

**Land Use analysis using GIS: A case study of
Richards Bay Minerals' Zulti South mining lease area.**

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DECLARATION

The work described in this dissertation was carried out in the discipline of Geography in the school of Applied Environmental Sciences, University of Natal, Pietermaritzburg, from January 2000 to December 2001, under the supervision of Doctor Trevor Hill.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any other university. Where use has been made of the work of others it is duly acknowledged in the text.

A handwritten signature in black ink, appearing to read 'C. Oellermann', with a long horizontal flourish extending to the right.

Carl Günter Oellermann

Abstract

The past centuries have been marked with massive land conversions from one land use category, usually natural vegetation, to another. The forces that drive these land use changes are complex and poorly understood. However, the study of land has been revolutionised by the introduction of spatial tools such as remote sensing and GIS that automate these complex issues and assist in the solutions of these geographic problems.

Land use identification and classification techniques were used in conjunction with GIS to consistently and accurately extract and incorporate land use data from a series of remotely sensed images of Richards Bay Mineral's Zulti South Mineral lease. Eight land use types from Zulti South were identified and mapped from six different remotely sensed images taken at different time periods between the 21st of September 1990 and the 1st of June 2001. This mapping technique was shown to have an accuracy of 87.6%.

The data collated from this study enabled the monitoring and representation of the temporal and spatial differences in land use within a GIS. From the analysis carried in the GIS the land use dynamics within the lease could be quantified and modelled.

The time series of the land use datasets indicated how much of the landscape is changing, what changes have occurred and where these changes are taking place. Accurate and timely mapping of land use provides vital information on the state of the mineral lease area and its environment, and facilitates the development of spatial trends from which predictions of land use and land use change can be made.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Land use is a central political and practical issue in contemporary society. The manner in which land is used affects and is vital to a country's economy and its social progress. Sommers (1981) points out that the relationship of people to the land has not only been a pervasive theme throughout human history but it has also shaped both the nature and quality of life on this planet. Throughout history the use and control of land has often been at the centre of struggles and wars. Rhind and Hudson (1980) explain that since the ownership and use of land may bring considerable power to those who possess it, control of land and land use has been and still remains a politically contentious issue.

One of the fundamental roles of a Geographer, is that of describing and explaining the variable character of the earth's surface. This involves observing, recording and assessing different earth characteristics in order to obtain a better understanding of the world we live in and the processes upon it. The earth's surface is however not static and there are continuous changes taking place upon it, continuous monitoring of different geographical aspects is therefore vital.

Throughout the world, human land use is a formidable agent of change, shaping the distribution of land cover and affecting fundamental ecological processes, hydrological and climatological regimes, biogeochemical cycling, and the persistent extinction of species (Vitousek *et.al.*, 1997). With the ever increasing human population and the resultant intensified pressures on land use activities; the need for geographic information, that is both spatially comprehensive and of appropriate resolution, is becoming more vital for effective management of land use.

This research is concerned with the spatial approach in monitoring land use and land cover change. The primary aim of this study was to develop a land use classification and Geographic Information System (GIS) framework to identify, assess, and predict areas of land use and land cover change. This was achieved by undertaking a project using Richards Bay Mineral's (RBM's) Zulti South mining lease area as a case study.

The study was undertaken with the understanding that, with the use of GIS and Remote Sensing, it is possible to monitor and collect thematic land use data on a continuing and regular basis, enabling accurate, rapid and consistent measurements of change and land use trends. Thus, providing accurate and presentable land use information to the relevant authorities, in order to facilitate their management and decision making thereof.

It was also understood that land is a finite resource and that the balance between land use activities upon it are dynamic and rarely in equilibrium. Monitoring land use provides a means whereby effective management can be achieved in an efficient and sustainable manner upon this dynamic resource. This was achieved without losing sight of the fact that land use is a pervasive and sensitive topic that has to be dealt with in a holistic manner, taking into account different views and perceptions of all those people and parties affected and involved; be it directly or indirectly.

1.2. LAND USE

Rhind and Hudson (1980, 3) state that "there can be no doubt of the significance of land use. On the one hand we all require land on which to live; on the other, the use of any given parcel of land affects not only those who reside there or have use of that land – for whatever purpose – but also those who live on or have use of adjacent and surrounding areas".

As humanity is undoubtedly dependent on this finite resource, it is important for us to monitor how land is used. This provides us with better insight into understanding why land is used or utilised, why its use changes, how these changes occur and what effects these changes have or can have directly or indirectly on those who reside on or surrounding the land. This spatial knowledge of the land facilitates the relevant authorities in managing and utilising the land more effectively and efficiently in a sustainable manner.

The rapid changes in South Africa's political situation, its population, and the ramifications of economic and rural development, have resulted in changes (often drastic) in the way that land is used in South Africa. This has led to numerous conflicts and issues as to the actual or intended use of particular parcels of land. Monitoring land use and its' changing patterns, with the knowledge of what previously and currently exists on a piece of land, generates spatial data that can facilitate authorities in resolving land use conflicts.

Although the importance of land use monitoring is understood and has been well documented, there still remains inadequate land use data world-wide (Rhind and Hudson, 1980; Fresco *et.al.*, 1994; Watson *et.al.*, 2001). Similarly, due to the continually changing nature of how a parcel of land is used, data quickly becomes obsolete, outdated and inadequate for present applications, unless continued monitoring takes place. Similarly in South Africa, land use monitoring is not a new phenomenon (Rivers-Moore, 1997; Read, 2001), however there remains relatively few examples or studies of land use monitoring. It must be noted that with the advent of better skills, tools and technology to monitor land use in South Africa, this situation is slowly changing.

1.2.1. Geographic Information Systems and land use monitoring

Until recently the collection and compilation of data and the publication of a printed map was a costly and time-consuming procedure. The amount of data involved, and the accuracy and detail required for these maps made mapping of localised areas difficult and often too costly to attempt. Quantitative spatial analysis was often extremely difficult to attempt within the units delineated on the map without collecting new data for the specific purpose in hand (Burrough, 1986).

Burrough (1986, 3) states, “there is now such a need for information about how the earth’s surface is changing that conventional map-making techniques are totally inadequate”. With the use of remote sensing and GIS, an unprecedented ability to collect spatial data on a continuing and regular basis has been found. These large data sets can be processed into digital form to provide rapid and consistent measurements of change and trends. This can be done relatively cheaply and accurately (Eastman *et.al.*, 1997).

The use of GIS to monitor and analyse land use has proved to be a popular technique, (see Iwao, 1998; Hohner, 1998; Read, 2001; Rivers-Moore, 1997; Saipothong *et.al.*, 2000). This is because GIS provides an array of spatial tools and techniques that can be combined with statistical analysis and remote sensing techniques to provide a powerful method of monitoring and analysing land use change and trends quickly, accurately and cost effectively on a continued basis.

1.2.2. The role of land use monitoring within Zulti South

Richards Bay Minerals (RBM) have registered mining rights over Zulti South, an area of State land between Richards Bay and Mlalazi lagoon along the east coast of northern KwaZulu-Natal, South Africa.

Here RBM intend to dredge-mine placer heavy minerals 'black sands', comprising ilmenite, rutile and zircon from aeolian sand dunes of recent age that run parallel to the beach in the lease area. This will be done in much the same manner as RBM have been doing for the last 25 years in their other two leases, Tisand and Zulti North, along the coast to the north east of Richards Bay. RBM currently has a world market share of approximately 25% of titania slag, rutile, high purity pig iron, and zircon, and contributes approximately 0.5% of South Africa's GNP (King, M. pers. comm. 2001). Considering that RBM is mining a finite resource within a fixed area, the Zulti South lease is essential in order to maintain RBM's production requirements to sustain international market contracts and the life of the company. Extensive exploration and planning of this area has occurred, and mining should commence within the next seven years (Barnes, J. pers. comm. 2001).

Zulti South lies adjacent to the rural township of Reserve 10. This region can be classified as relatively impoverished and largely undeveloped with most rural habitants dependant on subsistence farming to meet their food requirements. Historically this area has been associated with violence and faction fighting. With the constant increase in population and as the changing political situation in South Africa has afforded unauthorised occupants more rights under the new constitution, there has been a gradual encroachment into the currently unused Zulti South lease area by neighbouring Reserve 10 habitants. Although there has always been land occupation in the western extremity of the lease area, subsistence and grazing land have spread gradually into Zulti South.

As Zulti South is geographically separate from RBM's current operations in Tisand and Zulti North, and as there is very limited presence by RBM within this lease, it has been difficult to manage, discourage or prevent the surrounding community from invading and inhabiting land within Zulti South.

RBM in an effort to protect their investment and proactively manage any potential problems associated with land encroachment from the neighbouring community, decided to monitor the land use changes within the mining lease area (Cant, C. pers. comm. 2001). In meeting this objective, RBM hired aerial surveyors to fly and photograph Zulti South on a regular basis in order to produce orthophotos from which land use changes could be mapped. This commenced on the 16th of June 1990 and has continued on a regular basis until the present. The data obtained from this mapping at present is in a format that is of very little value to RBM, with the visual representations of the orthophotos being of more value than the land use mapping. RBM require more detailed monitoring of the land use changes so as to manage and proactively react to these changes.

1.3. AIMS AND OBJECTIVES OF THE STUDY

This study is concerned with the spatial approach in monitoring land use and determining how the data collected can be used to identify, assess and predict land use patterns. The aim is to develop a land use classification, remote sensing and Geographic Information System (GIS) framework to identify, analyse, assess and predict areas of land use and land cover change in RBM's Zulti South mineral lease area.

This study was exploratory in nature and therefore no formal hypotheses were formulated. In meeting the overall aim of the study numerous objectives were set. The objectives are as follows:

- To provide a review of available literature on land use and land cover, the importance of monitoring and analysis in land use studies, and the ability of a GIS in facilitating monitoring and analysis of land use change.

- To develop a land use classification, remote sensing and GIS framework for assessing and predicting land use changes. In order to illustrate this a GIS project was undertaken using RBM's Zulti South mineral lease area as a case study.

The aims within this GIS project were to:

- a) Develop a land use classification.
- b) Create thematic land use maps from the available orthophotos.
- c) Monitor and analyse the extent of land use change over a set period of time.
- d) Quantify and assess the change.
- e) Identify 'who' or 'what' causes this change.
- f) Identify areas or 'hotspots' where the majority of the change occurs.
- g) Determine the major impacts these changes have on Zulti South, RBM, the environment and the surrounding community.
- h) Determine a spatial trend with which predictions for future change can be made.
- i) Investigate the capability of GIS in effectively and accurately monitoring and analysing change, trends and patterns of land use in the mining lease area.

It is beyond the scope of this study to provide a complete analysis of the effects land use change has on the ecological, social or economic environment of the study area. An in-depth discussion of the sociological or environmental reasons for land use change is not intended, rather the emphasis is on understanding where these changes occur, predicting where they might occur and what effect these changes can have.

It should be noted that whilst undertaking this study, few South African examples of similar studies were found. It is therefore hoped by the author that this study will encourage more spatial and regional emphasis to the geographical scholarship on GIS and land use studies in South Africa.

CHAPTER 2

LITERATURE REVIEW

2.1. LAND USE

Realization of the general objectives of this research, depends on the understanding of how the processes of land use function; namely both the way in which land is allocated between different activities and the impact that change in those activities can have. Land use and land cover are two approaches for describing land. Together land use and land cover information provide a good indication of the landscape condition and processes that occur at or on a particular piece of land (Lathrop, 2000).

At first the term 'land use' may seem self-explanatory; but as so often happens, this apparent simplicity is deceptive (Coppock, 1991; O'Keefe and Wisner, 1977). Land use is defined as the way in which, and the purpose for which, human beings employ the land and its resources (Meyer, 1995). Thus, land use is seen as the social purpose of land and is distinguished by its function and not by its physical qualities (Longley *et al.*, 1999). This notion underlies the distinction between 'land use' and 'land cover'. The physical state or nature of the earth's surface, be it natural or artificial, is defined as land cover (Kivel, 1991; Meyer, 1995).

Distinction of land may initially be made on its form or function, that is, its use or its cover. In reality, however, the application of this distinction proves to be dynamic (Bibby and Shepherd, 1999; Kivel, 1991). Land function is often inferred from the appearance of the land, that is, what physical or natural structure covers a specific parcel of land. Indeed, what is described as land use often refers to land cover, especially the vegetative cover of land in rural areas (Coppock, 1991). The same land function on the other hand, can occur in different forms of land, for example a recreational function of land can be

found in the form of a forest park or a theatre building. Thus the land is used for the same function 'recreation' but can be found in different forms. Land use and land cover are interrelated themes. Land use change leads to land cover change and land cover change leads to land use change.

Land use is a broad, subjective and complex concept (Harper, 1997; O'Keefe and Wisner, 1977). For geographic applications in this research, the land use classification is a mixture of functional and morphological aspects of the land. The definition used to clarify land use has been adapted from the Land Use Classification for British Columbia:

Land 'use' is defined in terms of a specific combination of land activity and land cover. Land 'activity' is regarded as the active use man makes of the land. It is not to be confused with other variables, such as tenure, ownership, economic activity or land value. Land 'cover' is regarded as the vegetative, natural or artificial construction covering the land surface. (Harper 1997, 2).

Land use in this research is therefore understood as a function of culture and settlement patterns, as well as environmental characteristics (Black and Scott, 2000).

2.1.1. The importance of land

Land as an entity is finite (Olembo, 1994). In its broadest definition 'land' refers to "the combination in any place at any time of subsoil, soil, biotic, hydrological, and climatic characteristics which interact with social labour for the satisfaction of human needs" (O'Keefe and Wisner 1977, 2).

As stated by Bonte-Friedheim and Kassam (1994a, 377) "most people live on the land, from the land and with the land". The integrated concept of land incorporates land processes and systems of interrelationships between

physical, biological and social phenomena evolving through time (Speight, 1988). The primary function of land in human societies; beyond providing space for settlement, recreation and working space for industry, communications, and conservation, is to form a biophysical resource base for the production of biological products including foodstuffs, fodder, feeds and raw material for people, livestock and industry (Bonte-Friedheim and Kassam, 1994b). That is, not only are humankind's basic needs of food, fuel, water, clothing and shelter met from the land (FAO 1989; Davis 1976), but land is a source of biodiversity, minerals, fossil and renewable energy, and other natural resources which contributes to all aspects of human activities. "Land serves as a source of wealth and power, and together with labour, constitutes the two original economic factors of production" (Bonte-Friedheim and Kassam 1994a, 65).

Davis (1976) reaffirms the importance of land by stating that land is finite and absolutely necessary to human existence. Land use has many functions, not only in terms of biochemical cycles, or food and shelter for humans, but aesthetically, as landscapes. Land has an affect on weather; land forms part of the hydrological cycle, were freshwater is captured, stored and transported by land. Land is an integral part of the processes of transformation of energy and matter, including waste in the biosphere and the geosphere. Through these processes, the earth maintains spatial and temporal equilibrium (Bonte-Friedheim and Kassam, 1994a).

Humanity's utter dependence upon a thin layer of active soil is summed up in Albrecht's dilemma...

"To feed ourselves, we appropriate nature's bounty by plowing up the prairie soil, planting crops which produce more useful food than could be obtained from the wild, but in the process accelerate the loss of nutrients from the soil. The movement of productive soil from the land to the sea is hastened, to our peril, by this necessary human activity" (cited in Piper 1999, 189).

We abuse land as we regard it as a commodity belonging to us. When we regard it as a commodity to which we belong, we may begin to use it with love and respect (Leopold, cited in Fennell, 1999).

Since antiquity land has been recognized as having special importance, properties and value. Ownership of land and accompanying control of its many uses has always been a major cause of contention among people (Davis, 1976). Flesher (2001) suggests that although the ongoing problems in Kosovo and the former Yugoslavia are complex and multi-dimensional, the underlying issue is straightforward. It is the idea that peoples - ethnic or national groups - are tied to their land, and that the land brings them cohesion and unity. Flesher (2001) believes that this link between a people and their land means that two different peoples cannot occupy the same land. Although a radical view, this viewpoint is echoed throughout history; the nations of the Old Testament, Israel and Judah, were both subjected to similar treatment. More recently this viewpoint can be argued to exist between the Israelites and Palestinians, the Catholics and Protestants in Northern Ireland and more recently land issues in Zimbabwe.

Preston-Whyte (1994) suggests that land is an emotive issue in South Africa. Controversies surrounding land played its part in the run up to the 1994 elections, as well as during the post 1994 election wake. 'Land' and land issues are still probably the most contested of all terrains in the public debate in South Africa.

2.1.2. Land use studies

The relationship of people to the land has been a pervasive theme throughout human history and has shaped both the nature and quality of life on this planet (Lounsbury *et al.*, 1981). Land use issues concern people's interaction with earth space, a topic particularly germane to the discipline of Geography. Geographic literature has addressed the use, distribution, character and control of land since antiquity (Lounsbury *et al.*, 1981). It is no exaggeration to identify a well-established intellectual tradition of studying land use (Rhind and

Hudson, 1980). In the early 19th century Ricardo and von Thunen were both concerned with questions of rent and location in the agricultural land use context (Rhind and Hudson, 1980). Past and present arrangements and juxtapositions of land use have occupied a number of academics, drawn from a number of disciplines which include; agriculturalists, economists, geographers, planners and sociologists for many years (Rhind and Hudson, 1980). Interdisciplinary research on land use is a relatively new field. Fascinating new results are emerging that allow us to integrate results from various disciplines into a better understanding of what land use is, what drives it and how land use changes can lead to land cover changes (Fresco, 1994).

An unprecedented rate of population growth, increasing awareness of the fragility of the earth's resources and the growth of information technology has contributed to the increase of land use studies at national and regional levels around the world (Fresco *et al.*, 1994). Land use studies exist at a national level in most countries around the world. Comprehensive planning based mainly upon land use studies has occurred over the past 50 years in the United Kingdom (Kivel, 1991). Similar national land use studies have been undertaken in Australia, Japan and Thailand (Iwoa 1998; Saipothong, 2000; Speight *et al.*, 1988), with national and international Land use planning guide lines and classification systems in existence (FAO, 1998; Van Duivenbooden, 1995). A paucity of regional land use studies exist in South Africa. Rivers-Moore's (1997) study of land use change in the Midmar catchment area and Read's (2001) study of the Hazelmere catchment area are however, examples of the few land use studies that have taken place.

2.1.3. Land use data

The availability of accurate and current land use data, collected at the appropriate resolution level, with the desired classification scheme is very hard to obtain for specific user's needs. "Strange as it may seem, accurate data on actual land use and land use changes are not easily found" (Fresco 1994, 1).

Today's paradox is that, notwithstanding the great technological advances and our increased knowledge of the natural resource base, land use studies and planning has not become easier and the challenges are perhaps greater than ever (Fresco, 1994). This can be attributed to several factors such as the diversity of the land users and the diversity, goals of the study and the rate at which land use changes.

A reliable, accurate, up-to-date and accessible information base is a prerequisite for a full understanding of the nature and reasons for spatial variation in land use activities (O'Callaghan, 1996). The applicability of the land use data depends on how accurate and representative the data is. The importance is focused on how the data is classified, the scale for collecting, storing and representing the data, and the way in which the data is collected (Aldrich, 1981; Healey, 1991). The nature and quality of the information available for local and regional studies of land use depends to a large extent, on the way in which the information is collected in the first place. Errors can arise from human interpreters trying to identify form and function from remotely sensed data, as well as from ground surveys. The use of different spatial units makes the examination of changes over space and time very difficult (Healey, 1991). Healey (1991) argues that perhaps the most fundamental data constraints are the changes in the nature of land use activity.

"There is a bewildering variety of official and unofficial data sources available... However, most are limited by their spatial coverage, level of spatial disaggregation, frequency and completeness" (Healey 1991, 21). Increasing dissatisfaction with the official statistics available for sub-national analysis has encouraged many research workers to undertake their own surveys of land use (Healey, 1991). Coppock's (1991, 104) judgement that "the collection of adequate land use changes is always likely to present difficulties" unfortunately remains true.

Rhind and Hudson (1980), postulate that the usual aims for conventional land use surveys are:

- (i) to provide area and/or volume descriptions of the land uses within defined regions, or to define the land use at a particular point in space;
- (ii) to 'overlay' data for an area at different moments in time and thus produce rates-of-change in land use;
- (iii) to overlay different data sets for the same area to determine interrelationships between physical and socio-economic features;
- (iv) to carry out statistical analysis to explore relationships within an area – either aspatially or spatially;
- (v) to produce comparisons between areas at the same moment in time;
- (vi) to produce graphic representations of the data, either as maps or graphs.

In South Africa an 'information gap' exists between urban and rural land use data. Detailed land use studies in South Africa concentrate on urban areas, where the majority of land use surveys take place. Alternatively few detailed studies take place in rural regions, with most information pertaining to rural land use being of a low resolution. Therefore, to obtain detailed and accurate land use data in rural regions in South Africa (such as Zulti South) to monitor change, researchers typically have to undertake their own surveys of land use.

2.1.4. Land use change

"It goes without saying that forces driving land use changes are complex and act at various scales with different rates of change. Among them, the most obvious are population growth and concomitant growth in demand for land use products, which differ consistently across space" (Fresco 1994, 2). Land cover is constantly changing, as a result not only of seasonal climate variations, but also of human action.

The past centuries have been marked by massive land use conversion; the change from one land use category to another. This tends to be from natural ecosystems to agricultural or industrial land uses.

Olembo (1994) identifies the post Second World War period as a distinct period where the rate of this conversion increased rapidly. He suggested that this is very much related to human and domestic animal population explosions, particularly taking place in the developing countries. The most important land use change appears to be the intensification of land use through better management of production factors (Fresco, 1994).

Land use has to change to meet new demands. Change brings new conflicts between uses of the land, and between the interests of individual land users and the common good (FAO, 1989; Fresco, 1994). Land use change is necessary to provide more energy as well as space for ever-expanding industrial, residential and commercial areas, and transport systems (Lounsbury *et al.*, 1981). Examples of short-sighted land uses which damage land resources include the irresponsible clearance of forest on steep lands, or on poor soils, for which sustainable systems of farming have not been developed; overgrazing of pastures; and pollution by industrial, agricultural and urban waste (FAO, 1998). Such degradation of the land may be attributed to greed, ignorance, constraints of land tenure, uncertainty or lack of alternatives but, essentially, it is a consequence of using land today without investing in tomorrow (FAO, 1998).

The effects of past land use on present and future land uses are becoming so widespread, that they cannot be ignored in descriptions of production techniques.

As fewer and fewer areas of natural ecosystems are left, the future will be one of changes within the broad land use categories of arable and industrial lands (Fresco, 1994).

Land use problems result from a complex array of factors. Principal among these are:

- (i) Changes in the number and distribution of population within an area, particularly those resulting from rapid growth or migration
- (ii) Differences in values, attitudes, and perceptions of the inhabitants of an area or adjacent areas
- (iii) Land developments unsuited to the natural characteristics of the land
- (iv) The nature and type of land use controls and planning

(Lounsbury, 1981)

Sommers (1981) suggests that land use problems are pervasive at all levels of society and in all regions. It is therefore important to monitor and analyse land use to limit or prevent land use problems that may arise. A community that destroys its land forfeits its future (FAO, 1989). A major consequence of adopting the concept of sustainable development as an imperative, is that a different kind of relationship must be sought between nature and man – a relationship in which land, as an integral component of nature, is understood, exploited for different purposes and cared for with a view to enhancing its quality and potential over generations (Bonte-Friedheim and Kassam 1994a, 66).

2.2. REMOTE SENSING

The study of the land is being revolutionised by the introduction of many new techniques that allow continuous observation of land features and monitoring of land conditions. Application of remote sensing techniques can provide information on conditions of land surface as a function of time. The challenge at present is to channel these modern opportunities for research into a systems approach that recognises the interrelationships of the many factors involved in land use and that is focused on clear and relevant objectives rather than on the techniques themselves (Bouma and Beek, 1994).

2.2.1. Defining remote sensing

Remote sensing according to Kilford (1983, 256) is the “acquisition of information from a distance”. This definition is perhaps too simplistic and vague, ‘distance’ in this definition is relative and could be in terms of millimetres or kilometres. A more appropriate definition of remote sensing can thus be, ‘the examination, measurement and analyses of an object without being in contact with it’ (Arnold 1997, xiii). Alternatively Cracknell and Hayes (1991, 1) suggest that, “Remote sensing may be taken to be the observation of, or gathering of information about a target by a device separated from the target by some distance”.

2.2.2. Aerial photography and land use studies

Remote sensing is often regarded as synonymous with the use of artificial satellites. There are however numerous ways to gather remotely sensed data without the use of satellites. The current discipline of remote sensing grew out of aerial photography and photo interpretation (Hagget, 1975; Kilford, 1979).

The first aerial photographs of the earth’s surface is said to have been taken from a balloon by a Parisian geographer, Tournachon in 1858 (Hagget, 1975; Lo, 1976; Rhind and Hudson, 1980). From these photographs the Frenchman

Aime' Laussedat, generally known as the Father of Photogrammetry, applied the method of perspective to produce a map (Lo, 1976). Due to the limitation of balloons or kites as camera platforms, no further advances in mapping using aerial photographs occurred until 1909 when Wilbur Wright took the first aerial photograph from an airplane. (Congalton and Green, 1999; Lo, 1976). Although enormous strides were made in the civil applications of aerial photographs, the most rapid developments of aerial photography took place during the First and Second World Wars (Rhind and Hudson, 1980).

The interpretation of aerial photography has been extensively employed in identifying and mapping land uses (Bouma and Beek 1994). The extensive use of aerial photography for mapping and interpreting land use and land cover did not take place until after World War II (Congalton and Green, 1999). During this period many military staff familiar with the use and advantages of aerial photographs returned to civilian life, simultaneously military aircraft equipment for photo-reconnaissance were sold to commercial firms (Rhind and Hudson, 1980).

From the advent of the first aerial photographs to the launch of the latest satellite imaging system, remotely sensed data has become an increasingly important and efficient way of collecting map information (Congalton and Green, 1999). Aerial photographs offer a 'bird's eye view' of our terrestrial environment. This holistic view offered by remotely sensed data is irresistible because it is a view that can be readily understood and is inimitably useful (Congalton and Green, 1999; Rhind and Hudson, 1980).

From Space, we see a small ball dominated by human activity and edifice but by a pattern of clouds, oceans, greenery, and soils. Humans inability to fit its doings into that pattern is changing planetary systems, fundamentally. From space we can see and study the earth as an organism whose health depends on all its parts.

- World Commission on Environment and Development,
Our Common Future, 1987 (cited in Baker 1990).

Congalton and Green (1999, 1) postulate that as resources become scarce, they become more valuable, and the more valuable resources become, the greater the need for timely and accurate information about the type, quantity and extent of the resource. Knowing the distribution and locality of the earth's resources across space and how they interact spatially is critical to effectively managing those resources and ourselves. Aerial photography by virtue of its' special vantage-point, is an efficient surveying tool for inventorying and mapping land use (Lo 1976). Congalton and Green (1999, 2) state that "Because there is a high correlation between variation in remotely sensed data and variation across the earth's surface, remotely sensed data provides an excellent basis for making maps of land use and land cover".

Aerial photos as a source of land use data have both advantages and disadvantages. The overwhelming advantage of remote sensing methods over tactile methods based on ground survey are the consistency which can be ensured in data collection, the rapidity of survey and the obviate problems of access to land (Coppock, 1991; Rhind and Hudson, 1980). Interpretation of land use may be facilitated by the fact that the interpreter has a holistic view of the study area. Aerial photographs provide a permanent and comprehensive record of the earths' surface at the time of the photograph, such a record enables analysis of land use problems which were not seen at the time of the survey, but that appear at a latter stage (Coppock, 1991). The direct use of aerial photographs that have been collected in reasonably similar circumstances ensures that the user can be confident that the data source is internally consistent and synchronicity, or lack of it, is explicit (Rhind and Hudson, 1980).

The disadvantages of aerial photographs stem from the distortions inherent in them, the restrictions imposed by weather conditions and the time of day when the photographs are taken (Coppock 1991, Rhind and Hudson 1980). Although a wealth of information is stored in an aerial photograph, aerial photographs do not give a true representation of reality due to distortion (Barnes, 1982). There are three main types of distortions that can occur within an aerial photograph. These are; tilt distortions due to the camera in the

aircraft not being vertical; distortions resulting from variations in altitude of the aircraft; and those due to the variations in the height of the terrain being photographed (Rhind and Hudson, 1980). Barnes (1982) includes paper distortion caused when the contact print is stretched or distorted. Cloud coverage and the time of day can create shadows and poor visibility of the earths' surface that effect the quality of the image (Coppock, 1991).

Measurements taken from the aerial photographs are erroneous. In order to extract accurate information from an aerial photograph the image first has to be orthorectified. Orthophotos are rectified, vertical aerial photographs that have most of the parallax in the original photograph removed, therefore increased the relevance of aerial photographs. (Arnold, 1996). "Orthophotos allows measurement of distance and direction to be accomplished with the same degree of accuracy as on a topographical maps at similar scales" (Arnold 1996, 37).

2.3. GIS AND LAND USE

There is no shortage of application where GIS can make a contribution (Rhind, 1993). The challenge with GIS, is in determining what new value the more rapid, consistent, intelligent and overall more powerful mapping system can bring to land use monitoring, that is, determining specific problems and objectives that can be addressed by a GIS. It would appear then that GIS could provide an information system domain within which virtually all geography can be performed. GIS emphasizes a holistic view of geography that is broad enough to encompass nearly all geographers and all of geography (Openshaw, 1991).

The GIS field is characterized by a great diversity of applications which bring together ideas developed in many fields of agriculture, botany, computing economics, mathematics, surveying and zoology and, of course geography (Green et al. 1985).

2.3.1. Defining GIS

Obtaining a precise definition that encompasses all aspects of Geographic Information Systems (GIS) is problematic. Numerous GIS definitions exist and depending upon the application of the GIS, the emphasis of the definition changes from a view focusing on technology, applications, information systems or organizational perspectives. Antenucci (1991) suggests that “a precise definition of GIS that everyone could agree on matters less than the understanding gained from reviewing these definitions ... definitions are after all, simply a matter of convenient labeling to help with our communications about observed things”. According to Walford (1999) the problem in trying to tie down the nature of GIS to a specific definition is that the technology moves on and new facets emerge at a rapid pace.

A Geographical Information System (GIS) can be described as an organised collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information. GIS provides a means of integrating information in a way that allows understanding of complex spatial problems (Chou, 1996; ESRI Inc., 1990).

Similarly Green *et al.* (1985) defines GIS as is a group of procedures that provide data input, storage and retrieval, mapping and spatial analysis for both spatial and attribute data to support the decision-making activities of an organization.

GIS is “... a means of evaluating geographical relationships through spatial analysis, database management and geographical displays (Dunn *et al.*, 1997, 151). GIS are computer systems, which are based on the inputting of spatial co-ordinates of human or physical features on the earth’s surface (Hill *et al.* 2000).

Walford (1999) suggests that the term GIS is used in two different ways: first, to refer to an integrated system of computer hardware software, digital geographic data and other forms of it; and, secondly, to denote a specific application of such a system within a particular organizational context. The distinction between these uses of the term relates to the difference between GIS as a component of Information Technology (IT) and as a practical tool or method for handling and managing geographic data in a variety of situations.

“No single paragraph or concept can capture all elements of GIS” (Nyman, 1998). All definitions have two common features, namely that GIS are systems, which deal with geographical information linked to the earth's surface; and they identify GIS as capable of performing a number of functions with respect to this type of data (Walford, 1999). Thus GIS is considered to include a spatially referenced data and appropriate hardware and applications software to model and analyze this data. It needs to be borne in mind that GIS is a system and does not operate in isolation from its human components or its operating environment.

A GIS is not simply a computer system for making maps, a Computer Aided Design (CAD), or a Database management system (Antenucci, 1991).

Rather a GIS is a system of 3 interconnected components:

- spatial data,
- software/ hardware tools, and
- a specific problem or objective.

In short, a GIS does not hold maps or pictures, rather it holds a geographic database from which we can produce the maps.

DeMers (2000, 1) summarises GIS as more than computer software programmes specifically designed to assist in the solutions of geographic problems. “They automate known geographic concepts and ideas; render explanations of distributional patterns of people, plants, animals, places and things; and even predict new distributions and spatial arrangements through time”.

2.3.2. The Use of GIS in Land Use Monitoring

Bibby and Shepherd (1999, 953) state that “the representation and analysis of land cover has been a major area of GIS application since the introduction of the technology in the early 1970’s”. Rowlinson (1998) further emphasises this by stating that GIS has been used extensively for classifying and monitoring changes in land use and land cover.

GIS provides the tools to capture data, convert data, edit and update data, manage the data, perform hundreds of different types of spatial analyses, and create a high quality cartographic output. GIS brings data to life in a visual and analytical context (Walford, 1999). GIS can bring enormous benefits because of its ability to handle spatial data in ways that are precise, rapid, and sophisticated (Goodchild, 1993). Such systems can be characterised as “internally referenced, automated, spatial information systems, designed for data mapping, management, and analysis” (Berry 1993, 53).

GIS has been used extensively to generate information for land use policy and land use planning (Bibby and Shepherd, 1999). GIS enables spatial land use information to be collected via remotely sensed data, processed and analysed (Goodchild, 1993). Spatial relationships of the data can be summarised, analytically processed within GIS, used to extract information inherent in the remotely sensed data to produce a strategic picture of land use (Bibby and Shepherd 1999, Goodchild 1993).

Nyerges (1993) identifies three types of modes of GIS use: map, query and model. Similarly the use of GIS within land use monitoring plays three distinct roles: inventory, analysis and modelling.

Inventory

A critical GIS function is to store the most complete possible description of a study area (Langran, 1991). The inventory mode of GIS provides referential and browse information, accounts for features, form and function within the study area, and generates an accurate overview of the spatial realm.

Such information, usually in the form of visual data and maps, provides a user with the insight to clarify issues at hand and obtain an overall understanding of the study area (Nygers, 1993).

Analysis

The ultimate goal of analysis is to understand the processes at work in a study area. Analysis may be statistical, where data is examined for trends, patterns, and divergence from the norm. GIS is used to explain and exploit the patterns contained by and the processes at work, in the region (Langran 1991, Nyges 1993). A GIS is particularly useful in this field as it can monitor land use in the same geographic location and establish any temporal trends or changes in the form and function of land in the land use data.

Modelling

Model invocation is the third mode of use; analysis may compare the empirical stored data to theoretical models that approximate the data's character. A model brings together the locational, temporal and thematic aspects of land use in a geographic process (Langran 1991, Nyges 1993).

The purpose of models is to simulate complex geographical phenomenon such as land use represented in reality (Goodchild, 1993a). GIS is used to pre-process data, or to make maps of input data, or model results.

A GIS is not just a toolbox for resource inventory, land assessment and modelling, but it is also a valuable tool to researchers in land use management in terms of management concepts and theories. A GIS allows the organisation of data in order to understand their spatial relations, providing the basis for making more sensitive and intelligent decisions (ESRI inc., 1990). Thus GIS has a clear potential to provide support for the decision-making process.

GIS should not be seen as the panacea of all our ills and concerns of land use, but rather as a tool that helps us ask the right questions of spatial data pertaining land use and allows us to perform an intelligent analysis of the results we obtain. Thus, improving our understanding of our environment and

improve our decisions regarding future prospects and direction (Antenucci, 1991).

2.3.3. GIS and remote sensing

The main connection between GIS and remote sensing is that processed images from satellite and airborne data collection systems (i.e. remote sensing) can constitute a source of data dealing with terrestrial features, which can be combined with information from other sources in GIS. Raw remotely sensed data, once converted into a digital format, almost invariably needs to undergo some form of image processing before they can be used with GIS software (Walford, 1999).

Burrough and McDonnell (1998) have suggested that:

“The need arose for a marriage between remote sensing, earthbound survey, and cartography; this has been made possible by the class of spatial information handling tools known as GIS” (Burrough and McDonnell 1998,8; cited in Walford, 1999).

2.3.4. Temporal GIS

In Geography space is indivisibly coupled with time (Parkers and Thrift, 1980 cited in Langran 1992). Langran (1992) suggests that a reasonable goal of GIS is that they be capable of tracing and analysing changes in spatial information. In the developing field of GIS, there is a compelling need to describe spatial change over time. Dangermound (1984, 11) depicts the “elements of a GIS as time, location and attribute”. Although today’s technology treats only location and attribute (Dangermound 1984, Langran 1992). A major limitation of such a model that focuses purely on ‘location’ and ‘attribute’ elements is that it provides a ‘snapshot’ view of a spatial phenomenon, which gives no insight into how this feature changes over time (Antenucci, 1991).

A non-temporal GIS describes a spatial feature of the earth in only one state of time. This means that previous conditions and states of that feature are essentially forgotten and the anticipated or forecast of the future cannot be treated. (Langran, 1992). The process that cause states to change from one state to the next are thus obscured by a non-temporal GIS, making dynamics of the modelled world difficult to analyse and understand (Langran, 1992).

A temporal GIS traces the changing phenomenon of a study area, storing historic, current and anticipated geographic features (Langran, 1992). Through this procedure, a temporal GIS could respond to the following queries:

- Where and when did the change occur?
- What types of change occurred?
- What is the rate of change?
- What is the periodicity of change?

Given access to these types of data, a GIS could assess:

- Whether temporal patterns exist?
- What trends are apparent?
- What processes underlie the change?

Temporal GIS can therefore assist land use monitoring by assessing the temporal change and patterns present in the data. "Such assessments could form the basis for understanding the causes of change, leading to a better understanding of the processes at work in a region" (Langran 1991, 3).

2.3.5. Change and Time series analysis

As stated earlier land use change can have profound effects on both human and natural environments. “With ever increasing populations and the consequent need to extend agriculture into increasingly marginal environments, even fairly minor change can have profound consequences “ (Eastman *et al.* 1995, 2).

A time series is a set of numbers that measures the status of some activity over time (Arsham, 1994). It is the historical record of some activity, with measurements taken at spaced intervals with a consistency in the activity and the method of measurement (Arsham, 1994). Therefore change and time series analysis concerns the examination of change.

Land use change is not a simple phenomenon to detect. Change implies not only a difference in land surface characteristics between two dates, but also that the difference is uncharacteristic of the normal variation, caused by such factors as climatic or cropping seasons, between these dates. (Eastman *et al.*, 1995). Indeed the word implies some permanence in the changed characteristics.

Time series analysis concerns the examination of land use change over a sequence of remotely sensed images (Eastman 1995, Langran 1991). With GIS and remote sensing technology we have the ability to collect and process thematic land use data in digital form on a continued and regular basis, to provide rapid and consistent measurements of change and land use trends (Eastman *et al.* 1995).

2.4. SUMMARY

This chapter has broadly outlined the nature and use of GIS and remote sensing in land use studies, land use data acquisition and land use analysis. Mention is made of the importance of land, its use to humanity and the need for continued monitoring of its changing patterns. Some broad concepts of the use of GIS in land use monitoring, temporal GIS and time series analysis in examining and analysing land use data are addressed and discussed in this chapter.

CHAPTER 3

STUDY AREA

3.1. INTRODUCTION

Richards Bay Minerals have registered mining rights in the remainder of Reserve No. 10 No. 15830, Kraal Hill No. 1 and Kraal Hill No. 2 No. 10964, in the Umfolozi district, situated in the Administrative district of KwaZulu-Natal, South Africa. This land has been colloquially named by RBM as Zulti South (Figure 3.1). The land upon which the Zulti South mineral lease lies is state owned and is presently administered by the Ngonyame trust, which comprises of the tribal authorities of Mkhwanazi and Dube, (see Figure 3.2), the current chief is nKosi Dube (Environmental Management Programme Zulti South mineral lease, 1998).

RBM obtained mining rights to the Zulti South lease in May 1985 from the Department of Mining and Energy Affairs. In compliance with the changes in the statutory requirements of the Minerals Act, 1991 (Act 50 of 1991), RBM submitted an Environmental Management Programme to obtain a mining licence for the lease area. This was granted on the 31 of October 1995 and was renewed on the 20 of January 1999 (King, M. pers. comm. 2001).

3.2. LOCATION OF THE STUDY AREA

The Zulti South mineral lease area is located along the east coast of Northern KwaZulu-Natal, South Africa. It lies approximately 12 km to the south west of Richards Bay harbour, 7 km east north east of Umtinzini and 3 km due south of Esikhawini. The study area is 3073.86 hectares in extent and is located between 28°51'20"S - 28°56'30"S, and 31°50'00"E - 32°01'50"E, it is bounded on the east by the Indian Ocean and extends parallel to the coastline for a distance of approximately 18 kilometres.

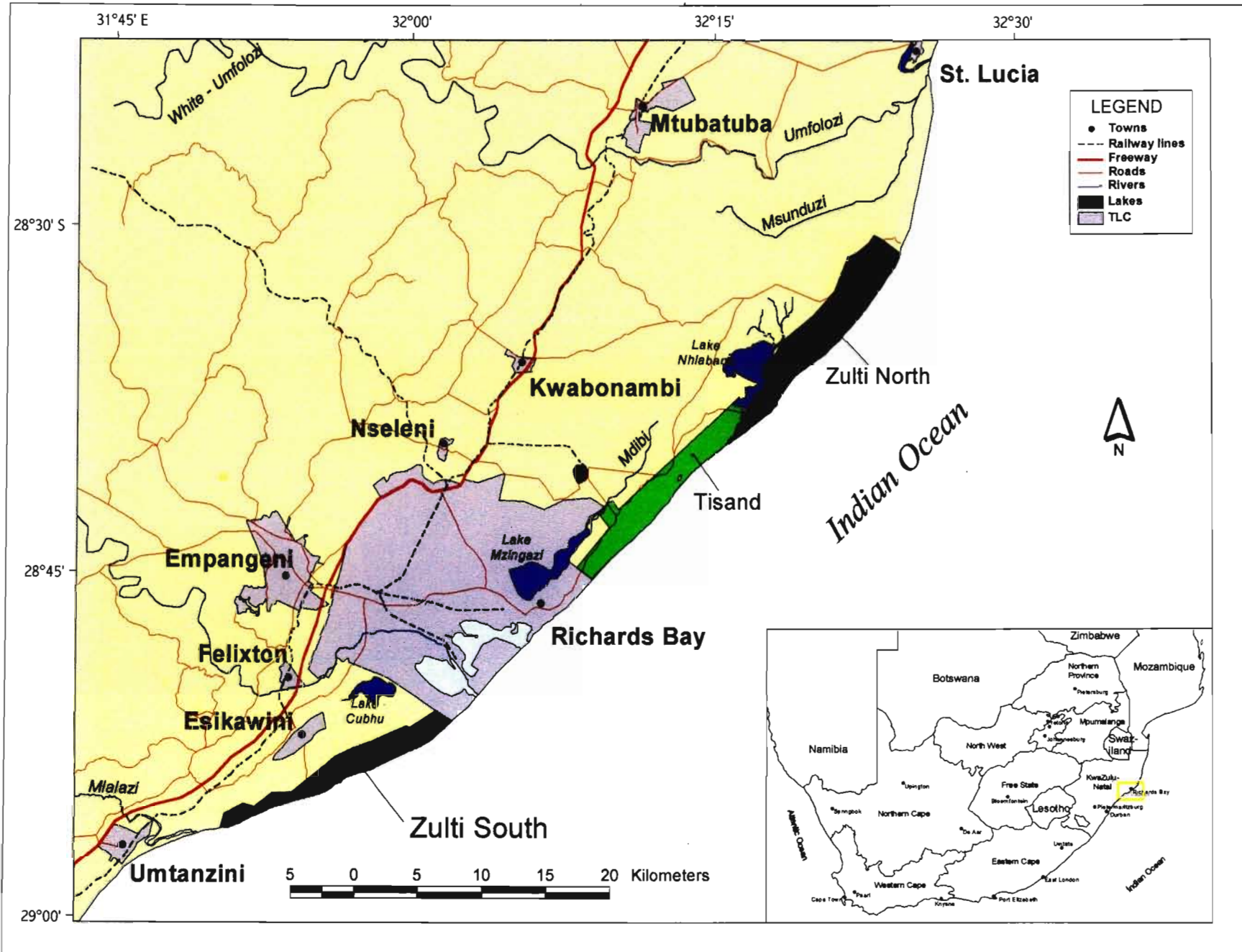


Figure 3.1: Locality map of Zulti South and Surrounds

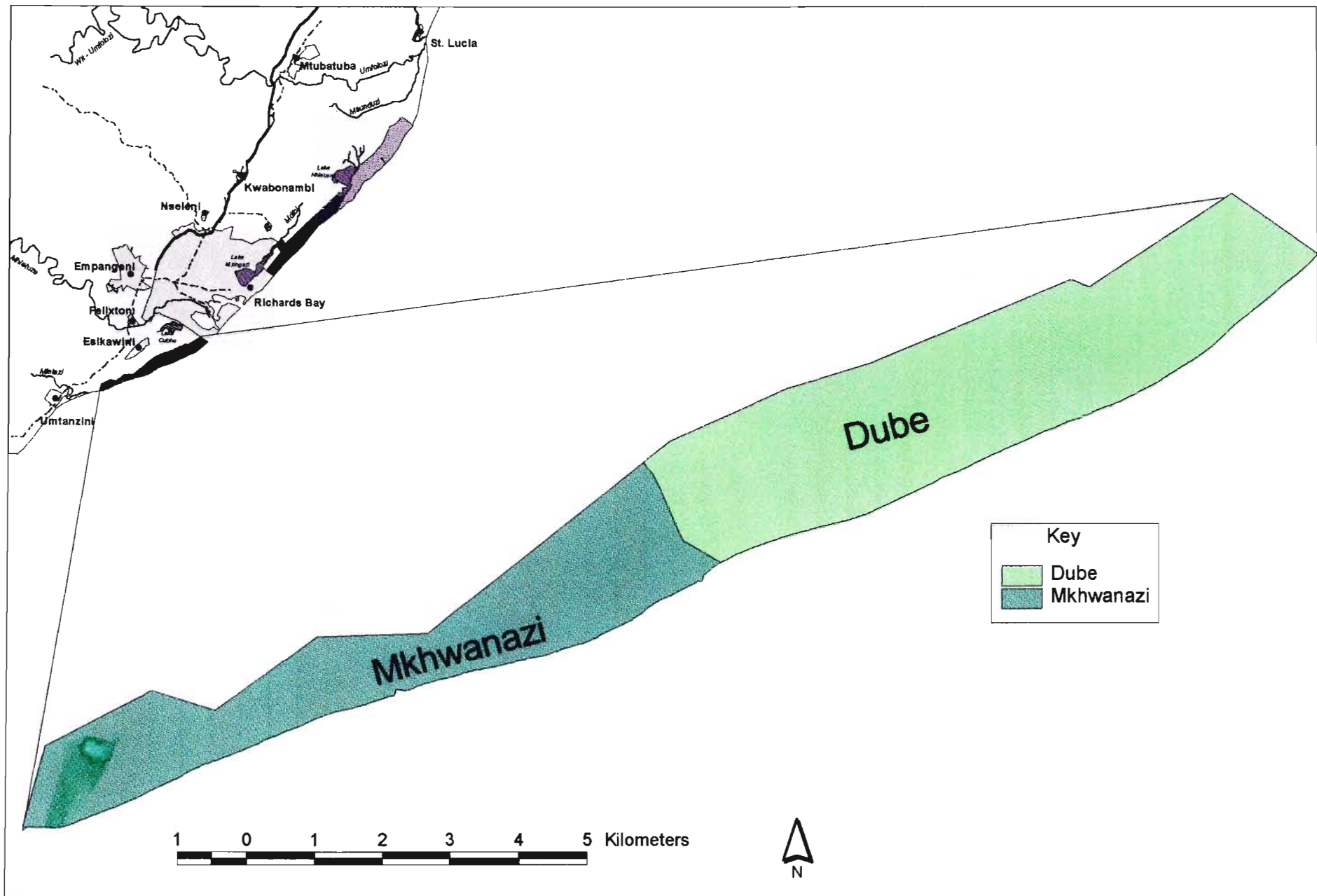


Figure 3.2: Tribal regions within Zulti South

The western boundary is surrounded by the township of Esikhawini and the informal tribal settlement designate as reserve 10, (Figure 3.1).

3.3. BIO-PHYSICAL ENVIRONMENT

Discussions on the bio-physical environment is given as background to the general consideration of the area, with particular emphasis placed on aspects considered important for land use and land use change. A detailed study of the biological and physical conditions in and around the study area falls outside the scope of this study.

3.3.1. Climate

The regional climate of the Richards Bay area, in which Zulti South falls, is described by Schutte (1965), as having a warm to hot and humid subtropical climate. The region is one of the highest rainfall areas in South Africa. Rainfall occurs throughout the year, with a peak in summer between January and March, the mean annual precipitation in the study area ranges from 1100 mm in the north to 1400mm in the south. Most of the rain is either of an anti-cyclonic or orographic nature, the latter being caused by the high coastal dunes that force on shore winds to rise, resulting in localised precipitation (Dent et. al., 1989).

The mean maximum temperature for 2000 was recorded as 26,7⁰C, with highest daily maximum temperature ever recorded reaching a maximum of 42,5⁰C in January (Table 3.1), the mean monthly minimum temperature for 2000 was 16,9⁰C. Frost has never been recorded in the area and the lowest daily minimum temperature ever recorded being 5,1⁰C (Environmental Management Programme Zulti South mineral lease 1998, Mine closure report 2001).

Table 3.1: Temperature statistics for the region in 2000

Mean Max. temp	26,7 ⁰ C
Mean Min. temp	16,9 ⁰ C
Mean Annual temp	21,8 ⁰ C
Range	9,9 ⁰ C
Highest recorded daily Max.	42,5 ⁰ C
Lowest recorded daily Min.	5,1 ⁰ C

The relative humidity in the region can be extremely high, reaching 85 - 90 percent in the morning (08h00) because of dew formation. As the day progresses, warmer temperatures and on shore winds drops the relative humidity to 75 - 80 percent by 14h00. The relative humidity increases by 20h00 due to the drop in the onshore winds and condensation from evening cooling, humidity here can rise 85-90 percent (Mine closure report 2001).

The predominant winds are from the SW and NE/NNE sectors. The speeds have been found to range from 14,4 Km/h to 21,6 Km/h but may average 25,2 Km/h to 39,6 Km/h during October to March (Zulti South Environmental Management Programme, 1998).

3.3.2. Geology

Numerous detailed studies have been carried out to describe the regional and site geology of the Richards Bay coastline (see Davis Lynn & Partners, 1991 1993). The purpose of this chapter is not to analyse or evaluate these studies but simply to give a general overview of the geology in the study area.

Along the coastal strip only sediments of cretaceous, tertiary and quaternary age are present. These rocks lie unconformably on Baenet granite-gneiss of the Tugela complex. Overlying the cretaceous and Miocene sediment is the Port Durnford formation, here sediments are made up of old dune, beach and swamp deposits lain down during the Pleistocene Period (less than 2 million

years ago). Recent unconsolidated dune sands unconformably overlie the Port Durnford formation (Environmental Management Programme Zulti South mineral lease 1998, Mine closure report 2001).

3.3.3. Topography

The Zulti South lease area occupies part of a coastal dune cordon extending parallel to the coast between Mhlatuze lagoon in the north and the Mlalazi River in the south. This dune cordon is 25 km long and varies in width from 0,5 km to a maximum of 2 km at approximately the centre of the lease area (Steffen, Robson and Kirsten, 1993).

The coastline is well defined by this coastal dune cordon, with sea facing dunes rising fairly steeply from the beach to elevations commonly between 40 and 50 meters above mean sea level. Over the eastern one third of the study area the topology is rugged and rises to maximum elevations of 80 meters above mean sea level. The central one third of the lease area is characterised by a fairly flat internal plateau varying in elevation between 40 and 50 meters above mean sea level. The southern one third is narrower and significantly incised, with the dune topography consisting of alternating ridges and valleys with elevation differences of up to 30 meters. Over most of the study area there is a pronounced orientation of topographic features (ridges and valleys) at approximately 45° to the coastline.

The landward side of the dune cordon slopes more gently westward from an elevation of 20 to 30 meters from the base of the dune cordon to an average of 40 meters some 4,5 km west of the cordon. An exception here is in the north eastern extremity of the lease area where there is a steep drop to an elevation of less than 10 meters above mean sea level at the base of the dune cordon (Zulti South Environmental Management Programme, 1998).

For the purpose of the research the topology of the lease was only distinguished between the Dune cordon and flatland regions (see Figure 3.3).

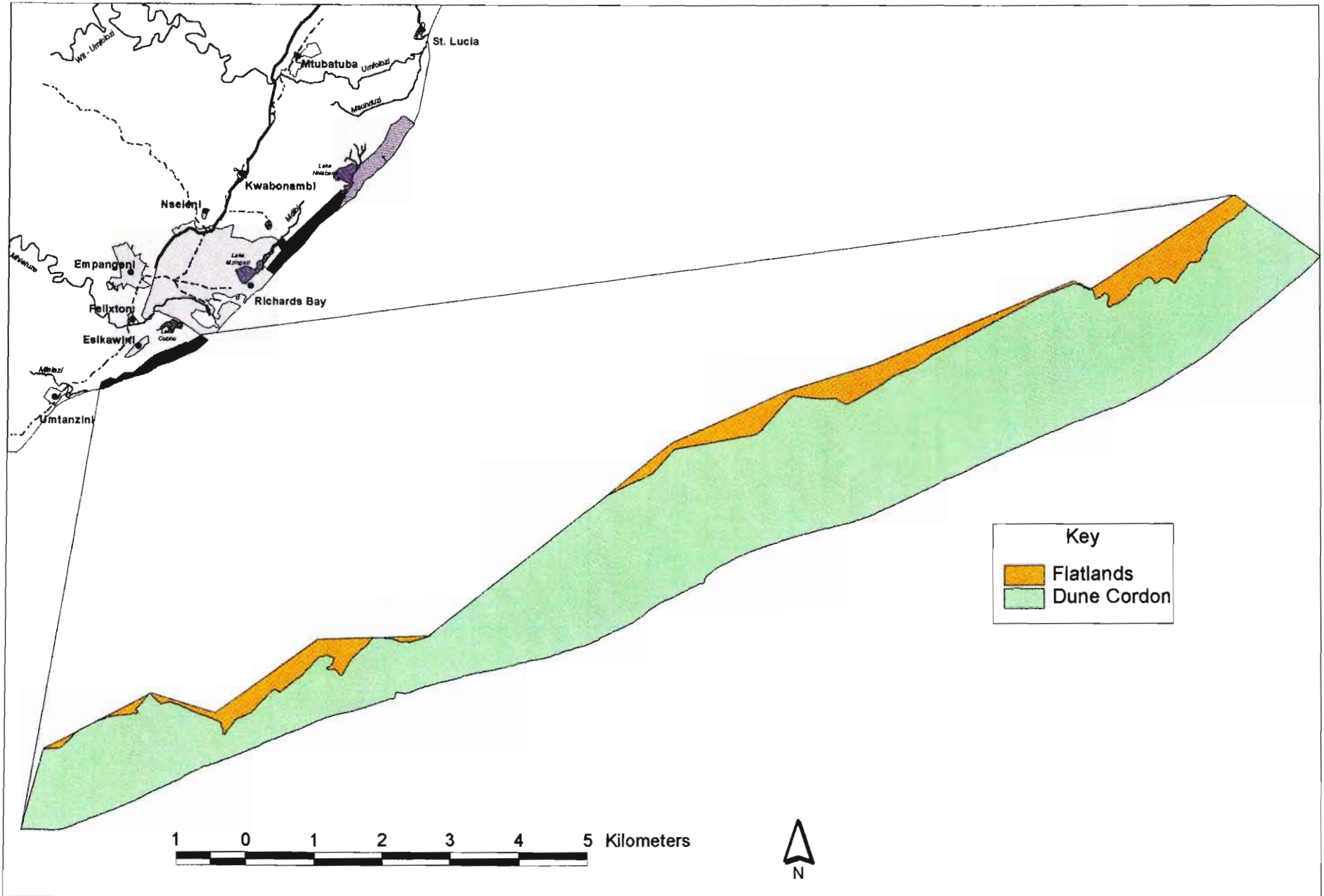


Figure 3.3: Topography of Zulti South

3.3.4. Soils

Steffen, Robertson and Kirsten (1993) conducted a detailed soil survey of Zulti South during July 1993. This soil survey indicated that within the survey area minor variation in soil forms were apparent. The soil samples that were collected and analysed by Steffen, Robertson and Kirsten (1993), were classified in accordance with soil classification¹ by the Soil Classification Working Group, Department of Agricultural Development, Pretoria 1991 (Macvicar, 1977).

The predominant soil form found in the main dune cordon was Namib², this soil and associated soils such as Oakleaf and Lusiki are medium grained sandy soils with a low clay content, these soils are relatively young and show little profile development. They are well drained, highly leached soils with poor moisture holding capacity and have a low nutrient status. Their low cation exchange capacity means that they have little ability to hold plant nutrients, and are generally acidic.

The soils found in the gentle undulating land inland of the dunes where found to be more structured with a higher clay content than the soils found in the dune cordon. The predominant soil forms here were Fernwood, Oakleaf and Tukulu, these soils remain relatively sandy, they tend to have a higher cation exchange capacity and are less well drained in comparison to the soils found in the dune cordon. These soils are acid and the nutrient status is poor.

In parts of the study area the hinterland drains down towards the dunes, here this water meets with the seepage from the dune aquifer, resulting in wetland areas along the fringe adjoining the dune. In this wetland area the predominant soil form is Champagne, other soil forms that were encountered in this area were Longlands, Valsrivier, Sweetwater and Sepane, these soils are wetland black wet soils marked with organic staining resulting from the slow decomposition of plants.

¹a taxonomic system for South Africa

² previously classified as Fernwood in the old Binomial Soil Classification System

3.3.4. Vegetation

The study area forms part of the southern extreme of the Mozambique coastal plain (Tinley, 1985). The vegetation type is classified by Acocks as Coastal forest and thornveld (Acocks, 1988). Lubke, Avis and Phillipson (1989) describe Acocks' approach to vegetation classification as simplistic and based on an agricultural concept. A more detailed description of the vegetation types that occur in the study area is given by Weisser (1987), an authority on the dune vegetation of Natal, based on detailed vegetation studies undertaken in 1982 and 1987. The motivation of these vegetation studies was to recognise the species composition, ecological status and conservation priority of the different vegetation types within Zulti South.

Weisser (1987) identified nine different vegetation types that occupy more than one percent (1%) of the study area, for the purpose of this study these have been grouped into six broad types. These are:

- Seaward dune thicket
- Mature forest
- Secondary dune forest and scrub
- *Acacia karroo* woodland
- Swamp and Hygrophilous forest
- Commercial forestry

Examination from aerial photographs taken from 1990 to 2000 show a completely vegetated dune barrier and an inland mixture of commercial forest areas, secondary scrub and natural forest. The natural vegetation was located mainly in the southern, coastal and northern part of the lease area. The total area occupied by the climax dune forest, hygrophilous and marsh communities that have a high conservation priority is small relative to that occupied by secondary forests and commercial plantations.

Comprehensive lists of rare, vulnerable and endangered plant species in the region of the lease area are not available (Weisser, 1987). Species in the lease area that are known to be vulnerable are the epiphytic orchids in the climax dune forest and *Aloe thraskii* in the seaward dune communities. The current condition of the lease area's vegetation has been described as severely disturbed and degraded due to various human-induced factors and intensive grazing (Weisser, 1987).

Dune thicket and pioneer species occur on the seaward-facing slopes of the dune cordon. Tinely (1985) describes this plant community as shrub-thicket community, this is a dense, unilateral community of multi-stemmed dwarf trees and shrubs with a compact canopy. Dune thicket form a dense canopy up to 6m in height with close to 100% cover, these woody plants are stunted and pruned by salt spray and onshore winds. In some parts of the seaward-facing slopes undercutting of the dune face and coastal slumping caused by wave action and ground water seepage has occurred. Consequently, this vegetation generally comprises of pioneer species that adapt to disturbed environments making way for dwarf woody coastal thicket species.

Coastal dune medium and high forest classes occur mostly on the landward face of the dunes, but also in some protected hollows, the lee of dunes and other obstacles in the dune area (Tinely 1985, Weisser 1987). The trees are taller than in the thicket and usually three strata occur - trees (4 - 20m high, 40 - 90% cover) shrubs (1 - 6m high, 10 - 50% cover) and herbaceous field layer (0,2 - 1,5m high, 3 - 70% cover). The climax dune forest communities are particularly important to conserve as it takes centuries for these communities to reach the climax state.

On the higher inland dunes and along the dune forest margins in the study area, secondary dune forest and scrub occur. This community consists of an abundance of shrubs and small tree species, which are transitional dune forests. The shrub canopy is 1 to 2m tall and has 50 - 90% cover, while the small trees are 3 to 5 m tall with 20 - 60% cover. *Acacia karroo* woodland occupy a large stand separating the dune forest from disturbed grasslands.

These woodlands occupy parts of the inland dunes, but are mainly found on the verge of lowland areas and in disturbed areas within the lease area.

Swamp and hygrophilous forests are found in areas of slow-flowing or stagnant water where trees grow on waterlogged soils. This formation is rare in South Africa and of particular conservation value. Much of the secondary grasslands and low shrub-lands were replaced by commercial forestry in 1957 by the then Forestry Department to stabilise drift-sands and control erosion (Zulti South Environmental Management Programme, 1998). Forestry plantations cover a major portion of the study area, here alien species of *Eucalyptus* and *Pine* hybrids are planted and harvested.

3.3.5. Animal life

A survey was undertaken in 1993 to determine the concentrations of commonly occurring as well as endangered or rare vertebrate species occurring in Zulti South. Vertebrate species lists for the study area were compiled by Steffen, Robertson and Kirsten (1993) from direct observations made in the survey and augmented from information extracted from Branch (1988 a & b), Brooke (1984), Maclean (1983), Passmore & Carruthers (1979) and Skinner and Smithers (1990).

Approximately 278 vertebrate species¹ potentially occur in Zulti South. In view of the lack of suitable habitat resulting from anthropogenic disturbances, it is unlikely that all these species still occur in the area, it is believed that approximately 208 species² currently reside in the study area. Of these 26 are listed in 'Red Data Book' as indicated in Table 3.2.

¹ 81 Birds, 85 mammals, 41 amphibians, and 71 reptiles

² 81 Birds, 45 mammals, 37 amphibians, and 45 reptiles

The species of birds, mammals, reptiles, and amphibians found during the animal survey, those previously sighted and those expected to occur there where recorded. A study of invertebrates was not included in this survey.

Table 3.2 List of Red Data Species occurring in Zulti South

Class	Species	Red Data Book Category	Habitat
Birds	Bat Hawk	Rare	Woodland/ forest
	Black Stork	Indeterminate	Grassland
	Blackrumped Buttonquail	Endangered	Grassland
	Black Coucal	Indeterminate	Grassland
	Blue Quail	Rare	Grassland
	Cuckoo Hawk	Indeterminate	Woodland/ forest
	Delegorgue's Pigeon	Indeterminate	Forest
	Grass Owl	Indeterminate	Grassland
	Martial Eagle	Vulnerable	Woodland
	Natal Nightjar	Vulnerable	Grassland
	Palmnut Vulture	Rare	Woodland
	Redwinged Pratincole	Rare	Grassland
	Pied Mannikin	Indeterminate	Forest
	Southern Banded Snake Eagle	Rare	Forest
	Spotted Thrush	Vulnerable	Woodland/ forest
	Wattle-eyed Flycatcher	Indeterminate	Forest
White Stork	Rare	Grassland	
Mammals	Leopard	Rare	Grassland/ woodland
	Serval	Rare	Grassland/ woodland
	Red Duiker	Rare	Forest
	African Wildcat	Vulnerable	Grassland/ woodland
	Honey Badger	Vulnerable	Grassland/ woodland
	Zulu Golden Mole	Indeterminate	Grassland
	Kuhl's Bat	Indeterminate	Woodland/ forest
Reptiles	African Python	Vulnerable	Mixed
	Gaboon Adder	Vulnerable	Forest

3.4. CURRENT INFRASTRUCTURE AND LAND USE

Zulti South is currently characterised by two conflicting uses of the land; that of legal formal land use and infrastructure, and illegal subsistence land use and infrastructure. Although the land is state owned, RBM and the tribal authorities have an understanding that habitants surrounding the lease will not encroach upon the dune cordon.

3.4.1. Formal land use and infrastructure

Currently very little formal land use activities occur within the study area, however the formal use of land within Zulti South includes all commercial plantations of *Eucalyptus* and *Pine* hybrids, two forestry stations, the Esikhaweni sewage plant and the Port-Durnford lighthouse. Due to political violence during the post 1994 election period, the Department of Water Affairs and Forestry withdrew all its activities within the lease, since then the southern forestry station has been abandoned and due to looting, just the walls of the buildings remain. There are still numerous plantation stands currently in Zulti South and as the Kwa-Zulu forestry department does not manage or harvest these trees, locals have free reign to harvest and remove the timber illegally (Barnes, J. pers. comm., 2001; Cant, C. pers. comm., 2001). The Esikhaweni sewage plant and the Port-Durnford lighthouse, are still in operation.

3.4.2. Subsistence land use and infrastructure

With limited official RBM presence, a growing population and ever increasing unemployment rate, habitants from surrounding communities have not been persuaded to remain off the lease area, and gradually encroachment on Zulti South has occurred. Although there has always been land occupation in the western extremity of the lease, the number of homesteads and the number of people living on the lease has gradually increased. Due to the nature of the topology in this region RBM currently do not intend to mine this portion of the lease and the road separating this flatland and dune cordon has historically been accepted as the boundary of the potential mining area (Mine Planning report, 1999).

Although agriculture is poorly suited in the area, with input costs likely to be high (Steffen, Robertson and Kirsten, 1998), slash and burn subsistence agriculture is increasing with cultivated fields of sugarcane, beans, pumpkins and yams growing. Several storage shelters have been erected within the cultivated fields to store crops and tools in the cultivated fields.

3.4.3. Mining

Although RBM intends to mine placer heavy minerals from the dune sands in the Zulti South mineral lease area, no mining has to date occurred. Mining has been predicted to commence within the next seven years time (Barnes, J. pers. comm., 2001). Numerous boreholes have, however, been drilled in an exploration attempt by RBM to quantify the ore body in the lease area.

3.5. SUMMARY

This chapter has briefly discussed the present physical and human landscape of the Zulti South mineral lease area. The location, the existing bio-physical and the present human environments and characteristics of the study area were also discussed.

CHAPTER 4

MATERIALS AND METHODS

4.1. INTRODUCTION

This chapter details and describes the methods used and the approach adopted in achieving the objectives set out in Chapter 1. The research focuses on illustrating how GIS can be utilised in monitoring, analysing and predicting land use patterns in RBM's Zulti South lease area. The land uses at distinct points of time from September 1990 to June 2001 in the study area are analysed, these dates were primarily based on the availability of aerial photography supplied by RBM.

The method used in achieving the objectives of this research, illustrated in the conceptual framework (see figure 4.1), is divided into three parts, namely; land use mapping, land use change analysis and land use prediction, can briefly be summarised as follows:

Land use Mapping

To create land use maps of the study area,

- a) a consistent supervised land use classification scheme was designed to interpret land use from the remotely sensed data;
- b) errors in the remotely sensed data were rectified;
- c) the boundaries between land uses were determined through photo-interpretation from each of the remotely sensed dataset;
- d) the location of the boundaries between land uses were digitised through an on screen-method, at an area threshold determined by the resolution of the remotely sensed dataset, and classified;
- e) a polygon coverage was built and cleaned from the digitised land use boundaries, land use data was attributed to each polygon as defined by the classification scheme;
- f) the coverage was saved as a classified choropleth land use map;

- g) the error in the land use map was assessed through an error matrix;
- h) errors were corrected and the correct land use data was attributed to the land use map.

Land use change analysis

To determine how and where land use had changed in the study area over the time period,

- a) the area of land occupied by each category of land use for each dataset was calculated,
- b) a time series comparison between the land use maps was modelled,
- c) the difference in the area occupied for each class between the different time periods was calculated,
- d) the location of the changed parcels of land were determined,

Land use prediction

In predicting possible future land use scenarios in Zulti south.

- a) the direction of spatial and temporal land use change was identified,
- b) hot spots of potential change were identified,
- c) trends and patterns observed from the land use maps were used to predict future land use scenarios.

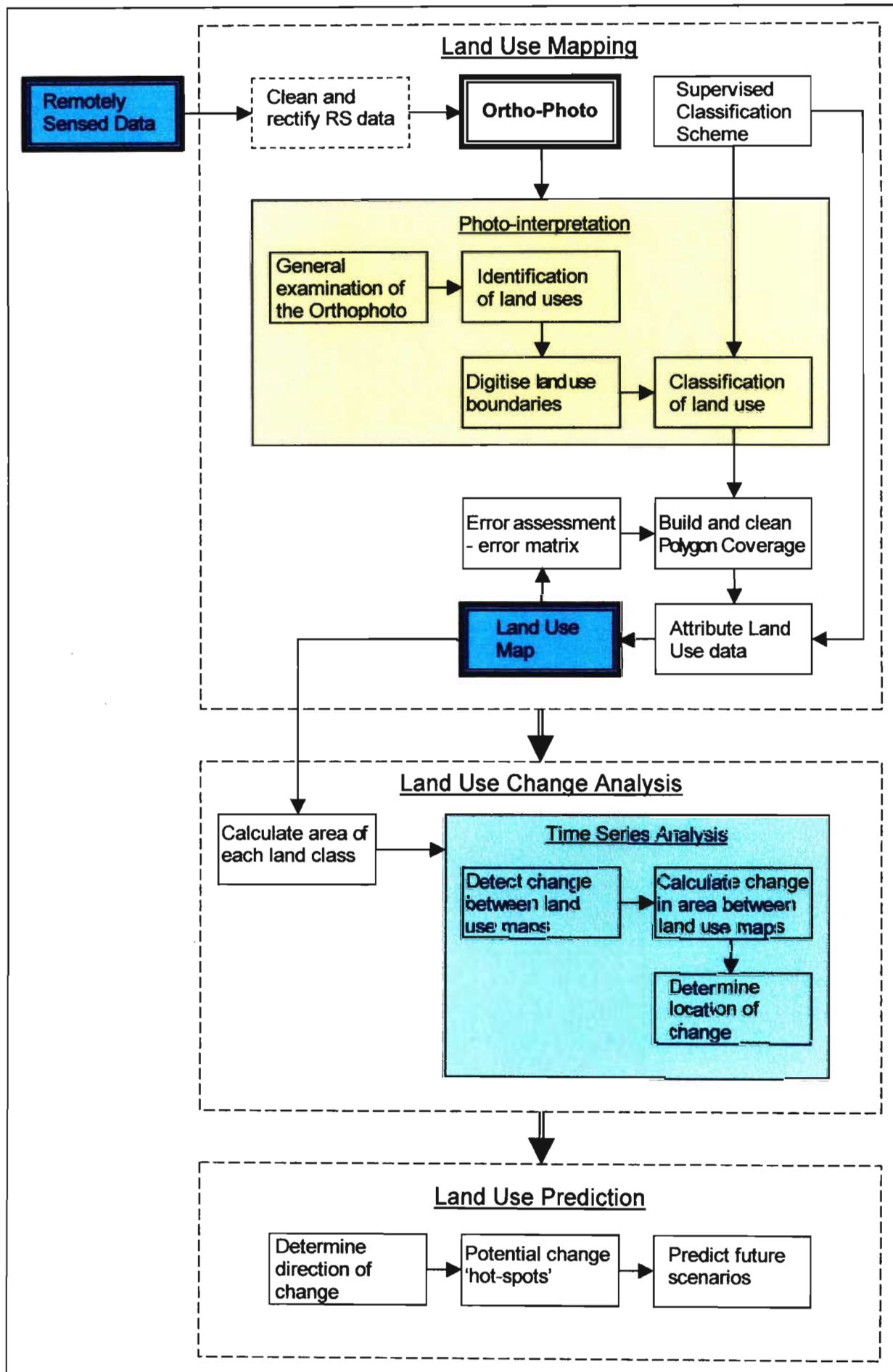


Figure 4.1 Conceptual framework of land use monitoring.

4.2. MAPPING LAND USE

In order to quantify and graphically illustrate land use in the study area it was necessary to create choropleth maps illustrating the distribution of land use at different time intervals. Thematic maps, also known as specific-purpose, single-topic or statistical maps show and contain particular features or concepts as well as their spatial attributes (Gozdyra, 2001). That is, they contain information about a single subject or topic, such as land cover or land use. Chrisman (2001), defines a choropleth map as a thematic mapping technique that displays a quantitative attribute using ordinal classes applied as uniform symbolism over a whole areal feature.

Choropleth maps are appropriate for portraying areas of equal value separated by boundaries such as land use (Burrough, 1986; Chrisman, 2001). Choropleth maps are created based on boundaries determined by the variation of the attribute being mapped, these boundaries define polygons enclosing areas that are assumed to be uniform, or to which a single description can be applied.

In this research it was necessary to map and illustrate temporal aerial divisions of different land use classes between September 1990 and June 2001 in Zulti South. To create these choropleth land use maps, the common boundaries between the land use classes had to be identified from the orthophotos and mapped. A supervised classification scheme to determine classes exhibiting common or uniform geographic characteristics first had to be determined, before common boundaries between these defined classes could be identified.

4.3. LAND USE CLASSIFICATION

As there are many different kinds of land and possible land uses, it is necessary to identify and classify land according to its characteristics and use potentials (Rhind 1993). Land use and land cover maps typically enumerate the types of land usages and vegetation covering the earth. For the purpose of this research, detailed observations of land use had to be classified into set defined groups or categories in order to characterise the land use features with some level of consistency and accuracy over time and space. Classification as defined by Di Gregorio (1996, 3), "is an abstract representation of the situation in the field using well-defined diagnostic criteria". Classification schemes are a means of organising spatial information in an orderly and logical way and are fundamental to any mapping project as they create order out of chaos and reduce the total number of classes (Congalton and Green, 1999).

To determine a set of land use classes to map land use at different time periods in the study area, a standardised classification scheme had to be defined and reviewed.

To achieve this scheme the following had to be reviewed:

- the anticipated use of the land use map;
- the relationships between features in the study area; and
- the level of detail required by the user.

4.3.1. Standardised Classification

Classification Standards provide a consistent model for classifying land uses based on their characteristics (Ducca and McDuffie, 2001). That many land use classifications exist, according to Rhind and Hudson (1980), should not come as a surprise, especially when the succinct summary is considered:

There is no one ideal classification of land use, land uses and land cover, and it is unlikely that one could ever be developed. There are

different perspectives in the classification process, and the process itself tends to be subjective, even when an objective numerical approach is used. There is, in fact no logical reason to expect that one detailed inventory should be adequate for more than a short time, since land use and land cover patterns change in keeping with demands for natural resources. Each classification is made to suit the needs of the user, and few users will be satisfied with an inventory that does not meet most of their needs (Anderson *et.al.*, 1976, 4).

In trying to define a standard *a priori*¹ classification scheme that would be appropriate in achieving the objectives of this research, the following desiderata were taken into consideration:

- the classes must be mutually exclusive;
- the classes must be totally exhaustive;
- should be hierarchical in nature;
- it has to meet the needs of the user;
- it has to be easily understood and applied;
- it has to be sufficiently stable for surveys carried out at different moments in time to be compared;
- a clear distinction must exist between the type of classifiers used;
- it should be suitable for mapping and monitoring purposes;
- it must be scientifically sound and practically oriented.

(Congalton and Green, 1999; Di Gregorio, 1996; Rhind and Hudson, 1980).

4.3.2. Proposed Land Use Classes

The classification scheme proposed in this research was prepared after an in-depth evaluation of RBM's needs, the land cover and land use within the study area, the level of detail required to meet the research objective and other existing standardised classification schemes (see appendix 1). Bearing in mind the criteria of land classification discussed above, the land use and land cover classes highlighted in table 4.1 below were selected and utilised.

¹ classes defined before actual data collection takes place

Table 4.1 Hierarchical land cover and land use classification scheme.

Primary Class	Secondary Class	Tertiary Class	Legend/ Label
Natural environment	Natural vegetation		Natural
	Wetlands		Wetlands
Agriculture	Commercial	Plantation	Plantation
	Subsistence	Cultivation	Cultivation
Developed land	Legal commercial		Formal
	Illegal	Rural residential	Homesteads
	Transportation	Roads	Roads
Disturbed Land			Disturbed

4.3.3. Description of classes

A classification scheme has two critical components:

- a set of labels, and
- a set of rules or definitions.

Without a clear set of rules, the assignment of labels to land use types can be arbitrary and lack consistency (Congalton and Green, 1999). If a rigorous set of rules and labels are not developed prior to mapping, the accuracy of the mapping is compromised, as difficulty will be found allocating geographic individuals to classes.

The following are a description of the different classes and rules selected for the research.

- **Natural** - this category incorporates all land that is covered by a minimum of 60% natural vegetation indigenous to the study area.

- **Wetlands** - this class includes all wetlands and areas covered by natural inland freshwater lakes or ponds, the open water body or the aquatic vegetation within it defines these areas.
- **Plantation** - all areas of land covered by a minimum of 60% commercial forests being either *Eucalyptus* or *Pine* are labelled as plantation.
- **Cultivation** - while this class may be used to cover a broad range of agricultural practices it is included here to account for areas of land that are under subsistence agriculture within the lease. All land that is under cultivation, has recently been harvested or planted are included within this class.
- **Formal** - this category incorporates all legal commercial land use or services within the lease area. This includes two forestry stations, the Esikhaweni sewage plant and the Port-Durnford lighthouse.
- **Homestead** - all rural residential dwellings and houses that occupy land illegally in the lease area define this class. This class includes storage sheds, outhouses and yards within its definition.
- **Roads** - the land used for the purpose of transportation, dirt roads and major footpaths were incorporated under the category of ROADS, this includes the verge directly disturbed by road use and users.
- **Disturbed** - in general this category includes all areas where significant vegetation cover has been removed in excess of 40%, land that is fallow, bare land, land that is in transition to another class, land that has been slashed and burnt or land that has an exotic vegetation cover greater than 40% (that do not fall into the plantation or cultivation class).

4.4. PHOTO-INTERPRETATION

Aerial photographs have been described as descriptive models of reality (Lo, 1976), whereby specific geographic themes can be deduced from them. The emphasis of this research is the extraction of land use information from aerial photographs taken of the study area. The technique of photo-interpretation is particularly geared towards the extraction of this qualitative data relating to our terrestrial environment (Lo, 1976). Photo-interpretation, which forms the basis of the study, is the act of examining photographic images for the purpose of identifying objects and judging their significance (Estes, 2001; Paine and Lube, 1980).

Photo-interpretation in this research, which can be viewed as a classification process, aims at assigning different land uses into their proper classes as defined by the author. In doing so a choropleth map of land use can be created, from which aggregated land use patterns can be analysed.

4.4.1. Methods of Photo-interpretation

There are three distinct stages of photo-interpretation (Lo 1976, Estes 2001), and these methods were used in identifying in interpreting land use information from the aerial photographs.

The three stage procedure as described by Lo (1976) is as follows:

- (1) **General examination.** This aims at gaining a general impression of what is shown on the aerial photographs is like. This involves selectively picking out objects or elements from the image so as to get a holistic view of the image that is being interpreted.
- (2) **Identification.** In identifying geographic features represented in aerial photos, several image characteristics may be used, these include pattern, shape, tone, texture, shadow, associated features, and size (Lo, 1976; Pain and Luba, 1980; Heyde, 1998).

- (3) **Classification.** As has been pointed out in section 4.3. classification involves assigning geographic features and objects that have been recognised and identified into their appropriate class as defined by the author.

4.4.2. Accuracy of Photo-interpretation

Photo-interpretation is essentially subjective, relying on human decision made by the interpreter. As Lo (1976, 252) states photo-interpretation "involves deductive and inductive evaluation of the various elements detected on the photograph in terms of common sense and field experience, supported by the interpreter's academic and practical background. In other words, human decision and judgment have to be exercised".

To reduce human error whilst interpreting an aerial photo Estes (2001) suggests that the interpretation should:

- be conducted logically one step at a time,
- should begin with the general and proceed to the specific, and
- should proceed from the known to the unknown.

These principles were adopted and followed whilst conducting the photo-interpretations within the research. This was done to reduce and alleviate the amount of human error and to provide a high level of consistency when interpreting the remotely sensed images.

4.5. DATA COLLECTION

RBM in trying to monitor and manage land invasion within the Zulti South lease area hired aerial surveyors¹ to fly and photograph Zulti South on a regular basis in order to produce orthophotos from which land use changes could be mapped. This commenced on the 16th of June 1990 and has continued on a regular basis until the present. Table 4.2 indicates when Zulti South has been flown and photographed by the air surveyors.

Table 4.2 Aerial photographs of Zulti South.

	Date	Scale	Type
1	16 June 1990	1/20 000	Colour
2	21 September 1990	1/30 000	B+W
3	7 July 1995	1/20 000	Colour
4	24 April 1997	1/20 000	Colour
5	20 October 1997	1/30 000	B+W
6	13 June 1998	1/20 000	B+W
7	19 October 1998	1/10 000	Colour
8	19 February 1999	1/10 000	Colour
9	19 August 1999	1/10 000	Colour
10	12 March 2000	1/10 000	Colour
11	16 October 2000	1/10 000	Colour
12	01 June 2001	1/10 000	Colour

The Air Survey Company of Africa orthorectified and mosaiced these aerial photographs to produce orthorectified digital images for each specific flight (Mine planning report, 1999). Certain of these orthophotos cannot be located, and the only data available to the author is highlighted in figure 4.3 below. The research is therefore structured around these seven flights. This data was received by the author in digital format and consists of vector data of land use activities, and orthographic raster images of the study area. Due to the digital size of the remotely sensed data, it was necessary to divide the data into six

¹ The Air Survey Company of Africa Limited

orthographic raster images, the flight that took place on the 01 June 2000, however, comprises of five orthographic raster images.

Table 4.3 Available Aerial Photographs

	<u>Date</u>	<u>Scale</u>	<u>Type</u>
1	21 September 1990	1/30 000	B+W
2	20 October 1997	1/30 000	B+W
3	19 October 1998	1/10 000	Colour
4	19 August 1999	1/10 000	Colour
5	12 March 2000	1/10 000	Colour
6	16 October 2000	1/10 000	Colour
7	01 June 2001	1/10 000	Colour

4.6. DATA CONSTRAINTS

The 19th of October 1998, 1/10 000 colour orthophoto does not cover the entire study area. It was therefore excluded from the study. Of the six available digital orthophotos received, four of these were not geo-referenced, in order to extract accurately referenced information from the remotely sensed data the orthophotos first had to be geo-referenced by the researcher.

The vector data obtained from air survey was in a format, whereby the x and y coordinates were inversed, the data was corrected by converting and transforming the vector data in ESRI's ArcInfo. It was decided not to use this data as the classification and accuracy was not consistent throughout the datasets.

As the aerial photographs were taken in both the wet and dry seasons as well as the planting and harvesting seasons, seasonal time effects on the land use and land cover are reflected in the remotely sensed data. This was taken into consideration whilst making comparisons between the datasets.

As was mentioned earlier photo-interpretation is essentially subjective, relying on human decision made by the interpreter. This involved deductive and inductive evaluation of the seasonal differences detected on the photograph in terms of common sense and field experience, supported by the interpreter's academic and practical background of the study area.

4.7. RECTIFYING THE REMOTELY SENSED DATA

Remote sensing is an efficient surveying tool for inventorying and mapping; it is capable of collecting data from spatial, temporal and spectral standpoints (Congalton and Green, 1999). Remotely sensed datum, is however, valueless if the image does not reflect real world map co-ordinates. Before land use information could be extracted from the remote sensed data, the data had to be cleaned, rectified and converted to an accurate representation of the area.

4.7.1. Projection

The Gauss Conform map projection was used throughout the research, as the acquired remotely sensed data was orthorectified using this projection. Furthermore (Roblin, 1969) considers conformal projections a suitable option as accurate distances, shape and azimuth (direction) can be produced. The following parameters were used to project the rectified orthophotos and land use maps:

Projection:	Transverce Mercator
Geodetic Datum:	Cape
Ellipsoid:	Clarke 1880
Central meridian:	33 ⁰ E

4.7.2. Geo-referencing

Geo-referencing is the process where images are rectified to fit into real world map coordinates, that is, it relates the image to a known spatial point (ER Mapper, 1998). Four of the six remotely sensed datasets obtained from the aerial surveyors were not geo-referenced, the coordinates of the corners of these orthorectified raster images were however known. To accurately determine ^here and what land use exists in the raster images, the images had to be geo-referenced.

The geo-rectification was achieved using ER Mapper 6.0 software, (see figure 4.2 for a detailed breakdown of the method and process followed to rectify the raster images). Here the raster images were converted into an ER Mapper Red Green and Blue (RGB) raster dataset. These uncorrected orthophotos were then processed through a geocoding wizard were polynomial rectification corrected the geometric distortions and associated the image to a spatial location as defined by the projection of known ground control points (GCP's) coordinates (in this case the sheet corners) from a geocoded vector map created in ArcInfo 3.2, to the corresponding locations on the uncorrected raster images. The uncorrected orthophoto is then rectified and saved as a geo-referenced orthophoto in an ER Mapper raster Dataset file.

Raster images by definition have to be a regular grid, ER Mapper calculates the extent of the rectified images and fills the gaps in the data to create the rectangular image (Cuthbert pers. Com, 2001). These appeared as 'black edges' attached to the orthophoto's to create rectangular grids. In order to remove these 'black edges' an inregion clipping process is recommended (Cuthbert 2001 pers. Com).

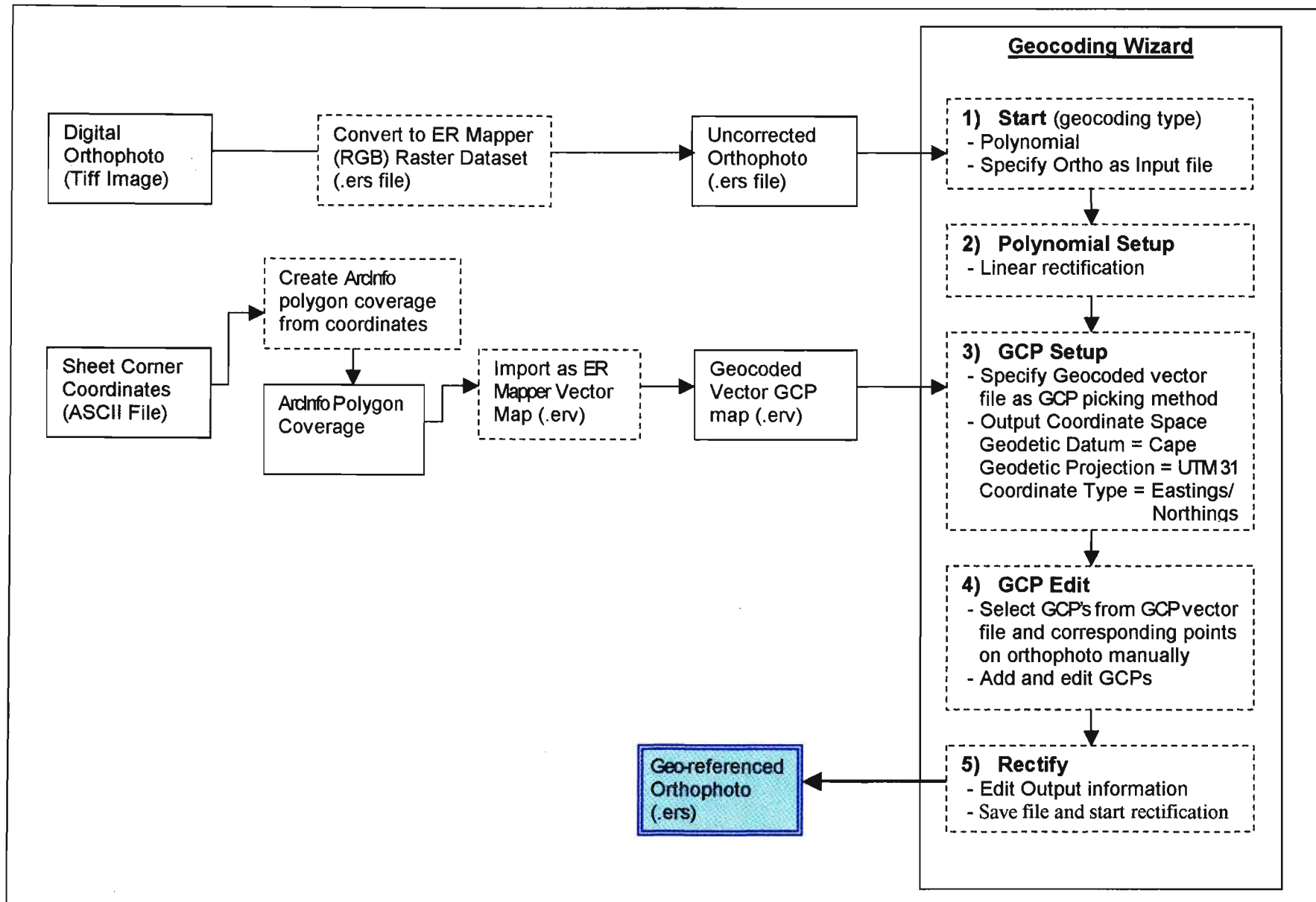


Figure 4.2 Flowchart of procedures followed in geo-referencing the digital raster images

4.7.3. Inregion clipping

The author obtained advice from Dominic Cuthbert sales director of ER Mapper (see Appendix 2), and the steps followed by the author are highlighted in figure 4.3. A raster region that masks the geo-referenced orthophoto raster dataset is created by the author and saved as REGION_0. The algorithm for the raster dataset is then edited, a standard inside region polygon test is performed for all three bands (i.e. RGB). The syntax of this algorithm states: `IF(INREGION(r1)) THEN INPUT 1 ELSE NULL`, this ensures that everything outside the region that masks the orthophoto is assigned a null value, whilst the raster values inside the mask remains the same. It is then possible to set the colour of the null value as white, the region masking the orthophoto is then removed and the cleaned geo-referenced orthophoto is saved as an ER Mapper algorithm.

The resulting digital images are geo-referenced orthophoto's that have a white background depicting areas of null value whilst retaining the corrected vertical aerial images of the study area. These digital images depict the exact world coordinates of the study area, thereby allowing a user to view the corrected vertical aerial images in the Gauss Conform map projection. While an extension does exist that allows ER Mapper algorithms to be opened and viewed in ESRI's ArcView software, the geo-referenced images were exported from ER Mapper as TIFF images, as most software packages recognise this format.

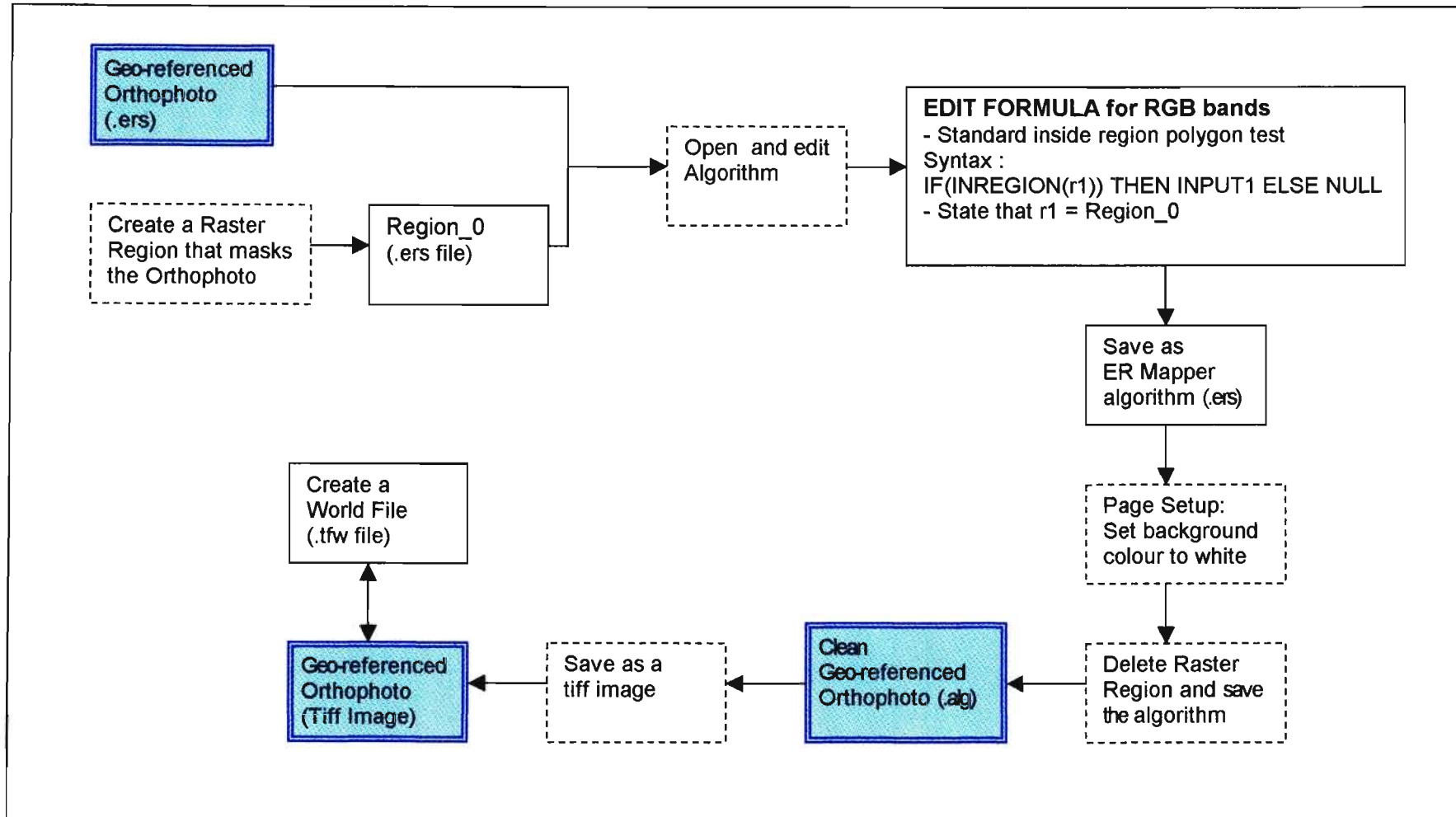
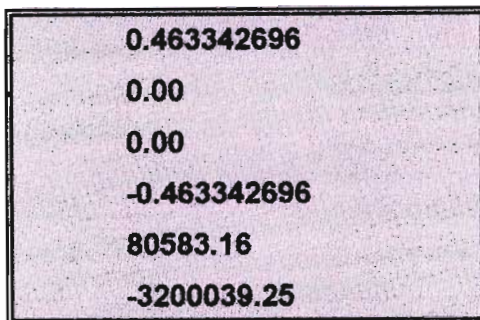


Figure 4.3 Flowchart of Inregion clipping procedure

4.7.4. World file

Images are stored as raster data, where each cell in the image has a row and column number. In order to display the images in real-world coordinates, it is necessary to establish an image-to-world transformation that converts the image coordinates (row and column number) to real-world coordinates. This information is typically stored in a separate ASCII file that accompanies the image file, and is generally referred to as a world file.

It was therefore necessary to create world files to accompany the digital geo-referenced orthophotos. The transformation contents and parameters stored in the world file are in a specific order (see figure 4.4).

A rectangular box containing six lines of text, representing the contents of a typical World file. The text is as follows:

```
0.463342696
0.00
0.00
-0.463342696
80583.16
-3200039.25
```

Figure 4.4 A typical World file

The first row depicts the x-scale of the image, and is in the dimension of a pixel in map units in x direction. The second and third row depicts the degree of rotation in the image, ArcView does not rotate images, and as the image has been geo-rectified these values are kept as zero. The fourth row indicates the y-scale of the image, and is in the dimension of a pixel in map units in the y direction. As the origin of an image is located in the upper left corner the value of the row decrease from the origin downward and is thus a negative value, whilst the value of the column increases from the origin outward to the left and is positive. The final two rows in figure 4.7.4. are the respective X and Y map coordinates of the centre of the upper left pixel.

4.7.5. Mosaicing

The corrected digital images produced thus far can only be viewed in isolation, in order to display all the images simultaneously these images first have to be mosaiced together. Mosaicing is the procedure of splicing two or more adjacent images together to form a single image (ER Mapper, 1998). ER Mapper software efficiently creates image mosaics with minimal user intervention through the use of a Mosaicing Wizard.

To mosaic the rectified orthophotos, the name and location of the first image has to be inputted into the Mosaicing Wizard (see figure 4.5), the file types and additional images to be mosaiced to this image are then selected. The feather blend option is selected to join the images seamlessly with the transformation clip limits set to 99%. The Mosaicing Wizard within ER Mapper will then combine these images to produce a single image of the entire study area.

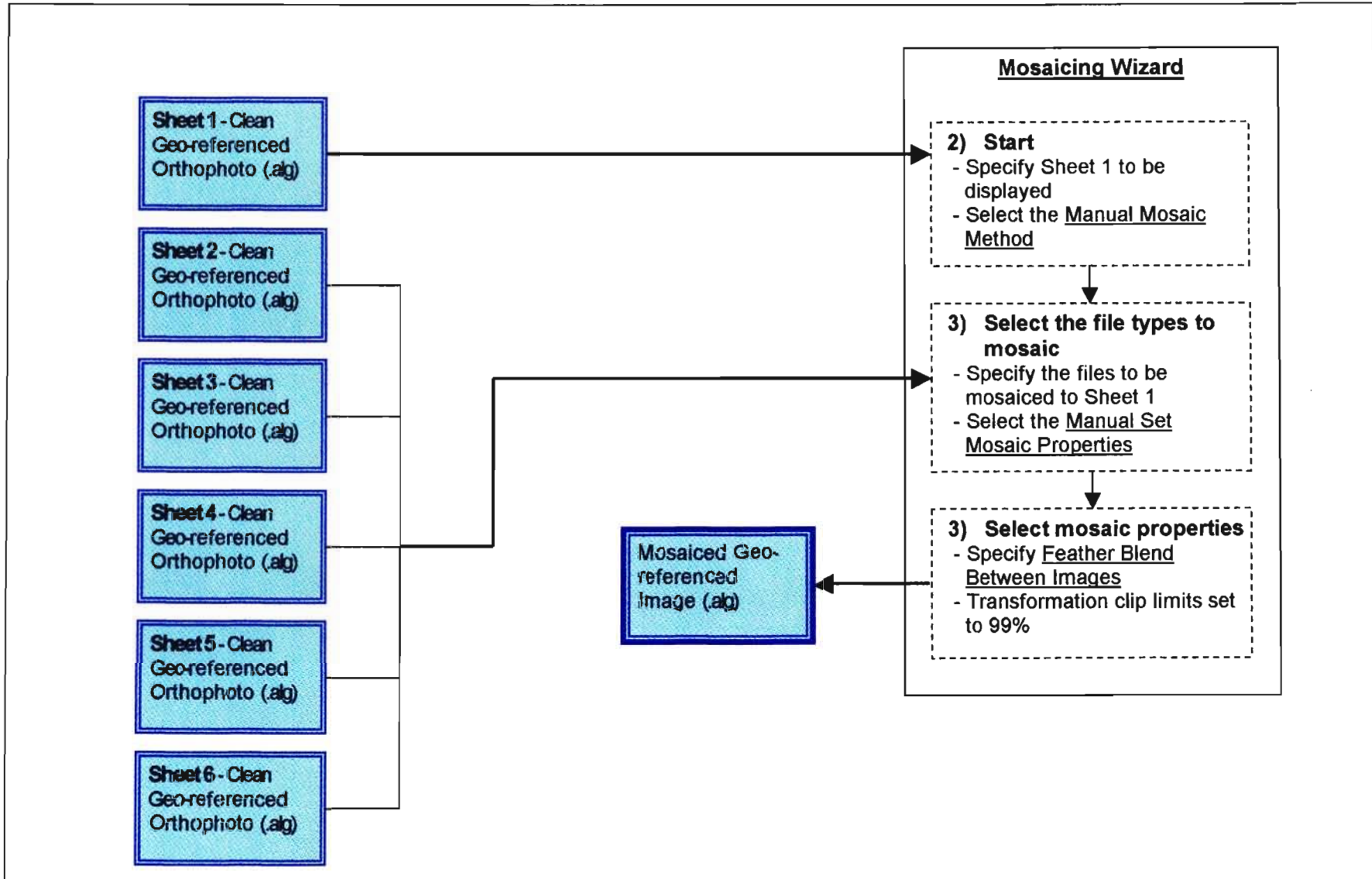


Figure 4.5 Flowchart of the procedure followed in mosaicing the images

4.8. CREATING LAND USE MAPS

To create choropleth maps and graphically illustrate temporal aerial divisions of different land use classes between September 1990 and June 2001 in Zulti South, common boundaries between the classes from the corrected orthophotos had to be identified through photo-interpretation techniques, mapped and classified through a supervised classification technique.

4.8.1. Digitising

Digitising is the process of converting hardcopy geographic information into digital vectors images¹. Traditionally digitising is done on a digitising tablet, a large board with an attached mouse (or 'puck'); the digitising table has a fine grid of wires embedded in it that acts as a Cartesian coordinate system, this underlying circuitry converted points where you clicked the puck into x and y coordinates. (Haddock, 2001). However, high-resolution digital imagery can be linked into GIS software packages allowing the capture, edits and delineation of features directly on the computer screen. This method of digitising is often referred to as 'on-screen' or 'heads-up' digitising.

The basis of heads-up digitising is to use the mouse pointer to trace around the image to be digitised directly on the computer screen using the scanned raster image as backdrop, recording the coordinates as it moves - in much the same manner as moving the puck on a digitising table or tablet (Gillings *et.al.*, 1998; Wu 1999). This method of 'heads-up' digitising is preferable as it obviates the need for a digitising tablet, and in most instances allows for greater precision because the digital image can be magnified for more exact digitising that is hardly possible on the digitising tablet. In addition to the ability to zoom in on an area of complexity, (Gillings *et. al.*, 1998) suggest that it is much easier to undertake the digitising in smaller time-periods, and therefore minimise error resulting from fatigue. This is because the digitised data can be

¹ A vector image is composed of lines and curves that are mathematically calculated between points

displayed and visualised directly on the screen allowing a user to see where they have or have not digitised.

The corrected digital orthophoto's of the study area were opened and displayed in Arcview, here it was possible to zoom in to identify locations of the boundaries between land use types through photo-interpretation. These boundaries were digitised directly on the screen in ArcView at an area threshold determined by the resolution of the aerial imagery, here the boundaries were then traced with the mouse pointer and saved as vector line shapefiles.

4.8.2. Editing and creating polygons

Once all the relevant data in the orthophotos were digitised, it was necessary to edit the shape files to eliminate errors such as undershoots and overshoots to create polygons. This process involves manually moving nodes at the beginning or end of arcs, which either overshoot or fell short of other lines, to join and close arcs to form polygons that identify areas of specific land use.

Once these shape files had the original parallax removed by manually snapping dangling nodes to their appropriate positions within ArcView, the polygon topology can be built by using the clean and build operations in ESRI's ArcInfo. Here the shape file is converted into a coverage and the clean operation is run, the automatic snap tolerance is set at zero as the errors were removed from the original shapefile. The final polygon coverage is then converted back to a shapefile containing polygons depicting the topology of land use in the study area.

4.8.3. Adding attributes

As the polygons do not contain attribute information pertaining land use information, the corresponding attribute table has to be manually edited to include the land use associated with each individual polygon. This is done via a supervised classification procedure using the land use classes previously defined in the research (see section 3.3.2.).

The resulting datasets represent geo-referenced choropleth land use maps of Zulti South. Each dataset represents the spatial land use patterns present at the time the aerial photographs were taken for each of the orthophotos between September 1990 and June 2001.

4.8.4. Ground Truthing

Assessing the accuracy of the final choropleth land use maps is essential in identifying and correcting sources of error. Congalton and Green (1999) suggest that "if the information derived from the remotely sensed data is to be used in some decision-making process, then it is critical that some measure of its quality be known" (p.4). Possible error could occur from the data capturing stage where incorrect boundaries were digitised, or the classification stage where mapped regions are incorrectly classified or represented on the land use maps. Accuracy of the land use maps were therefore assessed through an error matrix.

An error matrix is a square array of numbers set out in rows and columns that express the number of sample units assigned to a particular category in one classification relative to the number of sample units assigned to a particular category in another classification. In this research 50 random points of ground observations of land use were computed against what was mapped from the orthophotos on the first of June 2001. An error matrix is an effective way to represent map accuracy in that the individual accuracies of each category are plainly described along with both the error of inclusion and errors of exclusion (Congalton and Green, 1999).

In their study Fung and LeDrew (1988), found that the Kappa index of agreement produced the best means of assessing accuracy with which a given threshold could distinguish between the ground sites and the choropleth map. Kappa is simply a measurement of the proportion of the test sites that have correctly been classified.

Observations were impossible and insufficient to develop an error matrix for the other datasets due to land use conditions changing rapidly since the time the aerial photographs were taken, the visual comparison however did appear to generally confirm the land use maps validity.

4.9. DETECTING AND ANALYSING CHANGE

The substantive reasons for carrying out this GIS project was to illustrate the ability of GIS in facilitating spatial analysis and prediction of land use and land use change. This goal includes the quantitative characterization of land use at specific points in time in Zulti South, understanding the spatial patterns presented here, detecting and analysing change over the time series, and predicting this spatial phenomenon. The results of this GIS project would facilitate and form the basis for making decisions by the relevant authorities in RBM.

With the process of mapping the land use for each time period completed, this data could be manipulated and analysed to achieve the above goals.

4.9.1. Quantifying land use

In order to quantify the land use for each time period, the total area of each land use class was calculated. To achieve this the attribute table of each land use theme had to be edited and a new numeric field 'area' was added, through the field calculator an expression can be created to calculate area for each polygon in the theme. This function calculates the area based on the

distance units specified by the user. As this is meters the resulting answer would be in square meters. To convert the area to hectares the field calculator was again used to divide each answer by 10 000 to convert the units to hectares. By running the summary function and specifying total area for the land use, the total area of each land use class was determined (results in chapter5).

4.9.2. Time series analysis

To compare how land use has changed over the defined time period, a pair-wise image differencing technique was used over the time series. Here each image or dataset theme was to be compared to the base year image (1990). For the purpose for the research the base year was assumed to have no land use change. Each dataset was compared with the previous image to determine and quantify how land use has changed from one theme to the next. Through this technique it was possible to establish the locality and quantity of land use change, furthermore this change indicates the previous and present use of any parcel of land in the study area.

In order to achieve this each land use theme was converted to a grid with the ArcView 3.1. Spatial Analyst extension. Each land use class was then assigned a specific numeric value for each dataset. By using the map calculator the difference between the base year and other datasets could be calculated. With this, each cell in the output image is computed as the subtraction of the corresponding cell from the input dataset from base year. The result from the differencing operation is a continuum of difference values that represents a unique change from one class to the next. These numeric values were then assigned labels describing the direction of change or of no change.

These grids indicating 'change' were converted back into shapefiles were the total area of change was calculated using the field calculator and summary function in Arcview (see chapter 5 for results).

4.10. PREDICTING

To facilitate RBM in proactively managing their mineral lease area, future land use dynamics were predicted. Bonham-Carter (1996, 6) suggests that “the purpose of a GIS study is often for prediction... the modelling tools of GIS provide the means to apply spatial data in problem solving, and take spatial data beyond simply the retrieval and display of information”.

As the underlying factors that cause land use change are not fully understood or unpredictable in the short-run, the spatial patterns observed in the research were combined with statistical analysis to determine the trends in land use over time. In order to predict future land scenarios in Zulti South, land use change was assumed to be dependant on time. “Prediction is sometimes a research exercise to explore the outcome of making a particular set of assumptions” (Bonham-Carter 1996, 6).

In order to predict future land scenarios in Zulti South, the recorded land uses for each dataset for each land use type were modelled. The land use data recorded through GIS were combined with statistical analysis to determine the regression lines between land use and time. From these regression lines future land use could be quantified. This was done using the statistical software package SPSS 9.0 for Windows. Here land use data were entered into tables, and a logarithmic regression equation processed to determine the curve estimation between the land use type and time in the series. The significance of this line displays the relationship and closeness to the relationship between land use change and time can be measured allowing a confidence estimate to be placed on the predicted land use value.

4.11. SUMMARY

The steps taken to create the land use classification system for the remotely sensed data has been described. The techniques used for photo-interpretation are outlined and the methods used to reduce human error are described. The methods, tools and steps taken to create the land use datasets have been described and discussed. The procedure to assess the error of the final dataset was explained. The methods used to derive the amount of land use change through the time series is presented and described. Finally the techniques used to predict the future land use and land use changes in the study area are elucidated.

CHAPTER 5

RESULTS

The purpose of this chapter is to describe the results obtained from mapping land use, analysing land use change and predicting possible future changes in Zulti South. The spatial and temporal location of the land use between the 21st of September 1990 and the 1st of June 2001 are identified and the area occupied by each class described. The chapter then identifies the changes that have occurred between each dataset, as well as the change in land use from the base year. The relationship of change over the time series is described and predictions of possible future change are made.

5.1. LAND USE

The land use datasets produced from the remotely sensed data, show the spatial location and distribution of land use activities at specific time periods from the 21st of September 1990 and the 1st of June 2001. The final land use datasets are comprised of eight classes from a broad supervised classification. These are *Cultivation, Disturbed, Formal, Homestead, Natural, Plantation, Roads, and Wetlands*. Supervised classification was used to distinguish between these classes to produce choropleth land use datasets, from which the area occupied by each class could be attained. The final land use choropleth datasets are shown in figures 5.1 to 5.6. Here each land use class has been assigned a separate colour as displayed in the legend. The total area occupied by each land use class, for each dataset, is given in hectares in table 5.1. Also included in table 5.1 is the total area each land use class occupies as a percentage of the entire study area.

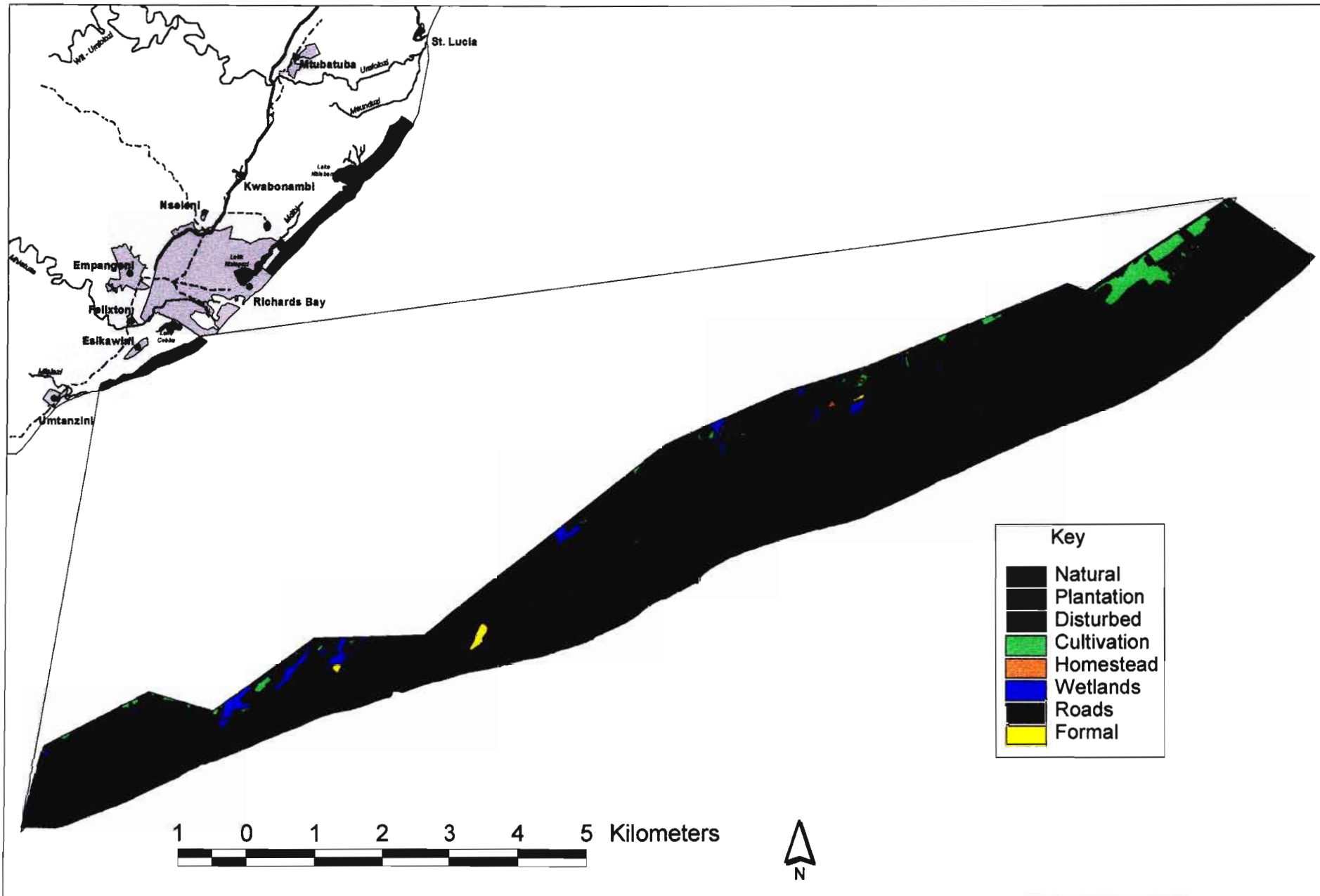


Figure 5.1: Land Use in Zulti South on the 21st of September 1990

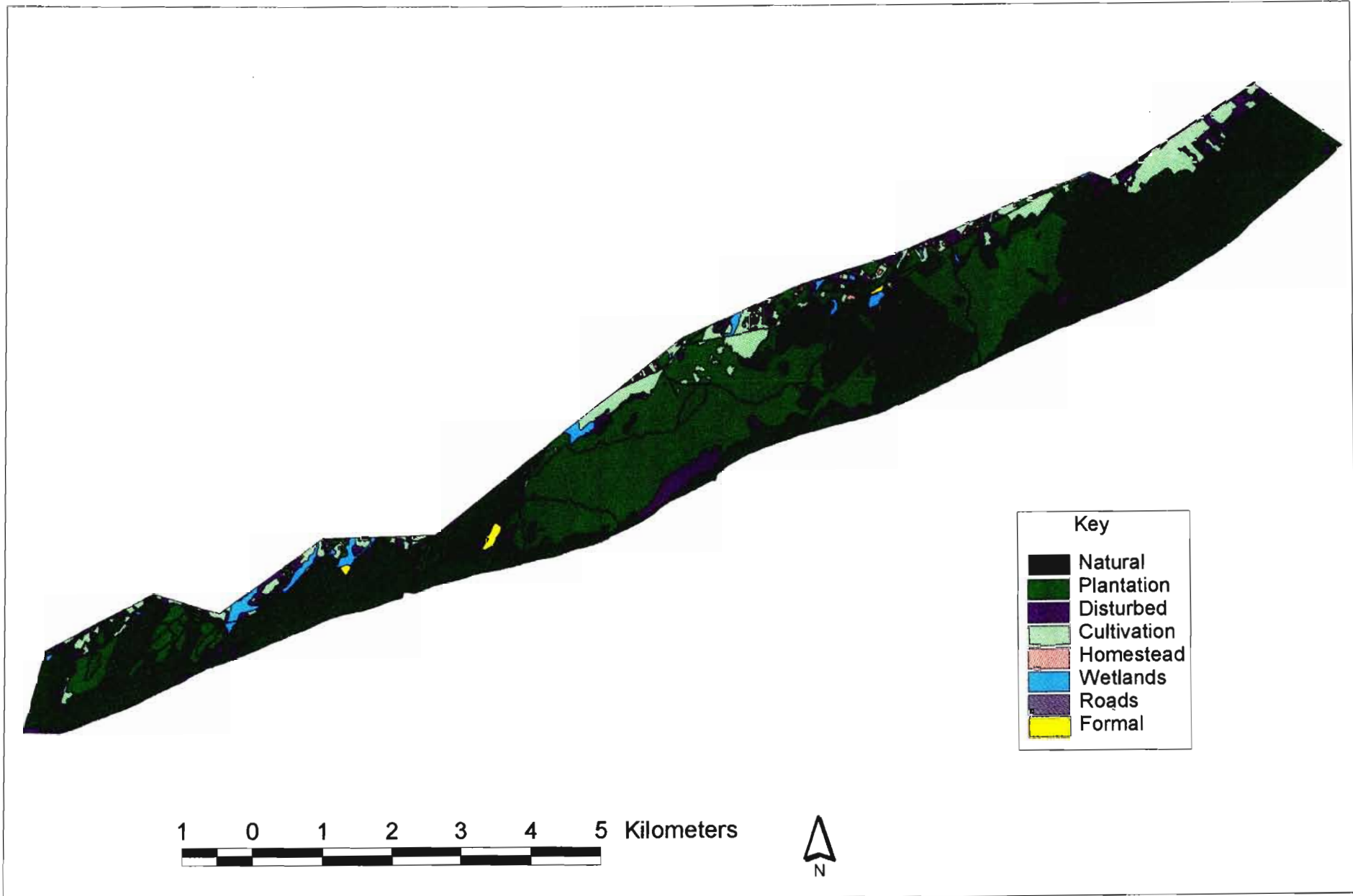


Figure 5.2: Land Use in Zulti South on the 20th of October 1997

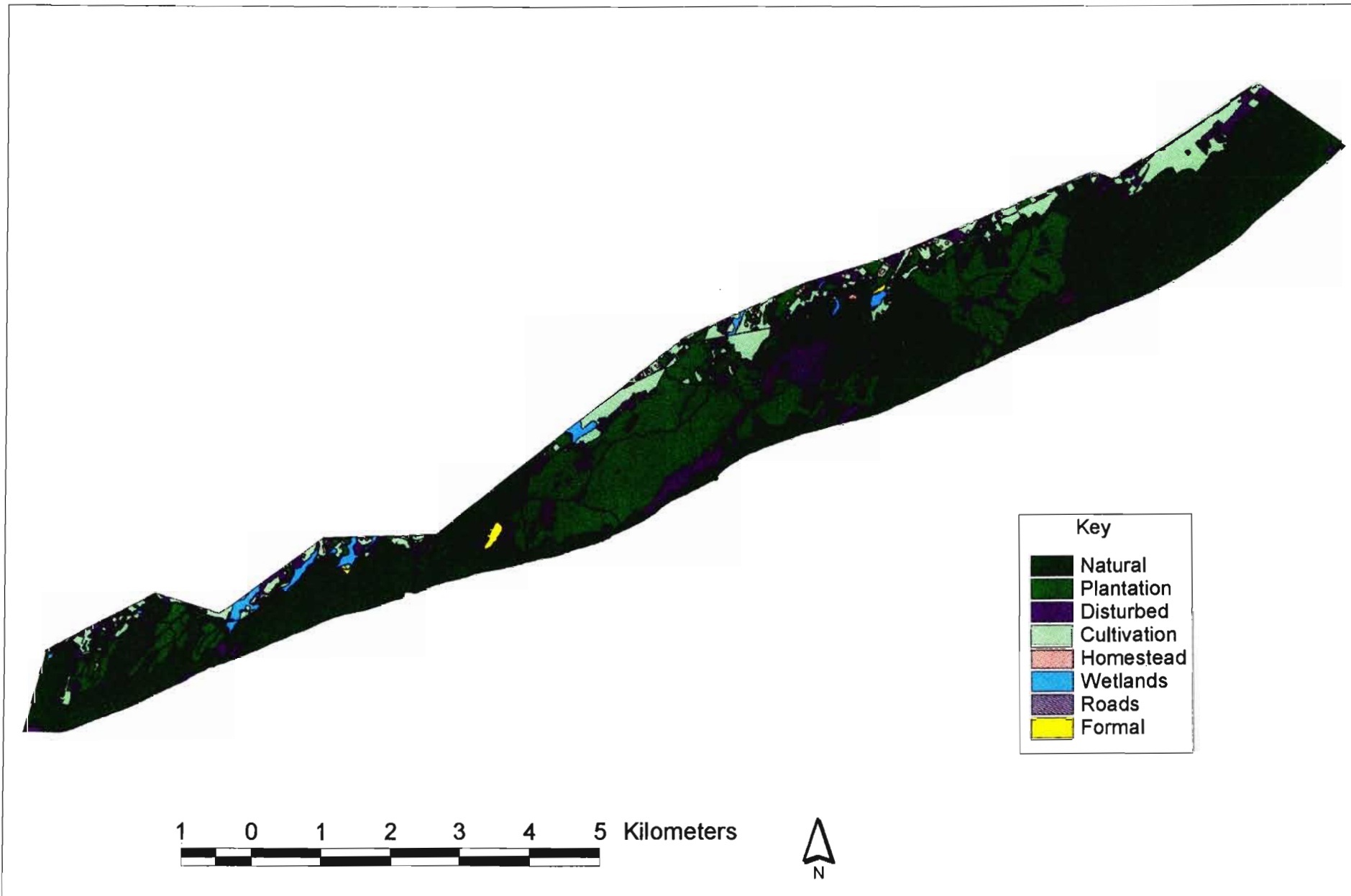


Figure 5.3: Land Use in Zulti South on the 19th of August 1999

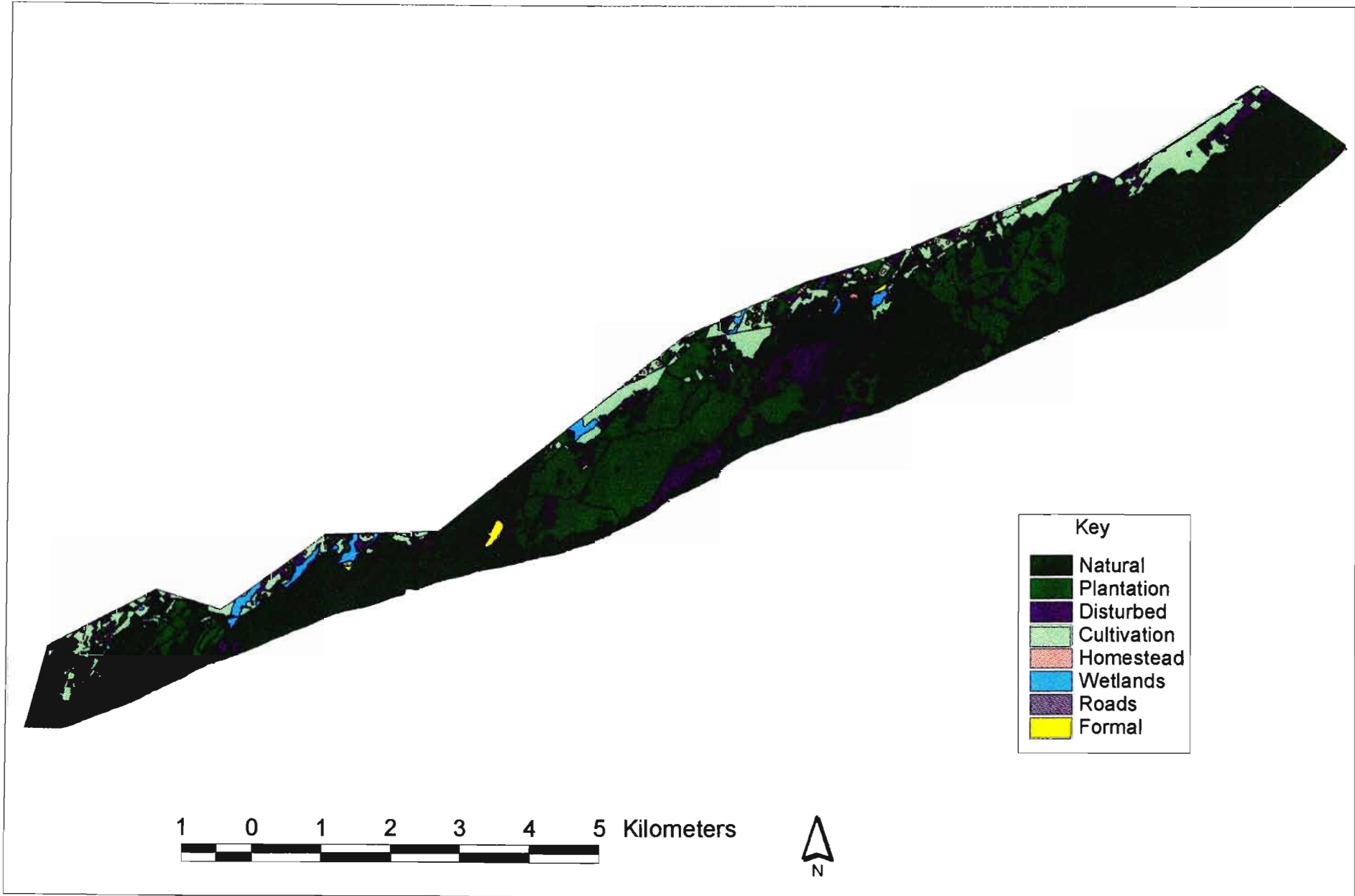


Figure 5.4: Land Use in Zulti South on the 12th of March 2000

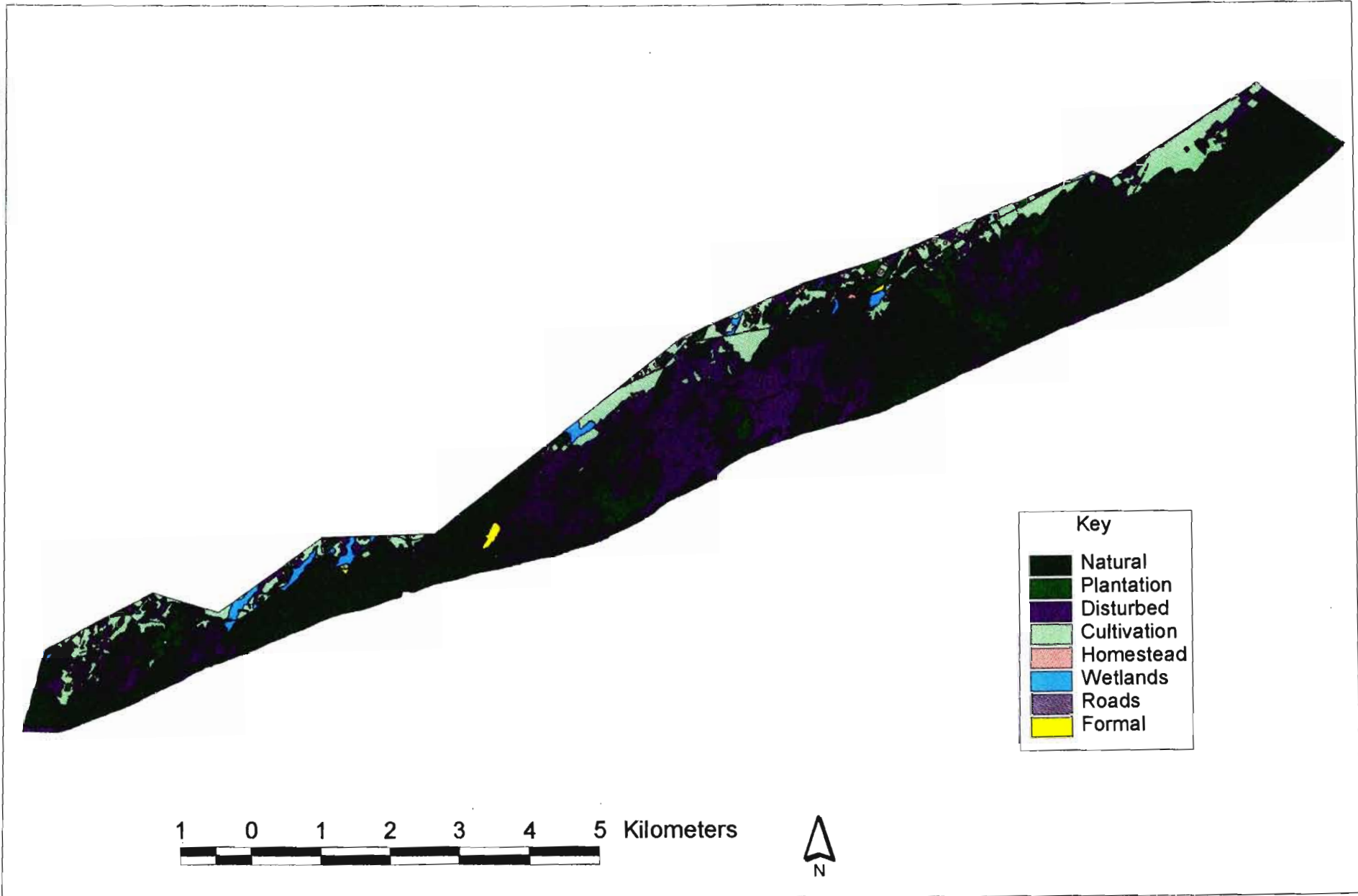


Figure 5.5: Land Use in Zulti South on the 16th of October 2000

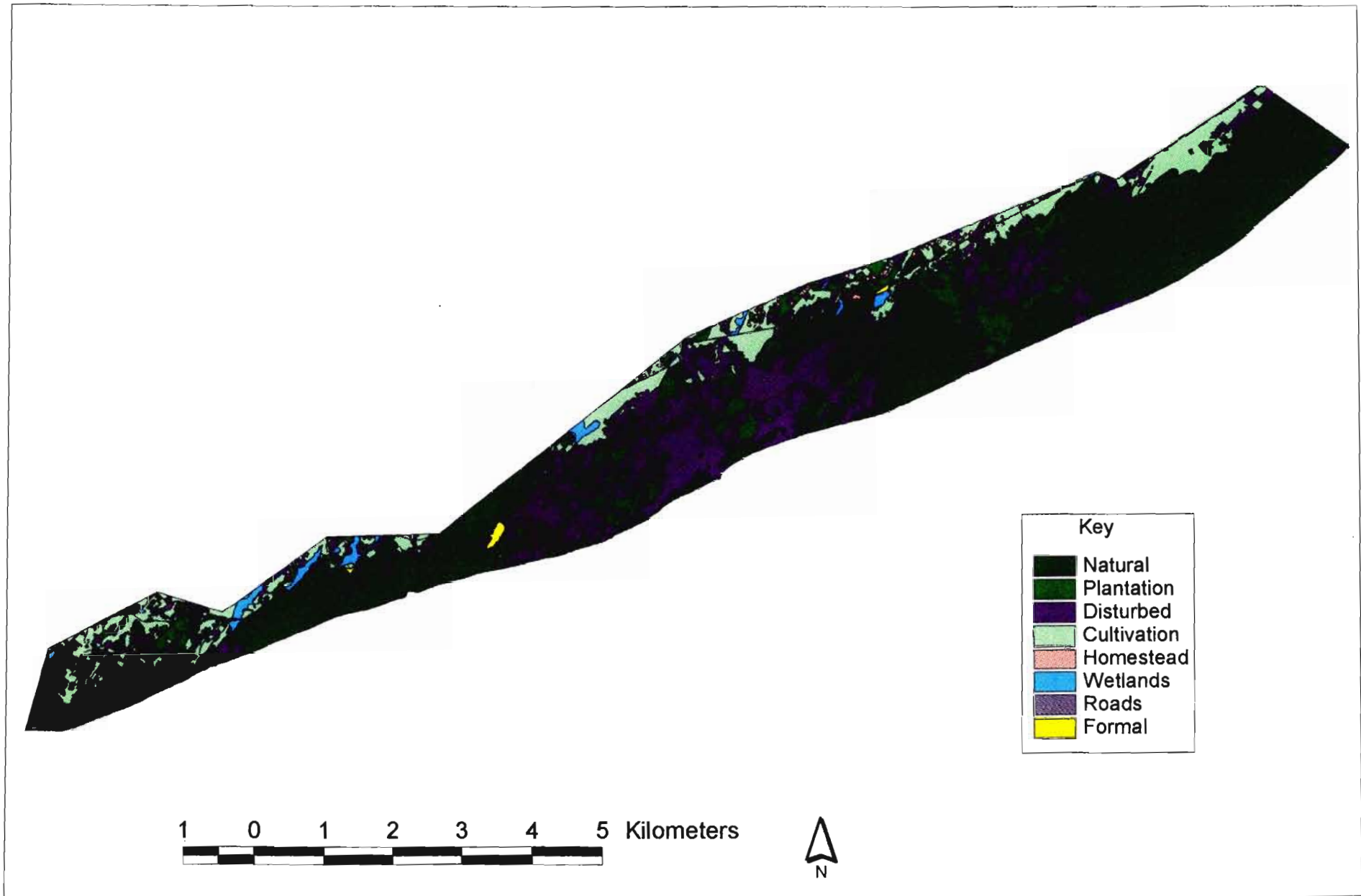


Figure 5.6: Land Use in Zulti South on the 1st of June 2001

Table 5.1: Area of each land use class from the respected dataset.

		Date											
		21-Sep-1990		20-Oct-1997		19-Aug-1999		12-Mar-2000		16-Oct-2000		06-Jun-2001	
		Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Land use type	Cultivation	74.8774	2.44	187.6585	6.1	231.8255	7.54	265.6361	8.64	289.2465	9.41	326.8655	10.63
	Disturbed	182.5752	5.93	198.4738	6.45	306.4748	9.97	340.8741	11.09	856.311	27.86	832.8999	27.1
	Formal	7.5979	0.25	7.5826	0.25	6.6817	0.22	6.681	0.22	6.6819	0.22	6.6811	0.22
	Homestead	6.4004	0.21	9.4801	0.31	10.5313	0.34	10.3678	0.34	10.6671	0.35	10.8213	0.35
	Natural	1692.8797	55.07	1605.7519	52.24	1593.991	51.86	1571.216	51.12	1475.4922	48	1428.8434	46.48
	Plantation	1033.3069	33.62	994.9987	32.37	866.4076	28.19	822.2042	26.75	378.6906	12.32	410.1757	13.34
	Roads	30.007	0.98	26.3154	0.86	19.4506	0.63	19.365	0.63	19.4642	0.63	20.5637	0.67
	Wetlands	46.2215	1.50	43.5441	1.42	38.5265	1.25	37.516	1.22	37.3127	1.21	37.0447	1.21

Dataset 1 Figure 5.1 (21st of September 1990)

Indicates that the majority of the lease area being covered by *natural* vegetation and commercial plantations. These land use types account for 55.1% and 33.6% of the total lease respectively (see table 5.1). These two land use classes are predominately found within the dune cordon of the lease area. Other significant land use contributions in Dataset 1 are: *disturbed* land accounting for 5.9% and *cultivation* 2.4% of the lease area. The majority of the *cultivated* and *disturbed* land and *homesteads* are found in the flatland regions along the north western boundary of Zulti South.

Dataset 2 Figure 5.2 (20th of October 1997)

The results show that the *natural* vegetation area in Dataset 1 has decreased to 52.2% of the lease area and commercial *plantations* 32.4% (table 5.1). The *cultivation* and *disturbed* land use classes have both increased and account for 6.1% and 6.5% of the study area respectively. It is evident from figure 5.2 that numerous small patches of disturbed and cultivated land have appeared alongside *roads* and along the border between *plantations* and *natural* vegetation since the previous dataset.

Dataset 2 Figure 5.3 (19th of August 1999)

The results obtained from Dataset 3 show that *cultivation* has increased in size and now accounts for 7.5% of the Zulti South lease area (table 5.1). Similarly *disturbed* land has increased from 6.4% in Dataset 2 to 9.9% in Dataset 3. The *natural* land use class accounts for 51.9% of Zulti South while the plantation land use class has decreased to 28.2% in Dataset 3. It is evident from figure 5.3 that the *disturbed* land use class has increased. Here an increased number of *disturbed* 'patches' of land use are evident within the dune cordon, with the majority of this disturbance taking place in the commercial *plantations*.

Dataset 4 Figure 5.4 (12th of March 2000)

Dataset 4 is characterised by a slight decrease in the *natural* land use class to 51.1% of Zulti South. *Plantations* account for 26.8% of the lease area, whilst *cultivation* and *disturbed* land contribute 8.6% and 11.1% respectively. From figure 5.4 it is possible to ascertain that the *cultivation* and *disturbed* patches have increased, whilst the *natural* and *plantation* stands have diminished. The majority of the *cultivated* lands, and all the *homesteads* are located within the flatland regions of Zulti South.

Dataset 5 Figure 5.5 (16th of October 2000)

In Dataset 5 land used for commercial *plantations* has diminished rapidly from an area of 822.2 hectares (26.8%) in Dataset 4 to 378.7 hectares (12.3%) in Dataset 5. Land covered by natural *vegetation* now accounts for less than half of the study area (48%). *Cultivation* increased to 9.4% of the study area, and *disturbed* land increased to for 27.9% of the study area (table 5.1). It is evident from figure 5.5 that dramatic land use change has occurred from the previous dataset. Here significant amounts of land previously covered by plantations are now represented in Dataset 5 by *disturbed* land. It is also evident that parcels of disturbed land within the *natural* land use class have grown thus displacing previously undisturbed *natural* vegetation.

Dataset 6 Figure 5.6 (1st of June 2001)

The results obtained in Dataset 6 show that *plantations* have increased in size from Dataset 5 and now account for 13.3% of the total lease area. *Disturbed* land decreased for the first time in the time-series, now accounting for 27.1% of the lease area, which is slightly lower than the previous area of 27.9%. *Natural* land decreases to 46.9%, whilst *cultivation* increases to 10.6%. From figure 5.6 it is possible to see that patches of previously disturbed *plantations* have reverted back to *plantations*, while other previously undisturbed *plantations* have become *disturbed*. Although the area occupied by *homesteads* has gradually increased from 0.2% (6.4 ha) in dataset 1 to 0.2% (6.8ha) in dataset 6, *homesteads* have remained within the flatlands of the lease area.

5.1.1. Accuracy Assessment

The error matrix of remotely sensed classes versus the field-derived classes is shown in Table 5.2. Here the fifty random ground truthed points are tabulated against the '01 June 2001' dataset to assess the accuracy of the dataset. The columns correspond to the 'true' ground truthed sites obtained from field observations. The rows represent the land use dataset mapped from the '01 June 2001' geo-rectified orthophotos. The diagonal represents the points that were correctly classified. The omission and commission errors, as well as the Kappa Index of agreement, are tabulated.

5.1.2. Community land use

The land use datasets produced from the remotely sensed data show the spatial location, distribution and surface area of the eight land use classes in both the Dube and Mkhwanazi tribal regions within Zulti South (Figure 5.1 to Figure 5.6). The results listed in Table 5.3 show the area (in hectares) that each land use class occupies within the respective tribal regions. The total area that each tribal land use class occupies is shown as a percentage of the total lease area (table 5.3).

The variation in the area of each land use class (table 5.3) provides an indication as to the amount of land use change in the tribal regions across the time series in Zulti South. The tribal variations of each land use class follow similar patterns to that of the entire lease area for Dataset 1 to 6 (table 5.1). The results of the significant changes are described below.

Dataset 1

Although the Mkhwanazi tribal region accounts for 40.3% of the lease and the Dube tribal region for 59.7% of Zulti South, the majority of the *disturbed* land is found within Mkhwanazi (93.5 ha, 3%). *Disturbed* land within the Dube tribal region extends across 89 ha which equals 2.9% of the total study area. The *natural* and *plantation* classes account for the largest share of land in both the tribal regions with 35% and 20.1% of *natural* land and 18.7% and 14.9% of

plantations occurring in Dube and Mkhwanazi respectively. The bulk of the *wetlands* (33.1 ha) are found in Mkhwanazi, with 13.12 ha found in Dube.

Dataset 2

The results of Dataset 2 indicate that the greater portion of *cultivation* change occurred in Dube. Table 5.3 indicates that cultivation has increased in Dube from 61.9 ha in Dataset 1 to 129.9 ha in Dube, and in Mkhwanazi from 12.9 ha to 57.7 ha in Dataset 2. The majority of *disturbed* land in Dataset 2 occurs in Dube (101.9 ha), with 96.5 ha occurring in Mkhwanazi. Beforehand the bulk of *disturbed* land was located in Mkhwanazi.

Dataset 3

The results obtained from Dataset 3 show that *cultivation* has increased to 74.4 ha and 157.4 ha in Mkhwanazi and Dube respectively. *Disturbed* land has an area of 119.7 ha in Mkhwanazi and 186.8 ha in Dube. Thus the total amount of *disturbed* land is greater in Dube than in Mkhwanazi. Similarly the total area of *homesteads* in Dube (7.7 ha) is greater than that in Mkhwanazi (2.87 ha) in Dataset 3.

Dataset 4

Dataset 4 (12th of March 2000) is characterised with the majority of the change occurring within Mkhwanazi tribal area. *Cultivated* and *disturbed* land increased from 74.4 ha and 119.7 ha (in Dataset 3) to 97.7 ha and 138.8 ha (in Dataset 4) respectively. *Cultivation* and *disturbed* land in Dube increase to 168 ha and 202.1 ha respectively.

Dataset 5

The *disturbed* land use class increased dramatically to 409.8 ha in Mkhwanazi and 446.5 ha within Dube. Table 5.3 indicates that the bulk of this change occurs in Mkhwanazi. The *natural* and *plantation* classes decrease to 505.7 ha and 165.7 ha respectively in Mkhwanazi and 969.8 ha and 213 ha respectively within the Dube tribal region (table 5.3).

Dataset 6

The results show that the *cultivation* land use class has increased in both the tribal areas. The greater part of this change took place in Mkhwanazi, with an increase from 111 ha in Dataset 5 to 186.1 ha in Dataset 6. *Disturbed* land use increased in Mkhwanazi to 413.15 ha, but decreased to 419.8 ha in the Dube tribal area. *Plantations* decreased in Mkhwanazi from 165.7 ha in Dataset 5 to 163.4 ha in Dataset 6. *Plantations* however increased in area in the Dube tribal area from 213 ha (in dataset 5) to 246.8 ha in Dataset 6 (table 5.3).

Table 5.2 Error matrix of map land use categories versus ground truthed data

		Ground Truth								Row total	Commission Error	Kappa
		Cultivated	Disturbed	Formal	Homestead	Natural	Plantation	Roads	Wetlands			
Land Use Map	Cultivated	8								8	0	1
	Disturbed	2	12				1			15	0.2	0.7368
	Formal			1						1	0	1
	Homestead				4					4	0	1
	Natural					11	1			12	0.083	0.8903
	Plantation					1	6			7	0.143	0.8299
	Roads							1		1	0	1
	Wetlands								2	2	0	1
	Column total	10	12	1	4	12	8	1	2	50		
	Omission Error	0.2	0	0	0	0.083	0.25	0	0			
Kappa	0.7619	1	1	1	0.8903	0.7093	1	1			0.8761	

Table 5.3: Area and percentage of each Land Use class in the tribal areas over the time series

	21-Sep-1990				20-Oct-1997				19-Aug-1999			
	MKwanazi		Dube		MKwanazi		Dube		MKwanazi		Dube	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Cultivation	12.9230	0.4204	61.9549	2.0155	57.7379	1.8784	129.9216	4.2267	74.3823	2.4198	157.4431	5.1220
Disturbed	93.5426	3.0432	89.0345	2.8965	96.5643	3.1415	101.9125	3.3155	119.6877	3.8937	186.7757	6.0763
Formal	6.5765	0.2139	1.0212	0.0332	6.5437	0.2129	1.0689	0.0348	5.6062	0.1824	1.0756	0.0350
Homestead	1.6328	0.0531	4.7595	0.1548	2.3686	0.0771	7.1114	0.2314	2.7974	0.0910	7.7329	0.2516
Natural	618.5800	20.1239	1074.2995	34.9495	591.7474	19.2510	1014.0146	32.9883	586.0462	19.0655	1007.9445	32.7908
Plantation	458.3176	14.9102	574.9893	18.7058	440.6111	14.3341	554.3876	18.0356	410.8083	13.3646	455.5952	14.8216
Roads	13.8210	0.4496	16.1848	0.5265	11.3737	0.3700	14.9517	0.4864	9.2563	0.3011	10.1872	0.3314
Wetlands	33.1030	1.0769	13.1198	0.4268	31.5498	1.0264	11.9952	0.3902	29.9121	0.9731	8.6093	0.2801
	12-March-2000				16-Oct-2000				01-June-2001			
	MKwanazi		Dube		MKwanazi		Dube		MKwanazi		Dube	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Cultivation	97.6479	3.1767	167.9875	5.4650	110.9747	3.6103	178.2731	5.7996	140.7893	4.5802	186.0774	6.0535
Disturbed	138.8219	4.5162	202.0511	6.5732	409.7889	13.3314	446.5221	14.5264	413.1518	13.4408	419.7471	13.6554
Formal	5.6064	0.1824	1.0747	0.0350	5.6064	0.1824	1.0756	0.0350	5.6064	0.1824	1.0748	0.0350
Homestead	2.6232	0.0853	7.7456	0.2520	2.6239	0.0854	8.0432	0.2617	2.5217	0.0820	8.2898	0.2697
Natural	567.6010	18.4654	1003.6151	32.6500	505.6648	16.4505	969.8273	31.5508	474.1564	15.4254	954.6761	31.0579
Plantation	387.9107	12.6197	434.2936	14.1286	165.6736	5.3898	213.0171	6.9300	163.3664	5.3147	246.8073	8.0292
Roads	9.1848	0.2988	10.1803	0.3312	9.2105	0.2996	10.2451	0.3333	10.2249	0.3326	10.3369	0.3363
Wetlands	29.1006	0.9467	8.4156	0.2738	28.9537	0.9419	8.36	0.2720	28.6796	0.9330	8.3541	0.2718

5.2. LAND USE CHANGE

In identifying the locality and type of land use change, 'land use change' datasets were created by comparing the different land uses over the time series in Zulti South. The type, direction, area and location of land use change are depicted between the datasets (figures 5.7 to 5.11), and from a base year (figures 5.12 to 5.15). The accumulative area for the different types of land use 'change' and 'no change' are displayed in table 5.4 and 5.5.

5.2.1. Change between the datasets

Datasets depicting the change between the land use were created by sequentially comparing the pixel for pixel raster change between the datasets from 21st of September 1990 to the 1st of June 2001. The location and distribution of different types of 'change' and 'no change' between the datasets are shown in figures 5.7 to 5.11. The change is quantified according to the type of change that has taken place, the accumulative change for each class is calculated in hectares and in addition it is calculated as a percentage of the entire lease (table 5.4).

Change between Dataset 1 and Dataset 2

The results showing the difference in land uses between the 21st of September 1990 and the 20th of October 1997 (Dataset 1 and 2) is shown in figure 5.7 and table 5.4. The results show that in Dataset 2 a total area of 2756 ha (89.7%) of the lease remains the same as that in Dataset 1. A total area of 63.1 ha (2.05%) across the lease area has changed from *natural* vegetation to *disturbed*, 48 ha (1.5%) of commercial *plantations* became *cultivated* lands, 37.8 ha (1.2%) of land changed from *disturbed* to *cultivated* land between Dataset 1 and Dataset 2. Other significant changes between the two Datasets were; 34.4 ha (1.1%) of the lease area changing from natural to cultivated land use classes, and 21.3 ha (0.7%) of the lease area changing from *plantations* to *disturbed*. The 'Other changes' class accounted for 24.8 ha (0.8%) of Zulti South.

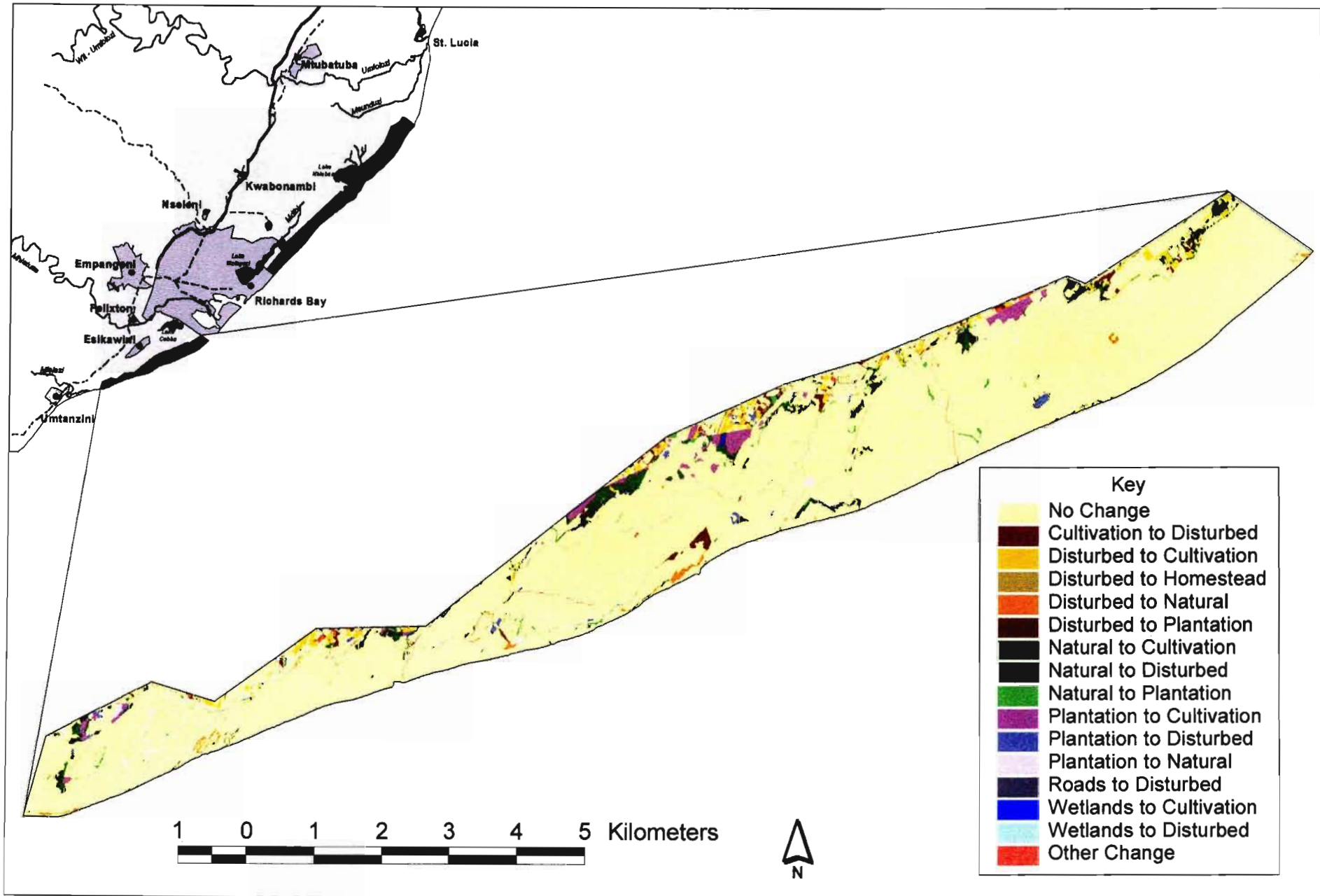


Figure 5.7: Land Use changes between the 21st of September 1990 and the 20th of October 1997

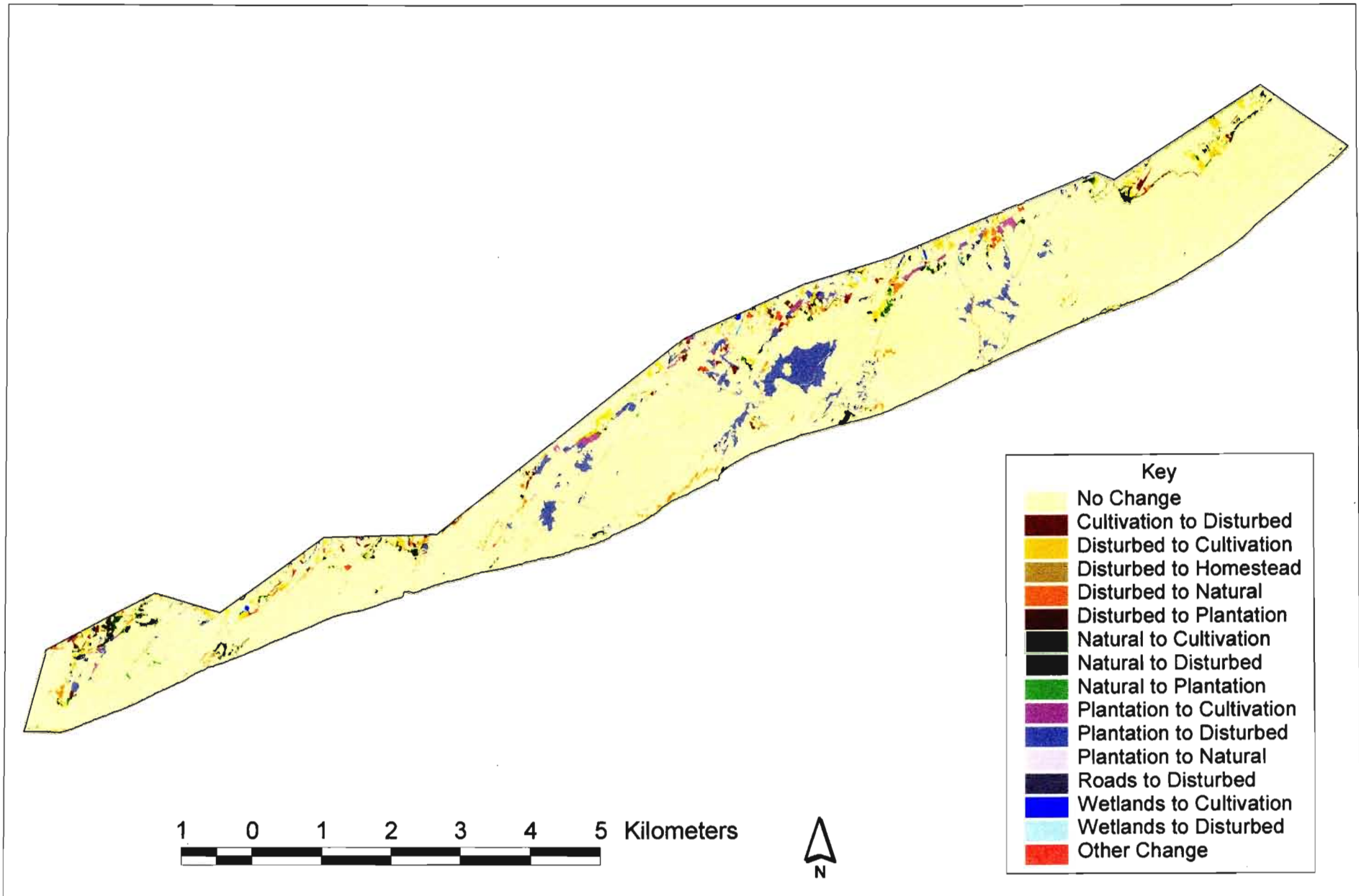


Figure 5.8: Land Use changes between the 20th of October 1997 and the 19th of August 1999

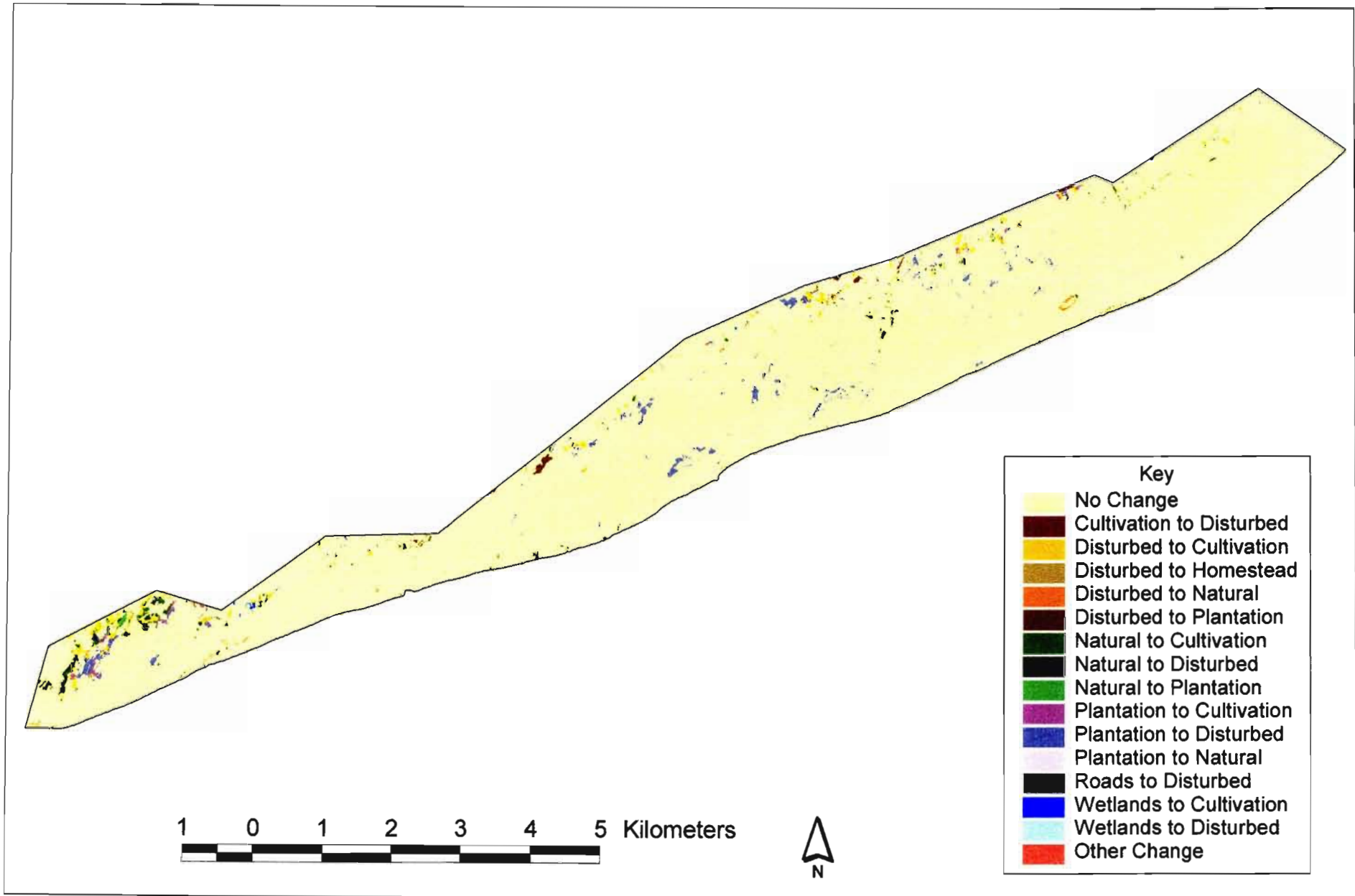


Figure 5.9: Land Use changes between the 19th of August 1999 and the 12 of March 2000

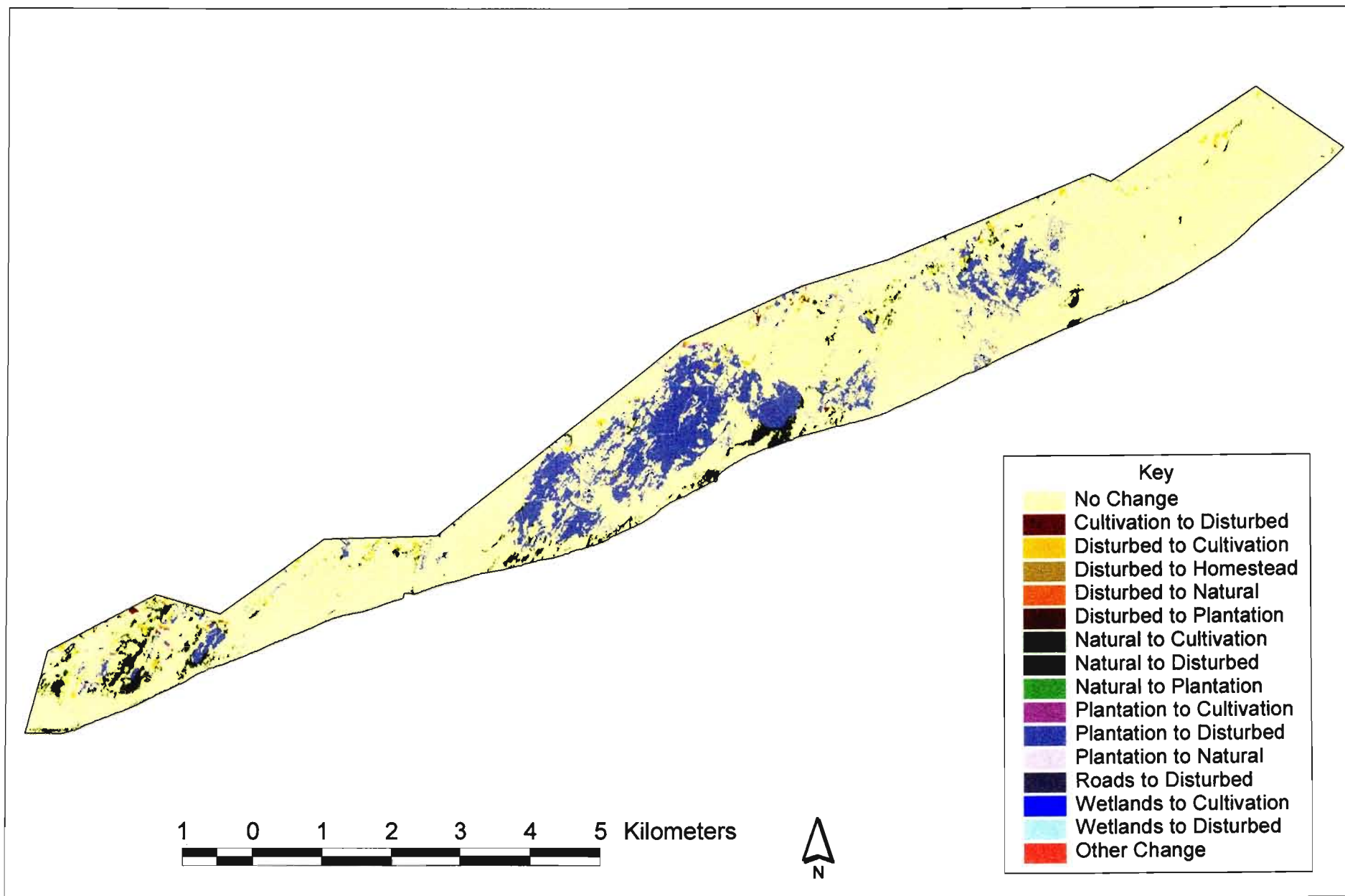


Figure 5.10: Land Use between the 12th of March 2000 and the 16th October 2000

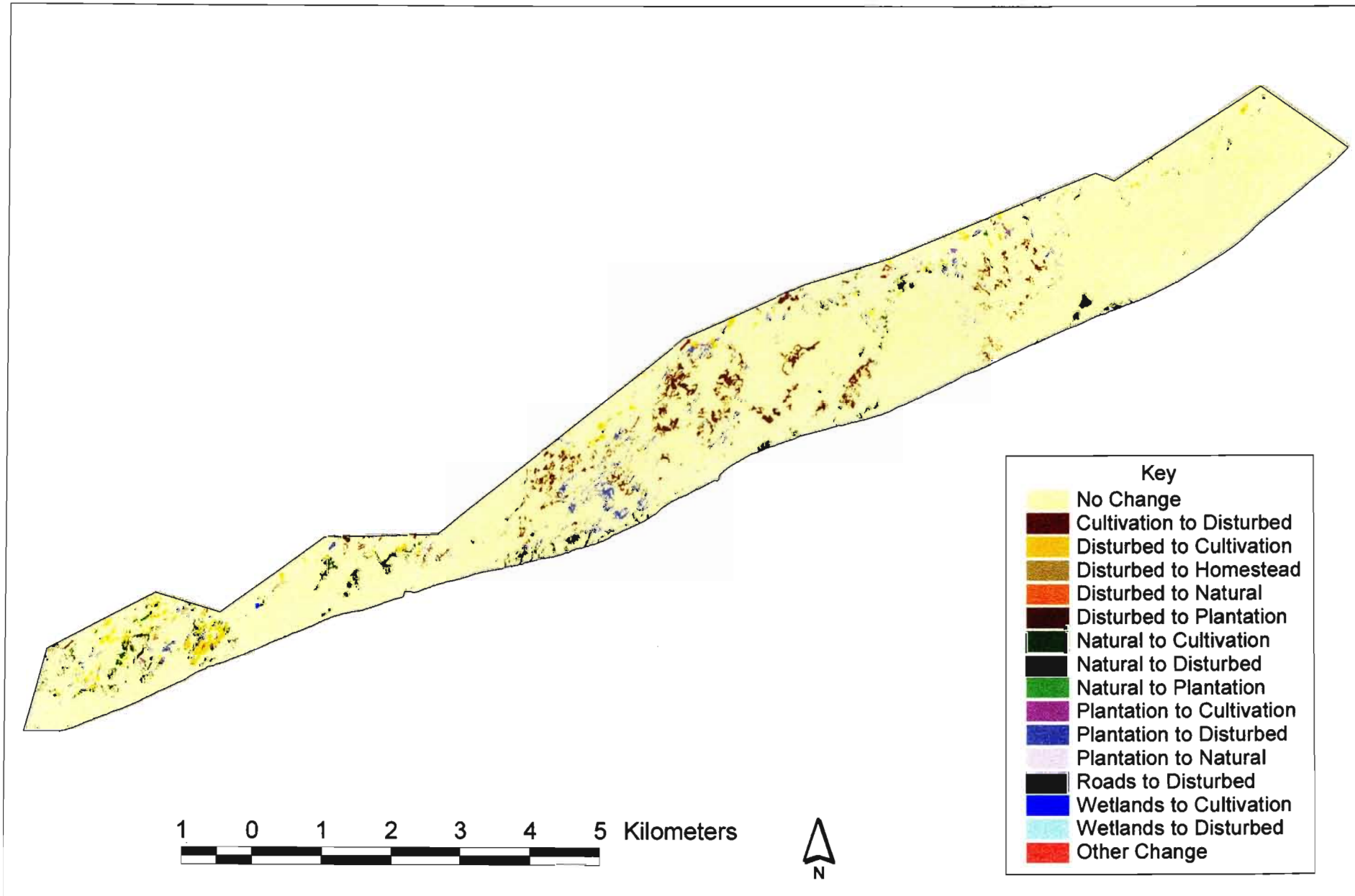


Figure 5.11: Land Use changes between the 16th of October 2000 and the 1st of June 2001

Table 5.4: Area and percentage of land use change between the Datasets

Type of Change	Date									
	21-Sep-1990 to 20-Oct-1997		20-Oct-1997 to 19-Aug-1999		19-Aug-1999 to 12-Mar-2000		12-Mar-2000 to 16-Oct-2000		16-Oct-2000 to 06-Jun-2001	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
No Change	2755.9833	89.6587	2762.2669	89.8631	2955.8468	96.1607	2506.0227	81.5269	2847.8542	92.6475
Cultivation to Disturbed	6.6997	0.2180	13.5841	0.4419	1.9434	0.0632	1.5941	0.0519	3.1112	0.1012
Disturbed to Cultivation	37.8468	1.2312	33.3729	1.0857	21.8693	0.7115	17.7343	0.5769	31.9483	1.0394
Disturbed to Homestead	3.0533	0.0993	1.2123	0.0394	0.0984	0.0032	0.1738	0.0057	0.299	0.0097
Disturbed to Natural	16.2512	0.5287	24.3879	0.7934	4.2328	0.1377	1.1047	0.0359	0.7293	0.0237
Disturbed to Plantation	20.8933	0.6797	8.2843	0.2695	6.4398	0.2095	3.0441	0.0990	85.8684	2.7935
Natural to Cultivation	34.4272	1.1200	9.0934	0.2958	6.4757	0.2107	3.2483	0.1057	5.2036	0.1693
Natural to Disturbed	63.124	2.0536	32.5752	1.0597	19.4648	0.6332	93.5445	3.0432	41.4922	1.3498
Natural to Plantation	20.6674	0.6724	5.8481	0.1903	1.4451	0.0470	0.1726	0.0056	0.1183	0.0038
Plantation to Cultivation	48.0345	1.5627	17.8134	0.5795	6.7137	0.2184	4.1385	0.1346	3.2723	0.1065
Plantation to Disturbed	21.3328	0.6940	124.7399	4.0581	45.3345	1.4748	442.2624	14.3879	51.0894	1.6621
Plantation to Natural	15.0318	0.4890	7.4237	0.2415	0.4376	0.0142	0.1776	0.0058	0.0746	0.0024
Roads to Disturbed	1.2872	0.0419	1.7981	0.0585	0.1264	0.0041	0.0328	0.0011	0.1324	0.0043
Wetlands to Cultivation	1.7233	0.0561	2.7798	0.0904	1.0359	0.0337	0.1669	0.0054	0.4328	0.0141
Wetlands to Disturbed	2.6953	0.0877	3.0367	0.0988	0.0459	0.0015	0.0532	0.0017	0.0245	0.0008
Other Change	24.8089	0.8071	25.6433	0.8342	2.3499	0.0764	0.3895	0.0127	2.2095	0.0719
Total Change	317.8767	10.3414	311.5931	10.1367	118.0132	3.8391	567.8373	18.4731	226.0058	7.3525

Change between Dataset 2 and Dataset 3

Land use changes between the 20th of October 1997 and the 19th of August 1999 show that 2762.3 ha (89.8%) of the lease area remains unchanged. The greatest portion of the change between these two datasets is that 24.7 ha (4.1%) of the lease has changed from *plantation* to *disturbed*. This change is clearly indicated in figure 5.8. Here the change (depicted by a pale blue) is generally located in the central portion of the lease. An area of 33.4 ha (1.1%) has changed from *disturbed* land to *cultivated* fields, 32.6 ha (1.1%) of the *natural* land use class has become *disturbed* in Dataset 3. Changes in the 'other change' category accounts for 25.6 ha (0.8%) of the total area of Zulti South.

Change between Dataset 3 and Dataset 4

The least amount of change between the datasets in the time series occurs between the 19th of August 1999 and the 12th of March 2000 (Dataset 3 and 4). The total area of land in Dataset 4 that remains unchanged from Dataset 3 is 2955.9 ha (96.2%). This can clearly be seen in figure 5.9 where the small amount of change that has occurred is highlighted. The majority of the change that does occur is concentrated in the south western corner of the lease. The greatest contribution to change (table 5.4) is that of the *plantation* land use class changing to *disturbed* 45.3 ha (1.5%). *Disturbed* land changing to *cultivation* accounts for an area of 21.9 ha (0.7%). Other significant change is that of *natural* changing to *disturbed*, with an area of 19.5 ha (0.6%).

Change between Dataset 4 and Dataset 5

The greatest amount of change between the datasets in the time series occurs between the 12th of March 2000 and the 16th of October 2000 (Dataset 4 and 5). The change in land use between the two datasets can clearly be seen in figure 5.10 where the change from *plantation* to *disturbed* accounts for 442.3 ha (14.4%) and the change from *natural* to *disturbed* accounts for 93.54 ha (3%) (table 5.4). *Disturbed* land use changing to *cultivated* land generates a total area of 17.7 ha (0.6%). The total amount of land that remains unchanged between dataset 4 and Dataset 5 is 2506 ha (81.5%).

Change between Dataset 5 and Dataset 6

The area of land in the Zulti South lease that remains unchanged from Dataset 5 (16th of October 2000) to Dataset 6 (1st of June 2001) is 2847.9 ha (92.7%). Some small patches where land use has changed is distributed throughout the study area (figure 5.11). *Disturbed* land changing to *plantation* with a total area of 85.9 ha (2.8%), accounts for the majority of the change (table 5.4). *Plantation* to *disturbed* land use has an area change of 51.1 ha (1.7%). *Natural* to *disturbed* land use has an area change of 41.5 ha (1.4%) and *disturbed* to *cultivation* has an area change of 32ha (1.04%) of the total area of Zulti South (table 5.4).

5.2.2. Change from the base year

The dataset depicting land use on the 21 of September 1990 (Dataset 1) was taken as the base year. Land use within this dataset was assumed to be unchanged. By comparing the differences in land use from the base year with each individual dataset in the time series, the type, direction and location of the total change that has occurred in Zulti South from the base year till the specific date of each dataset becomes evident. The change in the datasets from the base year is depicted in figures 5.7 and 5.12 to 5.15. The amount of change is shown in table 5.5. The amount of change is depicted in hectares and as a percentage of the total study area.

The results showing the difference in land uses between the 21st of September 1990 and the 20th of October 1997 (Dataset 1 and 2), were described in section 5.2.1 (is shown in figure 5.7).

Land use changes between the 21st of September 1990 and the 19th of August 1999 (Dataset 1 and 3) indicate that 2590.4 ha (84.3%) of Zulti South has had no land use changes between the two datasets (table 5.5). The bulk of the land use change from dataset 1 to dataset 3 is in the form of *plantation* changing to *disturbed* land totalling an area of 135.2 ha (4.3%) in the lease area (table 5.5). *Plantation* changing to *cultivation* between the datasets accounts for 60.4 ha (2%). *Natural* vegetation changing to *disturbed* land

equates to 68 ha (2.2%), *natural* to *cultivation* change adds up to 52.4 ha (1.7%). *Disturbed* to *cultivation* land use between Dataset 1 and 3 accounts for 48.7 ha (1.6%) of Zulti South.

The total area where no land change has taken place between the base year and the 12th of March 2000 (Dataset 1 and 4) is 2590.4 ha (84.3%). 162.1 ha (5.3%) of the total area of Zulti South has changed from *plantation* to *disturbed* (table 5.5). 77.5 ha (2.5%) of *natural* land has become *disturbed*. 75.7 ha (2.5% of the lease) of *plantations* in Dataset 1 have become *cultivated* fields in Dataset 4 (figure 5.13). *Natural* to *cultivated* land use class accounts for 65.4 ha (2.1%) and *disturbed* to *cultivated* accounts for 51.7 ha (1.7%) of Zulti South from the base year to 12th of March 2000.

The results of the land use change from the 21st of September 1990 to the 16th of October 2000 (dataset 1 and 5) shows that 2020.8 ha (65.7%) of the study area remains the same (table 5.5). The bulk of the change occurring is *plantation* changing to the *disturbed* land use class, contributing 585.4 (19.1%) of the lease. Other changes include: *Natural* to the *disturbed* land use class 155.9 ha (5.1%), *plantation* to *cultivation* 84.7 ha (2.8%), *natural* to *cultivation* 76.1 ha (2.5%) and *disturbed* to *cultivation* 54.7 ha (1.8%). This change tends to occur in the flatland regions of Zulti South the central portion of the lease and the south western corner of the lease (figure 5.14).

Land use change between the 21st of September 1990 and the 1st of June 2001 (Dataset 1 and 6) is represented in figure 5.15. Here 2006.24 ha (65.3%) of the lease has remained unchanged between the two datasets. *Plantation* to *disturbed* accounts for 17.5% of the lease (538.1 ha), *Natural* to *disturbed* 5.9% (181.7 ha), *plantation* to *cultivation* 3.3% (101.38 ha) and *natural* to *cultivation* accounts for 3% (93.3 ha) of Zulti South (table 5.5). *Disturbed* land in the base year changing to *cultivated* lands in Dataset 6 totals 1.9% (57.9 ha).

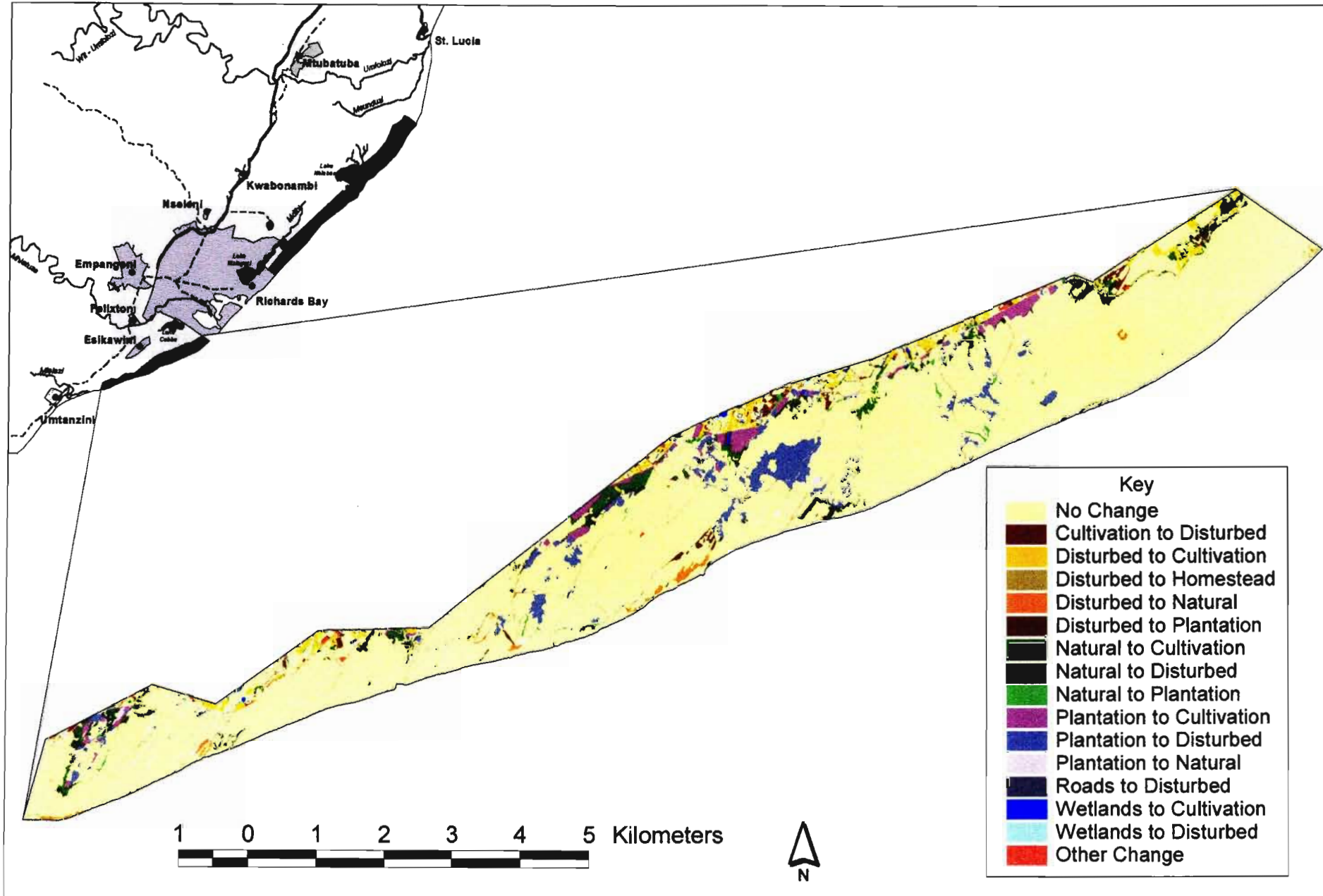


Figure 5.12: Land Use changes between the 21st of September 1990 and the 19th of August 1999.

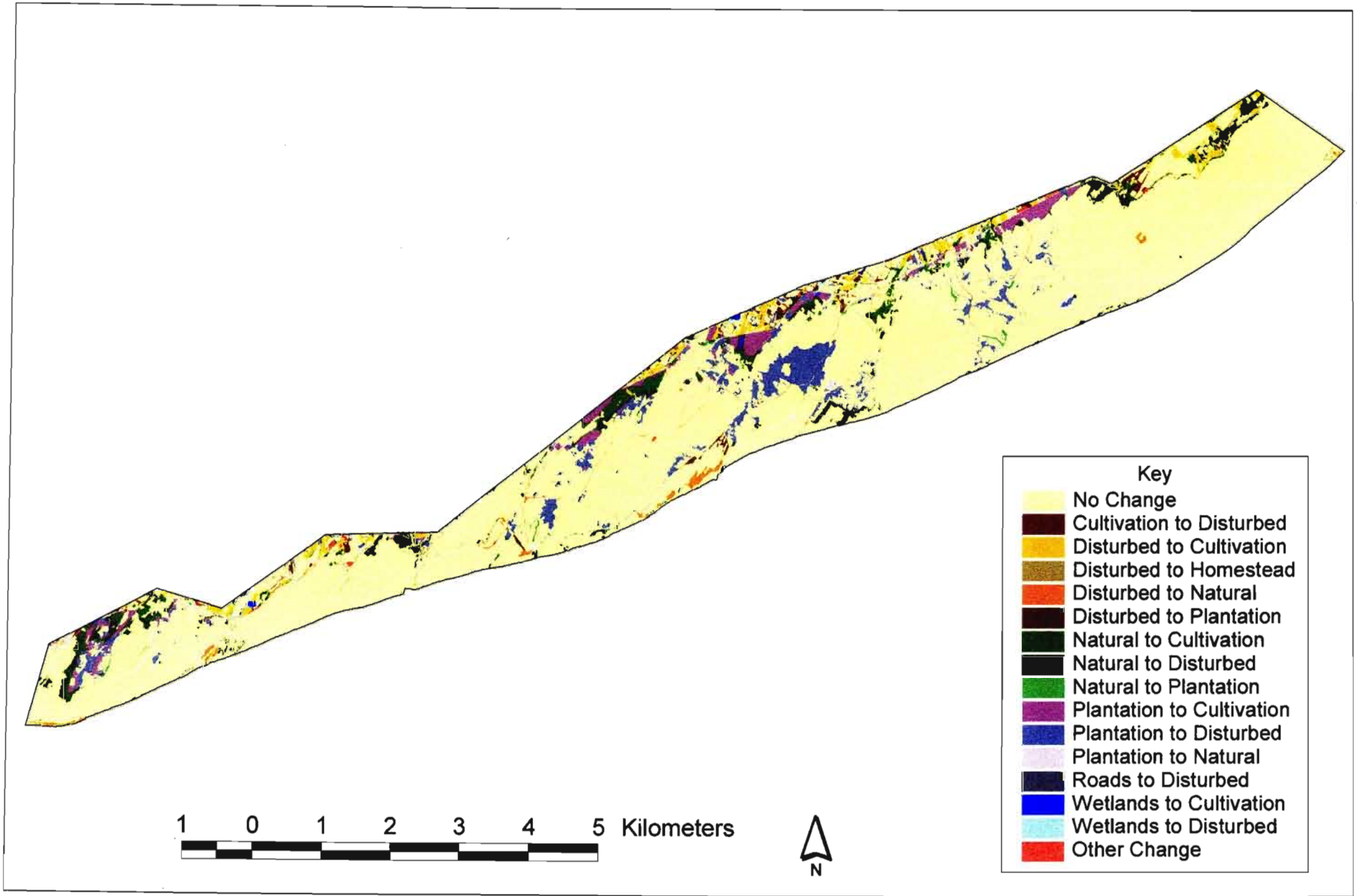


Figure 5.13: Land Use changes between the 21st of September 1990 and the 12th of March 2000

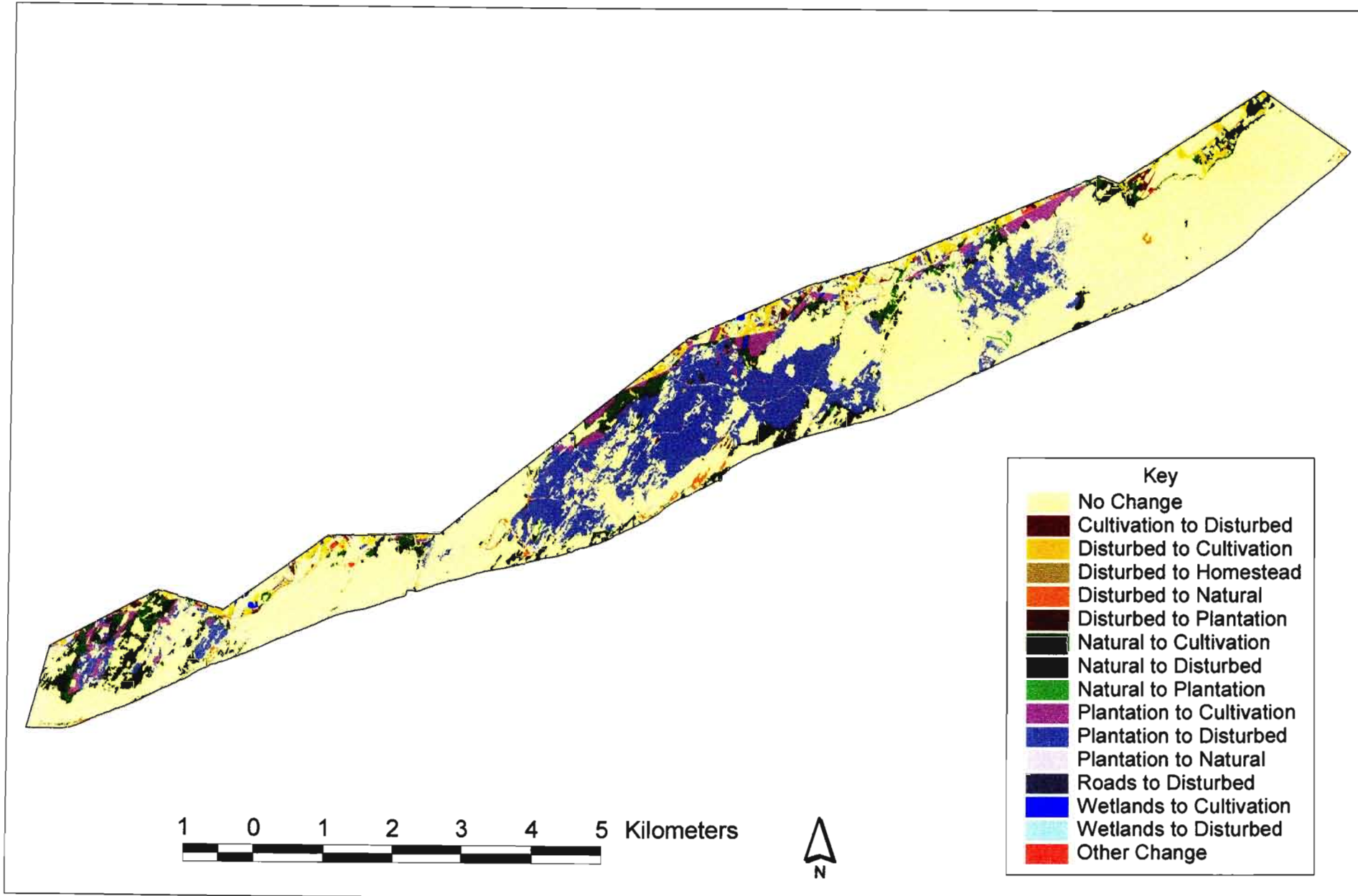


Figure 5.14: Land Use changes between the 21st of September 1990 and the 16th of October 2000

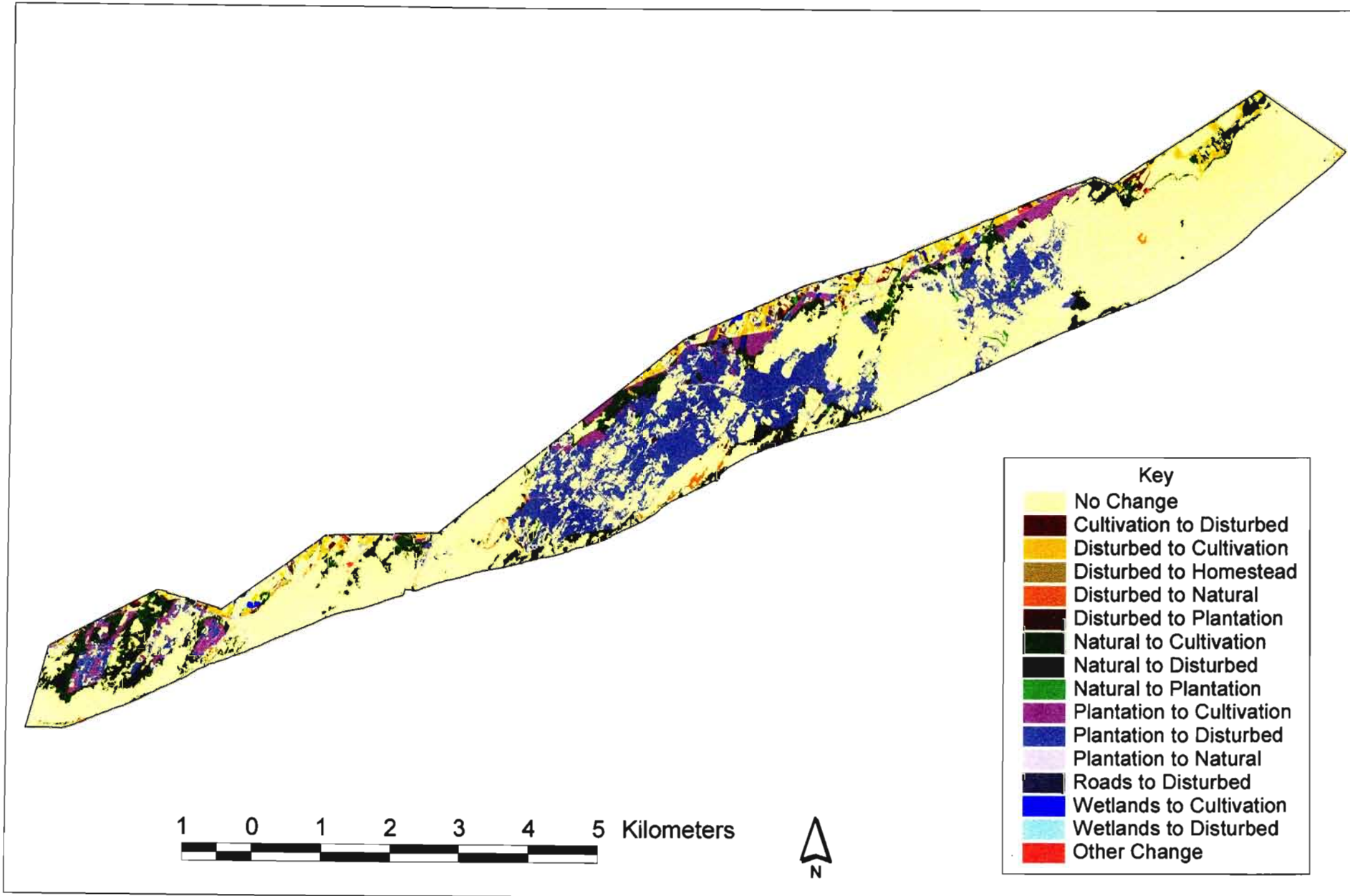


Figure 5.15: Land Use changes between the 21st of September 1990 and the 1st of June 2001

Table 5.5: Area and percentage of land use change from the base year

Type of Change	Date									
	21-Sep-1990 to 20-Oct-1997		21-Sep-1990 to 19-Aug-1999		21-Sep-1990 to 12-Mar-2000		21-Sep-1990 to 16-Oct-2000		21-Sep-1990 to 06-Jun-2001	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
No Change	2755.9833	89.6587	2590.3733	84.2710	2525.3429	82.1554	2020.7806	65.7408	2006.2384	65.2677
Cultivation to Disturbed	6.6997	0.2180	7.3296	0.2384	6.8794	0.2238	7.0716	0.2301	8.0981	0.2635
Disturbed to Cultivation	37.8468	1.2312	48.6468	1.5826	51.7075	1.6822	54.6487	1.7779	57.8474	1.8819
Disturbed to Homestead	3.0533	0.0993	3.5775	0.1164	3.5019	0.1139	3.6631	0.1192	3.7498	0.1220
Disturbed to Natural	16.2512	0.5287	20.2948	0.6602	20.3759	0.6629	14.45	0.4701	12.6954	0.4130
Disturbed to Plantation	20.8933	0.6797	19.7881	0.6438	18.6623	0.6071	12.1235	0.3944	12.9269	0.4205
Natural to Cultivation	34.4272	1.1200	52.4398	1.7060	65.425	2.1284	76.1316	2.4767	93.3298	3.0362
Natural to Disturbed	63.124	2.0536	67.8678	2.2079	77.4958	2.5211	155.8547	5.0703	181.7375	5.9124
Natural to Plantation	20.6674	0.6724	16.5813	0.5394	15.3211	0.4984	11.7835	0.3833	11.3845	0.3704
Plantation to Cultivation	48.0345	1.5627	60.3934	1.9647	75.7232	2.4635	84.6607	2.7542	101.3826	3.2982
Plantation to Disturbed	21.3328	0.6940	135.2319	4.3994	162.0876	5.2731	585.4427	19.0458	538.0546	17.5042
Plantation to Natural	15.0318	0.4890	14.8107	0.4818	13.8453	0.4504	10.3412	0.3364	9.2628	0.3013
Roads to Disturbed	1.2872	0.0419	2.374	0.0772	2.6826	0.0873	6.5236	0.2122	6.4361	0.2094
Wetlands to Cultivation	1.7233	0.0561	4.5342	0.1475	5.7619	0.1874	5.9207	0.1926	6.7406	0.2193
Wetlands to Disturbed	2.6953	0.0877	3.2273	0.1050	3.0592	0.0995	3.1693	0.1031	2.7943	0.0909
Other Change	24.8089	0.8071	26.3895	0.8585	25.9884	0.8455	21.2945	0.6928	21.1812	0.6891
Total Change	317.8767	10.3414	483.4867	15.7288	548.5171	17.8445	1053.079	34.2591	1067.622	34.732365

5.2.3. Total change

The total amount of change that has taken place throughout the time period between each dataset from the 21st of September 1990 to the 1st of June 2001 in Zulti South was calculated and added together to form a single choropleth map (figure 5.16). From this figure the total land use area that has 'change' in some form is indicated in red. Areas of the lease where 'no change' took place at all throughout the time series is shown in pale yellow. Change in this dataset is fixed, thus, if a specific piece of land changed its use several times throughout the time series, the total area of change indicated in this dataset would be given as the total area of that specific portion of land and not as a sum of the accumulative change upon it.

The total change that has occurred in Zulti South is summarised in table 5.6. Here the amount of 'change' and 'no change' in land use has been calculated in hectares and is given as a percentage that it contributes to the overall study area. The total land use change that has occurred across the time series totals an area of 1210.4 ha, which accounts for a total of 39.4% of the Zulti South lease area. The total area of land that has had no land use change within, totals an area of 1863.4 ha, and accounts for a total of 60.6% of the Zulti South Lease (table 5.6).

Table 5.6: Total Change from 1990 to 2001

Land use type	Total Change	
	Area (ha)	Area (%)
Change	1210.4211	39.3779
No Change	1863.4389	60.6221

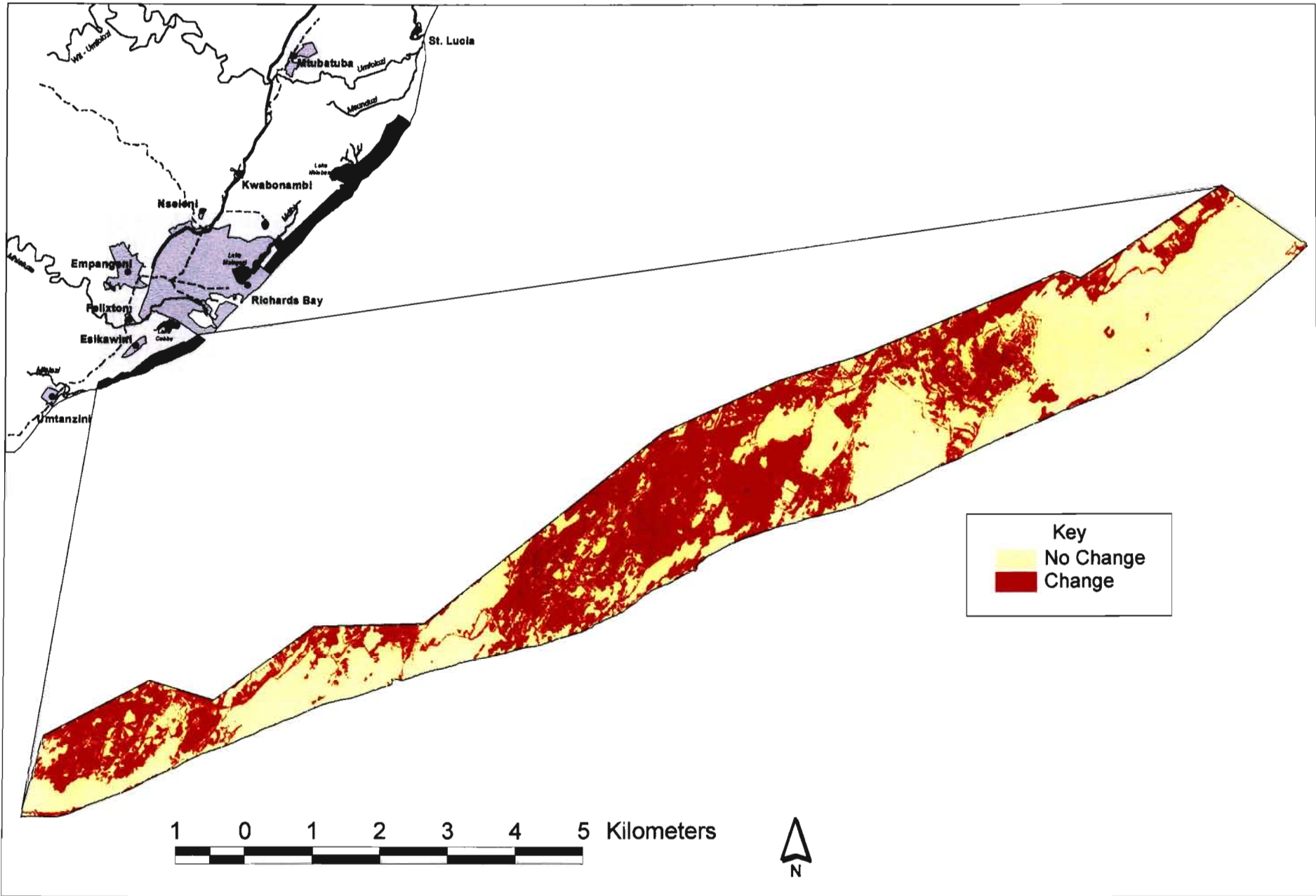


Figure 5.16: Total land use change from the 21st of September 1990 to the 1st of June 2001

5.3. PREDICTION

5.3.1. Land use prediction

The results from the logarithmic curve estimation regression equation used to predict the possible future area for each of the eight land use classes in the study area is shown in Table 5.7. The predicted area (in hectares) and the percentage that these land use types cover in January and June 2002 are depicted. The calculated land use area in table 5.7 expresses the correlation between the land use type and time, where change in land use is assumed to be dependant on time.

With the use of the regression equation, the *natural* land use type is predicted to remain the predominant land use type accounting for a total of 1363.8 ha (44.4%) of the land in January 2002. The *disturbed* land use is predicted to increase to an area of 1013 ha (32.9%). *Cultivation* land use type contributes a total area of 426.8 ha (13.9%) and *plantation*, 205.9 ha (6.7%) to the total area of the Zulti South lease in January 2002 (table 5.7).

Natural land use in June 2002 is predicted to decrease marginally from the predicted value in January 2002 to account for a total area of 1320 ha (42.9%). The *disturbed* land use type is predicted to continue increasing and in June 2002 the total area this class commands in the lease is 1137.1 ha (37%). Similarly land utilised for *cultivation* increases to 470.6 ha (15.3%). *Plantation* that has been a major contributor to the land use in Zulti South between the 21st of September 1990 and the 1st of June 2001, accounts for only 85.1 ha (2.8%) of the entire lease area (table 5.7).

Table 5.7: Predicted land uses in Zulti South in January 2002 and June 2002

Land use type	Predicted date			
	JANUARY 2002		JUNE 2002	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Cultivation	426.8161	13.8853	470.5774	15.3090
Disturbed	1013.0037	32.9554	1137.1238	36.9934
Formal	6.0690	0.1974	5.8661	0.1908
Homestead	13.1743	0.4286	13.9417	0.4536
Natural	1363.8095	44.3680	1320.0287	42.9437
Plantation	205.8518	6.6969	85.0463	2.7668
Roads	13.4390	0.4372	11.4249	0.3717
Wetlands	31.7290	1.0322	29.8899	0.9724

5.3.2. Community prediction

The predicted value for each land use class in January and June 2002 were calculated for the separate tribal regions of Mkhwanazi and Dube in Zulti South. The possible future area of each land use type in the Mkhwanazi and Dube regions is depicted in table 5.8 and 5.9 respectively. The area that each land use contributes within the tribal regions are tabulated against the entire area of Zulti South and is expressed as a percentage.

The predicted future land uses for the Mkhwanazi tribal area are shown in table 5.8. The *disturbed* land use type accounts for the greatest portion of the tribal region with an area of 477 ha (15.5% of Zulti South) in January 2002. *Natural* land use is predicted to have an area of 448.7 ha (14.6%), *cultivated* lands in Mkhwanazi add up to 180 ha (5.9%). *Plantations* are predicted to total an area of 91.3 ha (2.97% of Zulti South) in January 2002. By June 2002 (table 5.8) *natural* land cover in Mkhwanazi is predicted to account for 424.6 ha (13.8%), *disturbed* land will account for 535.8 ha (17.4%), *cultivation* is predicted to cover an area of 201.5 (6.6%) and *plantations* an area of 36.4 ha (1.2%) of Zulti South.

Table 5.8: Predicted land uses in the Mkhwanazi tribal region in January 2002 and June 2002

Land use type	Predicted date for Mkhwanazi			
	JANUARY 2002		JUNE 2002	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Cultivation	179.9138	5.8530	201.5224	6.5560
Disturbed	477.0205	15.5186	535.7696	17.4299
Formal	4.9599	0.1614	4.7461	0.1544
Homestead	3.1762	0.1033	3.3421	0.1087
Natural	448.7251	14.5981	424.6633	13.8153
Plantation	91.3119	2.9706	36.6904	1.1936
Roads	7.0136	0.2282	6.2384	0.2030
Wetlands	26.3753	0.8581	25.5240	0.8304

The predicted future land uses for the Dube tribal area are shown in table 5.9. The *natural* land use type accounts for the greatest portion of the tribal region with an area of 915.1 ha (29.8% of Zulti South) in January 2002. *Disturbed* land use is calculated to total of 536 ha (17.4%). Here *cultivated* lands in Dube are predicted to contribute 246.9 ha (8.03%) and *plantations* are predicted to total of 114.5 ha (3.7% of Zulti South) in January 2002 (table 5.9). The predicted land use in Dube for June 2002 (table 5.9) indicated that *natural* land cover is predicted to account for 895.4 ha (29.1%), *disturbed* land will account for 601.3 ha (19.6%), *cultivation* is predicted to cover 269.1 ha (8.8%) and *plantations* an area of 48.4 ha (1.6%) of Zulti South.

Table 5.9: Predicted land uses in the Dube tribal region in January 2002 and June 2002

Land use type	Predicted date for Dube			
	JANUARY 2002		JUNE 2002	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Cultivation	246.9030	8.0323	269.0557	8.7530
Disturbed	535.9789	17.4367	601.3493	19.5633
Formal	1.1063	0.0360	1.1154	0.0363
Homestead	9.9966	0.3252	10.5986	0.3448
Natural	915.0765	29.7696	895.3558	29.1281
Plantation	114.5380	3.7262	48.3539	1.5731
Roads	6.4183	0.2088	5.1782	0.1685
Wetlands	5.3457	0.1739	4.3566	0.1417

5.3.3. Land use change prediction

The predicted change in land use from September 1990 to January and June 2002 is summarised in table 5.10. The total area of land use 'change' and 'no change' is calculated in hectares. Similarly the predicted change in land use from June 2001 to January and June 2002 is summarised in table 5.11.

Total land use change from September 1990 to January 2002 is predicted to amount to 1443.7 ha (47.5%) of Zulti South, whilst areas of land that have not undergone any change between these two dates is calculated to be 1630.1 ha (53.7%) in January 2002 (table 5.10). Total land use change from September 1990 to June 2002 is predicted to account for more than half the lease, with a total area of 1614.7 ha (53.2%). The unchanged portion of Zulti South is predicted to account for 1459.2 ha (48.03%) in June 2002 (table 5.10).

Table 5.10: Predicted total land use change from September 1990 to January and June 2002

Land use type	September 1990 to January 2002		September 1990 to June 2002	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Change	1443.7201	47.5242	1614.7157	53.1531
No Change	1630.1362	53.6607	1459.1999	48.0338

Total land use change between June 2001 and January 2002 is predicted to amount to 327.9 ha (10.8%) of Zulti South, whilst areas of land that has not undergone any change between these two dates is calculated to be 2746 ha (90.4%) in January 2002 (table 5.11). The total land use change from June 2001 to June 2002 is predicted to increase slightly and account for a total area of 332.5 ha (10.9%), The unchanged portion of Zulti South is predicted to account for 2741.5 ha (90.2%) between June 2001 and June 2002 (table 5.11).

Table 5.11: Predicted total land use change from June 2001 to January and June 2002

Land use type	June 2001 to January 2002		June 2001 to June 2002	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Change	327.9351	10.7949	332.4754	10.9444
No Change	2745.9805	90.3919	2741.5094	90.2448

5.4. SUMMARY

The results of the analytical data produced in the research has been described, as well as illustrated through tables and figures. The locality, area and distribution of each land use type in the time series has been illustrated and described. The change in the land use types between the datasets and from the base year are listed and described. Reference is made to the type of change, the location of this change and the area depicted. The results from the land use and land use change predictions are tabulated and described.

CHAPTER 6

DISCUSSION

The purpose of this chapter is to discuss the results obtained in chapter 5 and to review and discuss the effectiveness of GIS in facilitating land use monitoring in Zulti South. The results, accuracy and classification of the land use from the remotely sensed images are discussed. The influence that the two rural communities have had on land use within the Zulti South lease is evaluated. The precise change in land use between the datasets in the time series are presented and the findings assessed. The predictions made of the future land use in Zulti South for January and June 2002 are then reviewed and evaluated.

6.1. LAND USE IN ZULTI SOUTH

In this section the spatial land use processes in Zulti South between the 21st of September 1990 and the 1st of June 2001 is discussed. The thematic maps (Figures 5.1 to 5.6), created using GIS and remote sensing techniques, display the dimensionality and spatial character of land use in Zulti South throughout this period. The precise area accounted for by each land use type in each of the datasets is displayed in Table 5.1. The variation in the land use figures between each dataset are examined to see how they contribute to spatial trends within Zulti South. The significance of each land use class within the various datasets, the accuracy of the land use datasets and the differences in land use within the two tribal lease areas, over the time span are discussed.

6.1.1. Land use

The land use datasets (Figure 5.1 to 5.6) show that the balance between the different land use types in Zulti South are highly dynamic, and rarely in equilibrium. The purpose for which the land surface is utilised, varies considerably throughout the time series (Table 5.1). By analysing the land use figures in Table 5.1, clear trends in each individual land use class becomes apparent.

These trends show either an increasing or decreasing area of land allocated for each defined land use in Zulti South (see Appendix 3). *Natural* land use accounts for the highest surface area in each of the six datasets. This land use type is however not static and steadily decreases through the time series (see Figure 1 in Appendix 3). A similar pattern in the *natural* land use type can be observed in the *plantation* land use class where the area utilized for commercial forestry rapidly decreases through the time series. There is a small increase in the area covered by *plantations* between Dataset 5 and Dataset 6 (see Figure 2 in Appendix 3). This slight increase in area can be attributed to the *eucalyptus* trees 'coppicing', this re-growth of *Eucalyptus* trees accounts for this difference.

As both the *natural* and *plantation* land use classes grow smaller, the land that is classified as *disturbed*, increases at an increasing rate over the time period (see Figure 3 in Appendix 3). This increasing trend is evident throughout the time series, with the most noticeable increase occurring between Dataset 4 and Dataset 5. A slight decrease in *disturbed* land does however occur between Dataset 5 and 6 (Table 5.1). This dramatic increase and then slight decrease in the *disturbed* land use category can be attributed to the sudden illegal felling and then gradual re-growth of the commercial *plantations* within the lease area.

An increasing trend in the *cultivation* land use type is noticeable when evaluating the figures in Table 5.1 (see Figure 4 in Appendix 3). Here a steady increase from 74.9 ha in Dataset 1 to 326.9 ha in Dataset 6 occurs. Through examination of the land use maps (Figures 5.1 to 5.6) it is evident that land under *cultivation* has gradually spread from the flatland regions into the dune cordon of the lease over the time period. The only other land use class with an area that has an increasing rate is that of the *homestead* class (see Figure 5 in Appendix 3).

The land utilised for *formal* purposes, that is, the two forestry stations, the Isikhaweni sewerage works and the Port Durnford lighthouse remains relatively constant throughout the dataset (see Figure 6 in Appendix 4). There is however a slight decrease in the area utilised for this land use type Dataset 2 and 3. This is due to the Department of Water Affairs and Forestry abandoning their southern most forestry station during a period of political unrest. Results in Table 5.1 indicate that *wetlands* in Zulti South have gradually decreased in area (see Figure 7 in Appendix 3).

Table 5.1 show that the area of land used by the *road* land use type decreased in size from Dataset 1 through to Dataset 4, the area used by this land use type then increased from Dataset 4 to Dataset 6 (see Figure 8 in Appendix 3). These results are indicative of the activities of the Forestry Department and RBM in the lease area. With the decreased Forestry Department activity in Zulti South, certain roads were not used or maintained, therefore becoming overgrown. These overgrown roads therefore account for the decrease in area of land used by the *road* land use type. With subsistence agriculture increasing in the dune cordon and with RBM's recent exploration work in the area, the *roads* have increased marginally from Dataset 4 to Dataset 6, this increase does not however account for as much area as in Dataset 1.

6.1.2. Accuracy Assessment

It was not possible to accurately assess the error in the land use classification of datasets 1 to 5, as numerous land use changes have occurred from the time of the aerial photography to the field observations. Although the field observations were insufficient to develop error matrices, visual comparison did however appear to confirm their validity. It was possible to obtain field observations for dataset 6 (1 June 2001), the results obtained for the final land use classification (Figure 5.6) were good (Kappa index of agreement 87.6%) (Table 5.2).

The largest errors encountered were the omission error of 0.25 in the *Plantation* class, 0.2 in the *Cultivation* class and a commission error of 0.2 in the *Disturbed* class. There are a number of reasons that could account for the commission and omission errors observed in the dataset; re-growth of commercial plantations and natural vegetation does occur, disturbance, clearing and cropping of commercial plantations, natural vegetation and cultivated areas is an ongoing phenomenon and could change from the time of the photograph to the time of the field observation and account for the error.

6.1.3. Community Land use

Zulti South is divided between the two tribal lease areas of Dube and Mkhwanazi. As previously stated the Dube tribal region accounts for 59.7% and the Mkhwanazi tribal region 40.3% of the Zulti South mineral lease. The discussion here is based on the significant findings tabulated in Table 5.3, illustrating the different land use processes underway in each tribal region.

The results (Table 5.3) have shown that the *cultivated* land use class in both the tribal regions are increasing as time progresses from Dataset 1 to Dataset 6. Although there is a greater amount of *cultivated* land in the Dube portion of the lease, *cultivated* land in Mkhwanazi between dataset 3 and 6 is increasing at a faster rate than in Dube (Figure 1 in Appendix 4). That is, the greatest portion of the *cultivation* land use increases between dataset 3 and 6 occur within the Mkhwanazi tribal region.

The *disturbed* land is the fastest growing land use type in both the tribal areas (see Figure 2 in Appendix 4). This land use type rapidly increases from Dataset 2 through to Dataset 6 for both the Dube and Mkhwanazi areas. There is however a decrease in the *disturbed* land within the Dube tribal region from Dataset 5 to Dataset 6 (Table 5.3). The results in Table 5.3 and Figure 2 (Appendix 4) indicate that the Dube tribe experiences the larger portion of the increasing *disturbed* land from Dataset 1 to 3, but the Mkhwanazi tribal region has a greater increase of this land use from Dataset 3 through to Dataset 6.

The greatest portion of land use in both the tribal areas throughout the time series is that of the *natural* class, with the majority of this class being located in Dube. Results in Table 5.3 indicate that this class is gradually becoming smaller and accounting for less area through the time series in both the tribal regions, this is illustrated in Figure 3 (Appendix 4). When observing the trends it is evident that there is a sudden sharp decrease in the area of this class from Dataset 3 through to Dataset 6 in the Mkhwanazi tribal region.

The figures tabulated in Table 5.3 show a gradual decrease in the *plantation* area in both the tribal areas from Dataset 1 to 4 (see Figure 4 in Appendix 4). Here Dube is attributed with the majority of the decrease. This decrease in area falls sharply from Dataset 4 to 5, with the greatest portion of the change occurring in Mkhwanazi. As the Forestry Department is no longer active in Zulti South, the change suggests that habitants, mainly, from the Mkhwanazi Tribe are removing timber from the commercial plantations in the lease area.

The figures in the homestead class (Table 5.3) show that highest portion of *homesteads* occur are contained in the Dube tribal region. The area under *homesteads* increases at a constant rate throughout the time period (see Figure 5 in Appendix 4). This trend does not occur in the neighbouring Mkhwanazi tribal land, were the area allocated to homesteads initially increase to Dataset 3 then begins to gradually decrease with minor variation from Dataset 3 through to Dataset 6.

Viewing all the results and figures presented in Table 5.3 and in Appendix 4 in a holistic manner, the variation in land usage within both the tribal portions of Zulti South throughout the study period can be summarized as follows. The shift in land uses from the 21st of September 1990 to the 19th of August 1999 (Dataset 1 to 3) can be characterised with the majority of land use change taking place in the Dube tribe. This should not come as a surprise as the Dube portion of the lease accounts for 59.7% of Zulti South. The majority of the land use change from the 19th of August 1999 to the 1st of June 2001 (Dataset 3 to 6) occurs within the Mkhwanazi tribal region. This period is characterised by accelerated variation in the land use as apposed to the gradual trends presented between Dataset 1 and 3. The only exception to this trend is shown in the Homestead land use class where the majority of the change occurs in Dube and not in Mkhwanazi.

6.2. LAND USE CHANGE

It is evident from evaluating the data (Table 5.1) from the six datasets that land use change has taken place in Zulti South. This change in land use is clearly depicted evaluating these datasets (Figures 1 to 6). Although it is possible to calculate the amount of change that has taken place in the time series from these datasets, the location and type of change cannot be deduced here. In determining what land use has changed, how it has changed and where it has changed, datasets depicting these changes were created.

The purpose of the following section is to describe the results in land use change derived from the sequential comparison between the datasets, and from the base dataset. The difference in the type, the area and the location of the land use change will be described and discussed.

6.2.1. Sequential change between the datasets

The results of the sequential comparison between the datasets are tabulated in Table 5.4, with the distribution and location of the land use change between the datasets displayed in Figures 5.7 to 5.11.

The results (Table 5.4) show that the land use change between the datasets in Zulti South is sporadic with varying changes in the land use occurring. This can be illustrated by viewing the differing total change figures (Table 5.4) between the datasets. Land use change between Dataset 1 and 2 amounts to an area of 317.9 ha (10.3%), this means that a total area of 317.9 ha or 10.3% of Zulti South has changed the function of its land use from the 21st of September 1990 to the 20th of October 1997. The change in land use between Dataset 2 and 3 totals an area of 311.6 ha (10.2%). The total land use change between Dataset 3 and 4 totals an area of 118 ha (3.8%), which in comparison to the rest of the figures in the time series is the lowest the total change. The largest total change between the datasets occurs between Dataset 4 and 5 with an area of 567.8 ha (18.5%) changing. The comparison between Dataset 5 and 6 indicates that 226 ha (7.4%) of Zulti South have changed the land use between these two dates.

By comparing the figures and types of land use changes within Table 5.4 certain patterns of dominant land use changes become apparent. The most noticeable patterns of change between the datasets are those of the *plantation* and *natural* land use class changing to disturbed land use (Figures 5.7 to 5.11). These two types of change tend to be the most dominant (Table 5.5) and account for a large portion of the total change between the datasets. The findings show that a significant portion of the total land use change between the datasets is accounted for by *disturbed* land becoming *cultivated* (Table 5.4). The *natural* and *plantation* land use classes reverting to *cultivated* lands show significant changes throughout the time series. Other dominant patterns of land use change are that of disturbed land reverting to the *natural* and *plantation* land use classes.

6.2.2. Change from the base year

The change in land use between each of the datasets is indicative of only the relative changes that have occurred between two datasets, these changes do not represent the holistic overview of the changes that have occurred up to that point in time at Zulti South. By comparing each of the six datasets in the study with the first dataset (21st of September 1990), the total amount of change, the types of change, where and when the change occurred during the time series can be determined. The results of these comparisons are tabulated in Table 5.5, with the locality and distribution of the changes presented in Figures 5.12 to 5.15.

The total area of land use change that occurs from the base dataset increases throughout the time series. That is, the total area of land that has changed its use when compared to Dataset 1 increases with time. This can be seen when comparing the total change in land use in Table 5.5. Land use change between Dataset 1 and 2 amounts to an area of 317.9 ha, which is 10.3% of the total surface area of Zulti South. This total land use Figure increases to 483.5 ha (15.7%) when comparing the land uses between Dataset 1 and 3. The total land use change between Dataset 1 and 4 is computed to account for an area of 548.5 ha (17.8%) of the mineral lease area. There is a sudden increase in land use change between the base year and Dataset 5, here land use change accounts for a total area of 1053 ha (34.3%) of Zulti South. This value increases only marginally to 1067.6 ha (34.7%), when comparing Dataset 6 with Dataset 1.

The trend described above indicates that as time progresses, areas of land that experience some form of land use change within Zulti South increase. Several distinct land use change patterns are noticeable when reviewing the Figures in Table 5.5. When comparing the datasets with the base dataset, these patterns reveal that the dominant type of land use change is that of *Plantation* becoming *Disturbed*. This is closely followed with the *Natural* land use type changing to *Disturbed*. Significant changes occur where both the *Natural* and *Plantation* land use classes change from Dataset 1 to *Cultivated* throughout the time series. Results in Table 5.5 indicates that the *Disturbed*

land use type changing to *cultivated* constitute the last dominant land use changes that occur when comparing each of the Datasets with Dataset 1.

6.2.3. Total Change

In analysing which areas of land in Zulti South has undergone some form of land use change, all the datasets were compared with each other in a GIS system. The resulting choropleth map (Figure 5.16) indicates the complete change that has taken place within the Zulti South mineral lease throughout the study period. That is, the Figure indicates the location and distribution of every particle of land that has undergone any form of land use change at any point of time between the 21st of September 1990 and the 1st of June 2001. The accumulative change over the study period amounts to an area of 1210.4 ha, this area constitutes a total of 39.4% of the entire Zulti South lease area (Table 5.6). Furthermore, an area of 1863.4 ha (60.6%) remains unchanged and retains the same type of land use upon it throughout the time period.

6.3. PREDICTION

In order to predict future land use dynamics in Zulti South, the spatial patterns presented in the land use data were analysed and subjected to a logarithmic regression equation to determine the spatial trend of each land use type. Assuming that a relationship between land use and time exists and that the change in land use is dependant on time, it is possible to predict the land use of Zulti South at future dates. From the curve estimation of the regression line it was possible to predict the area of future land uses within Zulti South. The results of the predicted land uses within the entire lease area and in the tribal regions and the results of the future land use changes are reviewed and discussed.

The future dates that were chosen to represent these predictions are January and June 2002. These two dates were chosen to facilitate RBM in realising the extent of the short-term land use change within the mineral lease area, therefore assisting them in proactively managing the Zulti South lease area.

6.3.1. Land Use Prediction

The results obtained from the land use predictions (Table 5.8) for January and June 2002 were good. The correlation coefficient ranges from a value of 0.667 for the *Disturbed* land use type, to 0.992 for the *Cultivation* land use type (see Appendix 5). This indicates that the predictions are highly significant with the significance level varying from, greater than 0.05 for the *disturbed* prediction to greater than 0.01 (for *cultivation*). These figures imply that the predictions made for the disturbed land has a greater than 95% confidence limit. The *Cultivation* predictions however have a confidence limit that is greater than 99%, that is, there is less than 1% chance that the predicted value for *cultivation* was determined coincidentally.

The predictions made for January 2002 (Table 5.7) indicate that the *natural* land use will remain the largest land use class with an area of 1363.8 ha (44.4%), this value however indicates that the natural land use continues to decrease. The *disturbed* land use type increases to an area of 1013 ha (32.96%), and the *cultivation* land use class increases to 426.8 ha (13.9%). The *plantation* land use type has decreased, and now accounts for an area of 205.9 ha (6.7%). The predictions made for June 2002 (Table 5.7) indicate that the *natural* land has decreased further and now has an area of 1137.1 ha (42.9%). The *disturbed* land use type continues to increase, with a total area of 1137.1 ha (37%), the *cultivation* land use class increases to 470.6 ha (15.3%). The *plantation* decreases to 85.1 ha (2.8%).

Both land use scenarios portrayed in January and June 2002 indicate that the current land use trends persist, showing an increase in the *Disturbed* and *Cultivated* land uses, as well as a decrease in the *Natural* and *Plantation* land use types.

6.3.2. Community Prediction

The results obtained from the land use predictions in the tribal regions of Mkhwanazi and Dube are tabulated in Table 5.8 and Table 5.9 respectively. The calculated regression equations for the land use types were found to be significant for both communities, with high confidence levels placed on the predictions of the future land uses in January and June 2002.

The correlation coefficients of the regression equations determined in the Mkhwanazi tribal region are good, ranging from 0.592 (*cultivation*) to 0.975 (*wetlands*). This indicates that the results are significant at the 0.07 to greater than the 0.01 levels. The correlation coefficients for the Dube area range from 0.732 for the *Disturbed* class to 0.962 for the *Cultivation* class, the significance levels therefore range from 0.03 to the 0.001 levels. These confidence limits indicate that the relationship between the land use types and time are highly significant, that is, the calculated logarithmic correlation lines for the data closely resembles the real world trends for the data.

The predictions made for the land use found within the Mkhwanazi and Dube tribal portions of Zulti South (Table 5.8 and 5.9) express similar trends to those observed in the land use prediction for the entire lease area. These trends follow those observed within the time series, the *cultivation* and the *disturbed* land use types continue to increase whilst all the other classes decrease in the tribal areas. The results (Table 5.8 and 5.9) indicate that in the short-term the majority of the land use change will occur within the Dube tribal region, and not in the Mkhwanazi as has been the case towards the end of the observed land use datasets.

6.3.3. Land use change prediction

The land use change predictions for January and June 2002 are shown in Table 5.10 and 5.11. The area of the total land use that has experienced 'change' or 'no change' from the base dataset (1st of September 1990) and from Dataset 6 (1st of June 2001) is predicted.

With the current rate of land use change in Zulti South, it is predicted that by January 2002 the total amount of land use change from the base dataset will account for 47.5% of the lease area (Table 5.10). This Figure increases to account for more than half the lease (53.2%) by June 2002. These figures were shown to be highly significant with the correlation coefficient for the 'change' and 'no change' land use types being 0.818, and the significance level being greater than 0.035. That is there is a 97.5% chance that these results are correct.

The total area of land use change from the 1st of June 2001 to January 2002 is predicted to total an area of 10.8% of Zulti South. The change from January 2002 to June 2002 is predicted to increase further to account for 10.9% of the lease (Table 5.11). The predictions made for the land use change between the datasets have low correlation coefficients, and therefore low significance levels. The correlation coefficient for both of the land use types is 0.002, with a significance level of 0.937. This essentially indicates that there is a 93.7% chance that the predicted values shown in Table 5.11 are not significant. These results were therefore rejected.

6.3.4. Accuracy of the predictions

The accuracy of the predictions cannot, unfortunately, be measured. The validity of these predictions will only be known once the true values of the future land use are recorded and compared with the predicted values. It must be noted that land use change between the datasets are sporadic, with anthropogenic factors being found to be the major cause of change. Due to the unpredictable nature of mankind and the varying land use patterns found between the datasets throughout the study, the accuracy and reliability of the predictions are not known.

It is however possible to determine the confidence values of the correlation equations placed on the land use data. Therefore, taking into account the current rate of change, and assuming all factors contributing to change remain

constant, the future land use in Zulti South can confidently be calculated through the correlation equation.

6.4. LIMITATIONS OF THE RESEARCH

Since the first aerial photographs were taken in 1990, the study was confined to changes in land use that took place between 1990 and 2001. Certain aerial photographs were incomplete or could not be located, and therefore were excluded from the study.

Before any analysis could be undertaken the remotely sensed data obtained from The Air Survey Company of Africa Limited, had to be converted and 'cleaned' for it to be of use in a GIS package. Although the air surveyors had previously digitised land use in Zulti South, the identification of different land uses was left to the discretion of different air survey analysts who had never been to the study area. This data was often found to be inaccurate, with a large number of the boundaries being incorrectly positioned or incorrectly labelled without a standard land use classification system. Therefore it was decided to create a land use classification system and re-digitise the entire series of datasets to ensure conformity in the interpretation and digitising. This proved to be a time consuming exercise that limited the amount of time spent on analysing the land use data.

The roads within Zulti South are all dirt roads and of poor quality, in order to gain access to many parts of the study area it was necessary to have a 4x4 vehicle. Trips into the study area were therefore limited to the availability of RBM employees and 4x4 vehicles going into the study area, as a result the field excursions into the study site were limited.

The time periods between the remotely sensed data used within the research is un-sequential with varying time periods between the datasets. This factor has two influences on the research, firstly it limited the amount of time-series analysis that could be performed on the data, as most analysis here requires

sequential data. Secondly the un-sequential nature of the datasets meant that analysis occurred between different climatic and cropping seasons therefore hindering the analysis between seasonal and absolute land use change.

6.5. SUMMARY

The results of the land use monitoring and mapping from the remotely sensed data provides a clear indication of the spatial dynamics of land use in each dataset. From the choropleth land use maps the area and location that each land use type occupied is shown and discussed, this was assessed further to investigate the land use in the tribal regions of the study area. The overall Kappa index of agreement for the final Dataset (Dataset 6) was 87.6%, showing that the land use mapping was accurate.

The results from the pairwise comparisons of the land use datasets were shown to contain specific spatial trends of dominant change between certain land uses throughout the study period. The dominant changes were shown to be from the *Natural* and *Plantation* to the *Disturbed* land use type, these changes were followed with *Disturbed* changing to the *Cultivation* land use type.

The findings from the predictions of land use dynamics in January and June 2002, and the significance of these predictions were discussed. The predictions indicate a continuance of current trends in land use and land use change patterns in Zulti South.

CHAPTER 7

CONCLUSION

The primary objective of this research was to investigate the capability of GIS in effectively and accurately monitoring and analysing the change, trends and patterns of land use. It was assumed at the outset of this research that the spatial approach adopted by using GIS for land use monitoring would provide better insight and understanding of the land use dynamics in Zulti South. The information generated through the land use monitoring would assist in answering the questions of; why land is used as it is, why its use changes, how these changes occur and who is responsible for the changes. Furthermore, the spatial data generated through the use of GIS and remote sensing in land use analysis generates spatial data that facilitates authorities in resolving land use conflicts brought about by these changes.

The objectives that were set-up to illustrate the capability of GIS in monitoring and analysing land use and land use change are outlined in Chapter 1. All of these objectives have been met within the limits of this research. The principle objectives were:

- to identify, quantify and map land use and land use change in Zulti South over a set period of time.
- to identify who is responsible for this change and where this change occurs.
- to determine the spatial trends of the land use patterns with which predictions of future land use dynamics can be made.

These objectives were achieved by undertaking a GIS research project using a series of remotely sensed images of RBM's Zulti South mineral lease area from the 21st of September 1990 to the 1st of June 2001.

7.1. LAND USE

As a consequence of the constraints within the remotely sensed data, the aerial images had to be geo-referenced and re-digitised. During this procedure it became evident that a new land use classification system was required to suit RBM's needs, to be practical and remain consistent throughout the study. A standard *a priori* land use classification system that would be appropriate in achieving the objectives in the project was therefore created.

Eastman (1997) states that GIS provides an array of spatial tools and techniques that when combined with remote sensing techniques provide a powerful method of monitoring and analysing land use change accurately, rapidly and on a continued basis. The results of this research tend to agree with Eastman's (1997) statement, where land use monitoring at various time periods were achieved quicker than that of a land based assessment.

The results of the thematic land use datasets indicate that land use in Zulti South is not in equilibrium, with land use consistently changing throughout the study period. It was shown in the research that with the use of GIS the quantity and location of each land use type in each dataset can be recorded. These land use datasets provide a sequence of 'snap shots' of the study area indicating the exact area and location of land use at that point in time. By comparing these 'snap shots' through the means of GIS tools the location, type and quantity of land use change from one dataset to the next is possible.

The land use patterns made evident from the research show an increasing trend in the area covered by the *cultivation*, *disturbed* and *homesteads* land use classes. Simultaneously, the area covered by *natural*, *roads*, *wetlands*, *formal* and *plantation* land use classes are decreasing in area over the study period.

7.2. LAND USE CHANGE

With regards to the changes in land use area over the time series, certain patterns of land use change are made obvious through the GIS analysis. From these results it was found that the dominant land use changes were from the *plantation* and *natural* land use types changing to the *disturbed* land use class, the trend here indicates that these changes increase in area over the time series. A significant increasing trend in the land use change occurs with the *disturbed* changing to the *cultivation* land use class throughout the study, other significant trends were observed over the entire time series with the *disturbed* land use changing into *plantation* and *natural* land uses, increasing in size over the study.

Furthermore it was determined that from Dataset 1 to 3, the majority of the change occurred in the Dube tribal region, from Dataset 3 to Dataset 6 the majority of the change occurred within the Mkhwanazi tribal region of the lease area. This suggests that, of late, the Mkhwanazi tribe has been responsible for encroachment onto the lease.

From the change datasets, the change within both the tribal regions appear to initially occur alongside *roads* especially those roads that pass through *plantations*, the change then spreads from these disturbed areas into the *plantations*. This suggests that the land use change is as a result of members of the tribes encroaching into Zulti South alongside the accessible roads. As timber is easier to clear than *natural* vegetation and as extra revenue can be generated from the sale of the timber, the *plantations* are felled and the land use changes to *disturbed*. The land use trends analysed through GIS indicate that the majority of this *disturbed* land use type will change to *cultivated* land whilst the rest will either remain *disturbed* or revert back to *plantations* as the trees coppice. The hotspots where land use change is likely to occur is shown to be that land alongside *roads*, recently *disturbed* land or *plantations* adjacent to *roads* and *disturbed* lands.

The location and area of every parcel of land that has experienced any form of land use change at any stage throughout the time series was calculated by comparing the land use in all the datasets. This area of land accounts for 34% of Zulti South (2345 ha).

7.3. LAND USE PREDICTION

It was possible to determine the future land use dynamics in Zulti South by combining GIS and statistical techniques to predict future land use and use changes. This knowledge of possible future land use scenarios can facilitate RBM authorities in proactively managing the mineral lease area, as the tribal region responsible for the change, the areas of likely change and rate of change is known. RBM can therefore with the aid of the spatial knowledge can target and attempt to discourage the negative land use changes whilst encourage the positive changes.

It was predicted that if the rate of land use change remained constant, by January 2002 the total area of land that would have changed its use from the base year would account for 45% of Zulti South. By June 2002 this total land use change would have increased to be 52%. Furthermore it is predicted that the majority of this change will occur in the Dube tribal region.

7.4. REFLECTIONS

The results of this study have emphasized how GIS as an analytical tool can accurately and efficiently contribute to land use monitoring and land use prediction. The spatial information generated through the use of GIS can assisting in the management and decision making process to efficiently manage and resolve land use problems.

Thiart and de Wit (2000) suggest that many GIS users become so involved in the technical problems and difficulties of assembling a large number of spatial

datasets that they frequently lose sight of the more substantive reason for carrying out a GIS project in the first place, namely spatial analysis of the data and modelling. This was found to be true in this research where the time spent on analysing the spatial data was limited due to the technical difficulties and challenges of assembling the land use datasets.

The results from this dissertation have proven to be useful, the objectives include the quantitative characterization, understanding and prediction of the spatial phenomenon of land use and land use change, which form the basis for making management decisions in Zulti South.

7.5. RECOMMENDATIONS

Further research in the different prediction techniques for land use could provide a valuable contribution, allowing society to assess likely impacts current land use trends in South Africa can have in the future.

It would be of value to assess the accuracy of the land use predictions carried out in this research. A GIS survey on the land use in Zulti South for January and June 2002, would enable the accuracy of the predictions to be assessed, refined and provide better prediction techniques.

It is recommended that an exploratory research is undertaken, exploring possible techniques that could prevent undesirable land change, or to facilitate the change in a sustainable manner. This would assist RBM in encouraging habitants to participate in sustainable land use practices.

7.6. CONCLUSION

In conclusion, this research has shown the ability of a GIS system in contributing to the spatial phenomenon of land use monitoring. The ability to generate consistent spatial land use data, accurately and rapidly was shown through the land use research undertaken in the RBM's Zulti South mineral lease area. Through the spatial tools and techniques provided within a GIS and combined with remote sensing techniques, it was possible to monitor land use at different time periods; compare and analyse the land use change between these dates and predict what future land use and land use change would be.

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Appendix 1

Land Use Classification

USGS Land Use and Land Cover Data (Miller, 2001).

Classification Codes

Classification Codes-first and second level categories

1 Urban or Built-Up Land

- 11 Residential
- 12 Commercial Services
- 13 Industrial
- 14 Transportation, Communications
- 15 Industrial and Commercial
- 16 Mixed Urban or Built-Up Land
- 17 Other Urban or Built-Up Land

2 Agricultural Land

- 21 Cropland and Pasture
- 22 Orchards, Groves, Vineyards, Nurseries
- 23 Confined Feeding Operations
- 24 Other Agricultural Land

3 Rangeland

- 31 Herbaceous Rangeland
- 32 Shrub and Brush Rangeland
- 33 Mixed Rangeland

4 Forest Land

- 41 Deciduous Forest Land
- 42 Evergreen Forest Land
- 43 Mixed Forest Land

5 Water

- 51 Streams and Canals
- 52 Lakes
- 53 Reservoirs
- 54 Bays and Estuaries

6 Wetland

- 61 Forested Wetlands
- 62 Nonforested Wetlands

7 Barren Land

- 71 Dry Salt Flats
- 72 Beaches
- 73 Sandy Areas Other than Beaches
- 74 Bare Exposed Rock
- 75 Strip Mines, Quarries, and Gravel Pits
- 76 Transitional Areas
- 77 Mixed Barren Land

8 Tundra

- 81 Shrub and Brush Tundra
- 82 Herbaceous Tundra
- 83 Bare Ground
- 84 Wet Tundra
- 85 Mixed Tundra

- 9 Perennial Snow and Ice
 - 91 Perennial Snowfields
 - 92 Glaciers

Classification and Mapping of Agricultural Land for National Water-Quality Assessment (Gilliom and Thelin, 2001).

- 1. Urban or build-up land
 - 11. Residential.
 - 12. Commercial and services.
 - 13. Industrial.
 - 14. Transportation, communications, and utilities.
 - 15. Industrial and commercial complexes.
 - 16. Mixed urban or built-up land.
 - 17. Other urban or built-up land.
- 2. Agricultural land
 - 21. Cropland and pasture.
 - 22. Orchards, groves, vineyards, nurseries, and ornamental horticultural areas.
 - 23. Confined feeding operations.
 - 24. Other agricultural land.
- 3. Rangeland
 - 31. Herbaceous rangeland.
 - 32. Shrub and brush rangeland.
 - 33. Mixed rangeland.
- 4. Forest land
 - 41. Deciduous forest land.
 - 42. Evergreen forest land.
 - 43. Mixed forest land.
- 5. Water
 - 51. Streams and canals.
 - 52. Lakes.
 - 53. Reservoirs.
 - 54. Bays and estuaries.
- 6. Wetland
 - 61. Forested and wetland.
 - 62. Nonforested wetland.
- 7. Barren land
 - 71. Dry salt flats.
 - 72. Beaches.
 - 73. Sandy area other than beaches.
 - 74. Bare exposed rock.
 - 75. Strip mines, quarries, and gravel pits.
 - 76. Transitional areas.

- 77. Mixed barren land.
- 8. Tundra
 - 81. Shrub and brush tundra.
 - 82. Herbaceous tundra.
 - 83. Bare ground tundra.
 - 84. Wet tundra.
 - 85. Mixed tundra.
- 9. Perennial snow on ice
 - 91. Perennial snowfields.
 - 92. Glaciers.

A Standard Classification System for the Mapping of Land Use and Land Cover (Siderelis, 1994).

1 Urban and developed land

- 1.01 Residential
- 1.02 Commercial and Services
- 1.03 Institutional
- 1.04 Manufacturing and Raw Material Processing
- 1.05 Transportation
- 1.06 Communication and Utilities
- 1.07 Industrial and Commercial Complexes
- 1.08 Mixed Urban or Developed Land
- 1.09 Public Assembly, Recreational, Cultural, and Entertainment
- 1.10 Mining and Resource Extraction
- 1.99 Other Urban or Developed Land

2 Agricultural land

- 2.01 Cropland and Pasture
- 2.02 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
- 2.03 Confined Animal Operations
- 2.99 Other Agricultural Land

3 Active forest Management and Harvesting

4 Water Bodies

- 4.01 Reservoirs and Artificial Lakes
- 4.02 Retention or Sediment Ponds
- 4.03 Artificial Drainage Lines
- 4.98 Other Water Bodies in Active Use
- 4.99 Non-used or Passively Used Water Bodies

5 Human-induced Bare Land

- 5.01 Altered Lands
- 5.02 Burn Areas
- 5.99 Other Human-induced Barren Land

6 Passive use on undisturbed land

7 Unused, Unknown use, and unmodified land

Land Cover Categories

- 1 Heavily Developed or disturbed Land
- 2 Cultivated Land
- 3 Herbaceous Cover and Shrubland
 - 31 Herbaceous Cover
 - 311 Managed Herbaceous Cover
 - 312 Unmanaged Herbaceous Cover
 - 3121 Unmanaged Upland Herbaceous Cover
 - 3122 Tidal Marshes
 - 3123 Non-tidal Marshes and Bogs
 - 3199 Other Unmanaged Herbaceous Cover
 - 32 Shrubland
 - 321 Managed Shrublands
 - 322 Young Pine Plantations
 - 323 Unmanaged Evergreen Shrubland
 - 3231 Pocosin and Bog Evergreen Shrubland
 - 3232 Unmanaged Upland Evergreen Shrublands
 - 324 Unmanaged Deciduous Shrubland
 - 3241 Unmanaged Deciduous Lowland Shrubland and Pocosin
 - 3242 Unmanaged Deciduous Upland Shrublands
 - 329 Other Shrubland
- 4 Forest Land
 - 41 Broadleaf Deciduous Forest Land
 - 411 Oak-Hickory and Oak-Chestnut Forests
 - 412 Mixed Mesophytic Upland Hardwoods
 - 4121 Maple-Beech-Birch
 - 4122 Yellow Poplar-Eastern Hemlock
 - 413 Bottomland and Wet Hardwood
 - 414 Hardwood Swamps
 - 419 Other Deciduous Broadleaf Forest Land
 - 42 Needleleaf Coniferous Forest Land
 - 421 White Pine Forests
 - 422 Hemlock Forests
 - 423 Spruce-Fir Forests
 - 424 Longleaf Pine Forests
 - 425 Loblolly-Slash Pine Forests
 - 426 Other Yellow Pine Forests
 - 427 Pond Pine Forests
 - 428 Atlantic White Cedar Forests
 - 429 Other Needleleaf Coniferous Forest Land
 - 43 Non-deciduous Broadleaf
 - 431 Maritime Non-deciduous Broadleaf Forests
 - 432 Bay Forests
 - 438 Artificial Broadleaf Evergreen Plantings
 - 439 Other Non-deciduous Broadleaf
 - 44 Mixed Deciduous-Coniferous Forest Land
 - 441 Oak-Pine
 - 442 Oak-Gum-Cypress
 - 449 Other Mixed Deciduous-Coniferous Forest Land
 - 48 Orchards and Tree Farms
 - 49 Other Forest Land

5 Water BODIES**51 Coastal/Marine Water Bodies****52 Inland Water Bodies****53 Linear Drainage****59 Other Water Bodies****6 Bare Land****61 Beaches, Bare Coastal Land, and Upland Sand Areas****62 Riverbanks and Bars****63 Exposed Rock****69 Other Bare Land****9 Other Unclassified Land Cover**

Appendix 2

ER Mapper Support

From: Dominic Cuthbert [dom.cuthbert@ermapper.co.uk]
Sent: Thursday, March 29, 2001 9:45AM
To: Carl Oellermann
Subject: Geocoding

Dear Carl

Thank you for your query and great to see that you have been using ER Mapper.

The problem you have is as a result of Working with Raster images. Raster images by definition have to be a rectangular grid.

When you are rectifying the images they are moving so that the pixels are in the right place, this is moving the image to an angle with North Directly up. When this happens ER Mapper fills in the gaps in the data to create the rectangular image, this gives the appearance of 'black triangles' on the edge of the image.

You can carry out an inregion clipping process to remove these "triangles" – best you look this up in the manual under definitions.

I hope this gives you some Ideas.

Best regards

Dominic Cuthbert
Sales Director

Earth Resource Mapping

Appendix 3

Land use trends

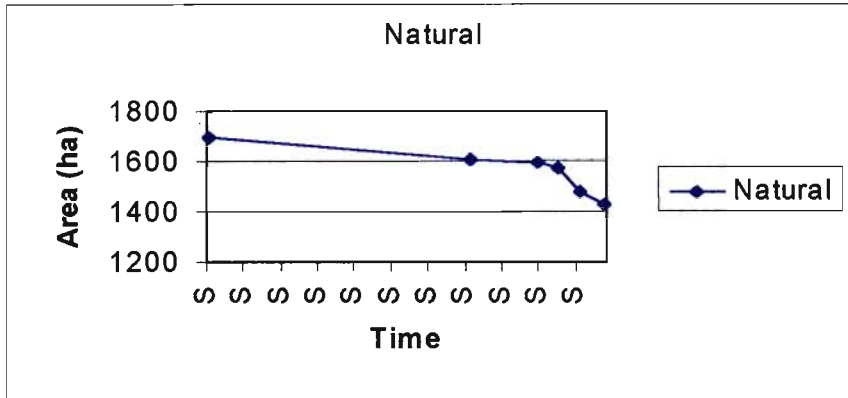


Figure 1: Natural land use trends in Zulti South

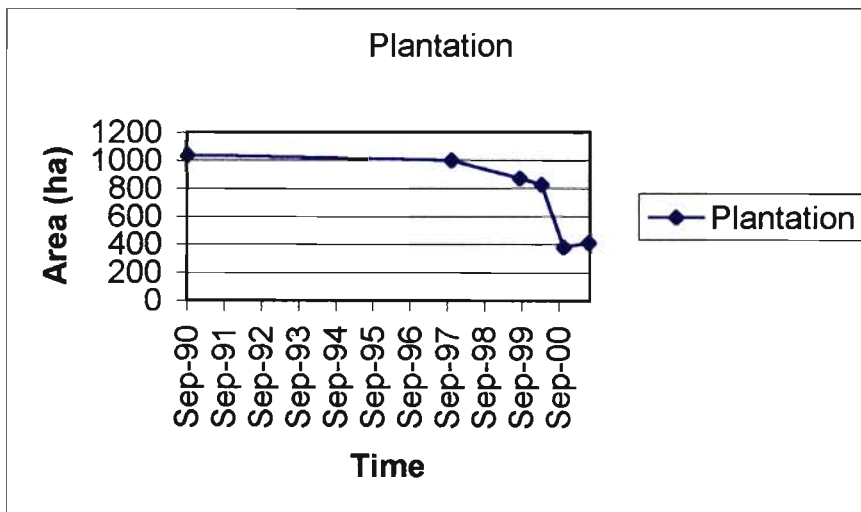


Figure 2: Plantations in Zulti South

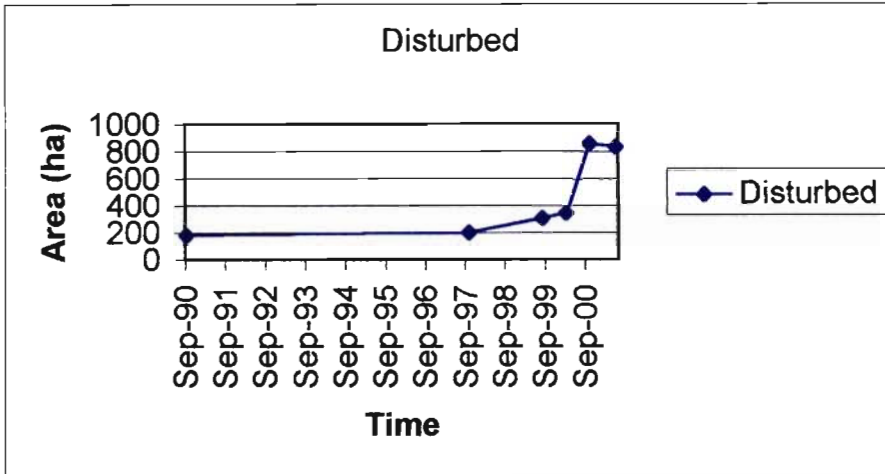


Figure 3: Disturbed land use trends in Zulti South

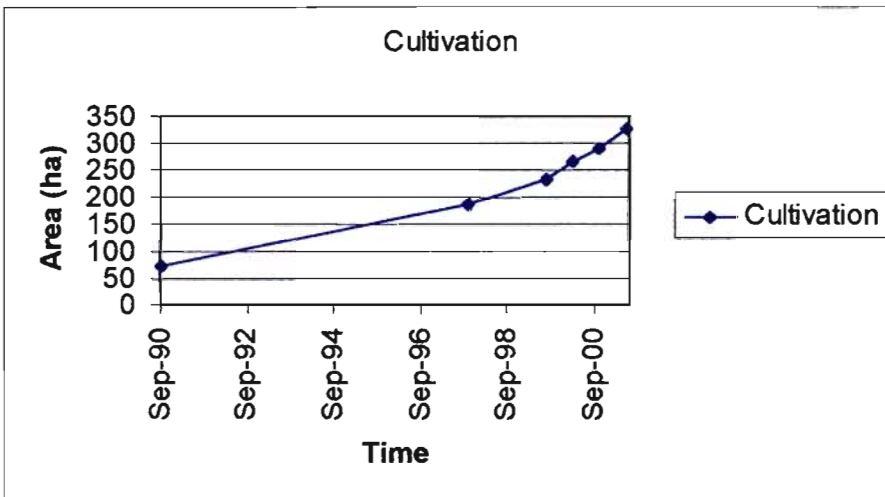


Figure 4: Cultivation trends in Zulti South

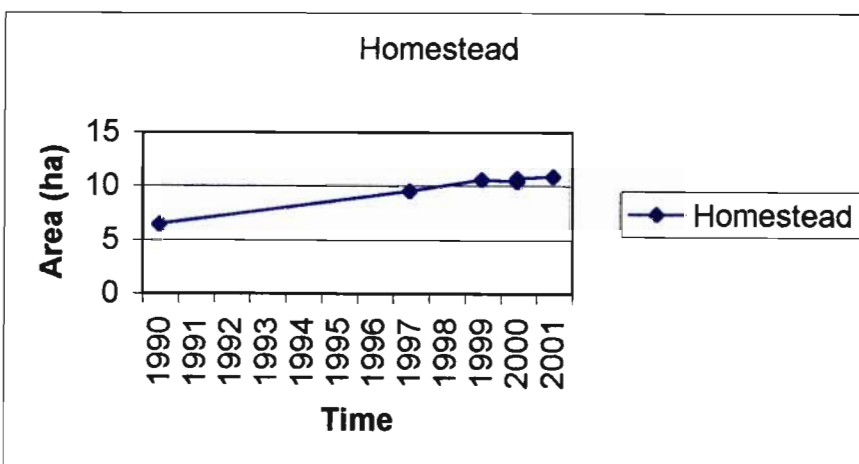


Figure 5: Homestead trends in Zulti South

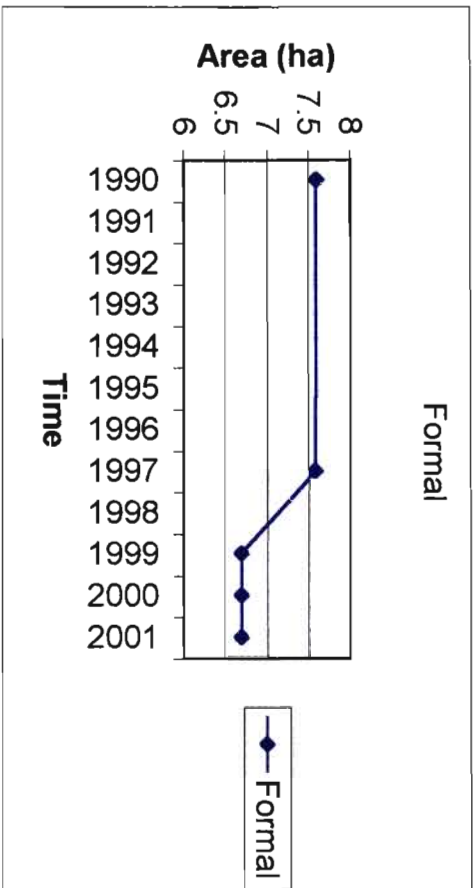


Figure 6: Formal trends in Zultti South

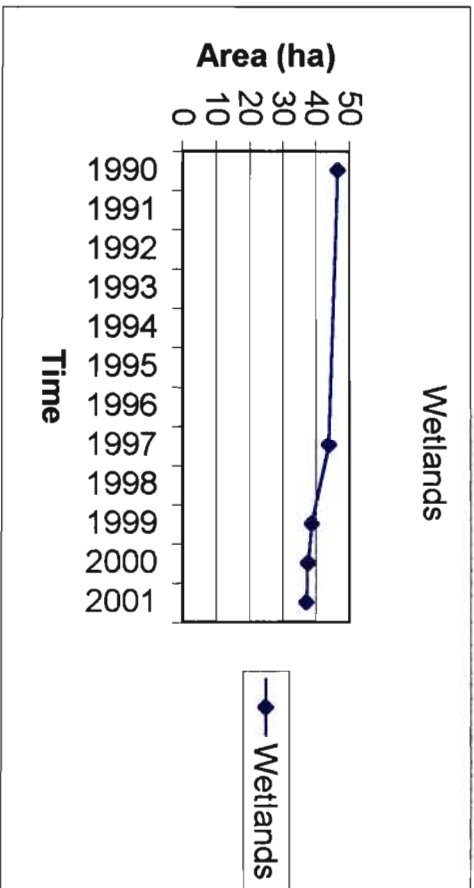


Figure 7: Wetland trends in Zultti South

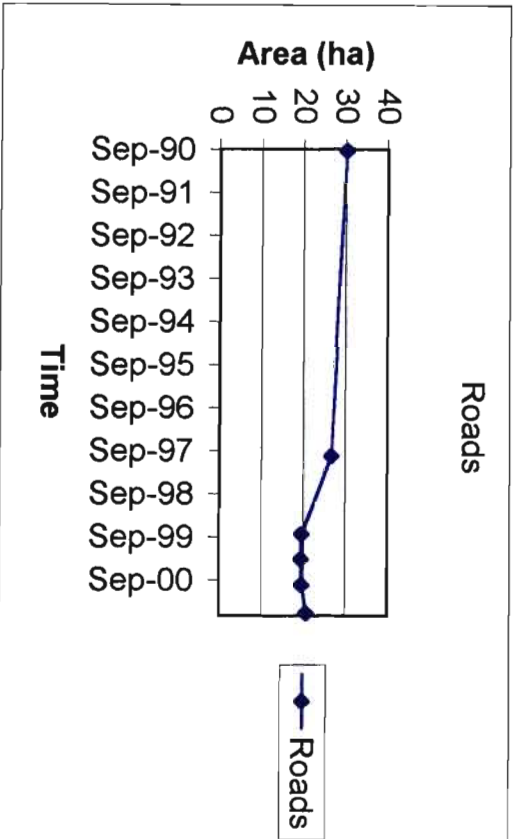


Figure 8: Road trends in Zultti South

Appendix 4

Tribal land use trends

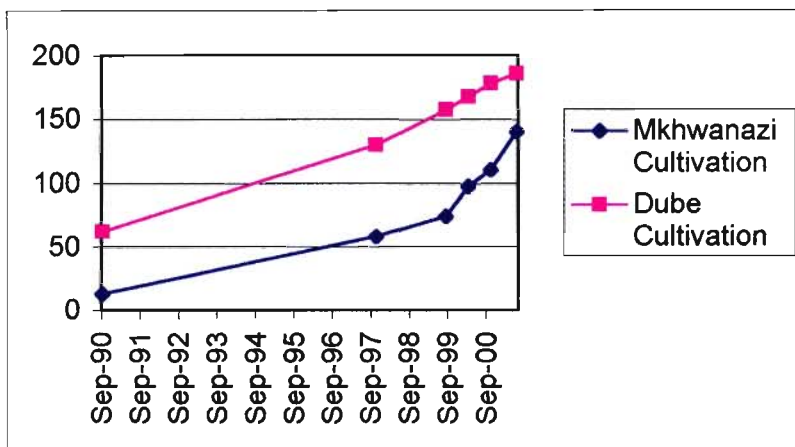


Figure 1: Cultivation trends in the Tribal regions

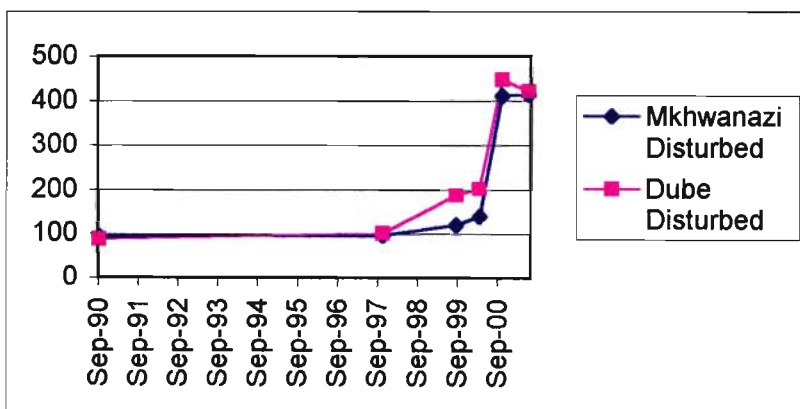


Figure 2: Disturbed trends in the Tribal regions

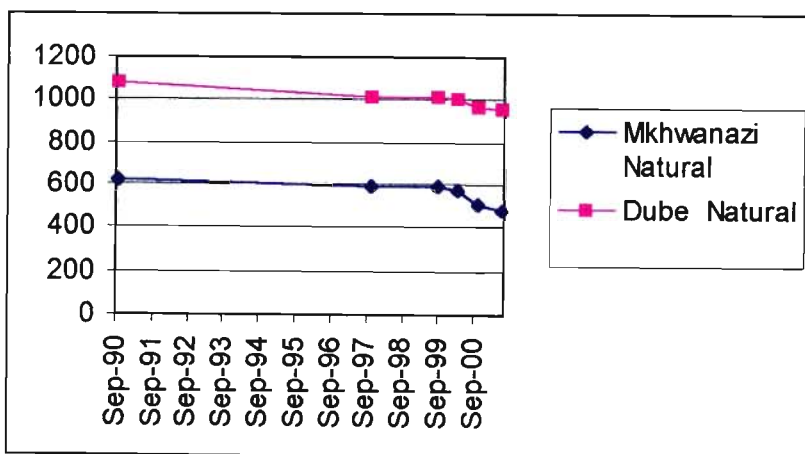


Figure 3: Natural trends in the Tribal regions

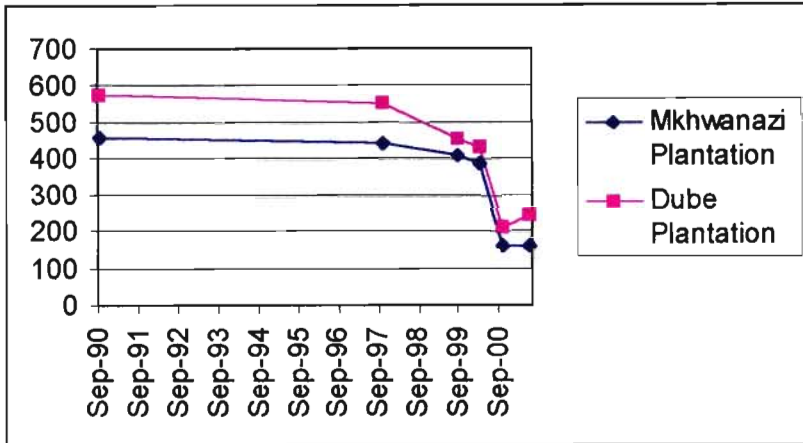


Figure 4: Plantation trends in the Tribal regions

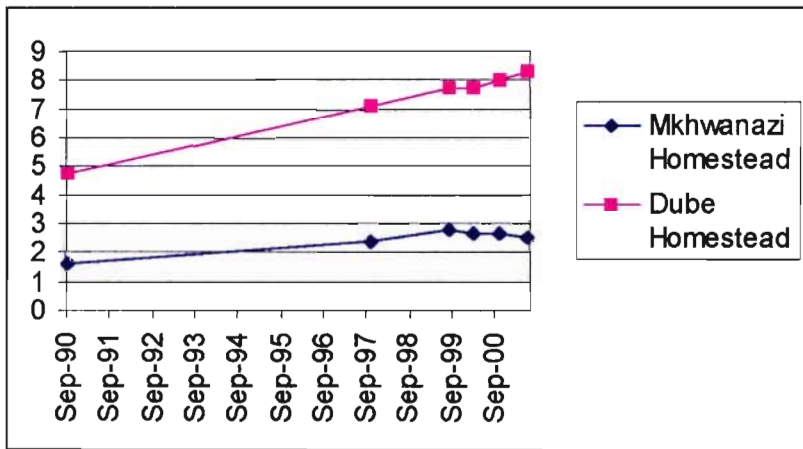


Figure 5: Homestead trends in the Tribal regions

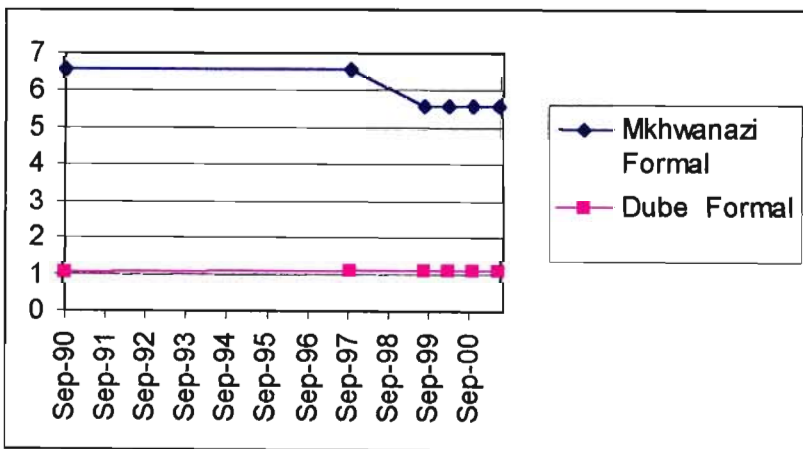


Figure 6: Formal trends in the Tribal regions

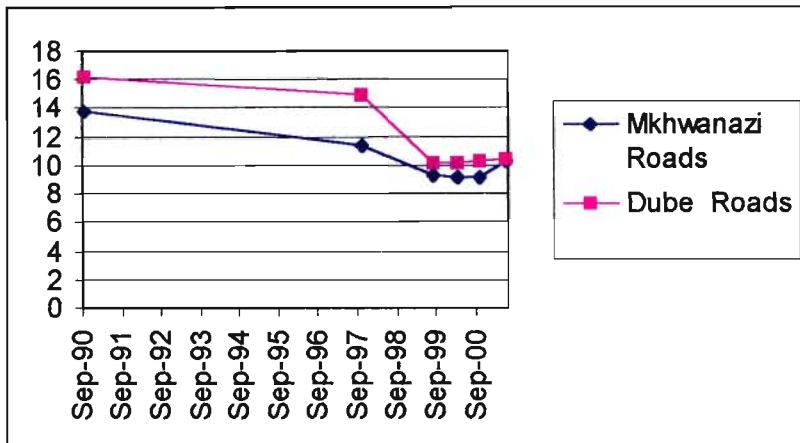


Figure 7: Road trends in the Tribal regions

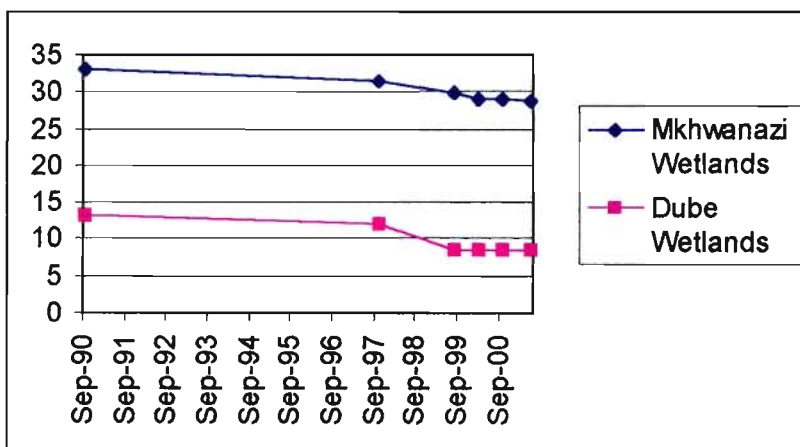


Figure 8: Wetland trends in the Tribal regions

Appendix 5

Zulti South land use prediction

Independent: Time

Dependent	Mth	Rsqr	d.f.	F	Sigf
Cultivation	LOG	0.992	4	500.33	0.000
Disturbed	LOG	0.667	4	8.01	0.047
Formal	LOG	0.775	4	13.75	0.021
Homestead	LOG	0.856	4	23.78	0.008
Natural	LOG	0.876	4	28.25	0.006
Plantation	LOG	0.734	4	11.02	0.029
Roads	LOG	0.817	4	17.81	0.013
Wetlands	LOG	0.928	4	51.55	0.002

Mkhwanazi land use prediction

Independent: Time

Dependent	Mth	Rsqr	d.f.	F	Sigf
Cultivation	LOG	0.972	4	139.48	0.000
Disturbed	LOG	0.592	4	5.81	0.074
Formal	LOG	0.780	4	14.21	0.020
Homestead	LOG	0.665	4	7.94	0.048
Natural	LOG	0.777	4	13.92	0.020
Plantation	LOG	0.665	4	7.95	0.048
Roads	LOG	0.741	4	11.47	0.028
Wetlands	LOG	0.975	4	157.83	0.000

Dube land use prediction

Independent: Time

Dependent	Mth	Rsqr	d.f.	F	Sigf
Cultivation	LOG	0.962	4	100.50	0.001
Disturbed	LOG	0.732	4	10.91	0.030
Formal	LOG	0.734	4	11.06	0.029
Homestead	LOG	0.894	4	33.64	0.004
Natural	LOG	0.931	4	54.12	0.002
Plantation	LOG	0.782	4	14.36	0.019
Roads	LOG	0.825	4	18.81	0.012
Wetlands	LOG	0.869	4	26.56	0.007

Land use change prediction (From base)

Independent: Time

Dependent	Mth	Rsqr	d.f.	F	Sigf
No Change	LOG	0.818	3	13.51	0.035
Change	LOG	0.818	3	13.51	0.035

Land use change prediction (from dataset6)

Independent: Time

Dependent	Mth	Rsqr	d.f.	F	Sigf
No Change	LOG	0.002	3	7.3E-03	0.937
Change	LOG	0.002	3	7.3E-03	0.937