LAND USE AND ITS IMPACT ON THE SUCCULENT KAROO.

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Submitted in fulfilment of the requirements of a degree of Masters of Science

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Abstract

The Succulent Karoo biome (SK biome) is one of the 25 internationally recognized biodiversity hotspots in South Africa with approximately 1940 endemic species. The SK biome is, however, poorly conserved with less than 5% of the area under formal protection. It is also highly threatened by a range of different land use practices. Considering the lack of protected areas and the high levels of endemism (about 40%), which characterize the region, the current and future land use practices are likely to be the key factors in determining the future conservation of the area.

Understanding the land use pattern and its drivers that have occurred in the SK biome provides a useful starting point for outlining the future research needs and establishing conservation goals. This project investigates a range of different land use practices such as urban settlement, mining, cropland, conservation and livestock production with their associated environmental drivers. The study used a Geographical Information System (GIS) to map the current extent of land use practices based on available data from different sources in the SK biome. The study also mapped the current extent of livestock density in two land tenure systems (private and communal) of Namaqualand and developed a statistical model to assess the future agricultural potential in the SK biome.

The current status of the land use practices in the SK biome shows that most of its area is used for extensive grazing (90%) followed by conservation (4.8%). Due to the aridity of the area, agriculture potential is low. The results confirmed that the conservation status of the SK biome is relatively low but improving, with 4.8% of the biome conserved. Only 3.5%, however, is formally protected in statutory reserves. The remaining conserved area (1.3%) is conserved in non-statutory reserves.

A detailed assessment of stock density at the cadastral level in Namaqualand revealed that 76 % of the communal farms are currently stocked below grazing capacity while 67% of the private farms are stocked below grazing capacity. About 18% of the communal areas are stocked above carrying capacity while 24% of the private farms are above the threshold set by the Department of Agriculture. These results for both communal and private farms are unexpected. The decrease in communal livestock has been facilitated by several factors such as the drought in 1998 and 1999, the additional land given to the communal farmers (200 000 ha) as part of the national government's land reform programme, and the fact that the Department of Agriculture maintains strict control, not only over the way in which animals are managed, but also in the number of animals permitted on the new land reform farms. This chapter presents results very different from previous studies due to the accurate and fine-scale mapping of livestock numbers.

Cropland expansion has been identified as one of the major land use pressures in the study area. A statistical GIS model was used to estimate the areas of future agriculture potential in the SKEP domain. Environmental land use drivers namely vegetation type, soil type, and climatic variables were the key determinants identified by the model. The model shows that agriculture potential is high in the Southern Karoo sub-region. This sub-region is believed to have fertile soils on arable foothills and lowlands. According to this model, 31% of the land is suitable for agricultural expansion but this percentage also includes the non-agricultural areas that are overestimated by the model. Sustainable agricultural intensification and a landscape planning approach to conservation are required to ensure biodiversity and environmental sustainability in Namaqualand and the Succulent Karoo biome

Keywords: Agriculture potential, GIS, conservation planning, land use practices, livestock production, Namaqualand, recommended stocking rate, Succulent Karoo.

CHAPTER 1 Introduction to the Succulent Karoo biome.

Background to the study

The Succulent Karoo biome (SK biome) is one of twenty-five internationally recognized biodiversity hotspots (Myers *et al.*, 2000). It covers approximately 112 000 km², extending through the southern and north-western areas of South Africa and the southern Namibia (Rutherford & Westfall, 1997) (Fig. 1.1).

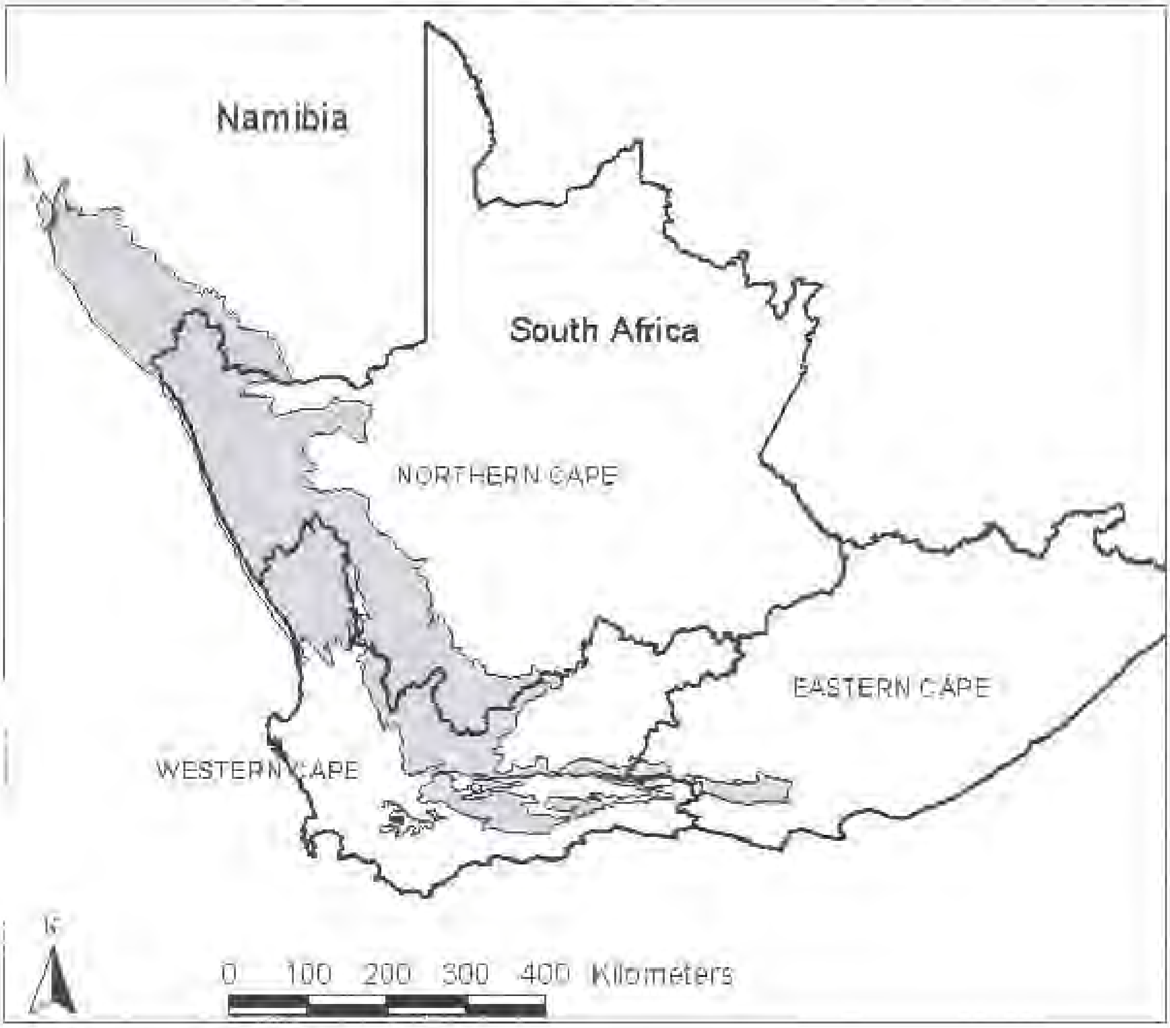


Figure 1.1: The boundary of the Succulent Karoo biome (shaded area) in relation to Namibia and three South African provinces (Rutherford & Westfall, 1997).

The planning phase of the SKEP project started in January to August 2002 and was led by Conservation International's Southern Africa Hotspot Programme. The goal of SKEP is to provide an overarching framework to guide conservation efforts in the Succulent Karoo. It aims to: 1. provide a hierarchy of priority actions to guide conservation goals, 2. build human resource capacity to implement the plan by including training and mentorship activities as part of the planning process, 3. generate the institutional and government support required to ensure its effective implementation. Since the SKEP project was initiated over a short time period I was given an opportunity, with this MSc project, to provide a detailed overview of land use practices and their impacts in the area.

The SK biome does not exist in isolation and in order to capture the outliers of the Succulent Karoo vegetation, and the transition zones between the SK biome and other vegetation types, the planning domain for the Succulent Karoo Ecosystem Plan (SKEP) has been made broader than the biome boundary itself (Fig. 1.2). These transition zones are important for understanding the impact of ecological processes such as climate change (Driver *et al.,* 2003). The planning domain covers a wide area with different land use patterns in different parts of the region, as well as different vegetation patterns and types. Because of these differences, the SKEP planning domain has been divided into four sub-regions namely: Namibia/Gariep, Namaqualand, Roggeveld/Hantam/Tanqua and the Southern Karoo.

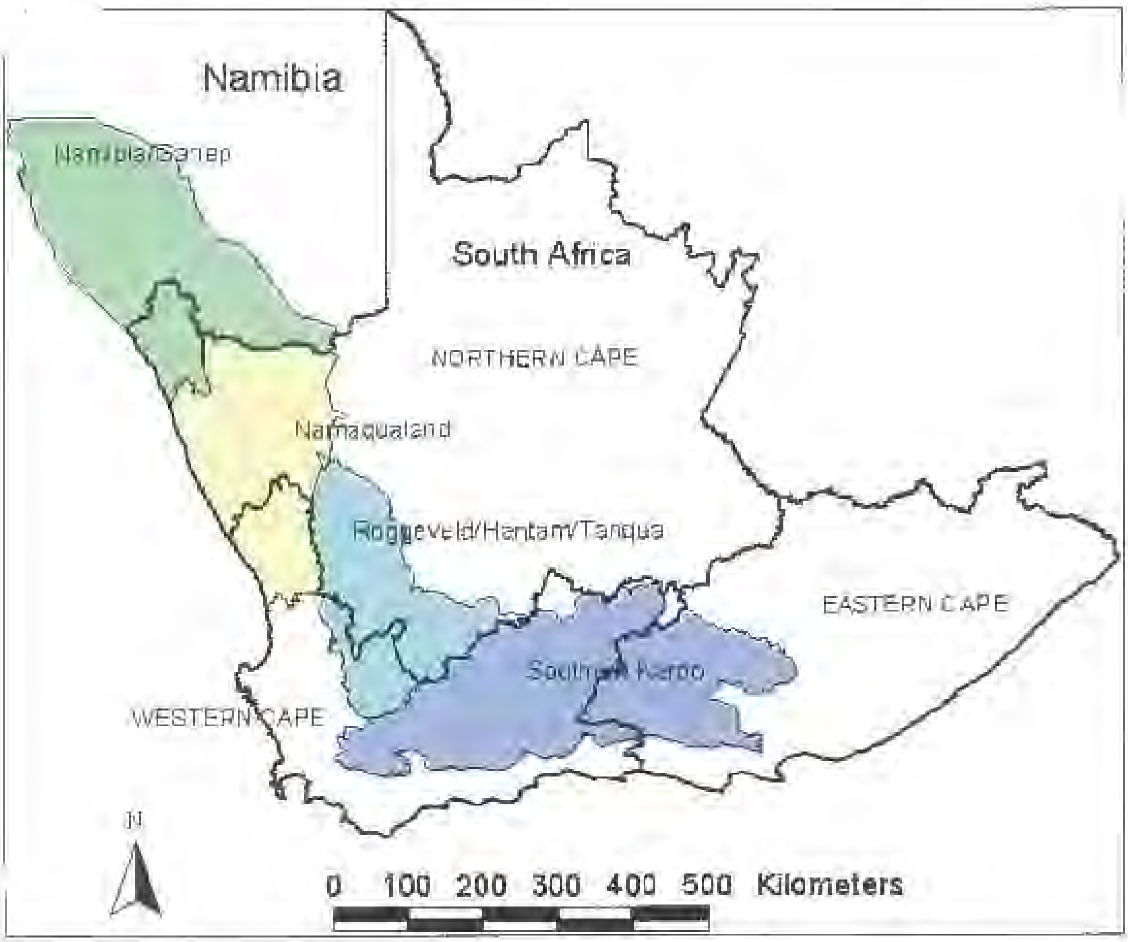


Figure 1.2: The Succulent Karoo Ecosystem Plan (SKEP) planning domain with the four sub-regions indicated.

Introduction.

Rainfall throughout the Succulent Karoo (SK biome) is less than 400 mm per year and occurs predominantly in winter. During summer, temperatures in excess of 40 °C are common (Desmet & Cowling, 1999; Myers *et al.*, 2000). The terrain of the SK biome is flat to gently undulating such as on the west coastal platform of the Knersvlakte and Tanqua Karoo. Hilly and more rugged topography occurs in Namaqualand, the Robertson and Little Karoo and parts of the Western escarpment. Altitudinal range is from sea level to about 1 500m, but most of the area lies below 800m (Low & Rebelo, 1996). The largest drainage systems are the Tanqua-Doring – Olifants rivers and the Gouritz river and its relevant tributaries. Most other rivers are small west-flowing systems including a relatively short section of the Orange river. The majority of river courses in the biome contain short-lived seasonal rivers (Rutherford & Westfall, 1986).

The geology of the SK biome includes shale, granite, quartz, and limestone. Quartz patches (desert pavement formed by a dense layer of white quartz pebbles) are scattered throughout the biome especially in the Knersvlakte and Little Karoo (Milton *et al.*, 1997; Schmiedel & Jurgens, 1999). Other geological units are the old basement complexes followed by the Ecca Group and Dwyka Formation of the Karoo Sequence, the Quartenary and Tertiary deposits and the Gariep Group of the Damara Supergroup (Rutherford & Westfall, 1986). The SK biome soils are generally lime-rich, weakly developed soils on rock (Dean & Milton, 1999). Other soil groups include sands, undifferentiated alluvial plains and neutral soils of the (red, yellow and grey) latosols plinthic catena (Rutherford & Westfall, 1986).

Plant biodiversity of the Succulent Karoo biome

The plants of the SK biome have adapted to cope with the summer aridity and the cool winter growing season (Esler, 1993; Low & Rebelo, 1996; Milton *et al.*, 1997). The vegetation is dominated by chamaephytes, which are often succulent shrubs, of which the Mesembryanthemaceae and the Crassulaceae are particularly prominent (Milton *et al.*, 1997). Phanerophytes are rare but include the well-known succulent tree, *Aloe dichotoma* in the north of the SK biome (Rutherford & Westfall, 1986). The SK biome, especially Namaqualand, is home to a phenomenal diversity of geophytes (for example in the genera *Gladiolus*, *Sparaxis*, and *Bulbinella*). The SK biome contains 4 849 vascular plant species of which 1940 are endemic to the biome (Driver *et al.*, 2002).

History of land use practices in the SK biome

Hunter-gatherers of the Later Stone Age (LSA) began occupying the SK biome in larger numbers from approximately 21 000 years ago, after the cooler glacial conditions that preceded this time abated. These people hunted zebra, wildebeest and eland on the coastal lowlands and played a part in the extinction of large grazing herbivores such as the hartebeest and the giant buffalo, which were the components of this LSA fauna (Deacon, 1992).

A significant event, which facilitated the expansion of the human population in the SK biome, was the introduction of the first domestic sheep, and later cattle and goats, by the Khoikhoi herders about 2 000 years BP (Deacon, 1992; Boonzaaier *et al.*, 1996). The effects that herders had on the SK biome's landscapes and ecology are not quantifiable, but given the estimated numbers of humans (50 000), cattle (250 000 to 500 000) and sheep and goats (up to 1 million) by the mid seventieth century, this must have been significant (Deacon, 1992). Soil erosion from diminished vegetation cover would have been an important disturbance factor (Deacon, 1992).

In 1679 the Dutch authorities issued permits for land occupation to colonial settlers and by 1760 farming extended throughout much of the SK biome. The colonists of the Western Cape, who significantly influenced natural processes, and reshaped the region's landscapes, introduced two important agricultural developments to the region. These developments were firstly the introduction of settled agriculture and secondly the use of the plough to cultivate the soil and grow crops. The awarding of more permanent holdings to encourage farmers to settle away from Cape Town (Penn, 1986) resulted in individual ownership of areas with the concomitant potential for overstocking and overgrazing.

Although much agricultural transformation had already occurred in the 18th and 19th centuries, the 20th century saw an increase in this trend. Dramatic changes in agricultural land use were introduced after the 1940s with the introduction of mechanized agriculture, which saw an increasing shift from veld-based grazing to the cultivation of soil for artificial pastures and cereal crops (Hoffman *et al.*, 1999). This shift is likely to have been enhanced further by incentives to clear land for cultivation, which were made possible by legislation promulgated in 1930, which served to protect South African producers (Hoffman, 1997). All the land use practices (tourism, mining, grazing, and cropland), however, have changed dramatically in the last 20 years.

Land use practices in the SK biome

A detailed analysis of each of the main land use practices is presented in chapter 2. What follows is a brief summary of land use practices in the SK biome.

Urban settlement

Although it only occurs in a fraction of the area, urban settlement has been highlighted as one of the threats to the biodiversity of the SK biome. This is due to population growth, which leads to agriculture expansion to meet the demand for food. This means that areas of natural habitat are converted to other land uses. Collection of plant material for the medicinal and horticultural trades also result from the expansion of urban settlements. This reduces the abundance of certain species in the wild and may lead to extinction of some (Krohne & Steyn, 1990).

Mining

Although it only affects 1% of the biome, mining is a significant threat to biodiversity in the SK biome as it irreversibly transforms landscapes making them unsuitable for plants (Milton *et al*., 1997). Limestone mining in the Knersvlakte is of great concern as limestone is a very unusual habitat in the SK biome and supports a unique and rare flora (Boonzaier *et al*., 2002). The entire northern extension of the SK biome is mineral & diamond rich and with various mining applications pending throughout the region, transformation as a result of mining operations represents a great threat. New markets and discoveries of base metals such as zinc and copper as well as gypsum and quartz deposits continue to transform large areas of limited habitat types (Boonzaaier *et al*., 2002).

Agriculture (cropland and livestock production).

Agriculture, which includes cropland and grazing, is the dominant land use in the SK biome. Due to the lack of water, however the area has little agricultural cropland potential. The mismatch of agricultural land use practices with the production potential of the land has contributed to wide spread desertification in the arid and semi arid parts of South Africa (Hoffman *et al*., 1999).

There are two main agricultural production systems in the SK biome: namely communal areas and private farms. These two systems differ in history and land use practices. Overgrazing on communal rangelands threatens the biodiversity of this region, as it results in a change in plant composition with an increase in poisonous plants (Hoffman *et al*., 1999; Todd & Hoffman, 1999). There are currently 14 communal areas in Namaqualand (Hoffman *et al*., 1998). These communal areas are Concordia, Komaggas, Leliefontein, Mesklip, O'Kiep/Nababeep, Pella, Pofadder, Port Nolloth, Richtersveld, Rietpoort, Soebatsfontein, Springbok, Steinkopf, and the Witbank farms (Hoffman *et al*., 1999, chapter 3). Both biophysical (rainfall, soil, topography, vegetation, and climate) and social driving forces (economic, increasing population density, land tenure regime and institutional capacity) affect the way in which the land is used in the communal areas.

The largest part of the land in the SK biome currently belongs to private landowners where extensive sheep and goat and to lesser extent cattle farming on natural rangeland remains the major agricultural practice. The distribution of different livestock breeds in the SK biome is determined largely by climate, especially rainfall and vegetation condition (Hoffman *et al.*, 1999; chapter 3).

Conservation

The SK biome has been internationally recognized as a biodiversity hotspot (Myers *et al.*, 2000; Driver *et al.*, 2002). The conservation status of this region is, however, very poor, with less than 5% of the area protected (Todd & Hoffman, 1999; Driver *et al.*, 2003) and only 3.5 % of the biome conserved in statutory reserves. These reserves protect only 90 of the 900 Red Data Book plant species (Driver *et al.*, 2002). With the lack of protected areas and the high levels of endemism (40%), which characterize the SK biome, the current and future land use practices are likely to have an important influence on the future conservation of the area (Todd & Hoffman, 1999; chapter 2 & chapter 4).

Land use impact and threats

Today many land use practices are threatening the natural resources of this biome. These include unsustainable agricultural practices, ill considered urban, industrial and mining expansion, and the removal of plants by traders and unscrupulous collectors (van Jaarsveld *et al.*, 2000). Alien plants in the SK biome include the tree *Prosopis* and grasses such as *Bromus tectorum* (Milton *et al.*, 1997). Invasive alien plants and mammals also pose a threat to many areas in the SK biome including the *Sperregebiet* in southern Namibia which supports more alien mammals than in any other area in Namibia (Driver *et al.*, 2002).

Unsustainable agricultural practices impact on biodiversity in various ways. Small stock farming is ubiquitous in the semi arid region and provides many people with their only source of income. Heavy livestock grazing, however, negatively affects the vegetation resources with a shift from palatable perennials to unpalatable plants particularly in the overstocked communal lands. Heavy grazing in the communal lands has also resulted in a reduction in total vegetation cover (Todd & Hoffman, 1999). This agrees well with other studies in arid and semi-arid regions whereby heavy grazing was associated with a shift from perennial to annual vegetation (Hoffman *et al.*, 1999; Kuiper & Meadows, 2000).

Mining impacts also have serious implications regarding the diversity of plant species. Large-scale mining completely transforms landscapes and makes rehabilitation very difficult (Driver *et al.*, 2003).

Why has this study been undertaken?

Most South African studies on land use practices (Hoffman *et al.*, 1999; Driver *et al.*, 2003) are not spatially explicit. More research on the spatial information is needed in order to understand current land use patterns and how they are likely to change in the future. Spatially-explicit information on current and future land use patterns can be used by ecologists, environmentalists and students conducting research, land use planners (including conservation planners), and affected parties in order to prioritise research and actions for the rich, yet threatened, flora and fauna of South Africa. Furthermore, there are no modelling studies of future land use practices. This study provides spatial information on current land use practices (including livestock production) and also develops a statistical GIS model predicting the agricultural potential of the SK biome and likely future trends.

Aims of the study and key questions

The overall aim of this study was to map the extent of current land use practices in the SK biome and to derive agricultural land use scenarios for 2010.

In particular, this study aimed to achieve the following:

- To assess the extent of current land use patterns (urban settlement, mining, cropland, grazing, and conservation) in the SK biome with an emphasis on livestock production systems in Namaqualand.
- To develop and compare future land use scenarios based on expert knowledge and statistical modelling in a Geographical Information System.

This dissertation answers the following questions:

- What are the main land use types and subtypes in the SK biome?
- What is the extent of each land use type in each sub-region (for South Africa only i. e. Gariep/Namaqualand, Roggerveld\Hantam\Tanqua, and Southern Karoo)?
- What is the extent of livestock production in the Namaqualand sub-region and how does this compare to recommended thresholds set by the Department of Agriculture?
- How do stocking rates differ between the communal areas and privately owned farms in the Namaqualand sub-region?
- Can statistical models and GIS be used to derive spatially explicit predictions of future agricultural land use in the SKEP domain?

Thesis structure

The thesis consists of three main chapters and a general conclusion.

Chapter 2: Current extent of land use practices in the Succulent Karoo biome and Succulent Karoo Ecosystem Plan (SKEP) planning domain.

This chapter contains a descriptive account of the current land use practices in the Succulent Karoo biome and SKEP planning domain.

Chapter 3: Livestock density in Namaqualand: a comparison of stocking density on private and communal areas.

This chapter provides a detailed assessment of the number of small stock (sheep & goats) currently occupying the communal areas and privately owned farming areas of Namaqualand. It compares these two tenure systems in terms of the recommended grazing capacity estimates suggested by the Department of Agriculture in the region.

Chapter 4: Future predictions of agriculture in the Succulent Karoo Ecosystem Plan (SKEP) planning domain.

This chapter provides a model of land use change in the Succulent Karoo biome and an evaluation of environmental driving forces that could influence agricultural change in the region in the future.

Chapter 5: General Conclusion

This chapter details the main findings and conclusions of this study. It also points to the key policy implications of this work for SKEP as well as for other land management initiatives and institutions.

CHAPTER 2 Current extent of land use practices in the Succulent Karoo biome and Succulent Karoo Ecosystem Plan planning domain.

Introduction

The earth's land surface has been substantially transformed due to the impact of urbanisation, industrialization, cropland and livestock production (White *et al.*, 1997). The transformation of natural vegetation to other land uses, such as those mentioned in chapter 1; represents the most important threat to biodiversity. Such biodiversity must be maintained and conserved as it provides essential goods and services and is of aesthetic value (Wessels *et al.*, 2002).

Most of the biodiversity-rich areas in the world face the problem of limited resources for conservation, and there is an urgent need for identifying priorities for conservation actions (Myers *et al.*, 2000). Conservation efforts have focused on maintaining biodiversity primarily by minimizing exposure to human activities through the establishment of networks of protected areas (Myers *et al.*, 2000). The long-term conservation of biodiversity is not dependent only on the establishment of protected areas, but also on maintaining hospitable environments and viable populations within managed land between protected areas (White *et al.*, 1997). Understanding the land use pattern and its drivers that have occurred in the Succulent Karoo biome, provides a useful starting point for outlining future research needs, establishing conservation goals and targeting ecological restoration efforts, and can be used immediately in local land-use planning efforts to conserve biodiversity (Hoffman & Ashwell, 2001; Driver *et al.*, 2003).

The study area, which is derived from the Succulent Karoo Ecosystem Plan planning domain (excluding Namibia) (hereafter referred to as the SKEP domain) covers approximately 192 205 km^2 while the Succulent Karoo biome (excluding Namibia) (hereafter referred to as the SK biome) (Rutherford, 1997) is 91 839 km^2 in extent. Namibia has been excluded from this analysis because of the difficulties in obtaining comparative land use data. Three sub-regions of the SKEP domain are recognized in the South African portion of the SKEP domain. These are Gariep/Namaqualand, Roggeveld/Hantam/Tanqua, and Southern Karoo. Current land use practices, especially livestock production, are of primary concern to the biodiversity of the SK biome where extremely high levels of plant endemism are found. These endemics are concentrated in four centres that fall within the SKEP domain. Three of these centres are in the Gariep/Namaqualand sub-region and one in the Southern Karoo sub-region (van Wyk & Smith, 2001). Local and point plant endemics, however, are found throughout the region (Desmet & Cowling, 1999).

While livestock production is the dominant land use practice not all land is managed in the same way. Two main forms of land tenure occur in the region, namely communal and privately-owned (freehold) farming systems. These farming systems differ considerably in land management which leads to large differences in stocking rates between the two farming systems (see chapter 3). Stocking rates generally increase with increasing annual rainfall (Van Den Berg, 1983). Over the last 30 years, stocking rates are thought to have been maintained very close to the recommended levels in privately-owned farming areas (Hoffman *et al.*, 1999). In the communal farming areas, particularly in Namaqualand, however, animals are kept for a wide variety of purposes such as for meat, milk, transport, and investment. There is thus little incentive for farmers to follow a market-based approach to their farming (Todd & Hoffman, 1998). Stocking rates are generally higher than those in privately-owned farming areas, which are broadly equivalent to the recommended grazing capacity (Hoffman & Ashwell, 2001; but see chapter 3).

Understanding the current pattern of land use practices and how land use patterns respond to environmental drivers is a research question of considerable importance in the SK biome. This chapter presents the results of current land use patterns in the SKEP domain, SK biome and the sub-regions of the SKEP domain. It aims to answer the following questions:

1. What are the main land use practices in the region?
2. How can these land use practices be integrated within a consistent and hierarchical classification system?
3. What is the extent of each land use practice in the SKEP domain, SK biome and in each sub-region of the SKEP domain?

Table 2.1: Reclassified land use categories in the Succulent Karoo biome using a hierarchical classification system based on Thompson (1996). Land use classes are arranged from most to least transformed areas.

Broad land use categories	Land use sub categories	Source of data
Urban settlement	Urban	ENPAT[1]
Mining	Diamonds Unspecified Heavy metal Other	NLC[2], SKEP[3] coordinators, GEOSCIENCE
Cropland	Wheat (monoculture) Wheat (polyculture) Lucerne (monoculture) Lucerne (polyculture) Orchards (export table grapes, wine, fruits, olives) Unspecified crop	ENPAT, NLC, SKEP coordinators
Grazing	<6.0 ha\LSU[5] 6.1-10.0 ha\LSU 10.1-17.0 ha\LSU 17.1-33.0 ha\LSU >33.0 ha\LSU	CSIR, Scholes (1998)
Conservation	National Park National Heritage Site State Forest Provincial Reserve Private Nature Reserve Municipal Nature Reserve Mountain Catchment Area Wilderness Area Conservancy Unspecified	ENPAT, NLC, SKEP coordinators

1 ENPAT= Environmental Potential Atlas of South Africa
2 NLC= National Land Cover
3 SKEP coordinators Succulent Karoo Ecosystem Plan coordinators who gathered data on different land use practices in regional workshops
4 CSIR Council for Scientific and Industrial Research
5 LSU = large stock unit

Methodology

Source of data: land use

The current extent of land use practices, namely, urban settlement, mining, cropland, livestock production and conservation were mapped at 1:250 000 scale from available knowledge of the region. Sources were the Succulent Karoo Environmental Plan (SKEP) workshops held during 2002, the National Land Cover (NLC) dataset, the Environmental Potential Atlas of South Africa (ENPAT 2001), and the Council for Scientific and Industrial Research (CSIR) grazing capacity model.

SKEP workshops

The first dataset was derived from a series of SKEP workshops held in the three sub-regions of the SKEP domain during 2002. Participants were selected from different government departments as well as local farmers, with expert information about land use practices in the region. At each workshop the coordinators were required to draw a polygon or a point on an overlay map identifying areas of current land use (e.g. cropland). The overlay map was digitized using Arc View GIS 3. An accompanying datasheet gave information about each polygon. An attribute table containing a more detailed breakdown of each land use type (e.g. specific crop-type cultivated) was added. The major land use practices identified in this process were urban settlement, mining, cropland, livestock production and conservation.

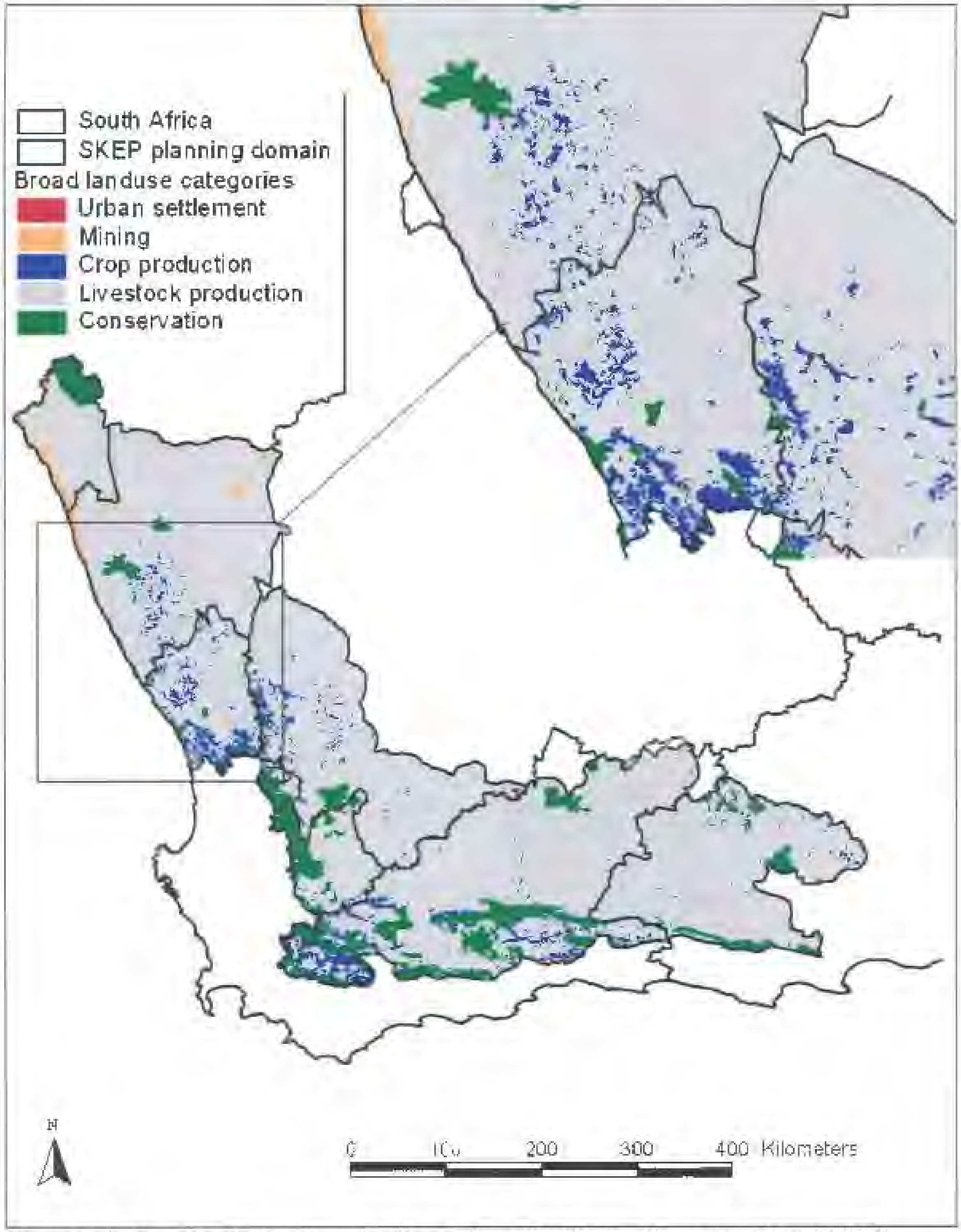


Figure 2.1: Broad land use categories for the Succulent Karoo Ecosystem Plan (SKEP) planning domain. Thpe enlarged section indicates an area where all five-land use categories are in evidence.

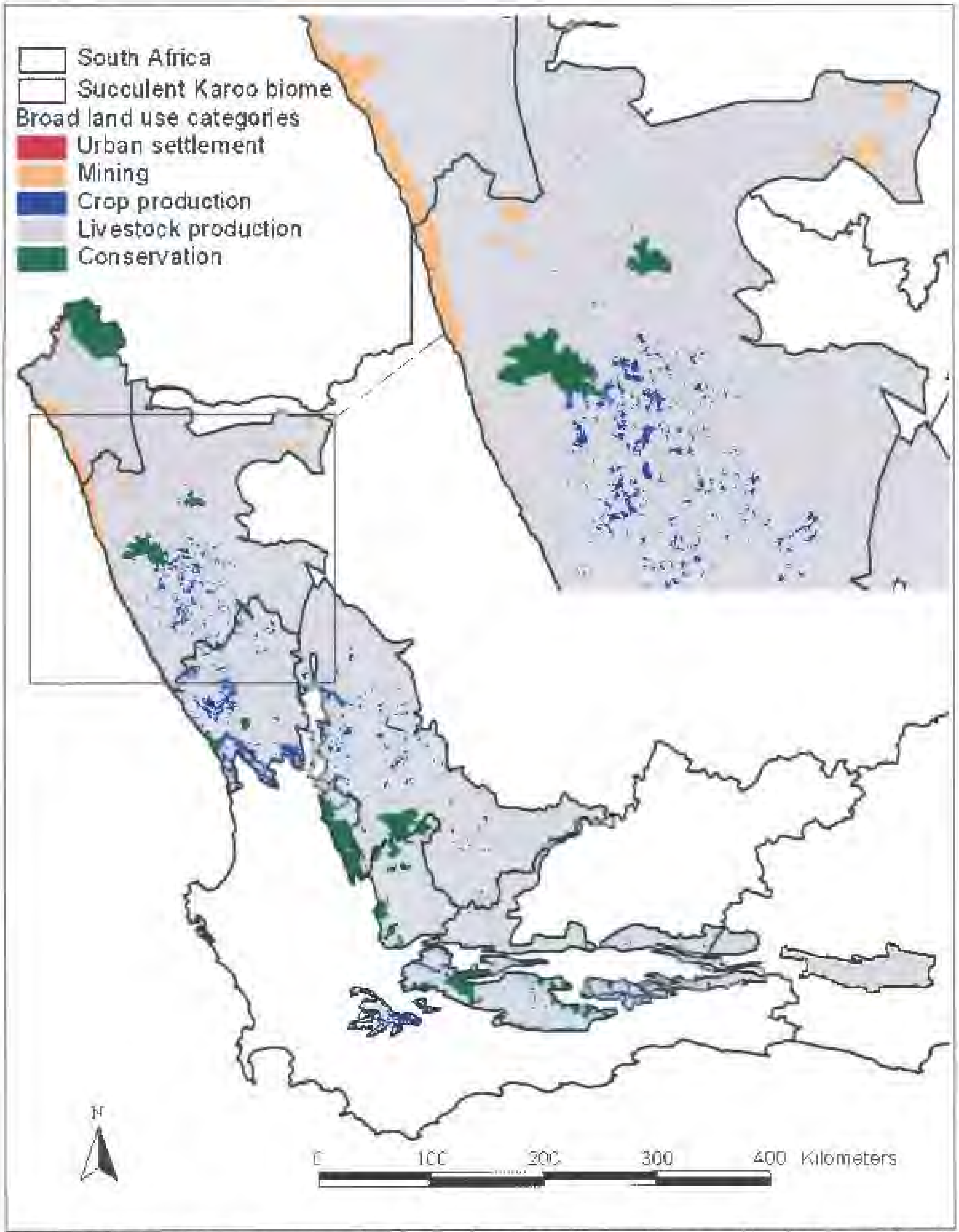


Figure 2.2: Broad land use categories for the Succulent Karoo biome outlined in broad detail above. The enlarged section indicates an area where all five-land use categories are in evidence.

National Land Cover (NLC) dataset

The NLC data (see Thompson, 1996) was used as the base map for all the land use practices that were digitised from the SKEP data. The information for each land use practice that fell within the SKEP domain was clipped from the NLC data. The NLC data identified the following land use categories: commercial/industrial, residential, mining, cultivated land, forestry, commercial farming, subsistence farming, conservation and vacant /unspecified land. The NLC data categories and boundaries were refined in the SKEP workshops.

ENPAT dataset

The ENPAT (2001) dataset was used for the urban settlement layer of the region and for categorical environmental factors such as geology and soil.

CSIR dataset

Grazing capacity data was obtained from the CSIR, where Scholes' (1998) model was used for the recommended grazing capacity in South Africa. This model used raster modelling procedures and it was important because it eliminates small polygons caused by minor boundary mismatches, and it guarantees that the mapped areas are homogenous within a given range limit (Scholes, 1998). The South African grazing capacity layer was clipped to the SKEP domain and then combined with the layers obtained from the SKEP domain, NLC and ENPAT data sources to produce a final GIS layer with urban settlement, mining, cropland, livestock production and conservation categories.

Classification system

The SKEP maps (Fig. 2.1 & Fig. 2.2) were classified according to their broad and relevant land use classes and from this I developed a hierarchical classification system. A hierarchical classification offers a high degree of flexibility and also provides the user with the ability to accommodate different levels (or sources) of information. Broad level classes represent aggregates of more detailed (often user-specific) sub-classes, or several sub-aggregate classes that can be re-combined into completely new aggregate classes (Thompson, 1996). I used the following five broad classes: urban settlement, mining, cropland, livestock production, and conservation, each of which was then subdivided into between 1 and 5 sub-classes (Table 2.1, Fig. 2.1 & Fig.2.2).

The category urban settlement includes rural settlements and urban areas, minor roads and construction sites. Mining includes quarries and mines, which were classified according to the mineral extracted (e.g. diamonds and heavy metals). Cropland production consists of the cultivation of crops, including land used for annual field crops such as wheat, perennial field crops (e.g. lucerne) and, tree and shrub orchards. Livestock production represents the land used for animal production on natural veld (desert, grassland, shrublands) and includes planted pastures used for grazing animals. Five livestock production sub-classes were decided according to the grazing capacity estimates derived from Schules (1998). Conservation areas consist of 10 sub-categories including proclaimed national, provincial and municipal conservation areas as well as state land (Hoffman & Ashwell, 2001).

GIS and statistical approach

Protocol

The GIS layers were joined together using the union tool in Arc View 3.2. The GIS layers were then clipped for the SKEP domain and SK biome. GIS layers for each land use category with its associated sub-category and the broad land use layer for SKEP and the SK biome were produced.

I calculated the area (in ha) of each land use category and sub-category using XTools in Arc View. Then the statistical attribute table containing information on the total area covered by each broad land use and its sub-category was exported to an Ms Excel spreadsheet. I produced summary graphs and tables in order to understand the current extent of each land use category and sub-category in the region.

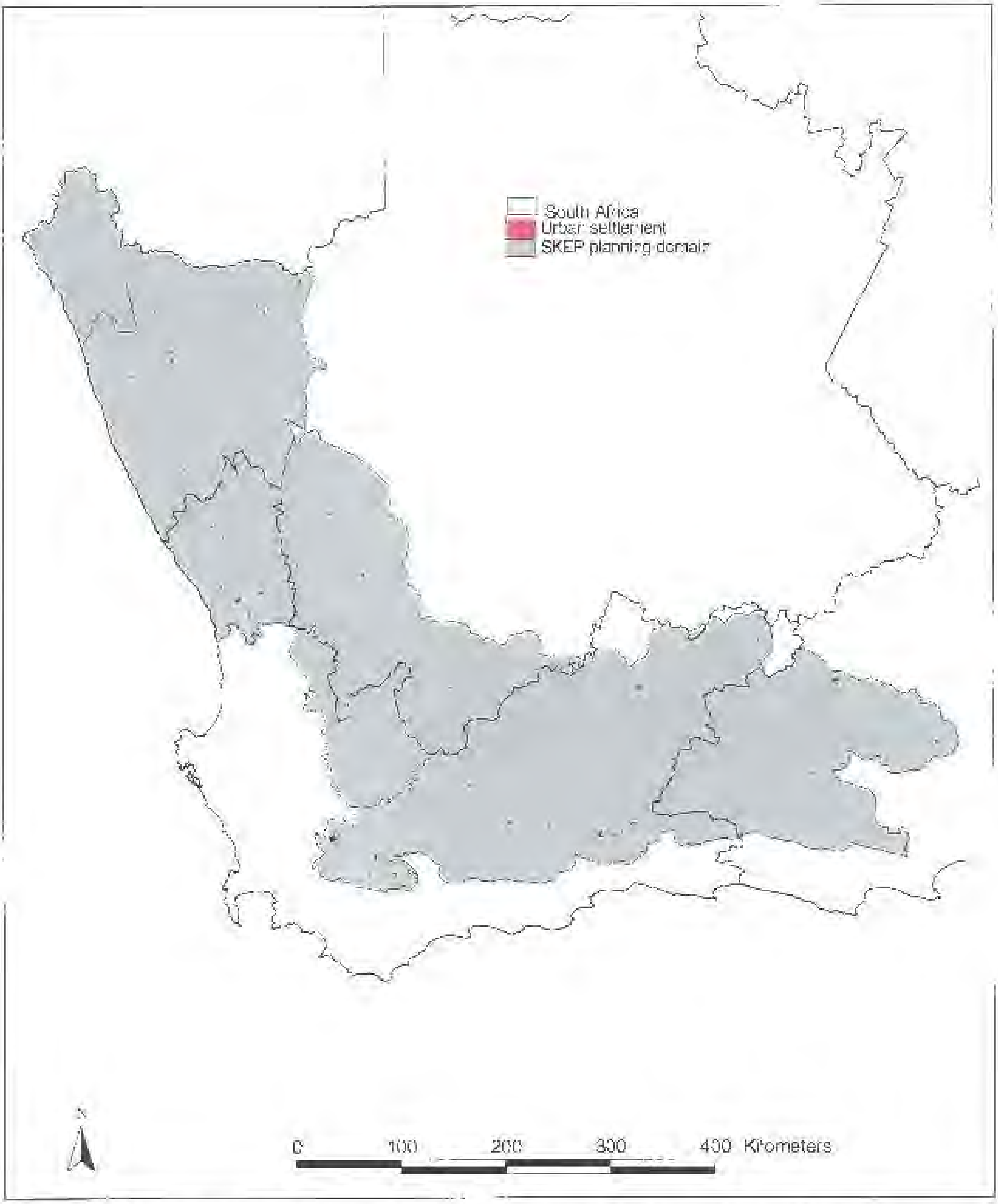


Figure 2.3: Map of the SKEP domain showing current areas of urban settlement (data are from ENPAT, 2001).

Results

Urban settlement

Urban settlement comprises less than 150 km^2 of the SKEP domain and 76 km^2 of the SK biome (Fig. 2.1). The area occupied by urban settlement is highest in Gariep/Namaqualand and lowest in the Roggeveld/Hantam/Tanqua sub-regions.

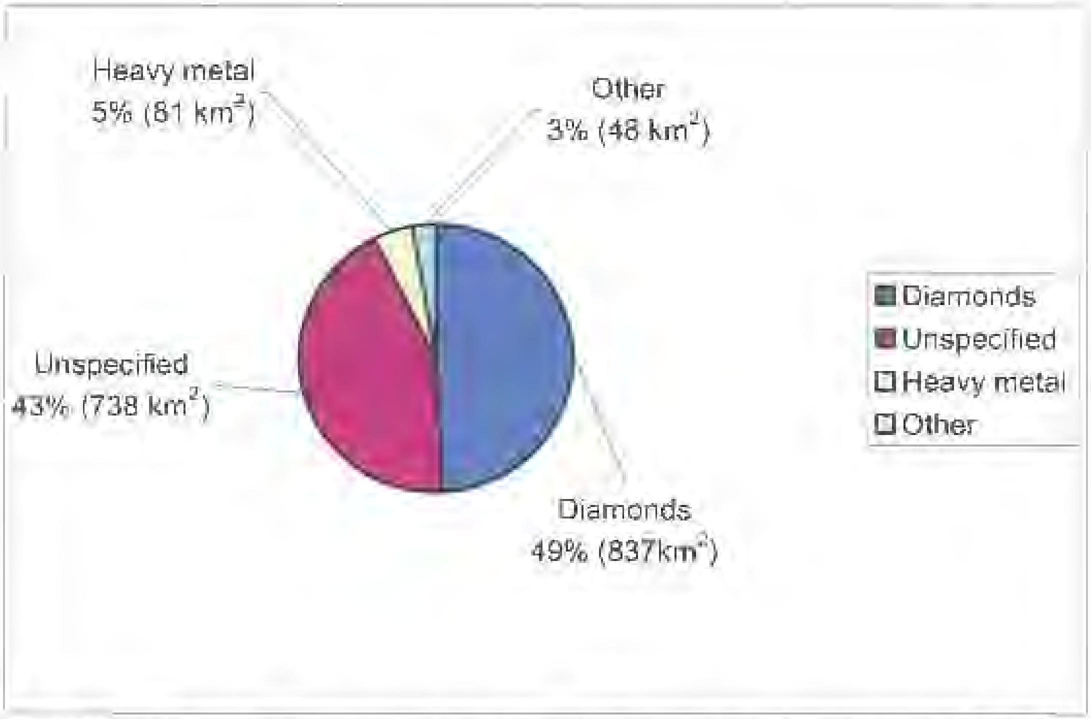


Figure 2.4: Percentage land covered by each mineral type for mining practices in the SKEP domain and SK biome. Since there is no difference in percentage values of the mined areas between the SKEP domain and SK biome, a pie chart has been used to display the results for both areas.

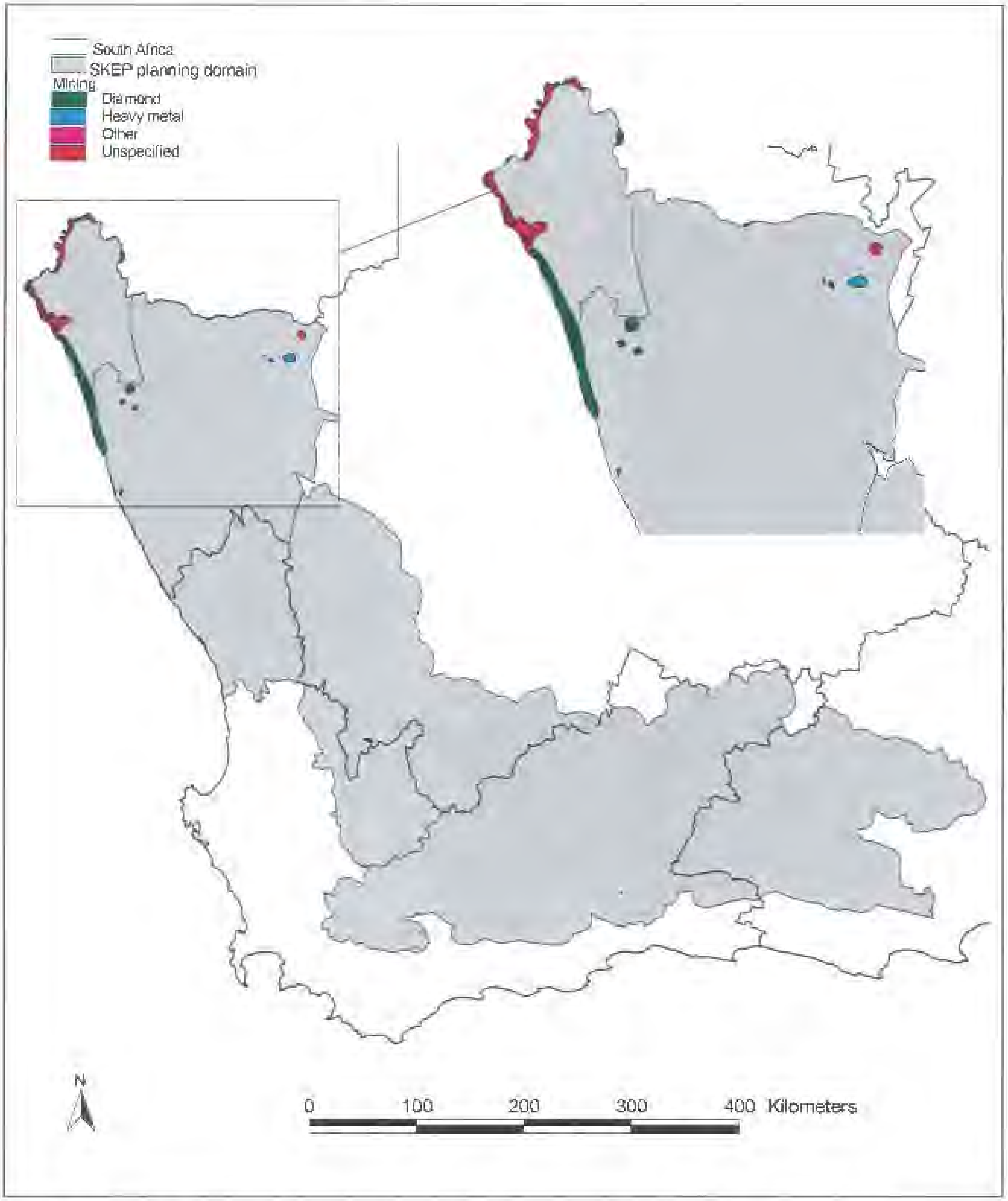


Figure 2.5: Map of the SKEP domain showing all the current mined areas. The enlarged area indicates that portion of the Gariep/Namaqualand sub-region where all four mining activities are undertaken.

Mining

Mining areas are found predominantly along the coast of the Gariep/Namaqualand sub-region. Diamond mining activities cover more than half (837 km^2) of the total mining area in the SK biome (Fig. 2.4 & 2.5).

Cropland production

Cropland production areas are distributed evenly across the entire landscape of the SKEP domain, SK biome and in the SKEP sub-regions (Fig. 2.8). Cropland areas only constitute 6 784 km^2 of the SKEP domain and 3 046 km^2 of the SK biome (Fig. 2.6 & 2.8).

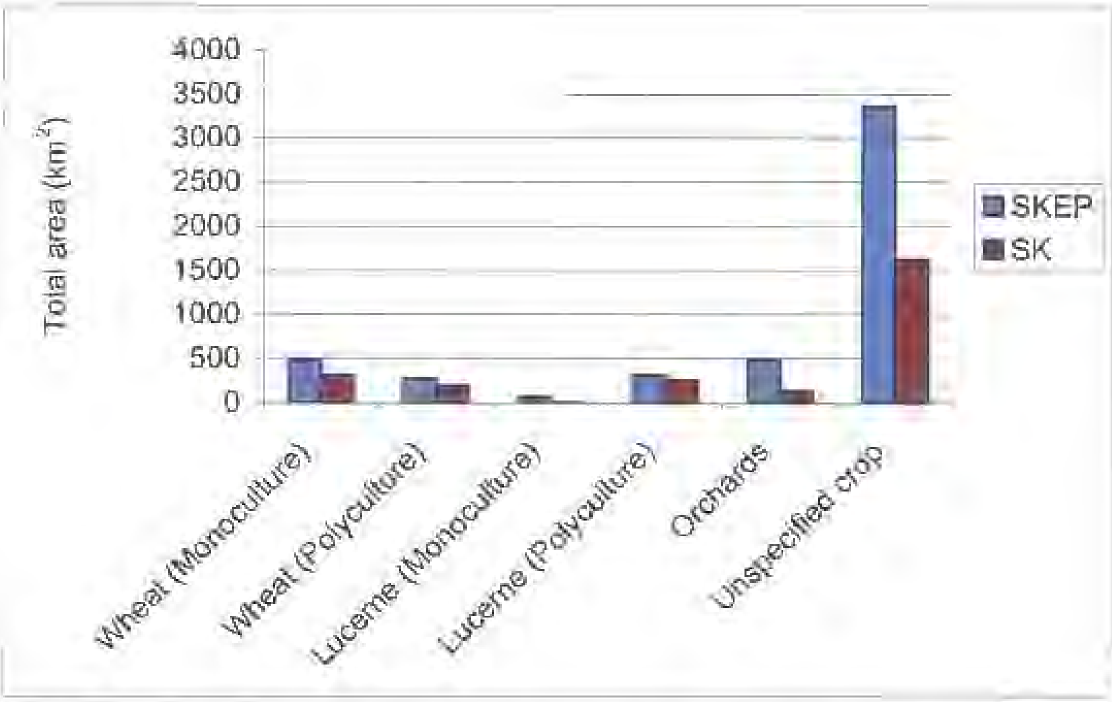


Figure 2.6: Total area covered by each crop type in the SKEP domain and SK biome

Wheat (as a monoculture crop) covers 10% of the cropland areas in the SKEP domain, and covers 6% in the SK biome. Orchards cover 10% of the cropland areas in the SKEP domain and only 3% in the SK biome. Wheat is grown primarily in the higher-lying mountains of the Namaqualand sub-region (Fig. 2.8). Other crop types cover only a small area (< 7%) in both the SKEP domain and the SK biome. For example, lucerne (as a monoculture crop) is the least cultivated crop and accounts for only <1% of the SKEP domain and the SK biome. About 67% of the SKEP domain and 33% of the SK biome cropland production areas were classified as unspecified.

Livestock production

Livestock production is the major land use type in the SKEP domain, SK biome and SKEP sub-regions (Table 2.2 & Fig.2.7). The grazing capacity data derived from Scholes' (1998) model, shows that 126785 km^2 of the SKEP domain and 65461 km^2 of the SK biome has a recommended grazing capacity of >33 square kilometer per large stock unit (km^2\LSU) (Fig. 2.7 & Fig 2.9). Areas with a recommended grazing capacity of 17.1 to 33.0 and 10.1 to 17.0 km^2/LSU are similar between the SKEP domain and the SK biome (10-11%). The areas with a high recommended grazing capacity (<6 km^2\LSU) (Fig 2.7 & Fig. 2.9) are relatively rare in the SK biome.

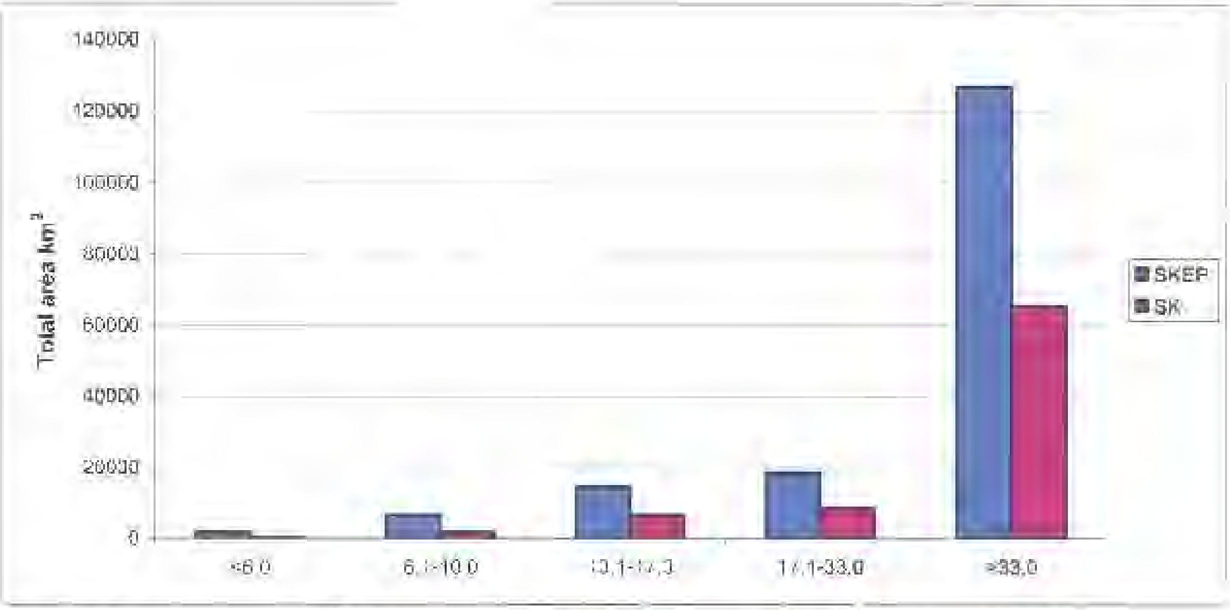


Figure 2.7: Total area (km^2) for each grazing capacity class (km^2/LSU) in the SKEP domain and SK biome

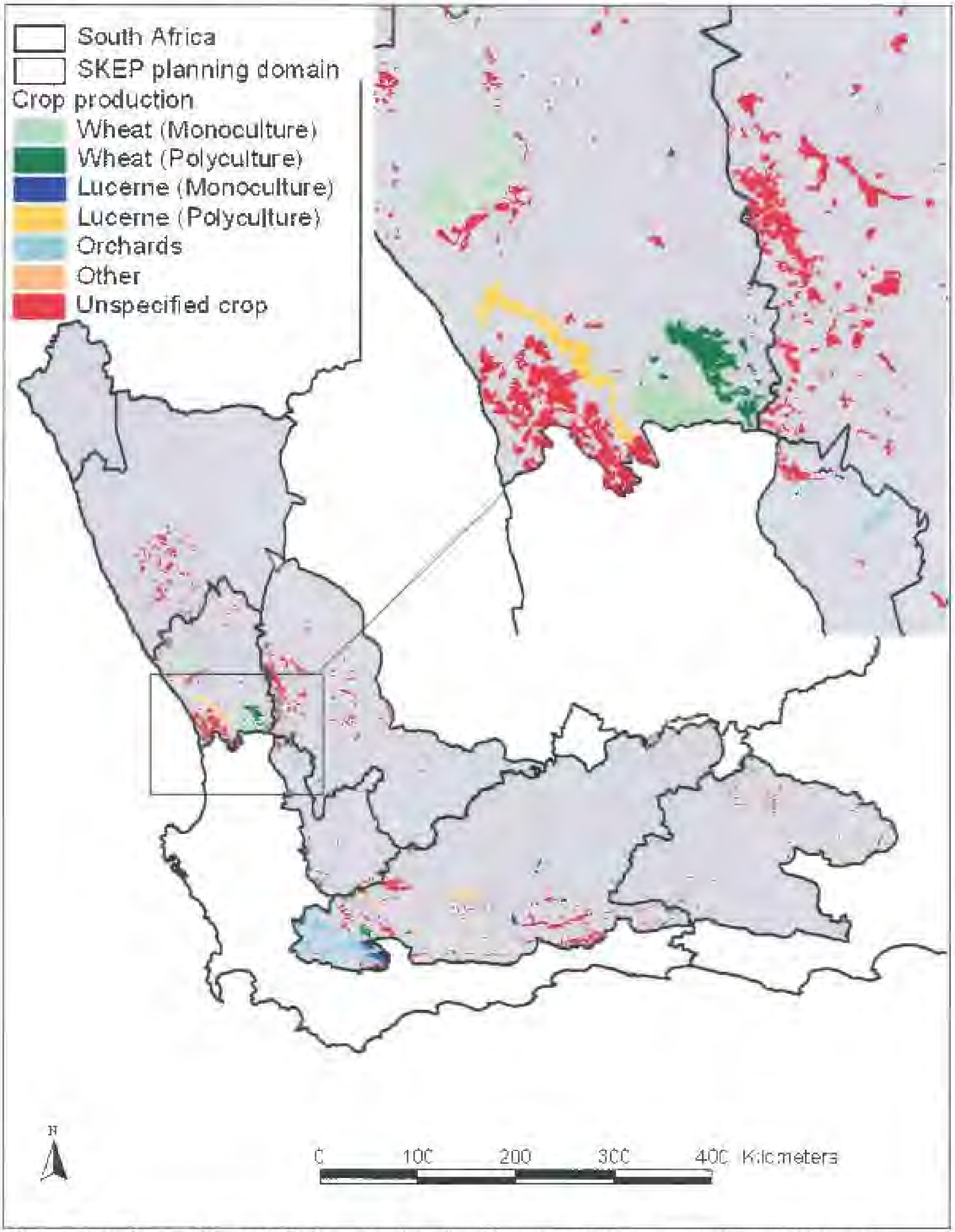


Figure 2.8: Map of the SKEP domain showing the areas that are currently used for crop production. The enlarged section indicates an area where all seven cropland sub-types are present.

Conservation

With 4.8% conserved in total (Table 2.2), only 3.5% is formally protected in statutory reserves (national parks and provincial reserves). The remaining conservation areas are non-statutory reserves such as municipal reserves and conservancies.

Discussion

Land use classification

It was essential for developing the hierarchical structure of the land use data in which broader categories and higher types in the classification could be more finely divided to support more detailed use. At a finer scale land use subcategories were consistently related to the broad land use categories (Table 1). This classification system enables us to target the sites that are heavily transformed based on current land use. Therefore subdividing land uses into sub-categories was useful, and more spatial information is required on grazing status as most of the land is used for grazing – Scholes' is only a model.

However, about 67% of the SKEP domain and 33% of the SK biome cropland production areas were classified as unspecified. The unspecified cropland areas were cultivated areas identified in the National Land Cover database, but for which specific crops could not be identified during the SKEP coordinator workshops.

Current land use practices

Current land use practices pose a major threat in the SK biome, SKEP domain, and the SKEP sub-regions. Although some of these land use practices, such as urban settlement and mining, represent smaller areas when compared to other land uses, they can lead to significant biodiversity loss in the regions (Cowling & Lombard, 1998). The conversion of natural habitat to other land use is greatest in the Southern Karoo sub-region, as the sub-region is characterized by a relatively high rainfall and rich soils (see chapter 4). Results indicate that the Southern Karoo sub-region is heavily grazed and cropped (Fig. 2.8 & Fig. 2.9). These areas possess also high-level of biodiversity, and according to previous researchers, major threats to biodiversity are found in areas where there is human interaction (Cowling *et al.*, 1999). In this regard community-based conservation can be of best practice in the sub-region.

Mining areas are mainly found along the coast of the Gariep/Namaqualand sub-region. Diamonds are mined predominantly within low-lying valley environments in the SK biome (Pallet, 1995). These valleys were mined primarily by diamond companies in the early days of colonialism and have been completely stripped of their sparse vegetation cover (Pallet, 1995). Vegetation growth and recovery after mining is often limited as a result of aridity, wind and nutrient-poor soils (Milton, 2001).

Most high rainfall areas are transformed by cropland production in the SKEP domain, SK biome and SKEP sub-regions (Fig. 2.8). Among the crops grown in these areas wheat is grown primarily in the higher-lying mountains of the Namaqualand sub-region (Desmet & Cowling, 1999). Currently, the Southern Karoo has been subjected to the highest levels of transformation by cropland production (Fig. 2.8). In addition to high levels of rainfall, previous studies has also shown that the proximity of perennial streams draining into the major basins where cropland occurs is also a contributing factor in the sub-region (Hilton-Taylor, 1994; Rebelo, 1997). The potential for cropland expansion in these areas is explored in detail in chapter 4.

A similar form of transformation has been seen in livestock production within the regions. The districts found at the arid end of the SK biome aridity gradient, tend to have a greater area of grazing land than the less arid magisterial districts. Therefore, the Gariep/Namaqualand, and Southern Karoo sub-regions (especially in the west) generally possess lower grazing capacities (Hoffman & Ashwell, 2001). Uncertainties in the livestock production analysis can be caused by the quality of the grazing capacity model that produced only one grazing capacity value for large regions such as Namaqualand. A preliminary evaluation of this model, done in the Eastern Cape, provided different results (T. Palmer, pers. com.). It has been suggested that a decrease in the stocking rate of the SKEP domain and the SK biome over the last 100 years reflects a decrease in the primary productivity of the region and this may reflect widespread desertification in the Karoo as a whole (Dean & MacDonald, 1994).

Given its global significance as a biodiversity hotspot (Cowling & Pierce, 1999), and its recognition as a conservation priority (Hilton-Taylor 1994; Rebelo, 1997), the Succulent Karoo biome is relatively poorly conserved (Cowling & Lombard, 1998). Perhaps of more concern is the fact that the formally protected areas do not adequately represents the biodiversity patterns and processes of the biome (Driver *et al.,* 2003).

Table 2.2: Summary statistics of the percent of area occupied by current land use practices in the SKEP domain, SK biome, and the SKEP domain sub-regions.

Broad land use categories						
Area	**Total area (km^2)**	**Urban settlement (%)**	**Mining (%)**	**Cropland (%)**	**Grazing (%)**	**Conservation (%)**
SKEP domain	192 000	0.1	0.9	3.5	87.6	8.0

SK biome	91 000	0.1	1.7	3.3	90.1	4.8
SKEP domain sub-regions						
Gariep/ Namaqualand	62 000	0.1	2.7	3.4	89.5	4.3
Roggeveld/Hantam/ Tanqua	44 000	<0.1	0.0	2.6	88.9	8.5
Southern Karoo	86 000	0.1	0.0	4.1	85.5	10.3

However, the current conservation status of the SK biome has been improved significantly in the last 20 years (Fig. 2.11). The Richtersveld National Park is currently the largest section of protected land within the Gariep/Namaqualand sub-region and was proclaimed in January 1994. It covers approximately 1 624 km^2 and remains the main tourist attraction within the area (Oppel, 2002). In Namaqualand there are two formally conserved areas: The Namaqua National Park (600 km^2), proclaimed in January 1994 and the provincial reserve Goegap Nature Reserve (150 km^2), which is comprised of several farms. The first farm, Karéhoute Kloof, was proclaimed on 17 August 1990 and the second, Melkboschkuil on 12 April 1994 (Boonzaaier, *et al.*, 2002).

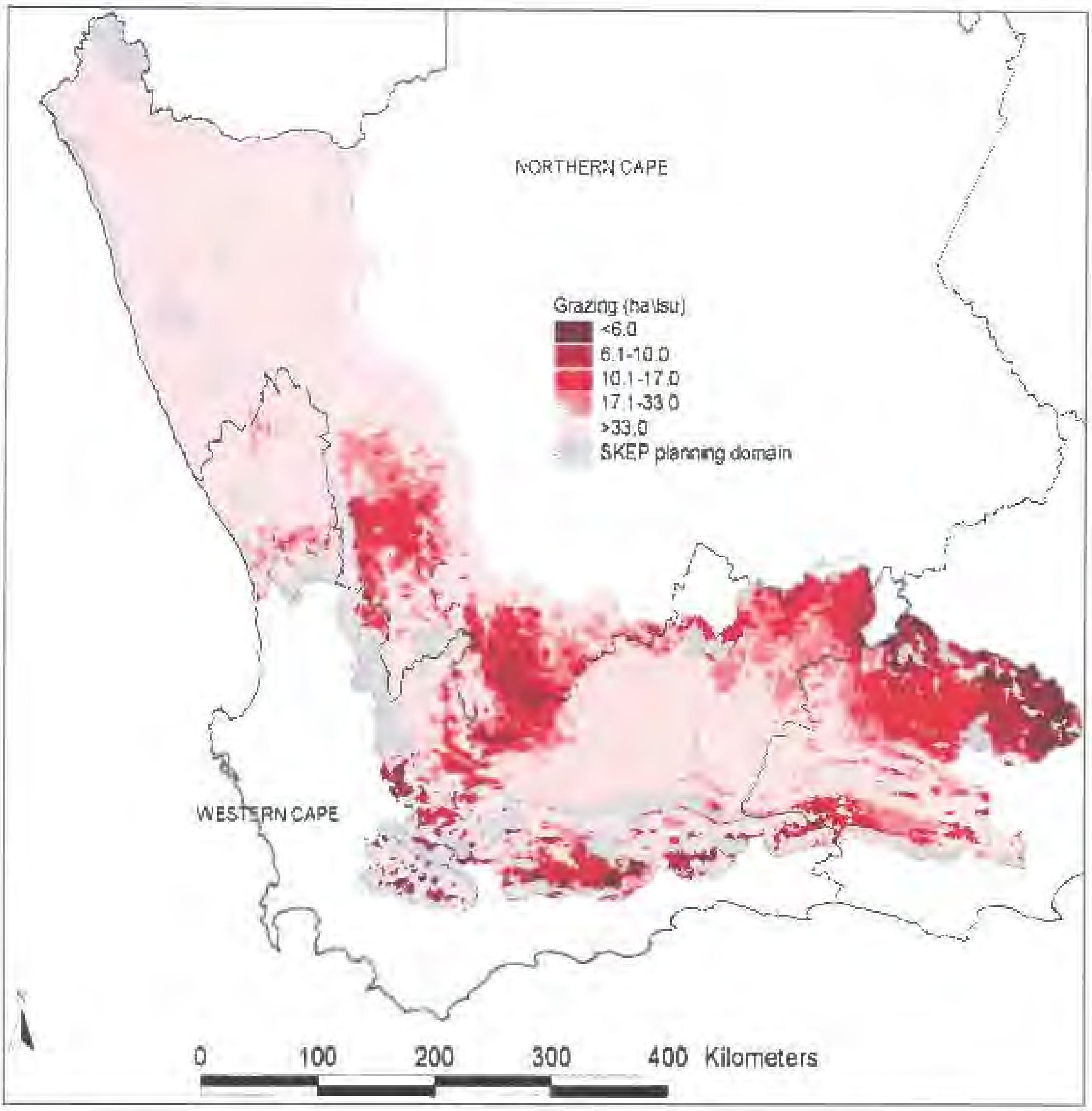


Figure 2.9: Map of the SKEP domain showing the recommended grazing capacity levels for the region (adapted from Scholes' 1998 model).

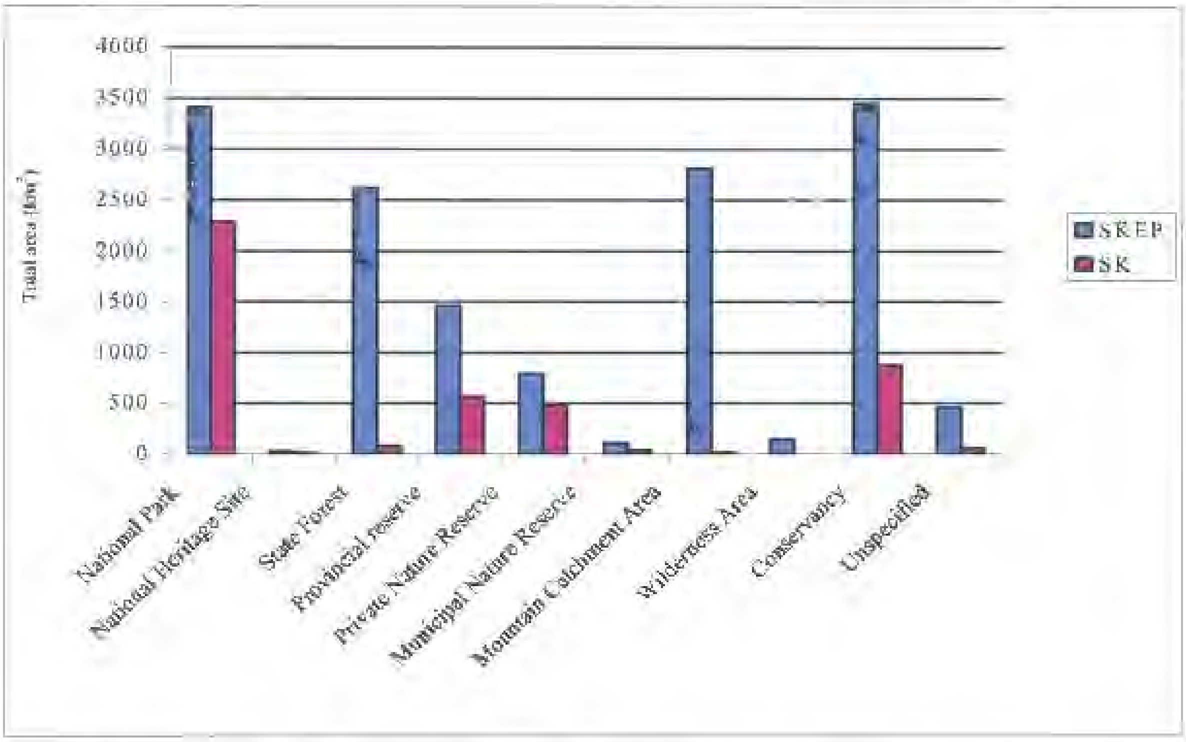


Figure 2.10: The total area and percentage land covered by each conservation category for the SKEP domain and SK biome.

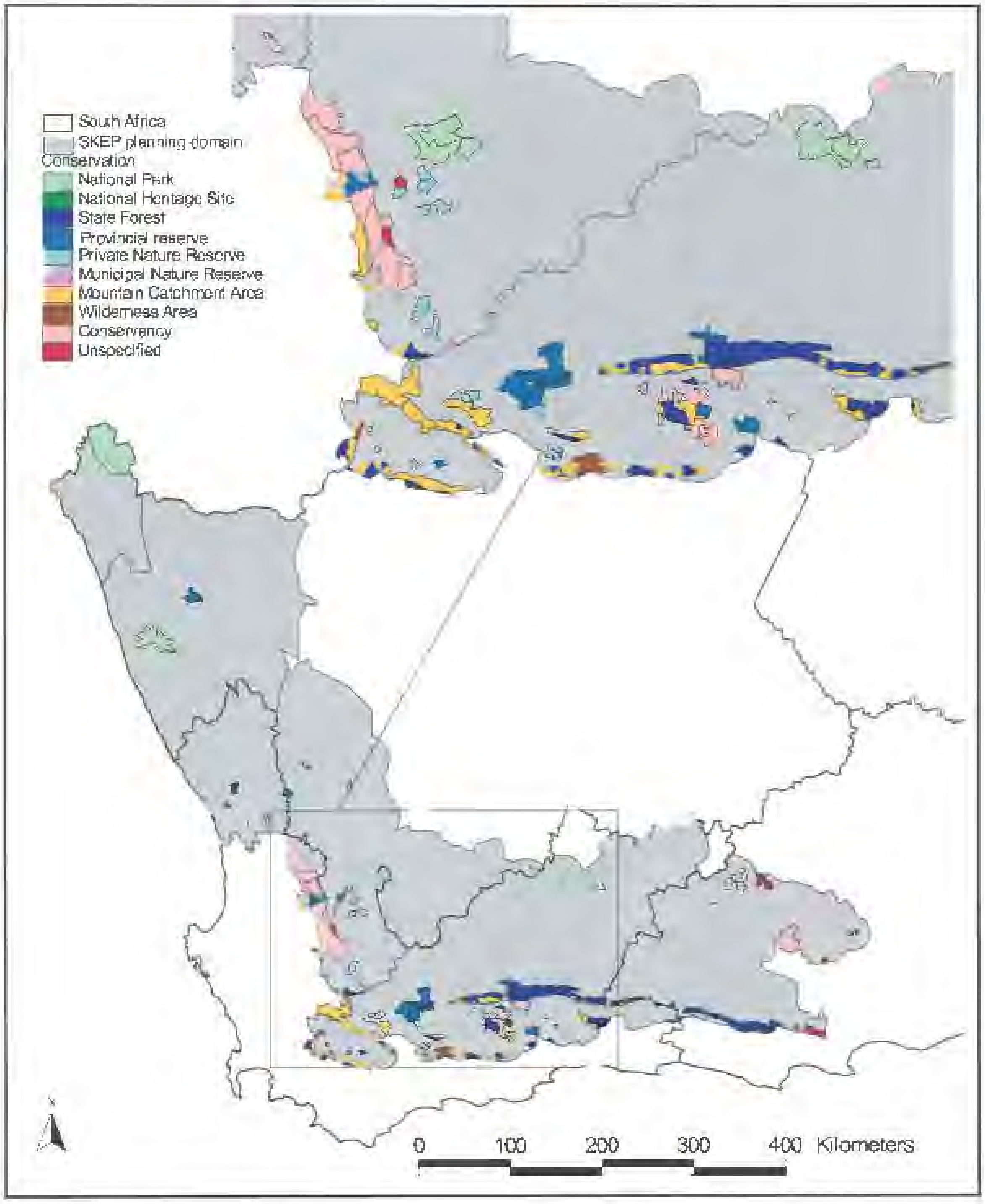


Figure 2.11: Conservation areas in the SKEP domain. The enlarged section indicates an area where all 10 conservation sub-types are present.

Implications for biodiversity conservation

As most of the biome's biodiversity has been severely transformed by land use practices, especially grazing (Hoffman & Ashwell, 2001), the Succulent Karoo biome is regarded as one of the 25 internationally recognized biodiversity hotspots (Myers *et al.*, 2000). Land use practices differ from one region to another within the biome. For example, diamond mining and grazing in the past dominated the Gariep/Namaqualand sub-region. The same land uses e.g. diamond mining now is supplemented by large scale- extraction of heavy metals (gypsum, titanium, marble) and other economically important commodities (diamond, gold, silver, coal, and others) which will further threaten the biodiversity of the region (NCA report, 2004).

Due to the aridity of the region, widespread desertification in the SK biome is of serious concern. However, due to limited data we couldn't map the extent of desertification of the region. The land use pressures that will further threaten the biodiversity of the region are, as follows: the expansion of communally owned land and associated overgrazing and desertification, mining for diamonds and heavy metals, and cropland expansion especially in the valleys of perennial rivers. In addition to these land use practices, the effects of global climate change and the illegal collection of succulents and geophytes are likely to have a major negative influence on the biodiversity of the Succulent Karoo biome (Cowling & Pierce, 1999; Rutherford *et al.*, 1999).

CHAPTER 3 Livestock density in Namaqualand: a comparison of stocking density on private and communal areas.

Introduction

In terms of the area used, grazing is the most important land use in Namaqualand and the Succulent Karoo biome (see chapter 1). However, natural grazing is usually insufficient in the arid zones, and herd owners often have to resort to feed supplements, particularly during droughts (De Pauw *et al.,* 2000). The issue of environmental degradation has been noted but there is a debate as to whether observed changes in vegetation are attributable to rainfall or to grazing by domestic livestock. The extreme annual climatic fluctuations in arid and semi arid environments make it particularly difficult to distinguish between the effects of grazing and climate on environmental degradation of the region, and few studies have managed to effectively separate the impacts of these factors (livestock, production, and rainfall) (Dean & Macdonald, 1994; Dodd, 1994; Seymour & Dean, 1999). The significant decrease in stocking rates for domestic livestock in Namaqualand over the last 100 years (Dean & MacDonald, 1994) is thought to reflect degradation and it has been suggested that the threat to biodiversity from overgrazing is most severe in communally grazed land (Cowling & Hilton-Tylor 1994; Cowling & Pierce, 1999). Rangeland degradation and its influence on ecological processes could, therefore, have important repercussions for the people of Namaqualand (Hoffman *et al.,* 1999).

Overgrazing pressure may have a negative impact on vegetation by directly increasing the mortality rate among established adult plants (Hunt, 2001) and by reducing the competitive ability of grazed shrubs (Milton *et al.*, 1997a; Riginos & Hoffman, 2003). Because of these processes, grazing may result in the altered dominance of perennials in favour of annuals (Todd & Hoffman, 1999). This change in vegetation from a perennial shrubland to an annual- and geophyte-dominated flora results in changed patterns of productivity (Cowling *et al.,* 1994; Huenneke & Noble, 1996). Heavy grazing not only affects the vegetation in Namaqualand. With heavy grazing, the area of soil covered by shrub species decreases, exposing a larger proportion of bare soil to erosion and nutrient loss. As open soils have a lower nutrient content compared to the soil under vegetation, the total soil nutrient budget for the heavily grazed area decreases as the area occupied by shrubs decreases (Allsopp, 1999). Bare soils are common in areas that have been overgrazed.

Previous studies have found that people, livestock grazing practices and the conservation of Namaqualand are inextricably linked (Todd & Hoffman, 1999). The current stocking rate in the semi-arid and arid rangelands of Southern Africa is determined by utilizable primary productivity of rangelands (Dean & MacDonald, 1994). Hoffman *et al.* (1999) suggest that, for the past 30 years, the Paulshoek communal area in Namaqualand has had a stocking rate at least twice that of neighbouring, privately-owned farms, which have been stocked at the recommended grazing capacity threshold set by the Department of Agriculture. This has resulted in marked differences between communal and private farms (freehold) in both densities of vegetation and dominant plant species (Todd & Hoffman, 1999).

Although Namaqualand has attracted the attention of researchers because of its unique biological features (Dean & MacDonald, 1994; Milton *et al.,* 1997b; Surplus People Project, 1997; Todd & Hoffman, 1999; Cowling *et al.,* 1999; Seymour & Dean, 1999; Desmet & Cowling 1999), few systematic surveys of stocking density have been undertaken (Dean & McDonald, 1994; Surplus People Project, 1997; Todd & Hoffman, 1999). Even fewer studies have occurred at cadastral level, which provides a spatially explicit analysis of land use pattern. The outbreak of scab in Namaqualand in 2002 led to a district-wide dipping programme by the Department of Veterinary Services, which gave an opportunity to record stocking rate at the cadastral level. Despite the controversial issue of livestock density and carrying capacities in the arid lands, I focused in livestock density and stocking rates in Namaqualand. To calculate the stocking rates between private and communal farms I used a calculation which was applied by du Toit, (2000) where, grazing capacity is the desired stocking rate for a given land management objective. Grazing capacity is thus expressed as follows: stocking rate is the flock of sheep, goats and herd of cattle usually expressed as x-number of hectares per animal since the capacity of natural pastures of South Africa to carry stock is so low on account of the low rainfall and the arid nature of the larger part of South Africa (du Toit, 2002).

In this study, I mapped the private farms and communal farms with their respective stocking rate in a Geographical Information System (GIS), with the aim of answering the following questions:

1. How do stocking rates differ between the communal areas and privately-owned farms in the Namaqualand sub-region?
2. What is the extent of livestock density in Namaqualand and how does this compare to the recommended thresholds set by the Department of Agriculture?
3. Which areas are "at grazing capacity", "below grazing capacity" and "above grazing capacity"?
4. How does stocking rate relate to rainfall, land cover and vegetation type?

Methodology

Study site

Namaqualand forms part of the Succulent Karoo biome (Cowling *et al.*, 1999; Desmet & Cowling, 1999), and is formally defined as a magisterial district within the old Cape Province of South Africa (Rutherford & Westfall, 1986; Milton *et al.*, 1997b). The region investigated in this chapter forms part of Namaqualand and is about 34 852 km² in extent (Fig. 3.1). It is comprised of more than 330 privately-owned farms and 14 main communal areas, which have significantly increased their area since 1994 as a result of the national government's land reform programme. Although mining companies also own a significant portion of Namaqualand, these areas were not investigated here due to lack of livestock data.

Namaqualand is a mild desert and its annual rainfall varies from about 50mm in the northwest to more than 400mm in the Kamiesberg (Cowling *et al.*, 1999). It is characterized by winter rainfall of less than 150 mm per annum (Rutherford & Westfall 1986; Cowling *et al.*, 1999). The geology of Namaqualand is extremely complex. The mountainous desert in the northwest, the Richtersveld, comprises a varied sequence of pre-Gondwana rocks that were extensively intruded at least a billion years ago, by granite and gneiss of the Namaqua Metamorphic Province (Cowling *et al.*, 1999; Desmet & Cowling, 1999). Namaqualand harbours about 10% of the world's succulent species (van Jaarsveld, 1987).

In addition to its diversity, the region contains large zones of transitional vegetation between succulent karoo and fynbos habitats. These zones are considered crucial for the conservation for both species diversity and for providing a buffer against climate change (Boonzaaier *et al.*, 2002).

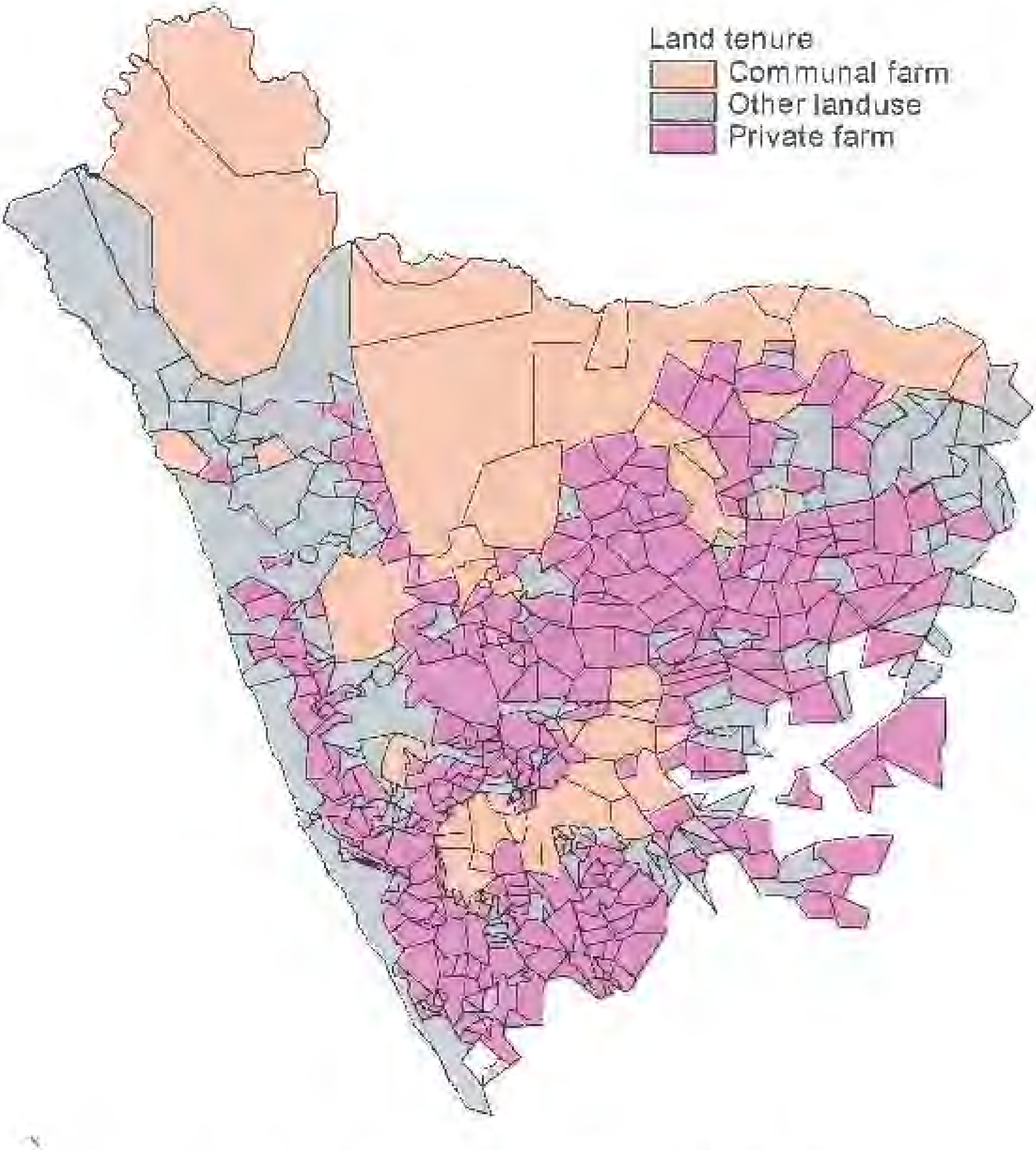


Figure 3.1: A land tenure map for the study area. Communal areas incorporate previous Act 9 areas, municipal commonage land as well as land recently purchased as part of the national governments land reform programme. Areas classified as being used for "other land uses" were not included in this study.

Data sources

Livestock numbers and ownership

An outbreak of scab in 2002 necessitated a region-wide dipping programme under the auspices of the Department of Veterinary Services in the Northern Cape Province's Department of Agriculture. At each dipping tank used, the number and type of animal (cattle, sheep, and goats) was noted and ownership determined. The farm boundaries where each herd was resident were hand drawn on the Namaqualand base map by Elrina van Aardt, the resident veterinary officer for the region and person responsible for the dipping programme. Both private and communal farm boundaries were drawn, and linked to an Ms Excel spreadsheet containing information on the farmer, farm names, and livestock numbers (cattle, sheep, and, goats). The total area in hectares and total numbers of livestock per farm was calculated for each farm captured in a GIS. For farmers who possessed more than one farm, livestock numbers were divided proportionately between farms. The number of ha required per large stock unit (LSU) was calculated by taking the area in hectares divided by livestock numbers and multiplied by the LSU value obtained from the Department of Agriculture. The LSU value for sheep was = 0.15, goats = 0.17 and cattle = 1.1.

Rainfall: CCWR

A layer of rainfall data obtained from the Computing Centre for Water Research (CCWR) (Shculze, 1997) was clipped onto the Namaqualand boundary and analysed in Arc View 3 GIS to understand the relationship between annual rainfall and stocking rate.

NDVI

A Normalized Difference Vegetation Index (NDVI) layer was obtained from the National Oceanic and Atmospheric Administration's (NOAA) AVHRR using the standard NDVI ratio of bands. Each 10-day composite consists of the maximum NDVI value with each 10-d period. The 10-d maximum value composites were derived from processed visible and near infrared 1 km AVHRR data (see details in Hoare & Frost, 2004). The NDVI layer was used to map land cover type (bare soils, low vegetation, medium vegetation and high vegetation). NDVI values between 0-33 were classified as bare soil; 33-72 low vegetation; 73-106 medium vegetation and 106-255 were classified as high or dense vegetation. This layer helped to assess how much of the area (in hectares) of each land cover type was covered by each grazing capacity category (above, at, and below grazing capacity).

Vegetation map

Low & Rebelo's (1996) vegetation map with different vegetation types, namely Mountain Fynbos, North-western Renosterveld, Upland Succulent Karoo, Lowland Succulent Karoo, Strandveld Succulent Karoo, Bushmanland, Orange River Nama Karoo (Fig. 3.2) was used to understand how much of the area in hectares of each vegetation type was covered by each grazing capacity category (above, at, and below grazing capacity).

Mapping stocking rate

The base maps for private and communal farms were digitized in Arc View GIS. Livestock numbers per farm were then assigned to the relevant polygon. On-screen digitizing of unidentified private farms was done using the Namaqualand cadastral deed for 2002 that was obtained from the Department of Agriculture. Farms with the same owner name were all considered to be the property of the owner whether they were adjacent to each other or not.

The recommended grazing capacity base maps, obtained from the Department of Agriculture, were also digitised in Arc View GIS (Fig. 3.3). The maps contained information about the recommended grazing capacity for a particular area.

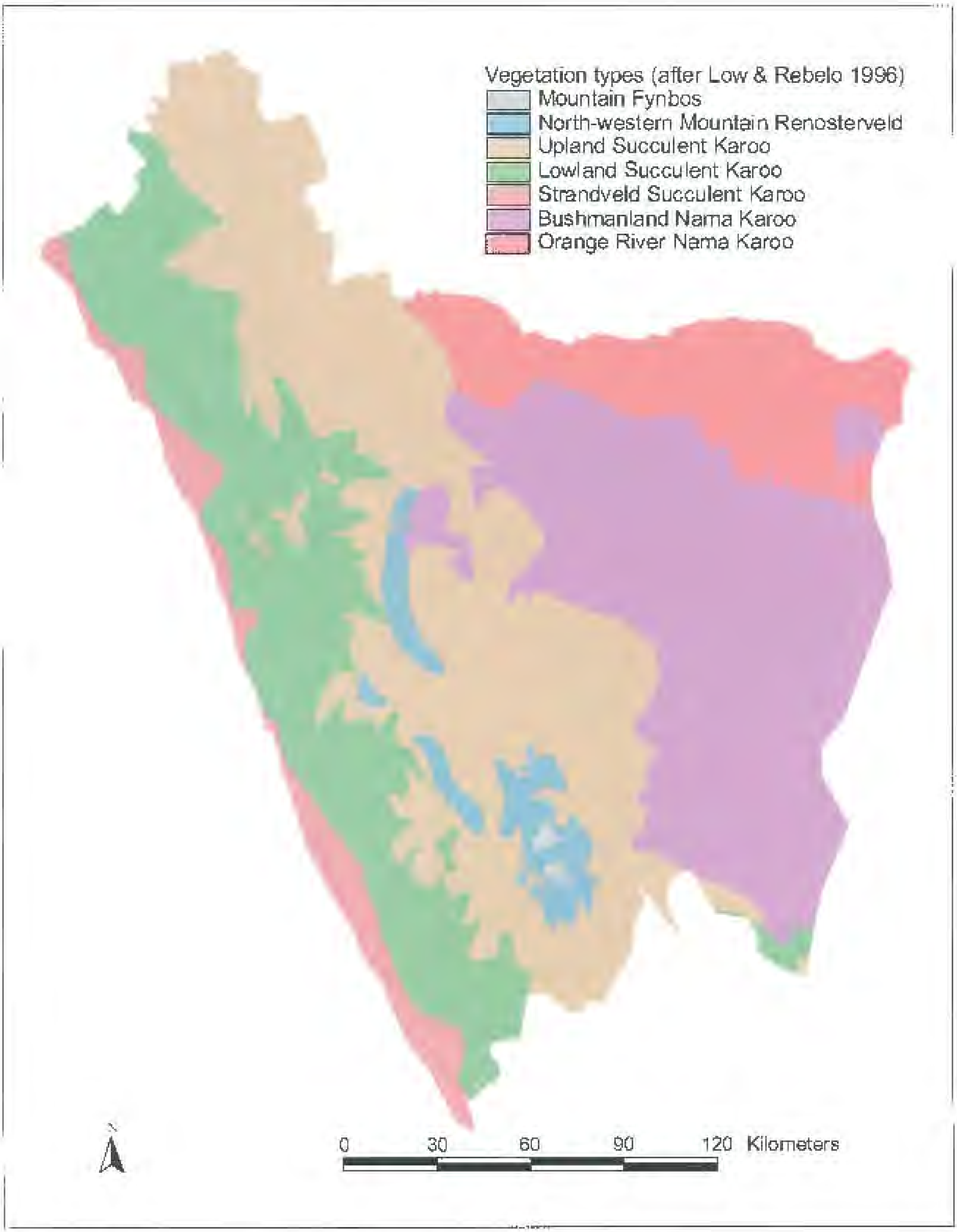


Figure 3.2: Vegetation map of the study area (after Low & Rebelo (1996)).

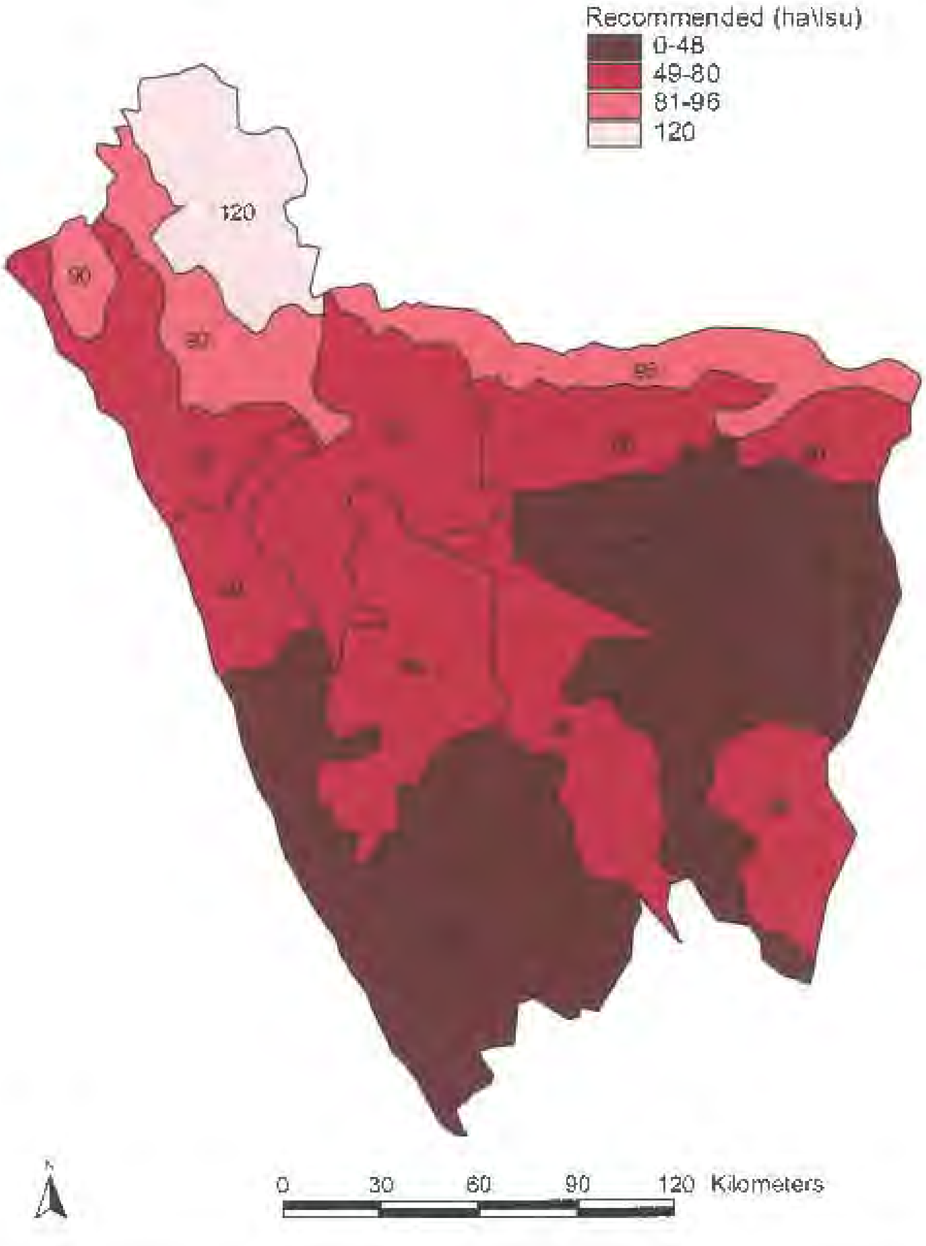


Figure 3.3: The recommended stocking rate for Namaqualand (expressed in ha\LSU) as recommended by the Department of Agriculture (digitised from 1:250 000 topographic maps).

Analysis

The current stocking rate (Fig. 3.4) and recommended grazing capacity map (Fig. 3.3) for Namaqualand, digitised from 1:250 00 topographic maps in the Department of Agriculture's offices in Springbok, were produced. The current stocking rate map was compared to the recommended grazing capacity map to assess which farms were "above", "at", and "below," the recommended grazing capacity (using +/- 5% error rate) in a GIS using spatial join. Factors such as rainfall, land degradation, and NDVI were analysed in relation to the 3 grazing categories mentioned above. The communal farms were analysed according to the main communal areas in the region and private farms were analysed according to Low & Rebelo's (1996) vegetation types.

Results

The study area consists of 322 private farms and 46 communal farms (grouped into 14 main communal areas), each covering half of the study area (Fig. 3.1, Table 3.1 & Table 3.2). Fig. 3.4 indicates the current stocking rate (ha\LSU) in Namaqualand as determined from the 2002 census. Sheep are the dominant animal type on the private farms while goats are more common than sheep in the communal areas. Nearly 80% of the land area for both communal and private farms complies with the recommended stocking rate set by the Department of Agriculture (Fig. 3.6). About 76% of the communal farms and 67% of the private farms are currently stocked below grazing capacity, while 18% of the communal farms and 24% of the private farms are above grazing capacity and 7% of the communal farms and 8% of the private farms are at grazing capacity (Fig. 3.5, Fig. 3.6 & Table 3.3). Statistical analysis also confirmed that these percentages are significant with a χ^2=0.001501.

Table 3.1: Livestock numbers and recommended stocking rate (ha/LSU) in the communal areas of Namaqualand. Mean recommended hectare per Large Stock Unit (LSU) is the total area of each farm divided by the sum of recommended hectares per LSU. Actual hectare per LSU is the total area of each communal farm divided by total livestock stock numbers of each farm. Percentages mean below or above recommended values is the mean recommended hectares per LSU minus actual hectares per LSU divided by the mean recommended hectares per LSUmultiplied by hundred.

Name of communal area	Total number of polygons	Area (ha)	No. Sheep	No. Goats	No. Cattle	LSU	Actual ha\LSU	Mean recommended ha\LSU	% Mean above or below (-) recommended values
Leliefontein	18	213736	8621	19391	354	3952	54	50	-7
Steinkopf	8	490353	18092	7196	0	3937	125	66	-88
O'Kiep/Nababeep	4	38830	1522	3404	0	806	48	54	11
Pella	3	186652	4112	7321	0	1862	100	78	-29
Concordia	2	175360	21056	7276	0	4394	40	60	33
Richtersveld	2	515849	6730	11417	0	2951	175	110	-60
Springbok	2	2197	77	126	0	33	67	54	-23
Komaggas	1	69374	4238	6139	0	1680	41	59	30
Mesklip	1	2169	186	118	0	48	45	54	16
Pofadder	1	13088	475	815	0	210	62	53	-18
Port Nolloth	1	15464	139	74	0	34	455	71	-541
Rietpoort	1	2864	80	257	0	56	51	45	-14
Soebatsfontein	1	12751	242	122	4	61	209	54	-287
Witbank	1	12189	832	577	0	223	55	96	43
Total for communal areas	46	1750876	66402	64233	358	20247	1527	903	-69

Table 3.2: Livestock numbers and recommended stocking rate (ha/LSU) in the privately-owned farms of Namaqualand according to Low & Rebelo's (1996) vegetation types. For an explanation of the last 4 columns, refer to Table 3.1

Vegetation	Total number of polygons	AREA (HA)	No. Sheep	No. Goats	No. Cattle	LSU	Actual ha/LSU	Mean recommended ha/LSU	% Mean above or below (-) recommended values
Upland Succulent Karoo	119	535984	120285	9828	4282	10864	49.3	50	2
Bushmanland	78	683463	136154	4048	2068	14638	46.7	48	2
Lowland Succulent Karoo	77	338234	62438	5750	1366	5814	58.2	48	-20
Orange River Nama Karoo	15	85855	16993	2118	193	1176	73.0	60	-21
Sand Plain Fynbos	12	46141	12497	1401	9	1129	40.9	45	9
North-western Mountain Renosterveld	11	23101	5947	1917	100	1027	22.5	45	50
Strandveld Succulent Karoo	10	19157	3434	166	21	303	63.2	45	-41
Total for private farms	322	1731936	357748	25228	8039	34951	353.8	342	-18

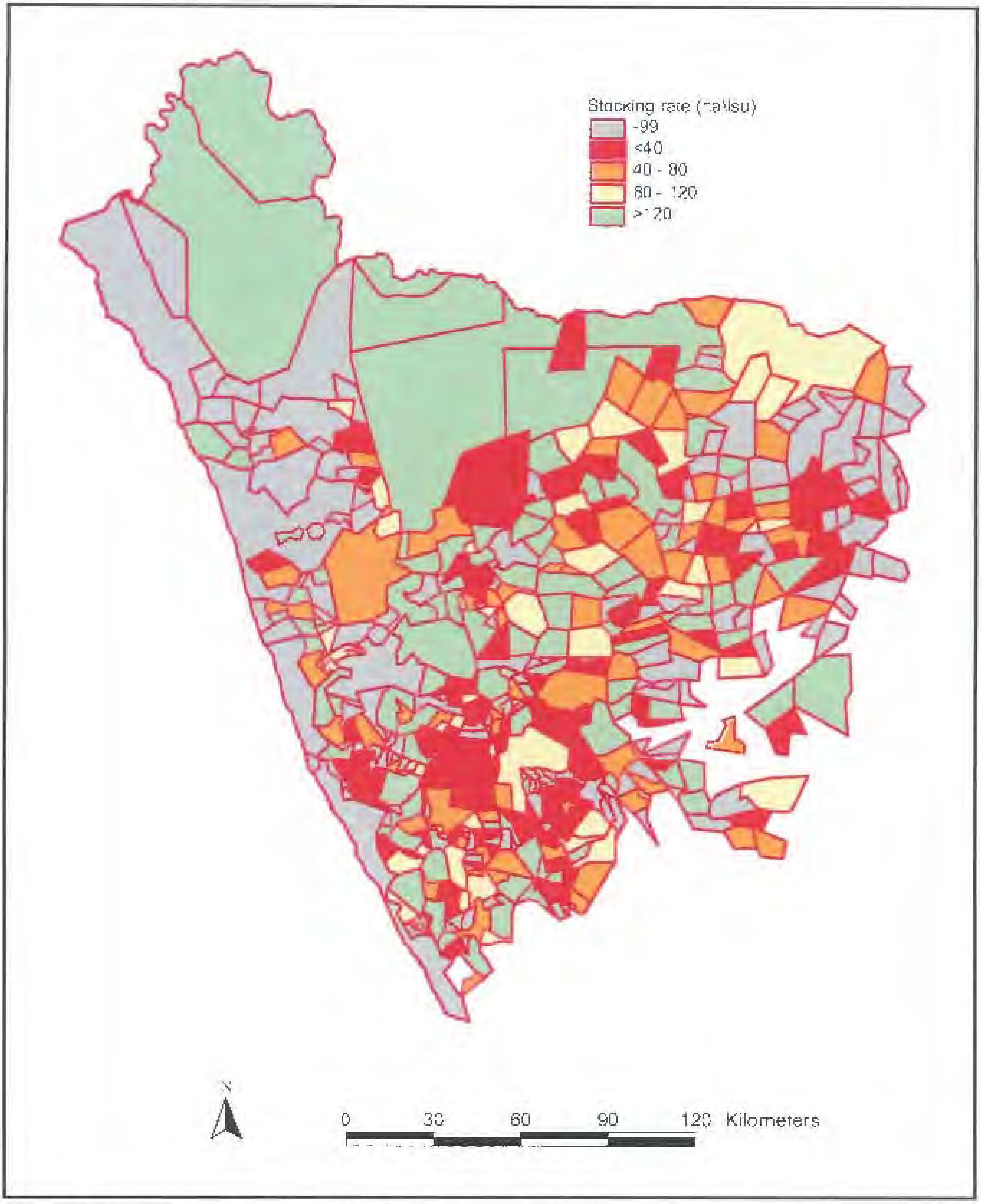


Figure 3.4: Current stocking rate (ha\LSU) in Namaqualand as determined from a survey carried out in 2002 by the Department of Agriculture's Veterinary Services division in the region

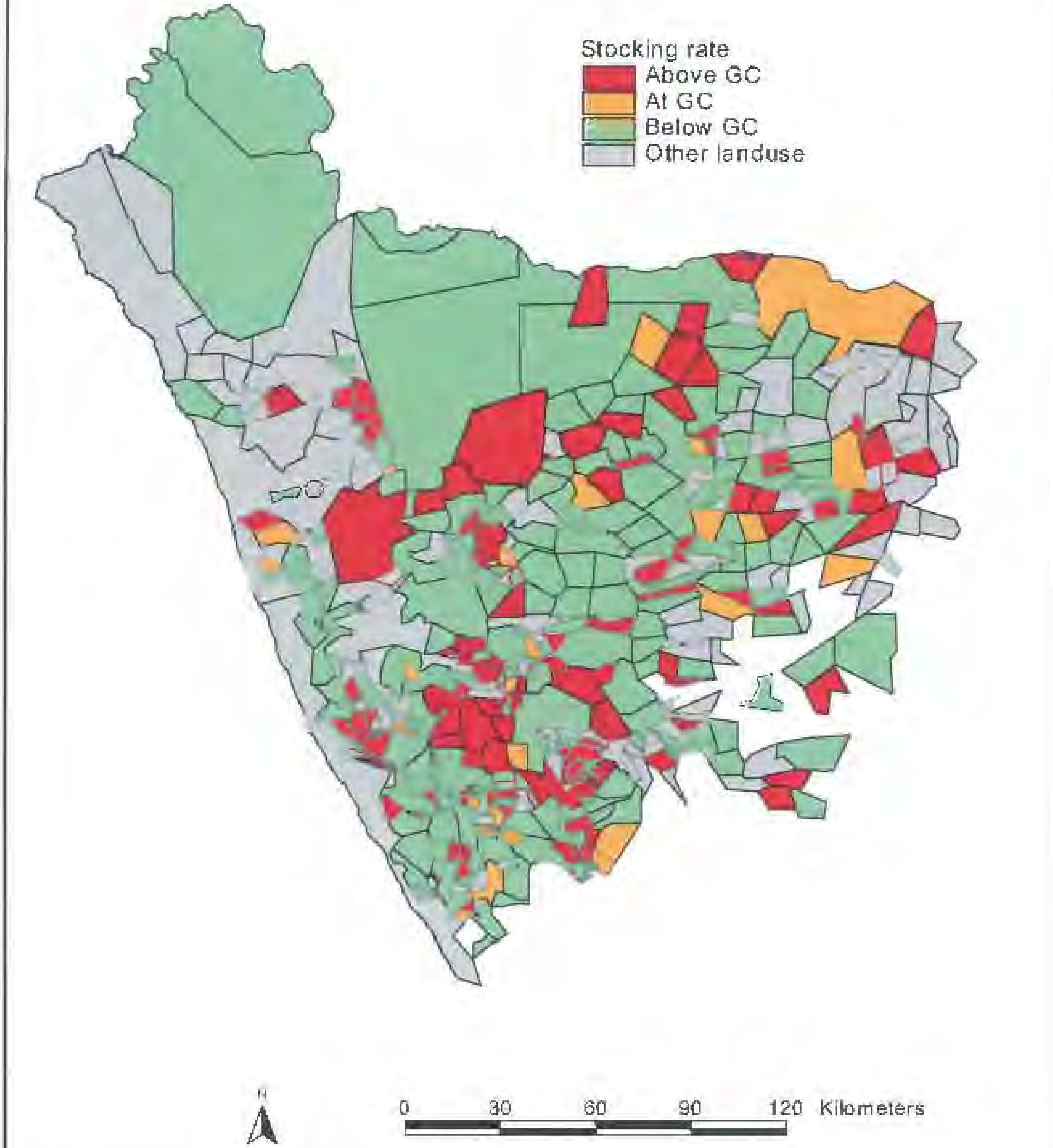


Figure 3.5: Stocking rates in the communal and private farms in relation to the recommended stocking rate (see also Fig. 3.3). The data are divided into 3 grazing capacity (GC) categories (above GC, at GC, and below GC) with an error rate of +/-5% used.

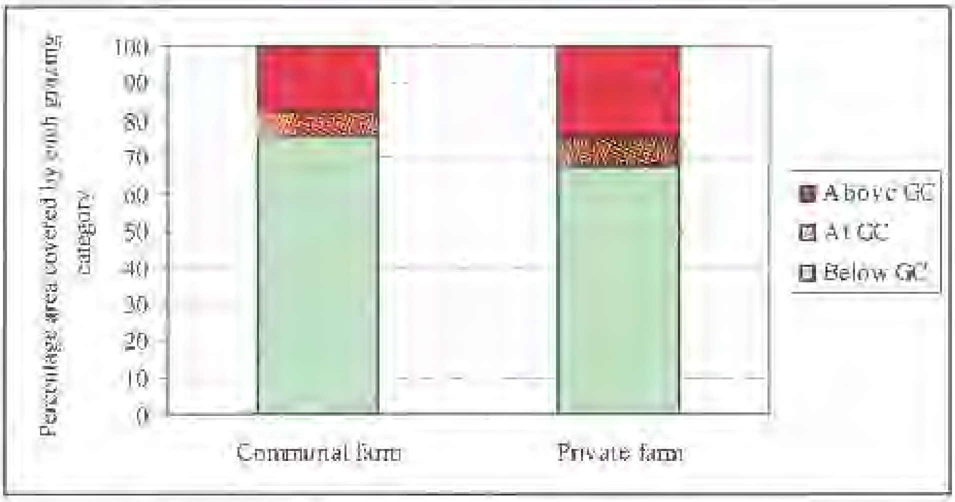


Figure 3.6: The percentage area of communal and private farms in relation to three stocking rate classes (above grazing capacity, at grazing capacity, and below grazing capacity).

Table 3.3: Statistical significance in percentage area above GC, at GC and below GC between communal and private farms using CHITEST (χ^2). χ^2= (actual range, expected range) = 0.001501. Actual range (expressed in percentage area) is the range of data that contains observations to test against expected values. Expected range (also expressed in percentage area) is the range of data that contains the ratio of the product of row totals and column totals to the grand total.

Actual percentage area

Rank	Communal farm	Private farm
Above GC	13.6	24.4
At GC	0.3	8.5
Below GC	86.1	67.1
Total	100	100

Expected percentage area

Rank	Communal farm	Private farm
Above GC	19.0	19.0
At GC	4.3	4.4
Below GC	76.7	76.6
Total	100	100

Livestock density in communal areas

Most livestock are found in the Leliefontein communal area, which comprises 18 farms (Table 3.1). The total number of livestock in Leliefontein is 28 366 animals. Cattle are least common in the communal farms and are only rarely found in Leliefontein and Soebatsfontein.

About 18 % of the communal farms in 2002 were stocked above the recommended grazing capacity (Fig. 3.5 & Fig. 3.6). Ten of the farms in the Leliefontein communal area, three in Steinkopf, and two in O'Kiep/Nababeep area are stocked above the recommended grazing capacity. Pella, Springbok, Komaggas, Witbank & Mesklip all have one farm stocked above the recommended grazing capacity. Concordia communal area with most of its farms mapped in one polygon is also stocked above the recommended grazing capacity. Most of the farms above grazing capacity are found in the Upland Succulent Karoo vegetation while all are characterized with low vegetation cover. The rest of the communal farms are below grazing capacity (76%) with 7 farms in Leliefontein, 5 farms in Steinkopf, 2 in O'Kiep/Nababeep, Pella, Richtersveld and 1 each in the communal areas of Concordia, Pofadder, Port Nolloth, Rietpoort, Soebatsfontein, and Springbok (Fig. 3.5).

Livestock density on private farms

The private farms are grouped according to Low & Rebelo's (1996) vegetation types, where most private farms are found in the Upland Succulent Karoo (119) followed by farms in Bushmanland Nama Karoo (78) and North-western Mountain Renosterveld (11) (Table 3.2). High livestock numbers are associated with the farms in the Bushmanland Nama Karoo (136 154). Farms in the Upland Succulent Karoo are also characterized by high livestock numbers (134 395 in total), with 120 285 sheep, 9 828 goats and 4 282 cattle, meanwhile the North-western Mountain Renosterveld is having high total number of livestock (345) when standardised per 1000 ha of the area. The Sand Plain Fynbos also possess relatively high livestock numbers (301 in total per 1000 ha).

About, 24% of the private farms are stocked above grazing capacity (Fig. 3.5, Fig. 3.6 & Table 3.2). These farms are mainly found in Upland Succulent Karoo (42 farms), Bushmanland (27) and Lowland Succulent Karoo (17). There are fewer farms in other vegetation types, which may be characterised as being stocked above grazing capacity (e.g. North-western Mountain Renosterveld (6), Orange River Nama Karoo (3), Mountain Fynbos (3) and Strandveld Succulent Karoo (1)). About 67% of private farms are stocked below grazing capacity and are scattered throughout the vegetation types of Namaqualand.

Current stocking rate in relation to rainfall, NDVI and vegetation type.

High rainfall areas, areas with high NDVI values and dominated by North-western Mountain Renosterveld generally have more livestock than recommended by the Department of Agriculture in the region (Fig. 3.7, Fig. 3.8 & Fig. 3.9). Livestock numbers are high in areas of high rainfall especially in the south of Namaqualand and most of these farms (communal and private) are grazed above grazing capacity. Bare soils and low vegetation cover classes derived from the Normalized Difference Vegetation Index (NDVI), are evident in most areas that are grazed below grazing capacity.

North-western Mountain Renosterveld and to some extent Bushmanland may be considered overstocked (Fig. 3.9). The other vegetation types have less than 20% of their area currently stocked above the recommended stocking rate threshold.

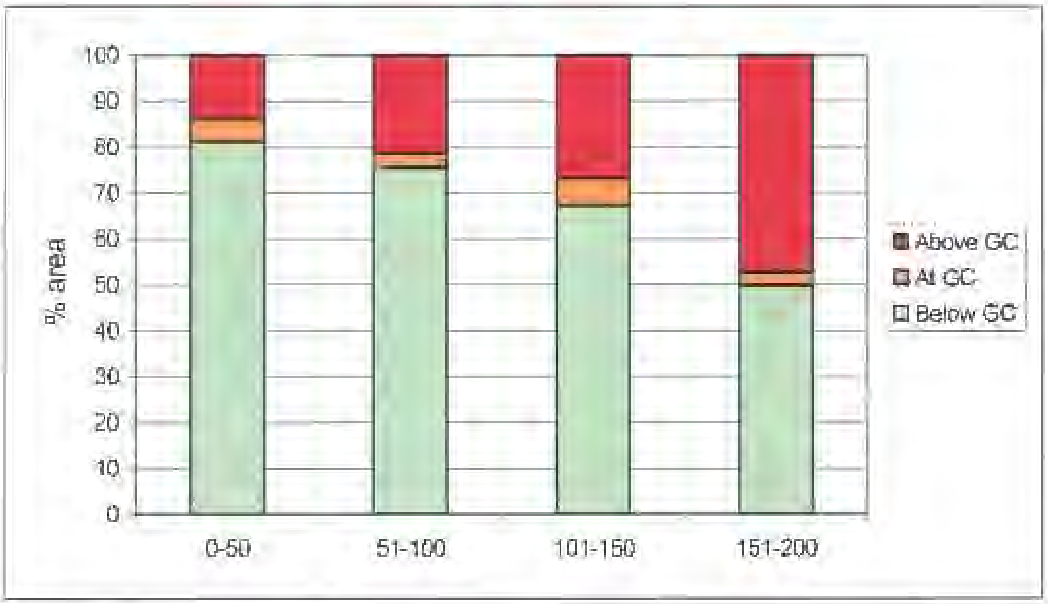


Figure 3.7: The percentage area of each grazing capacity category (above grazing capacity, at grazing capacity and below grazing capacity) in each of four mean annual rainfall classes (mm/yr) in Namaqualand.

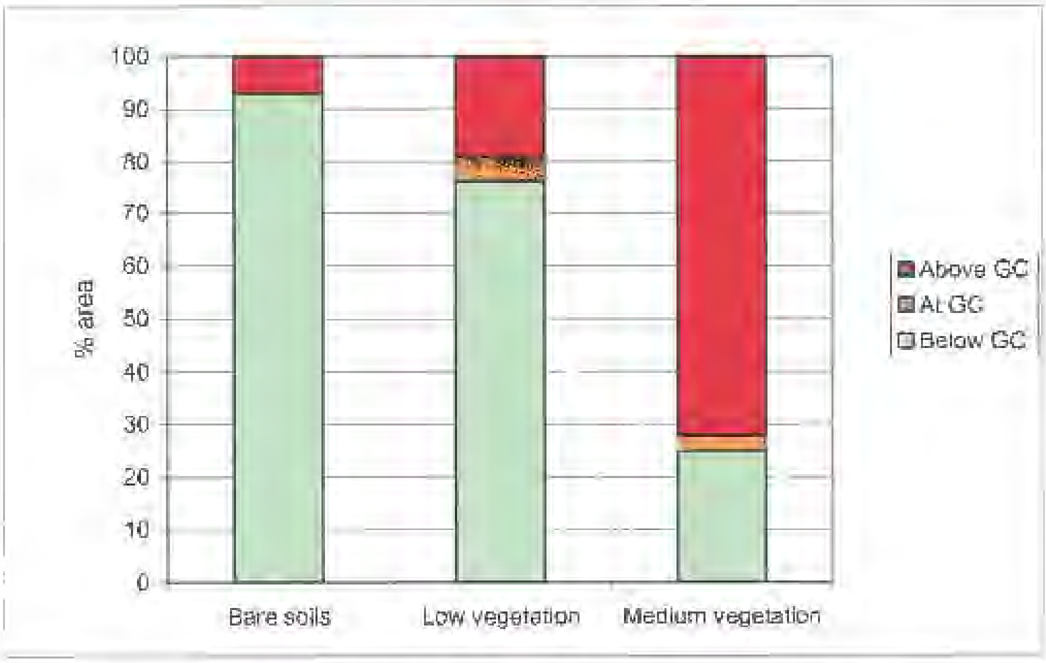


Figure 3.8: The percentage area of each grazing capacity category (above grazing capacity, at grazing capacity and below grazing capacity) in relation to each of three land cover classes in Namaqualand as derived from the Normalised Difference Vegetation Index (NDVI).

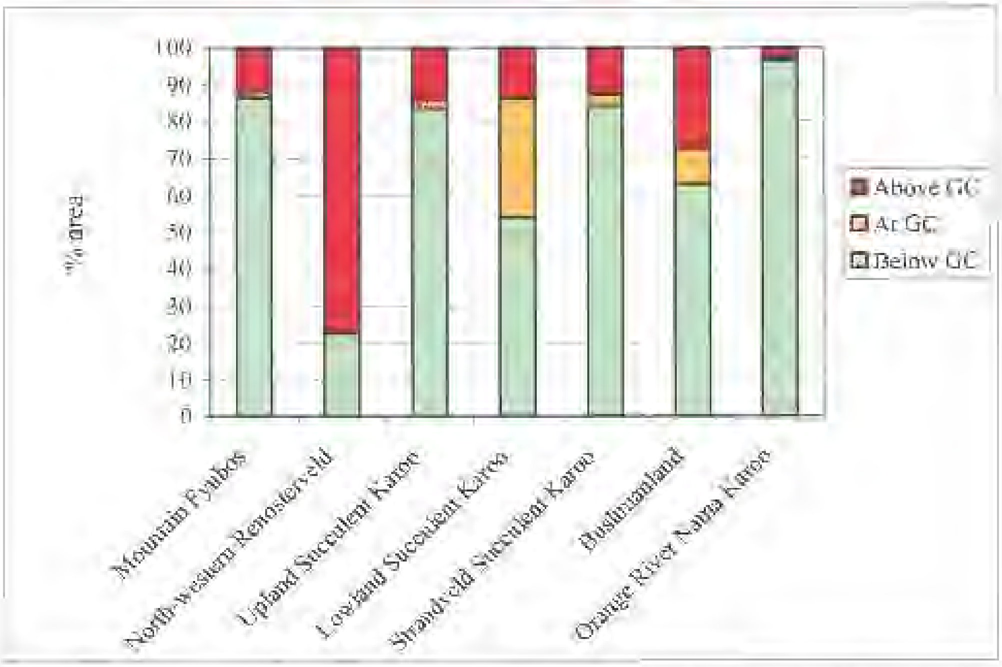


Figure 3.9: The percentage area of each grazing capacity category (above grazing capacity, at grazing capacity and below grazing capacity) in relation to seven vegetation types (after Low & Rebelo (1996)) in Namaqualand.

Discussion

Potential errors in the data

There are several potential sources of error in the data, which could affect this analysis. Firstly, the census might have only included a portion of the total stock in Namaqualand and might reflect, therefore, only some of the animals in the region. This is unlikely, however because scab is a very contagious disease and for a dipping campaign to be effective, all animals need to be treated. The Department of Veterinary Services went to great lengths to ensure that their campaign was as comprehensive as possible. An independent check on stock numbers for the village of Paulshoek revealed a difference of only 10 animals out of a total of 3 000 for the village (T Hoffman, pers. comm.)

A second potential source of error could lie in the allocation of stock numbers to individual farmers and their farm areas. While every effort was made to minimize this problem it is possible that some incorrect allocations were made. Ownership of land is an extremely dynamic process and cadastral maps do not keep pace with changes on the ground.

Finally, I could not establish information on farmers who might have held property outside the region and used these areas as part of their management system. The influence of this factor needs to be investigated further.

Animal numbers in communal areas and on private farms in Namaqualand.

Livestock numbers and proportions of the dominant animal breeds differ considerably in the two land tenure systems. Sheep are dominant on private farms, while goats are dominant in the communal areas. Cattle are frequent on private farms but are almost entirely absent from most of the communal areas and were only recorded in Leliefontein and Soebatsfontein.

This current stocking rate analysis is very different from previous studies (Surplus People Project, 1977; Hoffman *et al.*, 1999). It shows that the communal farms are generally stocked below grazing capacity when compared to private farms. The stocking rate is also unexpectedly high in private farms, which have more farms stocked above the recommended grazing capacity when compared to the communal farms.

Unlike earlier accounts (Dean & McDonald, 1994; Surplus People Project, 1997; Todd & Hoffman, 1998 Allsopp, 1999; Todd & Hoffman, 1999; Hoffman *et al.*, 1999), which have suggested that the communal areas in Namaqualand are overstocked, this study has shown that 76% of the communal farms are stocked below grazing capacity when compared to only 67% of private farms. The high number of animals on the private farms is surprising since previous studies have suggested that private farms are generally stocked either at or below the recommended grazing capacity. Data from this study suggest that many private farms contain more animals than recommended by the Department of Agriculture in the region. Less than

7% of the communal farms are at grazing capacity while 8% of the private farms have maintained the recommended grazing capacity provided by the Department of Agriculture.

Reasons for the high stocking rates on private farms could be because the official stocking rate data as reflected in tax returns and agricultural census, are not accurate (Dean & MacDonald, 1994). The real numbers of livestock on the land may be far in excess of those reported in agricultural returns. For example, the number of lambs in a herd is often not reported, game animals are often estimated conservatively and livestock belonging to farm labourers have often been ignored in the past (Dean & MacDonald, 1994). In this study as well there are no lambs reported. There have also been few censuses of stock numbers on private farms at farm scale in the past and this study has shown the importance of fine-scale surveys.

Stock numbers are significantly lower in communal areas in general when compared to previous surveys (e.g. Surplus People Project, 1997). In many areas, total stock numbers are now less than half the total population of animals that were counted in earlier surveys. Two main explanations could account for these differences.

Firstly, the decrease in livestock numbers on communal farms might be because of the severe drought, which occurred in the region during 1988 & 1999 (Todd & Hoffman, 1999; Hoffman *et al.*, 1999). Herd numbers in 2002 were still recovering from the large-scale death of many animals, particularly in the communal areas of Namaqualand. Animals in the communal areas were also affected more by this drought than those on the private farms because of the generally lower perennial shrub cover on communal areas (Todd & Hoffman, 1999; Hoffman *et al.*, 1999). They would also not have increased as quickly as herds on the private farms following average or near average rainfall in the region in 2000 and 2001. One reason for this is that vegetation condition and productivity are significantly lower in the communal areas than on the private farms (Todd & Hoffman, 1999).

A second, and probably more important reason for the lower stocking rates now evident on communal areas when compared to previous surveys is that additional land has been given to communal farmers as part of the national government's land reform programme in the region. Since 1994, communal land area has increased on average by 24% (200 000ha) (Department of Agriculture, unpublished data). Although farmers with larger herds generally utilize the "new farms", the Department of Agriculture maintains strict control, not only over the way in which animals are managed (e.g. stock posts are discouraged, donkeys are not allowed), but also in the number of animals permitted on the new land reform farms.

Implications of the findings

It is not surprising that communal livestock is declining and that this trend will continue in the future. The Department of Agriculture and municipalities have generally increased their control over the communal area grazing systems in the last five years. Stock numbers, in particular, are controlled especially on the newly-acquired land reform farms. While any infrastructural provisions such as roads and stock water points might exacerbate the negative environmental effects by encouraging further resource use beyond the carrying capacity of the land (De Pauw *et al.*, 2000) the Department of Agriculture is aware of this and is attempting to limit stock numbers. There is a need for long term survey of stock numbers and vegetation condition, particularly at fine-scale. This is because the private farms might be a problem in the future. The Department of Agriculture should also consider updating the recommended grazing capacity thresholds from time to time as several factors such as drought, livestock mortality and rainfall variability influence this figure considerably.

Chapter 4 Future predictions of agriculture in the Succulent Karoo Ecosystem Plan planning domain.

Modelling land use changes

Introduction

Several modelling techniques have been used to understand the drivers of land use change and for predicting future changes (Rounsevell *et al.*, 2002). Gaining a better understanding of the ways that land use practices are evolving is a priority concern of the global change research community. Models allow one to evaluate the sensitivity of land use systems to different drivers of change (such as environmental and socio-economic factors), and identify which drivers and processes are most important (Rounsevell *et al.*, 2002). These models provide information about the geographic scope and impact of land use change and can be used by resource planners to identify the areas that require priority attention for conservation (Verburg *et al.*, 1999a).

Differentiating between the terms land cover and land use is of importance in this study. Land cover consists mainly of the vegetation (natural or planted) and man-made constructions (buildings), which occur on the earth surface. Water, ice, bare rocks and sand, are also considered as land-cover classes (FAO, 1994). Land use can be defined as involving both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation or as the purpose for which the land is used (Turner *et al.*, 1995). Forestry, cultivated crops, conservation practices, livestock herding and fertilizer application are examples of land use classes (Turner *et al.*, 1995). The main focus of this study is on land use.

This chapter analyses the environmental determinants of land use and models agriculture potential in the SKEP planning domain. I first review land use modelling studies, focusing on the types of modelling approaches, the land use determinants used, and the limitations of land use models. Then, I present a model of agriculture potential for the Succulent Karoo Ecosystem Plan (SKEP) planning domain.

Modelling techniques of land use change

Modelling land use change is increasingly required as a key component in simulations of environmental processes such as land degradation (Folly *et al.,* 1996), climate change (Dale, 1997) and hydrology (Matheussen *et al.,* 2000). Such models are suitable for scenario analysis or impact assessment and may provide guidance to sustainable land resource planning management and conservation planning (Kok, 2001; Rouget *et al.*, 2003).

Modelling, especially if done in a spatially explicit and multi-scale manner, is an important technique for predicting future land uses, conducting experiments that test our understanding of key processes, and describing the problem in quantitative terms. Land use models should be exhaustive in the factors that affect land use practices and should be based on an analysis of the system at various scales (Kok & Winogard, 2002). Many different modelling approaches have been adopted for studying land use change (Velkamp & Lambin, 2001). This chapter focuses on spatially explicit land use models (Table 4.1).

Spatial land use models often use decision rules to describe the relationship between land use and human and biophysical factors. These decision rules are used to allocate predicted changes in land use (Verburg *et al.,* 1999b). These models aim at integrating diverse temporal and spatial scales to represent ecological system dynamics at the landscape level (Costanza *et al.*, 1990).

Table 4.1: Characteristics of spatial land use change models used in previous studies (Agarwal *et al.*, 2002)

Model category	Model approach	What it explains	Data required	Scale	Strengths	Weaknesses	References
Empirical, statistical	Multivariate statistical modelling, spatial statistics (GIS based models)	Why in the past? (Proximate causes) Where in the future? (Short term)	Land use type, land-use determinants	Local, Regional	Increases understanding of factors behind recent land use patterns. Allows projection of future land use patterns.	Human decision-making not explicitly considered. Errors are likely from misclassification of data at grid level or misalignment of map feature boundaries, and also from limited knowledge of historical land use patterns	Baker 1989; Gilruth *et al.*, 1995; Rouget et al. 2003
Stochastic	Transition probability models	Transition between land cover types. Simulate land use change	Land use type, land-use determinants	Local	Model shows processes, output (new land use map)	Land Use Change Analysis System tended to fragment the landscape for low proportion land uses due to the pixel-based independent grid method. Patch based simulation would cause less fragmentation but patch definition requirements often lead to their degeneration into single cell patches.	Berry *et al.*, 1996
Optimization	Deterministic & stochastic optimization models	Where, how fast in the future? (Underlying causes; scenarios)	Land use type, determinants	National	Incorporates agriculture and forest land uses. The model is dynamic, thus changes in one-decade influence land use change in the next decade. Good for long term policy impacts	Broad scale means that land capability variations within regions are not taken into account.	Adams *et al.*, 1996

Table 4.1 (cont.)

Model category	Model approach	What it explains	Data required	Scale	Strengths	Weaknesses	References
Cellular Automata	Agent based, analytical, economic	Why in the future? (Underlying causes) Change in land use over time	Existing land use data, remotely sensed imagery, extent of land use, elevation, slope, and roads.	Regional	Allows each cell to act independently according to rules, analogous to city expansion as a result of hundreds of small decisions. Fine scale data, registered to a 30m UTM grid.	Does not explore human decisions that lead to spread of built areas. Does not yet include biological factors.	Clarke *et al.*, 1998; Kirtland *et al.*, 2000; Britaldo et *al.*, 2002
CLUE	Multi-scale, spatial analysis, allocate land use changes, attempts to account for the entire system of complex interactions between historic and present land use, land use drivers	Identify priority areas for planning. Predict land cover in the future.	Spatially explicit data on the biophysical & socio-economic factors, Land use data, biophysical data- on soil conditions, relief and climate	National and Regional	Covers a wide range of biophysical and human drivers at differing temporal and spatial scales	Limited consideration of institutional and economic variables	Veldkamp & Fresco 1997, Pontius *et al.*, 2001

Table 4.1 summarizes the main types of spatial land use models. Empirical statistical simulation and GIS based models attempt to identify explicitly the causes of land use changes using multivariate analyses. These models are best suited to predict the changes in land use pattern (Verburg *et al.,* 1999). Other types of land use models have been developed such as optimisation and cellular automata. Optimisation models based on linear programming have been used mostly in agricultural land use studies (Verburg *et al.,* 1999). Cellular automata models have been used to predict future land use development under existing spatial plans and policies, and to compare land use planning and policy scenarios in terms of their effects on future land use development (Barredo *et al.*, 2003). The land use models are limited by different factors such as the scale at which the model has been performed. The major limitation of the empirical statistical model is that human decision-making is not explicitly considered. It also fails to explain historical land use patterns.

The CLUE model (Conversion of Land Use and its Effects) attempts to account for the differences between historic and present land use, socio-economic conditions and biophysical factors (Veldkamp & Fresco, 1996; Schoorl *et al.*, 1997). The CLUE model operates at two spatial-scales: fine (regional) and coarse (national) scales. At a relatively coarse scale it is used to calculate the general trends of the changes in land use pattern and to capture the influence of land use drivers. Based upon the general pattern of land use change calculated at this coarse allocation scale, but taking local constraints into account, the land use pattern is calculated at a finer level of scale. Depending on the application, the area studied and data availability, resolution of analysis will vary. For example, a spatial resolution of 9 x 9 km in Ecuador was chosen for the fine scale and 36 x 36 km for the coarse scale (Verburg *et al.*, 1999).

In the case of the SKEP planning domain, the statistical GIS models will be applied to understand the drivers of agricultural land use change and predict the future agriculture areas.

Spatial determinants of land use

Land use is a function of multiple factors such as culture and settlement patterns, economic factors and environmental characteristics (Black *et al.,* 1998). Understanding the spatial pattern of land use and its determinants is critical in monitoring changes and in assessing sustainable land management (Melloul & Collin, 2003). The land use determinants can be of various types such as biotic (vegetation), abiotic (climatic conditions), and socio economic (population density) (Kok *et al.,* 2001). The most commonly used land use determinants in previous studies include environmental factors such as climate, geology, soil, and topography, distance to the rivers, socio-economic variables such as food demand, policy reform and technology level and social variables such as population size, population growth, and population density.

Land use and future predictions

A better understanding of the factors determining land use can help predict future land use changes (Verburg *et al.,* 1999). Many studies have developed models of land use change to project and quantify future land use (see Riebsame *et al.,* 1994;Verburg *et al.,* 1999; Veldkamp & Lambin, 2001). Other studies have assessed the loss of habitat as the main cause of decline in biodiversity due to land use practices (agriculture and urbanization) (see Noss *et al.,* 1997; Wilcove *et al.,* 1998; Myers *et al.*, 2000; Rouget *et al.,* 2003). Other studies estimate risks to biodiversity by looking at the impact of future landscape alternatives on species distribution and abundance (see White *et al.,* 1997).

The human use of land alters the structure and functioning of ecosystems, and influences how ecosystems interact with the atmosphere, aquatic systems and surrounding land (Verburg *et al.,* 1999). Natural habitats are threatened by future habitat loss due to agricultural expansion, as mentioned above (Wilcove *et al.,* 1998; Rouget *et al.,* 2003). For example in the Cape Floristic Region, future changes in land use (agriculture - including plantation forestry, and alien vegetation) were singled out as the major threat to biodiversity of the region. The impacts were greatest on lowlands habitats especially those that have level topography, fertile soils and where rainfall was sufficient for agriculture. Land use/conservation planning is needed to avoid all these conflicting land use practices.

Planning is an integrative field. It collects information from a broad range of disciplines and synthesizes that information with community objectives into a plan to guide future land use in a region (Crist *et al.,* 2000). However, only recently have studies attempted to identify these patterns in a spatially explicit manner in relation to biodiversity patterns (Pressey *et al.,* 1996; White *et al.,* 1997; Higgins *et al.,* 1999; Abbit *et al.,* 2000; Rouget *et al.,* 2003). Pressures on biodiversity shows no sign of slowing down, yet resources for conservation action are limited. Therefore, planners need to be strategic to focus their efforts where they will have the greatest impact (Driver *et al.,* 2003). Detailed knowledge of achieving these threats to biodiversity should be an essential component of conservation planning (Driver *et al.,* 2003; Rouget *et al.,* 2003). The main reason for this is that conservation planning must operate within the constraints of current and likely future land use changes (transformed land usually has very low conservation value, and areas with high transformation potential are problematic for incorporating into reserve networks) (Margules & Pressey, 2000; Myers *et al.,* 2000; Pressey and Cowling, 2001; Rouget *et al.,* 2003).

Limitations of modelling land use change: the issue of scale

The issues of scale are considered to be very important and have been reported in most land use modelling studies. Scale is defined as both the limit of resolution where a phenomenon is discernible and the extent that the phenomena is characterized over space and time (Kok, 2001). Spatial resolution refers to the smallest geographic unit of analysis for the model, such as the size of a cell in a raster grid system. Spatial extent describes the total geographic area to which the model is applied.

Land use changes occur as a result of the complex interaction between human and the environmental factors that act over a wide range of spatial and temporal scales (Verburg *et al.,* 1999b). Models are constrained by the quality of the environmental factors (geology, soil, rainfall, and topographic variables) used in any analysis, and the spatial scale at which they have been collected (Stein *et al.,* 2001). The spatial scale of observations can influence the relations between land use patterns and the biophysical and socio-economic factors (Veldkamp & Fresco, 1996; De Koning *et al.,* 1999). For example, in areas with a rugged topography, land use patterns are closely related to topography when analysed at fine scale while these patterns are primarily determined by climatic conditions at coarser scale (Verburg *et al.,* 1999b).

Case study: land use modelling in the Succulent Karoo Ecosystem Plan (SKEP) planning domain.

Introduction

Agriculture is the most important land use practice in the SKEP planning domain and has changed considerably in recent times (Desmet & Cowling, 1999; Hoffman & Ashwell, 2001). Climatic conditions have been implicated as a primary factor affecting agricultural land use in most arid regions (Desmet & Cowling, 1999; Hoffman & Ashwell, 2001). The SKEP planning domain is one of the richest biodiversity hotspot in the world with most of its biodiversity occurring in unprotected areas (Wessels *et al.*, 2002; see Chapter 1). Identifying habitats susceptible to future transformation (Myers *et al.*, 2000; Rouget *et al.*, 2003) can help prioritise conservation actions. Habitats that are already modified should receive more protection effort than those relatively free of human activities (such as agricultural land, urbanization) (Rouget *et al.*, 2003). One strategy for implementing conservation decisions is to select areas on the basis of irreplaceability (contribution of the area in terms of conservation goal) and vulnerability (risk of the area being transformed) (Pressey *et al.*, 1996; Rouget, *et al.*, 2003).

Little attention has been given to identifying, in spatially explicit terms (Wilcove *et al.*, 1998), the factors that influence different agricultural land use practices, and how these are likely to change in the future. The first step, however, in projecting potential future changes in agricultural land use in the SKEP planning domain is to be able to understand the environmental correlates that control current land use distributions (see chapter 2). This chapter presents an approach to modelling the spatial distribution of agricultural land use (cultivated crops only) at a biome scale. The objectives of this chapter are to identify drivers of agricultural land use in the SKEP planning domain and to identify areas of future agriculture potential.

This chapter specifically aims to answer the following questions:

1. What are the environmental correlates of cropland production areas in the SKEP planning domain?

2. Can statistical models and GIS be used to derive spatially explicit future agricultural land use scenarios in the SKEP planning domain?

3. Where do we expect future crops to be sown and why?

Methodology

The approach was based on a statistical modelling approach using a Geographical Information System. The model in this study has been used to evaluate the relationship of cropland areas to environmental factors, and to develop a spatial model of cropland potential (i.e. areas likely to be converted to crops in the near future). The model assumed that environmental factors are the key determinants of agricultural land use within the SKEP planning domain. The model was validated by comparing model outputs against current land use data.

Sources of data

Computing Centre for Water Research (CCWR).

Climatic variables were provided by CCWR (Schulze, 1997), and were then clipped to the SKEP planning domain using the spatial analyst tool in Arc View GIS 3.

Environmental Potential Atlas of South Africa (ENPAT)

This dataset was used for the environmental factors such as soil and geology. The GIS layers that fall within the SKEP planning domain were clipped and merged.

Succulent Karoo Ecosystem Plan Planning domain (SKEP)

The vegetation map was obtained from the SKEP coordinators and used as the categorical variable. The GIS layer for cropland areas was obtained from the current land use map derived from chapter 2. This cropland production GIS layer was then converted to a grid of 500m-cell size.

Table 4.2: List of environmental factors used in the logistic regression model. Categorical variables such as vegetation types were obtained from the Succulent Karoo Ecosystem Plan (SKEP) and other categorical variables from Environmental Potential Atlas of South Africa. Mthot = minimum temperature of hot days, mtcold = minimum temperature of cold days, mintemp = minimum temperature, meantemp = mean annual temperature, gdays = growth days, gtemp = growth temperature, swsmin = soil water stress minimum, swsmax =soil water stress maximum.

		Factors	Type	Source
BIOTIC FACORS	Vegetation types	Shrubland	Categorical	SKEP
		Thicket	Categorical	
		Fynbos	Categorical	
		Grassland arid	Categorical	
		Renosterveld	Categorical	
		Succulent shrubland	Categorical	
		Other	Categorical	
		Sparse shrubland	Categorical	
		Grassland	Categorical	
		Wetland	Categorical	
		Void	Categorical	
ABIOTIC FACTORS	Soil types	Glenrosa/Mispah/lime soil	Categorical	ENPAT
		Red-yellow apedal	Categorical	
		Miscellaneous soils	Categorical	
		Pismacutanic	Categorical	
		Grey-regic sand	Categorical	
		Plinthic catena	Categorical	
		Melanic & red soils	Categorical	
	Geology types	Sediment	Categorical	ENPAT
		Igneous	Categorical	
		Mineral	Categorical	
		Metamorphic	Categorical	
		Unknown		
	Aspect	Flat	Categorical	CCWR
		North	Categorical	
		North East	Categorical	
		East	Categorical	
		South East	Categorical	
		South	Categorical	
		South West	Categorical	
		West	Categorical	
		North West	Categorical	
	Topographic	Altitude (m)	Continuous	CCWR
		Slope (m)	Continuous	
		Distance to rivers (m)	Continuous	DWAF
	Climatic variables	Mthot (°C)	Continuous	CCWR
		Mtcold (°C)	Continuous	
		Mintemp (°C)	Continuous	
		Meantemp (°C)	Continuous	
		Gdays (%)	Continuous	
		Gtemp (°C)	Continuous	
		Swsmin (% days under stress)	Continuous	
		Swsmax (% days under stress)	Continuous	
		Rainfall (mm)	Continuous	

Environmental variables

Land use drivers consisted of categorical and continuous variables (Table 4.2). Geology, soil and vegetation types were grouped as categorical variables.

Table 4.3: The % area for different geology types in the SKEP planning domain.

Geology	Km^2	Percentage
Sedimentary	14910.45	78
Igneous	20866.62	8
Mineral	8.28	<1
Metamorphic	149320.16	11
Unknown	7072.88	4
Total	192178.38	100.0

Geology was reclassified according to rock type and the percentage of each type was also calculated (Table 4.3). Soil types were reclassified according to their nearest class (Table 4.4). Vegetation was classified according to nine vegetation types (Table 4.5).

Table 4.4: Soil types classified according to its nearest class (Soil classification working group, 1991) and grouped according to its percentage area coverage in the SKEP domain.

Soil	Km^2	PERCENTAGE
Glenrosa/Mispah/lime soil	83785.68	44
Red-yellow apedal	52501.78	27
Miscellaneous soils	47089.84	24
Pismacutanic	6718.51	4
Grey regic sand	1328.34	1
Plinthic catena	474.25	<1
Melanic & red soils	132.94	<1
TOTAL	192031.34	100

Continuous variables were altitude (m), mean temperature of the hottest month (°C), mean temperature of the coldest month (°C), mean of daily minimum temperature (°C), mean annual temperature (°C), annual number of growth days (days), annual growth temperature (°C), soil water stress minimum (% days under stress), soil water stress maximum (% days under stress), and mean annual precipitation (mm).

Table 4.5: The % area of different vegetation types in the SKEP planning domain (arranged from most to least abundant).

Vegetation	**Km^2**	**Percentage**
Shrubland	108392.58	57
Thicket	18623.64	10
Fynbos	15683.93	8
Grassland Arid	13482.59	7
Renosterveld	12318.86	6
Succulent Shrubland	11445.61	6
Other	7361.17	4
Sparse Shrubland	3146.69	2
Grassland	1190.91	1
Wetland	118.82	<1
Total	191783.62	100

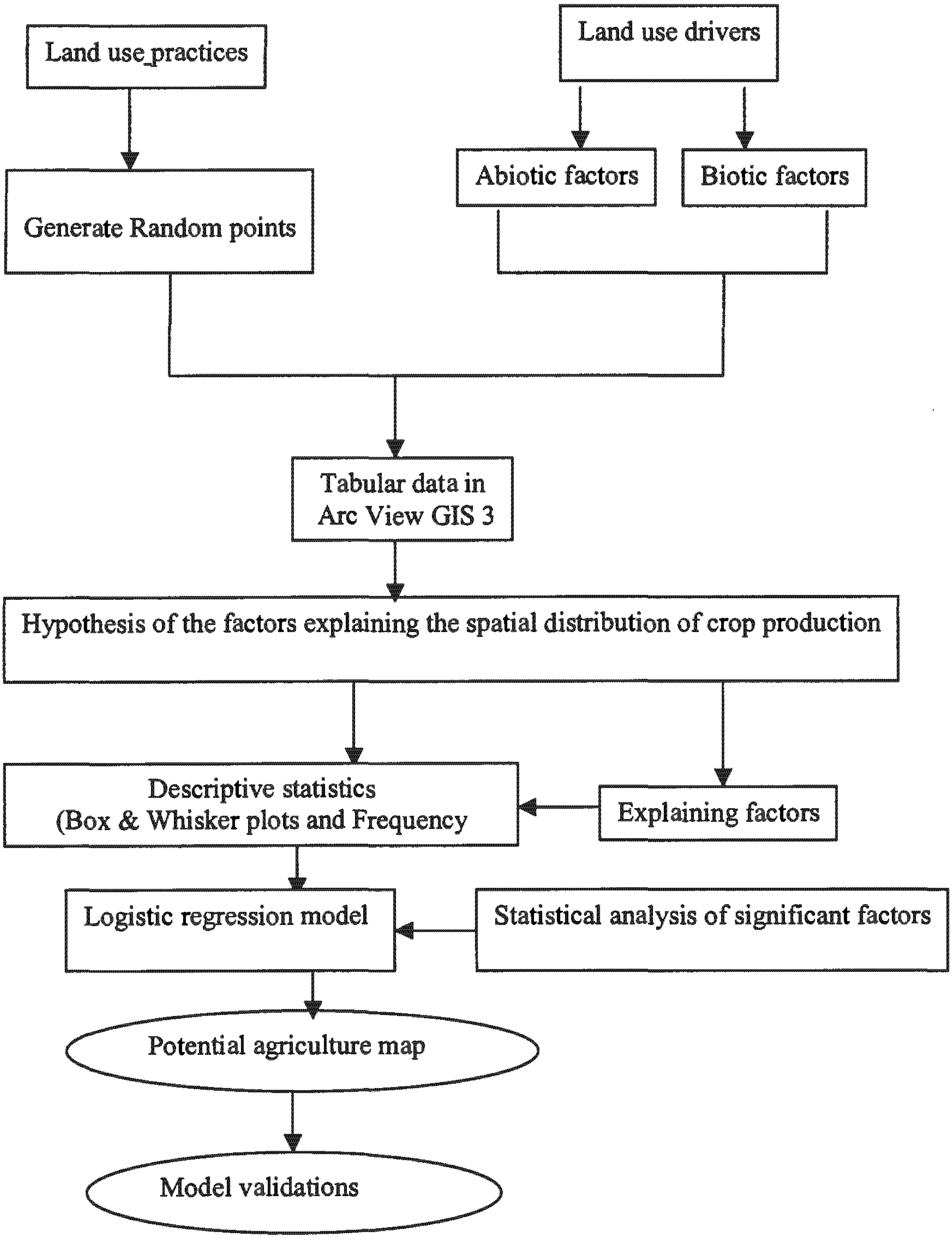


Figure 4.1: The approach used in this analysis to develop a statistical GIS model to explain the potential transformation of the SKEP planning domain by agriculture, primarily crop production.

Statistical approach

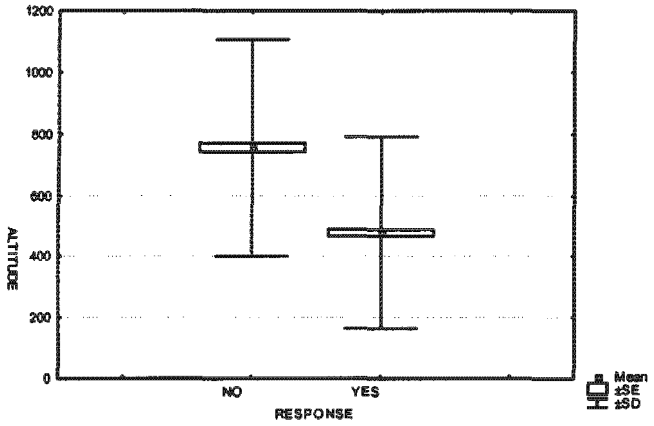
3.2.5.1 **Protocol**: The cropland shapefile was converted into a grid file (with a total of 675 495 grid cells). From the grid file 1000 random points of presence/absence cropland were generated using Arc View standard procedures. The random grid points were then transferred to Arc Info 7.2.1 to convert them into point shapefile. The points were then matched with the environmental land use drivers and the product was a tabular dataset of each land use and its drivers. The data was transferred to Statistica6 package, 2002 version for further analysis. Basic statistics (box & whisker and frequency tables) were derived in order to identify the variables showing the greatest influence on land use. Thereafter the logistic regression model was developed.

Logistic regression models can be used to identify potential drivers of land use pattern and for predicting future land use pattern. It was used to investigate the relationship between the dependent land use variables and a set of environmental drivers (McCullagh & Nelderll 1989; Rouget *et al.*, 2001). The full correlation matrix was produced, which gives the correlations between all pairs of variables. The correlation matrix was calculated between all independent variables (Table 4.6) to examine multicollinearity. Correlation is the measure of the relation between two or more variables. A value of -1 represents a perfect negative correlation and a value of +1 represents a perfect positive correlation. A value of 0.00 represents a lack of correlation (Van Den Honert, 1997). From this correlation matrix the variable most correlated with the dependent variable "land use" was chosen to enter the equation at the first step, provided that the resulting logistic regression model shows significant fit (Van Den Honert, 1997).

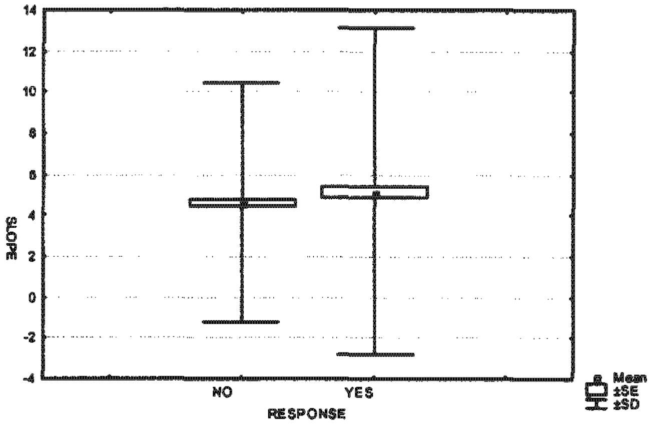
Table 4.6: Summary of the correlation matrix between environmental factors. Auto correlated variables were removed.

Variable	**Renosterveld**	**Swsmin**	**Glenrosa/ Mispah/lime soil**	**Slope**	**Rainfall**
Renosterveld					
Swsmin	0.1068				
Glenrosa/Mispah/lime soil	-0.1559	-0.0577			
Slope	-0.0633	0.0594	0.0886		
Rainfall	-0.1309	0.1864	-0.0702	-0.2894	
Mintemp	0.1679	0.3179	0.1388	-0.0061	0.3818

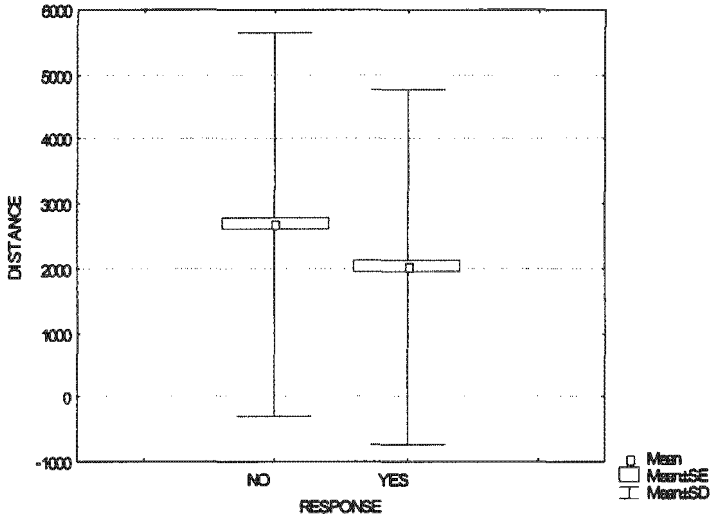
A step-wise logistic regression model was derived where the crop distribution (presence or absence) was used as the dependent variable, and all environmental factors as the independent variables. All non-significant factors were removed. The procedure of removing and adding variables was repeated until all variables qualify to run the logistic regression model. All the significant variables were used as the determinants of land use change in the SKEP planning domain. Model accuracy was derived using the classification of odds (% of cells correctly classified for presence and absence of cropping areas) and the Kappa statistics (Table 7). Kappa statistics also confirmed that the model performed well.



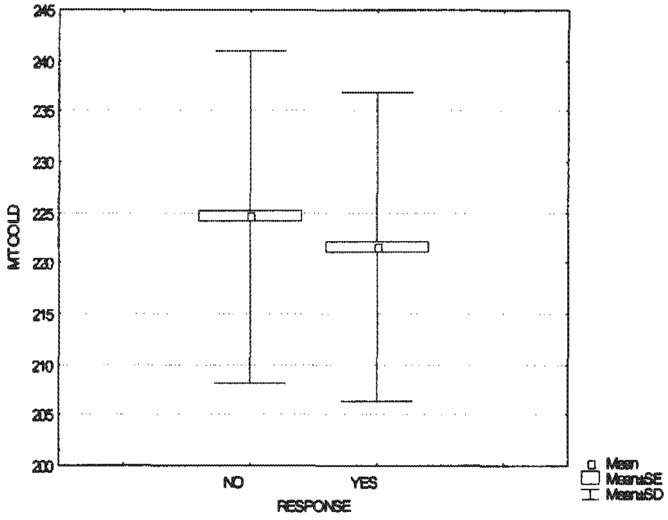
Altitude (Ns)



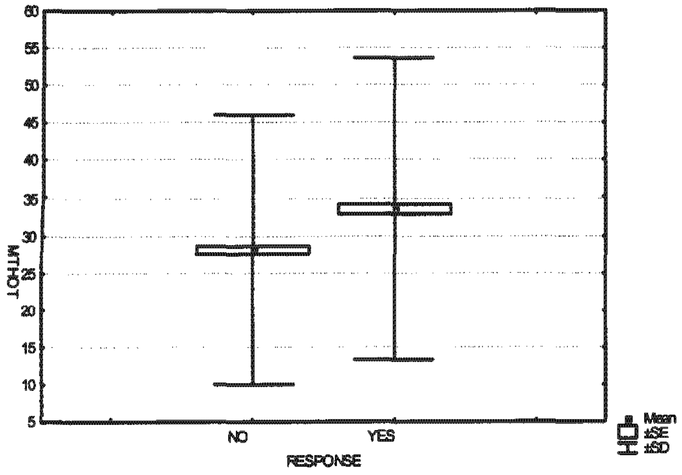
Slope (Ns)



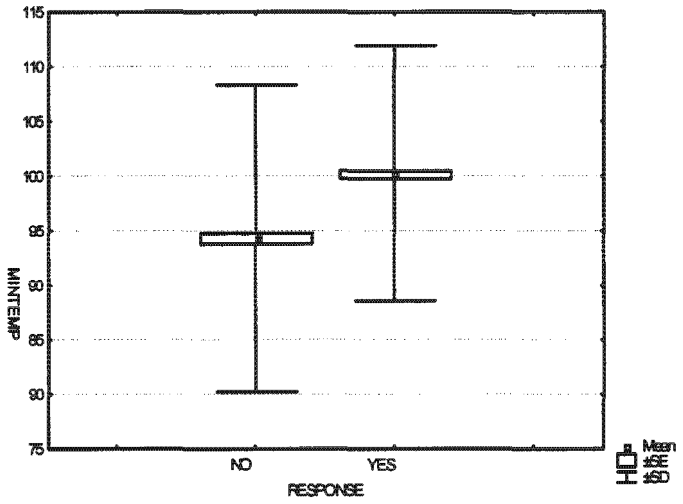
Distance to rivers (Ns)



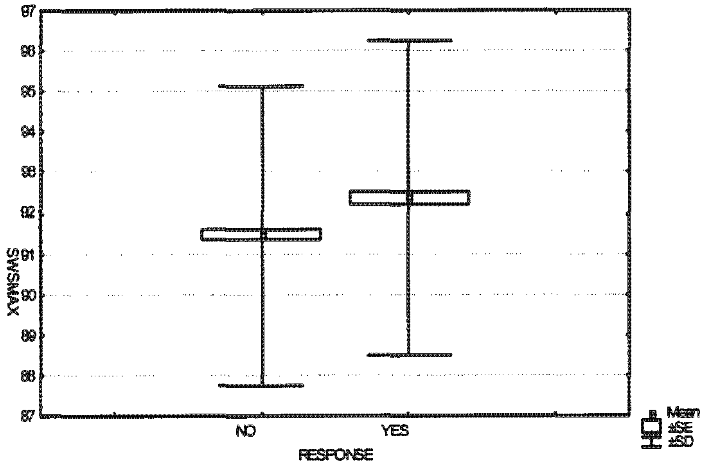
Mtcold (Ns)



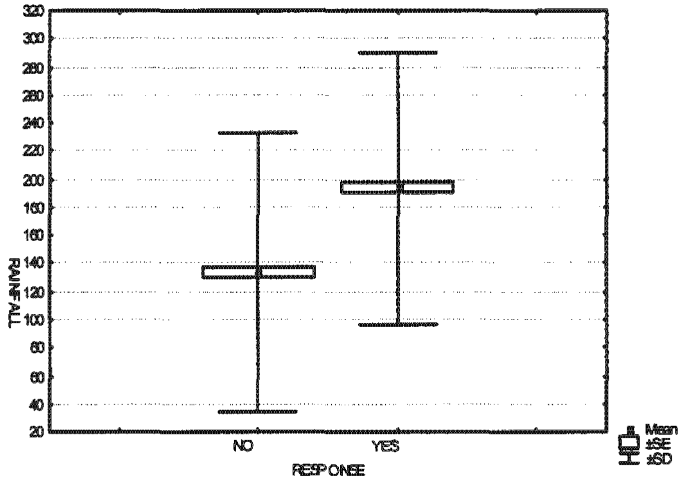
Mthot (Ns)



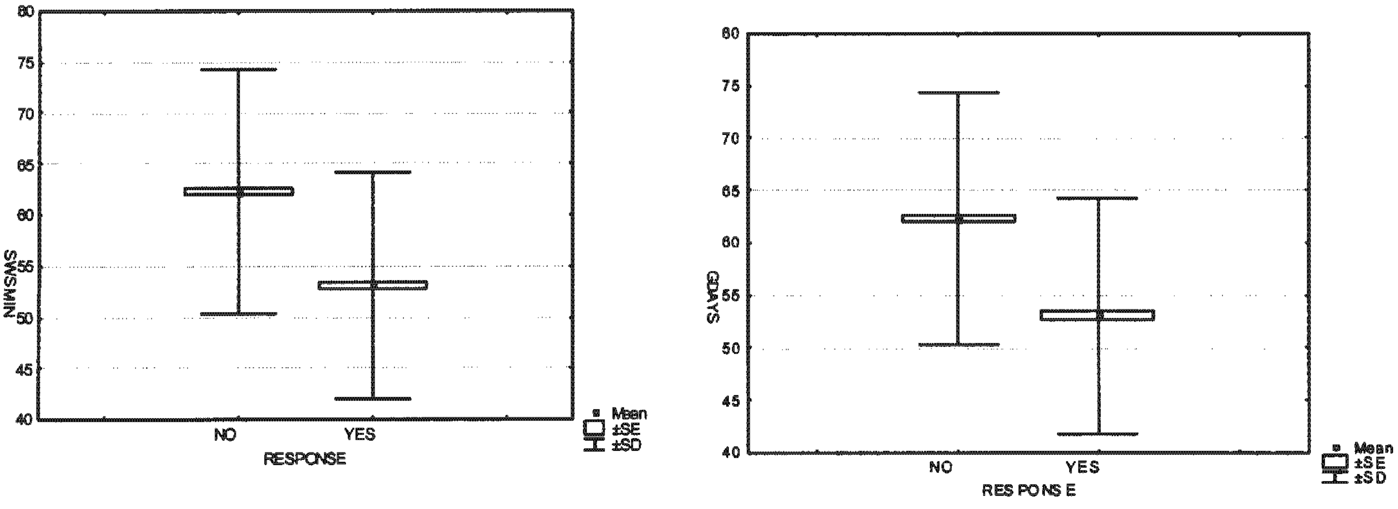
Mintemp (Ns)



Swsmax (**)

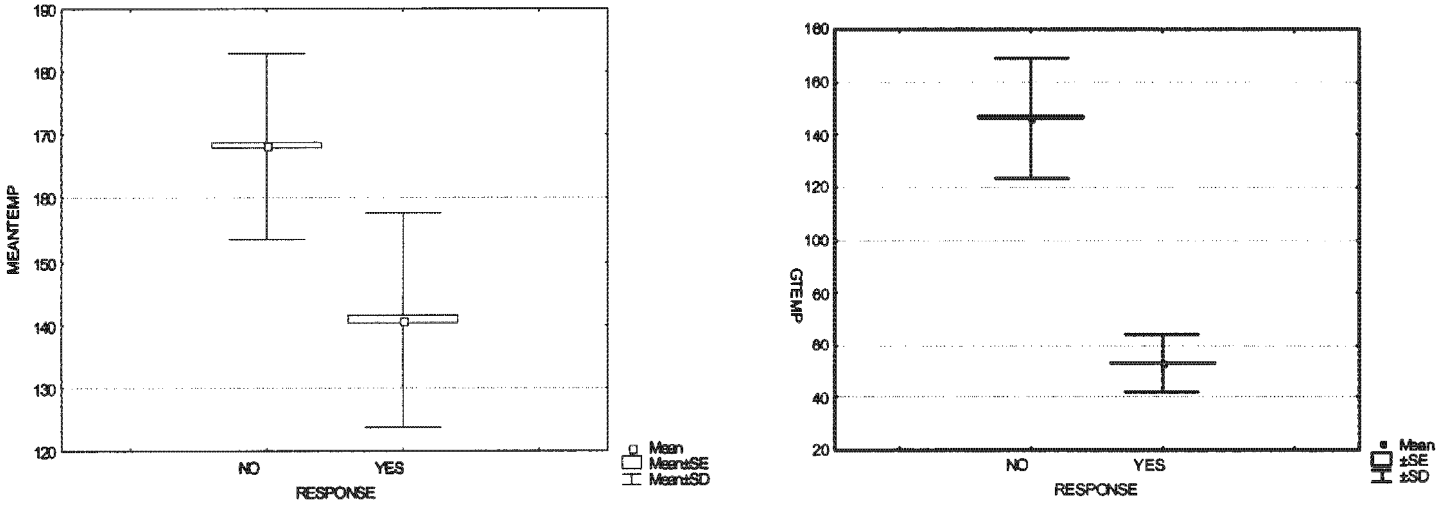


Rainfall (**)



Swsmin (*)

Gdays (**)



Meantemp(*)

Gtemp (**)

Figure 4.2: Box and Whisker Plots for all continuous variables. Significant variables are grouped as follows: p=0.01- 0.05 (*), p <= 0.01 (**), p>0.5 (Ns = not significant). The significant factors qualify to enter the model. No = absence of crops and yes = presence of crops. Some variables shows significant variation between no agriculture and agriculture areas in the box & whisker plots but when they are combined together in a logistic regression model they are not significant.

Results

Logistic regression model

The box & whisker plots (Fig. 4.2) for minimum temperature, mean temperature, growth days, growth temperature, soil water stress, and rainfall have shown variation between the presence/absence of cropland areas in the SKEP planning domain. Although they show variation, some are non significant in the final model. For the categorical variables (Fig. 4.3), no variation was found for aspect. Regarding vegetation, the renosterveld, shrubland and fynbos showed difference between cropland and non-cropland areas. Only the Glenrosa/Mispah/lime soil type showed variation between presence/absence of crops.

A model based on renosterveld vegetation type, soil water stress minimum, Glenrosa/Mispah/lime soil type, slope, rainfall and minimum temperatures explained 72% of the variance in cropland distribution (Table 4.7). Renosterveld, rainfall and minimum temperature affect the spatial distribution of cropland production positively whereas the others factors affect it negatively.

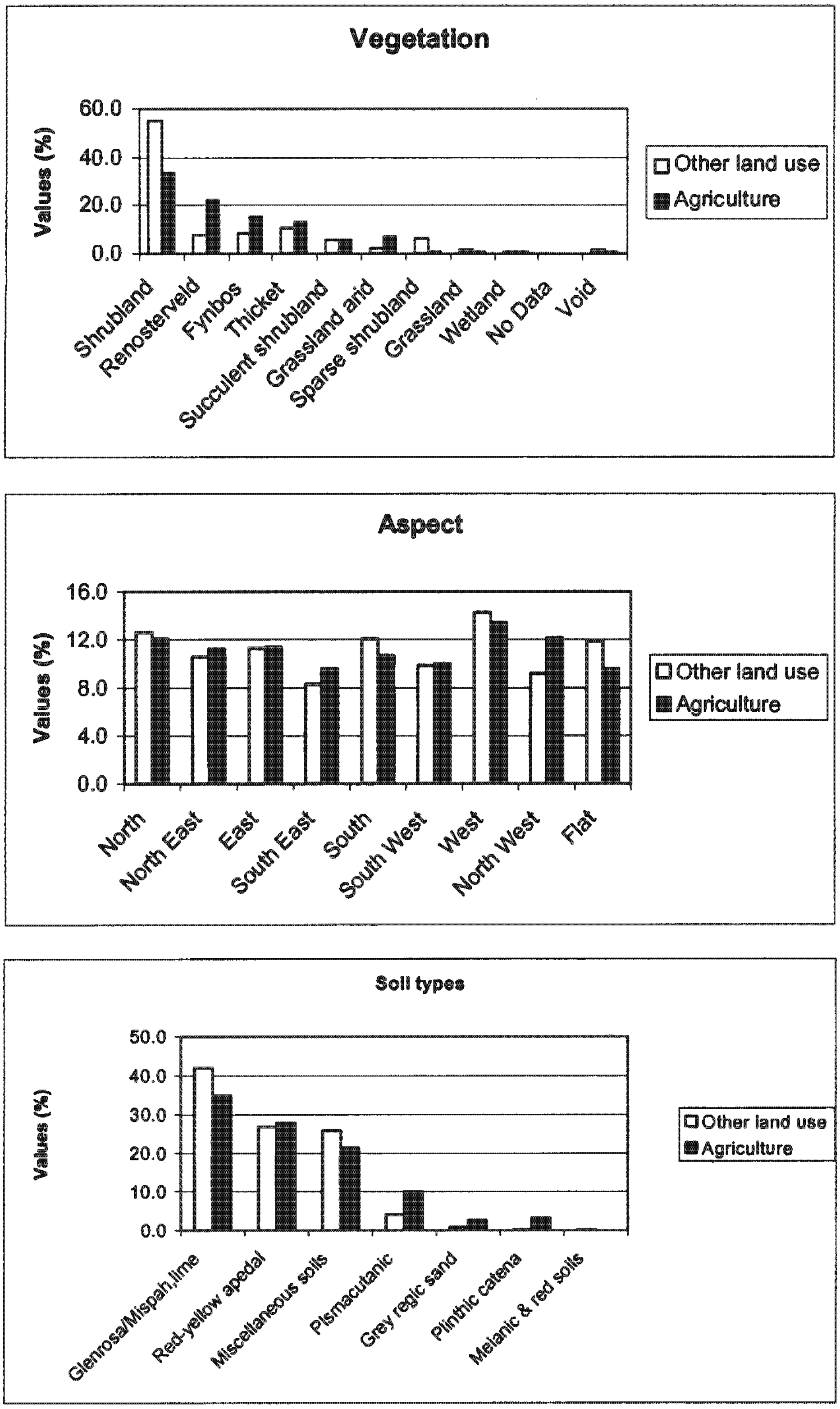


Figure 4.3: Frequency tables for vegetation types, aspect and soil variables

Table 4.7: Logistic regression results. The significant factors, coefficient, and standard errors of the model are indicated.

Variable	Coefficient/Estimate	Standard error	P-value	T-value
Constant	-3.000	1.000	0.000	-4.000
Renosterveld	1.000	0.000	0.000	7.000
Swsmin	-0.038	0.005	0.000	-7.510
Glenrosa/Mispah/lime soil	-0.339	0.114	0.003	-2.966
Slope	-0.085	0.012	0.000	-6.937
Rainfall	0.008	0.001	0.000	10.549
Mintemp	0.045	0.005	0.000	8.898

Table 4.8: Classification of classes: odds ratio. The odds ratio is useful in the interpretation of the results of the logistic regression model and is computed from a 2x2 classification table, which displays the predicted and observed classification of cases for a binary dependent variable. This represents the accuracy of the model (percentage of correctly classified cropland observations). K = 0.435

Calibration	**Observed**	**Predicted agriculture (>0.5)**	**Predicted other land use (<0.5)**	**Model accuracy**
	Agriculture	713	278	72%
	Other land use	261	656	72%

The validation results (Table 4.9) of the predicted map of agriculture potential confirmed that the model derived has performed better than randomly selected cells from the statistical GIS model. The model (Fig. 4.4) predicted high probabilities of agriculture potential (31%) in the Gariep/Namaqualand sub-region (where grid cells are > 0.5).

Table 4.9: Model validation using the full dataset. K = 0.1

Validation	Observed	Predicted agriculture (>0.5)	Predicted other land use (<0.5)	Percentage
	Agriculture	6504	18919	74%
	Other land use	509 846	213 059	71%

Discussion

Spatial extent of future land use transformation

What are the environmental correlates of cropland areas in the SKEP planning domain?

The logistic regression model indicates that high rainfall, high minimum temperature and the presence of renosterveld vegetation increase the probability of agricultural expansion in the SKEP planning domain (Table 4.7). Previous studies have also noted that rainfall is the major limiting factor of agriculture in the SKEP planning domain (Desmet & Cowling, 1999). Other studies have found that agriculture expansion is affected by the following factors: vegetation condition, slope (which affects soil condition, infiltration, run-off, and nutrition), and soil condition (i.e. permeability, texture, depth, water storage capacity and fertility status) (Rebelo, 1997; Wood & Low, 1998; Soil classification working group, 1999; Milewski, 2000). This level of detail for the correlates of cropland production was not available for this study.

More cropland was found on Glenrosa/Mispah/lime soil type, which is shallow and relatively lower in clay and less erodible. Due to these characteristics, this soil type is highly suitable for agriculture. Previous studies have shown that the decision to use agricultural land for cropland depends largely on the nature of the soil and water availability (Rounsevell *et al.*, 2002). Due to this higher rain use efficiency, areas on Glenrosa/Mispah/lime soil have a higher and more regular cropland production (Soil classification working group, 1999).

Can statistical models and GIS be used to derive spatially explicit predictions of future agricultural land use in the SKEP planning domain?

The statistical GIS model predicted 31% of agriculture potential including non-agricultural areas in the region. The model can be used to predict future agriculture land use at the broad scale but some limitations were found at the local (fine) scale. For example, in the Gariep/Namaqualand sub-region of the SKEP planning domain, the model identified cropland production potential in non-agricultural areas (Fig. 4.4). The model has overestimated the agriculture potential in the sub-region, which could be explained by several reasons.

Firstly, the model is not 100% accurate, as social variables, which are also important drivers of cropland production expansion in the SKEP planning domain, were not included in the model. Further changes are likely as a result of policy reform and socio-economic influences. The transformation of the natural resources of Africa's biodiversity for example, are due to economic and social driving forces that cannot be easily stopped as long as the goals of most people and their political representatives are to increase production of food for the growing population at all costs. Therefore, as Africa's population increases and demand for food and other agricultural products continues to escalate, greater demand will continue to be placed on landscapes to produce more food. This process is unfolding in the drylands of Africa, and is likely to exert further pressure on biodiversity unless concerted efforts are made to adopt more environmentally sound agricultural practices (Darkoh, 2003).

The second reason is that the model might not include all the environmental variables that could influence the spatial distribution of cropland production in the landscape. For example, soil depth, texture and nutrient status might be important determinants of cropland production but were not included in this analysis.

Where do we expect future crops to be sown and why?

The model accuracy (74% accurate with a Kappa of 0.435) confirms that certain areas in the SKEP planning domain are suitable for croplands (Fig. 4.4). Areas of potential agriculture are found mainly in the wilderness areas of the Cederberg and in the Southern Karoo. This agriculture potential is due largely to the presence of renosterveld vegetation in the region. This vegetation type occurs on fertile soils on arable foothills and lowlands. For this reason, most of it has been ploughed to plant grapes, fruit and wheat (Rebelo, 1996; Wood & Low, 1998; Milewski, 2000). All remaining renosterveld areas in the SKEP planning domain have agriculture potential in the future. Areas in the SKEP planning domain, where croplands are planted, vary considerably due to different soils and the amount of rainfall (see chapter 1). Vegetables and small grain crops are grown in higher rainfall areas, while dryland crops such as wheat, barley and oats and dryland lucerne are grown in the drier areas (Dean and Milton, 1999). Croplands will expand on Glenrosa/Mispah/lime soil in the future because they are capable of storing water from scarce rainfall events and later releasing it to plants.

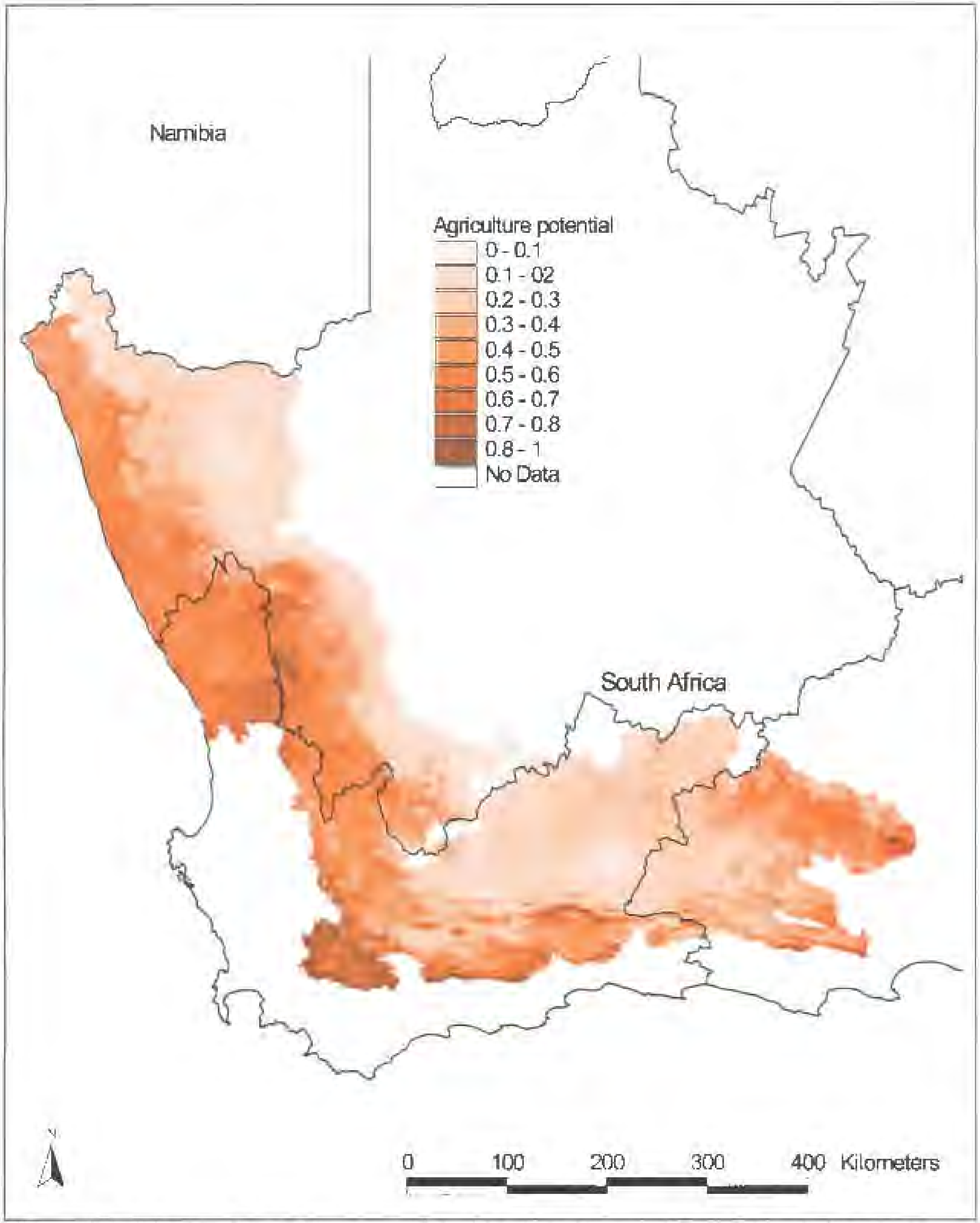


Figure 4.4: A layer of agriculture potential with values between 0 and 1, the darker areas (>0.5) are areas where cropping can be practiced. The lighter areas (<0.5) are areas where there is no cropping expected

Limitations of the model

The model was mainly limited by the availability of environmental factors used. Predicting the distribution of cropland production could be improved by integrating socio-economic variables in the model. Understanding the land use practices in the SKEP planning domain would require an understanding of historical changes in land use.

General Conclusion

Current land use practices in the Succulent Karoo biome.

There is little documentation of land use and its drivers in a spatially explicit way for the Succulent Karoo biome (chapter 2). However despite the lack of historical data on initial conditions, the current land use results have proven informative for local land use planning efforts (Black *et al.*, 1998; Driver *et al.*, 2003).

The major land use practices in the Succulent Karoo biome, in increasing order of area used are urban settlement (<1%), mining (2%), crop production (3%), conservation (5%) and livestock production (90%). These proportions are fairly similar in each of the three South African sub-regions of the SKEP planning domain where livestock production is by far the dominant land use practice in all sub-regions. While the area used for cropland production has declined over the last 50 years, the illegal collection of medicinal plants, particular in the Southern Karoo sub-region has increased recently. Unfortunately this land use practice did not form part of this study. The results confirmed that at least 4.8% of the Succulent Karoo biome is conserved, although only 3.5% is formally protected in statutory reserves and the rest in non-statutory reserves. The major concern, however, is that the formally protected areas neither represent adequately the biodiversity pattern nor the major ecological processes in the region (Driver *et al.*, 2003).

Livestock density in Namaqualand.

The current status of livestock density in Namaqualand suggests that overgrazing of land occurs not only in the communal areas of the region, but also on many of the private farms. Livestock density systems differ considerably in these two land tenure systems where sheep are dominant on the private farms while goats are dominant in the communal areas. The results suggest that 76% of the communal farms were grazed below grazing capacity in 2002 while 67% of the private farms are currently stocked below grazing capacity. About 24% of the private farms and 18% of the communal areas are grazed above the grazing capacity threshold set by the Department of Agriculture. This current stocking rate analysis is considerably different from previous studies, which suggested that it is the communal areas of the region only that are overstocked.

Several reasons can explain the high stocking density on private farms such as the lack of accuracy of official stock number data as reflected in tax returns and agricultural censuses. The actual numbers of livestock on the land may be far in excess of those reported in agricultural returns. There have also been few censuses of stock numbers on private farms at farm scale in the past and this study has shown the importance of fine-scale surveys. The reported decrease of livestock numbers on communal farms might be facilitated by the severe drought that occurred in the region between 1998 & 1999 and by additional land given to communal farmers as part of the national government's land reform programme in Namaqualand. This analysis suggests that there is an urgent need for a continued long-term survey of stock numbers and vegetation condition particularly at fine scale on both communal areas and private farms.

Agriculture potential

This study has shown that statistical GIS models can be used to estimate the areas of future agriculture potential in the SKEP domain (chapter 4). The environmental land use drivers such as renosterveld vegetation type, Glenrosa/Mispah/lime soil type, slope, minimum temperatures and rainfall are the key determinants of land use change as identified by the model. Greater agriculture potential exists in the Southern Karoo sub-region. This sub-region has more fertile soils and higher rainfall when compared to other sub-regions of the Succulent Karoo biome. The presence of renosterveld vegetation type in the sub-region is another reason why more of this area might be transformed by crop production in the future. Previous studies have noted that this vegetation type (renosterveld) occurs in fertile soils on arable foothills and lowlands.

Further study on socio-economic variables affecting policy reform and decision-making processes would likely improve our ability to model agricultural land use distributions (Rounsevell, *et al.*, 2000). Information on the temporal and spatial pattern of climate change and its implications for agricultural land use is also important for policy makers to develop future conservation planning and sustainable agricultural development strategies (Tao *et al.*, 2003). Finally, further studies on how urban settlement, population growth, and grazing, relate to agriculture expansion in the sub-region are required. Sustainable agricultural intensification and a landscape planning approach to conservation is probably the only way to ensure biodiversity and environmental sustainability in Namaqualand and the Succulent Karoo biome.

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