest degradation, also depends on the definition. Degradation of forest is a complex process (Lambin, 1999). According to Lamb and Gilmour (2003), forest degradation means a loss of forest structure, productivity and native species diversity. Lund, (2009a; 2009b) found out that more than 50 definitions of forest degradation, which are formulated by various purposes of management. According to FAO (2009), many of the definitions are either very general or they focus on the reduction of productivity, biomass or biological diversity. Some of the different definitions are given in Appendix 4 attached. Definitions that refer to multiple-use forests or multiple forest benefits may consider forest values comprehensively but are more difficult to apply universally in a consistent and transparent way. But generally, Forest degradation involves a change process that negatively affects the characteristics of a forest such that the value and production of its goods and services decline (Lamb and Gilmour, 2003).

Forest Degradation, deforestation and fragmentation are always confused terminologies when describing the status of a forest. In most cases, the term degradation is confused with deforestation. There are several definitions of forest degradation. According to Verolme *et al*. (1999), forest degradation is defined as *the deterioration of forest quality*. And according to David *et al*. (2003), forest degradation means a loss of forest structure, productivity and native species diversity. The FAO (2010a & 2011a) defines forest degradation as the reduction of the capacity of a forest to provide goods and services.

It should be understood that a degraded site may still contain trees meaning that a degraded site is not necessarily deforested. According to Bajracharya (2008), the distinction between degradation and deforestation at times is not clear.

The FAO (2000) of the United Nations, define forest degradation as changes within a forest that affect the structure and function of the stand or site which lead to lowering its capacity to supply products or services. Forest Degradation refers to the reduction of forest quality (density and structure of trees), ecology, biomass, species and genetic diversity (FAO, 2010). It is also described as the depletion of the forest crown to not less than 10%. Forest degradation can also mean the changing the forest from closed to open forest. The impoverishment of standing woody material mainly caused by human activities such as overgrazing, over-exploitation for forest produce such as firewood, repeated fires, attacks by insects and diseases, plant parasites or other natural causes such as cyclones may also lead to forest degradation.

According to FAO (2009), both natural and human-induced degradation are often interdependent, since human actions can affect the vulnerability of a forest to degradation from natural causes. For example, reduced tree stocking due to harvesting can lead to increased sensitivity to wind damage. At the same time, natural damage can also lead to increased human-induced disturbance, for example, natural forest fires can lead to encroachment by shifting cultivators. Or steeply sloping land can lead to widespread severe erosion. Natural and human – induced causes are difficult to distinguish when abiotic and biotic factors are triggered by changes in weather patterns or perhaps as a result of human-induced climate change that leads to a greater frequency, scale and impact of forest degradation (Obiri, 2002).

FAO has defined forest degradation as changes within a forest that affect the structure and function of the stand or site and thereby lowering its capacity to supply products or services. In practice, however, degradation is much more subjective; people can have quite different perceptions of the same landscape. For example, a wildlife enthusiast may see an impoverished forest, while a forester sees a productive forest regenerating after logging. Similarly, a forester may see a degraded forest while a shifting cultivator sees a piece of prime agricultural land. Almost inevitably, “degradation” is partially in the eye of the beholder. Not all landholders or managers will necessarily agree that degradation has occurred; even if they do, they may disagree about the most appropriate response.

In the study area, most of the forest degradation is caused by smallholder forest encroachment, shifting cultivation, grazing and fires. Forest fragmentation is also a form of forest degradation. Forest fragmentation refers to any process which results in the conversion of formerly continuous forest into patches of forest separated by non-forest land (Waiswa, 2011). According to McGarigal and Mark (1995), forest fragmentation is a landscape-level process in which forest tracts are progressively sub-divided into smaller, geometrically more complex and more isolated forest fragments as a result of both natural processes and human land-use activities.

Forest degradation is very subjective, for some people can have a different perception of the same landscape depending on the purpose of the land use David *et al*. (2003). A piece of forest land which has been recently logged, to a commercial forester, it is a land which has been harvested, which will regenerate with time, which is sustainable forest management. However, to a wildlife manager may look at it as a disastrous degraded forest, which can no longer serve as a source of food and protection to wildlife.

In the study, forest degradation will mainly refer to changes within the forest class that is from closed to open forest and grasslands. This means that it reduces the overall supply of benefits from forests, which include wood, biodiversity and other environmental services (FAO, 2006).

Degradation of forest cover is a complex process, with some degree of reversibility as the productivity of forests is partially controlled by many factors such as human activity, climatic fluctuations, aspect and type of soils. It is therefore recommended that long term series of observations should be carried out to detect trends in forest degradation (Geldenhuys, 2002).

Forest degradation can be halted or reversed by forest improvement or other management interventions, including restoration through silvicultural measures and the rehabilitation of degraded non-forest areas through reforestation.

2.2.3 Forest degradation in Eastern Cape

Many world economies are wholly or partly depend on forest resources (Waiswa, 2011; FAO, 1997) and the Eastern Cape (EC) is not an exception. Indigenous forests in EC play a central role in the social, cultural and economic development in the coastal areas of the Province. These forests are the major source of timber, building materials, recreation, wildlife habitat, water quality protection, protection from soil erosion, medicinal, cultural activities and tourism industry (Katende, 2012). Forests are important for atmospheric carbon sink and buffer against climatic change (Nezry *et al*., 1999). It is, therefore, imperative that these forests are protected and managed sustainably so that they continue to serve the purpose. If the degradation and deforestation continue unchecked, soon these indigenous forests will disappear and this is a big challenge to DAFF as a department. In order to address this problem, foresters and policy makers must have up to date reliable information as to be able to monitor and manage this resource sustainably.

There are many factors that lead to forest degradation, such as population growth, demand for coastal properties, poor agricultural methods, pests and diseases, poor political policies, climatic changes, land for low-income housing and associated services, poverty and associated increased human pressures on forests and urbanisation. These have been the main factors that have caused degradation of indigenous forests in Eastern Cape (EC). It is a fact there has been forest degradation in EC, but the extent is not known. Since 2002, rehabilitation in most of the degraded areas started in most areas managed by DAFF in the EC. But the impact of the rehabilitation is not known and cannot be easily verified (Geldenhuys, 2002).

In some areas of Transkei Coastal Platform forests, slash- and – burn is very common (Hassan and Haveman, 1997; Obiri, 2002). In the same forests, some small gaps were created in the forests by clearing to grow illegal drug plant *Cannabis sativa.*

2.2.4 Different levels of degradation

According to Sasaki *et al*. (2011), to facilitate communication about restoration strategies for forests modified from their primary, old-growth, or mature condition, the rate of degradation can be defined in four stages, ranging from **A**, slightly degraded to **D** highly degraded, as outlined below.

1. Forest in State A: Forests in this state are slightly degraded but retain some trees above the minimum diameter at breast height (DBH) for legal harvesting (DBH limits for tropical countries are provided in Tab. SM1 of the Supplementary Materials).
2. Forests in State B: In this state, the Forests are moderately degraded due to having lost their legally harvestable trees but retain many that are just smaller than the minimum cutting diameter (for legal harvest). Most of the indigenous forests around PSJ are in this state.

3. Forests in state C: This refers to forests that are highly degraded insofar as they contain only trees much smaller than the minimum cutting diameter.
4. Forests in state D: These are critically degraded. They have few residual trees of any size (but enough for the area to still be considered "forest".

Forestation "restoration" is referred to as management activities that help degraded forests recover their lost carbon stocks, biodiversity, and capacities to provide other goods and environmental services. According to Sasaki, *et al*. (2011), restoring of degraded forests has a huge potential for mitigating global climate change by enhancing carbon stocks. There are several approaches to restoring of degraded forests, the easiest and cheapest is to stop the causes of degradation and allow forests to regenerate on their own. The second approach and more expensive is to accelerate tree regeneration and growth through application of any of a variety of silvicultural treatments. The third general approach is to plant seeds or seedlings in natural or artificial gaps, a process often referred to as enrichment planting. This is the method being applied by DAFF in the degraded areas in the present study.

In order forest restoration to be successful, there is a need for appropriate incentives, policies, institutional arrangements, and local participation. According to FAO (2011), it is not easy to identify and assess the degree of degradation in a particular forest since people or organisations have widely different views of what constitutes degradation. For some, any forest management activity may cause degradation. For others, the forest is only degraded when it can no longer deliver needed goods and services. There is no globally agreed definition of forest degradation.

FAO (2002) defines forest degradation as "the reduction of the capacity of a forest to provide goods and services". Lund (2009), found more than 50 definitions of forest degradation, formulated for various purposes.

Shackleton *et al*. (2013), states that the perceptions of forest degradation are many and varied, depending on the driver of degradation and the goods or services of most interest. For example, a Commercial forestry manager who replaces a natural forest with a plantation to supply desired wood products is unlikely to perceive his forest as degraded. On the other hand, his plantation is less capable of providing many of the goods and services that a fully functioning natural forest would provide on the same site. This is because a commercial plantation reduces biodiversity generally associated with natural forests, which to others would constitute a degraded state.

Generally, forest degradation involves a change process that negatively affects the characteristics of a forest such that the value and production of its goods and services decline (Bryan *et al.*, 2012). The change process can be caused by a disturbance (although not all disturbance causes degradation), which may vary in extent, severity, quality, origin and frequency. The disturbance may be natural for example caused by fires (Page *et al.*, 2002), storm or drought, or it can be human-induced for example through tree harvesting, new road construction, shifting cultivation (Lawrence, 2005), harvesting trees for charcoal production (Ahrends *et al.*, 2010) or overgrazing. It can also be a combination of the two.

According to the FAO (2009), human-induced disturbance may be intentional or direct, for example, the disturbance caused by logging or grazing. It may be unintentional or indirect, for example, the spread of an invasive alien species.

Natural and human-induced degradation are often interdependent. The human actions can affect the vulnerability of a forest to degradation from natural causes. For example, reduced tree stocking due to over-harvesting can lead to increased sensitivity to wind damage. While natural damage can also lead to increased human-induced disturbance, for example, a natural forest fire can lead to encroachment by shifting cultivators (Chazdon, 2008). Distinguishing between natural and human-induced causes may be difficult when abiotic and biotic factors are triggered by changes in weather patterns (perhaps as a result of human-induced climate change) that lead to a greater frequency, scale and impact of forest degradation (O'Connor *et al.*, 2014).

Forest degradation is usually associated with a reduction in vegetative cover, especially trees (FAO, 2009). Degradation can be but is not necessarily a precursor to deforestation. Forests may remain degraded for a long time but never become completely deforested. But change can also be abrupt, for example when an intact forest is converted to another land use. Forest degradation can be halted or reversed by forest improvement or other management interventions, including restoration through silvicultural measures and the rehabilitation of degraded non-forest through reforestation.

Tree planting is always prescribed for countering the effects of degradation, whatever the causes and regardless of degradation level (Lamb *et al*., 2005). Unless there is a baseline, the measurement of the forest degradation or gathering data is difficult to obtain. A baseline is a reference state or the 'ideal state', against which change can be assessed (Shackleton *et al*., 2013). Given that forests are always changing, and that forest condition is partly a matter of perspective, establishing a baseline is not an easy task.

The starting point would be to use primary forests as a baseline, including the various successional stages. It is a reasonable approach though it has some challenges. Because even sustainably managed forests may lack some species, processes, functions or structures normally found in a primary forest. So from the start, this would be rated as 'degraded' in comparison already. Even if a sustainably managed natural forest was selected as the baseline condition, a challenge would be to define the threshold at which that forest loses its potential to fulfil its functions, depending on the definitions of the functions. Most plantations would be considered degraded according to the biodiversity criterion, as would any other forest that is managed for a selected set of goods and/or services. Degradation is relative, not absolute, and therefore should be classified along a continuum (Aragão & Shimabukuro, 2010).

2.2.5 Deforestation

According to United Nations Commission on Sustainable Development, deforestation is referred to as '*changing forests into other land uses'*. According to Bajracharya (2008), deforestation and degradation are both changes in forest landscapes, which can be induced by human activities or natural phenomena. Deforestation mean the physical act of completely removing the trees from the forest or the conversion of forests to non-forest, take for example area changed from forest land to settlement.

2.3 Forest Rehabilitation

There are various terminologies used such as restoration, rehabilitation or reclamation, depending on what is aimed to be achieved after addressing the degradation problem (David *et al.*, 2003). If the objective is to recreate an ecosystem as close as possible to that which originally existed at the site, that is restoration. The site will contain most of the original plant and animal species. On the other hand, the term rehabilitation is used where original productivity or structure is regained as well as some of the original biodiversity but not all. New tree species which are commercially viable may be introduced. The site may have become unsuitable for the original species (David *et al*., 2003).

Reclamation is the situation where productivity or structure is regained but biodiversity is not. This is when alien species are introduced. In such cases, there are a few, if any benefits to landscape biodiversity, but there may be social or economic advantages (Conner *et al.,* 2014).

In DAFF, it mainly rehabilitation that has been aimed at, though it is difficult to achieve. Most of the work is done in forest degraded areas. In some areas, the original species are introduced, while in other areas new indigenous species are planted or encouraged to grow naturally.

Several methods can be followed in rehabilitating forests. In this area of Eastern Cape, *Podocarpus henkelli* is being planted in large gaps in the forests. Other species have become established under the planted trees. According to Geldenhuys (2002), restoration actions are only successful if they are economically viable, or if they provide for the daily needs of the rural communities.

In some areas where the damage was made by severe tree bark harvesting for traditional medicine, rehabilitation was attempted by using forest seedlings of the same damaged species which are naturally growing in the understory of pine plantations (Geldenhuys and Delvaux, 2002).

2.4 Using Remote Sensing in determining the rate of forest Degradation

2.4.1 The difference between multispectral and hyperspectral imagery

There are three broad categories of sensors that can be used for retrieving the biophysical properties of vegetation, such as forest degradation and Deforestation. They are; Optical, radar and LiDAR (Mitchard, 2011).

Optical sensors such as Landsat, ASTER, MODIS, Quickbird, IKONOS and SPOT, detect reflected sunlight in form of electromagnetic waves from the Earth surface. These sensors are passive (Mitchard, 2011; Lillesand *et al*., 2008). Radar and LiDAR sensors are both 'Active' sensors. They transmit pulses of radiation and detect returns.

2.4.1.1 Optical Sensors

The images produced by optical sensors can be further divided into Multispectral and Hyperspectral sensors. They both measure reflected energy within several specific sections called bands, of the electromagnetic spectrum. Multispectral sensors usually have between 3 and 10 different band measurements in each pixel of the images they produce. Examples of bands in these sensors typically include visible blue, green, visible red, near infrared. Landsat has 7 bands, ASTER has 14 and MODIS has 36. The Hyperspectral sensors (For example, the AVIRIS airborne hyperspectral) have as many as 200 (or more) contiguous spectral bands (Baltsavias, 2002; Jensen, 2007; Lillesand *et al*., 2008; Kudenov, 2015).

Therefore, the difference between the Multispectral and the Hyperspectral is the number of bands. Hyperspectral sensors measure energy in narrower and more numerous bands than multispectral sensors. These numerous narrow bands of hyperspectral sensors provide a continuous spectral measurement across the entire electromagnetic spectrum and therefore are more sensitive to subtle variations in reflected energy. It has the ability to provide a high – resolution reflectance spectrum for each picture element in the image (Goetz *et al*., 1985; Karaska *et al*., 2004; Jensen, 2007).

Images produced from hyperspectral sensors contain much more data than images from multispectral sensors and have a greater potential to detect differences among tree species within the forest while multispectral imagery can be used to map forested area or non-forested area. Hyperspectral sensing has a potential to provide a substantial jump in the quality and quantity of spectral data obtained about earth surface features (Lillesand *et al*., 2008).

However, Hyperspectral sensing is a new area of science; it is still more expensive and needs special skills of specialists to be applied in determining forest degradation. By 2007, there were only three operating space-borne hyperspectral scanning systems, though several were in various stages of planning and development in different countries like Canada, Germany and India by then (Lillesand *et al*., 2008).

Hyperspectral sensors have some disadvantages of increasing volume data to be processed, relatively poor signal – to – volume ratios and unwanted atmospheric interference (Lillesand *et al*., 2008).

2.4.1.2 Landsat and SPOT Images

Landsat and SPOT are examples of the commonly used Optical, multispectral sensors. According to Strand *et al*. (2007) Landsat, ASTER, SPOT High-Resolution Visual, and Indian Remote Sensing satellite imagery, with spatial resolutions of 15–60 m, have been used for forest mapping at the national and subnational levels. It was observed that maps generated using imagery at this scale provide only rough estimates of forest type and structure. It is often difficult to distinguish plantations from natural forests (Strand *et al*., 2007).

This was illustrated in the example, UNEPWCMC (2007), when they mapped four classes of the plantation, at a coarse scale using Advanced Very High-Resolution Radiometer-based satellite images, but the dataset was too coarse (20 m) to be useful for the more nuanced identification of forest ecosystems.

Therefore Mid-resolution remote sensing can be used to generate a first approximation of change detection, for example in the relative abundance of ecosystems, such as the relative abundance of dry and wet tropical forests or of conifer and mixed-species temperate forests (Pettorelli *et al*., 2014).

2.4.1.3 Using images of higher resolution

Using a combination of 1 m resolution KONOS data and data from SPOT 4, Souza *et al*. (2003) developed a method for mapping degraded forest classes, which they defined as heavily burned or heavily logged and burned. However, even at this resolution, tree species could not be identified with accuracy. This means that even with images of resolution of 1m, it would be difficult to distinguish forest degradation clearly. If certain tree species has been targeted in a certain area, it would be difficult to use this method to identify whether they have been removed or not.

By implication, remote sensing can be used for broad forest information, for example, distinguishing deciduous from conifer, cultivated land from grassland, open from closed forest and heavily logged areas from areas cleared for cultivation. A rehabilitated area in form of restoration cannot be distinguished using these images. According to Lambin (1999), images must be evaluated at sufficient frequency to differentiate natural forest change from degradation.

2.4.1.4 Radar Sensors

"The word *radar* is an acronym for *radio detection and ranging*" (Lillesand *et al*., 2008). Unlike the Optical Passive (use sun energy, has no its own source of energy or illumination) sensors, Radar sensors use an entirely different type of technology. They are active (sensors supply its own source of energy) and sensitive to very different characteristics of the Earth's surface (Mitchard, 2011). It is an active remote sensing technique that involves the transmission of microwave signals to the direction or objects of interest. The signals are reflected or echoed back to the receiver (Campbell, 2001; Lillesand *et al*., 2008). Radar sensors are not commonly used in detecting forest degradation and deforestation trend studies. However, in the 1970s it was used in Brazil, for the reconnaissance survey. This information was later used as base maps for other studies. For it has the capacity of mapping vegetation typically varying from 1 cm to about 1 m. It also has the advantage of penetrating cloud covered areas, where optical sensors cannot work. According to Mitchard (2011), repeat imagery from Radar satellite can detect forest degradation. However, it is not yet commonly used in studies of degradation and deforestation trends. This is because of the technicalities which are involved in data collection. It is technically difficult and requires extensive training; another challenge is the lack of timely access to suitable satellite data, sophisticated computing equipment and appropriate software (Mitchard, 2011).

Radar and laser-derived spaceborne or airborne remote sensing can also be used to capture data for estimating both volume and biomass stocks. Their accuracy depends on the ability to calibrate and validate measurements with field-based data. These technologies are still expensive and experimental but show promise, particularly for areas that are difficult to access in the field.

2.4.1.5 LiDAR Sensors

According to Pettorelli *et al*. (2014), fine-scale assessments require expensive imagery such as LiDAR – of light detection and ranging and highly specialised study. LiDAR provides a unique capability of measuring in the three-dimension vertical structure of vegetation (Lefsky *et al*., 2002; Lefsky, 2010, Asner *et al*., 2012; Pettorelli *et al*., 2014).

The word *Lidar* is another acronym which stands for light *detection and ranging* (Lillesand *et al*., 2008). It works in the microwave portion of the electromagnetic spectrum. This is a spectrum with wavelengths ranging from 1mm to 1m (Lillesand *et al*., 2008). With these long microwaves, they are able to penetrate the atmosphere under virtually all conditions. It can see through the haze, light rain, snow, clouds, and smoke.

Lidar remote sensors are active sensors. This technology involves transmitting pulses of laser light towards the ground and measures the time of pulse return to the sensor. It is mainly for measuring terrain, therefore, it is of little use in measuring the degradation and deforestation trends, though it can be used in determining individual tree crown shapes (Lillesand *et al*., 2008).

2.4.2 Remote Sensing for Mapping of Biomass/Carbon

Modern remote sensing techniques have been identified as potentially important tools in support of the Kyoto Protocol and its signatories; in the quantification of above-ground biomass stocks and associated changes therein (Tomppo *et al.*, 2002; Rosenqvist *et al.*, 1999). However, remote sensing data are useful for indirect estimation of biomass/carbon value, should be complemented with the ground truth data (involving physical measurements of the trees) to be incorporated into empirical biomass equations (Zianis *et al.*, 2005).

Notably, use of remote sensing data allows for coverage of a large area and provides for systematic observation systems and historical archives of data (Rosenqvist *et al.*, 2003). Remote observations in combination with *in situ* measurements can be useful in a developing country (like South Africa), where huge uncertainties exist in the estimation of biomass/carbon values (FAO, 2008).

For remote sensing studies at the local or regional level, satellite images with finer resolution instruments has been used, such as Landsat (Mabowe 2006; Krankina *et al.*, 2004; Tomppo *et al.*, 2002;); ASTER (Muukkonen and Heiskanen, 2005); and, IKONOS (Mabowe, 2006). Biomass cannot be directly measured from remote sensing data; however, remotely sensed reflectance can be related to the biomass estimates based on *in situ* measurements (Dong *et al.*, 2003). Reflections of the red, green and near infrared radiances contain considerable information about forest biomass. Two main approaches predicting biomass using satellite images are the use of Solar radiation; and, use of Reflection Coefficients (Namayanga, 2002), which is primarily determined by the green foliage biomass (Christensen and Goudriaan, 1993).

Using reflection coefficients, indirect estimates of carbon can be generated using empirical relationships established with vegetation indices such as the normalised difference vegetation index (NDVI) and enhanced vegetation index (EVI) based on photosynthetically active radiation (PAR) and up-to-date reliable *in situ* data on biomass (carbon) stocks in the forests (Rosenqvist *et al.*, 1999). Many studies have demonstrated that vegetation indices (VIs) or simple band ratio obtained from satellite data provide useful estimates of carbon biomass content (Foody *et al.*, 2003). High correlations between spectral bands and vegetation parameters make it possible to use satellite images for estimating biomass in inaccessible areas such as mountainous regions.

Direct biomass estimation may also be possible with vegetation Light Detection and Ranging (LIDAR) observations (Drake *et al.*, 2002). The potential of forest biomass mapping has also been explored using Radar (Gaveau *et al.*,, 2003; Tomppo *et al.*, 2002) along with JAXA ALOS-

PALSAR L-band (24 cm wavelength) which gives a lower range of biomass (up to 50-80 t/ha). The BIOMASS mission, which is expected to launch around 2020 by ESA uses a longer wavelength (68 cm) and shows the potential of estimating higher levels of biomass (FAO, 2008). It will provide crucial information about the state of our forests and how they are changing.

2.5 Monitoring Forest Degradation Using Satellite Images

Forest degradation and its associated impacts have drawn the attention of the scientific, environmental and policy-making bodies. Spatial distribution of forest is large and hence some places are inaccessible. Uncertainties exist in current estimates of forest degradation, mainly due to the confusing definition of forest degradation with that of deforestation and general lack of quantitative, spatially explicit and statistically representative data. The implementation of incentives for Reducing Emissions from Deforestation and Degradation in developing countries (REDD) requires robust and reliable methods for estimating forest degradation (UNFCCC, 2007).

For this reason, the importance of satellite images to identify forest degradation, at both national and international levels is increasing. However, these means have not been entirely effective to identify or contribute to reducing forest degradation. The role of remote sensing as a tool for degradation monitoring is an essential in natural resource management and is still in a testing phase. Remote sensing data can support inventory approaches by informing on degradation patterns in forests in combination with ground-based monitoring of forest degradation. Mapping forest degradation and related carbon emissions are more challenging than mapping deforestation (Souza, 2005). Identification of small and gradual degradation is often not easy using remote sensing data alone and contemporary *insitu* information is necessary. Images with spatial resolutions less than ~20-25 m can be used to detect changes in the land as small as 0.05 ha (Rosenqvist *et al.*, 2003).

2.6 How to determine the appropriate image resolution

There are various methods that can be used in determining forest degradation using Remote Sensing. In some cases, aerial photos or satellite images can be used. The most common used are Landsat images. Other images used are Advanced Space-borne Thermal Emission and Reflection Radiometer – ASTER, and images of higher resolutions such as SPOT images. According to Joshi *et al*., 2015, Radar and laser-derived space-borne or airborne remote sensing can be used for detecting deforestation and forest degradation.

In their study, Joshi *et al*. (2015) concluded that disturbances in the forest environment can be detected using a series of observations of radar backscatter. This can be achieved by Mapping deforestation and forest degradation as continuous progressions in space and time rather than discrete events. Satellite imaging radar data can benefit such monitoring by providing information on both the spatial distribution and dynamics of disturbances.

In some cases, full-cover (Wall to Wall) is used but in most cases, a sampling approach is applied. In a sample-based approach, observations are made in sampling units (sample area), while in a full-cover approach the entire area of interest, for example, a landscape, province or nation is measured.

Remote sensing observations can be used in particular to determine the extent or area of land-cover (or land-use) classes. This can greatly assist in extrapolating volume and biomass densities generated by field-based measurement over large areas and over time in repeated assessments to estimate changes in volume and biomass, or to stratify the design of field-based sampling.

2.7 Detection of alien species using remote sensing

An invasive alien species is defined as a species not native to a given forest type that has invaded the forest and is causing harm in forests (Pimental *et al*., 2000). The invasion of alien species can cause a change in forest state and a consequent reduction in biodiversity and other forest goods and services. Many forests have been degraded by invasive alien species (Chornesky *et al*., 2005). It is not easy to detect the invasion of alien species using Landsat or SPOT images. The invasion of alien species like *Lantana camala* and Wattle (*Acacia* species) are the most degradation problems experienced in the areas of the indigenous forests around PSJ. As already observed, it is not easy to detect these invasions using the commonly used remote sensing methods.

2.8 Detection of soil erosion using remote sensing

The presence of soil erosion in forests is a prime indicator of forest degradation. Soil erosion can have a major impact on a range of forest services, such as reduction in water quality, polluted watersheds with nutrients and sedimentation. These signs can be indicators of soil erosion. The results of soil erosion are a reduction in soil fertility which leads to a potential reduction of forest productivity hence degradation. In an extreme form, it can also restrict access to the forest and hinder the extraction of products such as timber. It is not easy to detect forest degradation of soil erosion using Landsat images (Dumanski & Pieri, 2000).

In conclusion, satellite imagery can be used to assess change in ecosystem diversity at a scale of broad forest types (or ecosystems), but not for finer-scale forest types. Identifying finer degradation requires special techniques and expertise which might not be currently available in developing countries, where forest classification systems against which to measure change are also lacking. Therefore the adoption to satellite based monitoring of forest changes using Landsat imagery is timely because their freely available and have higher multi-temporal.

2.9 Structure of a typical indigenous forest

Indigenous forests in South Africa (SA), refer to vegetation formations which are dominated by many trees which are indigenous to SA and with a minimum height of 10m when in maturity stage (Scholes, *et al*. 2004). A typical indigenous forest can be classified into four layers as shown in figure 1.1 below.

Figure 2:1 Structure of Indigenous forest (Scholes et al., 2004)

The outermost layer, also known as Emergent Layer (A), is the very top layer and composed of only tallest trees. It is also known as the overstory. Animals such as monkeys, snakes and bats reside in this layer. The next layer is the Canopy Layer (B). It is the thickest layer and much of the rain is stopped by this thick foliage. Most of the forest trees grow to this height. There are some of the trees that grow in this layer, whose roots do not reach the ground. These are called air plants. Animals found in this layer include birds, monkeys, frogs, lizards, snakes and insects. The third layer is called the understory (C). This layer has dense vegetation, but not much sunlight, as it is blocked by the canopy layer. Animals found in this layer include birds, butterflies, frogs and snakes. The lowest layer is known as the forest floor (D). This layer is dark, damp, full dead leaves, twigs and dead plants. It is usually clear of vegetation, with little or no rains and winds reaching there. It is estimated that only 2% of the sunlight actually reaches this layer (Scholes *et al*., 2004).

2.10 Image classification in forestry

According to Lennartz and Congalton (2004), accurately mapping forest cover types using remotely sensed data has proven problematic. High species diversity and spatial variability make creating training areas of spectrally “pure” classes of forest cover types difficult. But with the advancement of higher spatial resolution satellite sensors, this has allowed improvement in the accuracies of the mapping forest cover types. These accuracies have been further increased by image processing techniques such as hybrid forms of the supervised and unsupervised classification methods.

In the beginning (1970s), with the Landsat program, satellite sensors have developed from pixels having a spatial resolution of 80 meters, to today's orbital sensors discerning pixels at sub-meter resolutions (Lennartz and Congalton, 2004).

According to Hopkins *et al*. (1988) and Moore and Bauer (1990), depending on the classification scheme used and the image processing techniques applied, the success of the original Landsat MSS for forest cover type classification has varied considerably. But generally, this sensor has generally been unsuccessful mapping forest cover types because of its coarse spatial, spectral, and radiometric resolutions.

However, the advancements of the Landsat program with the launch of the Thematic Mapper brought increases in spatial, spectral and radiometric resolutions resulting in the increased abilities of researchers to accurately classify forest cover types (Hopkins *et al*., 1988; Moore and Bauer, 1990). Although the discriminatory abilities for mapping forest cover types were increased in TM, the spatial resolution of this sensor limits its minimum mapping unit for classification to several acres rather than individual trees (Schriever and Congalton, 1995). The successes of the TM sensor for forest classification have been largely attributed to the increase in spectral resolution, especially the addition of the middle infrared bands, with only slight benefits gained by the higher spatial resolution (Hopkins *et al*., 1988, Moore and Bauer, 1990; Wolter *et al*., 1995).

Salajanu and Olson (2001) concluded that the SPOT sensor, with multispectral spatial resolutions of 20m, was able to map forest cover types more accurately than the equivalent multispectral bands of Landsat TM. However, many other authors determined that increases in spatial resolution negatively affect the accuracy of per-pixel based maximum likelihood classifiers because of the increased within class spectral variability.

There is, therefore, a need to develop novel image processing techniques in order to fully exploit the informational content of higher resolution images (Irons *et al*., 1985; Cushnie, 1987; Johnson, 1994; Marceau *et al*., 1994; Lobo, 1997; Franklin *et al*., 2001). In their study, Carleer and Wolff (2004) used IKONOS data to map tree species in Belgium. They utilised a mean filter in a 3m by 3m, moving the window to reduce the intraclass variance of the data. This technique improved their classification's overall accuracy to 85%, but effectively degraded the spatial resolution of the image. The mean filtering also created a higher proportion of mixed pixels.

According to Irons *et al*. (1985), the increases in spatial resolution increase the informational content of an image, thereby increasing within class spectral variability, increased spatial resolution but it decreases the amount of "mixed" pixels relative to "pure" pixels, counteracting any detrimental effects caused by increased spectral variability. However, Carleer and Wolff (2004), pointed to a need for classification methods adopting regional techniques (image segmentation) in order to fully capitalise on the potential of very high-resolution images for forest classification.

Over the years, remote sensing classification projects have seen increased accuracy results by combining the techniques of both supervised and unsupervised classifications, a process referred to as a hybrid classification (Fleming *et al*., 1975; Chuvieco and Congalton, 1988; Bauer *et al*., 1994; Jensen 1996). According to Fleming *et al*. (1975), many variations of the hybrid technique have been developed over time. The hybrid classification has an advantage compared to the singular application either of its component classifications for it capitalises on each of the techniques' benefits while minimising their drawbacks (Lennartz and Congalton, 2004).

Therefore, many forest land managers throughout the 1980's were slow in adopting automated classifications as a form of inventorying due to unacceptably low classification accuracies (Skidmore and Turner, 1988; Moore and Bauer 1990; Bolstad and Lillesand, 1992). But the evolution of sensor technology and image processing techniques has brought ever-increasing abilities to accurately map forest cover types. The advance in automated image classification has brought it closer to becoming a practical solution for using remote sensing by forest managers in forest inventory and other management decisions.

2.11 Change Detection Procedures

The present study makes use of optical sensors like Landsat to determine change trends of vegetation, particularly indigenous forests around PSJ over the last three decades. There has been some forest rehabilitation underway on some degraded patches of indigenous forests since 1998. The efficacy of these rehabilitation efforts is one of the mysteries the present study set out to unravel.

Change detection using remote sensing is defined as the use of multi-temporal data sets to discriminate areas of land cover change between dates of imaging (Lillesand *et al*., 2007). The types of changes that might be of interest can range from short to long term phenomena such as snow cover or floodwater on the one hand and deforestation, desertification or urban fringe developments on the other. Ashbindu (1988) defines change detection as a process of identifying differences in the state of an object or phenomenon by observing it at different times. It involves the ability to quantify temporal effects using multi-temporal data sets.

Ideally, change detection procedures should involve data acquired by the same (or similar) sensor and be recorded using the same spatial resolution, viewing geometry, spectral bands, radiometric resolution, same time of the day and same season. Factors like the difference in atmospheric conditions, sun angle and soil moisture may affect the results (Jensen, 1983). Since the study is a long term one (1986 to 2013), this was not practically possible. The impact of these factors may be minimised by selecting appropriate data. Selecting Landsat data belonging to the same time of the year may reduce the problems from sun angle differences and vegetation phenology changes (Singh, 1988). In the present study, imagery taken during late summer were utilised, as vegetation is still distinctively green.

There are various methods that can be used to discriminate changes between two dates, such as post-classification comparison and multi-date composite image" change detection algorithms. The latter includes the principal components analysis and temporal image differentiating amongst others (Lillesand *et al.*, 2008). It is however not appropriate for the present study, owing to the vastly different characteristics of the temporal imagery, particularly due to sensor and spatial resolution. Post-classification comparison entails the comparison of two or more independently classified images. The accuracy of the procedures depends upon the accuracy of each independent classification used in the analysis. The errors present in each of the initial classifications could be compounded in the change detection process. The post-classification change detection technique is applied because it does not only give the size and distribution of changed areas (either negative or positive), but it also gives the percentages of other land cover classes that share in the change in each land cover class individual (El-Hattab, 2016). Therefore from the critical review of literature – remote sensing has proved vital in detecting changes in landscapes covered by forests which are achieved through image pre-processing, processing and post classification procedures.

Chapter 3 : STUDY AREA

3.1 Location

The study area is located between 31^0 35’S and 31^0 57’ S and is situated along the coastline of the Transkei region of the Eastern Cape Province (figure 3.1 and 3.2). The area stretches from Mthatha Town and runs along Mthatha River on the western side, to Umzimvubu River on the eastern side. The Mthatha – PSJ road (R62) marks the northern boundary of the study area, while the eastern boundary is the Indian Ocean. It comprises of the grasslands on the northern side and the coastal indigenous forests on the southern side. The area covered is within 3128D, 3129C and 3129D of the South African grid map, covering 1,690 km^2. The altitude ranges between 0 m at the coast to 360 m above sea level at the Port St. Johns airstrip. This area was selected because it is one of the most indigenous forested areas in the Eastern Cape. It has equally suffered forest degradation in the recent years.

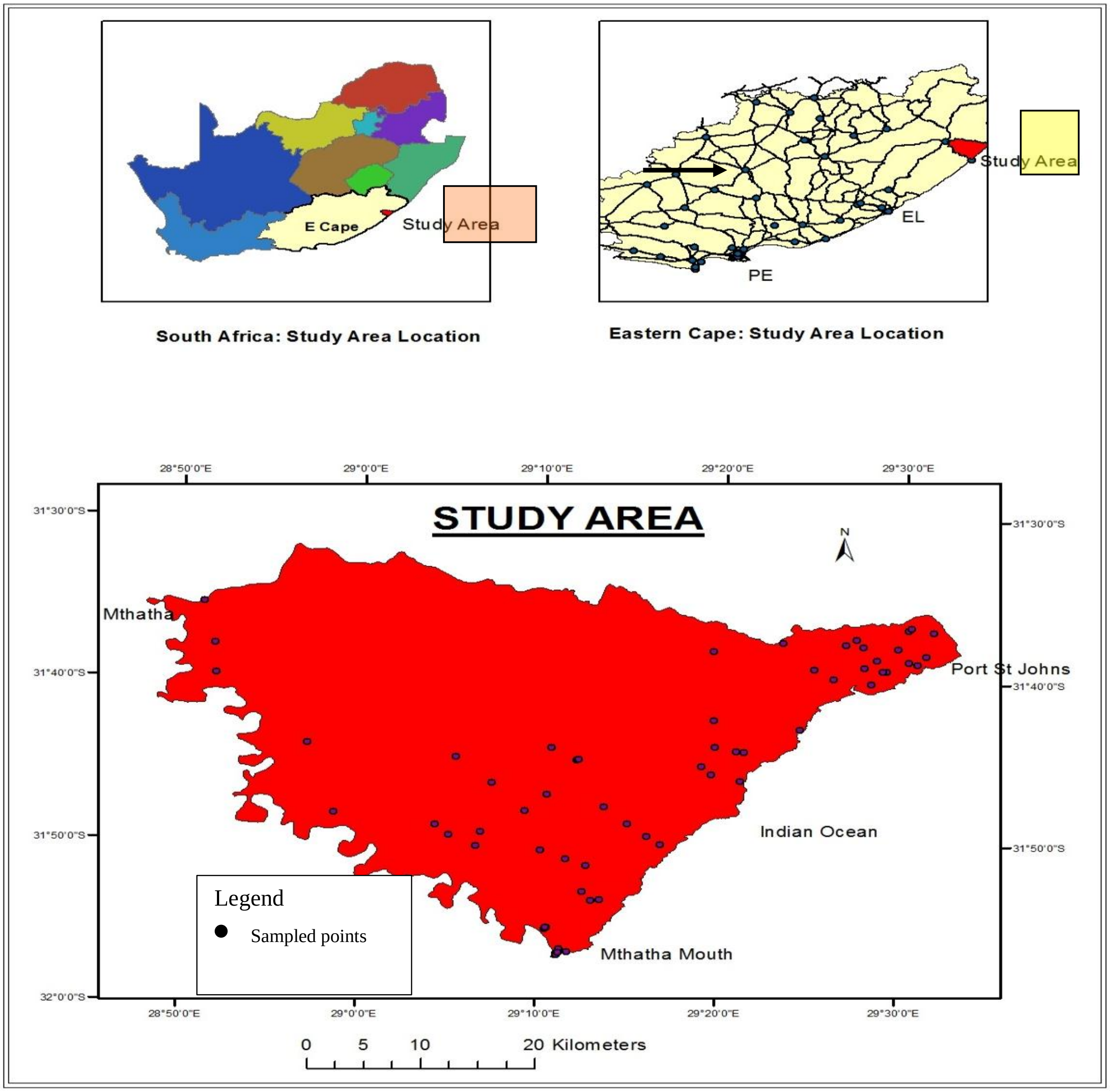

Figure 3:1 Study area location

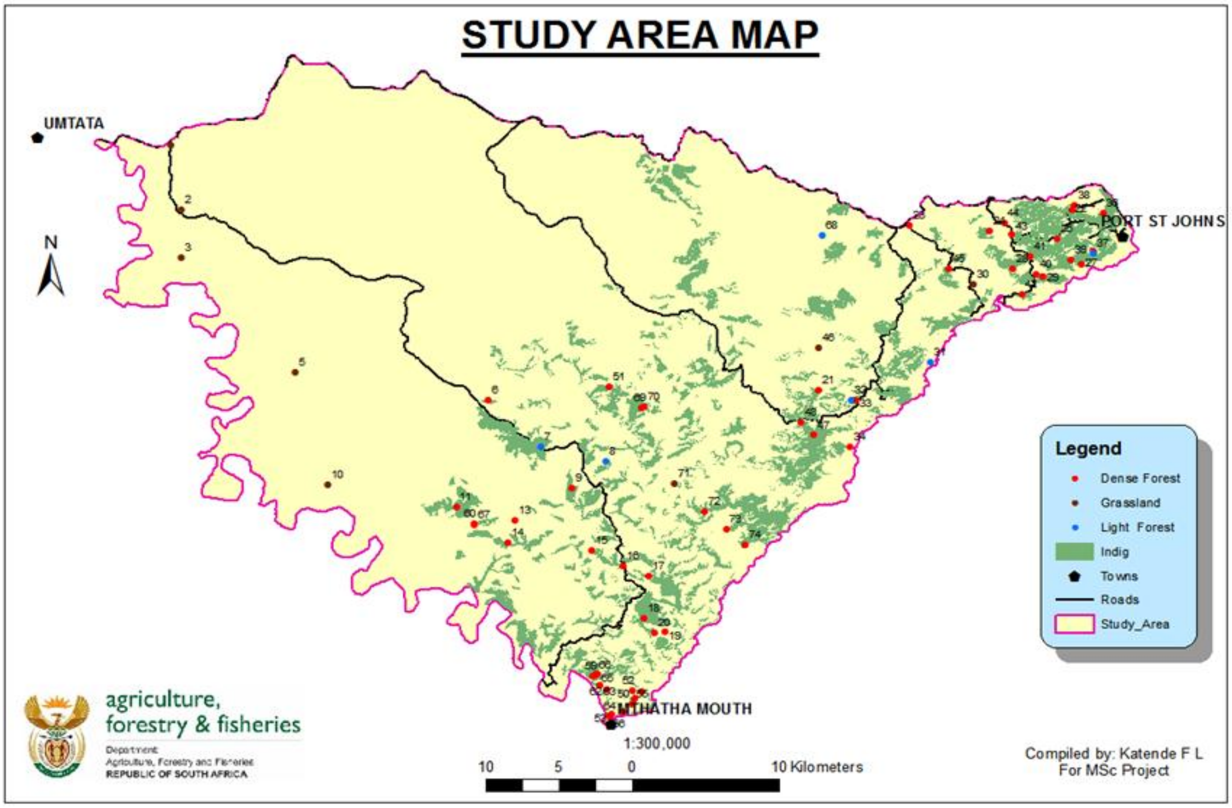

Figure 3:2 Study area showing locations of Indigenous Forests

3.2 Climate

According to Shone (1985), there are six climatic zones in Transkei, namely; The Drakensberg and Witteberg area, the High Plateau, the Escarpment, the Central Plateau, the Coastal Belt and the Rain Shadow and river Valleys. The study area of study falls under the Coastal Belt.

This area lies in the summer rainfall zone, with an average rainfall of 1000mm/annum (Shone, 1985; Katende, 2012). The rainfall is evenly distributed which is unlike in the Transkei inland. The coastal rain sometimes falls for several days. Peak rainfall months are December to March. January and June usually have the highest and lowest rainfall respectively. This area is snow and frost free. In summer the mean temperature ranges from 20^0 to 24^0 C and in winter it ranges from 11^0 to 18^0C (Shone, 1985; Katende, 2012). Port St. Johns has a very comfortable sub-tropical climate. A combination of mountains and the sea creates a temperate zone of its own.

3.3 Vegetation

According to Acock's (1953) vegetation classification, the study area falls under Coastal Tropical Forest type of vegetation. This type of forest is found below the altitude of 700m above sea level and receives rainfall of 500mm to 850mm/annum. The humidity is high; the vegetation is open thornveld with extensive forests. The thornveld is a combination of short grass, tall grass, shrubs and scattered patches of bush and forest. There are two types of thornveld; Ngogoni Veld and Eastern Province Thornveld along the coastal strip. The larger river valleys are dominated by the Valley Bushveld, where *Acacias* and *Euphorbias* species dominate; and two thornveld types.

According to Shone (1985) and Katende (2012), the coastal forests can be divided into three distinct types namely, the high forests, the dune forests and the mangrove forests. The high forests are characterised by big tree species such as *Millettia grandis* (umZimbeet), *Protorhus longofolia* (red beech, umHluthi) and *Cussonia spicata* (Cabbage tree, umSenge). They reach an average height of 20m. Movement within the forest is relatively easy except at the fringes and the river beds which tend to be dense.

The dune forests consist of a narrow strip of trees. On the seaward side, growth is stunted due to salt – laden sea breeze. On the inland side of the dunes, trees reach a height of 10 m. The dominant species in the dune forests are; *Mimusops caffra* (red milkwood, umHlophe) and *Allophylus natalensis* (umCandathambo). The importance of the dune forests is to stop sea sand from moving inland (Shone, 1985, Katende, 2012). It also provides shelter for recreational purposes.

The mangrove forests exist in mud flat areas mostly along the river mouths. The typical species are *Avicennia marina* (white mangrove), *Bruguiera gymorrhiza* (Black mangrove), and *Hibiscus tiliaceus* (lagoon hibiscus, umHolwa).

3.4 Geology and soils

The area is dominated by Beaufort sandstones of the Karoo System, with bands of the older Ecca and Dwyka series along the coast. The resultant soils are generally deep and acidic. They are highly leached and occasionally poorly drained (Shone, 1985; Katende, 2012).

3.5 Relief

Most of the area along the coastline consists of fairly steep slopes rising rapidly inland and often includes long stretches of the beach. Most of the coastline has been uplifted or created by falling sea levels in the recent geologic past (Van Eack *et al*., 1997). According to Shone (1985), much of the terrain of the coastal forests consists of steep escarpments and river gorges.

3.6 Natural habitation

The indigenous forests of Port Saint Johns are rich in a great variety of fauna and flora. Some of the animal and bird species threatened by extinction are found in this area. These include the Spotted Thrush, Barred Owl, Mangrove Kingfisher and Cape Parrot, Samango Monkey, Tree Dassie, Giant Golden Mole and Blue Duiker. There are valuable tree species found in this area, such as Giant Umzimbeet (*Millettia sutherlandii*), Forest Mahogany (*Tichilia dregeana*), Forest Ironplum (*Drypetes gerrandii*), Forest Fever Berry (*Croton sylvaticus*), Forest Bushwillow (*Combretum krausii*), and Small-leaved Jackal-berry (*Disopyros natalnesis*). There are rare and threatened trees such as Transvaal Stinkwood (*Ocotea Kenyensis*), Forest Potato Bush (*Phyllanthus macnaughtonii*), and Forest Canary-berry (*Suregada procera)* found in the area. Therefore, there is a great need to protect these indigenous forests.

3.7 The anthropology of PSJ

The community in this area is composed of a mixture of Pondo, Bomvana, Pondomeise, Tembu and Xhosa tribes. IsiXhosa is the predominantly used language in the area. Communities live under traditional leaders, the chiefs and retain the customs and traditions of their cultural groups. Most of the land is communal land, as according to 1913 Land Act. This means that Africans could not purchase land; all the land is held under a system of trust tenure. This limits the chances of land inheritance. This policy on communal land has a strong influence on the degradation of natural resources over the long term (Ainslee *et al*., 1996). Indigenous forests are used for cultural rituals and some tree species are used as traditional medicine.

Historically, traditional leaders had the responsibility of managing limited resources. They used to control the harvesting of live wood from the forests. But with time and due to political influence, the traditional control has become weak, and Government regulations have not kept abreast with reality on the ground (Shackleton, 1993). This has resulted in forests and woodlands being overutilised in many areas, including PSJ. With increased population, demand for forest resources has outstripped supply in most forests, resulting in depletion of dead wood resources and turn to the harvesting of live wood (Shackleton, 1993). For example, *Millettia grandis* which is a pioneer tree on the forest margin or on areas which are undergoing natural rehabilitation is at the same time the species which is in high demand by communities for building poles and woodcarving (Geldenhuys, 2002; Obiri 2002).

Rural poverty has forced people to pursue unsustainable practices which satisfy basic needs or offer quick cash returns. In PSJ, young indigenous trees are cut for firewood and sold along the roads. Poor Communities do not see any immediate cash value from indigenous forests, leading to an undervaluation of the resource. According to Muir (1990), some of the forests were subjected to commercial timber harvesting in the past but that that is no longer an immediate threat. According to him the threat recently is the subsistence harvesting of poles and firewood which exert pressure on the Eastern Scarp forests, which is the area of study.

There is a land claim by the communities on most of the indigenous forest gazetted land. This creates friction between Forest Managers and the local communities, which results in the destruction of indigenous forests. Indigenous Forests on the private land are protected under the Forest Act (Act 84 of 1984). Maize, beans, pumpkins and millet are the most commonly grown crops. Most of the families keep cattle, goats and chickens. With an increase in population, there has been tremendous pressure on forest land to create space for crop growing and grazing area.

The most commonly used tree species for a variety of uses are sneezewood, mangroves, pistol bush and monkey – rope. Fuelwood is the most commonly used means of cooking and warming the houses; it is estimated that over 90% of households in some villages obtain fuelwood from forests (DWAF, 2005). Wood is used for hut construction and fencing. Edible plants in form of fruits, wild spinach, fungi and roots, carvings, honey, hunting (which is an important source of protein in some areas), and grazing. Forests are considered an important winter resource of grazing while surrounding areas provide poor winter fodder (DWAF 2003, 2005).

It is estimated that about 80% of South Africa's population relies on traditional healers for their health needs. Medicinal plants are considered to be important subsistence products to local communities. But also they are often illegally harvested and sold at formal and informal markets across South Africa (Williams, 2004; DWAF 2005). Trade in medicinal plants in South Africa is a multi-million Rand hidden economy, largely operating from the main urban centres (Williams 2004). In 1997 there were an estimated 27 million consumers of traditional medicine and 100 000 practising traditional healers in the country.

According to Mander *et al.* (1997), traditional medicines trade in South Africa is a large and growing industry. There are some 27 million consumers of traditional medicine and the trade of these medicines contributes to an estimated R2.9 billion to the national economy. Medicinal plant species sourced from forests made up 49% of all species in the Durban markets Mander (1997). Williams (2004) found that 62% of all species (482 in number) traded at the Faraday Market in Johannesburg were forest or woodland species.

It is difficult to determine the rate of use of subsistence forest products. Lawes *et al.* (2004) and Shackleton *et al.* (2001) believe use is on the increase. In some areas, the use rates are already unsustainable. This is supported by the fact the number of medicinal plant gatherers is on the increase but the source is on the decline. Some of the species are under the threat of extinction such as high-value species like *Ocotea bullata*, *Siphonochilus aethiopicus* and *Warburgia salutaris*) (DWAF, 2005).

All these factors put more pressure on the indigenous forests. PSJ is among the areas with highest unemployment rate in South Africa. Cutting of indigenous tree species for sale as firewood along the main roads is common.

3.8 Economic activity of the communities in the Study area

PSJ Town which is part of the study area is a major tourist destination in the Eastern Cape. There is a high potential for the tourism industry in the area. This is because of the excellent climate throughout the year, excellent rivers, mountains and magnificent beaches.

Despite the fact that the soils and climate of PSJ are suitable for agricultural crops such as bananas, avocado, mangos and maize, crop production contributes very little to the local economy. It is subsistence farming practised in most areas. This consists of mainly poultry farming and food crops such as vegetables and maize. Commercial farming is minimal and is focused on spinach, cabbage and green maize. PSJ has two categories of Forestry, the indigenous forests and gum plantations. Most of the forests are owned by the state as state land managed through DAFF. Other forests are owned by communities.

According to Powell (2010), decades of intensive livestock farming have caused extensive degradation of large areas of the subtropical thicket vegetation. As far back as 2004, projects for the rehabilitation of degraded areas started in coastal forests around PSJ. These projects are run by Government Departments such as Department of Environment Affairs and Tourism (DEAT), Department of Agriculture, Forestry and Fisheries (DAFF) by means of the ‘Working for Water and Working for Woodlands’ programmes. Private bodies are also involved in the rehabilitation projects, such as Subtropical Thicket Restoration Project.

3.9 Encroachment on indigenous forest

With the settlement of the European in southern Africa since 1652, large diameter trees of selected species were harvested for building, furniture and railway sleepers (Geldenhuys, 2002; King, 1938 &1941; Phillips, 1963; McKenzie *et al.*, 1977; Scheepers, 1978; Cawe, 1986). But in the Eastern Cape Province, this stopped a long time ago. The most damage to indigenous forests re-emerged in the early 1990s.

Following the 1994 democratic dispensation, there were rumours that land which was managed by Government (including indigenous forests), would be returned to the local communities. On this basis, local communities invaded indigenous forests, felled trees and started cultivating land and settling in state land. This practice continued until 1999 when the new Indigenous Forest Management (IFM) unit was established in DWAF. The main work of this unit at the time was to halt the continuous invasion of the indigenous forests and to drive out those who had already settled in the forests. Intensive awareness campaigns were started by the Department and other organisations like Non-Governmental Organisations (NGOs) and institutions like Universities.

Where communities were removed from the indigenous forests, restoration projects were put in place. Projects like *Working – for – Woodlands* Program which was started by DWAF were introduced in the area. In 2004, the Department of Environmental Affairs and Tourism (DEAT) approached private companies like Environmental Offset Investments (EOI) to rehabilitate Coastal Forests of the Eastern Cape (Powel, 2006). The subsequent chapter presents field methodologies of how the study collected and processed both primary and secondary datasets.

Chapter 4 : MATERIALS AND METHODS

4.1 Introduction

This chapter shows methodologies outlined to address the stated study objectives through data capture, processing, analysis, presentation and quality control.

4.2 Assessment of changes in indigenous forests degradation and deforestation around PSJ between 1986 and 2013

4.2.1 Satellite images

A series of multi spatial-temporal Ortho-rectified and cloud free (0%) Landsat TM/ETM+ satellite images of the 30m spatial resolution were downloaded (http://glovis.usgs.gov) and analysed to quantify changes in forest degradation and deforestation. The selection of Landsat images in the present study was based on availability, frequent repeat cycle and ability to detect degradation over larger areas (Alberti *et al.* 2004; Goetz *et al.,* 2004; Yang, 2002). The selection was also made on the basis of availability and sequential summer season image capture of the images. The target period of the year was from March to May on a five-year interval (1986, 1991, 1996, 2001, 2006, 2011 and 2013) where a distinctiveness of degradation and deforestation was easier to define. The image specifications of the downloaded Landsat scenes for 1986, 1998, 2002, 2010 and 2013 years are presented in Table 4.1.

Table 4:1 Landsat image specifications

Years	Satellite/ Sensor	Date	Path	Row	Band No.	Resolution (m)
1986	Landsat TM	1986-04-09	169	82	3,2,1	30
1998	Landsat		169	82	3,2,1	30
2002	Landsat	2002-06-09	169	82	3,2,1	30
2010	Landsat TM/ETM	2010-05-06	169	82	3,2,1	30
2013	Landsat OLI	2013-06-15	169	82	3,2,1	30

4.1.1 Selection of training samples

A total of 500 training samples of representative sites were identified and used to validate the images because of their complexity and wider coverage. A sufficient number of training samples and their representativeness are critical in deforestation and forest degradation assessment. The random representative samples lying within the study area were generated using the prevalent land use dataset and Google Earth image (Astrium) of 2013 (see Figure 2.1).

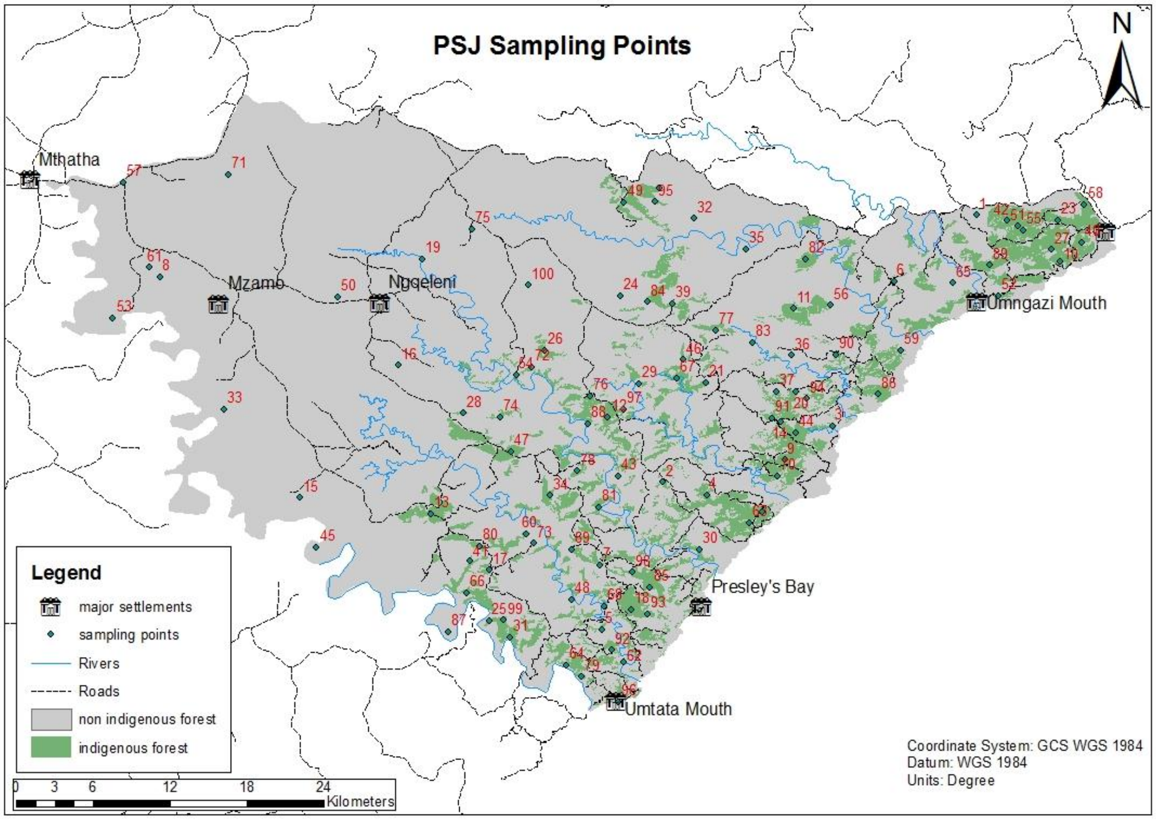

Figure 4:1 Sampling points in the study area in Port St John's

Table 4:2 Description of indigenous forest cover classes

Class Code	Class name	Description
1	Dense Forest	Thick vegetation stands evergreen trees forming a dense canopy
2	Light Forest	Evergreen trees formed of shrubs and woodland. In most cases composed of Acacia and *Lantana camala*
3	Grassland	Mainly grassland with scattered trees.
4	Non Vegetation	Areas without vegetation cover (Bald soil patches, exposed rocks, landslides, roads, buildings and airstrip),
5	Open Water	Rivers, streams, dams and ocean

In this case, 5 forest classes were defined: Dense forests, light forests (Shrubs and woodland), grassland, non – vegetation (buildings, bare surfaces) and water (Streams, rivers, dams and ocean). Examples of each class are given in Photo 1 to 5 attached as Appendix 3. This classification is based on a standard land-cover classification as described by Thompson, 1996 (Appendix 2). This is a South African (SA) classification system, but it is linked to existing or proposed land cover classification designs and datasets at both national (SA), regional (Southern African) and international levels (FAO's AFRIC-OVER) (Thompson, 1996).

4.1.2 Image pre-processing

The images were geometrically corrected due to differences in the sensors. Through this technique, visual identification of identical points (i.e. ground control points (GCPs), including those that were collected during field surveys using Differential Global Positioning System (DGPS), was done on both the image and the topographic map. Afterward, the satellite images were geometrically corrected using the polynomial transformation process and the Universal Transverse Mercator (UTM) projection system. The overall root mean square (RMS) error value of the final images produced ranged from 0.3 to 0.5 pixel, which was an acceptable error value for this study. Thereafter, the images were atmospherically corrected using the Dark Object Subtraction calibration algorithm.. Features in the images were selected based on the decision boundary feature extraction to reduce data redundancy inherent in the images. A maximum of three bands was used in the feature extraction from each period deemed appropriate to extract forest degradation features. The band combination allowed the implementation of the supervised classification algorithm. According to Lillesand and Kiefer, (1994), Courteney, (1997), the combination of bands 3,2 and 1 was found to be very effective in monitoring tropical deforestation and degradation in coast forests.

4.1.3 Image Processing

The overall objective of the image classification was to automatically categorise all pixels in an image into forest cover classes or themes (Lillesand and Kiefer, 1994). The images were classified using supervised classification algorithm to characterise the general extent of changes in and around the forested landscape. The supervised classification algorithm was used because of the elaborate *apriori* knowledge of the study area. The algorithm is also proficient in extracting quantitative information from remotely sensed image data. The maximum likelihood classifier was used to carry out supervised classification. The spectral signature library that was produced through the training stage, both in the laboratory and field, was fed into the maximum likelihood classifier to classify the satellite images. The image pre- and post- processing classifications were conducted in Idrisi Selva remote sensing software.

4.1.4 Post-classification

Many change detection techniques have developed recently; the most commonly used are image differencing, principal component analysis and post-classification comparison (Lu et al., 2004). The post-classification change detection technique was chosen for use in this study, because it does not only give the size and distribution of changed areas (either negative or positive), but it also gives the percentages of other land cover classes that share in the change in each land cover class individually.

Post-classification also bypasses the difficulties in change detection associated with the analysis of images acquired at different times of the year or by different sensors. An important advantage of this method is that it reduces the impacts of atmospheric, sensor and environmental differences between multi-temporal images, providing a complete matrix for change information.

4.1.5 Accuracy assessment

Overall accuracy, producer's and user's accuracies as well as Kappa statistics were generated from the error matrices. Kappa statistics has become a standard methodology for evaluating the accuracy of classified thematic maps which are produced from remotely sensed digital images by comparing them with either a sample of ground control points (GCPs) or with a reference map produced by photo – interpretation **(**Courteney, 1997). The reference dataset was based on ground truthed data collected and crossed with classified images to determine the classification accuracies for all the years given the historical and present prevalence of forest cover types – which information was obtained on interviews of forest managers. It is the correspondence between the remotely sensed data and the reference information (Congalton, 1991). In thematic mapping from remotely sensed data, the term accuracy is typically used to express the degree of correctness of a map or classification (Giles, 2001).

The accuracy assessment results revealed that the classified image/result for the 1998 year posted the highest overall Kappa classification accuracy compared to the 2013, 2010, 2002 and 1986 period. The error matrix results are presented here below in tables 4.3-4.7

Table 4:3 Accuracy Assessment of the year 1998

		Results 1998	
	Forest cover classes	**User accuracy (%)**	**Producer accuracy (%)**
Classified image	Non Vegetation	84.6	90.2
	Grassland	85.2	76.9
	Dense Forest	89.2	82.8
	Light Forest	72.2	76.4
	Open water	87.9	93.1
	Overall accuracy %	83.6%	
	Overall Kappa statistics	0.795	

Table 4:4 Accuracy Assessment of the year 2013

		Results 2013	
	Forest cover classes	**User accuracy (%)**	**Producer accuracy (%)**
Classified image	Non Vegetation	86.5	86.5
	Grassland	82.2	66.4
	Dense Forest	79.4	64.4
	Light Forest	47.2	75.6
	Open water	94.7	92.7
	Overall accuracy	76.20%	
	Overall Kappa statistics	0.701	

Table 4:5 Accuracy Assessment of the year 2010

		Results 2010	
	Forest cover classes	**User accuracy (%)**	**Producer accuracy (%)**
Classified image	Non Vegetation	88.57	91.1
	Grassland	84.8	77.2
	Dense Forest	86.6	67.7
	Light Forest	63.4	82.9
	Open water	94.1	94.1
	Overall accuracy %	82.2	
	Overall Kappa statistics	0.777	

Table 4:6 Accuracy Assessment of the year 2002

		Results 2002	
	Forest cover classes	**User accuracy (%)**	**Producer accuracy (%)**
Classified image	Non Vegetation	86.91	91.1
	Grassland	82.4	66.6
	Dense Forest	88.2	68.8
	Light Forest	55.2	74.7
	Open water	85.2	96.1
	Overall accuracy %	78.2%	
	Overall Kappa statistics	0.728	

Table 4:7 Accuracy Assessment of the year 1986

		Results 1986	
	Forest cover classes	**User accuracy (%)**	**Producer accuracy (%)**
Classified image	Non Vegetation	84.2	89.8
	Grassland	84.4	76.1
	Dense Forest	86.2	79.7
	Light Forest	66.6	76.4
	Open water	86.7	83.3
	Overall accuracy %	81%	
	Overall Kappa statistics	0.762	

4.2 Identification of forest degradation and deforestation in PSJ over the past 3 decades

The Landsat imagery (1986, 1998, 2002, 2010 and 2013 years) were useful in determining deforestation and degradation as temporal variations in the land area of forested landscape. The forest landscape structure and its patchiness can demonstrate scale of deforestation and degradation if any in a given landscape. The landscape metrics were computed for each year in this regards using the FRAGSTATS software.

FRAGSTATS, developed by the Forest Science Department, Oregon State University, U.S.A., is a program for quantifying landscape structure. The software produces several metrics: areas, patch density, size and variability, edge, shape, core area, and diversity.

FRAGSTATS can calculate several landscape metrics. However, many of them are highly correlated. In our analysis of the landscape structure at the class level, 11 indices were selected, including Class Area (CA), Percent of Landscape (PLand), Number of Patches (NP), Largest patch Index (LPI), Mean Patch Area (Area_Mn), Mean Shape Index (Shape_Mn), Mean Fractal Dimension Index(Frac_Mn), Perimeter Area Fractal Dimension (PAFRAC), Mean Euclidean Nearest Neighbor Distance (Enn-Mn), Mean Proximity Index (PROX_MN) and Interspersion Juxtaposition Index(IJI). For the analysis of landscape structure at the landscape level, 15 indices were selected, including Total Area(TA), Percent of Landscape(PLand), Number of Patches(NP), Largest patch Index (LPI), Mean Patch Area (Area_Mn), Mean Shape Index(Shape_Mn), Mean Fractal Dimension Index (Frac_Mn), Perimeter Area Fractal Dimension (PAFRAC), Mean Euclidean Nearest Neighbor Distance (Enn-Mn), Mean Proximity Index(PROX_MN), Contagion (Contag), Interspersion Juxtaposition Index (IJI), Patch Richness(PR), Shannon’s Diversity Index (SHDI), and Shannon’s Evennes Index (SHEI).

The definition and description of these indices that used in FRAGSTATS are given by the FRAGSTATS user’s guide (McGarigal and Marks, 1995). The raster version of FRAGSTATS was used in our analysis to ensure that a great number of indices could be calculated.

4.2.1 Effectiveness of rehabilitation efforts in the study area

In this study, rehabilitation was defined as areas formerly deforested or degraded that are under reforestation to rejuvenate forest cover density. The efficiency of forest rehabilitations was examined through key informant interviews, reports and field visits.

1. **Interviews**

   The information of the rehabilitated areas over the years was obtained from the respective IFM Estate Managers. The information was given in a format of rehabilitated area number, hectares, a method of rehabilitation and year. The rehabilitated areas range from 4.8 to 0.6 ha in size.

2. **Reports**

   Published and unpublished reports were obtained and reviewed to obtain historical and supplementary information on the extent, deforestation and rehabilitation of the forest. This information was collated with the results of satellite image analysis.

3. **Google earth mapping**

   Google Earth engine offers an opportunity to monitor changes in a wide range landscapes. The uploaded images on the engine are freely available and offered a high multi-temporal resolution. The engine was downloaded and used to monitor rehabilitation efforts over time. Astrium –CNES (2016, 2013, 2002, and 1998) based satellite images were used to highlight both rehabilitated and un-rehabilitated areas. These sites were identified through plotting the field collected coordinates using GPS units and visual verification on Google Earth.

4. **Field visits**

   The visits were conducted around the forest to validate the rehabilitated sites in accordance with the information provided by the forest managers. This activity was conducted in-conjunction with the ground truthing exercise to capture the different forest classes using GPS units. The rehabilitated sites were crosschecked, mapped and visually described.

The above paragraph marks the end of chapter 4, however the next section is chapter five that shows results following the chorological order as per the stated objective in chapter one.

Chapter 5 : RESULTS

5.1 Introduction

Chapter 5 presents results of the study ranging from the analysis of extent of changes in indigenous forests, forest degradation to deforestation. The results are presented in form of graphs, tables and map. This chapter also carries interpretations of the presented results.

5.2 Extent of changes in indigenous forests around PSJ between 1986 and 2013

Table 5 shows the extent of indigenous forest cover between 1986 and 2013. It reveals that the study area experienced quite stable dense forest cover and an increase in the area of light forest cover during the same period. The non-vegetated areas however increased in forest coverage from 2002 to 2013 (Table 5.1). The increasing trend in the area occupied open water in the study area is also noticeable.

Table 5:1 Extent of indigenous forest cover between 1986 and 2013

	1986		**1998**		**2002**		**2010**		**2013**	
Forest cover classes	**Area (Ha)**	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**
Dense forest	15,830	9.4	24,900	14.7	30,650	18.1	37,200	22	31,000	18.3
Light forest	49,120	29.1	44,900	26.5	32,430	19.2	41,400	24.5	45,900	27.1
Grassland	91,520	54.2	69,500	41.1	80,580	47.7	56,000	33.1	50,200	29.7
Non-vegetation	11,850	7.0	29,200	17.3	22,980	13.6	31,500	18.6	39,500	23.4
Open Water	620	0.4	500	0.3	2,290	1.4	3,000	1.8	2,400	1.4
Total	168,940	100	169,000	100	168,930	100	169,100	100	169,000	100

Whereas the dense forest area increased by 5% between the years 1986 and 1998, it experienced a slight reduction of 3.7% during the 2010-2013. The light forests recorded the highest forest depletion between the 1986-2002 period before recovering between 2010 and 2013 (Table 5.2).

Table 5:2 Changes experienced in indigenous forest

Forest/land cover classes	**1986-1998**	**1998-2002**	**2002-2010**	**2010-2013**
	%	**%**	**%**	**%**
Dense forest*	5.3	3.4	3.9	-3.7
Light forest*	-2.6	-7.3	5.3	2.6
Grassland**	-13.1	6.6	-14.6	-3.4
Non vegetation**	10.3	-3.7	5	4.8
Open Water**	-0.1	1.1	0.4	-0.4

Key:

*Forest classes

** Non forest classes

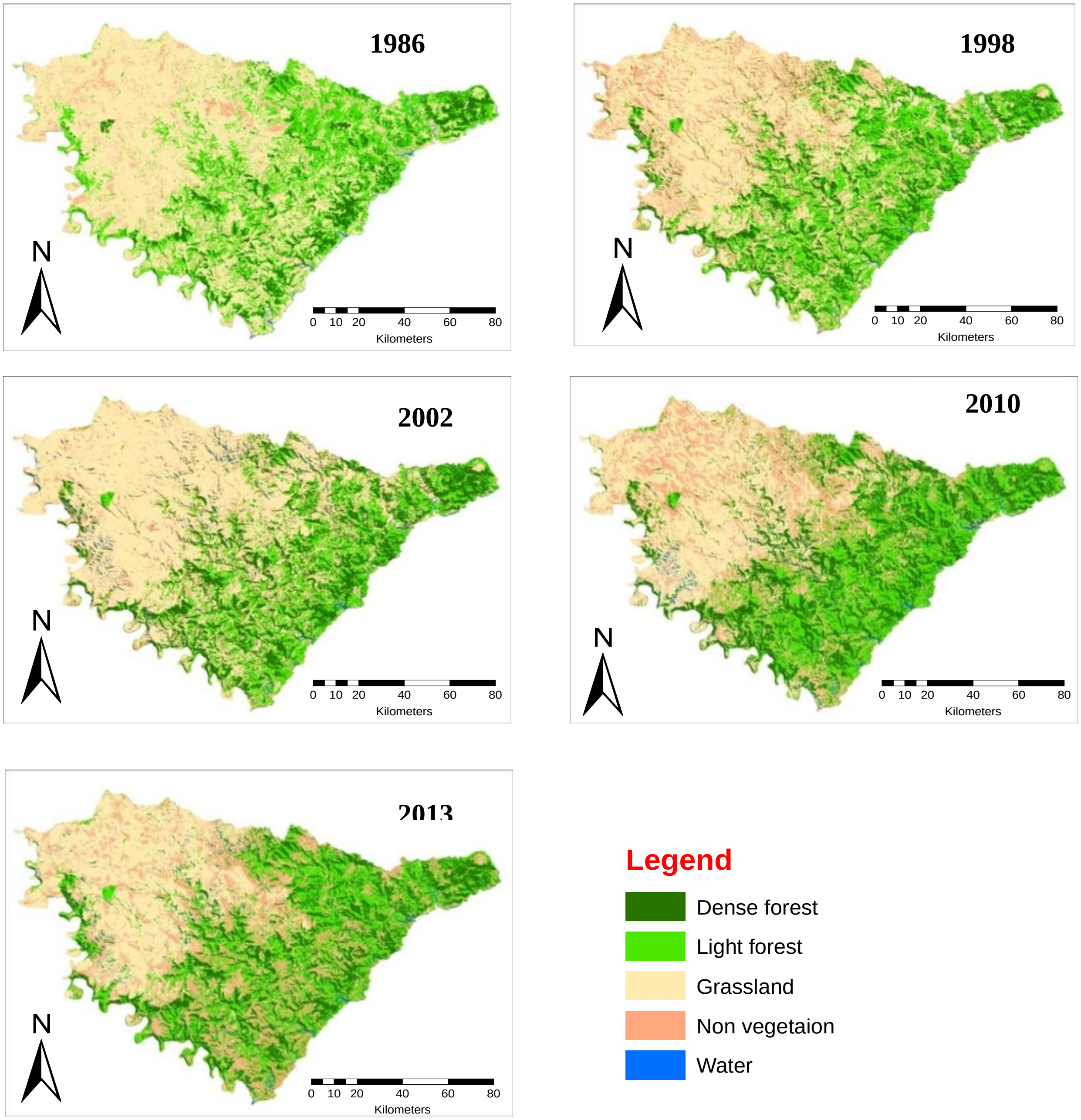

Figure 5:1 Extent of forest degradation and deforestation

5.3 Forest degradation and deforestation in PSJ over the past 3 decades

Patch class tables below show landscape metrics at the class level which demonstrates the indices of different patch types, while the landscape tables illustrate the landscape indices of the area of study. From the comprehensive analyses of the two tables (class and landscape) and the maps, the results presented as below.

5.3.1 Landscape level

From the table below 5.3 the highest number patches were recorded between 2002 and 1998, followed by between 2010 and 2013 and lastly 1986. Based on spatial connectedness of patches, the year 1986 had the highest landscape connectedness of forest vegetation (CONAT = 35.3) followed by 2002 and 1996 while the year 2010 and 2013 had the lowest landscape contiguity.

Table 5:3 Landscape level 1986 -2013

Year	TA	NP	LPI	AREA_MN	SHAPE_MN	FRAC_MN	PAFRAC	PROX_MN	ENN_MN	CONTAG	IJI	CONNECT	PR	SHDI	SHEI
1986	168908.3	4078	39.1737	41.4194	1.2419	1.0279	1.6335	209.4952	508.204	35.3905	62.125	98.7509	5	1.1198	0.6958
1998	168930	5558	28.6975	30.394	1.2575	1.0308	1.6297	123.6906	473.4592	23.1759	73.956	98.7635	5	1.3229	0.8219
2002	168933.6	6234	36.0116	27.0987	1.2228	1.0281	1.6325	98.3407	485.0009	24.547	82.4344	98.8121	5	1.3066	0.8118
2010	168958.8	5157	25.2548	32.763	1.2456	1.028	1.6371	110.4788	492.2359	20.3723	77.5595	98.8004	5	1.405	0.873
2013	168922.7	5075	25.9697	33.2853	1.2654	1.0293	1.6353	140.6954	510.5028	20.1015	77.988	98.2779	5	1.4252	0.8855

5.3.2 Landscape class level for year 1986

The main patch types were Light Forests and grassland having rough grains and covering 83 percent of the total area. The common structural characteristics of the two types are the distance between the patches and interspersion and juxtaposition index. Light forests have the largest patch index, mean patch area, mean shape index, mean fractal dimension index, mean proximity index and perimeter area fractal dimension. Of the two, grassland has a small proximity index indicating high continuity and a larger patch. Non-Vegetation has the highest number of patches and a smaller proximity index indicating more fragmented patches sparsely distributed and with the lowest interspersion and juxtaposition index implying that there are fewer, unevenly distributed patches. Water has the highest interspersion and juxtaposition implying that it is unevenly distributed, and it covers 0.3 percent of the patches with the highest distance between the patches. Dense forests cover 9.4 percent of the patches with a low interspersion and juxtaposition index compared to light forest, grassland and non-vegetation. This implies that it has a few, unevenly distributed patches. The high number of patches and low proximity index of dense forests implies larger patch sizes.

Table 5:4 Class level for 1986

TYPE	CA	PLAND	NP	LPI	AREA_MN	SHAPE_MN	FRAC_MN	PAFRAC	PROX_MN	ENN_MN	IJI
Light Forest	91412.42	54.1196	597	39.1737	153.1196	1.435	1.0403	1.6388	973.9526	412.1551	64.0067
Grassland	49121.27	29.0816	1113	12.3426	44.1341	1.3021	1.0297	1.6748	234.6218	459.6835	61.944
Non-Vegetation	11909.39	7.0508	1471	0.1539	8.0961	1.1289	1.0206	1.6283	2.5851	521.765	48.7247
Dense Forest	15909.27	9.4189	803	1.261	19.8123	1.2434	1.0314	1.5841	9.8299	532.423	50.3187
Water	555.94	0.3291	94	0.0235	5.9143	1.0615	1.0105	1.5233	0.4436	1273.615	84.5872

5.3.3 Landscape class level for year 1998

The main patch types were Light Forests and grassland covering 67.7 percent of the total area. Light forests have the largest patch index, mean patch area, mean shape index, mean proximity index and mean fractal dimension index. Of the two, grassland has a small complex index indicating high continuity and larger patches. Non-Vegetation covers 17 percent and has highest number of patches and a smaller proximity index indicating more fragmented patches. It has the lowest interspersion and juxtaposition index implying that there are fewer, unevenly distributed patches. Water has the highest interspersion and juxtaposition index implying uneven distribution of the patches. Water covers the smallest percentage of the patches of about 0.4 that are sparsely distributed of about 1271 m between the patches. Dense forests cover 14.9 percent of the patches with a relatively low patch index, mean shape area, proximity index. The similarity among classes except water is the mean distances between the patches 450 meters.

Table 5:5 Landscape class level for year 1998

TYPE	CA	PLAND	NP	LPI	AREA_MN	SHAPE_MN	FRAC_MN	PAFRAC	PROX_MN	ENN_MN	IJI
Grassland	44511.3	26.349	974	7.4559	45.6995	1.2989	1.0289	1.6664	178.3165	476.1694	78.1376
Light Forest	69936.53	41.3997	1073	28.6975	65.1785	1.3119	1.0351	1.6193	447.0502	422.9344	72.8122
Non-Vegetation	28681.45	16.9783	2164	0.8291	13.2539	1.2222	1.0302	1.6475	8.8867	441.2853	64.5307
Dense Forest	25136.43	14.8798	1204	0.9787	20.8774	1.2676	1.0326	1.5937	12.3154	479.3916	70.9957
Water	664.24	0.3932	143	0.0214	4.645	1.0182	1.0044	1.4405	0.3415	1271.047	97.7049

5.3.4 Landscape class level for year 2002

Light Forests is the main patch type covering 47.97 percent of the total area. Light forests have the largest patch index, mean patch area and mean proximity index. Dense forest, grassland and non-vegetation covered about 50 percent of the total class area. Comparing the number of patches and the proximity index of the three classes, all fragmented in many small rough grains and a fewer uneven distribution of the patches. The similarity between dense forests and grassland was that they both have the same nearest neighbour distance of 477 m close to that of light forests and non-vegetation that is between 430 to 441 m. The interspersion and juxtaposition index of the water is the highest implying an uneven distribution of patches with the smallest number of patches, mean patch area, mean patch size and proximity index indicating the largest distance between the patches.

Table 5:6 Landscape class level for year 2002

TYPE	CA	PLAND	NP	LPI	AREA_MN	SHAPE_MN	FRAC_MN	PAFRAC	PROX_MN	ENN_MN	IJI
Dense Forest	30833.01	18.2516	1079	1.716	28.5755	1.3021	1.034	1.6099	23.0514	477.2694	82.0583
Grassland	32240.91	19.085	1160	1.5642	27.7939	1.3126	1.033	1.6568	37.0324	477.9868	79.9612
Light Forest	81044.5	47.9742	934	36.0116	86.7714	1.2897	1.033	1.6277	571.3749	429.1681	84.7916
Non-Vegetation	22472.25	13.3024	2560	0.0705	8.7782	1.1615	1.0256	1.6518	4.4238	440.5167	75.9166
Water	2342.89	1.3869	501	0.0321	4.6764	1.0327	1.007	1.5683	0.4719	849.2849	92.1291

5.3.5 Landscape class level for year 2010

Light Forests, grassland, dense forest and non-vegetation were the main patch type covering 99 percent of the total area. Light forests have the largest patch index, mean patch area and mean proximity index. Comparing the number of patches and the proximity index among the four classes, dense forests and non-vegetation have the highest number of patches and lowest proximity index, implying more fragmented patches. The interspersion and juxtaposition index of the water is the highest implying that it is unevenly distributed patches. Other classes have the almost the same interspersion and juxtaposition index between 71 and 76 implying that there are fewer, unevenly distributed patches of light forests, grassland, dense forests and non-vegetation.

Table 5:7 Landscape class level for year 2010

TYPE	CA	PLAND	NP	LPI	AREA_MN	SHAPE_MN	FRAC_MN	PAFRAC	PROX_MN	ENN_MN	IJI
Light Forest	55958.61	33.1197	980	25.2548	57.1006	1.1999	1.0235	1.6254	330.2121	505.1857	75.6935
Non-Vegetation	31843.81	18.8471	1774	1.1068	17.9503	1.26	1.0322	1.6456	15.5898	453.4316	71.4841
Grassland	41193.71	24.3809	999	7.9119	41.2349	1.2612	1.0276	1.6511	171.0489	482.5069	75.246
Dense Forest	38381.52	22.7165	1091	1.6794	35.1801	1.3078	1.0316	1.6301	43.4605	458.5178	73.5518
Water	1581.18	0.9358	313	0.0299	5.0517	1.0412	1.008	1.5707	0.581	820.2042	95.5307

5.3.6 Landscape class level for year 2013

Light Forests, grassland, dense forest and non-vegetation are the main patch type covering 98.6 percent of the total area. Light forests have the largest patch index, mean patch area and mean proximity index. Comparing the number of patches and the proximity index of the four classes, dense forests and non-vegetation are among three with highest number of patches but with the lowest proximity index, implying more fragmented patches (Table 5.8). The interspersion and juxtaposition index of the water is the highest implying that it is unevenly distributed where it is mostly in bottom. Dense forests and light forests have interspersion and juxtaposition index between 64 and 69 implying that they are fewer, unevenly distributed patches of light forests, grassland, dense forests and non-vegetation. Grasslands and non-vegetation have interspersion and juxtaposition index between 78 and 80 implying that there are a few, unevenly distributed patches of light forests, grassland, dense forests and non-vegetation.

Table 5:8 Landscape class level for year 2013

TYPE	CA	PLAND	NP	LPI	AREA_MN	SHAPE_MN	FRAC_MN	PAFRAC	PROX_MN	ENN_MN	IJI
Grassland	45254.96	26.7903	1135	10.7815	39.8722	1.3084	1.0314	1.6644	259.8598	459.3617	78.7953
Light Forest	50265.64	29.7566	786	25.9697	63.9512	1.1446	1.019	1.6031	459.83	547.2239	68.7255
Non-Vegetation	39897.72	23.6189	1651	1.2288	24.1658	1.3196	1.0354	1.648	20.6436	433.694	79.9172
Water	2317.62	1.372	480	0.0299	4.8284	1.0392	1.0081	1.5895	0.4749	917.8507	99.2644
Dense Forest	31186.79	18.4622	1023	1.6819	30.4856	1.3292	1.0351	1.6143	22.8264	471.8584	64.9979

5.1 Effectiveness of rehabilitation efforts in the study area

For a visual appreciation of rehabilitation effort in the area of study, the locations of the rehabilitated areas are presented in the following section. The location of rehabilitated sites is highlighted with the placemarks as shown in Figure 5.2.

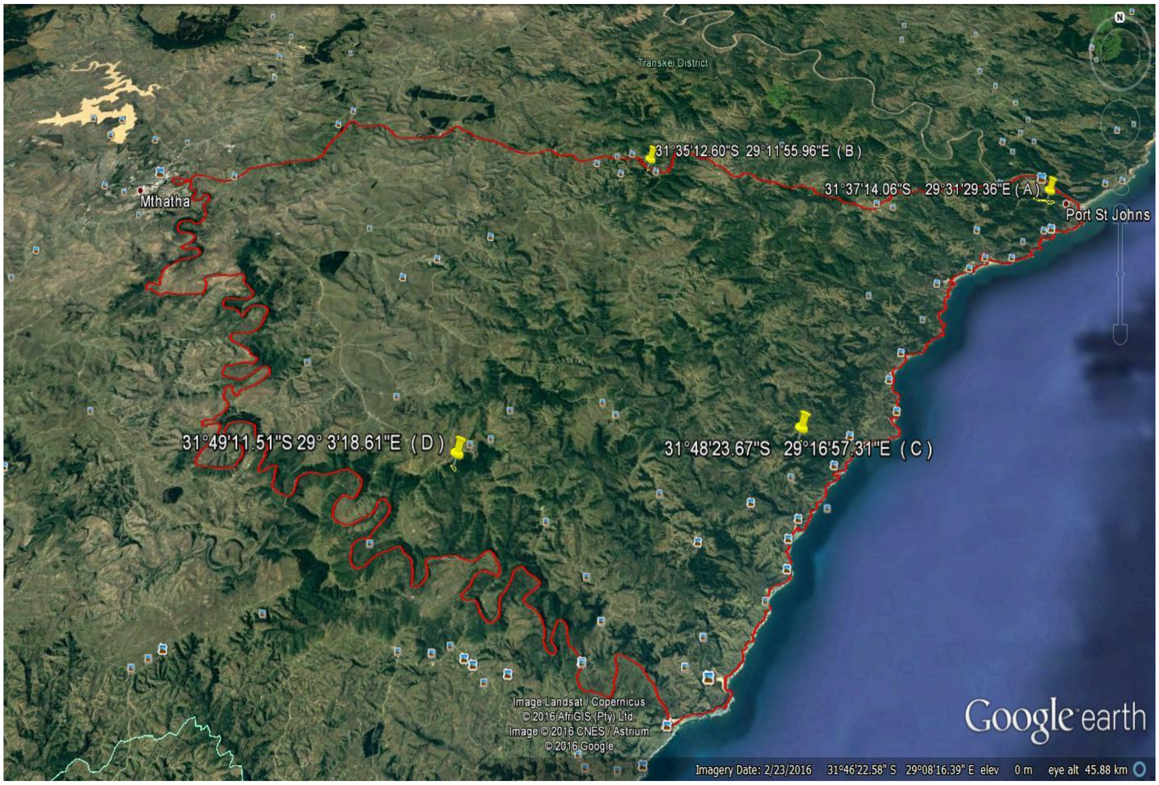

Figure 5:2 Location of rehabilitated areas on Google Map

The coordinates of the areas where rehabilitation took place are as shown in the map above. For example the coordinates of the area near PSJ town, which fall under Pungana state forest, the coordinates are 31^0 37’14.06”S 29^0 31’ 29.36’’E. 301 near Port St Johns and Xosheni forest near Libode. The images below show the areas which were rehabilitated in 2002. Period of rehabilitation are in October 2010, near PSJ (A), in November 2005 at Xosheni (B), in October 2002 Hluleka (C) and in October 2002 at KuZinja. The four rehabilitated areas were visited in 2013. Images showing the size and location of the rehabilitated areas are given in Figure 5.3 to Figure 5.6. For more details on the rehabilitation sites see annex 1.

Figure 5:3 The rehabilitated area at Pungana Forest on Google Map

Rehabilitated area at Pungana (A) (2.2Ha)

Figure 5:4 The rehabilitated area at Xosheni Forest on Google Map

Rehabilitated area at Xosheni (B) (0.6 ha.)

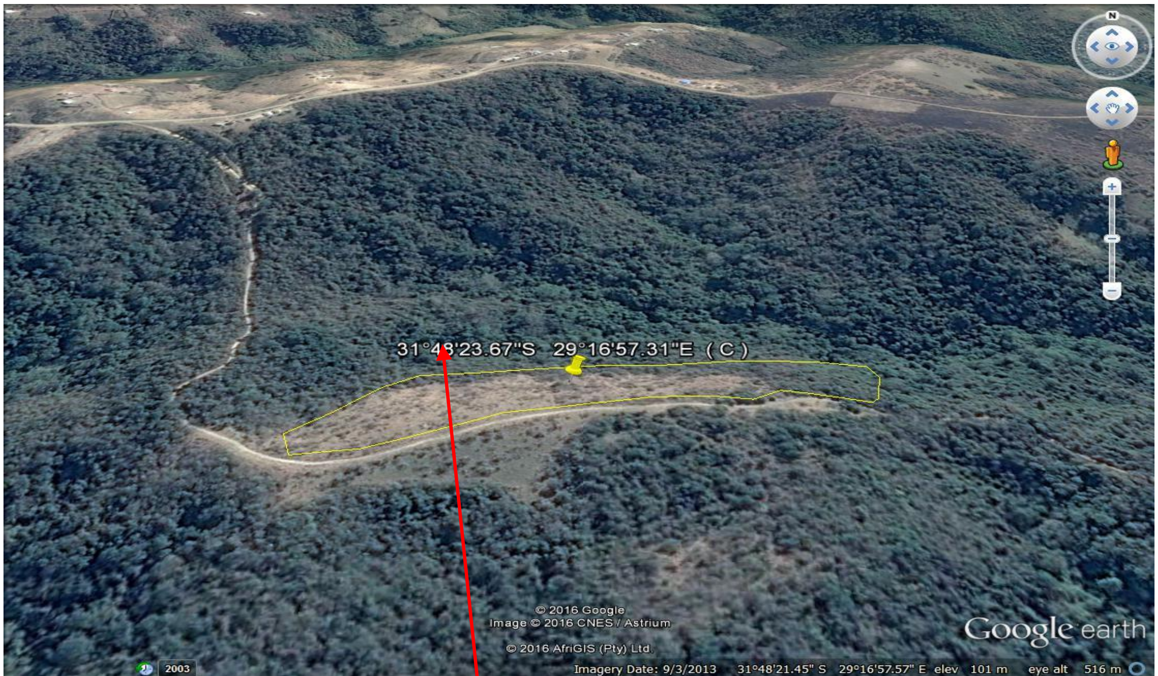

Figure 5:5 The rehabilitated area at Hluleka Forest on Google Map

Rehabilitated area at Hluleka (C) (2.0Ha.)

Figure 5:6 The rehabilitated area at KuZinja Forest on Google Map

Rehabilitated area at KuZinja (D) (4.8 ha)

The rehabilitated areas were once at different levels of degradation. Ranging from open grassland areas to areas infested with weeds such as *Lantana camala*. Using an area around PSJ (Labelled A) for example, the area used to be occupied by indigenous trees. Due to human activities particularly overcutting, trees were damaged over time and replaced by *Lantana camala* weed. In October 2010, steps were taken to rehabilitate the area by slashing. This would allow seeds of previously growing tree species to germinate. Figure 5.7 below shows what the area looked like before and after the rehabilitation exercise, entailing the slashing of *Lantana camala* as an initial stage of rehabilitation.

Figure 5:7 The area being rehabilitated by slashing at Pungana

Other areas that were identified as degradation hotspots were also marked on maps. With the assistance of the respective Estate Managers, field inspections were carried out to find out the condition of those areas on the ground by the time the field study took place in 2013. Managers gave a history of those areas as a background for the reasons which caused the degradation. They also gave their views as to how the rehabilitation should take place as to stop or reverse the degradation. As per today and as visually shown above, the indigenous forest has increased forest canopy density and the recovery stage was seen to be above 4 meters of tree stands (refer to annex 1 – appendix one) for detailed causes of degradation.

Chapter 6 : DISCUSSION

6.1 Introduction

This chapter presents the discussion accruing from the interpreted results and compares the findings with related studies and their similarities.

6.2 The extent in changes of indigenous forests around PSJ between 1986 and 2013

The purpose of this study was to examine changes in indigenous forests and hereafter spatial analytical analysis of these changes; the results revealed that the study area experienced quite stable dense forest cover and an increase in the area of light forest cover during the same period. The non-vegetated areas however increased in forest coverage from 2002 to 2013. This trend of changes was also reported by Obiri (2002) that some degraded forests in the Transkei Coastal Platform are in a recovery stage. These forests are dominated by *Millettia grandis*. However, this study was not possible to pick species difference using medium resolution images. But according to Burns (1986) secondary succession after fire in Eastern Cape Dune forest, they produce communities resembling those of the original dune forest in species composition, but repeated fires could lead to forest degradation and slow recovery potential. Differences in vegetation structure along the coastal areas could not be picked in the images.

The increasing trend in forest cover was observed in the study area. The increase was largely attributed to conservation efforts through de-agraianisation, forest restoration and rehabilitation. This observation was also made by Shackleton *et al*. (2013) in a study done in Willowvale which is close to the study area. He noted that the landscape changed substantially over the past 50 years (1961 to 2009). In addition, according to Conner *et al.* (2014), woody cover increased from 17 to 35% over the period 1937 to 1986 as was previously observed in the studied area. In some parts of Northern Kwazulu Natal, there was an increase of woody cover between 2 and 78% during the period of 1879 – 2011 (Russel and Ward, 2014). According to Shackleton *et al*. (2013), this trend was attributed to de-agraianisation, which is the shift of communities from cultivating the land as a primary source of wealth and food production. According to their study, cultivation abandonment has been going on for several decades, but the peak was reached during the time of political transition in South Africa in the early 1990s. From the interviews conducted with the local communities, these were the same reasons given for the changes in vegetation.

Russel and Ward (2014) also observed that the extent of natural forests area remains fairly stable, at least according to the National Land Cover (NLC) data sets, though there is evidence of a decline in certain areas and expansion in others. The benefits derived from natural forests are difficult to express in monetary terms. However, the specialist furniture industry in Knysna, Western Cape Province, based on 25000 m^3 of indigenous timber per year, contributes an annual amount of R20 million to the Gross Domestic Product (GDP). The rate at which natural forests are declining or expanding is unknown but property development and land invasions, noticeably in some parts of the country, seem to be the major threats to our natural forests. In addition the results of this study are coincidence with those made by Low & Rebelo (1996) that the estimates of the area covered by indigenous (closed canopy) forests vary between 0.25% () and 0.59% of the land surface (DEAT, 1997), with woodlands between 35 and 40% and plantations at about 1.4%.

There are many factors why communities abandoned land cultivation. These include soil exhaustion, unpredictable weather, lack of labour due to children attending school, migrant labour system to large cities and mines, lack of access to credit and income to purchase capital inputs like machinery and fertilisers and problem with livestock and wild animals destroying crops (Andrew *et al*., 1992; Timmermans, 2004; De Klerk, 2007; Shackleton *et al*., 2013).

Another contributing factor to deagraianisation, is the communal land tenure system, where the land is controlled by the chief and tribal authorities. Individuals or families do not own the land they were cultivating. The first democratic Government of South Africa in 1994 weakened the local traditional governing structures. During the same period, there was a restructuring process in all Government departments, which affected agricultural extension services and support to the communities as well (Everatt *et al*., 2001). This led to overgrazing on most of the grasslands leading, to the grazing lands being invaded by non-palatable shrub species and hardwoods.

Another contributing factor was the improvements in the state social welfare grants and pensions as well as expectations of development and employment promised by the politicians which may have lead to many people stop farming and migrate to cities. According to Hebink *et al*. (2007), the increase of Government social grants was the main reason of field abandonment in Eastern Cape. Most of the abandoned fields have been colonised by Acacia karroo, followed by other woody species like *Lantana camala* and *Castrum laevigatum*, which is an alien species (Shackleton *et al.*, 2013). Other tree species that have colonised the abandoned field lands are *Diospyrous lycioides, Millettia grandis* and *Acacia ataxacantha.* It's therefore important to note that it's the abandonment that has led into the growth of lighter forests

Most of the cultivated land used to be classified as grassland. When they were abandoned and turned into woodland, they are classified as light forests on the images. In these areas around PSJ, indigenous forests provide both direct and indirect benefits to the local communities.

6.3 Identification of forest degradation and deforestation in PSJ over the past 3 decades

The Landsat imagery were the main sources of identifying forest degradation and deforestation in the study area using the Landscape and class level metrics assessment. This study reveals that the highest number patches were recorded between 2002 and 1998, followed by between 2010 and 2013 and lastly 1986. Over the study period, distribution of patches clearly shows that forest degradation and deforestation rates were lower in the years 1986, 1998 and tremendously increased in the later period of between 2010 and 2013. This finding is similar to that made by Low & Rebelo (1996) in the Natural forests in South Africa are too fragmented and covers a smaller area of nearly half a million ha (492 700 ha), about 0.4% of South Africa's land surface area. At the class level, the light forests have the largest patch index, mean patch area, mean shape index, mean fractal dimension index, mean proximity index and perimeter area fractal dimension. This distribution could have occurred as a result of higher rainfall received along the southern and eastern coastline and in the country's mountainous regions. In addition, the temporal variations of landscape patches is attributed to the impoverishment of standing woody material mainly caused by human activities such as overgrazing, over-exploitation for forest produce such as firewood, repeated fires, attacks by insects and diseases, plant parasites or other natural causes such as cyclones may also lead to forest degradation

The main contributing factors to bare areas / the non-vegetated areas is the settlement caused by population increase over the years and soil erosion caused by poor agricultural methods such as overgrazing. According to O'Connor *et al.* (2014), severe grazing by livestock or wildlife could promote bush encroachment by reducing the fuel load or by reducing grass competition, at the same time; lack of grazing pressure should have the converse effect. Most of the abandoned fields turned into grazing areas. Due to lack of fencing and controlled number of animals kept by local farmers and frequent fires result in some areas being overgrazed. There was a reduction in cattle numbers, but with an increase of browsing animals like sheep and goats over the years (Smit *et al.*,1999).

According to Ward and Cleghorn (1970), Oates (1956) and Hester *et al*. (2006), cattle can contain woody growth under special circumstances but goats are the only livestock species that are effective in killing adult woody plants and of containing growth, especially if used in conjunction with burning. Elsewhere, in Botswana, wood density declined under sustained goat browsing within eight years (McKay, 1968), and by 60% within 13 years in a Namibian trial (van Niekerk, 1980). In the future, this might be a remedy to reduce woody encroachment on the grazing grasslands. Matsika *et al.* (2012) and Coetzer *et al.* (2013) also revealed that the rapid establishment of peri–urban areas led to the degradation of surrounding woodlands through unsustainable demand for fuel. This can be seen around Ludumo location in PSJ where Rural Development Program (RDP) houses were constructed in 2005. This affected the adjacent indigenous forests. Expansion of peri – urban areas creates a demand for fuel wood, other forest products and grazing land. This to a large extent explains the observed deforestation. Without proper control, some areas which were under forestland and grassland have turned into open bareland. Together with new housing schemes and population increase has resulted into expansion of open land.

The underlying causes of deforestation and forest degradation, and drivers of forest restoration,' include persistent high demand for wood; spiralling demand for land for plantations and other forms of agriculture; conflict over land tenure; industrialisation, urbanisation and infrastructure; poor central planning, lack of political will, and inadequate capacity; economic poverty and a lack of alternative livelihood options; neoliberal economic policies locking in unsustainable rates of consumption and poverty; and climate change. Meneses – Tovar (2011) similarly observed that deforestation and forest degradation are the second leading causes of anthropogenic greenhouse emissions following fossil fuel combustion, accounting for over 17% of global carbon dioxide emissions (IPCC, 2007). Forest degradation constitutes a significant proportion of greenhouse gas emissions.

6.4 The effectiveness of indigenous forest rehabilitation efforts in the study area

Recently timber harvesting is based on a sophisticated single-tree selection system. This has enabled the forests to recover from their secondary state into well-developed mature forests. Geldenhuys (2002) additionally noted that the changed fire regimes with less extreme fire conditions has led to the natural successional development of grassland, shrubland and woodland areas into forests during the current climatic regime. According to Shackleton *et al.* (2013), there has been a lot of urbanisation which has left some rural areas abandoned, and this has led to the development of secondary woody vegetation and forests in some areas.

The state (National or Provincial authorities) own and control most of the forest area, but many rural communities who live in relatively close proximity to the forests depend partly on the forest resources for their livelihood. So there is always a conflict between resources users and managers. Since 1994, the new political dispensation provided a different approach to the management of forests. The new Forest Act of 1998 (Act No. 84 of 1998), introduced Participatory Forest Management (PFMA) approach, which decided after realising that law enforcement alone could not save forests from destruction. PFMA is part of the set of Principles, Criteria, Indicators and Standards (PCI &S), set by the minister of DAFF according to the Act. PFMA provides the framework for better management of forest resources. The Act gives guidance on how to utilise timber and non – wood forest products sustainably. Recognition of values or importance of forests by the local communities is one of the basic requirements in order to reduce conflicts in land use options. In in this regard Vermeulen (2000) asserts that forest rehabilitation forms part of the forest management plan activities in the forests managed by the Indigenous Forest Management Programme of the Chief Directorate of Forestry. The activities are aimed at the rehabilitation of the destroyed forest areas, the conversion of abandoned plantation areas to consolidate existing forest patches, and to consolidate the forest edge into manageable borders such as a river or a road.

According to the Act, indigenous forests must be developed and managed so as to conserve biological diversity, ecosystems and habitats, to sustain the potential yield of their economic, social and environmental benefits. Forests are also supposed to promote the fair distribution of their economic, social, health and environmental benefits. They are meant to conserve heritage resources and to promote aesthetic, cultural and spiritual values. They are also to advance persons or categories of persons disadvantaged by unfair discrimination. It will always be a challenge to achieve real sustainable natural forests in poor rural communities with unemployment, who depend on forests for their daily livelihood. PFMA tries to address these issues as to ensure sustainable resource use and social economic development. Dachang *et al.* (2003) also points out that steps that have been taken to address issues of forest degradation, for example in the case of over harvesting of tree bark for traditional medicine have been addressed by assisting the users to form an association. This association works hand in hand with DAFF to implement legal and acceptable bark harvesting practices for sustainable management of the resource. Also to plant the desired species in the forest gaps, forest margins, open areas within nearby forest plantations and in community home gardens. They have also developed a trade chain whereby some barks are processed and packaged.

DAFF together with communities have started projects that will create employment to communities, such as bee keeping, fern harvesting for the florist industry, vine harvesting for basket making and tourist guide. According to Rocheleau (1999) and Venter, (2000) they demonstrated that there have been notable examples of successful collaboration between scientific research organisations and rural communities, which have been assisted by a greater emphasis on participation, partnership and negotiation in the research process. PFMA is now widely advocated and accepted as a strategy for rural development and natural resource management. PFMA can be interpreted in various ways, but according to Dachang, *et al.* (2003), PFMA is the mobilisation and empowerment of the local communities. Participation takes place at all the stages; of diagnosis, design and delivery. Local communities are involved together with local chiefs and head men with the researchers and extension staff of DAFF, and government officials to address forest degradation and improve livelihoods.

According to the forest rehabilitation systems, applied in natural forests were developed based on plantation forestry stands of pines, eucalypts and wattles so as to turn the degraded forests back to secondary forests using seedlings of natural species. Geldenhuys (2002) reported that the guidelines were drawn to assist managers in selecting of suitable indigenous species for use and on the approach to the establishment of such secondary forest systems. In some areas where *Cannabis sativa* used to be grown, the police have managed to control this practice and this has led to the regeneration of the forests, though there is no data available on the rate of regeneration.

The effectiveness of forest rehabilitation has been enhanced by the adoption of the sophisticated single-tree selection system for timber harvesting which has enabled the forests to recover from their secondary state into well-developed mature forests; changed fire regimes, with less extreme fire conditions, which has led to the natural successional development of grassland, shrubland and woodland areas into forests, during the current climatic regime; and the enactment of Forest Act of 1998 (Act No. 84 of 1998) which introduced the Participatory Forest Management (PFMA) approach that provides the framework for better management of forest resources, and recognition of values or importance of forests by the local communities in order to reduce conflicts in land use options. As a result of the above deliberate rehabilitation approaches, deforested areas, particularly the four areas specific sites sampled in the present study (Pungana state forest, Xosheni, Hluleka, KuZinja) have been fully rehabilitated since 1998.

From interpretation of the study results, this study proposes that future research is proposed to improve the identification of forest degradation and deforestation sites using remotely sensed data. A combination of coarse and medium resolution imagery like Landsat and high-resolution imagery is recommended for future studies.

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Chapter 7 : CONCLUSION

7.1 Conclusion

This study clearly shows that the emergence of the non-vegetated area increased gradually while the dense forest was observed to have experienced higher rates of forest degradation and deforestation than the light forest. Over the study period, the distribution of patches clearly shows that forest degradation and deforestation rates were lower in the years 1986, 1998 and tremendously increased in the later period of between 2010 and 2013. Anthropogenic activities if unregulated can be detrimental to natural land cover. The rise of population trajectories and demand for timber by the markets are huge threats to the conservation efforts made in forest conservation. Therefore, community engagement in the planning and implementation of rehabilitation programs is more likely to yield conservation fruits. The application of remote sensing can effectively monitor changes in forest cover with higher accuracies. The open source nature of Landsat imagery and capability to monitor large areas is an asset in the frequent quantification of forest landscape patches. Investment in frequent utilization of remote sensing techniques makes the forest monitoring cycle complete.

Landscape metric assessment is a plus in monitoring forest deforestation and degradation in heterogeneous landscapes. The metrics help to detail the landscape structure, function and change such as the patchiness, diversity and patch-area that are influential in understanding the ecology of an ecosystem. Based on spatial connectedness of patches, the year 1986 had the highest landscape connectedness of forest vegetation followed by 2002 and 1996 while the year 2010 and 2013 had the lowest landscape contiguity. This is related to landscape lesser forest degradation and deforestation. The metrics are a significant step in investigating forest related problems.

The observed effectiveness of forest rehabilitation has been enhanced by the adoption of the sophisticated single-tree selection system for timber harvesting which has enabled the forests to recover from their secondary state into well-developed mature forests; changed fire regimes with which has led to the natural successional development of grassland, shrub land and woodland areas into forests, in addition to the enactment of Forest Act of 1998. This study suggests strict enforcement of forestry laws and an increment in the funding of conservation programmes which are seen as timely solutions to the threats causing forest degradation and deforestation.

Chapter 8 : ANNEX

APPENDIX 1

DEGRADADED AREAS FIELD VISITS SUMMARY

Date of the Visit	Site Name	Name of Estate Manager	Coordinates	Degradation History	Rehabilitation Method	Present Status	Remarks
18 / 04 / 2013	Port St. Johns	Mr. Mgudlwa S B	31^0 37’14.06”S 29^0 31’29.36”E	Communities clearfelled all the trees along the road for firewood and other uses.	Planting Indigenous species seedlings	Trees are growing nicely	Awareness campaign is necessary
20 / 06 / 2013	Xosheni - Libode	Mr. Mngqete S M	31^0 35’12.60”S 29^0 11’55.96”E	Around 1995,Communities settled close to indigenous forest and destroyed the trees to create gardens.	Communities were stopped from using the area, weeds poisoned	Indigenous trees have started growing in the area	Awareness campaign is necessary
17 / 07 / 2013	Hluleka	Mr. Mkibi B	31^0 48’23.67”S	The area was overgrazed by animals from the nearby communities. All trees were	Planting Indigenous species seedlings	It has not been effective because the animals	Awareness campaign is necessary. Area need to be fenced.

			29^0 16’57.31”E	destroyed and it became a grass land.		have continued grazing in the same area. Destroying the seedlings	
20 / 08 / 2013	KuZinja	Mr. Mkibi B	31^0 49’11.51”S 29^0 03’18.61”E	Around 1995,Communities settled in the indigenous forest, destroying the trees.	Communities were removed from the forest and re-settled outside. Area allowed to re-grow naturally	Trees are growing nicely	Awareness campaign is necessary

Chapter 9 : REFERENCES

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