SPATIAL MONITORING OF NATURAL RESOURCE CONDITION IN SOUTHERN AFRICA

JOSEPH PETRUS ALBERTUS VAN DER MERWE

STUDENT NO: 14255774

Thesis presented in partial fulfilment of the requirements for the degree of Master Natural Sciences at the University of Stellenbosch.

SUPERVISOR: PROF HL ZIETSMAN

April 2005

AUTHOR'S DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirely or in part submitted it at any university for a degree.

Signature: ……………………….

Date: ……………………….

ABSTRACT

South Africa's natural vegetation and soils, which are essential resources for agricultural practices, are becoming degraded. Natural resource disturbances can also cause extensive harm to local communities and their economies. To allow successful natural resource monitoring, there is an urgent need for integrated GIS spatial data and development of remotely sensed indicators of key ecosystems processes. Satellite remote sensing provides the most cost-effective and reliable tool for generating these spatial data. The main objective of the study is, therefore, to develop and evaluate methodologies for assessing, mapping and monitoring the condition of natural resources in southern Africa with the aid of remote sensing and GIS. The resulting integrated spatial framework represents methodologies for, firstly, identifying and accessing vegetation and soil parameters on a gradient from pristine to degraded condition; secondly, identifying, assessing, processing and modelling GIS and remote-sensing spatial data to derived degradation maps, which identify rangeland condition and woody cover classes and, thirdly, comparing two satellite remote-sensing sensors (LANDSAT ETM and MODIS) and making statements of degradation. This approach could make an integrated spatial framework comprehensive in its considerations of provincial degradation mapping and robust enough to be used for monitoring on a national scale. By acquiring spatial and non-spatial data in a quantitative logically robust but accurate manner, integrated spatial frameworks provides the structure for combining specialized information as well as for analysis in an effective management programme. This could guide rangeland managers in assessing, mapping and monitoring of natural resources in a scientifically acceptable way. All of these factors emphasise the need for the development of a national rangeland monitoring strategy and monitoring system.

OPSOMMING

Natuurlike plantegroei en gronde van Suid Africa word as belangrike hulpbronne vir landboupraktyke beskou, en is besig om te degradeer. Degraderende natuurlike hulpbronne hou ’n gevaar in vir plaaslike gemeenskappe en hul ekonomie. Om suksesvolle monitering uit te voer, is geïntegreerde ruimtelike GIS data en die ontwikkeling van afstandwaarnemings-indikators vir sleutel-ekosisteem-prosesse, noodsaaklik. Satelliet afstandwaarneming verskaf die mees koste-effektiewe en betroubare tegniek om hierdie ruimtelike data te verskaf. Die hoofdoel van hierdie studie is, dus om, metodes te ontwikkel en te evalueer vir die meting, kartering en monitering van die toestand van natuurlike hulpbronne in suidelike Afrika, met behulp van afstandwaarneming en GIS. Die resultate van die geïntegreerde ruimtelike raamwerk verteenwoordig metodes vir, eerstens, identifisering en meting van plantegroei- en grondparameters op ’n gradiënt van optimale tot gedegradeerde toestande, tweedens, die identifisering, meting, prosessering en modellering van ruimtelike data afkomstig van GIS en afstandwaarnemingprodukte om sodoende degradasiekaarte te produseer, wat weiveldtoestand en houtagtige kroonbedekkingsklasse voorstel en derdens, om twee verskillende satelliet afstandwaarneming sensors (*LANDSAT ETM en MODIS*) te vergelyk en verklarings oor degradasie te maak. Die geïntegreerde ruimtelike raamwerk is dus op ’n provinsiale skaal omvattend genoeg vir die kartering van degradasie en besluitneming vir monitering op ’n nasionale skaal. Om ruimtelike en nie-ruimtelike data in ’n kwantitatiewe benadering logies en kragtig, tog akkuraat te verkry, verskaf die geïntegreerde ruimtelike raamwerk waarmee gespesialiseerde inligting gekombineer en analises in ’n effektiewe bestuursprogram benut kan word. So ’n raamwerk kan aan weiveldbestuurders riglyne verskaf vir die meting, kartering en monitering van natuurlike hulpbronne op ’n wetenskaplike en aanvaarbare wyse. Dit beklemtoon die behoefte vir die ontwikkeling van ’n nasionale weidingsmoniteringstrategie en moniteringsisteem.

ACKNOWLEDGEMENTS

I would like to thank the following persons and institutions without whom this study would not have been possible.

1) My gratitude to Jesus Christ the Son of God, for talents I have received and for the privilege to reign over his creation.
2) My parents and Madelein for their love, understanding and encouragement during the year of my study.
3) My supervisor, Prof. Zietsman, for his patience, inspiration, guidance and good advice.
4) The National Department of Agriculture - Directorate Land and Resources Management (NDA-DLRM) and the Agriculture Research Council – Institude for Soil Climate and Water (ARC-ISCW) for the financial assistance without which this study would not have been possible.
5) Dr. Theunis Morgental and Hennie van den Berg for their vital inputs and participation.
6) Dr. Hees for the language editing.

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CHAPTER 1: INTRODUCTION TO THEORIES OF MONITORING NATURAL RESOURCES

The sustainable management of natural resources has become a fundamental aspiration, hence the constant need for exact and up-to-date resource data. Spatial monitoring applications for natural resources are one of the primary means for Southern African countries to combat land degradation[1]. Spatial information is essential to measure the impact of human actions and to predict the future condition of natural resources[2] (Wilson & McLeod 1991; Taylor, Brewer & Bird 2000). Turk, Turk & Wittes (1972) point out that "A balanced ecosystem is considered to be a healthy condition."

The International Convention on Desertification defined land degradation in terms of the reduction in biological or economic productivity arising from human activity (United Nations 1994 as cited by Pickup 1996). According to Pickup (1996), estimating productivity in rangelands is a complex process, because one needs to take into account biological and economic productivity. Biological productivity may be expressed in terms of plant production and the species composition of the pasture, while economic productivity depends, among other things (such as the land use system), on how efficiently land managers use the resources and also on external market factors. The loss of biological and economic productivity is usually identified by comparing the current state of the soil and pasture with some kind of benchmark conditions (Pickup 1996). However, explicit links with the level of animal production, which is sustainable over a given time period are also required before a change in soil or vegetation can be regarded as land degradation (Wilson & McLeod 1991).

1.1 Rangeland condition and assessment theory

Rangeland condition[3] theory is highly controversial in South Africa and abroad, with people holding a wide range of views (Friedel 1991; Hurt & Bosch 1991; Du Toit 1995; Peel, Biggs & Zacharias 1998). The fundamental characteristic of any ecosystem is that it is not static and does not have a fixed composition. All ecosystems are, to a greater or lesser degree, dynamic with regard to time and space (Jordaan 1997). Pickup, Bastin & Smith (1994) point out that change in "rangeland condition is a

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[1] Land degradation refers to the decline in the condition of the land as a consequence of misuse or overuse, and involves changes to vegetation, soil, livestock, water quality and quantity, visual quality and production levels by humans, which all lower the quality of the land, making it less suitable for growing crops or raising livestock.

[2] Any resource occurring in the natural environment such as vegetation, soils, biodiversity, water, forests, minerals and related resources, which are essential to humans.

[3] The term rangeland condition is used in a generic sense to mean the "health" of a site, area or ecosystem.

linear and reversible change in the vegetation and soil, moving away from a climax condition mainly determined by climate and soil." It is assumed that shifts in rangeland condition can be inferred from changes in plant species composition away from some particular benchmark. In the ecological approach these shifts involve changes away from the climax situation. In the production approach the shifts take place away from a lightly grazed or ungrazed benchmark towards a less desirable plant species composition. This often involves a loss of palatable perennial grasses, usually including species with a low ecological status[4], in favour of unpalatable perennial and pioneer (temporary) herbaceous species and an increase in unpalatable woody shrubs, although other variations may also occur (Van der Merwe 1997; Pickup, Bastin & Smith 1994).

By knowing the process whereby the changes in plant species composition occur as well as the factors causing these changes, the degree of degradation as well as the rehabilitation ability of the rangeland, which is in a specific condition can be determined (Van der Merwe 1997). The development of large bare patches, which is a result of the degradation process, can be ascribed to natural causes, such as drought conditions, combined with ineffective grazing strategies, such as patch selection or the overgrazing of pasture vegetation with a high grazing potential (Van der Merwe & Kellner 1999; Kellner & Bosch 1992).

The degradation gradient approach for determining rangeland condition was developed in climatic-climax grasslands of South Africa using multivariate procedures (Bosch 1989; Bosch & Gauch 1991; Bosch & Kellner 1991). The degradation gradient method was found to provide indices for assessing range condition (Hurt & Bosch 1991). The approach emphasises that vegetation condition can be quantified along an ordination axis which represents rangeland degradation (Mentis 1983; Stuart-Hill, Aucamp, Le Roux & Teague 1986). Degradation gradients are determined at sample sites in deteriorating ecological conditions along a grazing gradient. The quantitative approach entails statistical tests (various classification and ordination methods) to select the appropriate model for rangeland condition. Habitat variation (e.g. clay content, soil type, etc.) in general occurs within a particular rainfall zone (e.g. biome), which can lead to large variations in the data set that make the identification of a reliable degradation gradient impossible (Gauch 1982; Bosch & Gauch 1991). However, the description of rangeland degradation models explains rangeland dynamics in a simple application of the Clementsian (Clements 1916) and the State and Transition theories (Westoby, Walker & Noy-Meir 1989) of ecological succession.

[4] The response of species (grasses) to grazing impact: it can increase or decrease (Van Oudtshoorn 1992).

1.2 Spatial solutions towards sustainable monitoring

Rangeland monitoring of vast landscapes has for many years depended on a rangeland manager's decisions, but a more effective method has to be designed, because this approach is no longer practical (Tueller 1989; Booth & Tueller 2003). According to Belward & Valenzuela (1991), studies of vegetation dynamics on regional and global scales are concerned with the community and biome levels of ecosystems, and not individual plants or populations. Repeated observation and measurement on these scales is not possible using conventional measurements.

Natural ecosystems are continuously changing (Coppin, Jonckheere, Nackaerts, Muys & Lambin 2004). The widespread nature of rangelands and concern for rangeland condition have stimulated a need to develop data collection and analysis systems at multiple scales (Reeves, Winslow & Running 2001). The launch of Landsat-1 in 1972 was the foundation of satellite remote sensing for modern natural resource monitoring. Satellite-based sensors have repetitive acquisition capabilities that have the potential to detect, identify and map changes that are important to rangeland managers (Tueller 1989; Coppin *et al.* 2004; Belward & Valenzuela 1991). Natural resource data collection through satellite remote sensing is the most logical approach to acquiring suitably distributed information over large areas in short time periods (Yang & Prince 2000; Sujatha, Dwivedi, Sreenivas & Venkataratnam 2000; Coppin *et al.* 2004; Booth & Tueller 2003).

According to Coppin *et al.* (2004), the spatial data capturing potential of remote-sensing sensors has stimulated great interest in establishing remote-sensing-based systems, in the domain of continuous monitoring of natural ecosystems, and in determining the condition of natural resources (Belward & Valenzuela 1991), such as for tropical deforestation assessment (Lambin 1999; Yang & Prince 2000), agricultural production forecasting, and rangeland degradation monitoring (Pickup 1996).

1.2.1 Rangeland parameters for remote-sensing monitoring

Remote-sensing sensors hold significant promise for the development of more consistent and cost-effective methods of monitoring rangeland productivity over vast areas (Tueller 1989; Wallace, Caccetta & Kiiveri 2004). Booth and Tueller (2003) acknowledged the challenge in detecting ecologically important changes over widespread land areas, with acceptable error rates, in ways that are financially viable. The error risk is a function of sufficient sample records and distribution for each parameter monitored. Parameters for rangeland monitoring, such as ground cover and its inverse, bare ground, are frequently discussed. Ground-cover measurements deal with soil stability and watershed function, which are most important ecological concerns and are well suited to remote-sensing frameworks (Booth & Tueller 2003).

Studies on spatial monitoring by Hostert, Röder & Hill (2003) emphasized that the development of vegetation cover is one of the primary indicators of land degradation, stability or regeneration in regions susceptible to overgrazing. Remaining alert to both the environmental and human impact on the vegetation cover is in itself a good way of monitoring vegetation condition (Belward & Valenzuela 1991). Vegetation is dynamic in responding and adapting to existing environmental conditions; these dynamics manifest themselves in changes in the distribution of vegetation types and changes in plant growth development stages. In either case monitoring such changes requires repeated observation and measurement (Belward & Valenzuela 1991).

The use of remotely-sensed information for estimating vegetation productivity is well represented in the literature and is an important driver of rangeland monitoring. Vegetation productivity is a measure of rangeland vitality and vegetation growth potential, which are important components of rangeland management and condition assessment (Tueller 1991; Reeves, Winslow & Running 2001). Early studies showed that it is possible to determine the standing biomass from the NOAA AVHRR NDVI imagery in some rangeland ecosystems (Palmer & Fortescue 2003). However, the NDVI[5] is shown to be sensitive to seasonal rainfall variations (Donoghue 1999). Empirical NDVI and regression models can be used to assess vegetation amount, production and yield, but for groundcover estimation spatial statistics may help to give better predictions (Donoghue 1999).

A number of studies have shown that woody canopy cover is strongly correlated with brightness indices (including the red-band reflectance, albedo[6], and Kauth-Thomas brightness) in semi-arid shrubland and woodland in Africa, Australia and North America (Musick 1986; Duncan, Stow, Franklin & Hope 1993; Larsson 1993 as cited by Yang & Prince 2000).

The studies of Kennedy (1989) and Wylie, Dendra, Piper, Harrington, Reed & Southward (1995) focused on biomass assessment with remote sensing derived regression-based prediction, and estimated biomass once in the growing season. These studies focused on total productivity at the end of the

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[5] NDVI, or Normalized Difference Vegetative Index, indicates the relative amount of vegetation (vegetation biomass) present per pixel in an image. It is calculated by subtracting the red from the near-infrared to generate a vegetation index, then dividing by their sum to normalize the values. NDVI = NIR-R/NIR+R.

[6] A measure of the reflectivity or intrinsic brightness of an object (a white, perfectly reflecting surface would have an albedo of 1.0; a black perfectly absorbing surface would have an albedo of 0.0)

season (Tucker, Vanpraet, Boerwinkel & Gaston 1983), which limited these models to isolated points in time. Spatial limitations exist because regression-based equations frequently perform poorly when applied to conditions contrasting to those used to develop the relationships either due to change in scale from the place of development or a shift in site characteristics (Reeves, Winslow & Running 2001).

Tucker *et al.* (1983) and Wylie *et al.* (1995) have studied the establishment of direct empirical relationships between spectral reflectance and biomass, while Choudhury (1987 as cited by Reeves, Winslow & Running 2001) shows the use of spectral reflectance to estimate the amount of absorbed photosynthetically active radiation (APAR). Tucker *et al.* (1983) and Wylie *et al.* (1995) confirmed the reliability of their approach for estimating live biomass. Numerous broad-scale studies (Thoma 1998 as cited by Reeves, Winslow & Running 2001; Tucker, *et al.* 1983; Kennedy 1989) have shown that live biomass is correlated to remotely sensed vegetation indices, particularly the normalized difference vegetation index (NDVI).

1.2.2 Spatial degradation monitoring with MODIS

The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor of the Earth Observing System (EOS) promises an improved and more suitable system for monitoring of rangelands, which will frequently estimate productivity (Reeves, Winslow & Running 2001). MODIS was successfully deployed by NASA on 18 December 1999; it has a viewing swath width of 2,330 km and views the entire surface of the earth every one to two days. Its detectors measure 36 spectral bands between 0.405 and 14.385µm, and it acquires data at three spatial resolutions – 250 m, 500 m and 1 000 m. Data of the satellite sensor are freely available and potential products for rangeland management include estimates of productivity, which make it possible to differentiate seasonal vegetation growth, estimate herbaceous quantity (grass cover), and monitor the rates and trends of change in primary production[7] (Reeves, Winslow & Running 2001).

The MODIS sensor, with various products available, is ideal for monitoring seasonal vegetation growth and provides classified information of critical growth stages. The evaluation of herbaceous production is equally important economically and biologically. Productivity estimates allow managers to evaluate long- and short-term forage availability, enabling land managers to detect potential forage shortages for both livestock and wildlife. In addition, monitoring biomass accumulation could provide an objective

[7] Synthesis of organic matter by plants, which is the main source of energy and nutrition for others consumers in the ecosystem (e.g. herbivores).

means of assessing utilisation levels, making a range manager's evaluation easier regarding livestock removal (Reeves, Winslow & Running 2001).

Productivity estimates may be an important aspect for determining whether present rangeland management practices are functional (Reeves, Winslow & Running 2001; Pickup, Bastin & Chewings 1994). Some forms of degradation may generate distinctive temporal and spatial patterns of change. These large-scale patterns are useful when assessing rangeland condition from remotely sensed data (Reeves, Winslow & Running 2001). Some current methods of determining rangeland condition place more reliance on change in species composition, though EOS productivity products can identify trends in decreased long-term productivity, indicating potential rangeland degradation (Reeves, Winslow & Running 2001).

1.3 Area of interest

The National Department of Agriculture's Directorate Land and Resources Management (DLRM) has in the past funded a number of projects to develop remote-sensing methods for the assessment of natural resource degradation (e.g. soil erosion mapping and modelling, bush encroachment, rangeland condition mapping) (Wessels, Van der Merwe, Smith, Van Zyl & Twyman 2001). The Maputaland study area forms part of chosen areas in which the DLRM is interested for assessing and mapping degradation (Fig. 1).

Maputaland falls within the KwaZulu-Natal province and the area's main sources of income are commercial and subsistence farming. Natural resources eco-tourism is also a viable and growing industry. The area is known for its high biodiversity and natural attractiveness, which is preserved in various natural parks, such as the Hluhluwe, Umfolozi, Mkuzi, Ndumu Game reserves and Thembi Elephant Park (Fig. 1). Resource degradation due to deforestation of woodlands, overgrazing and housing pressures is a real threat to sustainable development as pristine natural areas are becoming fragmented and limited to conservation areas. The area's population is also rapidly increasing and, because of the dependence on natural resources, pressure is increasing on natural resources as sources of fuel and food. Because subsistence farming is nearly the only form of agricultural activity, proper planning and management of rangeland must be addressed to avoid a serious problem from developing. The choice of the Maputaland with its diverse land uses and sensitive environment as a study area made it possible to evaluate methodologies for assessing and mapping the condition of natural resources with remote sensing and GIS.

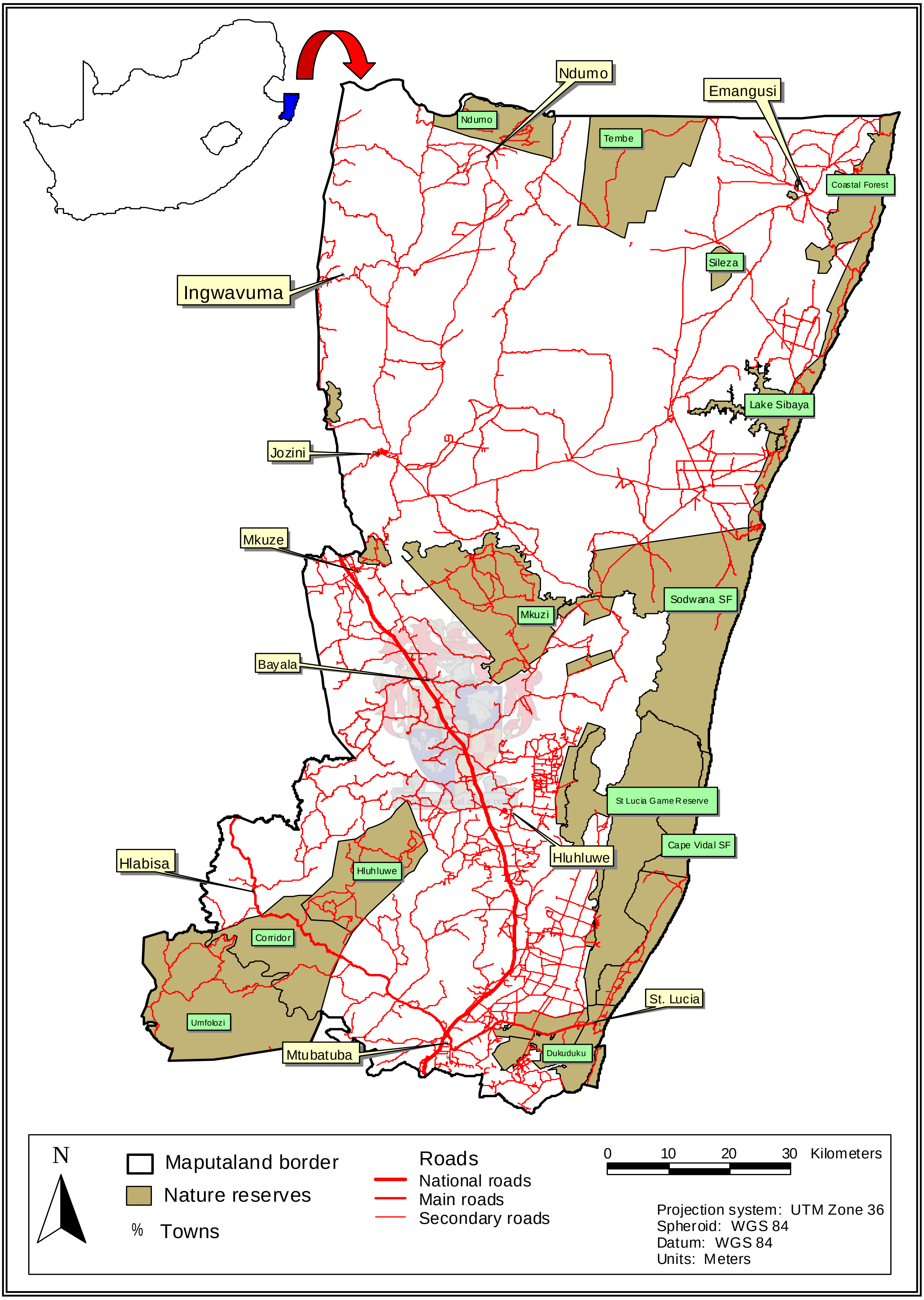

Figure 1 Maputaland study area

1.4 Research Problem and Objectives

South Africa's natural resources are degrading at an alarming rate. Natural vegetation and soils are vital resources for the agricultural practices of South Africa. Natural disturbances can also cause extensive harm to local communities and their economies. To allow successful natural resource monitoring, there is an urgent need for spatial data and development of remotely sensed indicators of key ecosystems processes. Satellite remote sensing provides the most cost-effective and reliable tool for generating these spatial data (Wessels *et al*. 2001; Davis, Quattrochi, Ridd, Lam, Walsh, Michaelsen, Franklin, Stow, Johannesen & Johnston 1991; Günter *et al*. 1995).

A monitoring system entails systematic and repeatable activities designed to measure changes in natural resources through space and time, and should be able to distinguish between climatic and landscape variability and management impacts (Wessels *et al*. 2001; Walker 1993). Booth & Tueller (2003) reviewed the value of satellite and high-altitude sensors for landscape-level evaluations, such as plant community distribution. Combining information from high- and low-altitude sensors appears to offer an optimal method for developing a practical system for cost-effective, data-based, rangeland monitoring and management (Booth & Tueller 2003). Although monitoring implies multi-temporal sampling, this study is limited to the use of vegetation field surveys undertaken at a single point in time to test the potential of using Landsat ETM imagery in combination with MODIS as a monitoring tool.

The important step, then, towards systematic spatial monitoring planning, is the development of a GIS and satellite remote-sensing monitoring framework. Furthermore, acquisition of integrated spatial data (e.g. natural stratification, transformation of natural vegetation, rangeland condition and woody cover maps) within a spatial modelling environment (GIS) to map and monitor areas susceptible to these various forms of degradation is important. The condition of natural resources could be measured within broad habitat types, designated by a natural stratification map, while comparisons of plots in different areas need be based on the same kind of information at the same level of detail (Van der Merwe 2003).

Near real-time satellite image acquisition and digital change detection is essential for the operational monitoring of rangelands. Remote sensing plays a significant role in areas such as inventory or mapping of cover types, monitoring of rangeland conditions relative to the norm and estimating vegetation cover or biomass[8]. Effective rangeland monitoring systems require repeated quantitative data at suitable temporal density and spatial scale, as well as appropriate methods and a theoretical

[8] Biomass is the organic matter produced by plants and is measured in mass per unit area.

framework to simplify and interpret these data (Wallace, Caccetta & Kiiveri 2004). The potential use of a near real-time monitoring approach may therefore contribute to a framework for optimized management of natural resources to prevent degradation. A reliable indicator could then be made available to land managers who carry the responsibility for monitoring the condition of natural resources.

The main objective of the study is, therefore, to develop and evaluate methodologies for assessing, mapping and monitoring the condition of natural resources in southern Africa with the aid of remote sensing and GIS. The specific goals are to:

1) analyze high- and medium-resolution satellite imagery (e.g. Landsat ETM & MODIS products) combined with ground observations/measurements, which can map rangeland condition and make statements of degradation;
2) compare the two satellite approaches (e.g. Landsat ETM & MODIS products) for the mapping and monitoring of degradation;
3) review the potential use of the MODIS satellite remote-sensing products and GIS for near-real time application in future monitoring and mapping of the condition of natural resources in a spatial environment.

The remainder of this thesis is divided into 3 chapters. In Chapter 2 the research design and underlying methodologies for the GIS and satellite remote-sensing approaches are outlined. The results obtained from applying the methodologies to data of the Maputaland pilot study area are represented in Chapter 3. The last chapter summaries the suitability of the GIS and satellite remote-sensing approaches for assessing, mapping and monitoring the condition of natural resources. A review and recommendations for potential uses of the MODIS products for near-real time monitoring for future degradation monitoring and mapping, are also presented.

CHAPTER 2: RESEARCH DESIGN AND METHODOLOGY FOR DEVELOPING AN INTEGRATED REMOTE-SENSING AND GIS MONITORING FRAMEWORK

The appearance of geo-informatics as a scientific discipline stems from the study area of the acquisition, storage, analysis and presentation of geospatial information. With its interdisciplinary roots, it bridges the fundamental disciplines such as computer science and the application-oriented fields such as Botany, Zoology, Pedology, Ecology and natural resources management. Although the science of Geography also bridges these disciplines, Geo-informatics is narrowly focussed on the science and related technologies of Geographical Information Systems and remote-sensing systems.

2.1 Research design

Figure 2.1 describes the research design and methodologies of the integrated GIS and remote-sensing framework developed for natural resources management and achieving the goals of this thesis. The development of the framework started with the definition of natural degradation classes (e.g. vegetation in pristine condition along a gradient to low herbaceous biomass or an increase in woody cover).

The tool for managing geospatial information, a GIS spatial database, is without any doubt the most important component within the framework. After degradation definitions were formulated on, a selection of appropriate GIS spatial data (e.g. soil, climate, vegetation) was done for analysis, storage and mapping purposes. The framework allows for modelling suitable GIS spatial data (e.g. vegetation stratification map), if empirical spatial data is not available.

The next part of the framework was to design a non-spatial database in Access to simplify the process of storing and analysing field data (e.g. vegetation and soil parameters). The database was an excellent tool for data manipulation, and to prepare field data captured for statistical analysis. Digital photos taken during fieldwork were made part of the GIS spatial database to facilitate image classification and feature monitoring purposes.

Another important part of the research design was the selection of appropriate satellite remote-sensing data (e.g. Landsat ETM and MODIS products). Remote sensing and its associated image analysis software (e.g. Erdas Imagine, TNT Mips), which form part of the framework, are a major source for geospatial information acquisition and extraction, and are important for natural resource management. Satellite remote-sensing products combined with ground observations were essential for rangeland condition mapping and to make statements of degradation. The framework describes a procedure to compare the two satellite approaches (e.g. Landsat ETM & MODIS products) and for assessing the potential use of MODIS satellite remote-sensing products and GIS towards future near-real time monitoring and mapping of degradation (Fig. 2.1). Interactions between the different approaches provide fundamental data. The methodologies of each aspect concerning the framework are explained in different sections in this chapter.

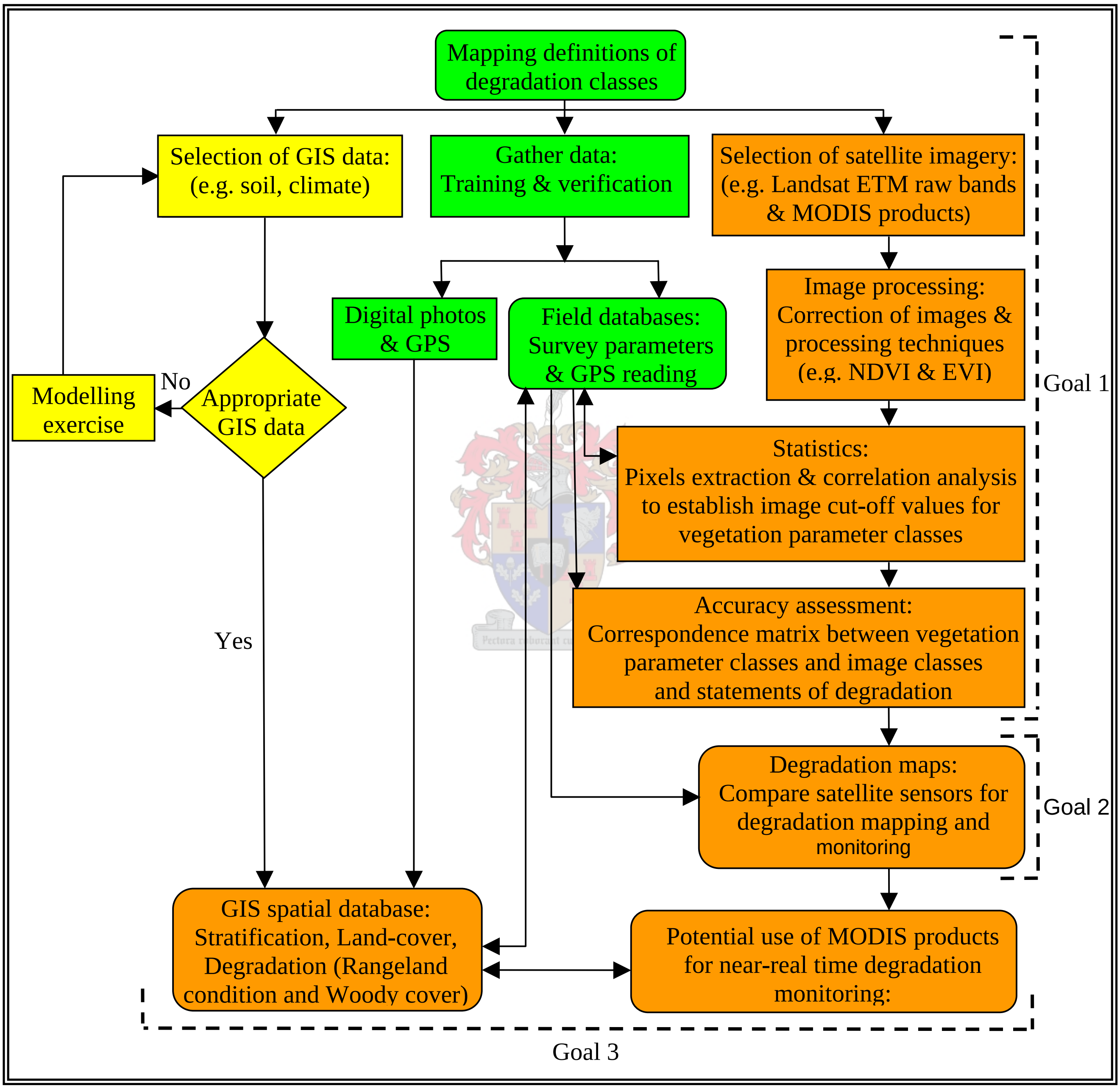

Figure 2.1 Flowchart illustrating the framework used for research design and the development of various methodologies

2.2 Study area and background of field sampling

The Maputaland study area falls within the KwaZulu-Natal province and consists of sensitive conservation areas such as the St. Lucia and Cape Vidal game reserves, and agricultural activities such as commercial farming, small-scale farming and forestry. (Fig. 2.2).

The study area is situated within the summer rainfall area (January to March being the wettest months) and has a subtropical climate. The average annual rainfall varies from 671 mm in the north to 1002 mm in the south. On average the daily maximum temperature is above 20 °C, while the difference between the minimum and maximum temperature is seldom more than 12 °C. The topography changes considerably from east to west and is associated with changes in the stratigraphy and lithography. The eastern region is a coastal sandy plain, originating from the continental shelf. The coastal plain is underlain with sediments, predominantly Arenite and Calcrete. The Josini River floodplain transects the central region from south to north and is mostly underlain by siltstone, conglomerate and alluvial sandy sediments. The western region is predominated by the Lebombo mountain range, which was formed by intrusion of Felsic and intermediate volcanic rocks (Rhyolite). The southwest is mostly undulating hills underlain by Basalt in the interior and Mudstone, Siltstone, Shale and Arenite in the extreme southwest (Morgenthal, Kellner, Van Rensburg, Newby & Van der Merwe In Press).

2.2.1 Random sampling

Many methods and techniques of accuracy assessment have been developed. In recent years it has become more universal to quantify uncertainty for a variety of spatial data. However, there is a direct correlation between sampling intensity and expenditure. A certain minimum sample size is necessary to make accuracy and probability statements with an acceptable level of confidence. But the cost involved in increasing the sample size may not validate the gain in assurance. Random point sampling has proved to be a very cost-effective way of making accuracy and probability statements for spatial data. Schowengerdt (1983) showed that 250 random samples are sufficient to make statements that will be within 5% of the real percentage at a 95% confidence level. As a rule 50 samples are the minimum required to make any statement (Congalton, 1991).

A method for providing stratified areas (e.g. condition classes) for random sampling would be to carry out an unsupervised classification with a Landsat ETM image; however, the total random sampling of the study areas would be costly and impractical.

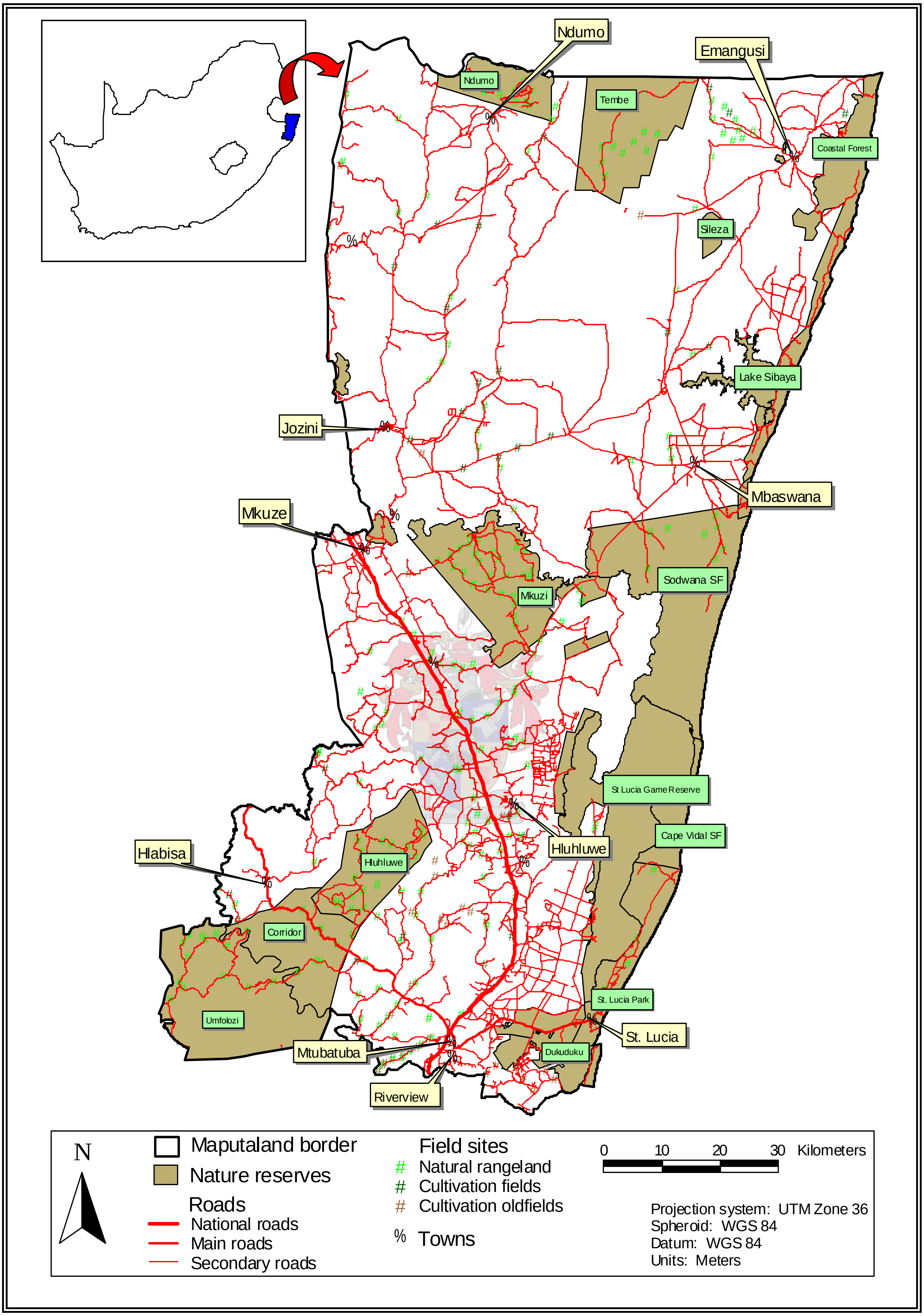

Figure 2.2 Random field sites in Maputaland study area

Sampling randomly along roads provided a cost-effective alternative (Ströhmenger, Van der Merwe, Smith, Van den Berg, Van den Berg, Dekker, Malherbe, De Nysschen, Van der Walt, Haasbroek, Morgenthal, Kellner, Van Rensburg 2003). Concerns that it may not be random enough were addressed by testing random sampling estimations in the study areas against the true percentage distribution of classes on the '94 - '95 Land-cover map (Thompson 1999). Several 'runs' for point sampling in other studies provide evidence that the true percentage distribution could be estimated within 5% using 200 point samples (Thompson *et al.* 2001) in areas with a good road coverage (Table 2.1).

The road coverage in the study area was adequate, except for a bias around settlements. To counter this bias the study area was divided into smaller blocks and roads were randomly removed in blocks with a higher than average density of roads. This procedure ensured a more even spread of roads and it was possible to estimate the percentage random distribution of land-cover classes (test) on an existing map (1994 - 1995 land-cover map of study area) within 5% of the actual GIS calculated areas (Table 2.1).

Table 2.1 Actual percentage land-cover (1994 – 1995) and randomly determined distribution for the study area

Land-cover distribution of study area (GIS calculation)		
Land-cover class	**Actual - % distribution**	**Test - random % distribution**
Natural	67.3	65.7
Forest	4.1	1.3
Cultivation	12.7	21.7
Transformed	4.3	7.7
Water	11.6	3.7
Total points	**300**	**300**

All the roads were 'double' buffered, creating sampling zones not closer than 30 m and not further than 80 m, from the road (i.e. sampling zones of 50 m on both sides of a road). This approach ensured that no sample site would fall directly on the road, thus eliminating the disturbance effect of the road. Randomly sampled sites for the study area were located in the buffer zones (Fig. 2.2). The geographical locations of all the sampling sites were uploaded to a global positioning system (GPS). The 'go to waypoint' function of the GPS was used to ensure easy location of the sample site on the ground. All sampling sites, roads and towns were printed on paper maps to facilitate fieldwork (Fig. 2.2).

2.2.2 Purposive sampling

Purposive sampled sites within various classes of condition or intensity of degradation, i.e. bush encroachment, overgrazing and soil erosion were subjectively located in the field. Efforts were made to sample sites of contrasting condition (e.g. fence line and water point effects) within all the perceived natural strata. After sampling a severely degraded site, a survey was completed of a nearby site in good condition on comparable soil and terrain (Fig. 2.2; Wessels *et al*. 2001).

2.3 Sample design and site selection

A practical approach in identifying field sites was to use a sample design. This enabled the field observer to sample environmental parameters (e.g. vegetation and soil) that could be used for analysis. Therefore, the purpose of this task was to develop and use a sample strategy for gathering field data and analysis purposes.

2.3.1 Stratification of sampled sites

Financial and time constraints dictated that no more than 280 sites could be sampled in the Maputaland study area (Figs. 2.2 and 2.3). Approximately 225 natural vegetation sites in Maputaland were surveyed within various classes of rangeland condition/intensity of degradation, i.e. bush encroachment and overgrazing were subjectively located in the field. The distribution of 280 sample sites between the natural rangeland and cultivation fields were divided into 198 natural random sites, 27 natural purposive sites, 22 old fields and 36 cultivated fields sites.

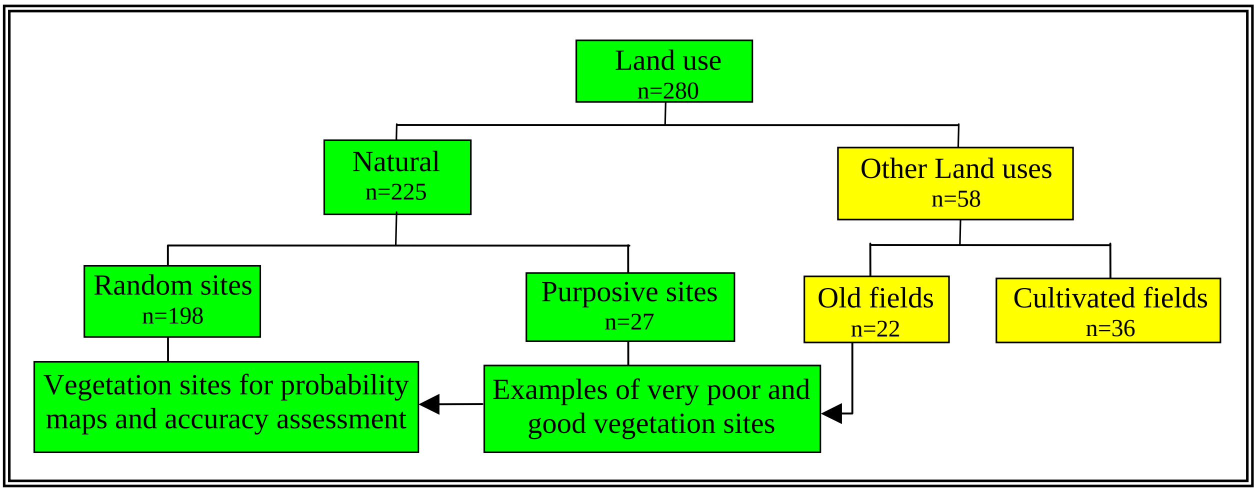

Figure 2.3 Layout of land use sites

Sites which fall within old fields (older than 5 years) were also used as examples for rangeland condition classes of various severity levels (Fig. 2.3). The additional 58 sites (other land uses) were useful for accuracy assessment, because of their value for randomness.

2.3.2 Site layout

In order to allow the positional accuracy differences caused by the differences between scales of field surveys, remote-sensing data and the final product, it was essential to identify internally homogeneous sampling sites large enough to be explicitly located on satellite imagery for the extraction of representative pixel values (Wilkie and Finn 1996). Sites had to be 250 m x 250 m, internally homogeneous and at least 250 m from other land uses (e.g. cultivated / forestry area) and 50 m from a road to avoid road-edge effects and mixed pixels (Fig. 2.4). In order to ensure that internally homogeneous sites were sampled, the following criteria were applied (Wilkie and Finn 1996):

1) Sites should have single cover type over more than 85% of the site, or uniform spatial distribution of cover types in a mixed site;
2) Sites should fall within a single terrain unit.

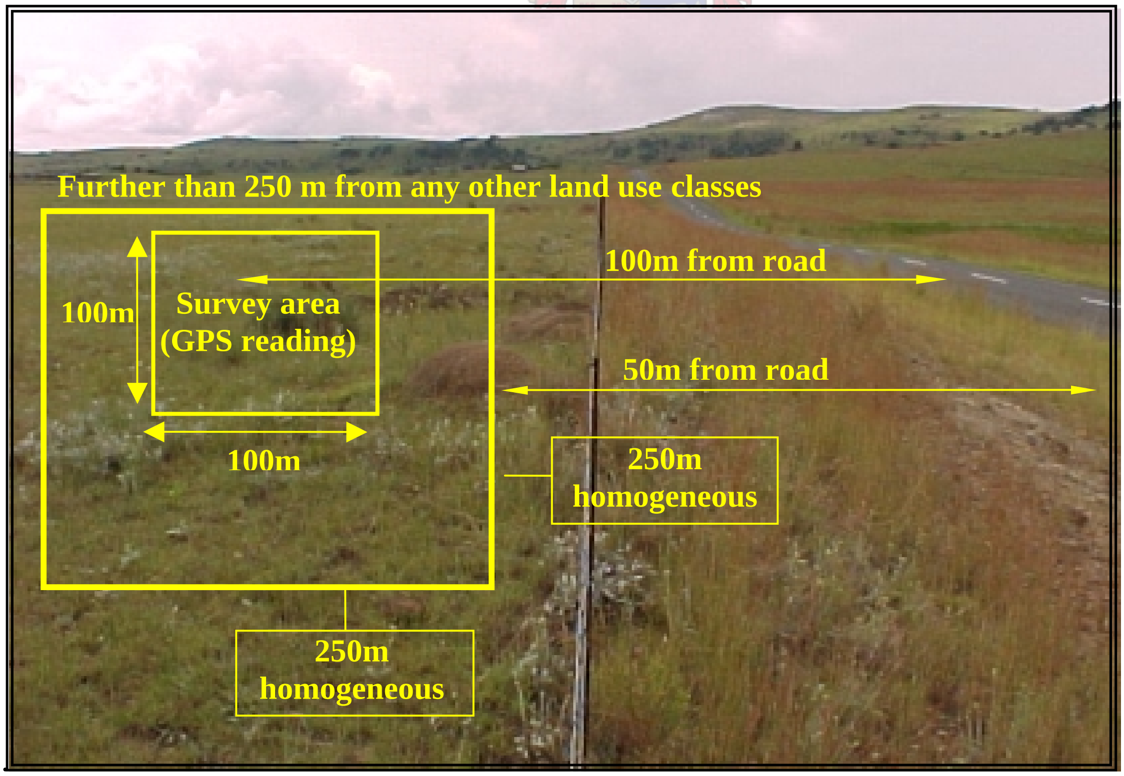

Figure 2.4 Layout of survey site

Although the field observer should make a concerted effort to ensure that the 250 m x 250 m area is homogeneous, the vegetation sampling and soil erosion assessment were conducted within the central 100 m x 100 m area (Fig. 2.3). Areas of steep slopes (>8%) were avoided during fieldwork (not sampled), since these areas are often problematic for remote sensing purposes due to shadow effects.

2.3.3 Site sampling: Field form

It was important to survey multiple habitat and vegetation parameters for the sampling sites. A quantitative estimation technique (Van den Berg, Booyens & Collet 1996) was adapted to sample vegetation parameters. The technique provides less precision but is more accurate, since more sites can be sampled within the same time than with conventional methods. These quantitative estimation techniques furthermore significantly reduced the time spent at each site (Appendix A).

Field survey data included the conventional site parameters such as slope, terrain unit, digital photograph and broad vegetation characteristics. A complete soil survey, subjective degradation rating (vegetation cover, standing biomass, species change, soil erosion, bush encroachment, overall degradation) and a complete floristic survey were also completed (Fig. 2.5, Appendix A).

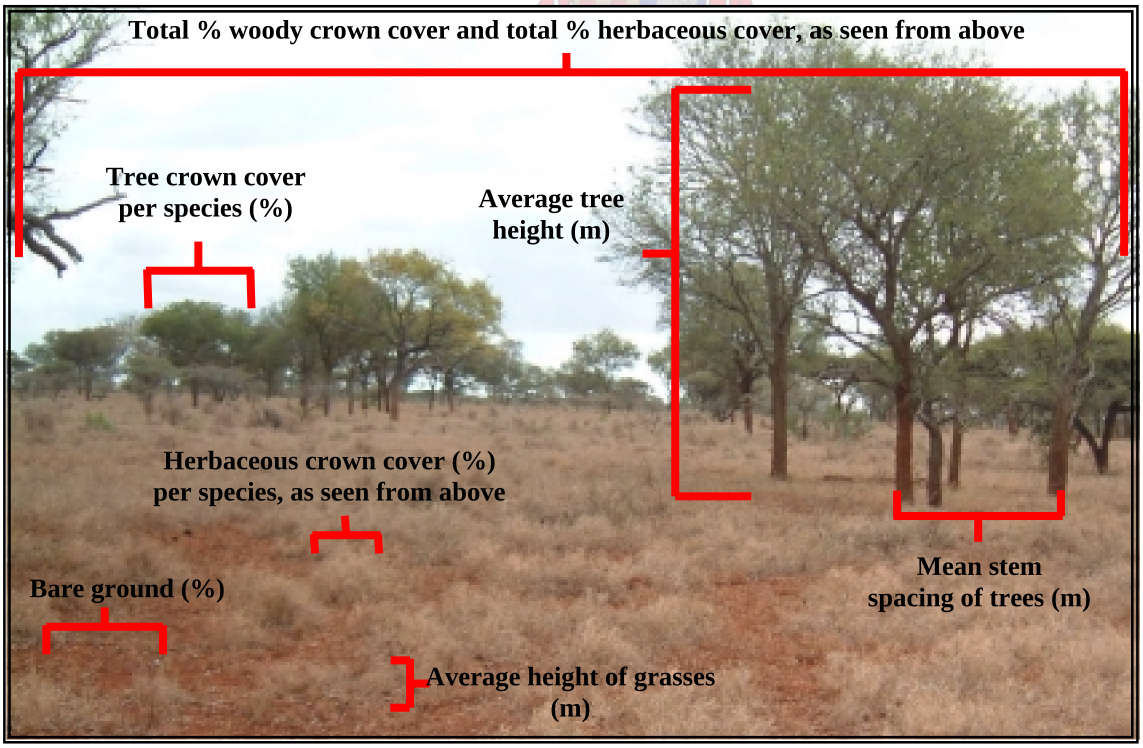

Figure 2.5 Vegetation parameters of survey site

2.4 GIS spatial and non-spatial integration approach

A practical approach to identifying condition classes was to use environmental parameters (e.g. vegetation and soil) and GIS data to classify the data into spatial units within which degradation classes can be mapped. Therefore, the purpose of this task was to classify the data (e.g. environmental and GIS) into useful and meaningful units for monitoring purposes. The databases are an important tool for managing information. A selection of appropriate GIS spatial data (e.g. soil, climate, vegetation) was done for analysis, storage and mapping purposes.

2.4.1 Field and digital photo databases

The field survey and photo databases of the ARC-ISCW[1] and NDA[2] were obtained, which contain quantitative data on vegetation, soil, terrain parameters and digital photos of the sample site and parameters. This represents a snapshot of vegetation and habitat condition in time, making this database invaluable for future monitoring in the area. This geo-referenced database (including digital photographs) represents a unique and valuable reference for future monitoring efforts (Fig. 2.1).

2.4.2 GIS spatial data acquisition

The GIS spatial data were also obtained from the ARC-ISCW and NDA, and included climatic data (e.g. average monthly and average annual rainfall), soil surfaces (e.g. land types), vegetation and land-cover data, a contour digital elevation model (DEM) and digital terrain model (DTM), and ancillary data such as road and river data. The spatial data were projected to the Universal Transverse Mercator, WGS 84, UTM zone 36, South.

2.4.3 Classification and ordination of vegetation data

Since the Maputaland study area is diverse, e.g. in terms of the variety of land cover types (e.g. rural areas, agricultural land, nature conservation areas), it is essential to stratify the natural environment of the study area into uniform environmental units within which degradation can be mapped and reported. Therefore, the purpose of this step was to compile a vegetation habitat type map, which stratifies the study area into meaningful and useful units for monitoring purposes (Fig. 2.6).

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[1] ARC-ISCW – Agriculture Research Council – Institute for Soil Climate and Water

[2] NDA – National Department of Agriculture

A process was followed to produce a vegetation habitat type map with classes within which there were meaningful relationships between floristic data and habitat/environmental factors (Fig. 2.6). This was done by comparing and integrating the non-spatial data (vegetation communities) and spatial data (e.g. climate and soil), using multivariate techniques (e.g. Canonical Correspondence Analysis – CCA; Fig. 2.6). PCord software (McCune & Mefford 1999) was used to classify (TWINSPAN[3] classification) and ordinate (CCA[4] ordination) the vegetation data.

TWINSPAN is a program for classifying species and sample sites, producing an ordered two-way table of their occurrence. The process of classification is hierarchical; samples are successively divided into categories, and species are then divided into categories on the basis of the sample classification. TWINSPAN classification has been widely used by ecologists. A classification was completed with the TWINSPAN classification (Hill 1979).

In order to test the primary environmental factors influencing vegetation community turnover through space, a CCA was performed (McCune & Mefford 1999). Canonical correspondence analysis (CCA) is a multivariate extension of weighted averaging ordination, which is a simple method of arranging species along environmental variables/gradients (Ter Braak 1987). CCA seeks structure in the main matrix (abundance of species in a set of sample units) in such a way as to maximize the strength of the relationship with the second matrix (environmental variables measured at the same sample units). In community ecology the ordination of samples and species is constrained by their relationships to environmental variables. While this facilitates interpretation, the method assumes that meaningful environmental variables have been measured.

2.4.4 Spatial integration of vegetation habitat type map

High-resolution spatial data (e.g. soil, climate, digital terrain model - DTM, digital elevation model - DEM; Fig. 2.6) and remote-sensing information (e.g. land-cover classes) were used to derive boundaries, whereas previously (Acocks 1988 and Low & Rebelo 1996) these boundaries were drawn by hand from field samples and other ancillary data, e.g. altitude maps.

All the spatial classes of the applicable data layers (clay, terrain, rainfall, DEM) were derived with the natural breaks classification method of ArcView. This is the classification method (default) in ArcView and identifies breakpoints between classes using a statistical formula (Jenk's optimization).

[3] TWINSPAN = Two-Way Indicator Species Analysis

[4] CCA = Canonical correspondence analysis

The optimal method is the "best" choice for grouping similar values together. The variance fit can be calculated for different numbers of classes. Where the curve flattens, or when the accuracy exceeds a desired threshold (say, 80%), this may be the appropriate number of classes to use. This method basically minimizes the sum of the variance within each of the classes. Natural Breaks finds groupings and patterns inherent in your data.

A potential clay forming data layer was compiled, which involved the clay database of the Land-types (1:250 000 scale) and a DTM (100 m). The integration process imposed the clay classes of the land-types into the DTM classes, resulting in a more refined clay theme.

Annual and monthly rainfall themes were created from interpolated rainfall stations. The final rainfall classes were derived from the annual rainfall theme. The DEM was reclassified to derive an altitude map. Steep areas were not sampled during fieldwork, due to the inaccessibility and the shadow effect on satellite images. The slope map was also created from the DEM.

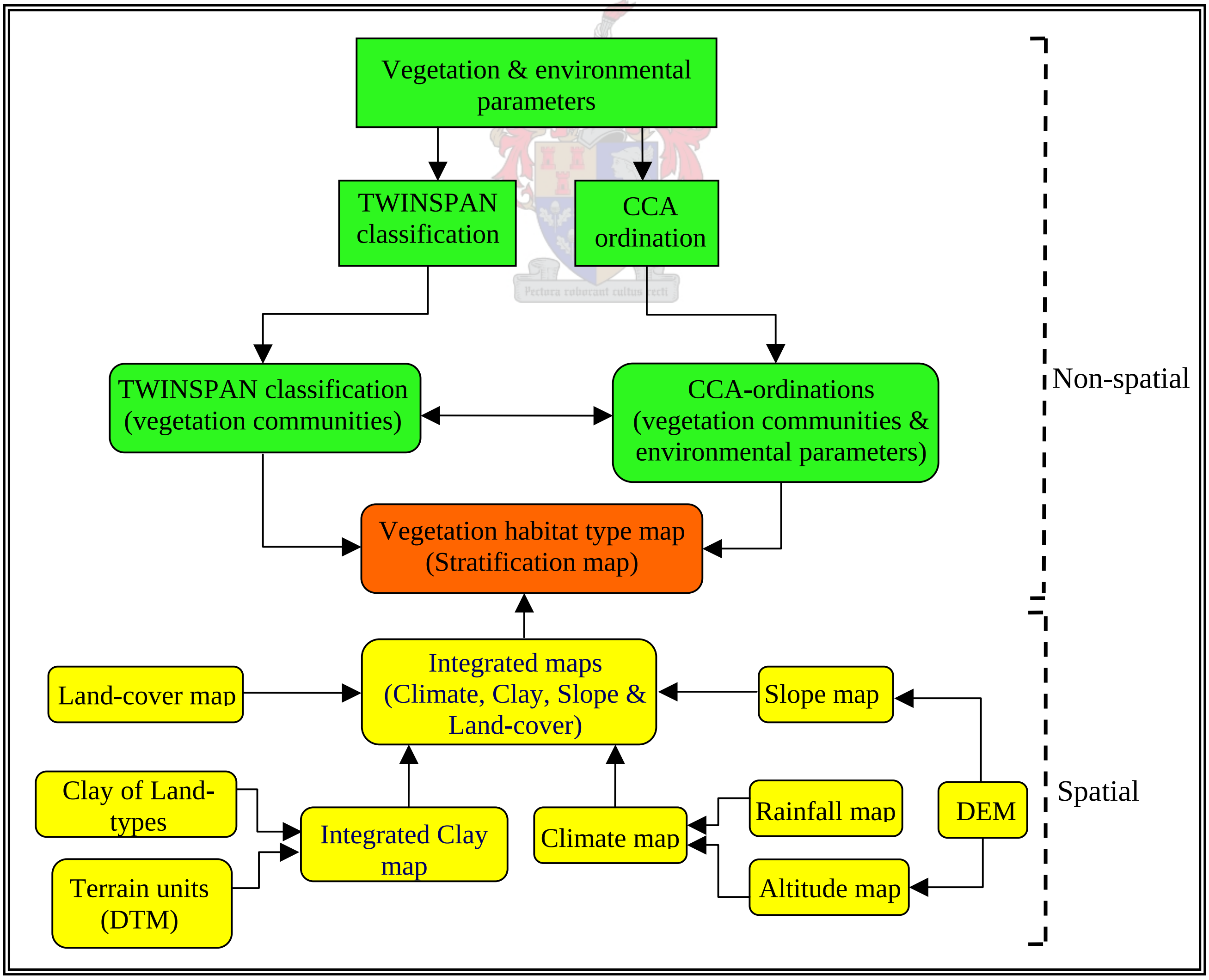

Figure 2.6 Flow diagram representing the spatial and non-spatial approaches

A Land-cover map of 2000 was obtained from the ARC-ISCW, which was compiled from Landsat ETM images. The land-cover product, consisting of 48 land-cover classes, was re-classed into 12 classes, which were used for drawing a distinction between natural and transformed classes and used for masking (overlay analysis) purposes.

The above-mentioned spatial data layers (e.g. slope, clay, rainfall, altitude and land-cover classes) were integrated for deriving the vegetation habitat type map.

2.5 Landsat ETM Satellite Remote Sensing

A practical approach to identifying degradation classes in the study area was to use satellite remote sensing to classify the images into spatial units within which degradation classes can be mapped. Therefore, the purpose of this task was to classify the images into useful and meaningful degradation units for monitoring purposes.

2.5.1 Landsat ETM images acquisition

Landsat ETM scenes (167_80 and 167_79) of 20 March 2001 were acquired for the study area from the ARC-ISCW and NDA (Fig. 2.7). Almost 90% of the study area is covered by a single image. The potential disadvantage of the March image is that “greenness” and “wetness” dominate the vegetation “cover” (“brightness”) signal detected by the satellite (Karfs *et al.* 2000). The spatial resolution of both images was 30 m x 30 m. The Landsat ETM images were projected to the Universal Transverse Mercator projection, using WGS 84, UTM zone 36, South, as input parameters.

2.5.2 Landsat ETM products

Several image processing techniques, including raw Landsat ETM bands, Bare Soil Index (BSI; Pretorius and Bezuidenhout 1994), Mid-Infrared Index (MIR; Nemani, Pierce, Running & Band 1993, Van Wyk 1999) and Principal Component Analysis (PCA ETM 3,5,7; Wilkie and Finn 1996), Tasselled Cap transformations (Tascap; Crist and Kauth 1986) were applied to the set of imagery (Table 2.2).

Since a multi-temporal analysis was not the primary goal of this study and Landsat ETM images were not directly compared over time, only a certain amount of pre-processing (e.g. geometric pre-processing – image registration & rectification) was done. Calibration is, however, crucial to do multi-temporal comparison of Landsat data in a monitoring system (Karfs *et al*. 2000; Collett *et al*. 1998). All these remote-sensing products have illustrated the potential for mapping bare soil, vegetation cover, herbaceous biomass or woody vegetation cover (Wessels *et al*. 2001).

Table 2.2 Formulas and abbreviations of remote-sensing indices (Landsat ETM)

Index	**Abbreviation**	**Formula**
Raw ETM bands[5]	RawBand	ETM Band 1,2,3,4,5,6,7,8
Normalized Difference Vegetation Index	NDVI	ETM4 - ETM3 / ETM4 + ETM3
Bare Soil Index	BSI	100 x sqrt. (ETM7 - ETM2 / ETM7 + ETM2)
Principle Component Analysis	PCA	PCA of ETM bands 357
Tasselled Cap (Brightness, Greenness, Wetness)	Tascap	Standard algorithm, weighted sum of bands.
Mid Infrared Index	MIR	ETM5 - ETM5min[6] / ETM5max[7] - ETM5min

2.5.3 Testing relationship between processed Landsat ETM imagery and natural vegetation parameters

Pixel values (9 pixels; Fig. 2.7) were extracted within a buffer polygon (50 m radius) around each survey point from the raw bands and processed satellite image products (e.g. NDVI). Basic statistical analyses (e.g. Spearman's correlation) were performed to explore the relationship between remote-sensing products and the observed and derived vegetation parameters, i.e. herbaceous biomass rating, rangeland condition rating (field estimates) and woody vegetation cover (trees and shrubs).

Nonparametric rank correlation (Spearman's correlation coefficient) was used to test relationships with the degradation ratings, since these ratings (from 1 to 5) were not measured on an absolute scale, but rather on an ordinal scale. Correlation analysis were performed to estimate the degree to which two variables vary together, while regression analysis estimates the relationship of one variable to another by expressing the one in terms of a linear function of the other (Fig. 2.7; Wessels *et al*. 2001).

The fieldwork sites were classified into three to five classes for each vegetation parameter based on the observed vegetation parameter values (e.g. rangeland condition < 20%, or >80%). Pair-wise t-tests

[5] Band 1 = Blue 30; Band 2 = Green; Band 3 = Red; Band 4 = Near IR; Band 5 = Mid IR; Band 6 = Thermal; Band 7 = Mid IR; Band 8 = Pan

[6] ETM5min = ETM5 pixel values at the fieldwork plot with the highest woody cover.

[7] ETM5max = ETM5 pixel values at the fieldwork plot with the lowest woody cover.

were used to test whether the different vegetation parameter classes differed significantly in terms of the pixel values extracted for each remote-sensing product (e.g. NDVI, PCA). Cut–off values between classes were accordingly calculated using the means, standard deviations or the 95% confidence limits of the classes. This allowed the creation of correspondence matrices between vegetation parameter classes and the statistically derived image product classes.

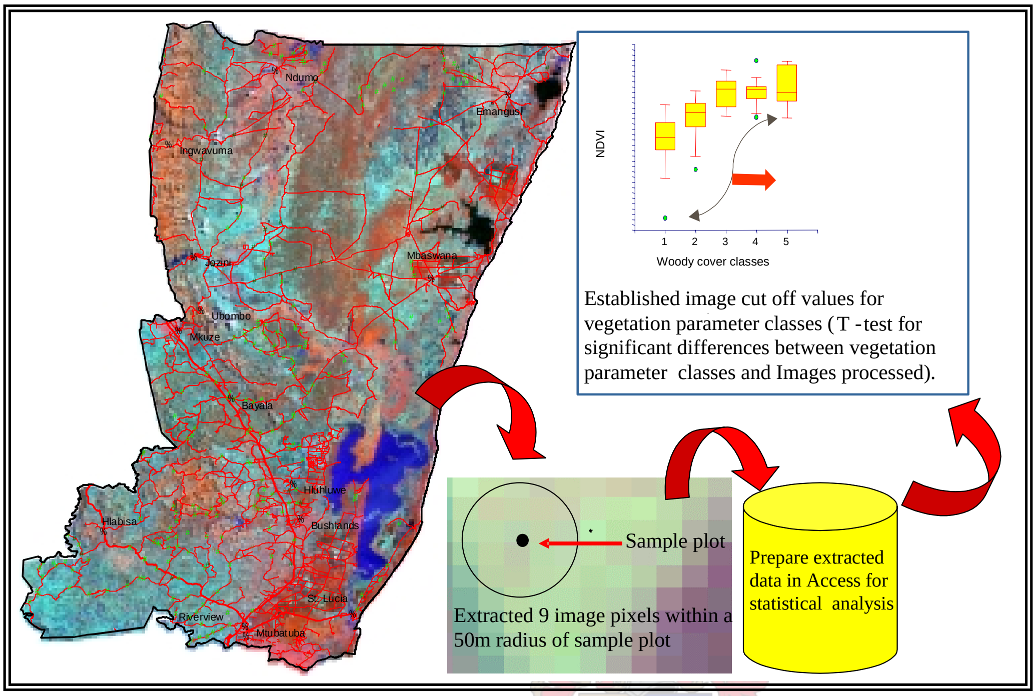

Figure 2.7 A method to establish relationships between vegetation parameters and Landsat ETM imagery (e.g. raw image bands and products from the indices)

2.6 MODIS Satellite Remote Sensing

2.6.1 MODIS products acquisition

Surface reflectance products of MODIS (20 March – MOD09Q: 250 m spatial resolution) were acquired for the study area, from the MODIS website (Land Processes Distributed Active Archive Center 2004). Additional MODIS products were obtain, such as vegetation indices (e.g. NDVI and EVI products - MOD13Q: 16-day 250 m spatial resolution). The MODIS products were projected to the Universal Transverse Mercator, WGS 84, UTM zone 36, South projection.

2.6.2 MODIS products

The MODIS vegetation indices are designed to supply consistent spatial and temporal comparisons of vegetation conditions by using the blue, red, and near-infrared reflectances (centred at 470 nanometers, 648 nanometers, and 848 nanometers, respectively). The MOD13Q1 product (250 m resolutions and 16-day compositing periods) contains two vegetation indices, the MODIS normalized vegetation index (NDVI) and the enhanced vegetation index (EVI).

The NDVI complements NOAA's advanced very high-resolution radiometer (AVHRR) NDVI products and provides continuity for applications that have involved AVHRR NDVI products. The enhanced vegetation index uses the blue band to remove residual atmospheric contamination due to smoke and sub-pixel thin clouds. The EVI also uses feedback adjustment to minimize canopy background variations and to enhance vegetation sensitivity from sparse to dense vegetation conditions. The MODIS NDVI is chlorophyll sensitive, whereas the EVI is more responsive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture.

The Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) image processing products, and the red, blue, NIR and MIR bands, were used for analysis (Table 2.3). The MODIS NDVI product contains atmospherically corrected bi-directional surface reflectances that have been masked for water, clouds and cloud shadows. The MODIS products were downloaded from the MODIS website and all the image pre-processing and corrections were done by NASA. These MODIS products have illustrated their potential for mapping vegetation cover, biomass and woody cover (Reeves, Winslow & Running 2001).

Table 2.3 Formulas and abbreviations of remote-sensing products (MODIS)

MODIS products	**Abbreviatio**	**Spatial resolution**
Normalized Difference Vegetation Index	NDVI	250m (16 days average)
Enhanced Vegetation Index	EVI	250m (16 days average)
Red Reflectance	RED	250m (16 days average)
Blue Reflectance	BLUE	250m (16 days average)
NIR Reflectance	NIR	250m (16 days average)
MIR Reflectance	MIR	250m (16 days average)

2.6.3 Testing relationship between processed MODIS products and vegetation parameters

According to the layout of fieldwork sites (Fig. 2.4), which were internally homogeneous (250 m x 250 m), it was possible to also use the field parameters in this scenario. Therefore, only one pixel value around each survey point (250 m x 250 m) was extracted from the MODIS products. The basic statistical analyses were also performed to explore the relationship between remote-sensing products and the observed and derived vegetation parameters (same approach as mentioned above; Fig. 2.7).

2.7 Accuracy assessment

Accuracy assessments enable the user to compare different methods and sensors, they provide information regarding the reliability and usefulness of remote-sensing techniques and support the spatial data used in decision making processes. Oindo and Skidmore (2003) suggested that to perform classification accuracy assessment correctly, it is necessary to compare two sources of information: the derived map and reference (e.g. field observed information). Analyses were performed to determine the errors of commission and omission between the soil and vegetation parameter classes and their predicted distributions derived from the vegetation habitat type and rangeland condition maps.

Statistics were generated for the Landsat ETM final rangeland condition products, from grid cells (3x3 cell values) enclosed by buffer polygons (Fig. 2.7). In the case of MODIS products, 2x2 cell values were extracted. The operation performs a zonal statistics analysis on the selected grid, with the buffer polygons representing the zones. The statistics reflect all those cells whose cell centers are located within the polygon boundary. For each polygon, this operation will calculate the following statistics:

1) ID value of polygon, taken from the ID field that was selected;
2) Count of cells, variety (number of unique values) and range within polygon;
3) Minimum, maximum, sum, mean, median and standard deviation of cell values within polygon
4) Majority (value with greatest number of occurrences) and minority (value with least number of occurrences) within polygon.

The majority cell values in the vicinity of each field site were used for the accuracy assessment. The results of the statistics were exported to the Access database for calculating the commission and omission errors.

2.8 Statements of degradation

To make a statement on the sampled condition of rangeland, only the randomly located field sites can be used, since the inclusion of the purposive located field sites would overestimate the occurrence of certain classes of condition. Statistics were produced by summing the number of estimated field degradation ratings (sampling sites), per condition class and expressing frequencies as percentages within the various vegetation habitat types.

An additional approach was to calculate the total area covered by classes of degradation. Further calculations of areas covered by degradation classes are completed within the specific vegetation habitat types. In this way degrees of degradation could be compared between the vegetation habitat types. Statistics were generated by overlaying the vegetation habitat type map (polygons) onto the rangeland condition maps (grids). Area coverage in hectare within each stratification unit was calculated to enable comparison between different classes of condition.

2.9 Summary

Chapter 2 summaries the research design and underlying methodologies for the GIS and satellite remote sensing approaches. The chapter described the methodologies for each GIS and satellite remote sensing approaches for the assessing, mapping and monitoring the condition of natural resources. The methodologies also described essential ground observation data for rangeland condition mapping, accuracy assessment and to make statements of degradation.

CHAPTER 3: RESULTS OF THE INTEGRATED REMOTE-SENSING AND GIS MONITORING METHODOLOGY

The results obtained from applying the methodologies to data of Maputaland are represented in this chapter. The chapter started with the analysis of environmental field data (e.g. vegetation and soil) which formed an essential part during the modelling and spatial integration of the vegetation habitat type map. Results of the two satellite remote-sensing sensors (Landsat ETM and MODIS) were compared with observed field data (e.g. biomass, cover) to compile rangeland condition maps. Correspondence matrices are computed between the satellite remote sensing products and observed field data for accuracy assessment.

3.1 Results of the GIS spatial and non-spatial environmental approach

It was essential to stratify the natural environment of the study area into uniform environmental units within which degradation could be mapped and reported.

3.1.1 Classification and ordination of vegetation data

The two broad vegetation communities (Clay Thornveld and Coastal Sandveld) were geographically separated by the TWINSPAN classification and CCA ordination results (Fig. 3.1). The environmental variables were selected by forward selection using a Monte Carlo Permutation test with 199 permutations. Very strong correlations occurred between environmental parameters and vegetation communities, average annual rainfall (r = 0.7 or 70%) and maximum temperature (r = 0.71 or 71%), respectively. Medium correlations occurred between vegetation communities and parameters such as clay (r = 0.4 or 40%), altitude (r = 0.45 or 45%) and slope (r = 0.3 or 30%), respectively. The length and the directions of the blue arrows in Figure 3.1 indicate the status of correlations between the vegetation communities and environmental parameters.

The four broad vegetation types (sub-communities) were also identified within the above-mentioned major vegetation communities from the TWINSPAN classification and CCA ordination (Fig. 3.1). The *Acacia nilotica* - *Acacia karroo* - *Dichrostachys cinerea* sub-community is situated to the left of the first ordination axis and is therefore associated with cooler, moist climates as found on higher altitudes and associated with clayey soils (Morgenthal, Kellner, Van Rensburg, Newby & Van der Merwe In Press). The *Acacia nilotica* - *Acacia karroo* - *Dichrostachys cinerea* community is typically Thornveld dominated by *Acacia* and *Dichrostachys* trees and shrubs. The vegetation is mostly associated with the southern areas in the Hluhluwe and Umfolozi Game Reserves extending northwards into the Lebombo Mountains. The *Cissus rotundifolia - Enteropogon macrostachyus* sub-community occurs to the north in the study area and is closely associated with the central and northern sections of the Natal Lowveld bushveld as described by Low and Rebelo (1996).

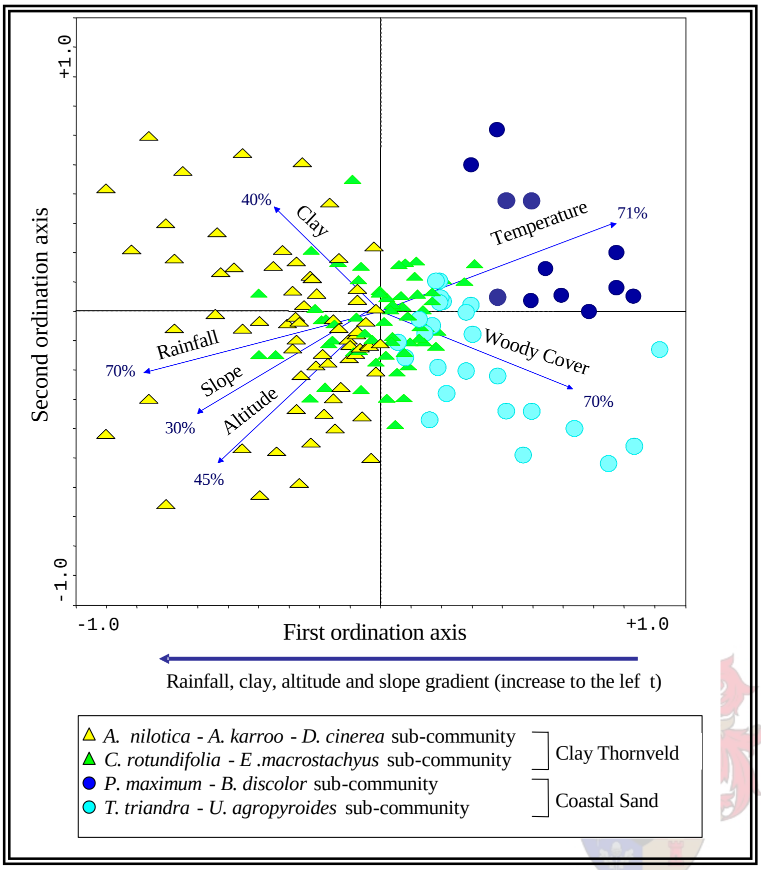

Figure 3.1 CCA ordination indicating the relationship between the vegetation communities and significant environmental variables selected during forward selection

The Clay Thornveld occurred on the rolling hills in the interior and the vegetation is mostly dominated by *Acacia* shrubs and trees (*A. nilotica, A. tortilis, A. luederitzii, A. karroo*), the shrub *Croton menyharthii* and tree species such as *Euclea* species (*E. divinorum* and *E. racemosa*). The vegetation structure is mostly woodlands, except where tree clearing has taken place. In the case of old fields small *Acacia* shrubs frequently occurred together with shrubs such as *Lippia* species (Morgenthal, Kellner, Van Rensburg, Newby & Van der Merwe In Press).

The *Panicum maximum-Brachylaena discolor* and *Themeda triandra-Urelytrum agropyroides* sub-communities are associated with sandy soils and lower elevations with higher temperatures (Figs. 3.1 & 3.2). The *Themeda triandra Urelytrum agropyroides* community was, according to Matthews *et al.* (1999), previously described by Myre (1964) as the *Themedeto - Salacietum* (Myre 1964). Matthews *et* *al.* (1999) described this vegetation type as a wooded grassland associated with relatively dry sands with a deep water table on dune crests and slopes.

The Coastal Sandveld community is associated with the coastal plains and dunes and therefore the soils are characteristically sandy. The vegetation is a combination of grasslands, palm trees and mixed Savanna, with variable degrees of resemblance to sand forests. Shrub species occur, such as *Corchorus junodii, Euclea natalensis* and *Helichrysum krausii*, while tree species such as *Eugenia capensis, Landolphia krikii, Parinari curatellifolia, Phoenix reclinata, Syzygium cordatum* and *Terminalia sericea* comprise the Coastal Sandveld community. Sand forests were excluded during fieldwork and are therefore not included in this study. The Coastal Sandveld community generally occurs along the coastal flats.

3.1.2 Spatial integration of vegetation habitat type map

Results from the CCA ordination (Figure 3.1) gave a very good indication of which major environmental parameters influenced the vegetation community turnover spatially, therefore these high-resolution data (e.g. soil, climate, altitude and slope) were used to derive vegetation habitat boundaries.

The Clay potential map (version 1) consists of 2 clay classes, namely the Low Clay class (<19% clay) and High Clay class (>19% clay). The Clay potential map (version 2) consists of 3 clay classes, namely the Low Clay class (<12% clay), Medium Clay class (12-29% clay) and High Clay class (>29% clay; Fig. 3.2). Both options were used to derive vegetation habitat type maps. Statements of degradation were made using the integrated map with the two clay classes, although both versions represented relatively good vegetation habitat type maps. The reason why the second version was not used, was because too few random field sites fell within the classes of the version with 3 clay classes.

The rainfall map consisted of two rainfall classes, namely the High Rainfall (>700 mm) and Low Rainfall (<700 mm) classes, while the altitude map incorporated High Altitude (>110 m) and Low Altitude (<110 m) classes. A slope data layer with a 100 m contour (DEM) was created and consisted of Flat (<=8%) and Steep (>=8%) Slope classes (Fig. 3.2).

An integration of GIS data layers and remote-sensing product (Land-cover map) were created for overlay analysis and masking purposes. Figure 3.2 represents the final vegetation habitat type map (2 clay classes) and illustrated the overlaid classified TWINSPAN vegetation communities. There were very good correlations between the derived habitat map and vegetation communities.

3.1.3 Assessment of relationship between clay (laboratory analysis) and vegetation classes and their predicted distribution.

Analyses were performed to determine the errors of commission and omission between the soil clay classes (laboratory analysis) and their predicted distributions derived from the vegetation habitat type map. The column figures indicate errors of omission. The row totals provide information on errors of commission.

In Table 3.1 numbers along the diagonal (bold) represent cases where sites were mapped correctly, in accordance with clay classes (percentage clay tested by laboratory analysis – 2 clay classes). Adding the number of correct classifications 217 (73 + 144), an overall accuracy of 78% of the total sample 280 (217/280) was calculated for the vegetation habitat type map. The proportional error of the vegetation habitat type map of the clay classes is therefore 22%.

Table 3.1 Error matrix illustrating correspondence between 2 clay classes (laboratory analysis) vs. derived clay on Vegetation habitat type map

Vegetation habitat type map (2 clay classes)	**% Clay of A-Horizon sampled - laboratory analysis**				
		Low clay (<19%)	High clay (>19%)	Totals (n)	Errors of commission
	Low clay (<19%)	**74% (n=73)**	26% (n=26)	99	26%
	High clay (>19%)	20% (n=37)	**80% (n=144)**	181	37%
	Totals (n)	110	170	**78% (n=280)**	
	Errors of omission	34%	15%		**22%**

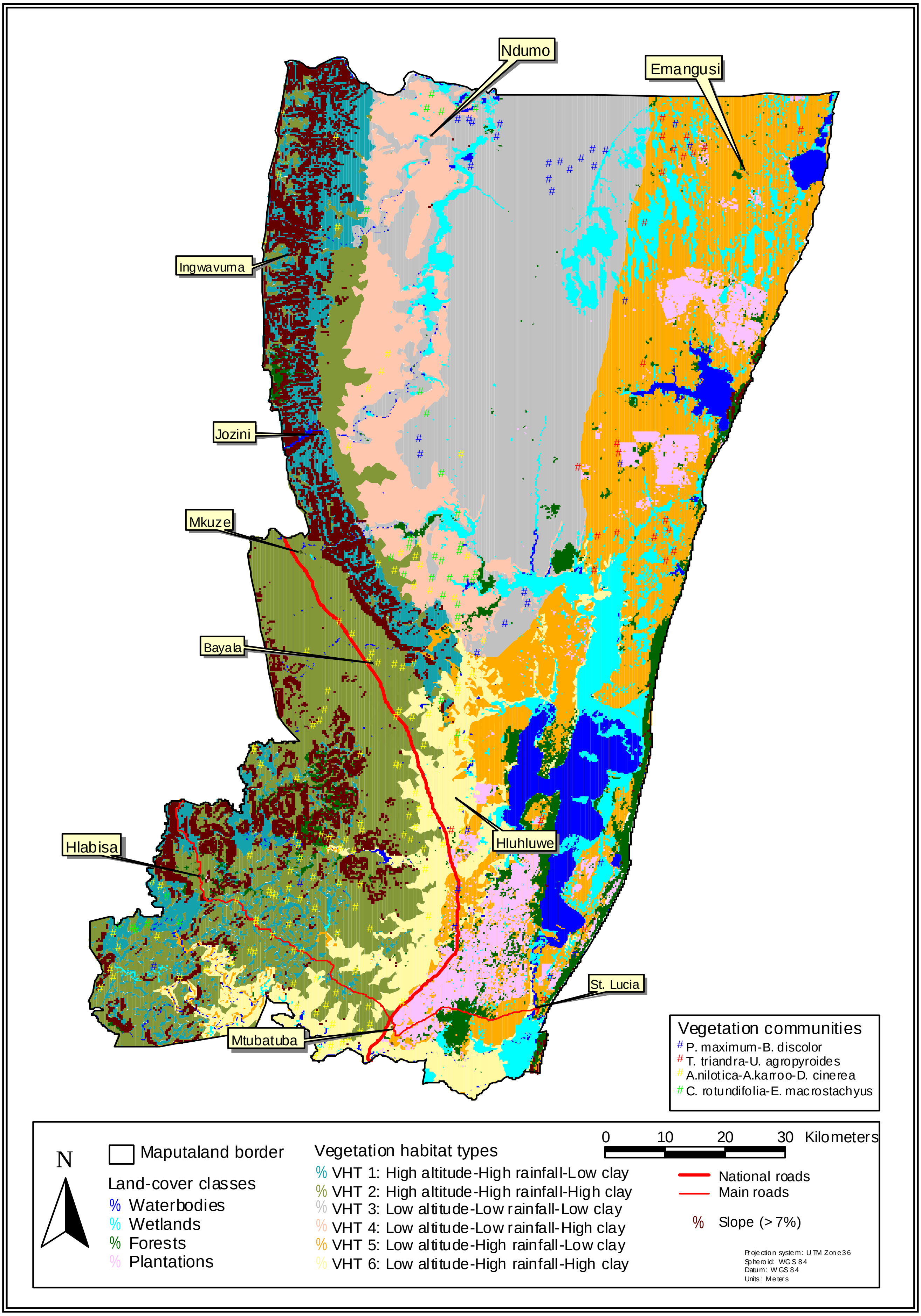

Figure 3.2 Vegetation habitat types and vegetation communities of Maputaland

Table 3.2 represent cases where sites were mapped correctly, in accordance with clay classes (percentage clay tested by laboratory analysis – 3 clay classes). Adding the number of correct classifications 185 (63 + 49 + 73), an overall accuracy of 66% of the total sample 280 (185/280) was calculated for the vegetation habitat map. The proportional error of the vegetation habitat map of the clay classes is therefore 34%.

Table 3.2 Error matrix illustrating correspondence between 3 clay classes (laboratory analysis) vs. derived clay on Vegetation habitat map

Vegetation habitat map (3 clay classes)	**% Clay of A-Horizon sampled - laboratory analysis**				
	Low clay (<12%)	Medium clay (12-29%)	High clay (>29%)	Totals (n)	Errors of commission
Low clay (<12%)	**88% (n=63)**	10% (n=7)	2% (n=2)	72	12%
Medium clay (12-29%)	15% (n=13)	**55% (n=49)**	30% (n=27)	89	45%
High clay (>29%)	4% (n=5)	34% (n=40)	**62% (n=73)**	118	38%
Totals (n)	81	96	102	**66% (n=280)**	
Errors of omission	22%	49%	28%		**34%**

In Table 3.3 numbers along the diagonal (bold) represent cases where sites were mapped correctly, in accordance within the field observations and classifications by TWINSPAN. Table 3.3 show a very high classification of Community 1.1 (92%, 94%) and Community 1.2 (67%) - TWINSPAN classification vs. map. Species such as *Acacia nilotica, Acacia karroo, Dichrostachys cinerea*, *Cissus rotundifolia* and *Enteropogon macrostachyus*, which form part of sub-communities 1.1 and 1.2, are associated soils with higher clay content.

A good correlation occurred between sub-community 2.1 (78%) and the map, while sub-community 2.2 correlated well with the Low Altitude-High Rainfall-Low Clay class of the map (Table 3.3). Species such as *Panicum maximum, Brachylaena discolor, Themeda triandra* and *Urelytrum agropyroides*, which are associated with sandy soils, formed part of above-mentioned sub-communities.

Table 3.3 Distribution of vegetation communities vs. derived vegetation habitat types on map

Vegetation habitat types - map (6 classes)	Vegetation communities (TWINSPAN and Ordination)					
		Sub-Com 1.1[1]	Sub-Com 1.2[2]	Sub-Com 2.1[3]	Sub-Com 2.2[4]	Totals (n)
	High alt, High rain <19% clay	82% (n=18)	18% (n=4)			22
	High alt, High rain >19% clay	**92% (n=69)**	5% (n=4)	3% (n=2)		75
	Low alt, Low rain <19% clay	7% (n=2)	11% (n=3)	**78% (n=21)**	3% (n=1)	27
	Low alt, Low rain >19% clay	33% (n=12)	**67% (n=24)**			36
	Low alt, High rain <19% clay	7% (n=3)	3% (n=1)	25% (n=10)	**65% (n=25)**	39
	Low alt, High rain >19% clay	**94% (n=24)**	3% (n=1)		3% (n=1)	26
	Totals (n)					225

3.2 Results of Landsat ETM products for remote sensing monitoring

When monitoring natural resources with remote sensing, the total vegetation cover or standing biomass is the parameter that is most often used as an indicator of rangeland condition (Karfs *et al*. 2000). The rationale for correlation analysis was to measure the amount of association observed between the remote-sensing products and the observed and derived vegetation parameters.

3.2.1 Testing relationship between processed imagery and natural vegetation parameters for monitoring rangeland condition

In the field an estimate rating of the amount of biomass present (1 - large amount of standing biomass; 5 - low standing biomass) were given. Comparative results were acquired between the vegetation parameter, herbaceous biomass and the visible red band (0.53), middle infrared band (0.55), Tasselled Cap-brightness (0.49) and the PCA357 (0.56) (Table 3.4). In the case of the overall degradation parameter, less significant results were obtain between the PCA357 (0.42) and the particular parameter.

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[1] *Acacia nilotica-Acacia karroo-Dichrostachys cinerea* Sub-community

[2] *Cissus rotundifolia -Enteropogon macrostachyus* Sub-community

[3] *Panicum maximum-Brachylaena discolor* Sub-community

[4] *Themeda triandra-Urelytrum agropyroides* Sub-community

Moderately significant results were obtained between Woody crown cover and the NDVI (0.52), MIR (0.38) and BSI (-0.38) (Table 3.4).

Table 3.4 Correlations of Landsat ETM (20 March 2001) indices vs. vegetation parameters

Landsat ETM Indices	**Vegetation Parameters**						
	Biomass	Bush encroachment	Woody crown cover	Stem spacing (<2.5m)	Stem Spacing (> 2.5m	Species change	Overall degradation
Visible Red	**0.53**	-0.20	-0.32	0.28	0.47	0.21	0.37
Middle Infrared	**0.55**	-0.19	-0.29	0.27	0.40	0.25	**0.40**
PCA357	**0.56**	-0.19	-0.31	0.28	0.38	0.16	**0.42**
NDVI	-0.43	0.35	**0.52**	-0.32	**-0.48**	-0.16	**-0.38**
BSI	0.28	-0.35	**-0.38**	0.10	0.2	-0.19	-0.03
MIR	-0.28	0.10	**0.38**	-0.14	-0.39	0.06	-0.05
TC-Brightness	**0.49**	-0.16	-0.23	0.24	0.33	0.09	0.27

3.2.2 Species composition and rangeland condition

Positive results from the Spearman's rank correlation (r = 0.71) and a very good trend (see Fig. 3.3) revealed that there is a strong correlation between herbaceous biomass and overall degradation (species composition) assessment. The good correlation of herbaceous biomass at a site at a given point in time verifies the function of the combination of parameters, such as defoliation, species change and other parameters that describe the overall degradation (Fig. 3.3).

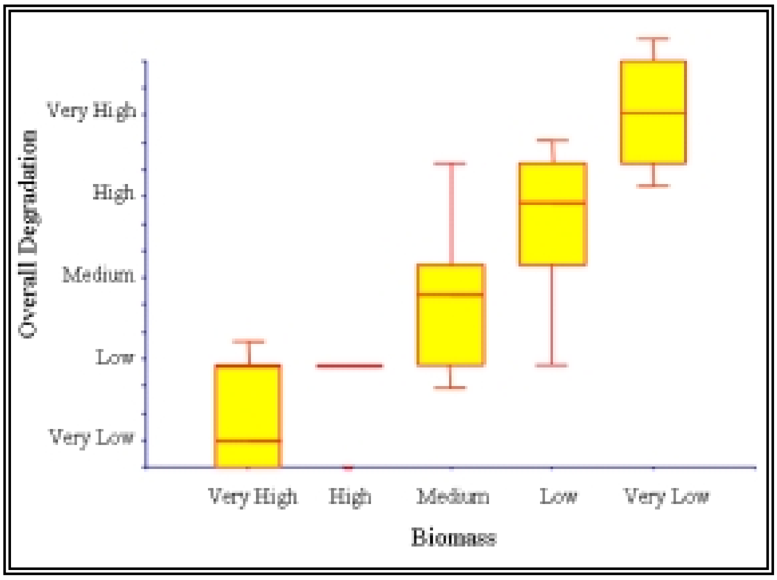

Figure 3.3 Box and Whisker plot of Biomass and Degradation scores (estimated in field)

3.2.3 Biomass

Spearman's rank correlation revealed that there is a good to moderate correlation between biomass and PCA357 (r = 0.56) (see Table 3.4), middle infrared (r = 0.55) and visible red (r = 0.53). The Box and Whisker plots (Fig. 3.4) revealed a very good trend line between the PCA357 and herbaceous biomass variables.

The statistics made it possible to identify clear cut-off values. The very high and high biomass classes and the very low and low classes were grouped together to produce the final rangeland condition map.

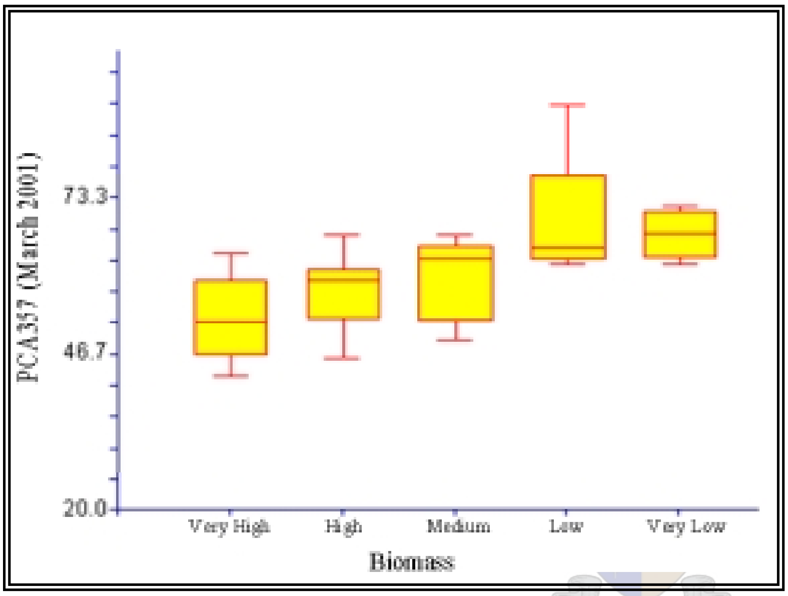

Figure 3.4 Box and Whisker plot of Biomass and PCA357 (March 2001 Image)

Contrasting herbaceous biomass conditions at two field survey sites as detected by PCA357 is undoubtedly visible in Figure 3.5. Therefore, the PCA357 (March 2001 Image) rangeland condition product gives a reliable indication of standing biomass and effectively maps severely degraded areas and areas with good rangeland condition at a 1:100 000 scale (Figs. 3.4 and 3.5). A method based on a "rule of thumb" was used for determining the mapping scale[5].

[5] The mapping scale was calculated by means of multiplying the cell size (e.g. 30m) by 3 (e.g. 3 x 30m = 1:100 000).

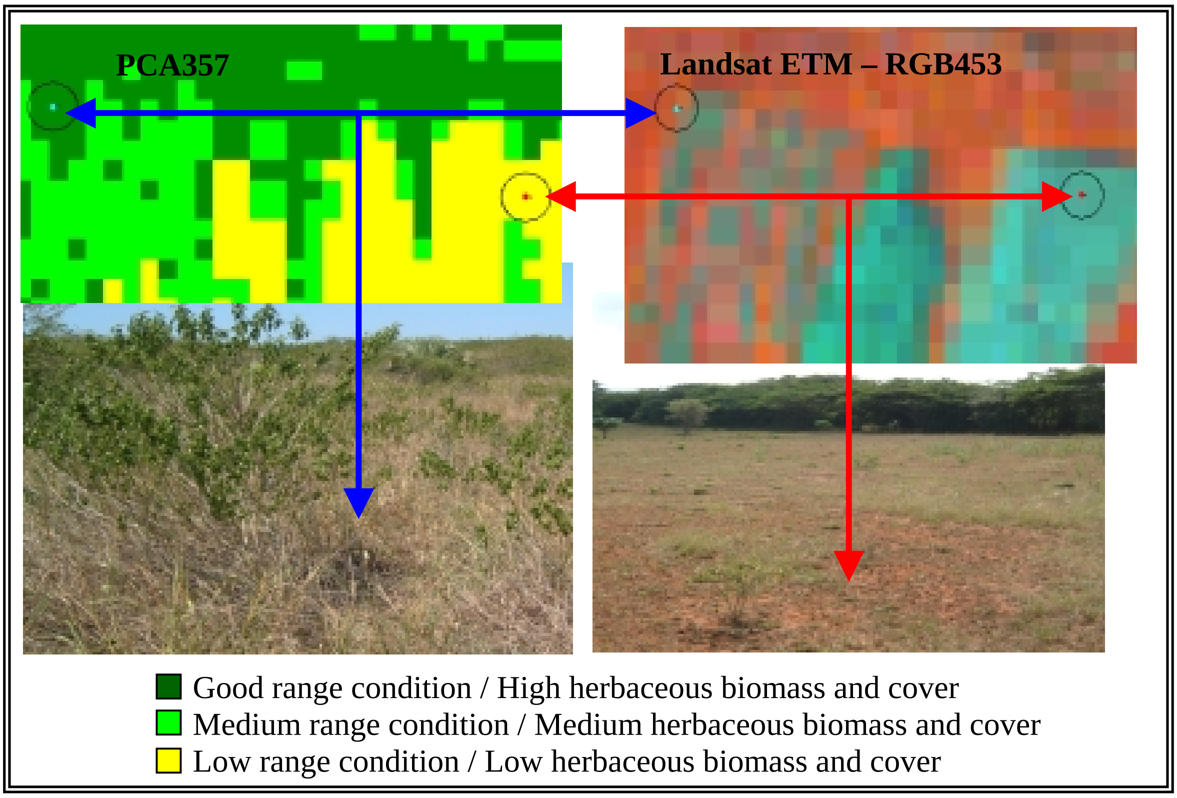

Figure 3.5 Contrasting conditions of standing biomass at two field survey sites as detected by PCA357

3.2.4 Woody vegetation cover

Table 3.4 and Figure 3.6 reveal that there is a less significant correlation between woody cover classes and NDVI-March 2001 (r = -0.40) and NDVI-August 2001 (r = 0.60). The classes were assigned as follows: Low (<30% woody crown cover), Medium (30-50% woody crown cover) and High (<50% woody crown cover).

The NDVI (March 2001) index gives a reliable indication of woody cover and effectively maps the woody cover classes for the rangeland condition product at a 1:100 000 scale. A t-test revealed that all classes differed significantly from one another in terms of NDVI values (Fig. 3.6). The 95% confidence limits of the classes were used to calculate NDVI cut-off values for map classes.

The woody cover classes, Medium (30-50%) and High (>50%), were combined and used for the final rangeland condition product. The land cover seems to fit very well on the Landsat image and was used as a mask to separate rangeland from other land uses (e.g. water bodies, wetlands, cultivation, etc.) (Fig. 3.8).

Figure 3.7, however, shows an example of where high woody cover is associated with negative species change and low biomass, but this will remain undetected by a satellite image (PCA) as a result of the darkening / shadowing effect of the dense tree cover.

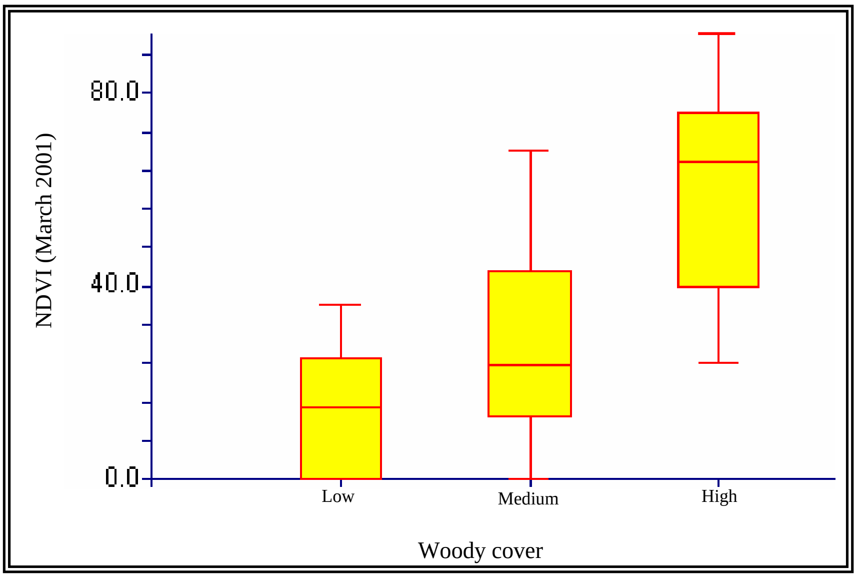

Figure 3.6 Box and Whisker plot of woody classes and NDVI (March 2001 Image)

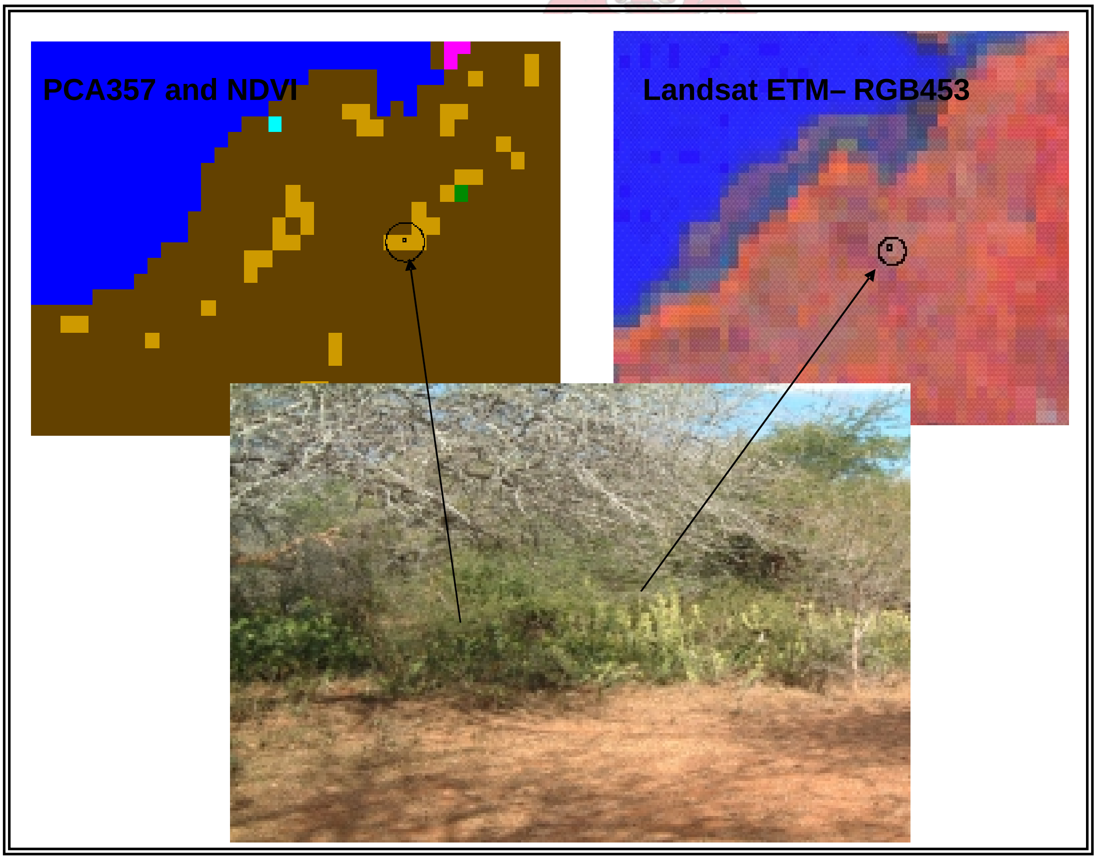

Figure 3.7 Poor rangeland condition and very low biomass concealed by high woody cover (>40%) detected by PCA 357 and NDVI satellite image products

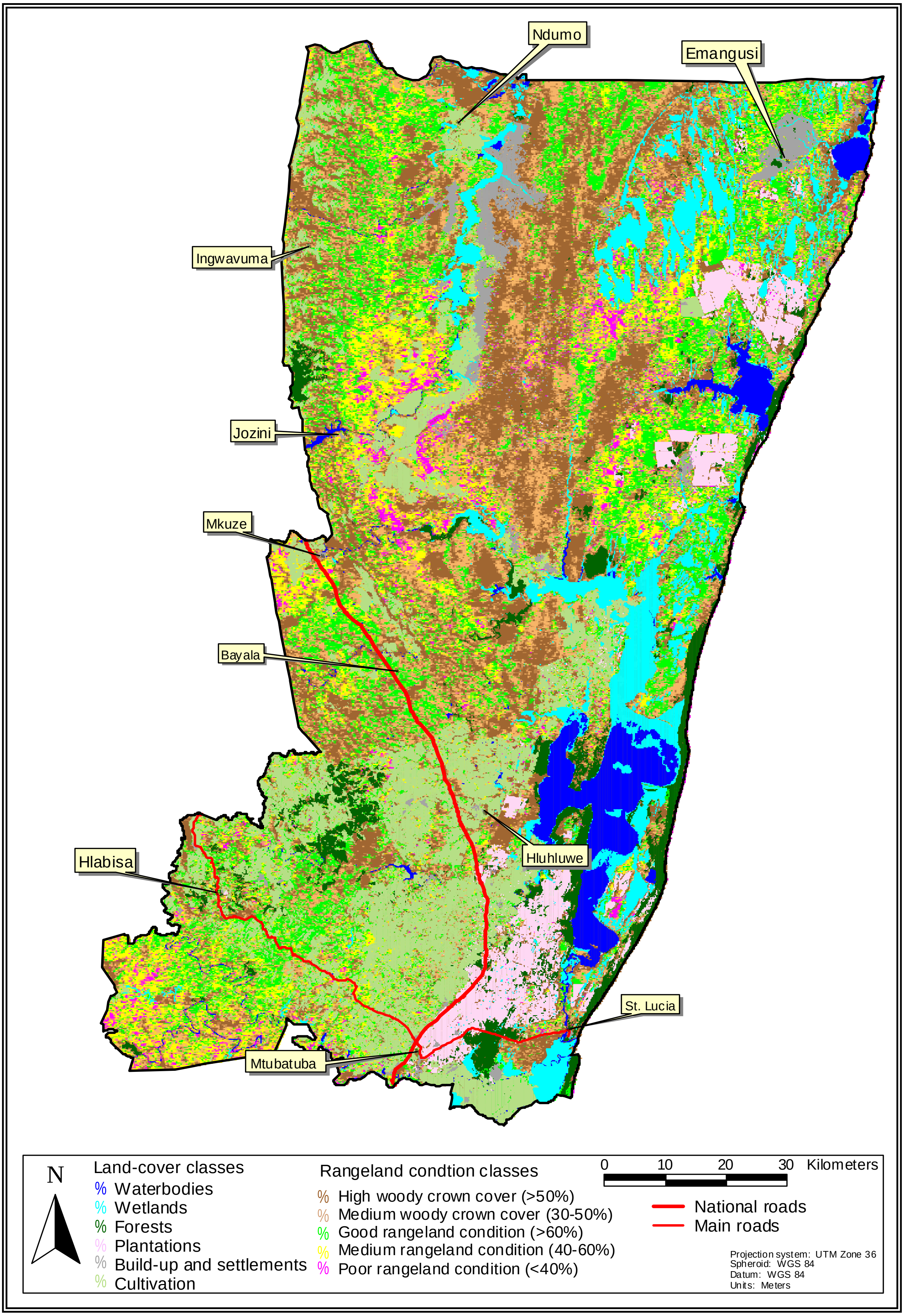

Figure 3.8 Rangeland condition derived from Landsat ETM products (PCA357 & NDVI)

3.2.5 Accuracy assessment

3.2.5.1 Correspondence of remote-sensing products and rangeland condition

Table 3.5 represents cases where sites were mapped correctly, in accordance with rangeland condition estimated during fieldwork. Adding the number of correct classifications 152 (115 + 30 + 7), an overall accuracy of 68% of the total sample 225 (152/225) was calculated for the rangeland condition map. The proportional error of the vegetation habitat map of the clay classes is therefore 32%.

Rangeland in good condition (>60%) has a 73% probability to be mapped as good, while sites in a poor condition (<40%) have a 33% probability to be mapped as poor using the PCA357 classification. Very few sites in a poor condition (n=7) were sampled during fieldwork, thus further limiting the statistical analyses.

Table 3.5 Correspondence matrix of a Landsat ETM product (PCA357 - March 2001 Image) classes and rangeland condition classes for located sites (n=225)

Landsat ETM product (PCA357) Rangeland condition map	Rangeland condition estimated during field work					
		Good (Classes 1 + 2)	Medium (Class 3)	Poor (Classes 4 + 5)	Totals (n)	Errors of commission
	Good (>60%)	**73% (n=115)**	12% (n=19)	15% (n=24)	158	27%
	Medium (40-60%)	7% (n=3)	**64% (n=30)**	29% (n=12)	45	36%
	Poor (40%)	33% (n=7)	33% (n=7)	**33% (n=7)**	22	67%
	Totals (n)	125	55	44	**68% (n=225)**	
	Errors of omission	8%	47%	84%		**32%**

3.2.5.2 Correspondence of remote-sensing products and woody cover

Table 3.6 represents cases where sites were mapped correctly, in accordance with woody cover estimated during fieldwork. Adding the number of correct classifications 137 (61 + 49 + 27), an overall accuracy of 61% of the total sample 225 (137/225) was calculated for the NDVI woody cover map. The proportional error of the NDVI woody cover map is therefore 39%.

Table 3.6 Correspondence matrix of a Landsat ETM (NDVI - March 2001 Image) classes and woody cover classes for located sites (n=225)

Landsat ETM product (NDVI) Woody cover Map	**Subjective estimated woody cover during field work**					
		Low (<30%)	Medium (30-50%)	High (>50%)	Totals (n)	Errors of commission
	Low (<30%)	**68% (n=61)**	6% (n=5)	27% (n=24)	90	32%
	Medium (30-50%)	16% (n=14)	**55% (n=49)**	29% (n=26)	89	45%
	High (>50%)	11% (n=5)	30% (n=14)	**59% (n=27)**	46	41%
	Totals (n)	80	68	77	**61% (n=225)**	
	Errors of omission	24%	28%	65%		**39%**

3.3 Results of MODIS products for remote sensing monitoring

3.3.1 Testing relationship between processed MODIS imagery and natural vegetation parameters for modelling rangeland condition.

The estimated ratings of the vegetation parameters were tested for relationships with the MODIS products. Comparative results were acquired between herbaceous biomass and NDVI (0.51) and biomass and EVI (0.46) (Table 3.7). In the case of the overall degradation, less significant results were obtained, i.e. NDVI (-0.40) and EVI (-0.36). Moderately significant results were obtained between Woody crown cover and the NDVI (0.42), MIR (-0.40) and red reflectance product (-0.40).

Table 3.7 Correlations of remote-sensing indices vs. vegetation parameters

MODIS products	**Vegetation Parameters**						
	Biomass	Bush encroachment	Woody crown cover	Stem spacing (<2.5m)	Stem Spacing (> 2.5m	Species change	Overall degradation
NDVI	**0.51**	0.30	**0.42**	-0.18	-0.27	0.30	**-0.40**
EVI	**0.46**	0.19	0.20	-0.12	-0.20	0.22	**-0.36**
RED	0.36	-0.25	**-0.40**	0.14	0.28	0.17	0.27
BLUE	0.30	-0.23	-0.36	0.10	0.24	0.12	0.19
NIR	0.29	0.1	-0.1	0.03	0.09	-0.13	-0.23
MIR	0.30	-0.27	**-0.40**	0.13	0.26	0.16	0.21

3.3.2 Biomass

Spearman's rank correlation revealed that there are moderate correlations between biomass and NDVI (r = 0.51) and EVI (r = 0.46) (see Table 3.7 and Fig. 3.9). The t-test and Box and Whisker plot revealed that the Very high class differed significantly from the Medium class in terms of NDVI values, while the Medium class differed significantly from the Very low class (Fig. 3.9). The very high and high biomass classes and the very low and low classes were grouped together to produce the final rangeland condition map. Therefore, the MODIS-NDVI (March 2001) rangeland condition product gives a reliable indication of standing biomass and effectively maps severely degraded areas and areas with good rangeland condition at a 1:750 000 scale (Fig. 3.12).

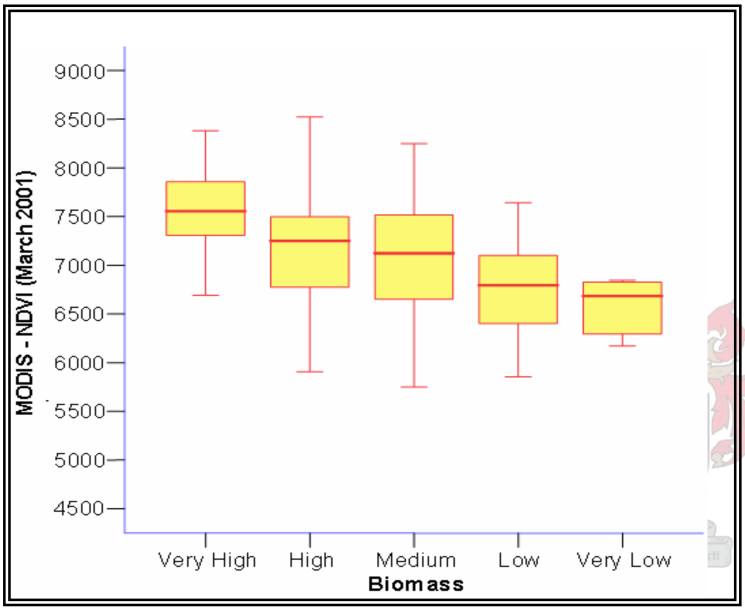

Figure 3.9 Box and Whisker plot of Biomass and MODIS-NDVI (March 2001)

3.3.3 Woody vegetation cover

Table 3.7 and Figure 3.10 reveal that there is a less significant correlation between woody cover classes and MODIS-NDVI-March 2001 (r=-0.42). The classes were assigned as follows: Low (<30% woody crown cover), Medium (30-50% woody crown cover) and High (<50% woody crown cover). A t-test revealed that all classes differed significantly from one another in terms of NDVI values (Fig. 3.10).

The woody cover classes, Medium (30-50%) and High (>50%), were combined and used for the final rangeland condition product. Therefore the MODIS-NDVI (March 2001) index gives a reliable indication of woody cover and effectively maps the woody cover classes for the rangeland condition product on a 1:750 000 scale (Fig. 3.12).

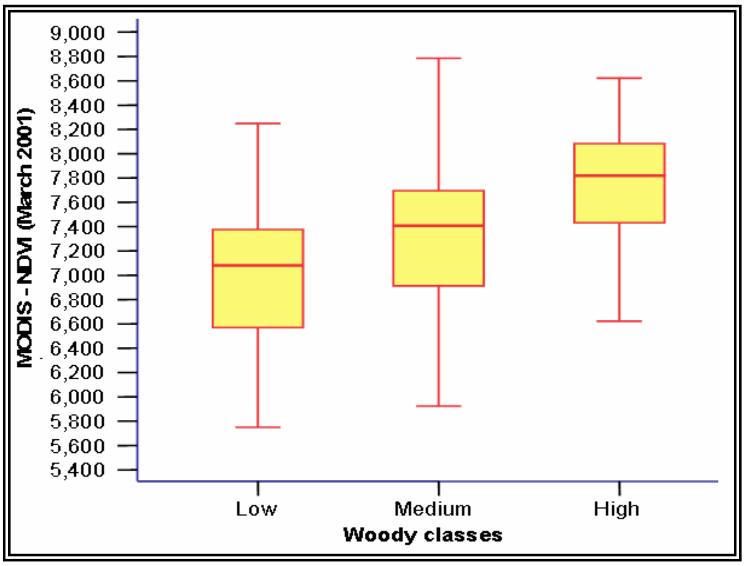

Figure 3.10 Box and Whisker plot of woody classes and NDVI (MODIS - March 2001 Image)

Figure 3.11 show an example of good rangeland condition associated with positive species change and high biomass, and dense woody cover.

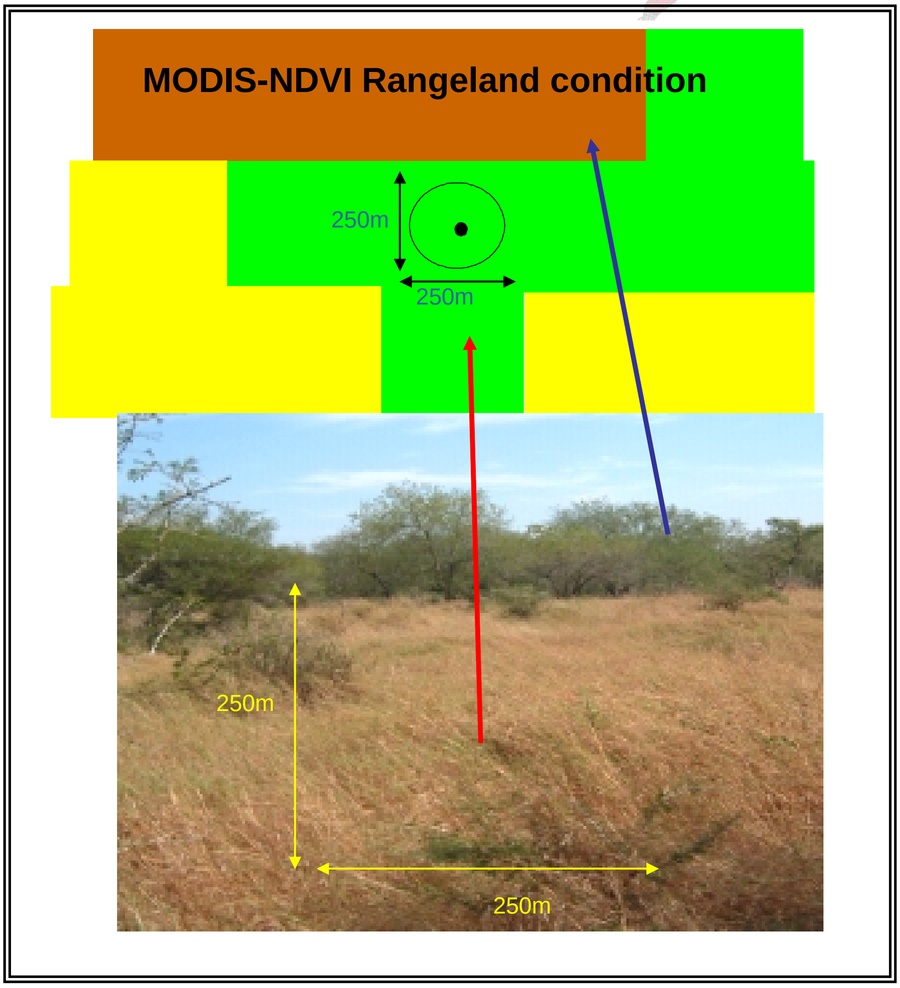

Figure 3.11 Good rangeland condition and high biomass concealed by high woody cover (>40%) detected by MODIS-NDVI satellite image products

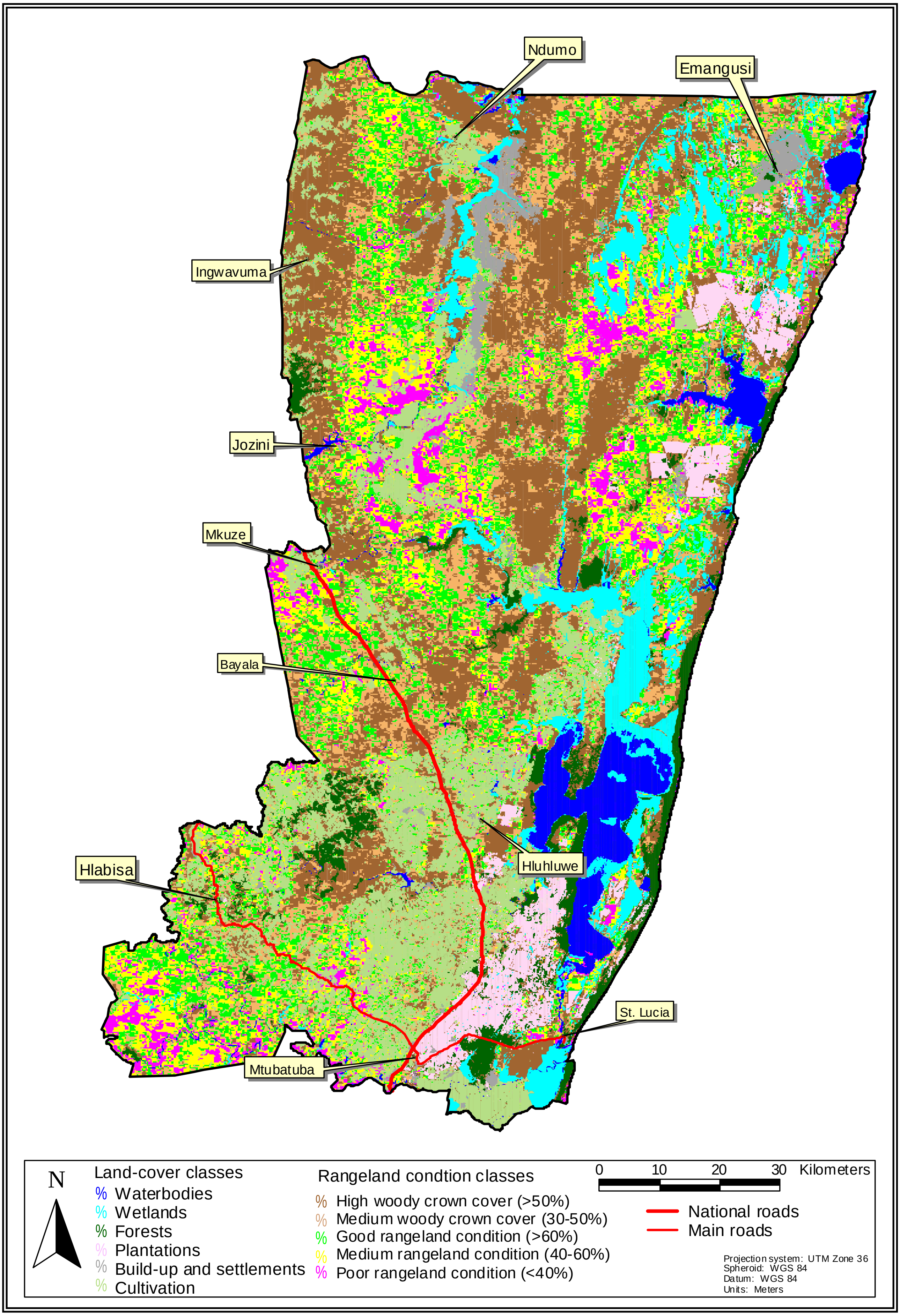

Figure 3.12 Rangeland condition derived from MODIS products (MODIS-NDVI's)

3.3.4 Accuracy assessment

3.3.4.1 Correspondence of MODIS products and rangeland condition

Table 3.8 represents cases where sites were mapped correctly, in accordance with rangeland condition estimated during fieldwork. Adding the number of correct classifications 148 (111 + 29 + 8), an overall accuracy of 66% of the total sample 225 (148/225) was calculated for the rangeland condition map. The proportional error of the vegetation habitat map of the clay classes is therefore 34%.

Rangeland in good condition (>60%) has a 71% probability to be mapped as good, while sites in a poor condition (<40%) have a 40% probability to be mapped as poor using the NDVI classification. Very few sites in a poor condition (n=8) were sampled during fieldwork, thus further limiting the statistical analyses (Table 3.8).

Table 3.8 Correspondence matrix of a MODIS product (NDVI - March 2001 Image) classes and rangeland condition classes for located sites (n=225)

MODIS product (NDVI) Rangeland condition map	**Subjective rangeland condition estimated during field work**				
	Good (Classes 1 + 2)	Medium (Class 3)	Poor (Classes 4 + 5)	Totals (n)	Errors of commission
Good (>60%)	**71% (n=111)**	18% (n=28)	11% (n=18)	157	29%
Medium (40-60%)	35% (n=17)	**60% (n=29)**	4% (n=2)	48	40%
Poor (40%)	40% (n=8)	20% (n=4)	**40% (n=8)**	20	60%
Totals (n)	136	61	28	**66% (n=225)**	
Errors of omission	18%	52%	71%		**34%**

3.3.4.2 Correspondence of MODIS products and woody cover

Table 3.9 represents cases where sites were mapped correctly, in accordance with woody cover estimated during fieldwork. Adding the number of correct classifications 144 (59 + 55 + 30), an overall accuracy of 64% of the total sample 225 (144/225) was calculated for the NDVI woody cover map. The proportional error of the NDVI woody cover map is therefore 36%.

Table 3.9 Correspondence matrix of a MODIS (NDVI - March 2001 Image) classes and woody cover classes for located sites (n=225)

MODIS product (NDVI) Woody cover Map	Subjective estimated woody cover during field work					
		Low (<30%)	Medium (30-50%)	High (>50%)	Totals (n)	Errors of commission
	Low (<30%)	**60% (n=59)**	21% (n=21)	18% (n=18)	98	40%
	Medium (30-50%)	20% (n=16)	**68% (n=55)**	12% (n=10)	81	32%
	High (>50%)	4% (n=2)	30% (n=14)	**65% (n=30)**	46	25%
	Totals (n)	77	90	58	**64% (n=225)**	
	Errors of omission	23%	39%	48%		**36%**

3.4 Statements of degradation

3.4.1 Statement of total area from field sites

According to Figure 3.13, the field ratings determined that between 12% (10% + 2%) of Maputaland is in a poor to very poor condition. The field estimations indicate that 61% (53% + 8%) of the sites were regarded as being in a good to very good condition (light to no degradation).

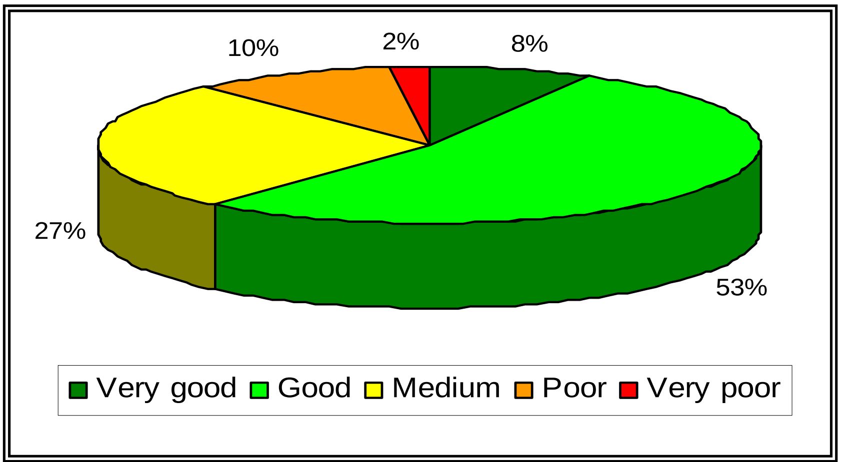

Figure 3.13 Percentage of sampling sites in various degradation classes as estimated by field assessment

3.4.2 Statements within vegetation habitat types from field sites

Field estimates in Figure 3.14 graphically portray the occurrence of degradation between the six vegetation habitat types. The vegetation habitat type (VHT) 5 has the highest score in the very poor condition class (8%), while VHT 3 and 6 have the highest scores (19%) in the poor condition classes. However, VHT 6 has the highest score (65%) in the good condition class. Within VHT 2 and 3 high scores also occur in the good rangeland condition class.

VHT 5 has the highest score of 67% (23% + 44%) in the very good and good condition classes, indicating that this vegetation habitat is, according to the subjective field estimates, the least degraded of all vegetation habitat types.

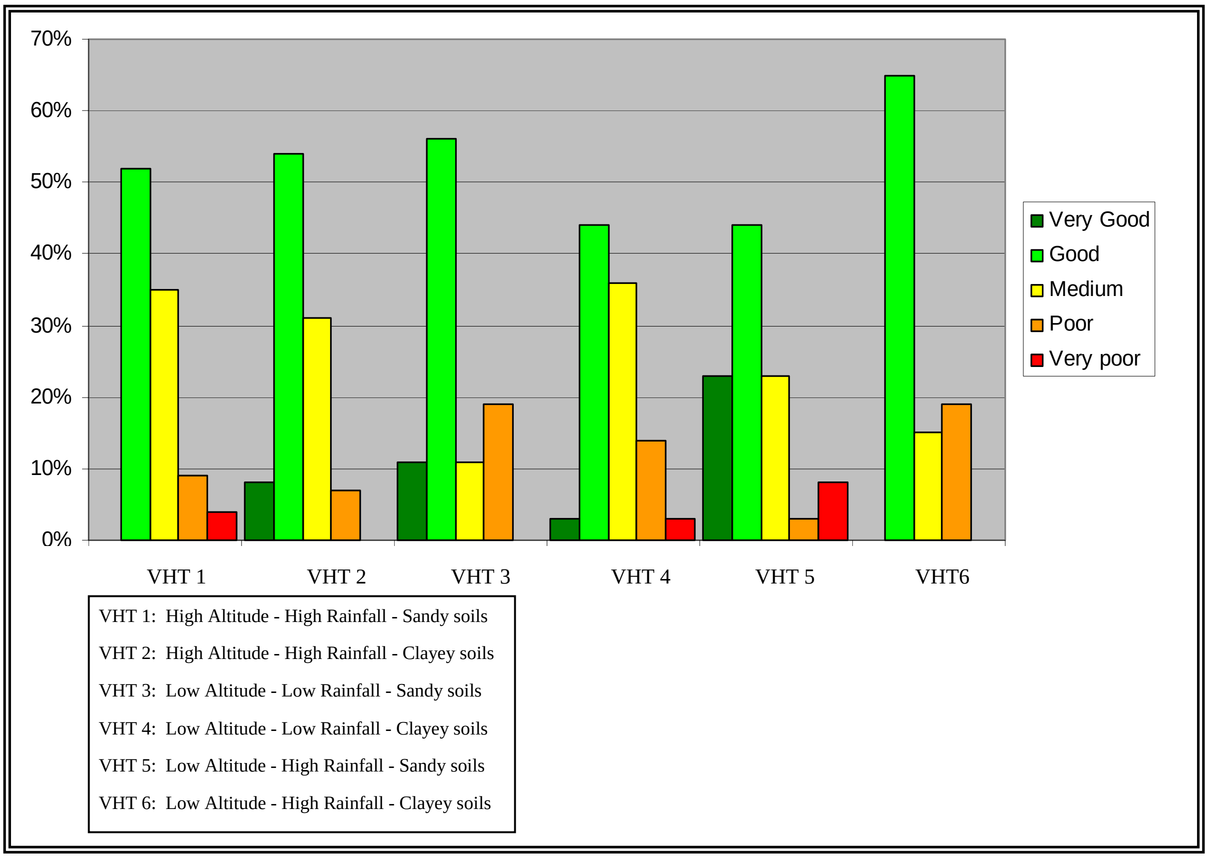

Figure 3.14 Proportional distribution of sampling sites within degradation classes estimated by field assessment

3.4.3 Statement of total percentage area covered by degradation classes on map from Landsat ETM products

Calculations of the relative presence of degradation classes from the total Landsat ETM products indicate that the study area consists of 16% (good), 10% (medium) and 2% (poor) rangeland condition classes (Fig. 3.15). The high and medium woody cover classes have 21% and 18% cover of the total area.

Other land-cover classes occupy 33% (Cultivated classes – 13%, Wetlands – 8%, Water bodies – 4%, Build-up and settlements – 3%, Forest – 5% and plantations – less than 1%) of the total area.

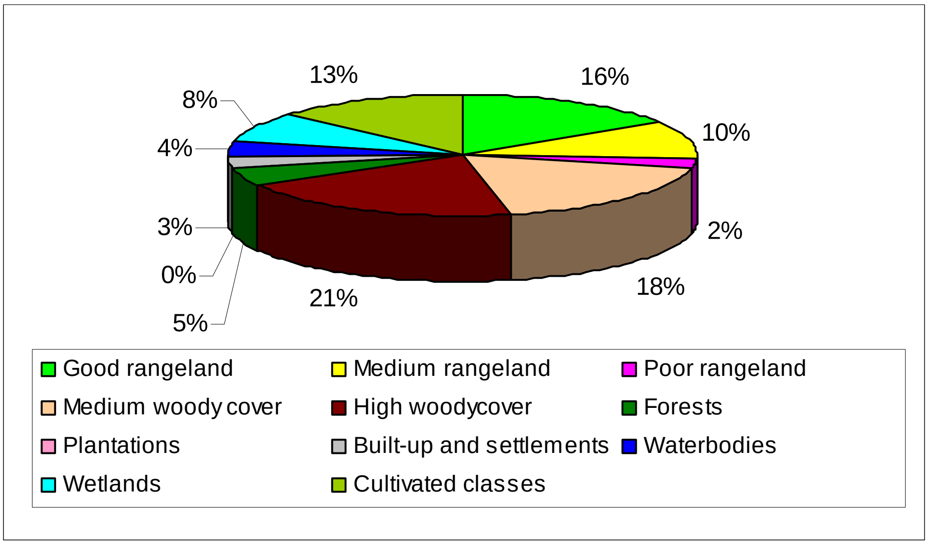

Figure 3.15 Percentage of area covered by various land-cover and degradation classes as calculated from Landsat ETM products

3.4.4 Statement of area covered by degradation classes within vegetation habitat types on map from Landat ETM products

Figure 3.16 indicates areas in hectare covered by degradation classes within the vegetation habitat types as calculated from Landsat ETM products. The results expresses degradation classes in terms of hectare between the six vegetation habitat types. The Vegetation habitat types (VHT) 3 and 5 have the highest calculated areas in the poor condition class, 6 869 ha and 6 727 ha, respectively. According to Figure 3.16, VHT 2 (48 628 ha) and VHT 5 (59 724 ha) have the highest calculated areas in the good condition class. VHT 3 consists of the highest calculated areas within the woody cover classes (67 351 ha – medium and 93 718 ha – high). Figure 3.16 indicates that VHT 5 has highest area of 93 669 ha

(59 724 ha + 33 945 ha) in the good and medium condition classes, which makes VHT 5 the least degraded area type.

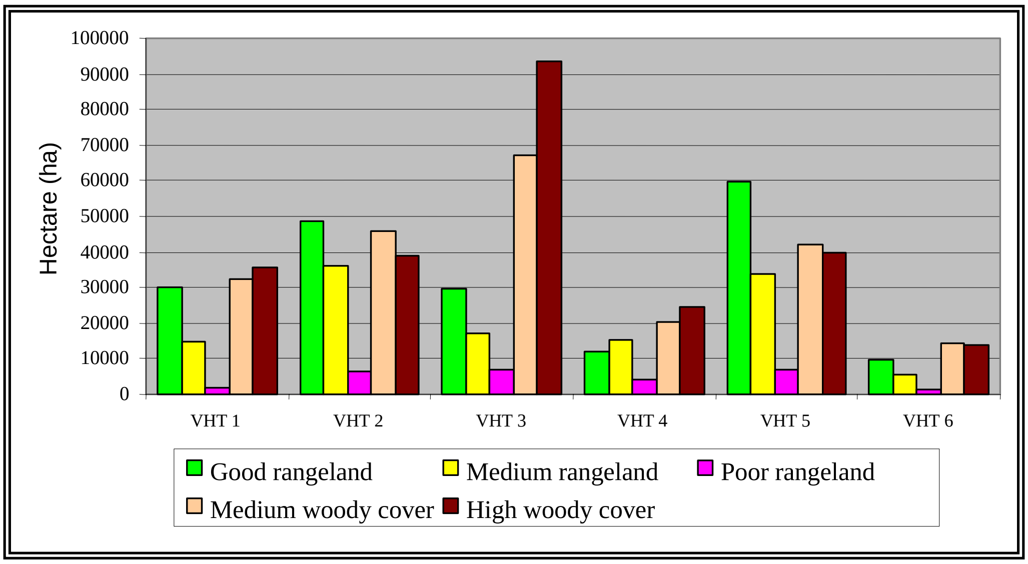

Figure 3.16 Area covered (ha) by degradation classes within the vegetation habitat types as calculated from Landsat ETM products

3.4.5 Statement of total area covered by degradation classes on map from MODIS products

Assessments of the MODIS products were also done within the study area. Figure 3.17 indicates percentage areas of 13% (good), 11% (medium) and 5% (poor) of the rangeland condition classes. The high and medium woody cover classes occupy 22% and 16% cover of the total area. The other land-cover classes have a total percentage cover of 33% (Cultivated classes – 13%, Wetlands – 8%, Water bodies – 4%, Build-up and settlements – 3%, Forest – 5% and plantations – less than 1%) within the study area.

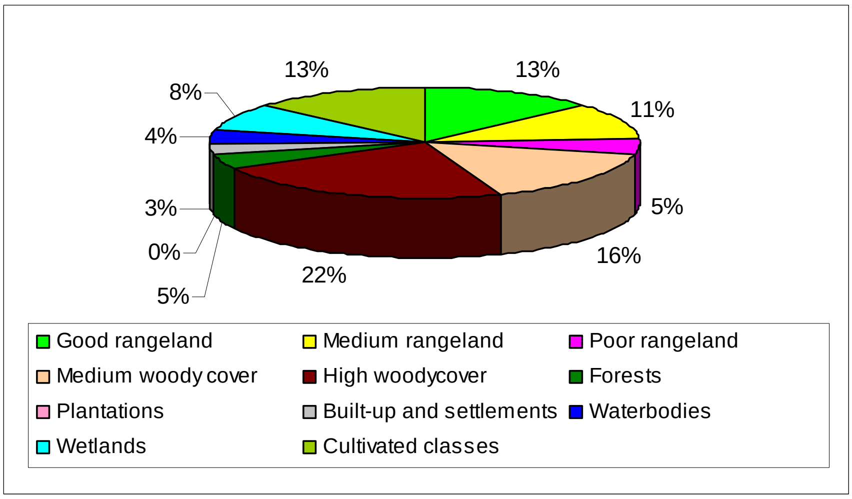

Figure 3.17 Percentage of area covered by various land-cover and degradation classes as calculated from MODIS products

3.4.6 Statement of areas covered by degradation classes within vegetation habitat types on map from MODIS products

Figure 3.18 indicates areas covered by degradation classes within the vegetation habitat types as calculated from MODIS products. The results of the calculations expresses the degradation classes in terms of hectare between the six vegetation habitat types. The VHT 2, 3 and 5 have the highest calculated areas in the poor condition class, 14 738 ha, 12 231 ha and 12 674 ha, respectively. VHT 2 (42 161 ha) and VHT 5 (43 544 ha) have the highest calculated areas in the good condition class. VHT 3 consists of the highest calculated areas within the woody cover classes (medium -54 026 ha and high - 100 569 ha).

In terms of the areas in the good and medium condition classes, VHT 2 has the highest area covered (79 419 ha), while VHT 5 is slightly lower (77 160 ha); however, VHT 5 has the highest area covered in only the good condition class (43 544 ha).

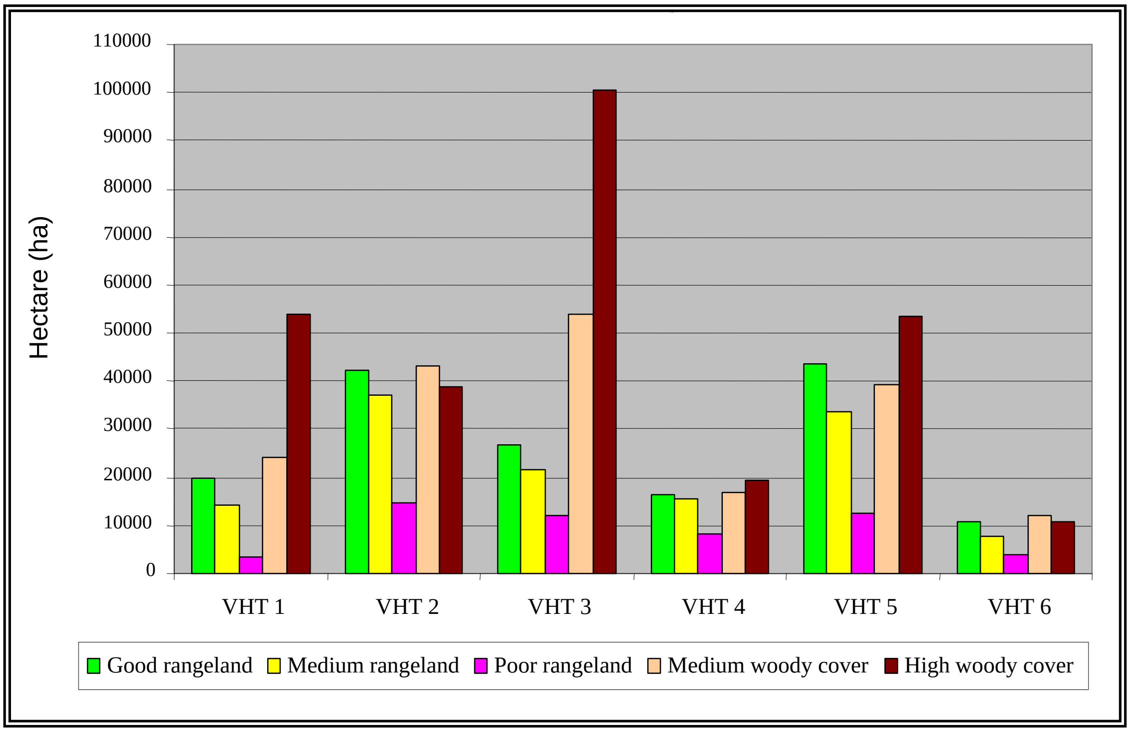

Figure 3.18 Area covered (ha) by degradation classes within the vegetation habitat types as calculated from MODIS products

Figure 3.19 illustrates degradation classes of the Landsat ETM and MODIS products, within various vegetation habitat types (VHT), towards the centre of the study area. Very good correspondence between the two products are visible within classes of degradation.

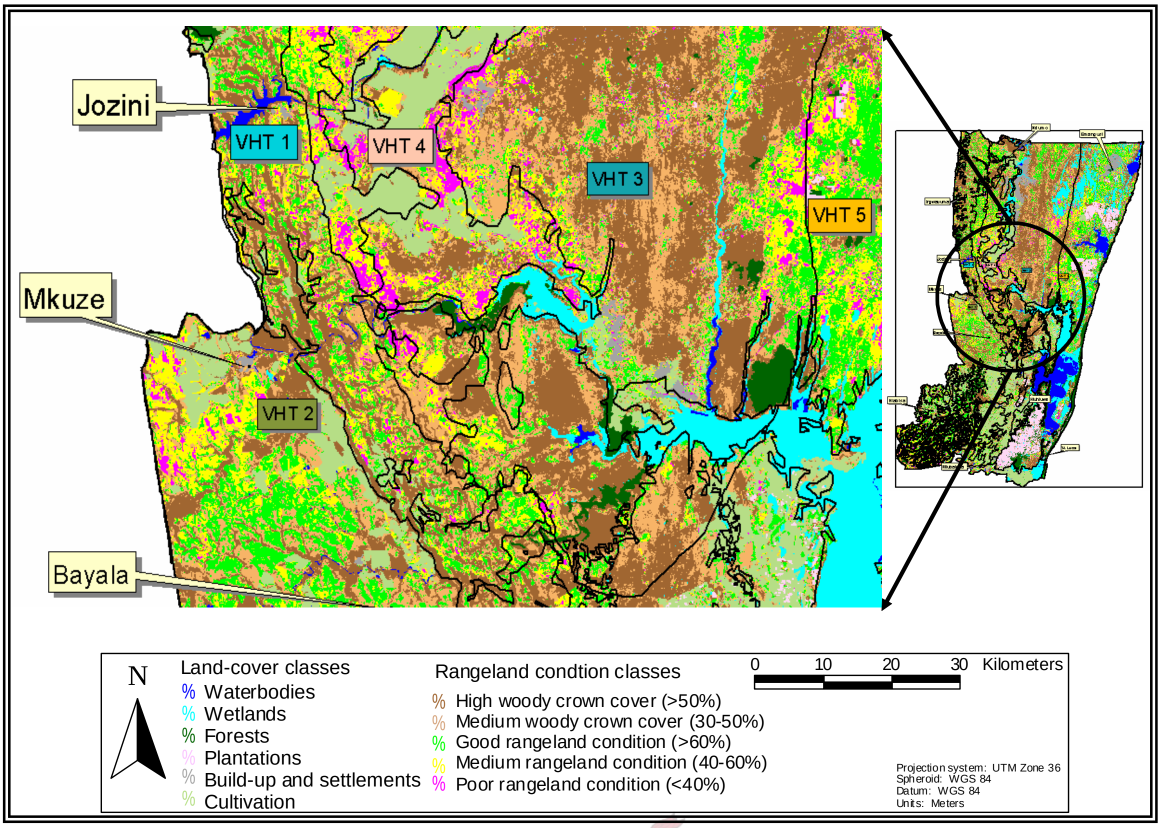

Figure 3.19 An illustration of degradation classes from Landsat ETM products, within various vegetation habitat types

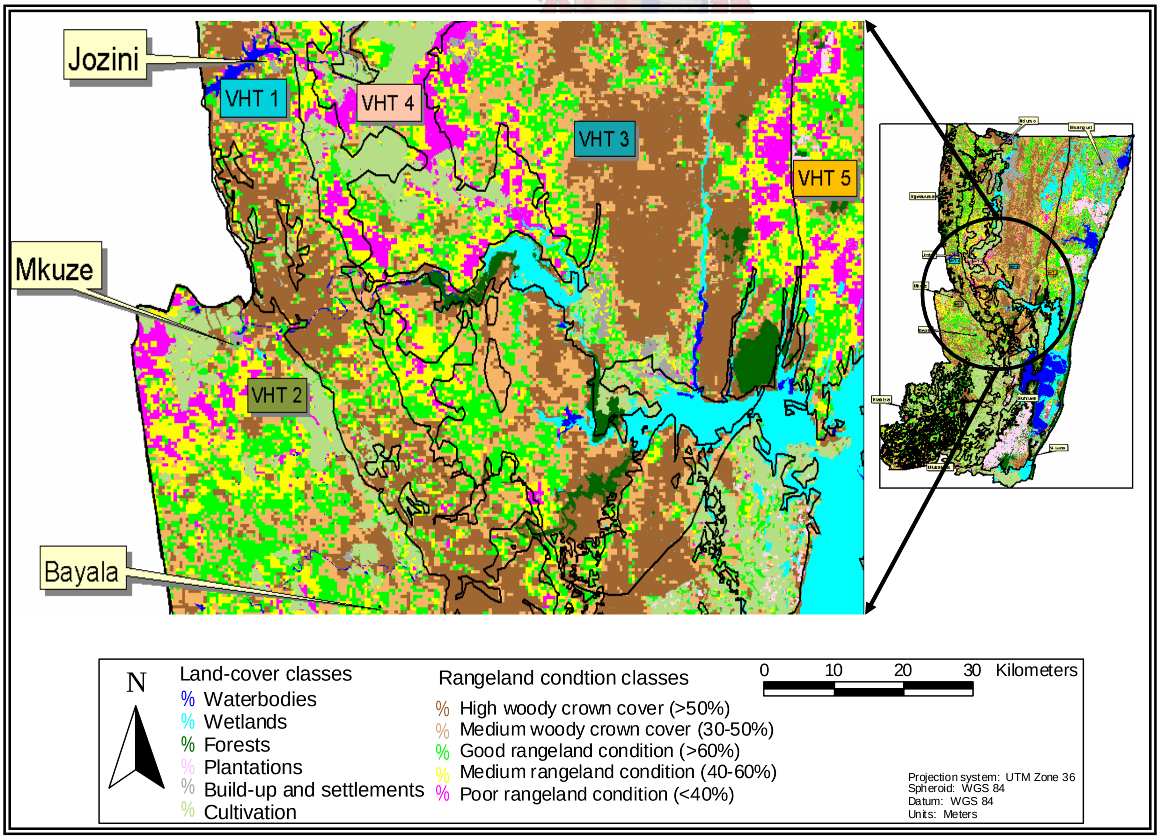

Figure 3.20 An illustration of degradation classes from MODIS products, within various vegetation habitat types

3.5 Discussion of results

3.5.1 GIS spatial and non-spatial environmental approach

The vegetation classification data were essential to identify homogenous management areas. The TWINSPAN classification and multivariate ordinations (CCA) were used to identify homogenous vegetation habitat types and to describe the vegetation communities. Within these homogenous vegetation units gradient analysis was conducted and low-frequency grasses and forbs and outlier sites were deleted during analysis. Studies from Bredenkamp and Theron (1976) identified and described vegetation communities, which were combined into management areas and are recommended for rangeland management systems.

The vegetation classification of the study area shows two major vegetation types (Clay Thornveld and Coastal Sandveld) based on soil clay content. In the coastal region, although relatively homogenous in terms of soil and topography, the vegetation is relatively heterogeneous, consisting of a variety of natural forests and vegetation associated with palm trees and grassland (Morgenthal, Kellner, Van Rensburg, Newby & Van der Merwe In Press). Some clear similarities were also found with the classifications of Lubbe (1997) and Matthews *et al*. (1999). The vegetation in the coastal areas was associated with sandy soils (Sandveld community) and coastal plains and dunes. The vegetation is similar to sand forests.

The vegetation of the inland areas was associated with soils with higher clay content and the rolling hills and mountains of the Lebombo mountains and the alluvial pediments of the Pongola River valley. The *Acacia nilotica* - *Acacia karroo* - *Dichrostachys cinerea* sub-community was particularly associated with the hills of the Umfolozi and Hluhluwe Game Reserves as well as the foothills and mountains of the Lebombo mountains. The *Cissus rotundifolia* - *Enteropogon macrostachyus* sub-community was strongly associated with river valleys of the Pongola and Mkuze rivers (Morgenthal, Kellner, Van Rensburg, Newby & Van der Merwe In Press).

Comparing on-site and laboratory-tested clay percentages and other habitat data (climate and altitude), the vegetation communities (TWINSPAN and CCA-ordination; Table 3.3) showed clear relationships between habitat data and vegetation associations (Van den Berg, Beukes, Bredenkamp, Van Rooyen, Pretorius & Kruger 1993; Bredenkamp and Theron 1976), making it possible to map vegetation distribution using high-resolution habitat data (Van den Berg, Bredenkamp & Van Rooyen 1993). The

CCA's (Fig. 3.1) confirmed the strong relationship between species and community turn over and environmental gradients (i.e. altitude, rainfall, temperature, and clay content).

The best available spatial data layers for climate and soil were integrated, providing a spatially accurate GIS product (Fig. 3.2) (Franklin 1995; MacDonald 1997). Relatively high-resolution data – at least 1:250 000 scale – were used to derive habitat boundaries. Oindo and Skidmore (2003) suggested that to perform classification accuracy assessment correctly, it is necessary to compare two sources of information: the GIS-derived classification map and reference (e.g. laboratory-tested clay information). Therefore an error matrix is a standard method to represent accuracy. Tables 3.1 and 3.2 represent cases where sites were mapped correctly, in accordance with clay classes. The accuracy of the vegetation habitat type map (map with 2 clay classes) is 78%, while the version with 3 clay classes has an accuracy of 66%.

Figure 3.2 represents the final vegetation habitat type map (2 clay classes) and illustrated the overlaid classified and vegetation communities from the multivariate analysis ordination. Very good correlations between the derived habitat map an vegetation communities exist. However, the vegetation habitat type map (2 clay classes) was used for the final map, because a more realistic distribution of fieldwork sampling sites occurred within the different units to make appropriate statements of degradation. Both versions (2 and 3 clay classes) represent very good stratification units. The vegetation habitat type map therefore serves as a reliable map for the stratification of natural vegetation for monitoring purposes.

The digital photos taken at each sample site, the vegetation species with their cover/biomass and various condition class ratings which were surveyed and captured in the databases, serve as ideal references for future monitoring purposes. The digital photo database was spatially linked with the fieldwork sites and was incorporated into a GIS and was useful during image processing and analysis. The GIS spatial database representing field parameters (vegetation and soil) will form an import input for analysis during future monitoring activities (Wessels, Van der Merwe, Smith, Van Zyl & Twyman 2001).

Although various methods and techniques exist for estimating vegetation parameters (e.g. biomass, condition), complications in calibration and optimizing were encountered during the field measuring for monitoring ecological parameters. Differences in natural environmental factors such as climate and landscape variability were not always clearly observable during fieldwork. This influenced the adapt-survey technique and could be responsible for some inaccurate field measurements.

3.5.2 Satellite remote-sensing products and comparison between the sensors

When monitoring natural resources with remote sensing, the total vegetation cover or standing biomass is the parameter that is most often used as an indicator of rangeland condition (Karfs *et al*. 2000). The rationale of correlation analysis was to measure the amount of association observed between the remote-sensing products and the observed and derived vegetation parameters.

During field surveys an estimated rating (e.g. quantity biomass present) was given within field sites, which differed from a very high to a very low amount of standing biomass. The fieldwork sites were initially classified into five classes for each vegetation parameter based on the observed vegetation parameter values. Pixel values from each field site were extracted for each remote-sensing product (e.g. NDVI, PCA) and pair-wise t-tests were used to test whether the different vegetation parameter classes differed significantly from the pixel values. Cut–off values between classes were therefore calculated using the means, standard deviations or the 95% confidence limits of the classes. Within these field sites it was possible to conduct adequate statistical analysis, although field sites with outlier values were deleted during the analysis to obtain better results.

Herbaceous biomass recorded in the field was medium to good, which correlated with the Landsat ETM products, such as the visible red (0.53), middle infrared (0.55 and PCA357 (0.56), while woody cover correlated moderately to poor with the NDVI (0.52), BSI (-0.38) and MIR (0.38) (Table 3.4). Studies of Price, Guo and Stiles (2002) revealed good results using vegetation indices such as the PCA during the active part of the growing season for discrimination among grassland types, which provide a good indication of herbaceous biomass and rangeland condition.

This relationship between vegetation species composition and the satellite image (e.g. PCA357) relies heavily on the association between rangeland species composition (overall degradation) and herbaceous biomass (Fig. 3.3). In general the relatively moist and clayey areas of Maputaland produce higher herbaceous biomass. Intensive gazing, but mostly severe degradation / species change, therefore causes very low standing biomass. There are exceptions, where field sites with low biomass still have a relatively vigorous species composition. These sites were probably recently exposed to intensive grazing or inaccurate estimations during fieldwork. On the other hand, sites dominated by unpalatable grass species (e.g. *Sporobolus africanus*) result in high biomass, but the low rangeland conditions (overall degradation) cause most of the exceptions. During fieldwork the vegetation cover was strictly applied as the inverse of bare soil rather than a combination of biomass and cover. Therefore a site dominated by *Cynodon dactylon* (pioneer grass species) would still have a good general vegetation cover rating, but a low biomass. The correlation between the satellite image and estimates of basal cover is therefore weak. Standing biomass rather than ground and basal cover therefore dominates the signal detected by the satellite (Fig. 3.5).

A rangeland condition PCA357 product of Landsat ETM was derived, which proved to be a significant indicator of rangeland condition, despite the fact that all negative species changes do not result in lowered biomass production (Wessels, Van der Merwe, Smith, Van Zyl & Twyman 2001). The range condition product was overlaid with the land-cover data to separate water bodies, wetlands, forestry, urban areas and cultivation from rangeland condition classes. From the final product was derived rangeland condition with classes (high, medium and low) and woody cover classes (30-50% and >50% woody crown cover).

A correspondence matrix in Table 3.5 represent cases where sites were mapped correctly, in accordance with rangeland condition estimated during fieldwork. An overall accuracy of 68% was calculated for the rangeland condition map (PCA357 product). Rangeland condition class in a good condition (>60%) has a 73% probability to be mapped as good, while sites in a poor condition (<40%) have a 33% probability to be mapped as poor. A small number of sites in a poor condition (n=7) were sampled during fieldwork, thus further limiting the statistical analyses (Table 3.5). Table 3.6 represent cases where sites were mapped correctly, in accordance with woody cover estimated during fieldwork. An overall accuracy of 61% was calculated from the Landsat-NDVI woody cover map. However, Figure 3.7 demonstrate an example of where high woody cover is associated with negative species change and low biomass, and remains undetected by a satellite image as a result of the darkening or shadowing effect of the dense tree woody cover.

From these results it can be seen that products (PCA357 and NDVI) derived from Landsat ETM images can be used to reliably map rangeland condition and woody cover in Maputaland at a 1:100 000 scale. The PCA357 rangeland condition product should significantly improve a field investigator's ability to locate degraded to severely degraded areas in Maputaland, which consists generally of homogeneous grassland and areas with a mixture of grassland and a woody component (less than 30% woody crown cover).

Results of the MODIS products showed moderate correlations between herbaceous biomass and values of NDVI (0.51) and EVI (0.46) (Table 3.7), while less significant results were obtained between, woody crown cover classes and NDVI (0.42), MIR (-0.40) and Red reflectance (-0.40) products. MODIS-NDVI products representing rangeland condition proved to be significant indicators of rangeland condition and woody cover (Reeves, Winslow & Running 2001). Rangeland condition classes (high, medium and low) and woody cover classes (30-50% and >50% woody crown cover) were also derived for the final map.

Table 3.8 represents a correspondence matrix of cases where sites were mapped correctly, in accordance with rangeland condition estimated during fieldwork. An overall accuracy of 66% was calculated for the rangeland condition map from the MODIS product. Table 3.9 represents cases where sites were mapped correctly, in accordance with woody cover estimated during fieldwork. An overall accuracy of 64% was calculated for the MODIS-NDVI woody cover map. From these results it can be seen that MODIS-NDVI products can be used to reliably map rangeland condition and woody cover in Maputaland at a 1:750 000 scale. The MODIS-NDVI rangeland condition product should also improve a rangeland manager's ability to demarcate degraded areas.

3.5.3 Statements of degradation and comparison between the sensors

Overall statements on the rangeland condition of Maputaland were made using randomly located sites. On the basis of small sampling theory, 200 random sites allow a reliable overall statement to be made on the condition of the vegetation at a 95% confidence level (Ma & Redmund 1995). The condition ratings from the field sites found that 12% of the study area is in a poor to very poor condition and 61% of field sites were regarded as being in a good to very good condition (Figure 3.13).

The calculated area (in hectare), presented in percentages, of the final rangeland condition product (Landsat ETM) indicates that the rangeland condition classes of the study area consists of 16% (good), 10% (medium) and 2% (poor) areas, respectively (Fig. 3.15). The high and medium woody cover classes have 21% and 18% cover. Figure 3.17 indicates the results of the calculated areas of the MODIS rangeland condition classes: 13% (good), 11% (medium) and 5% (poor), respectively. The high and medium woody cover classes have 22% and 16% cover of the total area. Very similar results between the two satellite remote-sensing products were produced.

Results of vegetation habitat types from field sites revealed that the vegetation habitat type (VHT) 5 is the least degraded of all vegetation habitat types, while VHT 3 and 6 have the highest scores in the poor condition classes (19%; Figure 3.14). VHT 5 is associated with a wetter climate and therefore moist conditions improve the plant vitality; this occurs during most of the year, making this area less susceptible to degradation. VHT 3 is associated with lower rainfall and more sandy infertile soils, which makes this area more susceptible to degradation.

Degradation statistics (total hectare within each VHT of the Landsat ETM products) revealed that VHT 3 has the highest calculated area in hectare, within the poor condition class (6 869 ha) (Figure 3.16). Figure 3.16 indicates that VHT 5 has the highest area of 93 669 ha (59 724 ha + 33 945 ha) in the good and medium condition classes, which makes VHT 5 the least degraded in terms of degradation per hectare.

Figure 3.18 indicates the area in hectare covered by degradation classes within the vegetation habitat types as calculated from MODIS products. The VHT 2, 3 and 5 have the highest calculated areas in the poor condition class, 14 738 ha, 12 231 ha and 12 674 ha, respectively. These results show that VHT 5 also has the highest calculated area in the good condition class (43 544 ha).

Good associations between the two remote-sensing products are evident within classes of degradation, which make both products from the satellite remote-sensing sensors ideal in principle to map degradation at the different scales. The choice of sensor for environmental remote sensing is mainly dictated by area extent. For large area mapping, the primary sources of data have typically been high temporal, low spatial resolution sensors with wide area coverage such as the MODIS products. In contrast, data from low temporal, high spatial resolution sensors, such as Landsat ETM, have been the primary data source in support of local to regional scale applications. The obvious advantage of high spatial resolution data is the increased spatial detail.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

4.1 Introduction

This thesis presented an integrated GIS and remote-sensing spatial framework that is aimed at monitoring and mapping natural resources at small and medium scales. The methodology can address natural resource degradation at a national scale; this could become essential for monitoring sustainable development by establishing a framework to acquire spatial data for the development of remotely sensed indicators of key ecosystems' processes. The conservation of natural resources has become important. Therefore, developing methodologies for assessing, mapping and monitoring ecosystems for the protection of natural resources and human communities is essential to ensure sustainable economic growth. Integrating GIS and remote-sensing technologies can address these problems by providing methods to present data in a spatially accurate manner.

4.2 Implementation of satellite remote sensing and GIS methodologies

Methodologies that were developed and applied during this study are presented within an integrated spatial framework for converting information into functional products, particularly for natural resource audits and monitoring on a provincial and national scale. By operating on a broad scale and integrating different ecosystems and human activities (e.g. land use), the integrated spatial approach becomes a tool with which to support the management of change and the conservation of natural resources and thereby contribute towards a more sustainable future.

The function of the non-spatial database, which consisted of vegetation and soil parameters, was crucial for data capturing and manipulation, and for preparing captured field data for statistical analysis, while the digital photo database facilitated image classification and could assist in future natural resource monitoring.

The methodologies demonstrated how to derive vegetation habitat types by using multivariate statistical techniques, utilizing data gained from fieldwork and integrating these data within a spatial GIS approach. These stratification units addressed environmental habitats by simplifying broad vegetation communities into simpler units for monitoring purposes. The methodologies also demonstrated that the vegetation habitat types could be used to make statements of degradation within its various stratification units.

Rangeland condition maps, derived from products of the two sensors, identified significant degradation classes, which should significantly improve a rangeland manager's ability to delineate pristine to severely degraded areas in Maputaland. It was shown that the rangeland condition maps (both satellite products) could be used for mapping of degradation classes at different scales (1:100 000 and 1:750 000) and thus also be used for future spatial monitoring.

The data (spatial and non-spatial) derived from these methodologies provide spatially oriented digital information to the GIS spatial database that are easily accessible. For rangeland managers the overlay and analysis of spatial data relating to vegetation and soil maps, range condition maps, productivity maps, ecological sites and grazing management systems are important for identifying conflicting uses and putting these into perspective for rapid professional interpretation, evaluation and action.

4.3 Comparison of satellite remote-sensing products and sensors

The study has demonstrated methodologies utilizing data in various statistical analyses and deriving correspondence matrices testing associations between the two satellite remote-sensing products, which are visible within classes of degradation and are ideal in principle to map degradation at different scales. The correspondence matrix is ideal for validation purposes, which compares different sensors and provides information regarding the reliability and usefulness of remote-sensing techniques and supports the spatial data used in decision-making processes. The correspondence matrices give therefore a good indication between vegetation parameter classes and image classes for mapping, monitoring and making statements of degradation.

4.4 A review of MODIS products for future research opportunities towards near-real time monitoring

Methodologies for monitoring rangeland condition in southern Africa with satellite remote sensing have become crucial because this is related to variation in agricultural production and climate change, with implications for natural resource management. Block, Franklin, Ward, Ganey & White (2001) review universal requirements for the monitoring of natural resources to evaluate the change or trend in resources. They list the following:

1) Monitoring should assess the state or condition, as well the dynamics of natural resources;

2) Monitoring should entail repeated sampling of the variable(s) of interest to measure change or trends and the sample must be scaled to the variable and question being addressed (White & Walker 1997);
3) The population to be monitored needs enough time to transform as a result of management treatments;
4) Monitoring should be done over a practical time period to include the range of environmental conditions, allowing for applicable estimates of process variation.

Studies from Pickup (1996) revealed the insensitivity of grazing to the effects of land degradation until forage is in short supply, which is more detectable during droughts. Another factor reducing sensitivity to land degradation relative to the effect of rainfall unpredictability is the timing of rainfall events. The insensitivity to land degradation (except in times of drought) becomes greater as rainfall unpredictability increases and the forage supply becomes more unstable. Increased instability means that forage will be in surplus for a longer time, since utilization cannot adjust quickly to forage production, unless there is very active buying and selling or movement of animals. By contrast, grazing management systems in which rainfall unpredictability is relatively low should feel the impact of degradation on animal production more constantly. Nevertheless, it is likely that the impact of increased susceptibility to drought is greater in areas where rainfall variability is high (Pickup 1996).

Studies from Pickup, Bastin & Chewings (1994) revealed that rangeland succession in arid ecosystems is largely driven by rainfall. Irregular rainfall on many rangelands therefore necessitates the use of high temporal resolution monitoring tools. However, productivity measures of the MODIS products can be used to identify areas of periodic re-growth and in response to rainfall may enable rangeland managers to alter grazing management systems for efficient utilisation of vigorous re-growth (Reeves, Winslow & Running 2001). The majority of biomass estimation studies on remote-sensing climate information are not discussed here. However, Reeves, Winslow & Running (2001) state that MODIS's productivity estimates merge satellite data and daily climate inputs with essential principles of plant growth. This approach allows the assessment of productivity across numerous rangeland sites and biomes.

Pickup, Bastin and Chewings (1998) demonstrated vegetation growth along grazing gradients and that the variation in growth can detect change in rangeland condition. The grazing gradients approach is simple and can be put into practice using archived satellite remote-sensing data. Spatial information on rangeland condition, which is important for grazing management systems, is therefore directly available, whereas monitoring by other methods may not produce results for years while essential spatial data are accumulating. Therefore, productive information derived from the MODIS satellite will indicate the spatial extent of vegetation response constantly and immediately over remote rangeland. Long-term productivity trends can be monitored with EOS-derived net primary production (NPP[1]) measures, providing a useful tool for assessing rangeland condition (Reeves, Winslow & Running 2001).

Although multi-date change detection was not a goal for this study, is it important to know and apply certain crucial digital change-detection methods for future near-real time monitoring. Coppin *et al.* (2004) point out that there is sufficient evidence to support the use of multi-date satellite imagery for successfully detecting and monitoring of changes in natural ecosystems. The great spatial extent of rangelands, combined with the recent emphasis on rangeland condition, has created a need for more efficient and cost-effective spatial management tools.

Coppin *et al.* (2004) reviewed different digital change-detection methods in the optical/infrared domain, with the emphasis on natural ecosystems, and provided the following guidelines to ensure accurate change detection:

1) The registration for multi-date imagery is crucial, as well as the radiometric calibration to eliminate differences in atmospheric conditions. Phinn (1998) and Tueller (1989) agree that spatial, spectral, radiometric and temporal attributes of remotely sensed data determine the type and quality of information able to be extracted (Yang & Prince 2000). The choice of change-detection algorithm will depend on the application and the data sets involved (Donoghue 1999);
2) Vegetation indices are more strongly related than the responses of single bands;
3) The performance of image differencing and linear transformation is usually better than other bitemporal change-detection methods;
4) Seasonal patterns and inter-annual variations in land surface attributes can be detected using high temporal frequency data from wide-field-of-view sensors, but it is important to remove sensor-related artefacts in time series and that a suitable profile-based change-detection method is applied;
5) The effectiveness of using remote-sensing imagery for change detection will be enhanced by the integration of remote-sensing and GIS techniques, and by the use of expert systems and ecosystem simulation models. The combination of GIS databases and remote-sensing products is a powerful tool for integrating and analysing spatial data (Tueller 1989).

[1] The rate at which plant biomass is created in a community.

4.5 Recommendations

The conclusion regarding this integrated approach is that it is a complicated task to develop a measuring tool for monitoring ecological changes in rangeland conditions that vary naturally through time (climate variability) and space (landscape variability). A standardized field surveying technique that is fast and provides reliable and repeatable quantitative absolute measurements of vegetation density per herbaceous vegetation communities and species is essential. This will enable the completion of rapid and accurate fieldwork, which could be used for areas of interest during future degradation mapping and monitoring. Long-term grazing trials would be a way to determine the resilience of vegetation habitat types and to determine points at which irreversible damage in terms of both vegetation productivity and quality occur.

A Margfit method could be used during future studies; this is an iterative proportional fitting procedure that can be used to normalize the correspondence matrix (Congalton & Green 1999). The normalization process eliminates differences in sample sizes used to create the matrices. As a result, the individual cell values within the matrix can be directly compared.

The new vegetation map of South Africa could be used during future studies to obtain stratification units, and therefore these units could be recoded into more generalized units for monitoring purposes (Macdonald 1997). By repeating the model at a national scale, managers would get an idea of the spatial scale at which degradation could be mapped and the sustainability that could be achieved. All this emphasises the need for the development of a national rangeland monitoring strategy and monitoring system.

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APPENDIX A: FIELD DATA SHEET[1]

Site no (e.g M1)	Pedologist :	Date	Latitude	Longitude
			S	E

Location (e.g. nearest town)	

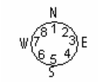
Potential Biome									
Grassland	1	Savanna	2	Thicket	3	Other	4	Forest	x

Natural rangeland					
Random sites	1	**Comparison site number refer to cultivated fields number 6 below (same habitat)**			
Subjective sites					
Vegetation degradation sites	2	Reference sites	3	Comparison to field sites	4

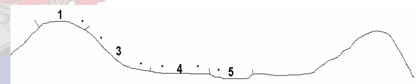
Cultivation:									
Old fields	5	***Term of old fields***		Short (1-3 years)	A	Medium (4-10 years)	B	Long (> 10 years)	C
Cultivated fields	6	Type of crop		Stage of crop					

Digital camera				
Photo no. on flashcard	Digital photo position	X	Digital photo numbers (e.g. M1_1)	Photo –direction (e.g. NNE)
	Foto 1 = Landscape			
	Foto 2 = Vegetation (from above)			
	Foto 3 = Soil profile (from above)			

Aspect (e.g. NNE) **Slope (%)** **Terrain position**



------------%



Soil data:

Description of (* Sand Grade mm)
1 (Fi=0.05-0.25)
2 (Me=0.25-0.5)
3 (Co=0.5-2.0)

Description of (Structure:)**

Type:	**1** (Block diameter) (cm)	**2** (Granule, crumb diameter) (cm)	**3** (Prism, column diameter) (cm)	**4** (Plate thickness) (cm)	(Apedale) (cm) **5** (Single grain)	**6** (Massive)
Grade						
1 (Fine)	<1	<2	<2	<0.2		
2 (Med)	1-2	2-5	2-5	0.2-0.5		
3 (Coarse)	>2	>5	>5	>0.5		

Surface dry	1	Surface wet	2	Parent material	

Horizon	Sample no (e.g. M1_A)	Ca HCl	Depth (cm)	% Clay	*Sand grade Fi	Me	Co	Colour Wet	Dry	**Structure Type	Grade	Diag hor (e.g. Orthic)
0A			0-7.5									0-7.5
A1		Y N			1	2	3			1 2 3 4 5 6	1 2 3	
E		Y N			1	2	3			1 2 3 4 5 6	1 2 3	
B21		Y N			1	2	3			1 2 3 4 5 6	1 2 3	
B22		Y N			1	2	3			1 2 3 4 5 6	1 2 3	
C/R		Y N			1	2	3			1 2 3 4 5 6	1 2 3	

Depth limiting material:	Rock	Saprolite	Calcrete	Hard plinthite
	1	2	3	4
Effective depth (cm):	Stone line	Gleyed material	Structured layer	
	5	6	7	8

Water table	Present	Depth (cm)
	Y N	

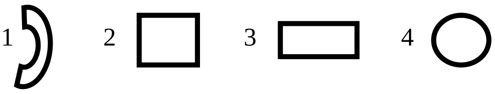
Soil form - red book		**Soil form – blue book**	

[1] Field data sheet obtained from the ARC-ISCW and adapted for research in the Maputaland study area.

APPENDIX A: FIELD DATA SHEET (CONTINUE)

Site no (e.g. M1)	Botanist

Site shape 1 2 3 4



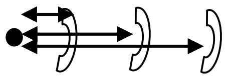
Size of site

……m …..m

If subjective site - specify degradation gradient type:

Watering point	1	Settlement	2	Fence line		3	Old land	4	Other	5
Distance(m)				'Good' side	'Bad' side					
				1	2					
Zone (only watering point)	1		2	3						

1 2 3



Comparable site numbers (same habitat)	

General vegetation parameters:

Dominant	Species	Average height (m)	Dispersion	
			Random	Clumped
Trees **(>2,5m)**	1.	m	1	2
	2.	m	1	2
	3.	m	1	2
	4.	m	1	2
Shrubs **(<2,5m)**	1.	m	1	2
	2.	m	1	2
	3.	m	1	2
	4.	m	1	2
Grasses	1.	m	1	2
	2.	m	1	2
	3.	m	1	2
	4.	m	1	2
Forbs / sedges	1.	m	1	2
	2.	m	1	2
	3.	m	1	2

Dominant woody seedling species			Average distance (m)
1. 2. 3.			

Soil Erosion Assessment: (Use % diagram)

Rill erosion (less than 0.5 meters):			
Class	Depth (cm)	Symbol	% area
Small	<10	R1	
Moderate	10 - 30	R2	
Big	30 - 50	R3	

Gully erosion (deeper than 0.5 meters):		
Class	G	% area
Minor: (< 1m deep)	G1	
Moderate: (1 - 3m deep)	G2	
Severe: (> 3m deep)	G3	

Sheet erosion		
Class	S	% Area
Islands of remaining soil < 2 cm	S1	
Islands of remaining soil > 2 cm	S2	

Other erosion features			
T	Terracettes	L	Landslides
W	Wind erosion	B	Stream bank
C	Surface crusting		

General subjective degradation assessment:

Class	**Herbaseous basal cover**	**Herbaseous Biomass**	**Soil erosion****	**Bush encroachment**	**Species change**	**Alien plants**	**Overall degradation**
No degradation	1(good)	1(high)	1 (none)	1 (none)	1 (none)	1 (none)	1 (none)
Light	2	2	2	2	2	2	2
Moderate	3	3	3	3	3	3	3
High	4	4	4	4	4	4	4
Very high	5(bad)	5(low)	5 (severe)	5 (severe)	5 (severe)	5 (severe)	5 (severe)
Comment:				Species:		Species:	

APPENDIX A: FIELD DATA SHEET (CONTINUE)

Site no (e.g. M_1)	Botanist

NB use % diagram and calibrate regularly

Total grass basal cover (2,5cm) **(absolute cover)**	Total ground cover 5cm (including bare rock and litter - **(absolute cover)**	Total herbaceous crown cover **(Grass and Forbs from above) (absolute cover)**	Total woody crown cover **(absolute cover)**
%	%	%	%

Crown cover distribution **(Relative cover, total must be 100%)**		Stem spacing for woody species **(shrubs < 2.5m)**	Stem spacing for woody species **(trees > 2.5m)**
Grasses	%	m	m
Forbs and sedges	%		

Grass species		**Woody species**		
Grasses (Relative crown cover – total must be 100%)	**%**	**Woody (Relative crown cover – total must be 100%)**	**Type (e.g tree or shrub)**	**%**
	100%			**100%**

Herbaceous cover (Relative crown cover – total must be 100%)			
		Total Forbs	
	100%	**Total Sedges**	