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Land-cover Change: Threats to the Grassland Biome of South Africa

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June, 2007

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Submitted in partial fulfillment of the degree of Master of Science in Resource Conservation Biology

Declaration

This thesis was supervised by Dr B. Erasmus.

I hereby declare that this thesis, submitted for the degree of Master of Science in Resource Conservation Biology at the University of the Witwatersrand, Johannesburg, is the result of my own investigation unless acknowledged to the contrary in the text.

Ruwadzano Matsika
May, 2007

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EXECUTIVE SUMMARY

The Grassland biome of South Africa has been identified as critically endangered and the biome in South Africa most requiring conservation attention through the implementation of efficient, sustainable systematic conservation plans. The ability to predict where land-cover transformation as well as information on the occurrence and severity of current land cover transformation activities, as threats to biodiversity, is required as part of the systematic conservation planning process. Neke & du Plessis (2004) predicted land cover transformation and the severity of the impact on biodiversity in the Grassland biome. This model was based on potential land use suitability models and land cover information for the 1994/5 season extracted from the National Land Cover database (NLC1994). These predictions were tested by assessing actual land cover change in the Grassland biome using observed differences in grassland land cover between the NLC1994 and NLC2000 databases.

Methodology

Because of differences in format and land-cover classification between the original datasets, both NLC1994 and NLC2000 had to be modified before any analyses could be carried out. These differences exist because different techniques were used to collate the respective datasets, thus introducing the potential for significant mapping error in the original datasets and more significantly erroneous results with respect to landcover change detection. The implications of this were presented in the discussion. Both datasets were spatially resampled and class-standardised and it was felt that this would significantly reduce any the impact of any such existing errords in the original datasets. Thereafter landcover information for the Grassland biome was be extracted and the comparative landcover analyses executed. The analyses carried out included:

- Landcover change per landcover class within the Grassland biome with emphasis on the Grassland landclass losses and gains
- An assessment and comparison of the relative fragmentation of the remaining grassland patches in both datasets
- An assessment of current grassland habitat degradation

- The comparison of the predicted land cover change as given by Neke & du Plessis (2004) against the observed grassland changes
- The creation of a new Grassland Transformation threat map reflecting current land cover change threats, and including information pertaining to the threats to Grassland biodiversity posed by invasive alien plants, road effects, urban areas and soil erosion hazards.

Results and Discussion

25% of the remaining grassland patches underwent transformation to other land classes. Grassland clearing for cultivation, bush encroachment and bushland vegetation regeneration were the main causal factors behind the observed grassland losses. However, grassland vegetation regeneration on formerly cultivated land, bush clearing and reclassification of degraded lands as grasslands in the NLC2000 dataset contributed to a net 2% gain in area of the grassland land class. The remaining grassland patches are more fragmented than they were in NLC1994, the average patch size (NLC2000) is three times smaller and the total number of grassland patches has increased (also by a factor of 3) and the remaining grassland patches are more isolated. The largest, least fragmented grassland patches occur along and to the west of the Great Escarpment as it traverses the Grassland biome. Most of the predictions of grassland transformation were realised, however the model used by Neke & du Plessis (2004) consistently underestimated and in some cases failed to predict the occurrence of grassland transformation in the central interior of the Grassland biome. Current, measurable human activities that act as grassland transformation agents were incorporated to create a threat map showing the extent and severity of land-cover transformation activities within the biome; grassland bird species richness information was then incorporated into this map to create biodiversity transformation threat map. This map was used to show the location and severity of the impacts of human transformation activities on grassland biodiversity. Both transformation threat map reflect the current situation across the biome today and were compared against the Potential transformation threat map produced by Neke & du Plessis (2004). The human transformation threat map confirmed the inability of the Neke & du Plessis model to make correct predictions of land cover change away from the eastern,

high altitude boundary of the biome. Given that the biome is defined by its climatic characteristics, the incorporation of global climate change effects would further refine the results gained, and perhaps provide more accurate predictions.

As aforementioned, there are however factors existing within the original datasets used in this analysis that may have affected the accuracy of the landcover change analyses. These factors are centred on the potential effects of mapping errors within either of the NLC datasets. The delineation of landclass boundaries in the NLC1994 dataset is one such factor- placing a line over what is in reality a gradient of changing vegetation, is a subjective exercise and depends entirely on the technician involved this in itself may have introduced a fair amount of error in the mapping process. When coupled with the automated classification techniques used, for the most part, for the NLC2000 dataset, it becomes apparent that it is highly unlikely that even in the absence of actual landcover change the same boundaries would be drawn between two landclasses in the same area. This would provide false positive results for landcover change where in fact this is as a result of mapping errors. This is acknowledged and included in the interpretation of the results and it is felt that in spite of this, all possible steps were taken to minimize the impact of these effects on the reslults.

The analysis allowed the identification of the current land cover transformations leading to grassland loss. However, land-cover change is only the physical expression of the complex interactions between socio-economic factors. To create effective and sustainable conservation plan for the Grassland biome, with an aim to reducing habitat loss requires an action plan to address these factors as the ultimate drivers of land cover change.

INTRODUCTION

1.1 Why the Grassland biome?

The grasslands of the world are facing a major conservation crisis (Hoekstra *et al.,* 2005) with the grassland terrestrial ecosystem type being shown to display the largest degree of habitat loss worldwide (Scholes & Biggs, 2005). This land-cover transformation results in a landscape that is fragmented, in which the ecosystem composition, structure and function are compromised due to the interference with ecological processes (With 1996). While this situation is by no means unique to the grasslands of the world, it has been predicted by Sala *et al.,* (2000) that together with Mediterranean vegetation, the grasslands will experience the most biodiversity change in the next 100 years since these ecosystems are sensitive to all global change drivers. The major driver of this expected biodiversity change will be human-driven land use/ cover change (Sala *et al.,* 2000 also Soule 1991, Dale *et al.,* 1994; Scholes *et al., 2005*).

In the past, conservation areas were created in an *ad hoc* manner (Pressey 1994, Margules & Pressey 2000). It is likely that most of these do not effectively represent biodiversity and conservation needs as they stand today (Pressey 1994, Lombard 1995). The IUCN recommends that a minimum of 10% of any landscape should be conserved in order to save 50% of the biodiversity it contains (Shafer 1990). Yet less than 7% of the Grasslands have been conserved worldwide (White *et al.,* 2000). In South Africa, the area covered by the Grassland biome is of great importance in terms of aquatic and terrestrial biodiversity (Reyers *et al.,* 2005) but only 2.8% of the total surface area of the biome has been placed under formal protection (DEAT, 1997), a total that falls far below the recommended figure.

The Grassland Biome of South Africa is critically endangered (Olsen & Dinerstein 1998; Reyers *et al.,* 2001) and it is the biome in South Africa most urgently requiring conservation attention (Rebelo, 1997). Human land use activities have had a high impact upon the available natural resource base resulting in widespread land-cover transformation (Neke & du Plessis, 2004, Reyers *et al.,* 2005). This biome is resource

rich and provides a wide range of ecosystem services that facilitated human settlement in the area in the past (O'Conner & Bredenkamp 1997; Reyers *et al.*,., 2005). These services include water and nutrient cycling, soil stabilisation, carbon sequestration, energy supply, provision of food through current agricultural activities and forage for livestock (Reyers *et al.,* 2005). At least 29.2% of its entire area has been transformed by human land use (Fairbanks *et al.,* 2000; Neke & du Plessis 2004) and it is the second most threatened biome in South Africa, after the fynbos biome. In light of the valuable services provided by this biome and the fact that it houses a large portion of the South African populace and economic activities it is evident that there is high pressure on the remaining, available ecosystem resources. Efficient conservation plans are required to ensure the sustainability of these remaining ecological communities into the future. Habitat loss through land cover and land-use changes is expected to be the leading threat to biodiversity in the Grassland biome (Sala *et al.,* 2000) and more information about this phenomenon is required. Understanding the processes behind and the ecological consequences of land-cover change should be a conservation planning priority for the biome (Rouget *et al.,* 2003; Williams, 2007).

1.2. Human land use: presenting the threats to biodiversity

It is well established that those land-cover types with variety of potential land-uses are especially vulnerable to future transformations because of the opportunity they present to a variety of development options (Fairbanks & Benn 2000). These development activities lead to habitat destruction and have been linked to the extremely high current species extinction rates that are being experienced worldwide, far exceeding historical global extinction rates by a factor as much as 10 000 (Wilson 1988, UNEP 1995)- a dire situation for the Grassland Biome of South Africa to face. Clarifying the extent to which any potential conflicts between development potential and conservation importance may occur would allow for more efficient and effective conservation planning by focusing the allocation of limited resources available – both monetary and spatial, for conservation planning on the areas most at risk (Margules and Pressey 2000). The threats in the Grassland Biome of South Africa have arisen from anthropogenically-induced habitat transformation because of its development potential. This biome contains a wealth of

resources that have potential to be and most of which are currently being exploited for economic benefit in any number of ways. These include large coal and diamond deposits, gold fields and agriculturally productive land (SANBI 2005). The Grassland Biome supports the largest urban centre in South Africa consisting of the Johannesburg-Midrand-Pretoria urban complex (Rutherford & Westfall 1994) and several other large metropolitan areas such as Bloemfontein. There is rapid urbanization and urban sprawl and this is associated with localized depletion of natural resources and unprecedented pollution of the local environment[1]. It is important to be able to predict not only the effects of extractive uses, urban sprawl and alien species invasion on biodiversity (Margules and Pressey 2000) but also where these threats are likely to arise that we may plan means to combat their effects. The human activities behind these observed grassland habitat losses present threats to biodiversity in these areas. Iinformation about the character and location of these threats in the Grassland biome is required.

1.3. Threat prediction at the landscape level

There has been a recent surge in research focusing on the systematic and quantitative assessment of current and future risks to biodiversity at the landscape level (White *et al.,* 1997, Margules & Pressey 2000; Fairbanks & Benn, 2000; Wessels *et al*., 2000; Reyers *et al.,* 2001, Cowling *et al.,* 2003, Lombard *et al.,* 2003; Rouget *et al.,* 2003; Neke & du Plessis 2004; Reyers, 2004; Rouget *et al.,* 2004; Reyers *et al.,* 2005). Given that the biodiversity of an area cannot be fully quantified, surrogate measures are often used and when one works at the landscape level one assumes that all finer aspects of biodiversity are adequately represented too (Noss 1987, 1990; Pressey 1994; Fairbanks & Benn 2000; Wessels *et al.,* 2000). It can be argued though that when using this "coarse-filter" approach (Noss 1987, 1990) rare species with very restricted distributions will not be represented (Noss 1983) or included in conservation plans and that in fact working at this level may not allow for inclusion of all necessary elements for biodiversity retention (Lambeck 1997). Use of purely species-based approaches for conservation planning also has its disadvantages (van Jaarsveld *et al.,* 1998, Maddock & du Plessis 1999, Fairbanks & Benn 2000, Reyers *et al.,* 2001) and as such it has been suggested that the best

[1] http://www.unep.org/aeo/213.htm. Accessed on-line on 20/01/2007

techniques will use a combination of the two approaches. However, for one to successfully implement conservation plans it is important to have information on those land uses that pose both current and future threats to conservation interests, as well as the techniques to identify them (Faith & Walker 1996, Reyers *et al.,* 2001, Ricketts & Imhoff 2003) especially when working at the landscape level (Rouget *et al*., 2003, Rouget *et al*., 2006).

Neke & du Plessis (2004) equated threat with any land-use resulting in land-cover conversion from grassland to any other land-cover class and produced a threat map for the grasslands biome. This was achieved by developing land-use suitability maps for afforestation, agriculture, urban expansion, mining and stock farming and then developing a framework for scoring the relative severity of these land-uses on grassland biodiversity. Assessing the areas according to the likelihood of transformation and the severity of this land-cover change on biodiversity produced the threat map. They found that at least 44.7% of the grasslands had been transformed and the remaining semi-pristine areas were highly fragmented. In terms of transformation threat- the highest levels of threat occurred in the species rich, high rainfall eastern areas of the grassland biome- and that those areas with the highest threat levels had all been transformed by human land-uses- predominantly afforestation. This was to be expected since there is often a high positive correlation between species richness and human land-use and the threat exists where the two coincide (Ricketts & Imhoff 2003). This reinforces the notion that ecosystems must therefore be managed in such a way as to allow for both optimum human productivity and development, and biodiversity (Pimental *et al.,* 1992, Daily *et al.,* 2001). Bush encroachment and invasive alien plants were a root cause of land cover transformation (8.9%). This was associated with urban centres and the perimeter of the biome itself and this was suggested to be worth monitoring. Invasive alien plants (IAP) cause land cover transformation- they disrupt ecosystem structure and function and are a threat to biodiversity where they occur (Richardson *et al.,* 1997). Invasive plants have been ranked alongside deforestation, urbanisation, pollution and cultivation as "major agents" of land cover change (Cronk & Fuller 1995)**.** Neke & du Plessis (2004) also found that the large expanses of the area that had been transformed by agriculture were in

actual fact unsuitable for this land-use and were most probably sustained by government subsidised irrigation and supplementary fertilisation. The South African Agricultural policy was changed in the mid-1990s and with the removal of subsidies it will be of great interest to see whether there has been any change with respect to the occurrence of agriculture in these marginal areas.

The inclusion of the effects of the road network on biodiversity within the Grasslands biome by Neke & du Plessis (2004) might have added an extra dimension to the analysis of threat, especially considering that the construction and maintenance of roads has been a major source of land-cover change. Road effects on biodiversity include the habitat transformation occurring as a result of their construction, fragmentation, increased mortality through road kill incidences, barriers to movement, conduits of exotic plant species invasion (Forman & Alexander, 1998), chemical pollution by vehicles, modification of animal behaviour (Trombulak & Frissell 2000) to list a few. Their presence and utilisation pose a serious threat to biodiversity (Trombulak & Frissell 2000, Stoms 2000, Reyers *et al.,* 2001, Theobald 2003). Furthermore, the effects of roads on biodiversity extend for some distance away from the actual road itself and the width of this road effect zone depends on the nature and utilisation of that road (Forman & Alexander, 1998; Stoms 2000; Reyers *et* al., 2001). Reyers *et al.,* (2001) used a method similar to that used by Stoms (2000) to determine the road-effect zone for the South African road network as a threat to biodiversity in the country. This method has since been incorporated into threat assessments for conservation planning purposes in South Africa by Reyers (2004), Rouget *et al*., (2004) and Reyers *et al.,* (2005).

Theobald (2003) developed a method to assess the level of potential threat to biodiversity in Colorado (USA) to help guide conservation planning. This method used two indicators of threat- roaded areas and housing density (as a measure of development). Together they provide useful indicators of the intensity of human land-use activities. He then assessed which land-cover types would most likely be at risk from future development and came up with status and threat categories- land was classified as threatened depending on it meeting certain criteria. Thereafter the "conservation potential" of each threatened patch

of land was also computed- this potential was defined by the spatial characteristics (shape, degree of fragmentation) of that identified area. In so doing he was able to grade the landscape into four levels of existing conservation effort- from those not currently protected and requiring maximum effort to those needing little conservation effort in relation to their risk to future developments. Such a method could be used to avoid prioritising areas that will likely be too compromised by anthropogenic transformation and development pressure in the future, regardless of what protective measures are currently instituted (Myers 1979).

As part of the Grasslands Biodiversity Assessment by the South African National Biodiversity Institute (SANBI), Reyers *et al.,* (2005) carried out a spatial assessment of the Grassland biome in terms of biome boundaries, ecosystem services, existing conservation efforts and land cover impacts. Through which they identified priority areas for conservation within the biome. An assessment of land-cover change in the Grassland biome was incorporated into the identification of priority areas. The assessment was an extension of the National Spatial Biodiversity Assessment- NSBPA, (Rouget et al., 2004) and made use of the same datasets as proposed for this project, that is, the National Land Cover Datasets for 1994 and 2000. They merged the different land cover types to give aggregate land cover classes and then assessed per centage land cover change per class. There was no attempt to further analyse the observed land-cover change as it was felt that differences in resolution and methods used to compile the two datasets made this difficult. The report touched lightly on fragmentation of the grassland patches together with land cover diversity and physiognomy, as descriptors of landscape structure. The report concluded that the differences in land-cover change were not significant. However regardless of whether or not the observed figures of land cover change are statistically significant, the nature of the resultant fragmentation, especially with regards to the grassland vegetation type has major implications for biodiversity within that landscape. These changes signify the realisation of threats to biodiversity in the Grasslands Biome.

Landscape level ecological and evolutionary processes have been successfully integrated (as biodiversity surrogates) into conservation planning processes in several instances in

South Africa (Rouget et al., 2003, Cowling et al., 2003, Reyers, 2004; Reyers et al., 2005; Rouget et al., 2006). The shift from species-based approaches to ecosystem approaches in conservation planning may be made possible through identification of spatial components of landscape processes that may be used as biodiversity surrogates (Cowling et al., 2003, Reyers 2004) including land cover transformations (Fairbanks &Benn, 2000; Rouget et al., 2003, Rouget et al., 2004, Reyers et al., 2005) and setting conservation targets for these components through expert assessment and spatial analyses (Margules & Pressey 2000, Cowling et al., 2003, Rouget et al., 2003). Incorporating extant patterns of habitat transformation over a given landscape allows the identification of those areas in need of urgent conservation attention based on the severity of observed habitat degradation (Rouget et al., 2003).

1.4. Land-cover Change Detection

Land-cover change is defined as an alteration in the surface components of the vegetation cover (Milne 1988) or as the "spectral or spatial movement of a vegetation entity over time" (Lund 1983) and change detection involves the identification of the differences in the vegetation entity by observing it at different times (Singh 1989) Worldwide, land-cover change has occurred mostly as a result of human activities and is a major cause of biodiversity loss (Soule 1991)**.** The ability to accurately describe rates and location of land-cover conversion is important for a number of reasons including understanding the carbon budget, the drivers of land-use change, efficient and effective biodiversity conservation and land management practices (Defries & Townshend 1999, Fairbanks *et al.,* 2000, Wessels *et al.,* 2000). Most methods used to identify land-cover change using remotely sensed data require human analysis to identify clusters produced during unsupervised classification, to create training data in supervised methods or to visually interpret satellite images (Townshend *et al.,* 1995)**.** However there are numerous automated software-based methods that carry out post-classification change detection analysis (Lu *et al.,* 2003; Coppin *et al.,* 2004)

There are four possible types of land-cover change on a landscape, land class entities may become a different category, expand or shrink, alter shape, shift position or become more

fragmented (Khorram *et al.,* 1999). Furthermore change detection depends on the ability of the analysis system to adequately assess the baseline situation and to account for differences in seasonal and directional variability (Hobbs 1990). It is also important, where possible, to determine whether the changes are associated with shifts in spatial alignment of the land-cover entities with respect to environmental or climatic gradients (Lu *et al.,* 2003) as well as to relate them to the extant land-uses. Land-cover changes caused by human activities are generally more permanent fixtures on the landscape (Coppin *et al.,* 2004) and in longitudinal studies this aids in their identification.

A very important aspect that should be considered when looking at land-cover change detection is the length of time between the datasets. Aldrich (1975) suggested that a minimum of three years was required to detect non-forest to forest changes. Parks *et al.,* (1983) used Landsat MSS data and suggested a minimum one year interval to detect urban or agricultural development. Using Landsat TM images Coppin and Bauer (1995) found that four- and six- year intervals provided good results in the detection of human-caused canopy cover changes. Given these figures one could safely assume that a period of 5 years would be adequate to detect land cover change within the Grassland biome of South Africa using the National Land-cover databases for 1994/5 and 2000/1. This would of course be in the context of detecting the causal human land uses that could be used as proxy indicators of threats to biodiversity.

1.5. Biodiversity and habitat degradation: loss and fragmentation

Habitat loss and fragmentation are mainly responsible for the current biodiversity loss or species extinctions occurring worldwide (Hastings 1980, Ehrlich & Ehrlich 1981, Wilcox & Murphy 1985, Wilcove *et al.,*. 1986, Groombridge 1992, Hassell *et al.,* 1993, Tilman *et al.,* 1994, Fahrig 1997, Bender *et al.,* 1998; Fahrig 2003, Reyers *et al.,* 2005). Although the terms habitat loss and fragmentation are used almost synonymously in the literature (Fahrig 2002), they refer to different processes and have different impacts on biodiversity (Bender *et al.,* 1998; Fahrig 2003). Habitat loss is the more noticeable of the two and its impacts are obvious and always negative (Fahrig, 2003). Habitat loss alone results in a decrease in species richness (Findlay & Houlahan 1997, Bender *et al.,* 1998),

genetic diversity (Gibbs 2001) and population abundance and distribution across the entire landscape (Best *et al.,* 2001.,Gibbs 1998; Donovan & Flather 2002).

Many studies have been carried out on different landscapes to characterise the nature of habitat fragmentation, how best to describe this process in a scientifically robust manner (Krummel *et al.,* 1987, Milne 1988, McGarigal & McComb 1995, Cain *et al.,* 1997, Tinker *et al.,* 1998, Griffith *et al.,* 2000, Jaeger 2000, McGarigal 2000, Cumming & Vernier 2002, Southworth *et al.,* 2002, Neel *et al.,* 2004, Kamusoko & Aniya 2006) and to define the link between fragmentation and biodiversity loss (Gaston 1997, Brooks *et al.,* 1997, Bender *et al.,* 1998, Harrison & Bruna 1999, Gaston *et al.,* 2003, Fahrig 2003) It is characterised by an initial decrease in the focal habitat area (patch size) and a corresponding increase in edge influenced habitat (Neel *et al.,* 2004), a situation may arise whereby the focal habitat type or land cover class may still be connected but will show increasing perforation (Jaeger 2000). Neel *et al.,* (2004) illustrated that as the process continues, isolated patches of the focal habitat type will continue to fragment until finally a peak in the number of patches is experienced when that land cover class comprises 15-30% of the total landscape.

Fragmentation is a phenomenon that may occur as a result of habitat loss but it is also a complex naturally occurring landscape scale "process in and of itself" (McGarigal & McComb 1995, Bender *et al.,* 1998; Fahrig 2003). It involves the transformation of large, contiguous habitats into a number of smaller, increasingly isolated patches that are separated from each other by a matrix of habitats different to the original, with a decrease in the total area of the original habitat (Wilcove *et al.,* 1986, Bender *et al.,* 1998, McGarigal *et al.,* 2002; Fahrig 2003). Fragmentation changes the spatial configuration of that landscape (Fahrig 2003) and therefore alters the specific properties of that ecosystem that make it suitable for the associated floral and faunal species to persist. Increased edge effects, decreased patch areas and therefore smaller available home ranges (Bender *et al.,* 1998), decreased connectivity and increased isolation between the remaining patches are all associated with habitat fragmentation (Fahrig 2003). The implications of on-going fragmentation are not the same for all species- initially the changes in the landscape

create artificial selective pressures that are hostile to specialist, large-bodied species, and favourable to smaller, edge-specialist or habitat generalist species (Bender *et al.,* 1998, Harrison & Bruna, 1999; Gibbs & Stanton, 2001, Fahrig 2003). With time however, as the amount of habitat lessens and average patch sizes decrease, fewer species can be supported on a given patch (Lawton 1993) and the size of the populations of those species will decrease (Gaston *et al.,* 2003). This increases the risk of local extirpation of these species through meta-population processes (Lawton 1993, Brooks *et al.,* 1997, Gaston 1997, Gaston *et al.,* 2003) as habitat decreases and isolation increases. The risk of species extinction increases as their abundance and occupancy across a landscape decrease (Lawton 1993, Gaston 1997); this double jeopardy (Gaston 1997) will be in effect in the Grassland biome if both habitat loss and fragmentation continue. It is hoped that timely intervention on the part of conservation planners will prevent such a situation from arising.

Huxel and Hastings (1999) showed that habitat fragmentation in terms of patch size and connectivity or isolation has a definite bearing on the efficacy of species restoration and management plans. Bender *et al.,* (1998) found that the effect of fragmentation on the organisms occupying a landscape differs depending on their responses to the resultant edge effects and decreasing core habitat areas. It is apparent that both habitat loss and fragmentation should be taken into consideration when devising species conservation plans (Huxel & Hastings, 1999) and this applies equally to landscape management.

However, it is difficult to describe fragmentation and there is no universally accepted measurement, as a result literally hundreds of landscape fragmentation metrics (referred to as fragmetrics by McGarigal 2000) have been developed (McGarigal & McComb 1995 Tinker *et al.,* 1998, Griffith *et al.,* 2000, Jaeger 2000, McGarigal 2000). The use of which depends upon whether one wishes to describe landscape composition ("the features associated with the variety and abundance of patch types without reference to spatial characteristics" McGarigal 2000) or landscape configuration (the "spatial character and arrangement of patches" McGarigal 2000). Furthermore, the use of these fragmetrics is determined on whether one is looking to describe structural (physical composition of the

fragments) or functional (from the perspective of a particular organism or ecological process) aspects of the fragmented landscape (McGarigal 2000).

The use of wildlife corridors and/or stepping stones as linkages between remaining habitat patches to counteract the effects on species of fragmentation has been debated in the literature (Simberloff *et al*., 1993) and advocated as a means of improving connectance and therefore species dispersal & migration between patches in a landscape (Bennet 2003). However, ecological landscape processes mould the environments within which current biodiversity and these species interactions exist. With the recognition that many large scale, ecological processes are aligned along environmental gradients (Laurance & Laurance 1999, Cowling & Pressey 2001; Midgley *et al.,* 2003), the value of the inclusion of corridors, aligned along these environmental gradients, to conserve these landscape processes in conservation planning has become apparent (Rouget et al., 2005) and should be considered for use in the Grassland biome.

1.6. The aim of the project

In order to effectively apply conservation plans it is necessary to find a means of balancing the notion of conservation value with transformation threat (Faith & Walker 1996) but to achieve this, robust techniques to predict threats (manifested at the landscape level by land-cover change or habitat transformation) need to be developed (Ferrier 2002, Neke & du Plessis 2004). This project seeks to contribute to the effort to fill this gap in knowledge by looking at the land-use practices that were identified as potential threats to biodiversity in the Grasslands Biome by Neke and du Plessis (2004), and verify whether they pose such a threat as shown by actual land-cover change between 1994 and 2000 National Land-cover Databases. The main idea is that land-cover change will serve as a proxy for biodiversity loss, using the coarse filter approach (Noss 1987, 1990, Fairbanks & Benn 2000 Reyers *et al.,* 2000) through changes in ecosystem function, composition and systems (Margules and Pressey 2000). Thus any land-use practice, current or recent past, that causes said land-cover change will be considered as non “biodiversity-friendly” and therefore a threat. Distributional data for threatened endemic Grassland bird species shall be used to represent biodiversity within the biome as is often done for conservation

planning purposes (Noss 1990, Humphries *et al.,* 1995, Ferrier 1997, Margules & Pressey 2000, Ferrier 2002).

Therefore the aim of this project is to test the realisation of potential threats to the grassland biome between 1994 and 2000 as they were predicted by Neke & du Plessis (2004). The specific objectives are:

1. **To describe the spatial configuration of any observed land-cover change on biodiversity friendly land-cover change in the Grasslands Biome**

2. **To test the realization of potential threats to biodiversity as predicted by Neke & du Plessis (2004)**

3. **To evaluate the outcome of the land-cover change detection and devise a new threat map based on the rate and extent of transformation.**

This analysis is not a quantitative assessment of land cover change within the Grassland Biome and as such, conventional Gaussian statistical methods of analysis shall not be carried out. It is not the intention of this research project to comment on the statistical significance of any of the observed land cover changes. Rather, this report will offer a description of the observed land cover changes and provide valuable information on the general state of the Grassland Biome in terms of the remaining semi-pristine grassland patches and the influence of human biodiversity-unfriendly land use practices.

Given this, what are referred to as "general hypotheses" below, should be viewed as guidelines around which the descriptions of the results were carried out.

1.6.1 General Hypotheses

Objective 1

1.1 There will be land-cover changes for those classes that are characterised by anthropogenic use and those immediately surrounding them.

1.2 There will be outward expansion of urban/ built up areas into surrounding land-cover classes.

1.3 Protected areas will show no significant land-cover change that can be attributed to anthropogenic causes

1.4 There will be increased fragmentation of areas of high conservation value that are not formally protected

1.5 The remaining grassland fragments will have shrunk in size

Objective 2

2.1 The potential threats to biodiversity as predicted by Neke & du Plessis (2004) will be realised, that is, all areas that were predicted to be high threat areas will have been transformed to non-biodiversity friendly land-use practices

Objective 3

3.1 Incorporating actual land-cover changes as threats to biodiversity, as well as the influence of the road network, invasive alien plant species & human demography data in the Grasslands Biome will produce a new threat map similar to that of Neke & du Plessis (2004)

MATERIALS & METHODS

2.1. Study Area

2.1.1.Grasslands Biome of South Africa

The Grassland Biome is one of seven biomes that make up the South African landscape. It is centrally located and it shares boundaries with the Savanna, Thicket, Nama Karoo and Forest biomes (figure 1). The largest portion of it boundary is shared with the Savanna biome and in recent years there has been observable bush encroachment from the Savanna biome into the Grassland biome (Bews 1917, Dyer 1937, Acocks 1953, Comins 1962, Morris 1976, Bredenkamp & Bezuidenhout 1990 in O'Conner & Bredenkamp 1997). The interaction at the interface between the Grassland biome and the other biomes is a major contributing factor to the high animal and plant species diversity found here as well as its role as the most agriculturally productive biome in South Africa[2]. The reported areal extent of the Grasslands Biome differs in the literature due to variations in the definition of the biome itself and therefore the location of its boundaries (Reyers et al 2005). Figures vary from 334 001 km2 (Low & Rebelo 1996) to 373 984 km2 (Driver et al 2005). In terms of political boundaries, the Grassland Biome covers an area ranging from the interior of the Eastern Cape and KwaZulu/Natal provinces over the escarpment and into the central plateau as shown in figure 2. Thus the biome makes up the greater portion of six provinces in South Africa and approximately 24,6% of South Africa (Low & Rebelo 1996) Lesotho and a portion of Swaziland also lie within the Grassland Biome as shown in figure 1. The spatial extent of the biome is mostly defined by climatic variables such as frost, rainfall and temperature as well as soil moisture (Rutherford & Westerfall 1994, Rutherford 1997, O'Conner & Bredenkamp 1997). However, the area of the biome that is realized as such is determined by the interplay between these climatic factors, topography, fire, soil and human landuse such as grazing practices (O'Conner & Bredenkamp 1997, Rutherford 1997).

[2] (http://www.fao.org/docrep/008/y8344e/y8344e08.htm. Accessed on-line on 04/02/2007

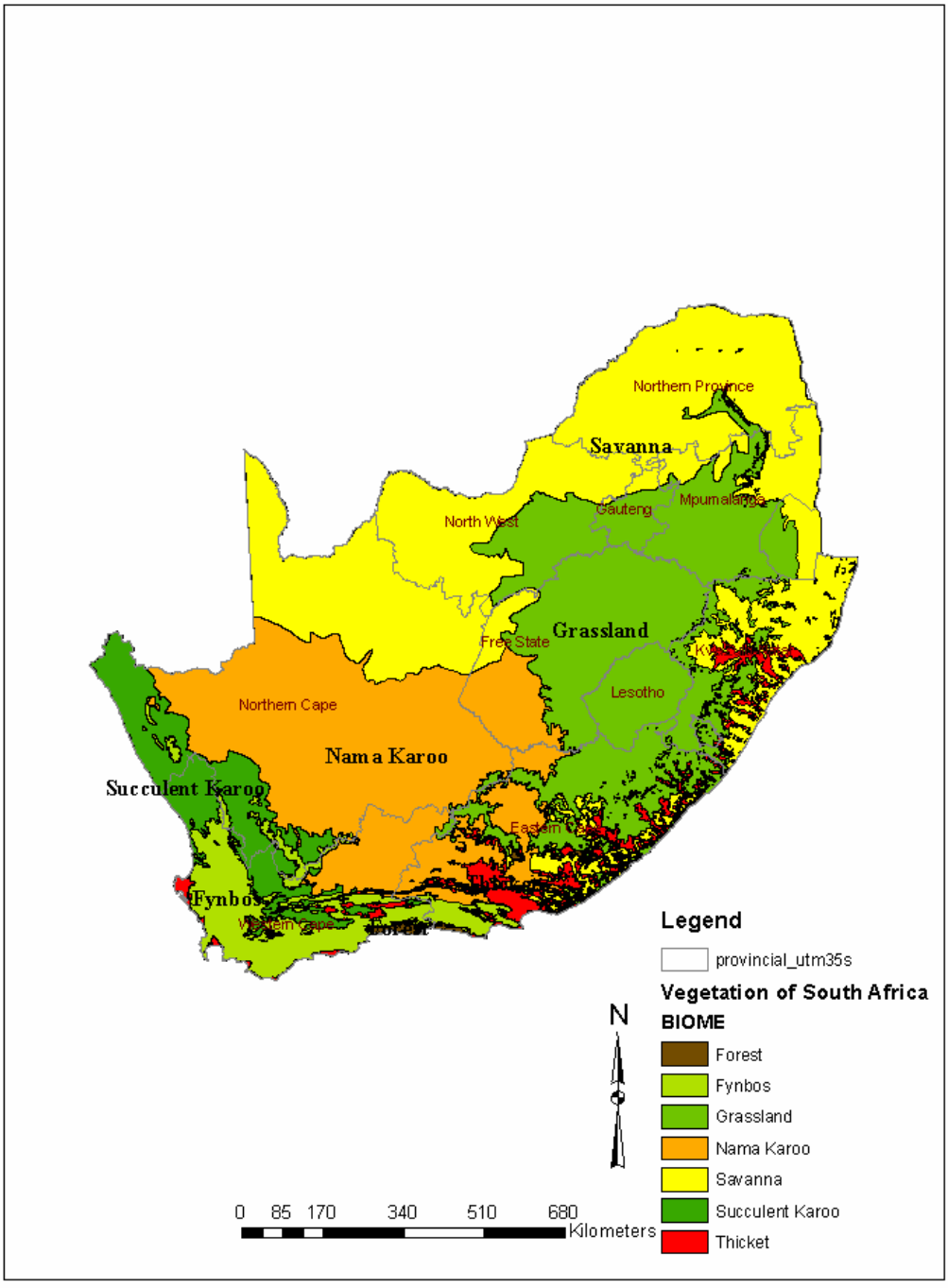


Figure 1. The biomes of South Africa in relation to the provincial boundaries; adapted from Low & Rebelo (1996).

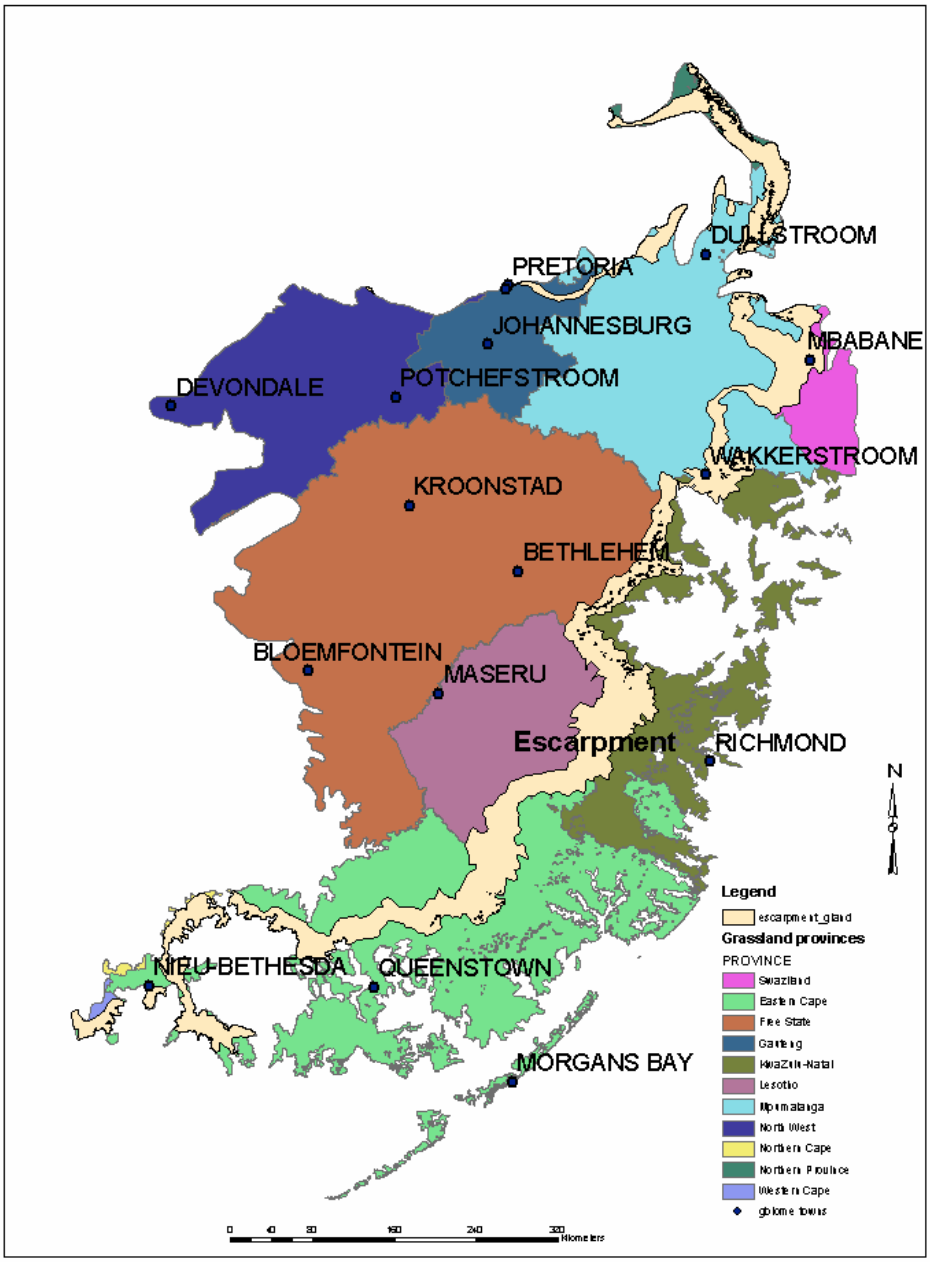


Figure 2. Provincial composition of the Grassland biome as defined by Low & Rebelo (1996); with reference towns and location of the Great Escarpment across the biome[3]

[3] Http://bgis.sanbi.org accessed on-line on 24/02/2007

2.1.2. Topography & Geology

The topography of the Biome shows a fair amount of variation- it is mainly flat, open expanses of grassland with rolling hills and valleys (O'Conner & Bredenkamp 1997) becoming mountainous towards the Drakensburg escarpment (Rutherford & Westfall 1994). Consequently there are large variations in altitude, ranging from 300m above sea level over the Eastern coastal lowlands to over 2800m above sea level in the Drakensberg Mountains (Rutherford & Westfall 1994). Soil cover in the Grassland Biome is dominated by the red-yellow-grey latosol plinthic catena- which constitutes almost half of the Grassland biome (Rutherford & Westfall 1994). Other soil types include black and red clays and well drained sandy soils (Rutherford & Westfall 1994, O'Conner & Bredenkamp 1997). Soil erosion is limited where there is high vegetation cover but can be severe where vegetation has been reduced due to poor land management practices (Rutherford & Westfall 1994).

2.1.3. Climate

The biome exhibits a highly variable climate, as a result of the large surface area it covers, as well as the varying topography of the landscape. The mean annual rainfall gradient ranges from 400mm to more than 1200mm per year (O'Conner & Bredenkamp 1997) although Rutherford & Westfall (1994) give an upper range limit of 2000mm per year. The mean annual rainfall follows a gradient across the landscape that decreases as one moves westwards[4]. Rainfall occurs mostly in the summer months (October to March/April) with a Summer Aridity Index (SAI) between 2.0 and 3.9 (Rutherford & Westfall 1994). SAI is an aridity index showing average moisture conditions over the four wettest months of the year, where higher values indicate increasing aridity to a maximum of 9 (Rutherford & Westfall 1994). The temperatures experienced range from "frost-free to snowbound, sub-zero temperatures in winter" (O'Conner & Bredenkamp 1997). The occurrence of frost and sub-zero minimum winter temperatures increases with increasing aridity and/ or altitude (Rutherford & Westfall 1994, O'Conner & Bredenkamp 1997)

[4] http://www.fao.org/docrep/008/y8344e/y8344e08.htm. Accessed on-line on 04/02/2007

2.1.4. Biodiversity: Flora

Although the vegetation structure is generally uniform across the biome, the plant species, vegetation dynamics and ecosystem functions all show a high degree of variation (O'Conner & Bredenkamp1997) in accordance with the rainfall gradient (Rutherford & Westfall 1994). O'Conner & Bredenkamp (1997) identified six major regions of vegetation within the Grassland Biome. These and the biophysical characteristics of the terrain they are associated with are described in the table below.

Name	**Dominant taxa**	**Geology**	**Soil type**	**Altitude(m)**	**Mean annual rainfall Range (mm/ year)**
Central inland plateau	*Themeda triandra Eragrostis curvula*	sandstone, shale, lava, mudstone	deep red, yellow eutrophic, clay	1400-1600	600-700
Dry western region	*Eragrostis lehmanniana E. obtusa Stipagrostis obtusa*	mudstone, shale, dolomite, dolerite	shallow sands	1200-1450	450-600
Northern areas	*Trachypogon spicatus Diheteropogon amplectans*	quartizites, shale, andesitic lava, sandy loams	shallow, lithosols	1500-1600	650-750
Eastern inland plateau	*Themeda triandra Aristida junciformis Eragrostis plana*	sandstones and shales	deep sandy loam, black clay	1500-1800	650-950 (frost)
Eastern mountains and escarpment	*Hyparrhenia hirta Aristida diffusa*	Drakensberg complex	Leached, shallow, rocky soils	1650-3480	900- 1500
Eastern lowlands	*Hyparrhenia hirta Sporobolus pyramidalis*	Drakensberg foothills-dolerite	Shallow, rocky soils	1200-1400	850

Table 1. Vegetation types of the Grassland biome (Adapted from O'Conner & Bredenkamp 1997) described in terms of the dominant vegetation, geology, edaphic and climatic characteristics.

Only one in six plant species within the biome is actually a grass (SANBI 2004). The vegetation generally consists of grasses and bulbous plants such as arum lilies, orchids and aloes, as well as some dicotyledonous plants (SANBI 2004). Canopy cover is rare and its occurrence is influenced by mean annual rainfall as the likelihood of canopy cover decreases with rainfall (Rutherford & Westfall 1994). There is high plant species diversity; the biome shows higher plant species richness at the $1000m^2$ scale than the Fynbos Biome (Cowling et al 1991). There are at least 3 788 plant species (Gibbs Russel 1987) of which 78% are located in areas under formal protection (Siegfried 1991).

2.1.5. Biodiversity: Fauna

Of the 34 mammal species that are endemic to South Africa, 15 are found within the Grassland Biome, including some threatened species (SANBI 2004) like the Rough-haired golden mole (*Chrysospalax villous)*, Gunning's golden mole (*Neamblysomus gunningi),* Robust golden mole (*Amblysomus robustus).* Historically this area was part of the natural range of large grassland antelope (Rutherford & Westfall 1994). The biome has been designated an Endemic Bird Area, EBA (Bibby et al 1992, Stattersfield et al 1998) and 52 of the 122 Important Bird Areas of South Africa are located here (SANBI 2004). In order for an area to be designated EBA status it must support at least 2 endemic bird species with distribution range of less than 50 000 km². There are three such species found within this area- Rudd's Lark (*Heteromirafra ruddi)*, Botha's Lark (*Spizocorys fringillaris)* and Yellowbreasted Pipit (*Hemimacronyx chloris)* - all of which are considered threatened on a global scale (Stattersfield, *et al.*, 1998 from the grasslands facts website). Furthermore- of the 14 globally threatened bird species found in South Africa 10 are found in the Grassland Biome (SANBI 2004). There are 24 endemic reptile species found within the biome (Branch 1998). 31 of the 107 threatened South African butterfly species are also found within this area (Henning & Henning, 1989) and at least half of these are endemic to the Grassland Biome (McAllister 1998a). The Grassland Biome also contains 5 of the 17 designated RAMSAR wetlands of South Africa (DEAT, 1997).

2.2. Methods

2.2.1. Background

The South African National Land Cover (NLC) databases for 1994/5 and 2000 were the principal raw datasets for the analyses to assess threats as posed by observed grassland vegetation cover loss over the Grassland biome. Other datasets were used and these are described in the order of the analyses for which they were used. Both NLC datasets were derived from seasonal Landsat imagery (Thompson 1996, Thompson et al 2000) compiled over the 1994/5 and 2000/1 rainfall seasons respectively. Land cover classification for both datasets was based on the same hierarchical framework so that the classification categories could be merged or split up depending on the needs of the researcher (Fairbanks & Thompson, 1996). The minimum mapping unit (MMU) for the NLC1994 dataset was set as 25 ha (Fairbanks & Thompson 1996, Fairbanks *et al.* 2000). This translates to a pixel resolution of 500m * 500m as the lowest spatial denominator that one can use and still extract meaningful information from this dataset (Mark Thompson pers comm.); therefore all datasets were converted to raster grids of this resolution. After resampling, each 25 ha pixel was allocated landcover class code according to maximum area represented within that cell. All spatial datasets were transformed to WGS 1984 geo-reference system and then projected in the Universal Transverse Mercator (UTM) projection to UTM zone 35S- the zone which projects the extent of the Grassland biome with minimum distortion. All datasets were clipped to the extent of the Grassland Biome since this is the area of interest. The shapefile used for this purpose is based on the biome boundary definition as given by Low & Rebelo (1996) - thus the total area of the biome for this project by default is 334 001 km^2.

Spatial analyses were executed in either ArcGIS v9.1 (Esri software) or IDRISI Andes (Clarke labs) depending on the analysis and functionality required. The IDRISI Geographic Information System (GIS) was used primarily to assess the land cover change using the Land Cover Change Modeler. All other spatial analyses were executed in ArcGIS. FRAGSTATS v3.3 (McGarigal *et al.,* 2002) was also used to assess spatial distribution and fragmentation of the remaining grassland patches.

2.2.2. Data Analysis: Objective 1

"To describe the spatial configuration of any observed land cover change on "biodiversity friendly" land-cover (semi-pristine grassland vegetation) in the Grasslands biome"

Table 2 below describes the raw spatial datasets that were used for this analysis.

Data	**Description**	**Geographic coordinate system**	**Projected coordinate system**
South African National Land-cover Database (1994/95) – NLC1994	70 individual mapsheets Scale= 1:250 000) ArcGIS shapefiles Minimum Mapping Unit, MMU is 25ha- pixel size would be 500m*500m Classified to 31 land cover classes	Clarke 1880 (Cape Datum)	-
South African National Land-cover Database (2000) – NLC2000	ERDAS IMAGINE raster image Scale 1:50 000 (Thompson et al 2000) Resolution:30m*30m Classified to 49 land cover classes	WGS 1984	-
Grassland Biome outline	ArcGIS shapefile	WGS 1984	Albers Equal Area
South African National Parks	ArcGIS shapefile Downloaded off SANBI website bgis.sanbi.org	WGS 1984	

Table 2. Raw Data that was used in the analyses of Objective 1

2.2.2.1. Assessment of Land-cover change

The NLC1994 vector tiles (spacemaps) were merged to a single vector shape file displaying land cover for all of South Africa. This was transformed to WGS84 geographic co-ordinate system and then projected to zone UTM35S. The NLC1994

image was then clipped to the extent of the Grassland biome using the Grassland biome outline. The output from this was a shapefile, hereafter referred to as the Grassland Land Cover 1994- GLC1994. This was then converted to a raster grid, at a resolution of 500m * 500m (25ha pixel size). The output (GLC1994) was a raster grid showing land cover in 31 land cover classes over the Grassland Biome.

The NLC2000 raster image was received in WGS84 and projected to UTM35S (table 2); thereafter the Grasslands Biome area was extracted using a mask specified to the extent of the Grasslands Biome shapefile. This image was then resampled from the original resolution of 30m * 30m to a resolution of 500m * 500m. The output (Grassland Land Cover-GLC2000) showed land cover over the Grassland biome described in 49 land cover classes.

These operations were carried out in ArcGIS v9.1 using standard GIS techniques.

Thereafter both GLC1994 and GLC2000 were imported into IDRISI Andes as GeoTIFF images and reclassified to the same land cover classification scheme as shown in table 3 below. These are the same land cover classes used by Neke & du Plessis (2004).

AGGREGATE CLASS	**code**	**1994/5 LAND-COVER CLASS**	**code**	**2000 LAND-COVER CLASS**
Forest & woodland	1	Forest and Woodland	1	Woodland
	2	Forest	2	Forest
Thicket & bushland	3	Thicket and bushland (etc)	3	Thicket and Bushland
	4	Shrubland and low Fynbos	4	Shrubland and low Fynbos
Grassland	5	Herbland	5	Herbland
	6	Unimproved grassland	6	Natural grassland
	7	Improved grassland	7	Planted grassland
Forest plantations	8	Forest plantations	8	Forest plantations: Eucalypt spp
			9	Forest plantations: Pine spp
			10	Forest plantations: Acacia spp
			11	Forest plantations: other/mixed spp
			12	Forest plantations: clearfelled

Waterbodies	9	Waterbodies	13	Waterbodies
Wetlands	10	Wetlands	14	Wetlands
Degraded	11	Barren rock	15	Barren rock & soil (natural)
	12	Dongas and sheet erosion scars	16	Barren rock & soil (erosion:dongas & gullies)
			17	Barren rock & soil (erosion:sheet)
	13	Degraded: forest and woodland	18	Degraded: forest and woodland
	14	Degraded: thicket and bushland (etc)	19	Degraded: thicket and bushland
	15	Degraded: unimproved grassland	20	Degraded: unimproved grassland
	16	Degraded: shrubland and low fynbos	21	Degraded: shrubland and low Fynbos
	17	Degraded: herbland	22	Degraded: herbland
Cultivated land	18	Cultivated: permanent - commercial irrigated	23	Cultivated: permanent- commercial irrigated
	19	Cultivated: permanent - commercial dryland	24	Cultivated: permanent - commercial dryland
	20	Cultivated: permanent - commercial sugarcane	25	Cultivated: permanent - commercial sugarcane
	21	Cultivated: temporary - commercial irrigated	26	Cultivated: temporary - commercial irrigated
	22	Cultivated: temporary - commercial dryland	27	Cultivated: temporary - commercial dryland
	23	Cultivated: temporary - semi-commercial / subsistence dryland	28	Cultivated: temporary - subsistence dryland
			29	Cultivated: temporary - subsistence irrigated
Urban / built up land	24	Urban / built-up land: residential	30	Urban / built up land: residential
			31	Urban / built up land: rural cluster
			32	Urban / built up land: residential formal suburbs
			33	Urban / built up land: residential – flatland
			34	Urban / built up land: residential – mixed
			35	Urban / built up land: residential – hostels
			36	Urban / built up land: residential - formal t/ships
			37	Urban / built up land: residential - informal t/ships
			38	Urban / built up land: residential - informal squatter camps

	25	Urban / built-up land: residential (small holdings: woodland)	39	Urban / built-up land: residential (small holdings: woodland)
	26	Urban / built-up land: residential (small holdings: bushland)	40	Urban / built-up land: residential (small holdings: bushland)
	27	Urban / built-up land: residential (small holdings: shrubland)	41	Urban / built-up land: residential (small holdings: shrubland)
	28	Urban / built-up land: residential (small holdings: grassland)	42	Urban / built-up land: residential (small holdings: grassland)
	29	Urban / built-up land: commercial	43	Urban / built-up land: commercial – mercantile
			44	Urban / built up land: commercial - education, health, IT
	30	Urban / built-up land: industrial / transport	45	Urban / built-up land: industrial / transport – heavy
			46	Urban / built up land: industrial / transport – light
Mines & quarries	31	Mines & quarries	47	Mines & quarries: underground and subsurface
			48	Mines & quarries: surface
			49	Mines & quarries: mine tailings & waste dump

Table 3. Aggregate classes that were used to standardize land cover classes in NLC1994 & NLC2000 based on a hierarchical landcover classification framework (Thompson 1996)

Once both raster images had been reclassified (figures 3, 4), they were input into the Land Cover Change Modeler in IDRISI and were assessed for differences in land cover with a focus on the grassland land cover class.

A change matrix was constructed to summarise all potential changes between different land cover types. In this matrix, highly unlikely conversions such as forest to water body, were defined *a priori* to identify potential mapping errors as well as to facilitate interpretation of the results. However, as is discussed in the results, since the focus was on the natural grassland vegetation, this was only to be applied to land cover change of the grassland land cover class to the other land cover types.

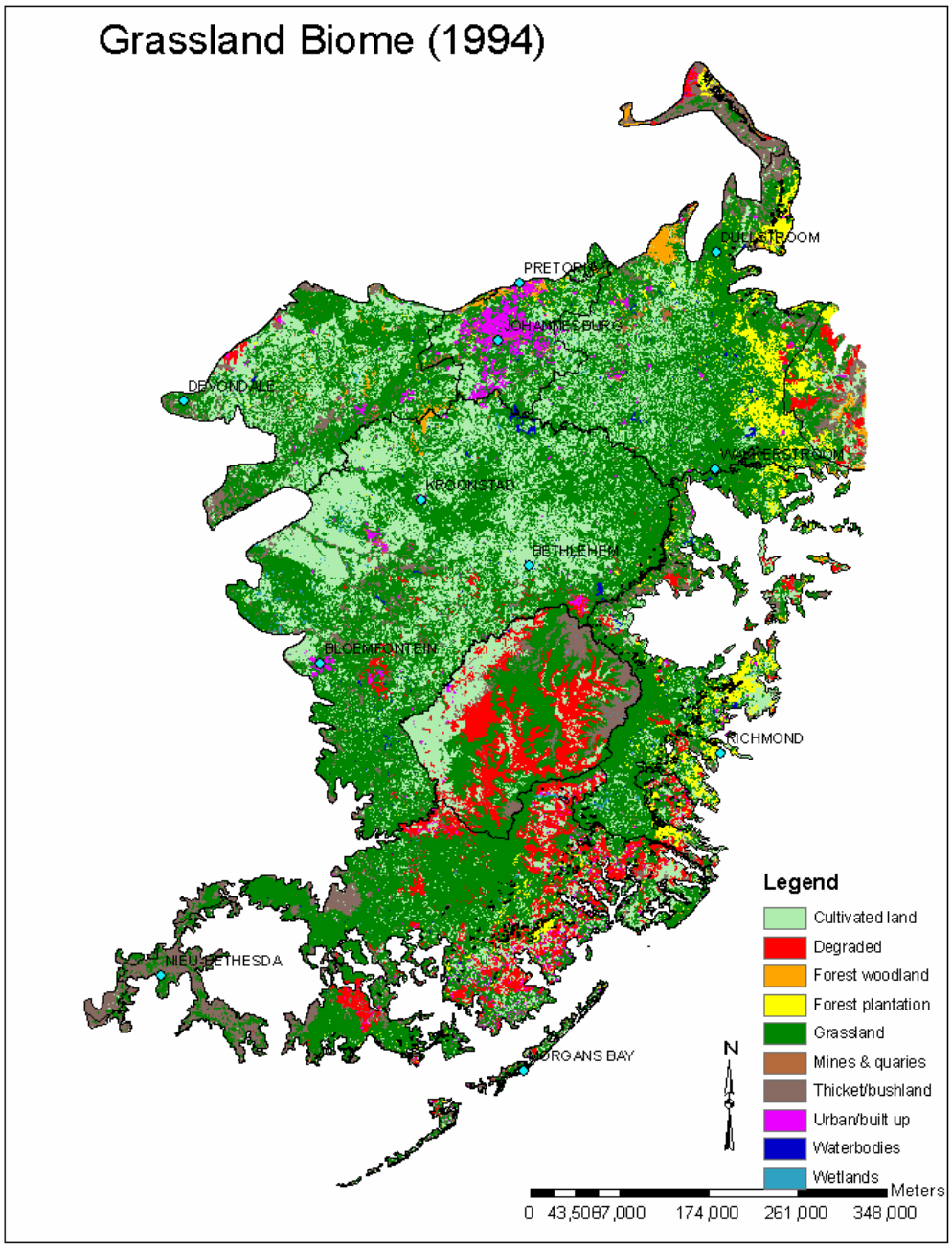


Figure 3. Land cover in the Grassland biome in 1994/5 (GLC1994)

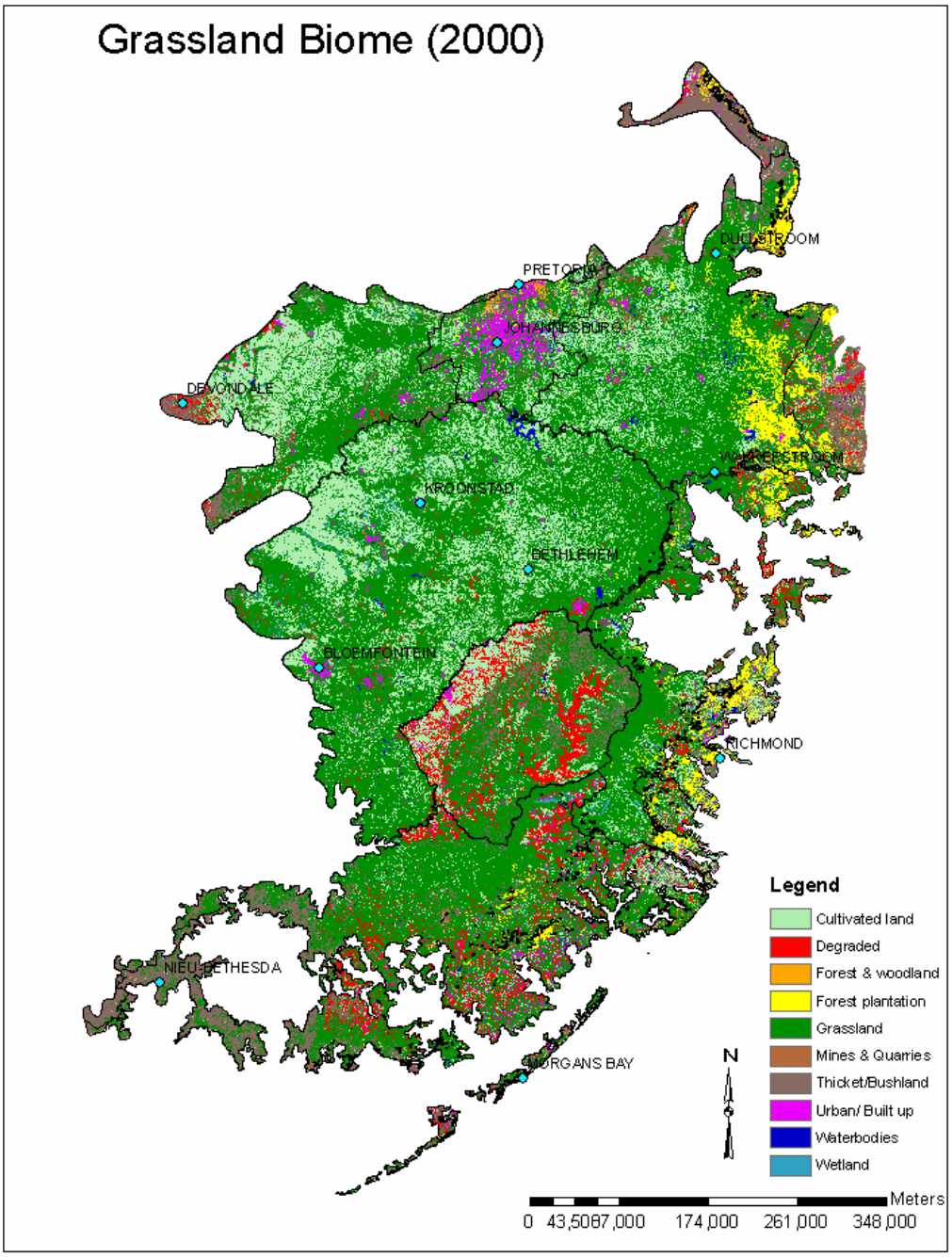


Figure 2. Landcover in the Grassland biome in 2000/1 (GLC2000)

2.2.2.2. Assessment of Grassland fragmentation

This study will require an evaluation of fragmentation of the remaining semi-pristine "natural" grassland without particular reference to specific organisms or ecological processes- as such the focus will be on structural metrics. A perusal of the extensive literature available on this topic resulted in a list of common metrics most often used to describe habitat fragmentation from the structural perspective (Table 4) but all reflect possible threats to biodiversity. GLC1994 and GLC2000 were run through FRAGSTATS to assess and describe the nature of the remaining fragments or patches of grassland vegetation in the Grasslands Biome in terms of the spatial configuration and degree of fragmentation relative to the GLC1994. Analysis was carried out at the class level and the metrics that were used described all aspects of fragmentation with respect to patch area, shape complexity and isolation (Table 4). Each metric was chosen based on the implications of what it measures to grassland biodiversity. The total number of patches, average patch size and inter-patch distances will affect species richness and density and population dynamics (Lawton 1993, Gaston 1997) as will edge effects and patch shape. The metrics that were chosen are those that were the simplest to interpret.

Fragmetrics	**Description**	**Units**	**Range**
Number of patches (NP)	Total number of patches of the focal land cover class Simplest measure of fragmentation but not easily interpreted on its own	none	NP> =1, with no limit
Patch area distribution (Mean patch area)	Simplest measure of spatial configuration	ha	Statistical measures
Mean Perimeter Area Ratio	Describes patch shape complexity		
Perimeter Area Fractal Dimension	A measure of shape complexity that is not affected by varying patch sizes of the focal class A fractal dimension greater than 1 for a 2-dimensional landscape mosaic indicates an increase in patch shape complexity.	None	$1 \leq$ PAFRAC ≤ 2

	PAFRAC approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters		
Euclidean Nearest Neighbour (mean)	Mean measurement of nearest distance to the nearest neighboring patch of the same type, measured from patch edge to patch edge (cell centre at patch edge to cell centre on nearest patch edge) describes patch isolation and land cover class sub division Also used to assess dispersion: Where ENN_Variance>= ENN_mean then focal class shows more clumped than random distribution & vice-versa	metres	ENN > 0, without limit
Mean Shape Index	Simplest measure of shape complexity of focal class patches SHAPE = 1 when the patch is maximally compact (i.e., square or almost square) and increases without limit as the patch shape becomes more irregular.	None	SHAPE ≥ 1, without limit
Clumpiness Index	Measures focal class aggregation CLUMPY equals -1 when the focal patch type is maximally disaggregated; CLUMPY equals 0 when the focal patch type is distributed randomly, and approaches 1 when the patch type is maximally aggregated.	None	$1 \leq CLUMPY \leq 1$
Landscape Shape Index	Measure of class aggregation Quantifies the amount of edge present in the focal class relative to what it would be if the focal class was maximally compact. LSI = 1 when the landscape consists of a single square or maximally compact (i.e., almost square) patch of the corresponding type; LSI increases without limit as the patch type becomes more disaggregated (i.e., the length of edge within the landscape of the corresponding patch type increases).	None	LSI ≥ 1, without limit

Table 4. Selected fragmentation metrics used in FRAGSTATS to describe grassland fragmentation, Descriptions are taken from McGarigal & Marks (1995)

Both standard and moving window analyses were carried out on the datasets. When the standard analysis is chosen, the input images are evaluated per selected metric. The output is a file produced for each organizational level- patch, class and landscape, giving the calculated values per metric. For the latter a moving window, of user-specified shape and dimensions is passed over every cell in the landscape of interest, evaluating each selected metric. The results are colour-graded raster images of areas with high/low values of the fragmentation index of choice across the input landscape of interest (McGarigal 2000). The moving window analysis provides a spatially explicit evaluation for the fragmentation indices. This provides visualization of the results of the standard analysis which may be difficult to understand in the context of the entire landscape of interest when the output is a single number.

A 10000m * 10000m square moving window was used for the moving window analysis, this was based on the maximum remaining grassland patch area class (>100km2) described in Neke & du Plessis (2004). The 8-cell neighbour rule was applied for standard analyses.

2.2.2.3. Assessment of Grassland degradation

A simple assessment of whether or not there has been loss of grassland vegetation does not provide sufficient information for input into conservation planning activities. Information referring to the condition of the remaining grassland patches in terms of a holistic description would be more useful. Such a description should capture information about the presence or absence of non biodiversity-friendly" land uses, as signified by grassland loss, the average patch size within that area, the relative isolation of these patches as well as the associated average patch size complexity (which provided a simple, non-scale dependant indicator of edge effects). These are all descriptors of fragmentation. This assessment was used to capture the information captured by the separate fragmentation analysis of habitat loss and fragmentation onto a single image. That gives spatially explicit information about the location and occurrence of grassland degradation.

This information given by the combination of actual grassland vegetation loss (an indicator of activities or processes, human induced or otherwise, that pose threats to biodiversity) and degree of fragmentation of the remaining patches was therefore required for the creation of the composite threat map of observed or extant threats to Grassland biome biodiversity. The output from the FRAGSTATS moving window analyses for Average patch size (AREA_MN), Mean Euclidean Nearest Neighbour distance (ENN_MN) and Mean Shape Complexity (SHAPE_MN) on the GLC2000 dataset were used in conjunction with the Grassland transformation map (showing where gains and losses in the Grassland land cover class had occurred). These metrics were chosen for input over the others produced in the FRAGSTATS analysis because they were the simplest and easiest to translate to indicators of threat.

Because of the differences in units of measure, amongst the four input images it was necessary to classify the data to impact classes. Classification in terms of assigning "Impact scores" was carried out as shown in table 5 below. The images were assigned the same weighting in the Raster calculator (Spatial Analyst) and then added together in a standard overlay operation in ArcGIS to create an image showing Grassland degradation. The output showed the relative condition in terms of degradation severity of the remaining grassland patches in terms of occurrence of non biodiversity-friendly activities or processes and fragmentation, with higher scores suggesting poorer condition and therefore a more negative impact on the associated biodiversity.

Grassland land cover loss	***Impact Score***	**patch size (ha)**	***Impact score***	**inter-patch distance (m)**	***Impact score***	**patch shape complexity (no units)**	***Impact Score***	
Yes	*1*	< 867	*4*	> 4251	*4*	> 5	*3*	Maximum Score= 12
No	*0*	867 - 2192	*3*	2141 - 4252	*3*	3 – 5	*2*	Minimum Score= 1
		2192 - 4750	*2*	1300 – 2141	*2*	>3	*1*	
		>4750	*1*	< 1300	*1*			

Table 5. Classification scheme used to incorporate score the individual datasets to assess Grassland degradation,

This output in itself gives valuable information- that should red flag areas of concern when considering the remaining semi-pristine grassland patches.

2.2.2.4. Grassland degradation over high conservation value areas

There are over 250 nature reserves within the biome (Category 1 – 3 as defined by the IUCN categories), as shown in the map of grassland degradation- figure 6 - so an exhaustive assessment of the occurrence of grassland change per protected area was beyond the scope of this investigation. There are seven identified biodiversity hotspots in Southern Africa (DEAT 2003). The names and the area under protection are listed in table 6 below.

Southern African Hot-spot	**Area conserved (%)**
Wolkberg	13.3
Maputaland	10.0
Eastern Mountain	5.5
Pondoland	7.0
Albany	6.5
Succulent Karoo	2.0
Cape: lowlands mountains	3.0 50.0
Kaokoveld (Namibia)	7.0

Table 6. Identified biodiversity hotspots of Southern Africa and conserved area (Adapted from DEAT, 2003).

Only the Eastern Mountain hot-spot lies completely within the Grassland biome. It contains the Maloti-Drakensberg Transfrontier Protected area between Lesotho and South Africa which was established in 2001. The transfrontier protected area extends over the Ukahlamba-Drakensberg World Heritage Site[5] (National Park) and the Golden Gate

[5] http://www.maloti.org Accessed on-line on 12/04/2007

Highlands National Park on the South African side[6]. The corresponding area on the Lesotho side includes the Sehlabathebe National Park, Ts'ehlanyane Nature Reserve and Bokong Nature Reserve[6]. The shapefiles of the protected areas were downloaded from the on-line SANBI mapping resource- http://www.bgis.sanbi.org. The Lesotho component of the protected area is represented by the proposed boundaries of the Lesotho National Park (as shown in the results).The entire area encompasses the water catchments along the Lesotho escarpment and the Maloti Mountains in the Free State and the Drakensberg range through the KwaZulu/Natal, Eastern Cape and Northern Cape provinces[7]. Before 2001, during the period of interest, there were no conservation activities focusing on the mountain ecosystems of Lesotho[6] which is in direct contrast with the situation directly on the other side of the border where the area is well protected by the Ukahlamba-Drakensberg National Park. Therefore it was of particular interest to assess the Grassland degradation, with respect to the protected area network over this particular conservation area. The location of the Eastern Mountains hotspot is shown in figure 5 below. Visual inspections of the grassland degradation over each conservation area were carried out and described.

[6] http://www.tbpa.net/case_08.htm Accessed on-line on 12/04/2007
[7] http://www.sanbi.org/biodiversity/umthombo2.pdf Accessed on-line on 12/04/2007

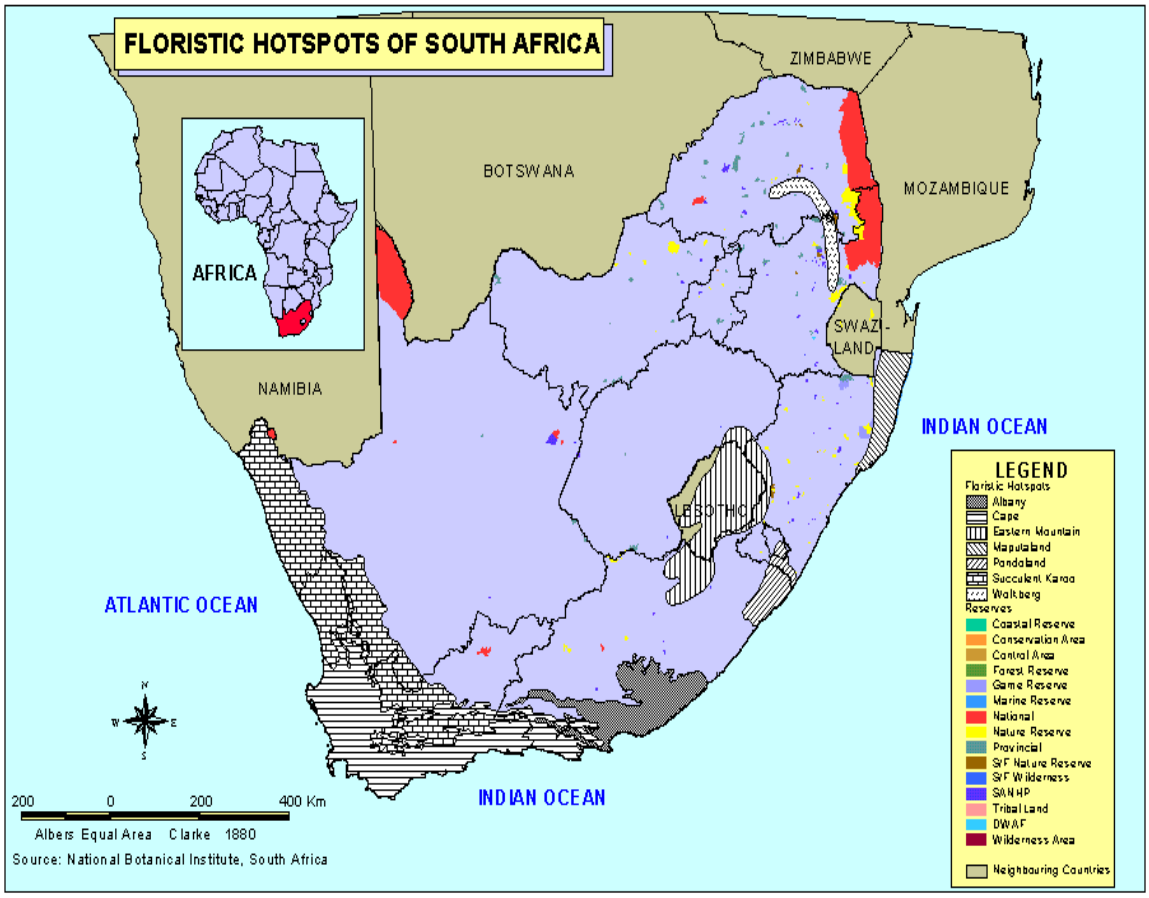


Figure 5. The location of biodiversity hotspots in South Africa[8] to illustrate the location of the Eastern Mountains hotspot

2.2.3. Data Analysis: Objective 2

"To "test" the realization of potential threats to biodiversity as predicted by Neke & du Plessis (2004)"

The data sets used in the analysis of Objective 2 are briefly described in table 5 below. The map of grassland land class changes displayed the occurrence of persistence, gains and losses in spatial extent of the grassland class. The occurrence and location of grassland losses was interpreted as an indicator of activities that pose threats to grassland biodiversity in those areas, referred to as non "biodiversity-friendly" land uses. The map of grassland degradation summarises the location and relative of severity grassland loss and fragmentation. It is a more complete assessment of the occurrence of grassland

[8] http://www.ngo.grida/no/soesa/nsoer/ Accessed on-line on 12/04/2007

transformation caused by non "biodiversity- friendly" landuses within the biome. Where possible the associated land uses were identified using the NLC2000 database and therefore red-flagged as representing current threats to grassland biodiversity. I was unable to secure the original potential transformation threat maps produced by Neke & du Plessis. Therefore the analysis was restricted to a visual comparison of the maps (table 7), and a qualitative evaluation of the written predictions of threat published in Neke & du Plessis (2004).

Source	**Format/ description**
"The threat of Transformation: Quantifying the Vulnerability of Grasslands in South Africa"- Neke & du Plessis (2004)	Description of transformation threats and transformation threat intensity map Transformation threat map
Grassland Land cover change map (1994 – 2000) of grassland land cover gains and losses	IDRISI raster grids Output from Objective 1- Land cover Change Modeler
Map of Grassland degradation	IDRISI raster grid Output from Objective 1

Table 7. Raw data that was used in the analysis of Objective 2.

Furthermore, because explicit reference was made as to the patch size distribution characteristics of the remaining semi-pristine grassland areas, the status of the remaining grassland vegetation patches, average area and location relative to the predicted threats were also considered using the output from the FRAGSTATS moving window analysis of mean grassland patch size (for GLC2000).

2.2.4. Data Analysis: Objective 3

"To evaluate the outcome of the land-cover change detection and devise a new threat map based on the rate and extent of transformation."

The new threat map was created using a method similar to that used by Neke & du Plessis (2004) in that several factors posing threats to biodiversity through land cover loss

were identified and spatially overlayed in a GIS using a scoring system to come up with impact scores. However, the threat map created by Neke & du Plessis (2004) used a combination of potential land use information and actual land cover information (from NLC1994) to create a potential transformation threat map. Fairbanks & Benn (2000) state that mixing such datasets may make "results & conclusions drawn questionable" therefore the new threat map was created using only actual land cover information to show occurrence of extant land cover threats to biodiversity in the Grassland biome. It incorporates layers showing observed land-cover transformation, road effects, soil erosion hazard, invasive alien plants and the impact of urbanisation in the Grassland Biome. Where applicable the same classification schemes as those of Neke & du Plessis were used. In this way, the method used to create the transformation threat map of Neke & du Plessis can be assessed against that reflecting existing transformation threats. The list of inputs is described in detail in table 8 below. The map of Grassland degradation had already been created as part of the analysis of Objective 1.

Description	**Source**	**Format**
Grassland land cover degradation map	Output from Objective 1	IDRISI raster grids
Invasive alien plant species richness within biome	SAPIA raw database	Dbf files- Number of alien invasive plants recorded at QDS displayed on QDS grid
Road effects	Coverage of entire roads network in South Africa	Coverage (vector) WGS84
Urban threats in Grassland biome	Extracted from GLC2000	WGS84 UTM35S
Soil Erosion Hazard	Provided by Jay le Roux (unpubl thesis, ARC-ISCW	Raster grid Resolution (100m*100m) WGS84
Threatened endemic grassland bird species richness		Dbf files Species richness at QDS displayed on QDS grid

Table 8. Input data layers used to create the composite transformation maps of observed threats to biodiversity

The new threat map was related to current land-cover classes and land-use types, the protected areas network, "high conservation value" areas and species distribution coverages for threatened endemic Grassland biome bird species- these were used as a surrogate to illustrate the biodiversity impacted by these observed threats.

2.2.4.1. Invasive Alien Plants

The South African Plant Invaders Atlas, SAPIA raw database was provided by the ARC-Plant Protection Research Institute, Weeds division. The data provided information on the species richness of detected invasive alien plants (IAP) per quarter degree square, QDS, for all of South Africa from which species richness information for the Grassland biome was extracted. This grid was converted to a raster grid at the same resolution as all other datasets (25 ha pixels) and clipped to the same extent (figure 6).

The QDS species richness values ranged from 0 – 329 species/QDS. For input into the composite threat map- the data were split into four classification groups using natural breaks (table 9). The severity of the threat posed by alien plants to grassland biodiversity is by no means equal across all invasive species- some species have more deleterious effects than others. However, invasion of the grassland landscape by alien plant species causes changes in ecosystem composition and thus alters ecosystem function and structure (Higgins & Richardson 1996, With 2002) and presents a threat to natural biodiversity at all hierarchical levels (van Wilgen et al., 2001). The presence of Invasive Alien Plants indicates replacement and therefore loss of the "natural" grassland vegetation and species richness was used as an indicator of the relative replacement threat to grassland biodiversity; higher species richness infers higher threat to biodiversity.

Species richness/ QDS	**Impact score**
97 – 329	4
47 – 97	3
19 – 47	2
0 – 19	1

Table 9. Impact scores used to classify the threat posed by species richness of invasive alien plants

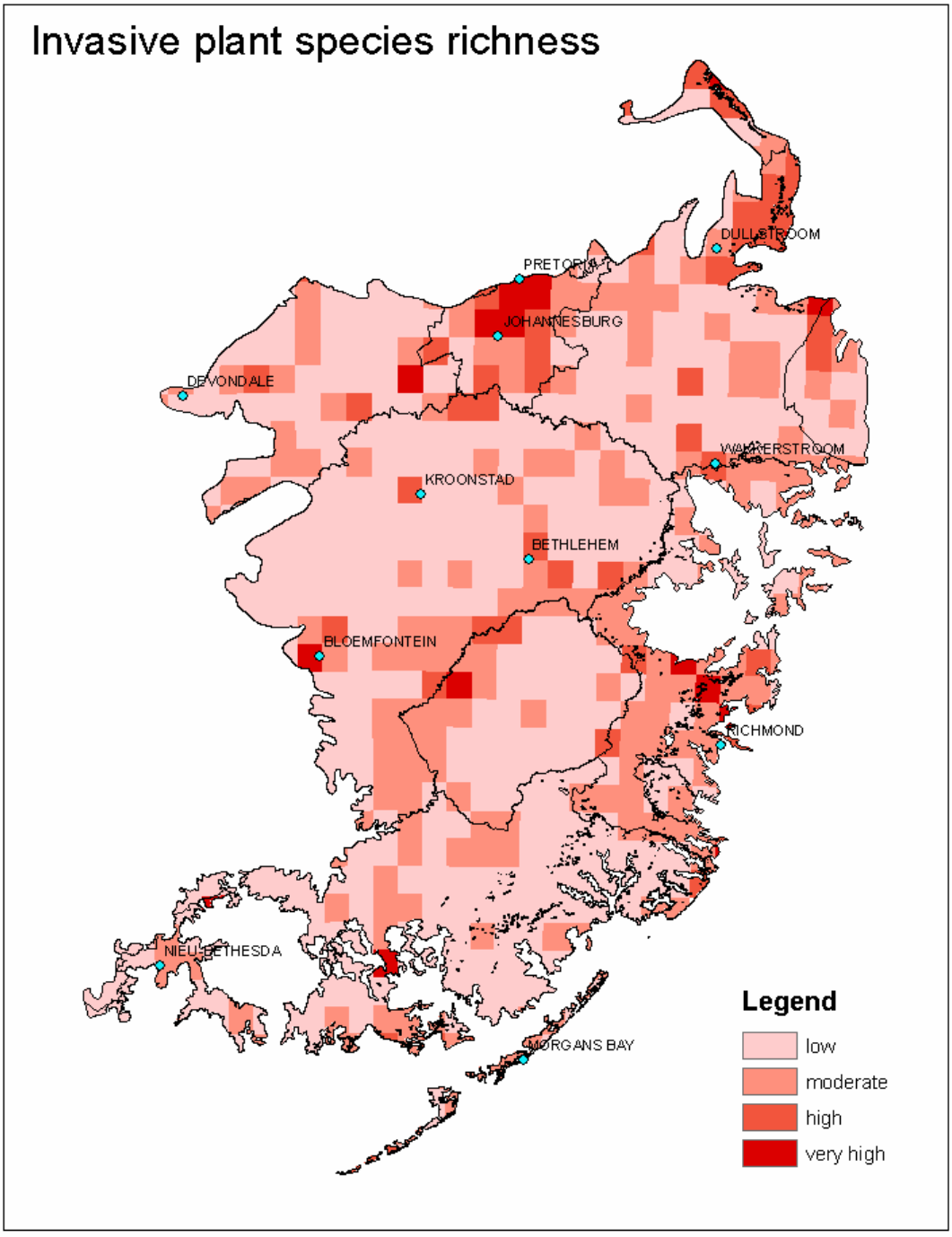


Figure 6. Invasive Alien Plant species richness across the Grassland biome

2.2.4.2. Road effects

The spatial extent of the road effect zone is used as an ecological indicator representing potential impacts or threats to biodiversity presented by the presence and utilization of the road. If looked at in conjunction with actual threats (as shown by those land-uses resulting in land-cover change) and identified biodiversity hotspots as well as the protected areas network, this may enhance the new grassland threat map and identification of areas within the Grassland biome of high conservation value.

The areal extent of the roads was calculated for roads within the Grasslands Biome using similar methods to those used by Stoms (2000); Reyers *et al.* (2001); Rouget *et al.*,(2004) and Reyers *et al*. (2005). A shapefile of all roads in South Africa was clipped to the extent of the Grassland Biome. The road network information did not extend over the borders into Lesotho or the portion of Swaziland that lies in the biome. These areas were therefore not assessed for road effects. Given that the value of the buffer width extends to either side from the road, and from the information given by Reyers et al (2001), it was determined beforehand that road types lower than Main roads would be lost during the conversion to raster format at the pixel size of 500m * 500m. Therefore only the road types presented in Table 10 were extracted from the road network. Each road type was then buffered to the extent of the affected distance as shown in Table 10 below, based on the method used by Reyers et al, 2001. Thereafter each road was assigned the appropriate threat score; the road effect zones thus created were converted to raster format, with the same resolution as the land transformation map (500m * 500m).

South African Surveyor General Description	**Buffer width (m)**	**Threat/ Biodiversity Impact Score**
National route	1000	3
Freeway	1000	3
Arterial	500	2
Main	250	1

Table 10. Buffer width for each road type for calculating road effect zone applied on either side of the road (Reyers et al 2001)

2.2.4.3. Urban Impact

The method used was based on that of Neke & du Plessis (2004). The urban areas within the Grassland biome were extracted from the GLC2000 dataset. Areas were calculated and grouped according to the classification scheme used by Neke & du Plessis (2004) as shown in table 11 below.

Urban area size (km^2)	**Impact Score**
> 100	4
> 30 & < 100	3
> 1 & < 30	2
<1	1

Table 11. Threat scores assigned to urban areas according to size, as in Neke & du Plessis (2004)

2.2.4.4. Soil Erosion Hazard

This was used as an indicator of unsustainable land-use practices such as deforestation or overgrazing, however, soil erosion is also a naturally occurring phenomenon (le Roux 2006 unpubl) and as such can not be solely used to indicate the presence of unsustainable land use practices. This layer was provided by Jay leRoux (ARC-ISCW) and was created through the use of the Revised Universal Soil loss Equation (RUSLE) with a GIS. The map (Figure 7) provides information about the erosion potential over a given area described in tons/ha/year. The soil erosion hazard over the Grassland biome was extracted in the standard manner, classified and a threat score assigned to each category appropriate to its erosion hazard level (table 11).The classification classes were adapted from Bergsma et al. (1996). The erosion map as it was provided did not include soil erosion information for Lesotho and Swaziland.

Erosion hazard	Soil loss tons/ ha/ year	Impact/threat score
Very high	>60	4
High	25 – 60	3
Moderate	12 – 25	2
Low	< 12	1

Table 11. Erosion hazard classes and threat scores as adapted from Bergsma et al. 1996)

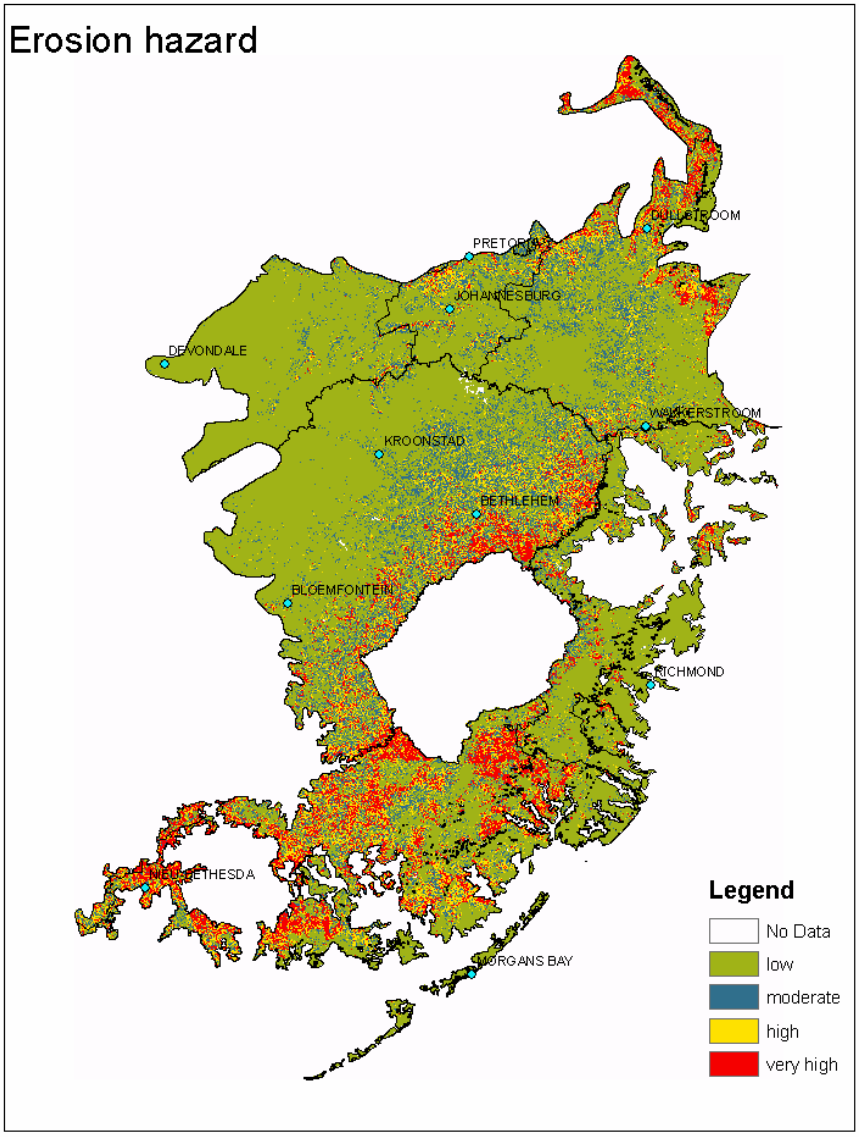


Figure 7. Erosion hazard over the Grassland biome (South Africa only) provided by Jay le Roux (ARC-ISCW)

2.2.4.5. Species richness of threatened grassland birds

The distribution of threatened grassland endemic bird species was extracted from the South African Birds Atlas bird distribution (van Rensburg *et al*., 2002) and displayed as species richness per Quarter Degree Square (QDS) for input into the transformation threat map as shown in figure 8 below. This was converted to a raster of the same dimensions as all the other datasets. The species richness numbers were divided into four groups using and ranked with a potential impact score, ranked from lowest to highest species richness (1 – 4). The higher the species richness, the higher the severity of the impact of threats (non biodiversity friendly land-uses) will be.

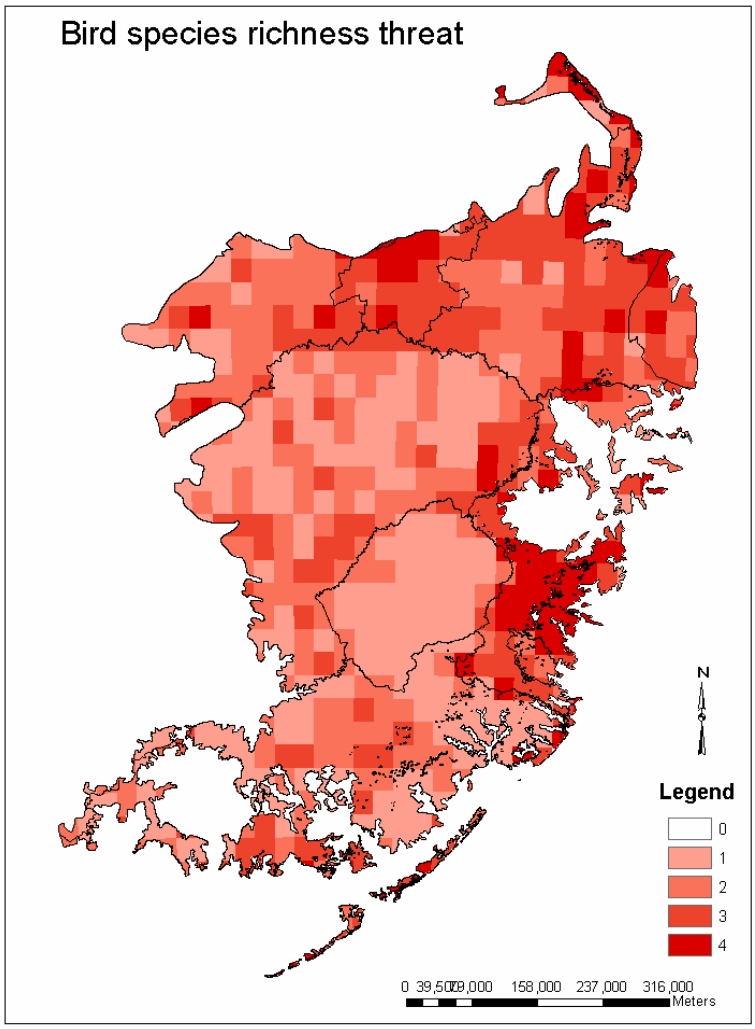


Figure 8. Species richness map of threatened and endemic birds in the Grassland biome

2.2.4.6. Creation of the Composite Grassland Transformation Threat Maps

The use of land classes as surrogates for biodiversity has been widely advocated as an acceptable and better alternative to species distribution data in conservation planning (Noss 1990, Faith & Walker 1996, Reyers *et al*., 2001; Lombard et al 2003). Often, it is the only viable option over areas where species distribution data may be deficient (Faith & Walker 1996). Such an approach also allows the incorporation of landscape level ecosystem processes into biodiversity assessments (Noss, 1996; Rouget et al., 2003; Cowling et al., 2003; Lombard et al., 2003). There are some problems associated with the conventional use of species-based approaches in conservation planning including those of data incompleteness (Ferrier 2002) and spatial biases of more observable and known taxa (Haila & Margules 1996). Furthermore purely species-based approaches may miss entire habitat types (Lombard et al., 2003). Fairbanks & Benn (2000) highlighted that the hierarchical nature of biodiversity (Noss, 1993) means that in order to achieve more representative measures of biodiversity, such assessments should aim to incorporate data layers for more than one level of biodiversity. Integrating land-cover change data with spatial distribution data of biodiversity and protected areas may provide information on the location of biodiversity vulnerability to habitat loss (Menon & Bawa, 1997). This was integrated together with the threats posed by road effects, urban areas, invasive alien plants and soil erosion to create the map showing the extent of current grassland biodiversity threats.

Therefore, two versions of the composite grassland threat map were created. The first map hereafter referred to as the Human transformation threat map shows only transformation threats that are occurring with respect to extant human land use activities. The threats to biodiversity are implicit in the occurrence and severity of grassland land class degradation (habitat loss and fragmentation). The input layers were the Grassland degradation, alien invasive plant species richness, road effects, urban impact and soil erosion hazard maps of the Grassland biome (table 6).

The second version, referred to as the Biodiversity threat map captures exactly the same information but with the inclusion of the endemic, threatened grassland bird species richness layer (table 6). Reasons for carrying this out were twofold. This version of the grassland threat map displayed where and to what degree biodiversity and human non "biodiversity-friendly" land uses coincide. Furthermore, it has been suggested in the literature that species information combined with land class-biodiversity surrogates gives more effective and representative information with regards to biodiversity (Pressey 1994, Lombard et al 1997, Noss et al 1999, Reyers et al., 2002, Cowling et al., 2003).

The general method used to create either version of the grassland threat map were the same and were standard GIS operations carried out in ArcGIS v9.1.
The input layers were combined in a standard overlay procedure using the raster calculator in Spatial Analyst. The biodiversity threat scores were tallied for each grid cell for all the input layers. The grid cells were classified according to their threat scores as high, intermediate and low and from this a threat map was created. Table 12 shows the classification used to create the human transformation map, which reflects only the occurrence and severity of transformation threats within the Grassland biome.

Threat Score	Threat category
12 – 19	High
6 – 11	Intermediate
0 – 5	Low

Table 12. Classification of threat score used to assign threat levels across the biome

This threat map was compared to that produced by Neke & du Plessis (2004). It was also described in terms of location of zones of threat and the associated land uses.

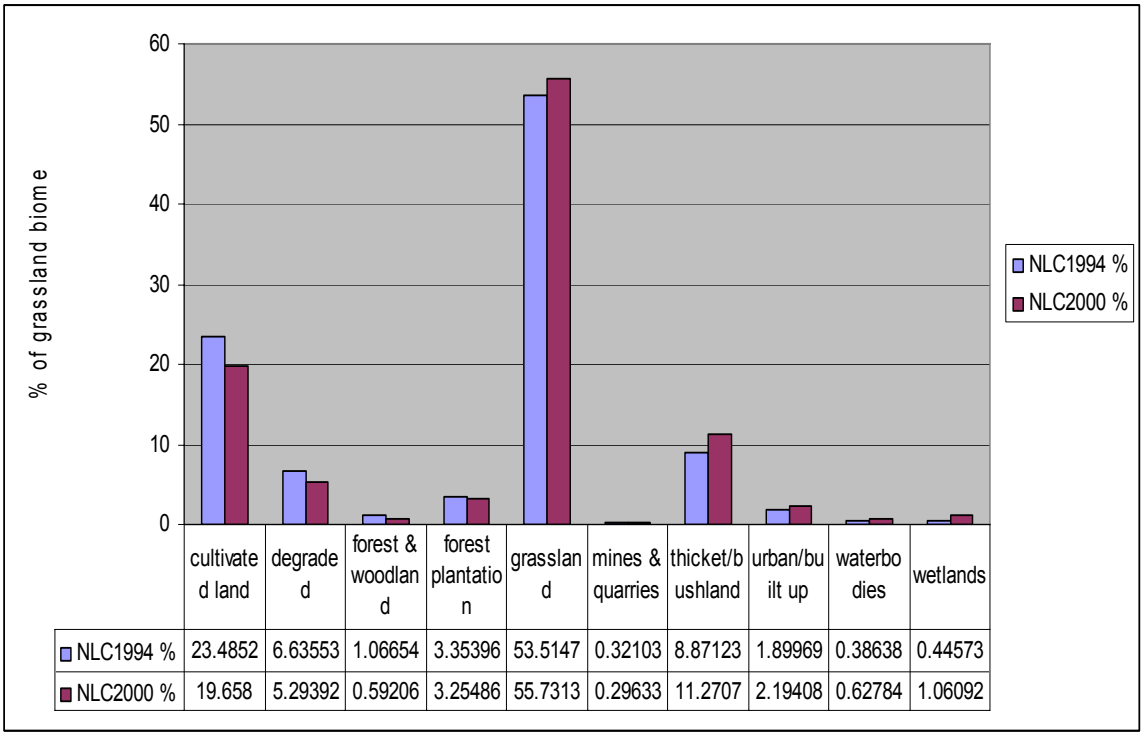
The surrogate biodiversity data was incorporated into this human transformation threat map using the same method as above to create the biodiversity transformation threat map. This provides information on the where the transformation threats coincide with the threatened grassland endemic birds and also the relative severity of that threat on them.

3. RESULTS

The results are presented in the same order as the analysis was conducted: land cover change analysis, the evaluation of these results against the predictions of change (Neke & du Plessis 2004) and finally, the transformation threat maps incorporating the results of the land cover change analysis.

3.1. Results for Land-cover change analysis

The differences between all 10 land-cover classes were quantified in the Land-cover Change Modeler in IDRISI. All the results pertaining to the analyses of land class transformations were calculated by the Land-cover Change Modeler. The results include data on the total extent of each land cover class in NLC1994 and NLC2000. Figure 9 below shows the percentage of the total area of the Grassland biome that each land cover class contributes in each data set. The differences between the bars correspond to the total land cover change experienced per land class.



	cultivated land	degraded	forest & woodland	forest plantation	grassland	mines & quarries	thicket/bushland	urban/built up	waterbodies	wetlands
NLC1994 %	23.4852	6.63553	1.06654	3.35396	53.5147	0.32103	8.87123	1.89969	0.38638	0.44573
NLC2000 %	19.658	5.29392	0.59206	3.25486	55.7313	0.29633	11.2707	2.19408	0.62784	1.06092

Figure 9. Percentage that each land class contributed to the total area of the Grassland biome in both NLC1994 & NLC2000.

The most noticeable increases have occurred over the grassland, thicket/bushland and urban settlements land classes, whilst the other classes have experienced a decrease in area. IDRISI Land-cover Change Modeler allowed for a further breakdown of these observed land class changes. The figures of change per land class are presented in tables 3.1 and 3.2 below.

In most instances, land-cover change for a given land class occurs as a "swapping" process- gains in area through conversions to that land class are accompanied by losses, at other locales, to other land classes (Pontius *et al*., 2004). Each land class experienced both gains and losses in area from conversions to and from the other land classes. The total land cover change experienced by each land class, in terms of gains and losses in area, is also shown in table 3.1. It is the difference between the gains and losses- net change, which determines whether a land class is said to have contracted or expanded in area. Table 3.2 shows the net figures of change experienced by each land class after gains and losses have been accounted for.

The largest total land class conversions were experienced by the cultivated land, thicket/bushlands, grassland, degraded land and wetlands classes respectively (table 3.1, 3.2). Cultivated and degraded lands experienced a relatively large net decrease in area and from table 2 one can see that this is mostly as a result of their transformation to the grassland land class. Most of the increase in bushland area can be attributed to grassland conversion to bushland as a result of bush encroachment. Finally, although the grassland land class experienced large losses in total area, the observed gains as a result of transformation of the other land classes were large enough that there has been an overall increase in grassland area (figure 9, table 3.2). The grassland land class transformations area were further analysed and the results are presented below.

	Bushland 2000	Cultivated 2000	Degraded 2000	Forest & Woodland 2000	F plantation 2000	Grassland 2000	Mines & Quarries 2000	Urban/ Built up 2000	Waterbodies 2000	Wetlands 2000	TOTAL AREA LOST (KM^2)
Bushland 94	√	872.50	809.25	380.50	292.00	11494.25	35.25	176.75	111.00	285.75	**14 457.25**
Cultivated 94	2377.50	√	3959.25	156.00	514.75	25218.75	92.25	1011.00	216.00	630.00	**34 175.50**
Degraded94	1463.00	2777.50	√	62.00	57.50	10241.75	3.00	710.75	102.50	57.00	**15 475**
Forest &Woodland94	1585.75	85.75	66.00	√	148.50	1068.00	1.50	33.00	9.00	15.00	**3012.50**
Forest plantation94	1000.00	329.25	85.25	235.25	√	2197.50	18.00	66.00	16.50	43.75	**3 991.50**
Grassland94	15580.00	16711	5809.75	544.25	2579.00	√	291.75	1306.75	646.50	1648.00	**45 117**
Mines & Quarries94	39.00	79.50	2.25	0.75	6.25	368.00	√	68.75	23.75	20.25	**608.50**
Urban/ Built up 94	340.25	347.50	232.75	47.00	43.00	1254.50	75.25	√	20.50	43.75	**2404.50**
Waterbodies 94	31.25	53.25	11.75	2.00	9.50	227.50	4.75	10.50	√	102.75	**453.25**
Wetlands94	54.75	136.50	17.75	0	10.00	450.00	4.25	4.25	114.00	√	**791.50**
TOTAL AREA GAINED (KM^2)	**22 471.50**	**21 392.75**	**10 994**	**1 427.75**	**3 660.50**	**52 520.25**	**526.00**	**3 387.75**	**1 259.75**	**2 846.25**	

Table 3.1. Land cover class conversions experienced per land cover class in km^2 (1994 – 2000).

		LAND COVER CLASS CHANGE IN KM^2 (1994 – 2000)										NET LAND COVER CHANGE (KM^2) (1994 – 2000)
		Bushland	**Cultivated**	**Degraded**	**Forest & Woodland**	**F plantation**	**Grassland**	**Mines & Quarries**	**Urban**	**W/bodies**	**Wetlands**	
NLC1994 LAND COVER CLASS	**Bushland**	√	1505.00	653.75	1205.25	708.00	4085.75	3.75	163.5	-79.75	-231.00	**8014.25**
	Cultivated	-1505.00	√	-1181.75	-70.25	-185.50	-8507.75	-12.75	-663.50	-162.75	-493.50	**-12782.75**
	Degraded	-653.75	1181.75	√	4.00	27.75	-4432.00	-0.75	-478.00	-90.75	-30.25	**-4481.00**
	Forest &Woodland	-1205.25	70.25	-4.00	√	86.75	-523.75	0.75	14.00	-7.00	-15.00	**-1584.75**
	Forest plantation	-708.00	185.50	-27.75	-86.75	√	381.50	-11.75	-23.00	-7.00	-33.75	**-331.00**
	Grassland	-4085.75	8507.75	4432.00	523.75	-381.50	√	76.25	-52.25	-419.00	-1198.00	**7403.25**
	Mines & Quarries	-3.75	12.75	0.75	0.75	11.75	-76.25	√	6.50	-19.00	-16.00	**-82.50**
	Urban/ Built up	-163.50	663.50	478.00	-14.00	23.00	52.25	-6.50	√	-10.00	-39.50	**983.25**
	Waterbodies	79.75	162.75	90.75	7.00	7.00	419.00	19.00	10.00	√	11.25	**806.50**
	Wetlands	231.00	493.50	30.25	15.00	33.75	1198.00	16.00	39.50	-11.25	√	**2054.75**
	NET LAND COVER CHANGE (KM^2)	**-8 014.25**	**12 782.75**	**4 481.00**	**1584.75**	**331.00**	**-7 403.25**	**82.50**	**-983.25**	**-806.50**	**-2054.75**	

Table 3.2. Net land cover change experienced per land cover class in km^2 (gains – losses, taken from table 3.1)

3.1.1. Grassland land class transformation

The figures of change that are of interest in this project are those specifically pertaining to land cover conversion of the grassland habitat land cover class. However, it is important to set the context within which this change is occurring. Thus all land cover transformations are described and discussed only in reference to the contribution that they may have had on the observed grassland land cover gains or losses. Considering only net figures of change does not provide a complete picture of the land cover change processes in action across the landscape (Mertens & Lambin 2000, Pontius et al., 2004). In order to have a comprehensive description of grassland transformation during the area of interest the gains and losses in area that ultimately result in a net increase in area were further analysed. The grassland transformations were extracted and are displayed in figure 10 below, with the actual figures of grassland change presented in table 3.3.

Transformation type	**Area (Km^2)**
Losses	45 117.00
Persistence	133 622.75
Gains	52 520.25
Grasslands Area 2000 = persistence+gains	186 143.00
Grasslands Area 1994 = persistence +losses	178 739.75
Net area gained= $\lvert Area_{2000} - Area_{1994} \rvert$	7403.25

Table 3.3. Grassland land class areas that have undergone transformation between NLC1994 & NLC2000

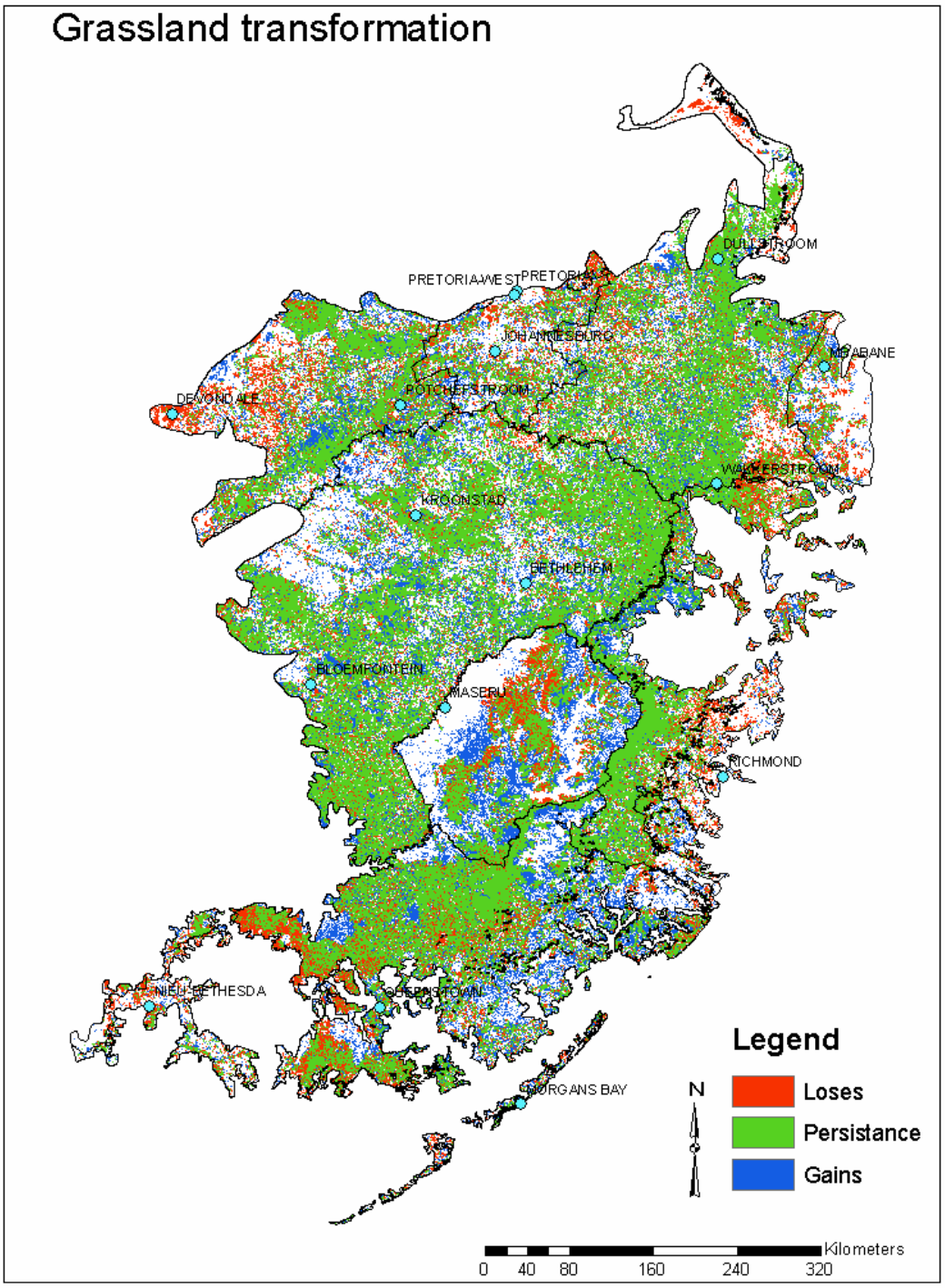


Figure 10. Land-cover conversion of the grassland land class (1994 – 2000)

Figure 10 shows the spatial occurrence of the grassland land class transformations. Only the grassland land class was analysed for gains and losses, therefore blank spaces in figure 10 represent the area consisting of the other land classes. The grassland area that has not undergone any transformation detectable by the imagery that was used is labeled persistence**.** It can be seen from this map (figure 10) that persistence of grassland vegetation has occurred throughout the biome. Grassland cover transformations (losses and gains) have also occurred throughout the extent of the biome but they are especially noticeable along the biome boundary and in the central region of Lesotho. It appears that the spatial extent of the grassland land cover class has contracted away from biome boundary, this is especially noticeable along the eastern boundary. The grassland transformations, gains and losses are discussed in detail further on. It should be noted that the occurrence of gains does not negate the impacts of the losses that have been detected.

It is apparent that the gain in grassland land cover was sufficiently large enough to off-set the incidences of grassland transformation- there has been a net increase of 7403.25 km^2 in the total area of the grassland class (table 3.2,3.3). The remaining grassland patches now make up 55.7% of the total area of the Grassland biome, an increase of 2.3% over the grassland extent as it was in 1994. The grassland land cover that has been lost between 1994 and 2000 constitutes 25.2% of the grassland area as it was in 1994, that is, over a period of 6 years, 25.2% of the grassland habitat land-cover class was lost to alternate land uses.

The three land classes exhibiting the largest land cover changes, relative to the other classes (table 3.2) and excluding the grassland class are cultivated, thicket/bushland, and degraded. These are also the same three classes that have contributed the most to the grassland habitat land cover conversion (Table 3.2). Their total contribution to grassland land cover change, relative to the other land classes are illustrated in figure 11 below.

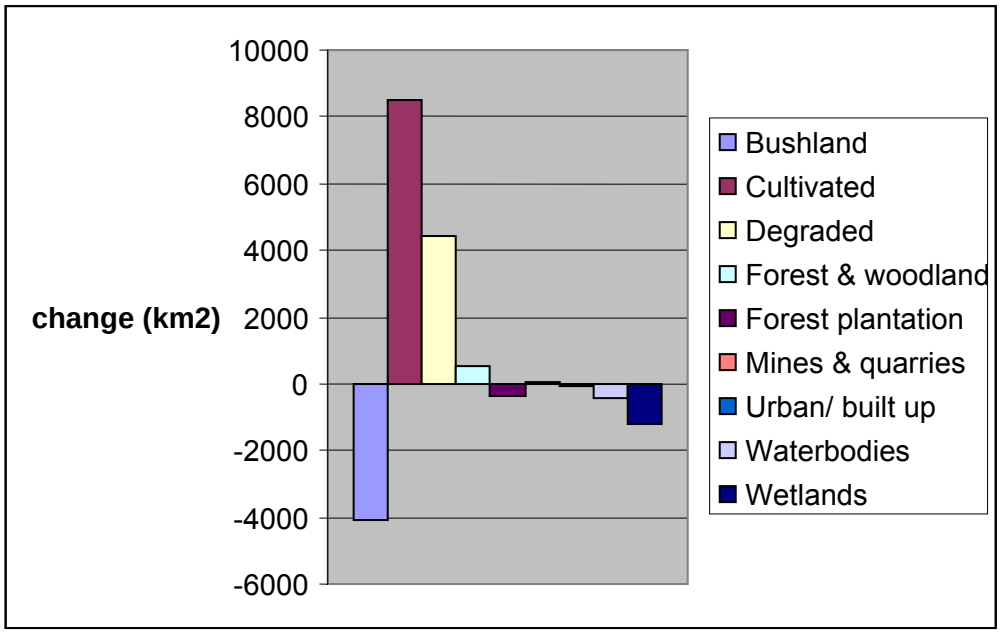


Figure 11. Net contribution of each land-cover class to total grassland land cover change between 1994-2000. Negative values denote land class conversions causing loss of grassland area

The positive values in figure 11 show the area and land cover class contributing to the total observed gains in grassland area, conversely negative values denote that the land class contributes to the losses in grassland land class area and by how much. Therefore the cultivated and degraded land classes contributed the most to the total gains in grassland area whereas the bushland (and wetlands) experienced net increases in area and thus contributed the most to the observed grassland losses.

There are some land cover transformations that are highly improbable- such as a change from an urban area to forest plantation, these are obvious and easy to identify. It is very difficult to identify these unlikely changes where conversion from a natural state is concerned, as the land cover change is most likely due to changing human land use of that site. Therefore, all land cover conversions pertaining to the grassland habitat were assessed, including the highly unlikely transformations back to grassland cover as these contributed to gains. These included the apparent gains in grassland cover by conversion from urban areas and mines and quarries (Table 3.1). The unlikely transformations were not removed from the total figures of change because their effects were small compared

to the more extensive class conversions, accounting for only 3% of the observed gains in the grassland class. Even highly unlikely conversions such as mines transforming to waterbodies could occur where quarries and old mine shafts and tunnels fill with underground water upon cessation of mining activities. This may have been an issue of the quality of the NLC2000 dataset since it had not been assessed for accuracy and error of land cover classification; this is addressed in greater depth in the discussion.

3.1.1.1. Grassland land class gains

The spatial distribution of the observed gains in grassland area from each of the other land cover classes are shown in figure 12 below. Thereafter the contributions of each land cover class to the "gains" in grassland cover are presented as a bar graph in figure 13. Were one to consider this alone, then the largest contributing factor to these apparent gains would be the regeneration of grassland vegetation on land that was formerly under cultivation. This, together with clearing of large tracts of thicket/bushland areas and reclassification of degraded land cover to grassland respectively contributed the most to the observed gains (89.35%). The other land class conversions to grassland cover were marginal in comparison and are not treated in greater detail. The clearing of tree stands, in commercial plantations and indigenous woodlands due to clearcutting and/or fire, contributed less than 7% to the overall gains. From figure 10 one can see that bush encroachment is actually the main net cause of grassland losses. The areas that have been invaded by bushland vegetation are greater than the areas that have been cleared and thus gains detected. Conversely the transformations of the cultivated and degraded lands to grassland areas are therefore significant enough to supercede the observed losses to these classes, since they are largely responsible for the observed gains (figure 10).

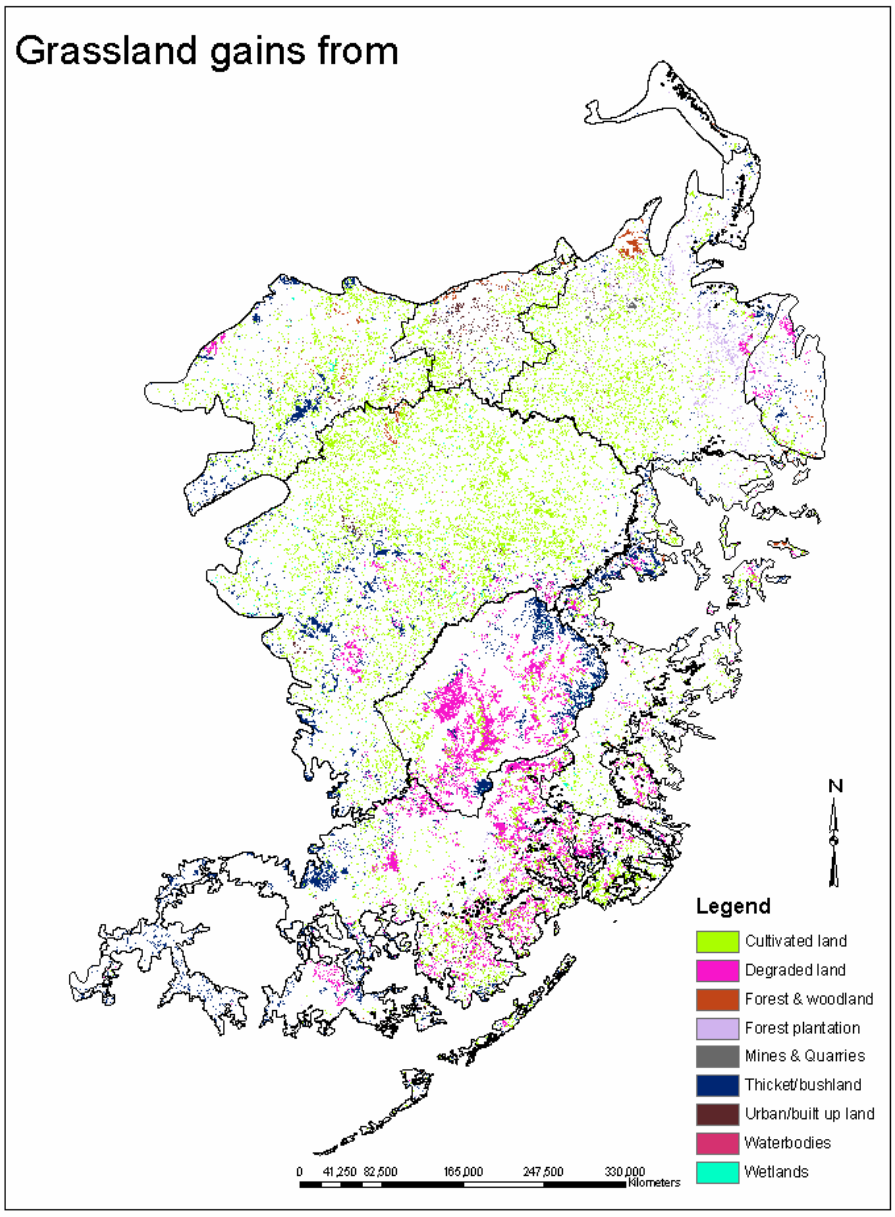


Figure12. Spatial distribution of the observed gains in the grassland class from all other land cover classes

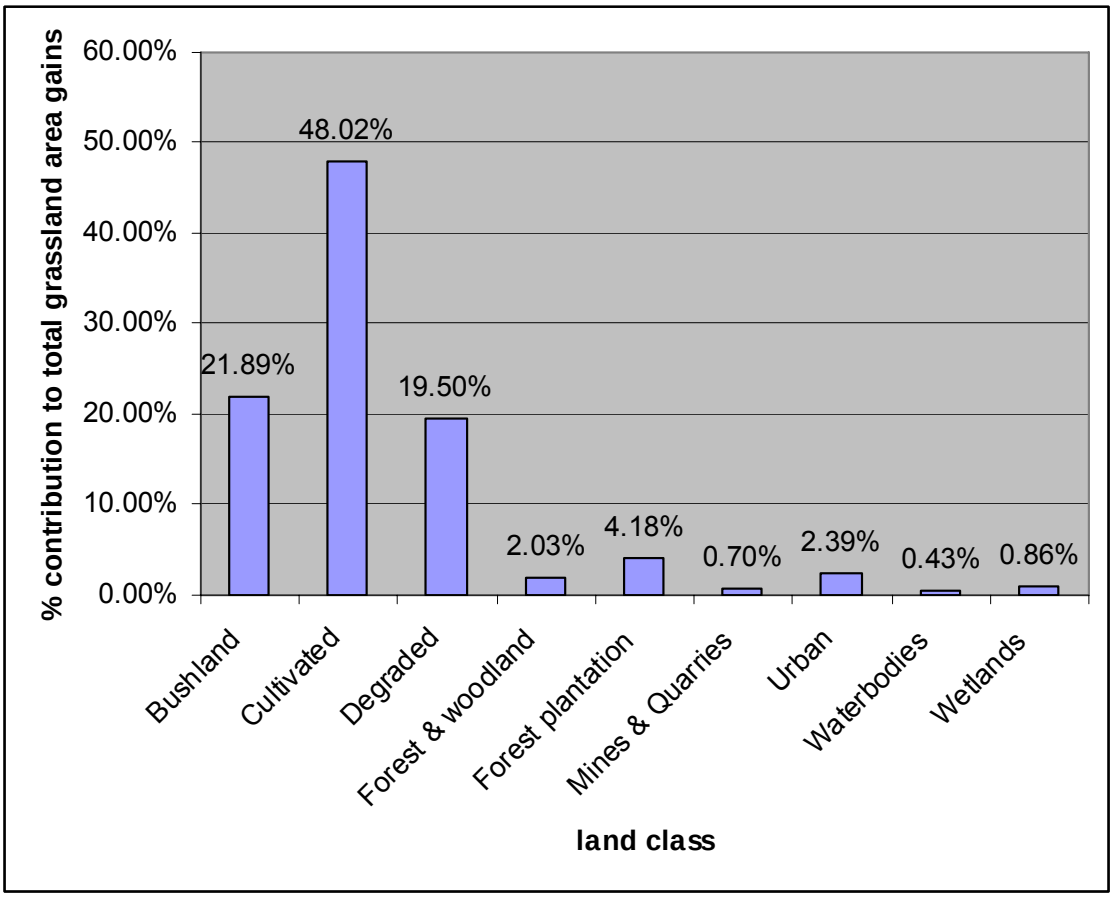


Figure 13. Percentage contributed by each land cover class to the observed gains in grassland cover. Percent values are derived from table 1.

3.1.1.1.1. Grassland vegetation regeneration on cultivated land

The largest overall net change is shown by the cultivated land cover class (table 3.2). This class showed a net decrease of 12 782.75 km^2 in areal extent- over 60% of which was converted to grassland. Furthermore, in all other incidences of land cover conversion of the cultivated land class there is a net loss to other land cover with no net gain detected. So there was a general decrease in the land under cultivation between 1994 and 2001as a result of conversion to other land classes. The observed grassland gains from cultivated lands mostly occurred in areas conventionally associated with intensive farming activities in the Free State, North-West and Mpumalanga provinces (figure 12). The graph in figure 5 shows that in fact regeneration of grassland vegetation on cultivated lands contributed the most to grassland gains.

3.1.1.1.2. Thicket/Bushland clearing

Thicket/Bushland clearing in the biome is the second largest contributing factor to the observed gains in grassland cover (figure 13). This has occurred across every province in the Grassland biome (figure 12). However, there is a very noticeable band of bush clearing along the eastern, mountainous border of Lesotho with South Africa (KwaZulu/Natal). There were also extensive gains in grassland cover across the Free State, Eastern Cape and Northern Cape provinces, especially in the areas along the interface with the Nama-Karoo biome.

3.1.1.1.3. Reclassification of degraded lands

The reclassification of degraded lands to grassland cover has occurred through out the biome but this is most noticeable across the Lesotho central plateau and in the Eastern Cape (figure 12). These observed gains may actually be an artifact of the different classification methods used to collate the two NLC databases and therefore data quality (Mark Thompson, pers.comm). The classification of degraded land cover for the NLC 1994 was based on the loss of above ground cover and this may have resulted in the misclassification of large tracts of grassland patches depending on the season the satellite images used were taken (Mark Thompson, pers.comm).

Although there may have been an overall gain in grassland cover (2% increase), the loss of patches of the natural grassland vegetation is still alarming because it represents loss of suitable habitat for the many floral and faunal species that are endemic to this biome and are specially adapted to this vegetation. Where a patch of habitat is lost completely through conversion, there is a corresponding loss of whatever biodiversity was supported by that patch; even if the loss of the habitat is not complete removal of that patch but reduction in its area. The fact that there has been "gain" of the detected grassland habitat type elsewhere does not mitigate this loss.

3.1.1.2. Grassland land class losses

The spatial distribution of the land cover conversions from the grassland land cover class (losses) are presented in the map below (Figure 14).

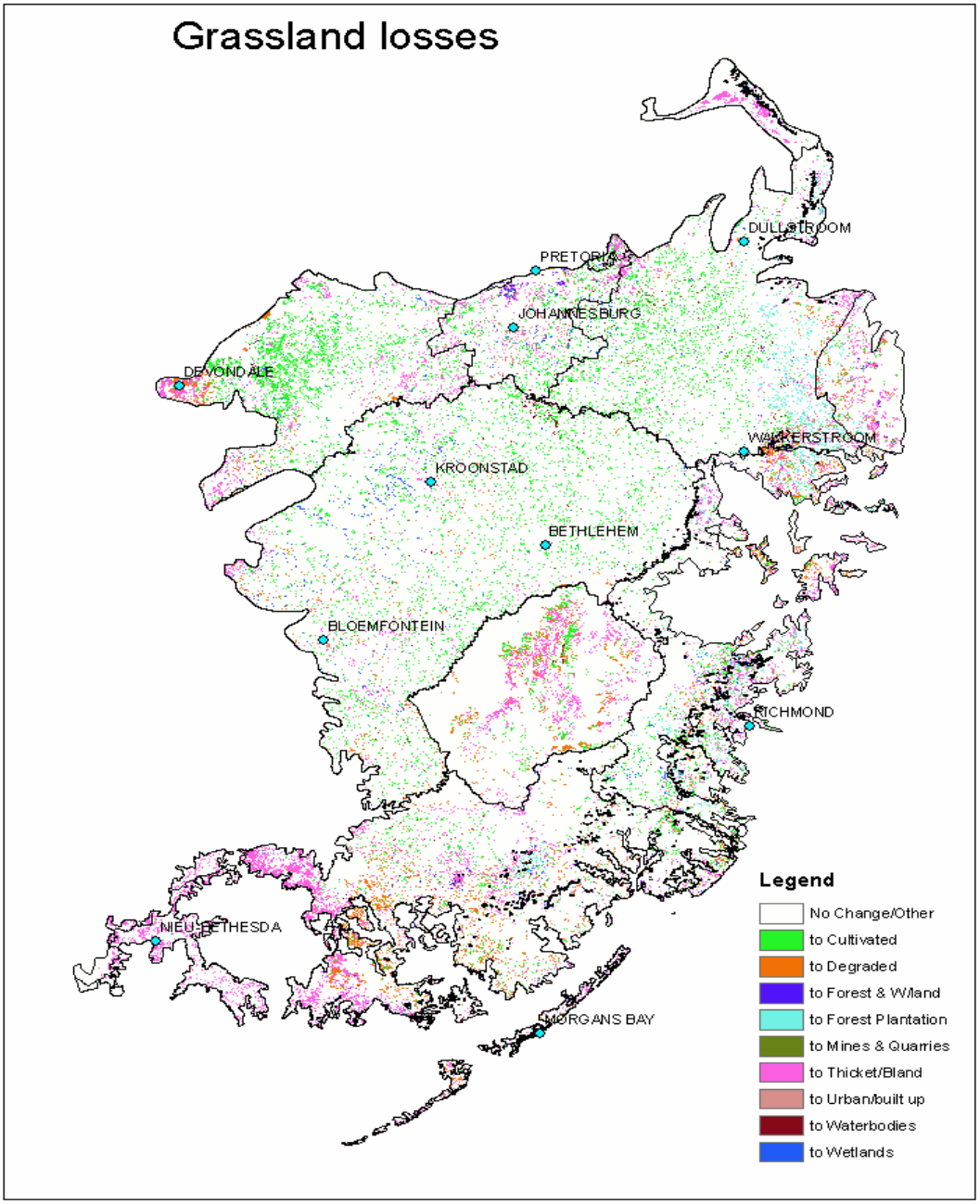


Figure 14. Spatial occurrence of grassland losses described with respect to the grassland cover conversion per land cover class

From figure 15 below it can be seen that land use change from grassland to cultivation and increasing bush encroachment respectively are almost equally responsible for grassland habitat loss- together they account for 71% of the grassland conversion. The other land cover conversions are marginal in comparison- transformation to a degraded state and commercial forestry activities are the next largest contributors to change at 13% and 6% respectively. It has been suggested that the bush encroachment into the biome be used as a proxy indicator of invasive alien plant spread into the biome (Neke & du Plessis 2004), where it is established that spread of Invasive Alien Plants is linked to human activities (Richardson et al, 1997). If one takes this into account and considers the nature of the next most relevant contributors to grassland cover change, it is clear that human land use activities are without a doubt causing extensive grassland habitat loss within this biome.

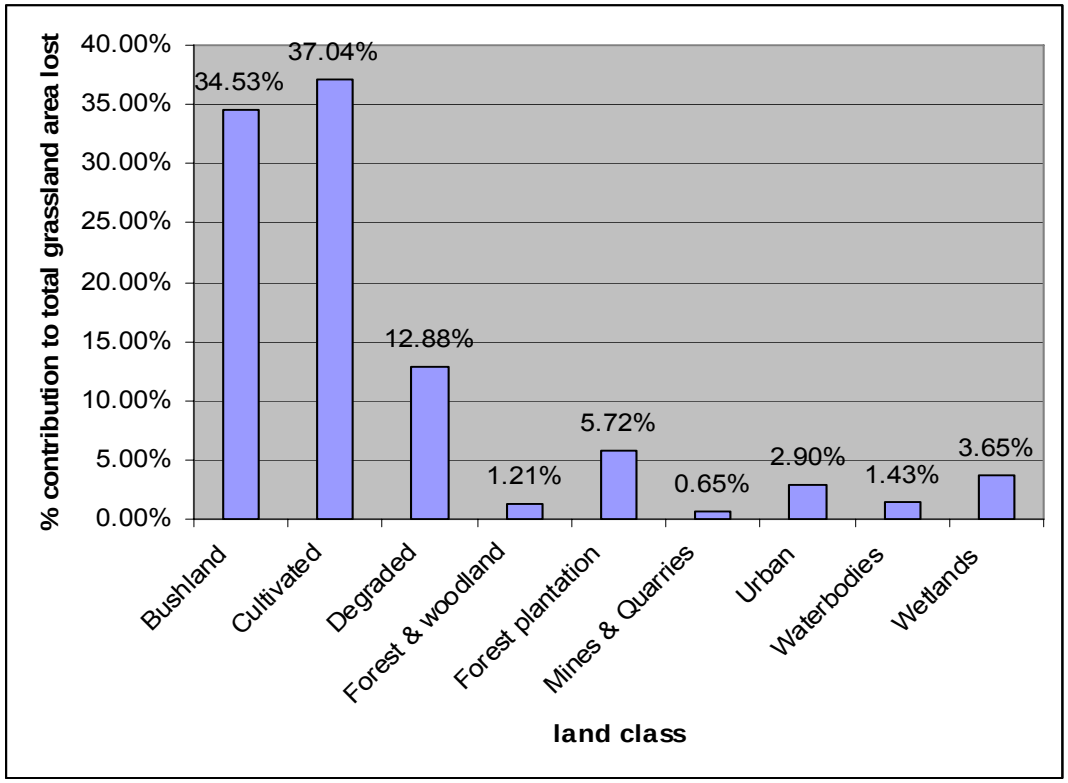


Figure 15. Percentage contributed by each land cover class to the observed losses in grassland cover. Percent values are derived from table 1

As aforementioned, the land cover conversions that experienced the most change within the biome have also contributed the most to the observed grassland land class transformations. This has been manifested especially through grassland losses to thicket/bushland, cultivated areas and degraded areas. These are further described below.

3.1.1.2.1. Increasing Bush Encroachment

Bush encroachment is a major cause for concern because it is the most significant net contributor to grassland habitat loss- over 4,000 km ^{2} of semi-pristine grassland vegetation has been lost to bush encroachment and presumably the increasing spread of invasive alien plant species (Neke & du Plessis 2004). The Thicket/ Bushland cover class has experienced the largest gain- an overall increase of over 8000 km^2. More than half of the observed net increase is due to conversion from grassland vegetation. Bush encroachment into the remaining grasslands is responsible for the largest overall loss of this habitat type. This indicates an increasing presence of invasive alien plants, transforming the structure of the landscape from grassland cover. From the map above showing the spatial distribution of grassland cover loss transformation (figure 14) it can be seen that most of the conversion of grassland to thicket/bush is occurring at the boundaries of the biome where there is interaction with the other biomes. There are very noticeable patches of conversion in the North-Western province- an area that is important for agriculture the top-most section of the biome that lies in the Northern province and Swaziland– these areas are bounded by the Savanna biome, KwaZulu/Natal- where the biome interfaces with the Thicket biome and in the Northern Cape portion of the biome that intrudes into the Nama-Karoo biome. The occurrence of bush encroachment and perhaps in the case of the Northern Cape desertification, are known phenomena and have been well described in the literature (Bews 1917, Dyer 1937, Acocks 1953, Comins 1962, Morris 1976, Bredenkamp & Bezuidenhout 1990, O'Conner & Bredenkamp 1997). It is not possible to identify the factors that could be driving this bush encroachment into the biome at this scale and from the available information. According to van Wilgen et al (2001) the grasslands of the Drakensberg escarpment have also been highly impacted by conversion to thickets of alien plant species and this is apparent in figure 4. Furthermore, there is also conversion from grassland to bushland in central Lesotho- at the very core of

the Grassland biome itself thus it is difficult to make sweeping statements about the possible causal factors although these could include the aforementioned bush encroachment, desertification, human disturbance of the landscape.

Conversion of bushland to grassland has been detected but this may largely be as a result of human bush clearing activities (perhaps manual clearing or fire, natural or otherwise) causin regeneration of grassland not as a natural event but as a result of human interference, a similar phenomenon may be the cause of the apparent conversions of woodlands and forest plantation areas to grassland

3.1.1.2.2. Waterbodies & Wetlands

Particular care was taken in the interpretation of the conversions to Waterbodies and Wetlands given that 2000/1 was a particularly high rainfall season in Southern Africa and seasonal phenomena such as the surface extent of waterbodies and wetlands could have been affected by this. This is a likely explanation for the net increase in wetlands land cover by over 2000 km^2, especially considering that most of the change was observed in the grasslands and cultivated areas. It is likely that this observed increase from converting over a 1000 km^2 of grassland habitat was not as a result of the creation of new wetlands but the increased surface extent of pre-existing wetlands due to the high rainfalls at this time.

3.1.1.2.3. Urban Expansion

The grassland habitat lost to urban expansion is small when compared with the other land cover classes (1306.75 km^2), however for this land cover class in particular, the area of land that has been converted to grassland habitat (1254.50 km^2) must be viewed with suspicion as a potential case of misclassification or mapping error and an artifact of the different methods used to carry out the classification of the respective datasets. Considering the results for growth of the Urban/ Built up areas one could assume that there has been urban expansion within the Grassland biome and at a superficial level one would assume that this expansion would be associated with known urban centres- since urban expansion usually denotes increasing urban sprawl. However this would be an

erroneous assumption in this case because although there was a net increase in the Urban/ Built up class extent, further analysis showed that the increase could not be perfectly related or traced to the growth of identifiable urban areas from the original dataset. Instead this increase was linked to an increased number of smaller urban areas from the grassland biome extraction from the NLC2000 dataset, mostly located in the interior of the Grassland biome, rather than expansion of the larger complexes such as Johannesburg-Pretoria and Bloemfontein in Gauteng and Free State provinces respectively. So urban expansion has occurred and this is mostly associated with smaller urban centres and small holdings that may not have been large enough to detect in the initial survey (NLC1994). Such outward expansion is usually associated with increasing human populations and therefore an increased demand for space and resources.

3.1.2. Grassland Fragmentation

The results of the fragmentation analysis of the remaining semi-pristine grassland patches carried out in FRAGSTATS are presented in table 3.4 below.

Fragstats metrics	**GLC1994**	**GLC2000**
Total area (km^2)	178,739.75	186,143.00
Proportion of landscape (%)	53.5	55.7
Number of Patches	4,017	13,503
Mean patch Area (km^2)	44.50	13.79
Area_range	148,421.25	162,755.25
Area_coefficient of variation	5264.38	10160.90
Total Edge (m)	242,578,000	360,229,000
LSI	143.37	208.71
Mean Shape Index	1.44	1.25

ENN_MN (m)	1,282.27	1,144.12
ENN_variance (m)	520,418	123, 974
CLUMPY	0.8187	0.7402
PARA	56.76	69.19
CONNECT	0.0223	0.008

Table 3.4. Fragstats results of landscape metrics run on grassland patches (NLC1994 & NLC2000)

The grassland habitat land cover class has become more fragmented between 1994 and 2000. The number of patches has trebled and the average patch size is three times less than what it was in 1994. The corresponding increase in total edge implies more severe edge effects as the core area of the remaining patches has decreased and the perimeter: area ratio (PARA) has increased. On average the remaining patches have become more isolated from each other even though the distance between patches appears to have decreased (ENN_MN) this is best interpreted taking the decrease in patch size and higher patch numbers into account as shown in figure 16 below. That there is increasing patch isolation is also suggested by the decrease in connectivity- again by a factor of approximately 3 (CONNECT).

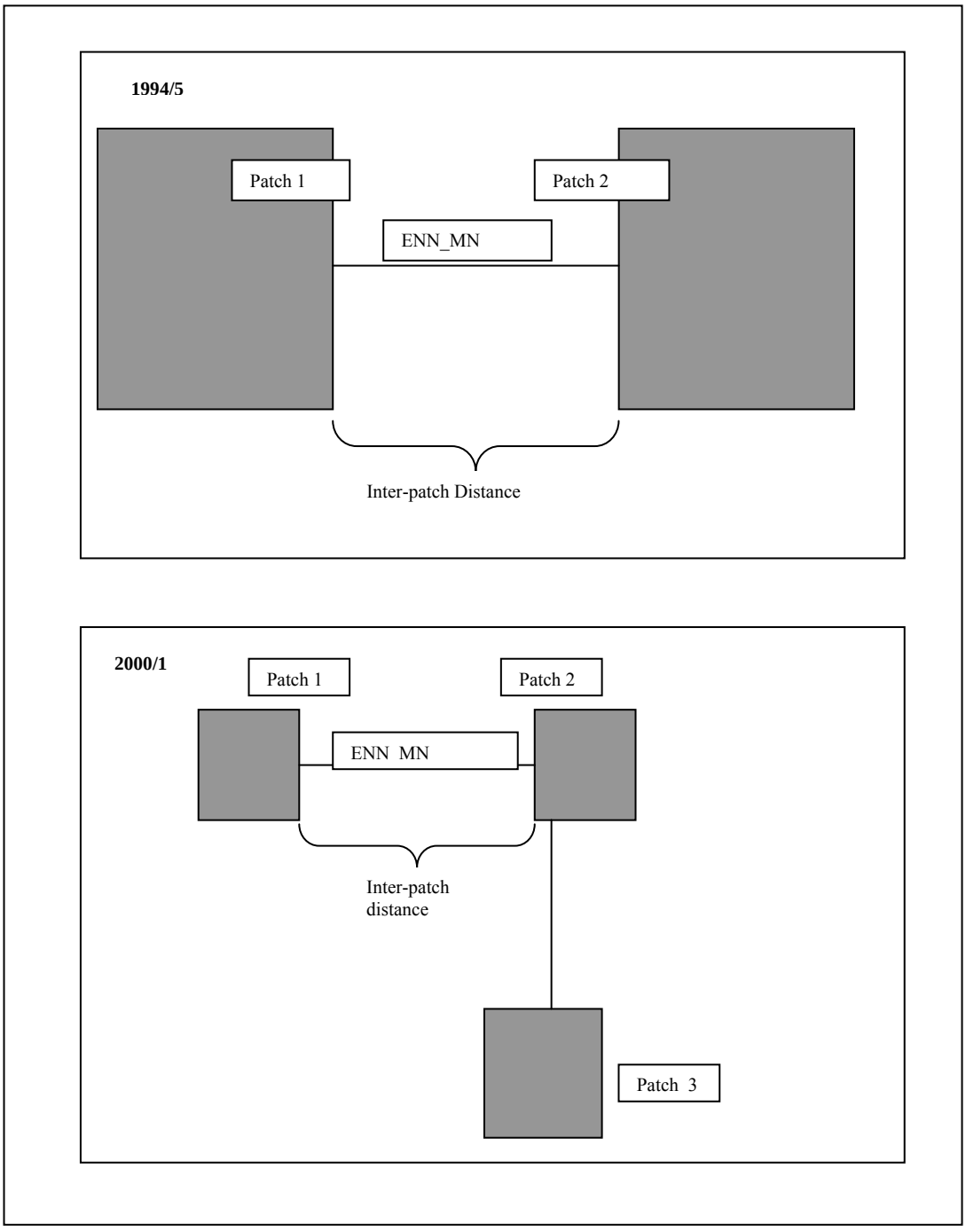


FIGURE 16. Illustrating patch isolation of the remaining grassland, where ENN_MN is Euclidean Mean Nearest Neighbour distance between patches

The remaining grassland patches show an aggregated or clumped dispersion (ENN_MN< ENN_variance, CLUMPY) across the biome landscape, although the grasslands have

become marginally disaggregated over time, the CLUMPY for the NLC2000 dataset is still close to 1, indicating that the remaining patches are aggregated in clumps. This is not surprising and is a function of spatial auto-correlation- fragmentation of larger patches will result in smaller patches, aggregated in clumps, in the area that was formerly the full extent of the parent grassland patch. From figure 10 we can see that this pattern extends throughout the biome area, such that the overall shape of the grasslands biome, as it would be without transformation, is maintained. As the remaining grassland patches have become smaller- reduced by a factor of 3, there has been a corresponding increase in the number of grassland patches. This must be taken into consideration for the interpretation of the shape metrics. Overall, grassland patch shape has not become more complex in spite of the higher PARA value- in fact, the Mean Shape Index values suggest that the patches have not only become more compact but the shape has become less convoluted. Although the literature suggests that an increasing perimeter to area ratio is usually related to increasing patch shape complexity this is a scale dependant relationship, and the same effect will be produced by a decreasing patch size (McGarigal 2000) as is the case in this situation. Similarly the increase in total edge of the grassland vegetation class is better explained by the increasing number of grassland patches than by the notion of more convoluted patch shapes.

The Fragstats indices provide information on the average trends of fragmentation- they do not give spatially explicit information- to this end, the results of the FRAGSTATS moving window analysis on mean patch size are presented below (figures 17, 18). Both images (for NLC1994 and NLC2000) provide visual information about grassland patch size distribution across the biome.

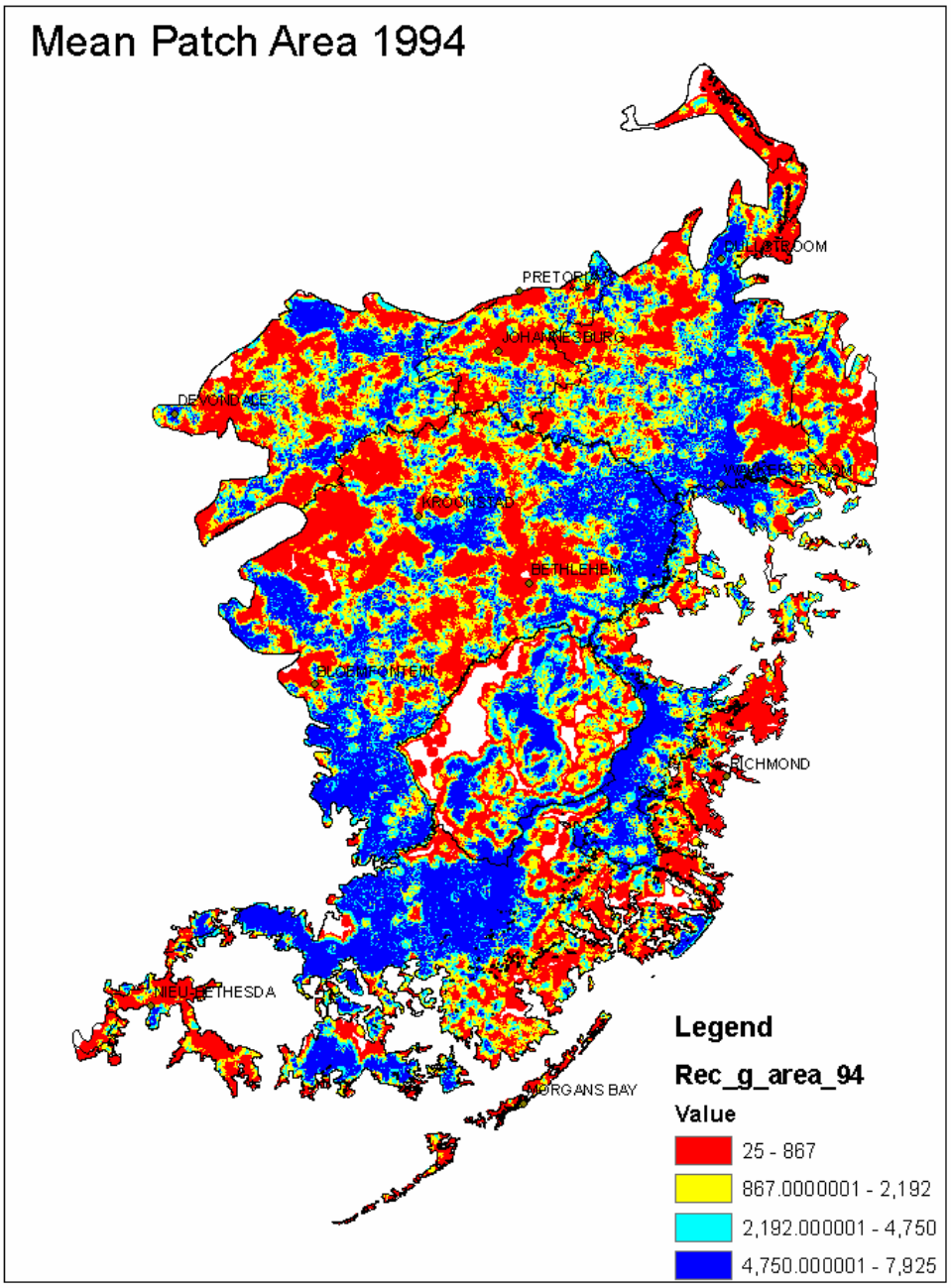


Figure 17. Results of fragstats moving window analysis showing mean patch size distribution in the Grassland biome (1994). Areas are given in hectares

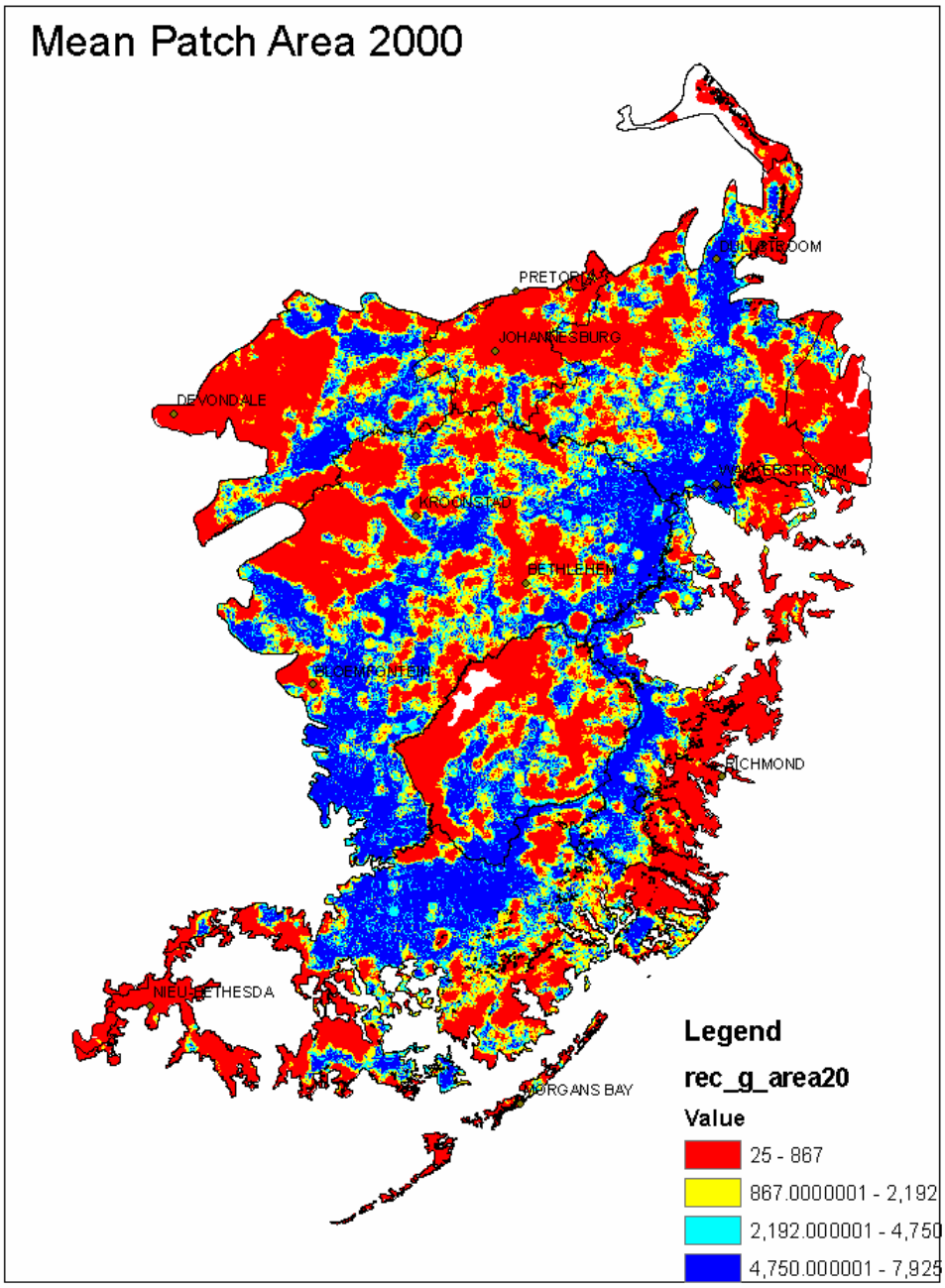


Figure 18. Results of fragstats moving window analysis showing mean patch size distribution in the Grassland biome (2000). Areas are given in hectares

There may have been an overall decrease in patch size but this does not occur uniformly across the landscape. The average decrease in patch size is most detectable where there has been identified grassland cover loss. The increased range for area values, when considered together with the results of the moving window analyses tells us that the larger patch sizes have been well conserved or rather the least transformed by human activities thus habitat transformation in terms of loss and decreasing patch sizes is associated with the smaller grassland patches. This would suggest that there has been a change in the lower limits of area ranges and this supports the suggestion that most of the habitat loss has occurred in association with the smaller patch size classes. This is supported by the higher value for the coefficient of variation for mean patch size- this, when interpreted together with the higher patch numbers and decreasing patch size suggests that the size of the remaining grassland patches is greatly varying, with smaller patches where they were previously more uniform in area and larger (McGarigal 2000).

There is a clearly identifiable band that runs through the biome along the escarpment and mountain ranges, and large areas across the Free State that consists of the largest grassland patches. These areas are the least susceptible to patch area contraction and splitting as they are clearly identifiable in both datasets. These large patches form the areas of grassland habitat persistence (figure 10) and thus form a core area within the biome that is not highly affected by transformation processes. These zones of persistance run across the highest part of the Grassland biome which is traditionally sparsely populated by humans and difficult to exploit. The large grassland patches that have persisted across the Free State do not coincide with any obvious geographical features that could possibly explain their persistence. According to Neke & du Plessis (2004) these areas show low suitability for cultivation and forest plantations- these land use activities were associated with large scale land cover conversion for NLC1994. These areas may in fact be associated with rangelands and livestock ranching (www.sanbi.org**)** that may not necessarily bring about land cover changes per se but may result in land cover modification which will still have an impact on biodiversity as the structure of the grasslands may be affected by livestock grazing- although this may not be apparent at the

large scale at which the analysis was carried out. The occurrence of these aspects of fragmentation- depends on the nature of the land use practices over that piece of land. Non-biodiversity friendly land uses require surface cover conversion and are therefore associated with intense fragmentation.

3.1.3. Assessing Grassland habitat degradation

Grassland degradation can not be considered solely in the context of habitat loss, decreasing grassland patch area sizes, decreasing patch isolation and the shape of the remaining fragments- all have an effect on the remaining biodiversity. Mean patch area, number of patches, patch shape complexity and inter-patch distances are amongst the best descriptors of landscape fragmentation (Neel et al 2004). The occurrence of habitat loss was incorporated into these results to provide grassland degradation map (figure 19). From which information on the degree of actual grassland degradation or transformation within the biome was drawn.

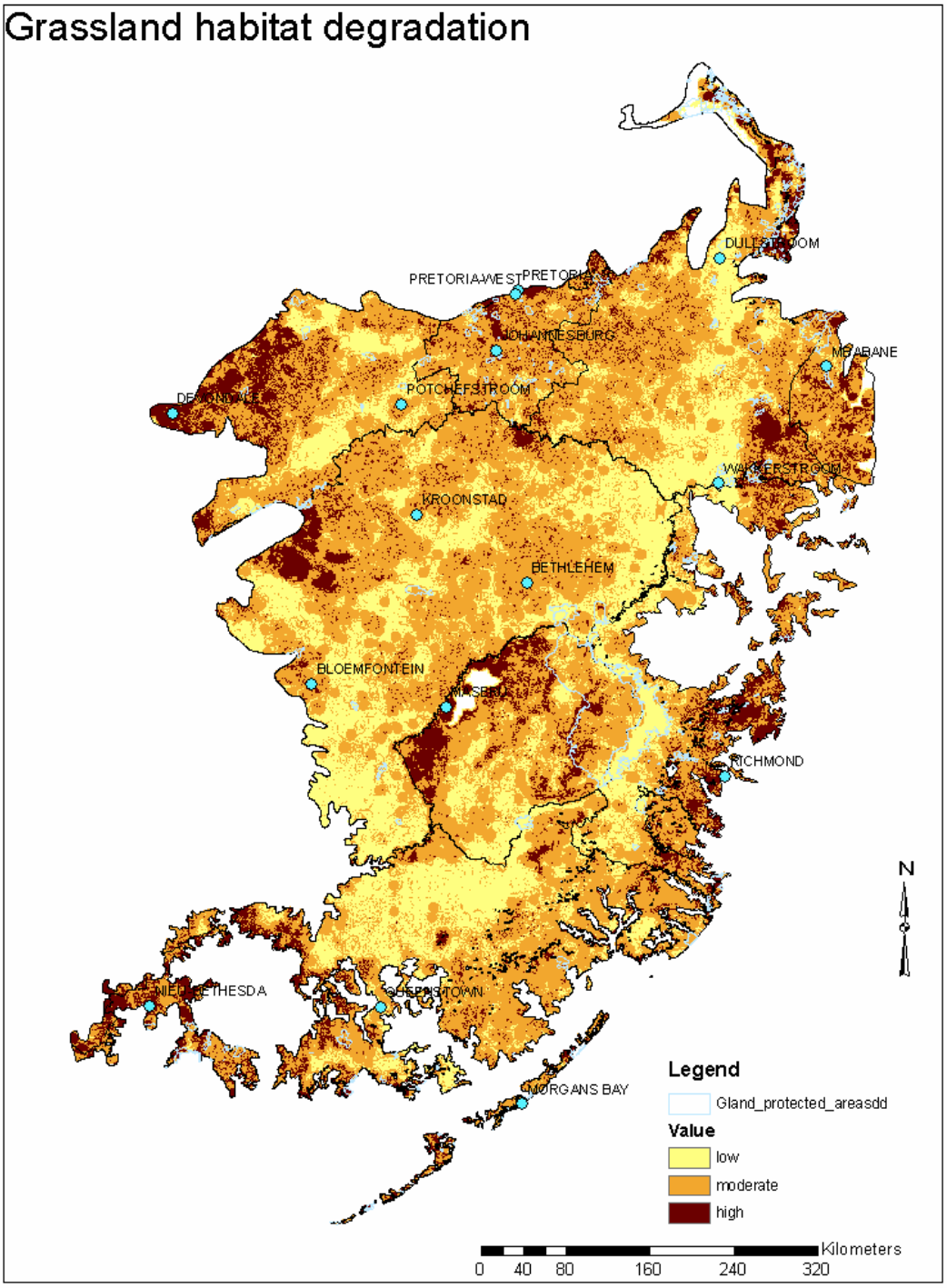


Figure 19. Map showing Grassland Degradation a visual representation the combined effects of grassland loss and fragmentation

Grassland degradation	Km^2	%
Low	49 700.18	26.7
Moderate	109265.94	58.7
High	27 176.88	14.6

Table 3.5. Area in km^2 and percentage of grassland degradation areas in the Grassland biome

Only 26.7% of the grassland vegetation remains untransformed or in a semi-pristine state these areas of low transformation add up to a total extent of 49 700.18 km^2. Considering the full extent of the biome- what would be classified as grassland land cover were it not for the observed transformation, it can be seen that the remaining patches of grassland that have been the least impacted upon by habitat loss and transformation represent only 14.8% of this former extent. The least degraded grasslands form a belt that runs across the biome along and to the west of the escarpment and mountainous areas in the east and then up into the interior Free State Province, stretching into the North-West province. This is the same zone that has shown grassland cover persistence and has the largest remaining intact grassland patches.

The majority of the Grassland biome area (58%) is experiencing moderate degradation. This includes most of the interior grassland biome and urban areas. The grassland areas that are in the worst condition (high degradation) are the same areas that have undergone extensive grassland losses, that have most probably resulted in either complete loss of grassland patches or shrinkage giving rise to relatively smaller grassland patches and larger inter-patch distances. Where these areas may not have been clearly visible in the map showing grassland gains and losses (figure 10) they are now clearly visible. There is some association of severely degraded grassland habitat with the larger urban complexes such as Johannesburg-Pretoria and Maseru but it is not as pronounced as one would have thought. For the most part, the areas of high degradation are associated with cultivated, - most noticeably in the North-West province, along the western Lesotho border with the Free State province and in the Free State province itself, and with the commercial forestry plantations in the KwaZulu/Natal and Mpumalanga provinces.

3.1.3.1. Grassland degradation over the Eastern Mountains hotspot

There is an obvious difference in the degree of grassland degradation in the areas of high conservation value on either side of the Lesotho-South Africa border. The Ukahlamba Drakensberg Park shows mostly low grassland degradation whereas the proposed area to be covered by the Lesotho National Park shows moderate degradation with some instances of high grassland degradation. The observed degradation on the Lesotho side is associated with thicket/bushland clearing and observed gains from degraded lands. This may have caused an increase in the number of small grassland patches observed over the area and thus inflated the observed degree of fragmentation.

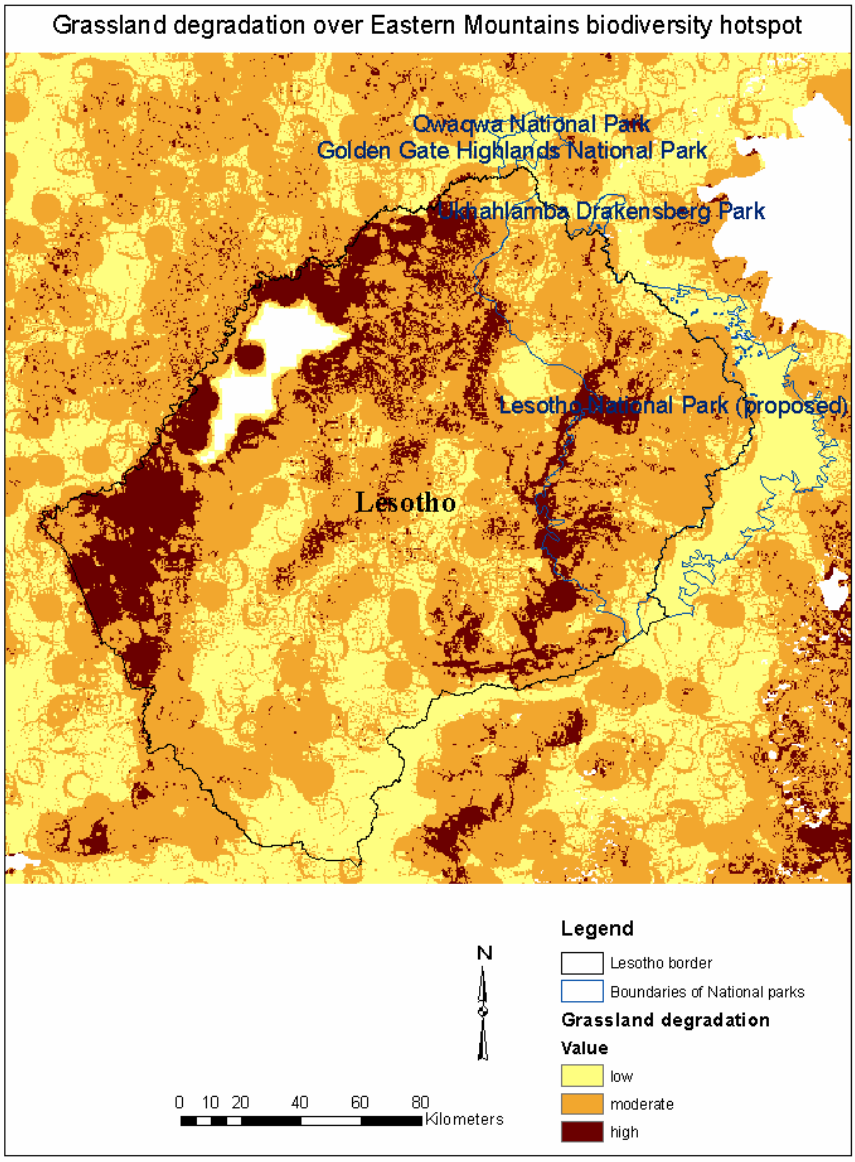


Figure 20. Grassland degradation over the Eastern Mountains biodiversity hotspot showing differences in grassland degradation between Lesotho National Park (proposed area) and the Ukahlamba-Drakensburg Park. These make up the larger proportion of the Maloti-Drakensburg Transfrontier Protected area. Extracted from the Grassland degradation map (figure 19).

3.2. Results for testing predictions of threat- Neke & du Plessis (2004)

There were unanticipated difficulties in obtaining the original electronic images of the transformation threat map from the authors. As such, all "testing" was carried out in a qualitative manner, as described in the methods. The results therefore took the form of a discussion, describing where the predictions held true and where the predictions fell short and are presented below.

3.2.1. Assessing predictions of transformation

The map of grassland degradation **(**figure 19**)** was used to assess if and where predictions of grassland transformation (Neke & du Plessis, 2004) held true in reality, to "test" their predictions as it were. This map was used because it offers a holistic visualisation and description of the actual incidences of grassland transformation- providing not only affirmation as to whether transformation did occur but also the relative severity of that transformation as a function of the intensity of fragmentation and habitat loss experienced at a given site. The predictions of threat made by Neke & du Plessis (2004) as they are described in the paper (Box 1) and shown in the published map of threat- figure 21 are summarized below.

- Transformation (intermediate and high threat) likely to occur in a concentrated band running along the eastern edge of the biome, extending west to encompass most of Gauteng, across northern Mpumalanga and westward to Swaziland.
- Relatively small, isolated incidences of transformation scattered across the interior Grassland biome- most noticeably around Bloemfontein and portion of biome falling within the Northern Cape- adjacent and intruding into the Nama Karoo biome.
- High transformation especially in high rainfall, species rich areas along the escarpment- associated with commercial forestry plantations- especially in KwaZulu/Natal and west of Swaziland
- Intermediate transformation over large portion of Swaziland
- Low incidence of transformation over Lesotho

Box 1 Summary of the Transformation Threat predictions by Neke & du Plessis (2004)

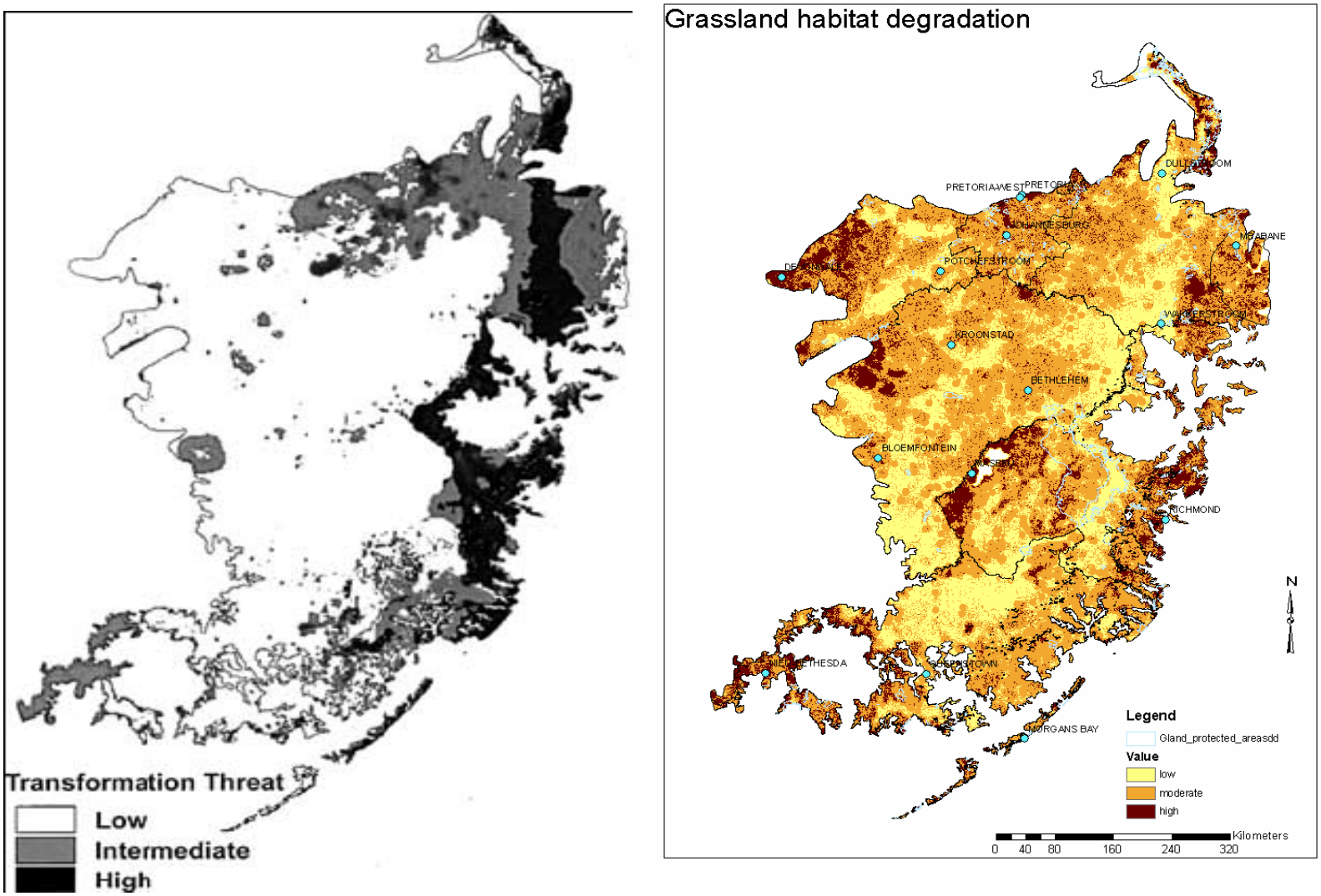


Figure 21. Transformation threat map (Neke & du Plessis, 2004) compared against the Grassland degradation map

Overall the predictions of transformation and the general spatial predictions of where they will occur have been realized. There has indeed been grassland transformation along the eastern edge of the biome, over the south-west tip and in the Bloemfontein area. This affirmation of transformation should be interpreted carefully given that the areas that were predicted to have high transformation threat (from a pristine state) had already been transformed when the predictions of transformation were made. Therefore, taking the "testing" of these predictions on the basis of presence/absence of actual change one could say that the majority of the predictions of transformation were upheld, except for the predicted high intensity transformation over northern KwaZulu/Natal along the provincial boundary with the Free State. However, the model of Neke & du Plessis (2004) underestimated the occurrence of grassland cover transformation in the interior of the biome, especially the incidences of high land cover transformation or degradation, as it has been labeled here, in the North-Western and Free State provinces as well as along the western Lesotho border. The proportions of land that show grassland transformation also differ from the predicted area displayed in figure 21.

The area stretching from the band of transformation threat along the eastern edge of the biome across the interior to the western boundary that was predicted to have low probability of transformation has in fact experienced substantial change. The loss in grassland cover has not occurred evenly across the biome- rather the incidences of loss are clumped together so much so that they can be delineated for descriptive purposes. Of particular interest are the incidences of grassland loss and high fragmentation in the North Western province, upper Free State, central Free State (around Bethlehem) and in Lesotho along the Western border and in and around the Lesotho National Park. (highlighted in the map of fragmentation and grassland condition)

The prediction of high transformation occurring along the escarpment does not in fact hold true. This is the band that is associated with the largest, intact semi-pristine grassland patches that have actually undergone very little transformation (figures 10, 18, 19). It is thought that this persistence may be attributed to the terrain which may be

difficult to exploit or transform even though the biophysical and climatic attributes of this region such as high rainfall, cool climate and good soils would have made it theoretically highly attractive for human exploitation. Since the predictions of transformation were based on human land use suitability information, it is clear that these did not consistently reflect the actual occurrence of land cover change caused by human land use across the entire biome.

Of concern is the inability of the map to predict the land cover loss in the interior of the biome- the clumped distrinbution of these areas of high intensity fragmentation suggests that this is associated with a common land use activity over each area. For instance, the dominant land use over the area in the North Western province that shows high fragmentation is agriculture. Similarly the areas of high fragmentation in Gauteng are associated with the Johannesburg-Pretoria urban complex, the Ekhuruleni metropolitan area and the many industrial sites within this area where the dominant land use is human urban settlement and industry.

3.3. Results for the assessment of current threats to Grassland Biodiversity (Current threat maps)

The threat map shows the extent of current human transformation threats in the South African portion of the Grassland biome. Two of the input datasets, road effects and soil erosion hazard, did not have information extending into Lesotho and Swaziland. An assessment of current transformation threats including these countries would have given inaccurate information. These transformation threat maps (figures 22, 23) illustrate the current extent and relative severity of observed and measurable landscape-transforming activities. The grassland biodiversity within these areas has already been impacted upon; it is the biodiversity in the immediate surrounds that is then facing future threat.

Figure 22 below provides a human transformation threat assessment for the Grassland biome contained within South Africa. This map provides information as to the location of extant non biodiversity-friendly land uses and the severity of the associated impacts within the biome. It provides a visualization of where grassland habitat transformation, as

it is induced by human, non-biodiversity friendly land use is occurring. Table 3.5 provides information about the areas within the Grassland biome that are currently facing high, medium and low transformation threats respectively.

The highest human transformation threats are currently associated with urban/ built up areas, most noticeably the Johannesburg-Pretoria complex and Bloemfontein. There are also high transformation threat zones in the Northern Cape, Eastern Cape, Limpopo and Mpumalanga provinces. The influence of the roads can be seen clearly in this map. The National routes and freeways are clearly identifiable as tracts of high impact threat cutting across what would otherwise be large continuous tracts of low threat grassland vegetation land-cover. When one considers this, the severity of the road effects becomes apparent and the action of roads as agents of fragmentation is clarified in this threat map. Although the actual traffic and frequency of use of the roads has a bearing on the actual severity of the threat they pose, the effect of roads in biodiversity threat assessments should still be taken into account. Furthermore, in some transformed land cover types, such as cultivated lands, the road verges and hedges may actually act as refugia for natural species (Witkowski, Thompson pers comm.).

The intermediate human transformation threat zones occur across the biome. The blocky appearance is as a result of the coarser resolution data from the invasive alien plant species richness layer.

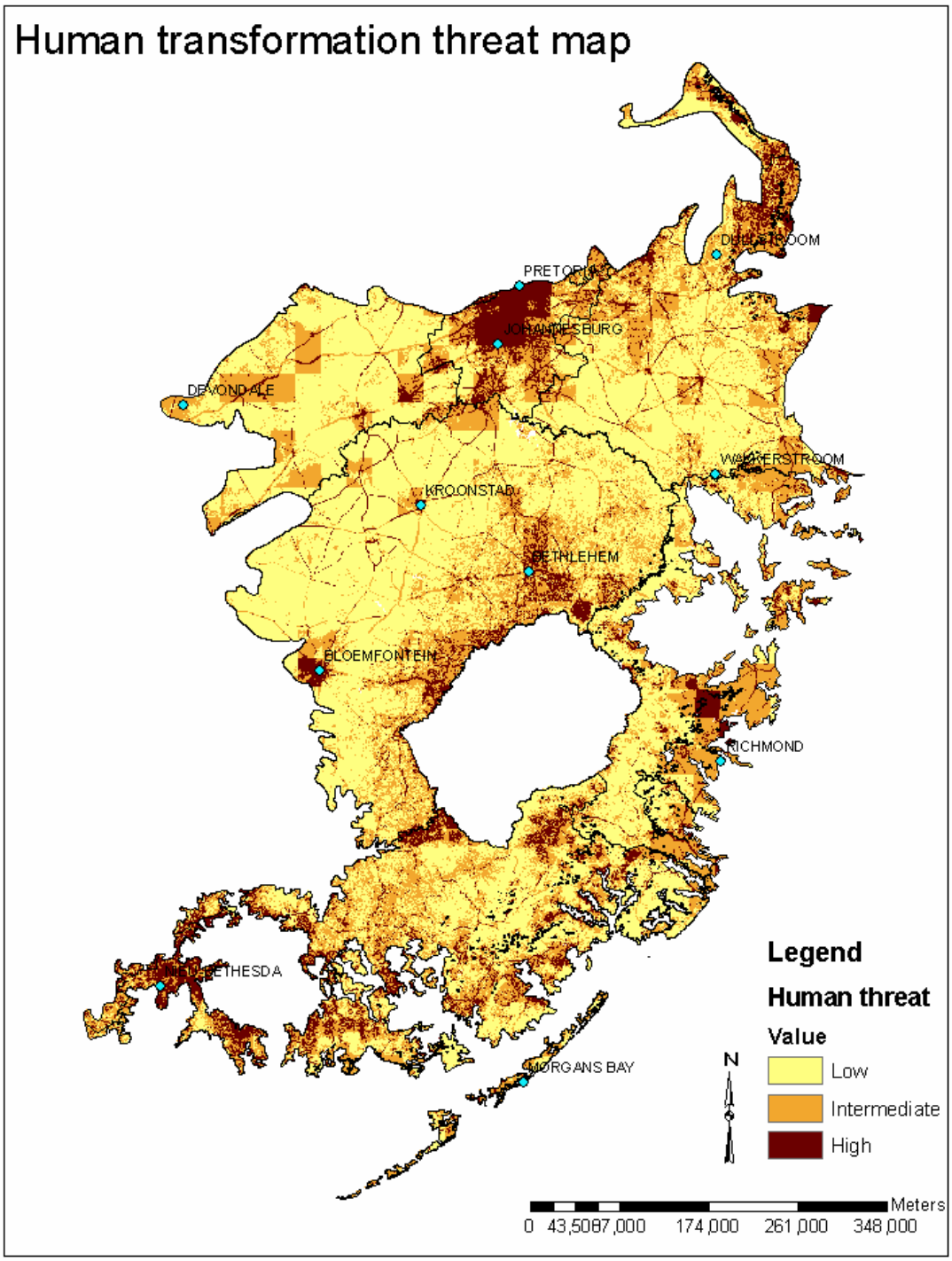


Figure 22. The location and relative severity of current human transformation threat activities across the South African Grassland biome

Threat	Km^2	% of SA Grassland biome
Low	164 784.95	55.9
Intermediate	92 267.78	31.3
High	37 732.51	12.8

Table 3.5. Surface area of Grassland biome under each human transformation threat class as shown in figure 22

3.3.1. Current transformation VS Predicted transformation threats

The map of current human transformation threats (figure 8) shows a different pattern from that suggested by Neke & du Plessis (2004) (figure 7). The greatest threat is associated mostly with the larger urban areas of the biome most noticeably Johannesburg-Pretoria, Bloemfontein and Potchefstroom and the northern and south-western tips of the biome, rather than the high rainfall band in the eastern area of the biome. Not only has the areal extent of the high impact transformation threat zone been underestimated, the prediction of its spatial occurrence is also inaccurate. There is a large zone of intermediate grassland transformation threat running along the western edge of the Lesotho border, extending down into the Northern and Eastern Cape and up into the Free State that should not be there; similarly the model used by Neke & du Plessis fails to account for the intermediate threat area in the North Western Province- according to the predictions made both zones are located in low transformation threat areas. Generally the predictions of transformation in the eastern high rainfall areas have actually been observed but there the similarity between the predictions and the occurrence of the actual transformation threats ends.

3.3.2. Threats to biodiversity: Potential VS Actual

Incorporating the biodiversity information from the species distributions of threatened endemic grassland birds into the human transformation threat map (figure 8) provides information about where human threats coincide with biodiversity. This output is referred to as the Biodiversity threat map and is presented as figure 10 below. Table 6 below that accompanies this table and provides information about the surface area experiencing the respective level of threat to the biodiversity it holds.

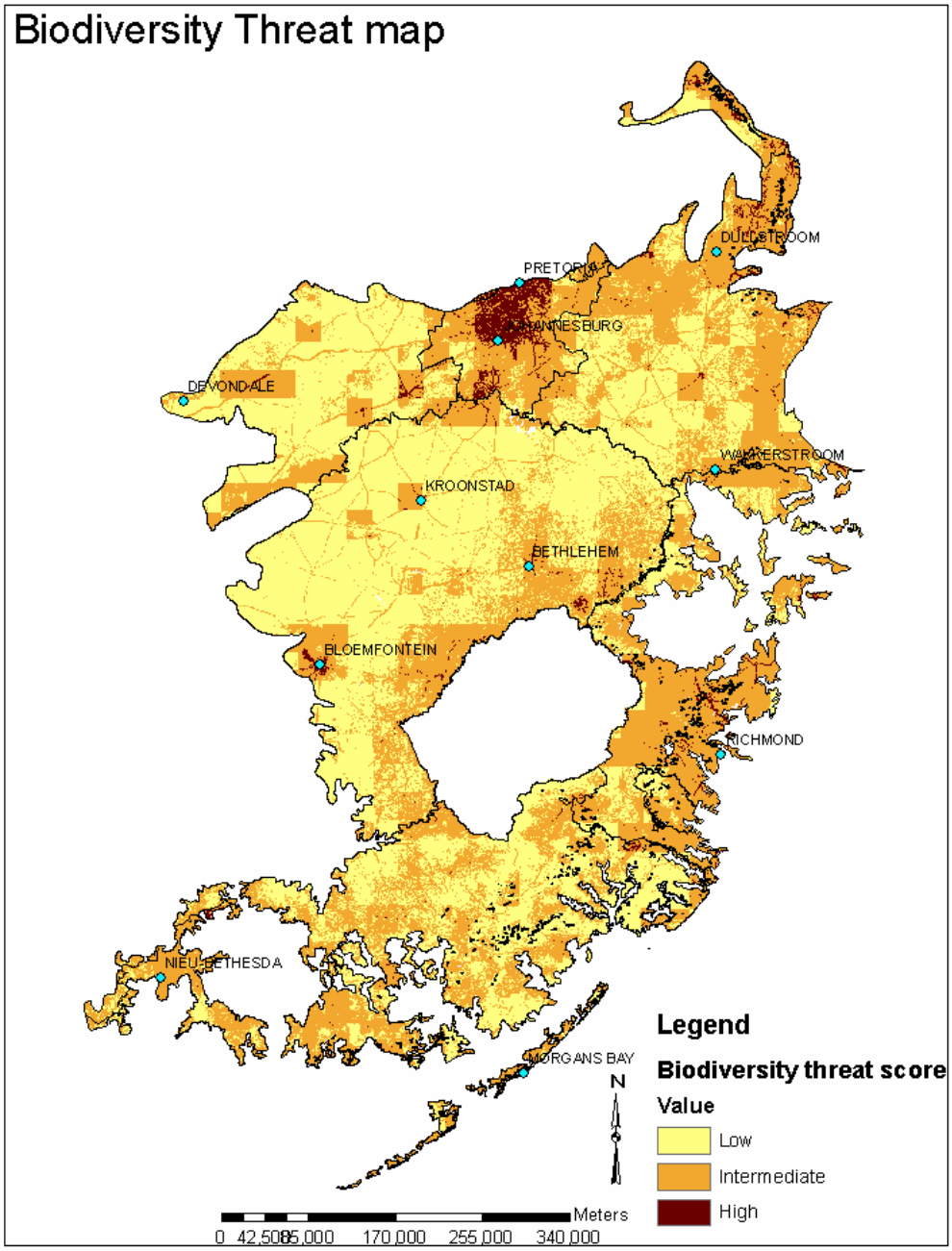


Figure 23. Biodiversity transformation threat map for Endemic threatened grassland birds. Provides information on where human non-biodiversity friendly activities coincide with biodiversity and the severity of their impact

Threat	Km^2	% of SA Grassland biome
Low	147 982.2	50.2
Intermediate	139 433.4	47.3
High	7 369.6	2.5

Table 3.6. Areas of transformation threat intensity for biodiversity per threat class in the South African Grassland biome

With the incorporation of the biodiversity information the current transformation threat map resembles the predicted threat map of Neke & du Plessis (2004). If one merged the transformation threat classes of High and Intermediate threat instances, to simplify the occurrence of transformation threat to high/low format- then the overall distribution of actual transformation threat has occurred as it was predicted. However, again, the intensity or severity of the threats posed by the grassland transformation does not follow the patterns that were predicted, the trends follow the same descriptions as for the human transformation threat map (figure 9) without the species distribution information. The occurrence of high impact transformation was overestimated by Neke & du Plessis (2004) especially along the eastern edge of the biome. Less than 3% of the South African Grassland biome has high intensity transformation threats to biodiversity (Table 6)- these are the areas where threatened, endemic grassland bird species are facing the most threats as posed by human activities and habitat loss. These birds are facing the most threats in and around urban areas, especially in Gauteng where the land is under intensive use for industrial, manufacture and service provision activities.

Again, similar to the human transformation threat map (figure 9) there is an underestimation of intermediate grassland transformation impact across the biome's interior, particularly the area running along the western edge of the Lesotho border. Almost half of the biome within South Africa has been classified as having ongoing activities that pose an intermediate threat to biodiversity.

DISCUSSION

4.1. Methodological Critique

4.1.1. Sources of error in the Land-cover Change Analysis

There were numerous sources of error that may have affected the accuracy of the land cover change detection results. The sources of error include the differences in data compilation and classification methods, land cover misclassification and human error (Reyers *et al*., 2005; Mark Thompson pers comm.). These errors could have occurred at any stage in the compilation of the NLC1994 and NLC2000 datasets and may be confounded with the results of the land cover change analysis. Quantifying how much of the observed land cover change is actually as a result of error in the change detection process would require information on the accuracy of the individual datasets. This could not be carried out in this case because where the NLC1994 dataset has undergone rigorous accuracy assessment (Fairbanks & Thompson 1996), the NLC2000 accuracy assessment results are not in the public domain. Until the NLC2000 database metadata are available, it will be difficult to determine the error component in these results. However, at the centre of this analysis is the assumption that appropriate actions were implemented to minimize or remove the influence of the identified sources of error.

NLC1994 and NLC2000 were compiled using different classification methods. The NLC1994 was compiled through manual digitization of 1:250 000 space maps into vector tiles with a minimum mapping unit of 25ha (Fairbanks & Thompson 1996). In contrast, the NLC2000 database was compiled using an unsupervised classification technique (Mark Thompson pers comm.) at a finer resolution of 30m*30m pixel size. Thus each dataset would have incorporated different classification errors; human misclassification errors for the NLC1994 and spectral misclassification errors for the NLC2000 database. However since both databases were compiled along the same hierarchical land-cover classification framework (Thompson 1996) the classes could be merged and in this way the majority of the misclassification errors would have been filtered out (Mark Thompson pers comm.). Furthermore, the resampling of the NLC2000 dataset to a coarser resolution of 500m*500m (25 ha) using a majority proportion rule would have also contributed to

the filtering out of the finer-scale mapping errors. Because the NLC2000 dataset had not undergone any accuracy assessment or ground-truthing, there was no correction for mapping error and therefore no way to verify that observed changes were as a result of actual changes or misclassification during the NLC2000 classification process.

Human error would have been introduced through two main pathways. Different groups of people were involved in the NLC1994 database compilation from those in the NLC2000 database compilation and also, a larger number of people were directly involved in the NLC2000 mapping process than were involved in the NLC1994 process. These human errors would have been manifested through land cover misclassification. The methods used to reduce the influence of these misclassification errors have been previously discussed.

Seasonality of images used to derive the two datasets means that some of the observed changes- especially as they pertained to the gains and losses in the grassland, cultivated and degraded land cover classes could have been seasonal and therefore not indicative of a real change in land cover. For example- the degraded land cover class in the NLC1994 was defined as loss of above ground cover (Thompson 1996) but depending on the time of the year (as influenced by human activities, rainfall, temperature and fire) any of the three land cover classes could experience conversion to the degraded land cover class as it was given.

4.1.2. Use and interpretation of Fragstats metrics

The use of FRAGSTATS metrics requires one to apply a single conceptual model to describe the landscape of interest (either island biogeography or habitat matrix-corridor model) (McGarigal & Marks 1995, McGarigal *et al*., 2002). The conceptual model one chooses to apply may influence the choice and interpretation of the landscape metrics chosen to describe fragmentation on that landscape (McGarigal 2000). However, it is difficult to describe a large landscape in terms of a single conceptual model (McGarigal & Marks 1995).

Most landscape metrics provide a suite of indices describing landscape patterns and structure without explicitly focusing on functional characteristics of the landscape (McGarigal 2000). This makes it difficult to describe the fragmentation index values in terms of effects on landscape ecosystems. These fragmentation metrics can only describe patterns, they cannot determine cause and effect of the observed patterns and they are scale dependant (Getis 2002). Essentially this means that the value of the grassland fragmentation metrics and consequently their interpretation, would change if the analysis was carried out over the entire South African extent rather than only the Grassland biome. This makes it difficult to assess the degree and nature of fragmentation over the South African grasslands and compare it with other grasslands worldwide; for example, if one wanted to assess the standing of the biome in terms of global grassland fragmentation trends. One of the difficulties faced when working at the landscape level is that the effects of land cover fragmentation will vary across spatial scales depending on the organisms under consideration (Olff & Ritchie 2000, McGarigal 2000) and this created difficulties in describing the severity of the observed grassland fragmentation to biodiversity. However, since this analysis was carried out without particular focus on a specific organism, the fragmentation metrics could only be interpreted in terms of the landscape units (grassland patches) under consideration.

Some of the metrics are difficult to compare- for example those indices that have no upper limit, the absence of a ceiling makes it difficult to relate those values in terms of the significance of the observed differences between NLC1994 & NLC2000.

4.1.3. Testing predictions of land-cover change

Due to difficulties faced securing the original data used by Neke & du Plessis (2004) for comparative purposes, the actual "testing" of the predictions made was carried out as a visual inspection of the occurrence of landcover change and the differences and similarities with the threat map. Ideally this should have been carried out via the use of Spatial Analyst in ArcGIS to compare loss of grassland cover with possible transformation threat. Given the definition of threat for this analysis, relating grassland cover loss to the potential transformations as they were provided by Neke & du Plessis

(2004), as well as from the actual descriptions that were provided in the text of this paper were adequate to fulfill the second objective, The word “test” is in quotation marks to highlight the fact that it was not the intention of this study to provide quantitative values of how well the predictions upheld the situation on the ground but rather to describe whether the trends and patterns they described have come to pass.

4.1.3.1. Assumptions of negative impact

There were two threat factors whose presence, for the purposes of this project, were assumed to impact negatively on grassland biodiversity- Invasive Alien Plants and road effects. The inability to distinguish between positive and negative effects of some components of the composite threat map is an issue that should be addressed in future assessments of their impact on biodiversity. Roads can have positive and negative effects depending on the land cover around it, so roads may need to be sectioned in good/bad areas, that is, verges and hedges in agricultural landscapes may harbour natural species. This depends on the dominant on-going land cover/ land use activities within that area (Mark Thompson, pers comm.) Furthermore, the use of SAPI A species richness data for invasive alien plants per Quarter Degree Square (QDS)- may not actually be a good indicator of threat because not all invasive plants have the same impact on biodiversity; there are differences in the nature and severity of their invasion across a landscape. In future analyses an alternative could be use of the spatial sedistributions of the 10 most invasive and high impact alien plant species in the Grassland biome- then threat would have been scored on the basis of species richness of the 10 plants.

4.1.3.2. Urban threat evaluation

An alternative and perhaps more meaningful method to assess this would have been to base the biodiversity impact score of urban areas not on the current spatial extent of the urban areas but rather on the either the rate or magnitude of urban expansion between the 1994 and 2000 data. This would have given information on the actual or observed transformation threat posed by each urban or built-up area. Although spatial extent is still a good measure of threat- in this case it provides information on potential threat. The assumption upon which this scoring of urban areas according to size being that the larger

urban areas presumably pose a larger threat because they signify a higher potential for human activities that could cause land cover conversion such as urban sprawl, industrialisation and service provision. However, in this case this proved difficult. Although there was a net increase in the urban area land cover class, (table 2) further querying of the data showed that this was as a result of the detection of new urban areas in the GLC2000 dataset, mostly across the interior region of the grasslands rather than sizeable expansion of identifiable urban areas. It is not clear whether the detection of the "new" urban areas is due to new human settlements and built-up areas cropping up (which would be an example of urban sprawl) or due to misclassification in either or both data sets. Especially since the level of accuracy of the NLC2000 dataset has not been evaluated.

4.1.3.3. The effect of incorporating different resolution data sets

In the creation of the threat maps, the biodiversity distribution data (endemic grassland birds and invasive alien plant distributions) were provided at a much coarser resolution than the rest of the input datasets. As a result there was dilution of the spatial accuracy of the identified areas of threat- especially with reference to the high threat zones. It is highly likely that there would have been some loss of information. However, the patterns of the occurrence of threats to biodiversity are still detectable and still provide valuable information as to the status of the Grassland biome in South Africa today.

4.2. Testing Predictions of Land-cover Transformation Threat

For the purposes of this project, confirmation of the predictions of transformation threat (Neke & du Plessis 2004) was realized by observed grassland class loss or transformation (degradation in figure 19). The predictions of grassland transformation held true but the model used by Neke & du Plessis (2004) underestimated the extent to which the grasslands have been transformed, as well as the spatial distribution of the land cover transformations. The results show that there are two major causes of grassland transformation within the Grassland biome; cultivation and bush encroachment are mostly responsible for grassland habitat loss. However, the areas that show the highest grassland degradation in the Free State and North West provinces, as well as in Lesotho,

are areas that were predicted to have low transformation threat potential. This is surprising considering that the predictions incorporated information about cultivation suitability for the main crops commonly grown in the Grassland biome and these are areas that are associated with agriculture. As the predictions of threat are held up against the reality of observed transformation, it must be remembered that all areas that were classified as having high potential transformation threat (and impact on biodiversity) had already been transformed at the time of the first analysis, this means that in all probabilities an intensification of the transformation already present was to be expected between the datasets. Unfortunately this could not be discerned from the data available.

If one considered only the information garnered from an analysis of the relative degradation of the remaining grassland patches in terms of loss and fragmentation- a very disturbing picture becomes clear, an alarmingly small proportion, less than 27% of the remaining grassland patches are in a relatively good condition, having low incidences of transformation and fragmentation. This proportion actually comes up to little less than 50,000 km^2, which accounts for about 15% of the total extent of the Grassland biome. From the data available it is not possible to quantitatively assess and therefore validate the observations of grassland degradation and what this translates to in terms of the implications for the biodiversity within the remaining grassland patches but a prediction of the possible impacts on biodiversity can be made from the literature.

4.2.1. Transformation between Cultivated land and Grassland habitat

It would appear from the results that regeneration of grassland vegetation from formerly cultivated land is the leading contributor to the observed gains or increase in the grassland land cover class extent. This suggests that land which was once under intense cultivation is now either lying fallow and re-colonisation or regeneration of grassland vegetation is occurring, or that there has been a change in the type of cultivated crops, at a very large scale such that these crops have a similar enough to grassland vegetation to give the same spectral signature as the semi-pristine grasslands, and thus misclassification has occurred. However, it is highly unlikely that the latter has occurred to such a great extent and it is more probable that it is a combination of the two

suggestions. There was a net conversion of cultivated lands to other land cover classes and this decrease has been detected in similar studies of the Grassland biome over the same time frame (Reyers et al 2005, Murray 2005). Taking mapping errors into consideration, this still suggests that there is less land under cultivation within the Grassland biome than there was in 1994. Such a pattern of land cover conversion suggests that there may have been a shift in land tenure policies in these areas, as this could have a possible bearing on the remaining grassland patches it would be of interest to investigate whether this is indeed the case. It was predicted that there would be a decrease in cultivation in the grasslands after the South African government stopped subsidizing agricultural activities in the mid-1990s (Neke & du Plessis, 2004) since most of these agricultural activities were mostly maintained through costly irrigation programmes and it would appear that this has indeed occurred but the drivers of this change can not be verified or investigated at the coarse scale at which this investigation was carried out.

However, herein lies an interesting state of affairs, there seems to be a contradiction in the results- whilst the conversion from cultivated land is the largest contributor to the net gain in grassland habitat extent (figure 4), the transformation of natural grassland vegetation to cultivation by humans is also the leading reason behind grassland habitat loss (figure 6). This would seem to suggest that perhaps the observed "gains" from cultivated lands may be a misrepresentation of the current state of the grasslands that in fact, the detected gains are as a result of seasonality- land lying fallow as part of a management plan or at a particular stage in the growth of the cultivar that produces a spectral signature similar to the grassland land cover class. There was an increase over the period of interest in the area of land within the Grassland biome used to cultivate sugar cane, sunflowers, soya beans, fodder crops such as Lucerne (Murray 2005) which may or may not have contributed to the misclassification of such large tracts of cultivated land as grassland. Even the other studies that detected the same decrease in cultivated lands state that these results should be interpreted carefully due to the inherent differences between the two datasets (Reyers et al, 2005).

We must also remember that patterns of land use/ land cover change are shaped by the interaction of economic, environmental, social, political and technological forces (Lambin et al 2001). Using satellite imagery and GIS analyses allows us only to detect the incidences of change, we cannot identify the drivers of this change within the Grassland biome. These observations are therefore for the most part simply that- descriptors of the ground situation. We can only comment on the land cover conversions that are associated with the observed changes and make suggestions at to the possible consequences and effects on biodiversity but cannot delve deeper into the causal factors or comment on process. This is of particular interest in this case since changing Government agriculture policies (removal of subsidies and dropping maize prices over the period of interest) may have confounded the realization of the predicted transformation threats.

4.2.2. Bush encroachment and invasion by alien plant species

The spread of invasive alien plants across a landscape is facilitated by fragmentation and habitat loss (Harrison & Bruna 1999, With 2002), especially with the increase in edge effect, given that it is known that aggressive alien species attain particularly large concentrations at the edges of the natural vegetation of an area (Harrison & Bruna 1999). Given the condition of the grasslands, it therefore does not come as a surprise that bush encroachment and the establishment of thickets has contributed the most to degradation of the grassland habitat land cover class as a whole. It is unfortunate that the species composition of the newly established thickets could not be confirmed as this would give a better indication of the threat posed by the observed bush encroachment. Although their impact as agents of land cover transformation (resulting in disruption of ecosystem functioning) does indeed classify them as threats, alien plants do not all have the same impact on ecosystems (Richardson et al, 1997). Previous studies have identified a subset of plant species that are particularly invasive and pose threats to biodiversity in the Grassland biome, these include *Prunus persica, Solanium mauritianium, Acacia mearnsii, A. dealbata,* triffid weed,*Chromolaena odorata,* , *Rubus* species *Melia azedarach* and *Jacaranda mimosifolia, Eucalyptus* spp, *Lantana camara* (Richardson et al 1997, van Wilgen *et al.*, 2001, Richardson & van Wilgen 2004). It would have been of

interest to see whether these are in fact the same species that are behind the observed bush encroachment. The impacts of these invasions are well documented- and include increased water consumption, out-competing and replacing indigenous grassland species, decreasing the diversity of ground-dwelling invertebrates, decrease landscape diversity (overall decrease in biodiversity), increasing soil erosion, decrease productivity, poison livestock and game, alter nutrient cycles and therefore impair ecosystem functioning (Richardson et al 1997, Baars and Neser 1999, van Wilgen et al 2001, le Maitre et al 2002). Invasion by alien plants is a very real threat to biodiversity in the Grassland biome, one that requires urgent action now. There are various projects, most noticeably the Working for Water and Working for Wetlands projects that are currently in place in an attempt to combat this phenomenon, that have been running since 1995[9]. Since the period between the data collection includes the time at which these programmes were begun it is difficult to comment on the effectiveness of these initiatives as information on the rate of spread before then is not readily available. However, even with active programmes fighting this threat the establishment of thickets in the biome is still the main contributor to grassland habitat loss. Either more resources need to be given over to this fight or the mode of combat needs to be reconsidered, or the drivers of this conversion are beyond the reach of direct, physical human interference to stop. In any case, this needs to be red-flagged as a real concern for any and all conservation activities, plans or policies within the Grassland biome, now and in the future.

4.2.3. Biodiversity hotspots, National Parks and Grassland Degradation

The Eastern Mountains biodiversity hotspot over the Lesotho highlands and the Drakensberg Mountain range is an area of high conservation value[10] but it is also divided by the Lesotho-South Africa border. Of particular interest is the differing land uses on either side of the border during the period of interest (1994-2000/1). The Lesotho highlands are under cultivation and human settlement and the grasslands here are impacted upon by bush encroachment, cultivation activities and land degradation. In direct contrast to this, the land within the hotspot on the South African side is under

[9] http://www.dwaf.gov.za/wfw/ Accessed on-line on 20/01/2007
[10] http://www.maloti.org Accessed on-line on 12/04/2007

formal protection, specifically through the Ukuhlamba Drakensberg Park. The impacts of the differences in land use are very obvious (figure 10)- the Ukuhlamba Drakensberg Park exhibits low grassland degradation and the corresponding area in Lesotho exhibits medium to high grassland degradation. However, the Maloti-Drakensberg Transfrontier conservation area was established in 2001[11,12]. This joint project between the governments South Africa and Lesotho seeks to improve conservation activities within the biodiversity hotspot, especially on the Lesotho side of the border where there had been no formal protection of the Lesotho highlands[13]. The region in Lesotho that is to be included in the Maloti-Drakensberg Transfrontier conservation area is encapsulated by the proposed boundaries of the Lesotho National Park[14]. This particular transfrontier project presents a unique opportunity to measure the effectiveness of the grassland conservation programmes that are and have been implemented in this region since its inception in 2001, using the Ukuhlamba Drakensberg Park as a control. It would be of great interest to continue to monitor grassland degradation over this area into the future.

There are degraded areas whose extent begins immediately outside the boundaries of the Qwaqwa and Golden Gate Highland National parks. This suggests that there are processes in this area that are bringing about such transformation. The fact that there is an observable difference in grassland condition on either side of the artificial boundary imposed by the national park limits suggests that these processes are as a result of human non-biodiversity friendly land use activities. These two National parks are specifically mentioned because this phenomenon is most noticeable over this locale and this is not to imply that it is not occurring elsewhere. A plausible interpretation is that in these areas the protected areas are serving their purpose - to maintain biodiversity by excluding threats (Soule 1991, Faith & Walker 1996, Margules & Pressey 2000). However, the association with areas of degradation and the implication of non-biodiversity friendly human uses beginning at their very fences brings the future sustainability of some nature reserves into question. In the event that local human-exploited grassland resources were

[11] http://www.sanbi.org/biodiversity/umthombo2.pdf Accessed on-line on 12/04/2007
[12] http://www.maloti.org Accessed on-line on 12/04/2007
[13] http://www.tbpa.net/case_08.htm Accessed on-line on 12/04/2007
[14] http://bgis.sanbi.org Accessed on-line on 24/02/2007

to become exhausted or scarce, it is possible that local rural communities may begin to look to these protected areas as resource bases, including space for settlement. If and when such a situation occurs there may be increased incidences of conflict between the people living in and around these nature reserves and the conservation priorities of land and wildlife management policies. Such a scenario may seem to be a far-fetched extraction from the observed incidence of high grassland degradation near these protected areas but it is not. Most detrimental impacts on conserved habitats come from the surrounding landscapes and communities (Saunders et al 1991, Fox et al 1996). It is an aspect that should be taken into due consideration as it does have implications for maintaining biodiversity and the role of reserve areas. In fact such a scenario is addressed in South Africa's policy for biodiversity and conservation, one of the objectives of which is to "promote socially and ecologically sustainable development in areas adjacent to or within protected areas" (DEAT, 1996). It is recognized that for protected areas to be viable and sustainable entities within the social context in which they exist they must be socially, economically, and ecologically integrated into their immediate environment (Hobbs & Saunders 1991, DEAT, 1996). Striking the balance between conservation and local economic development in such rural settings is a challenge for many nature reserve managers requiring widespread consultation and co-operation between conservation and protected area management teams and the surrounding communities (Saunders et al 1991, Fox et al 1996). Given that such incidences of grassland degradation are evident in such close proximity to some of the larger protected areas, this may indicate that this is something that had not been adequately addressed before since it is not clear how many years of human exploitation by the surrounding communities would have produced the observed impact. It remains to be seen whether the new policy and plants, specifically addressing such issues as they are described in the South African policy paper will bring about a change in this regard or indeed, have any impact at all.

4.3. Human influences in grassland transformation

The transformation threat maps assess and illustrate the impact of current human activities across the grassland biome, yet no direct measure of human presence such as human population density within the Grassland biome was used. This was because it

would have been difficult to prove the relationship between human densities and grassland degradation in a robust manner (Ed Witkowski pers. comm.) Instead indicators of human land use activity, such as urban settlements and roads were used to assess the threats posed by humans. However, the actual change (increase or decrease) in areal extent of urban areas is not central to land cover change issues (Lambin et al 2001) as it does not adequately capture the indirect human activities emanating from that expansion that will cause grassland transformation within the biome. So although there was a relatively small increase in urban extent, this should not be taken as an indicator of low threat posed by these urban settlements. The very fact that high threat areas are mostly centred about large urban complexes disputes this interpretation. The ecological footprints of these expanding urban areas extend further than the extent of the built up areas, in terms of provision of imported goods and services for the inhabitants of these areas, peri-urban agriculture, demand on water resources and electricity, intensification of agricultural practices as demand increases- resulting in increased use of chemical pollutants etc (UNEP 2006, Lambin et al 2001) to name a few. However, these indirect transformation threats that altogether constitute the ecological footprint of a given urban area are difficult to define in a spatially explicit manner (UNEP, 2006). Thus, in the case of this analysis of transformation threats, using the methods described, it is possible that the spatial extent and magnitude of urban/built up areas has been under-represented.

Concentrated human settlement in a given area also influences land cover changes in other areas within the biome through urban-rural linkages such as roads and railway lines (Lambin et al 2001). Thus the inclusion of roaded areas to assess transformation threats to grassland biodiversity was vindicated in that they are clearly identified as strips of high threat areas cutting across swathes of low threat grassland habitat. The actual impact of roads in terms of increased mortality and disturbance is influenced by other factors such as traffic volumes, road use and season etc (Stoms 2000, Reyers et al 2001). Thus in reality, of the roads that were included in the analysis some will have greater impact on biodiversity than others depending on these factors. However, their action as agents of fragmentation is clearly illustrated (figures 22, 23) and it is felt that this alone warrants their classification as high transformation threat zones. The possible repercussions of

urban expansion and perhaps higher densities of humans in some areas, all bring about grassland habitat loss and fragmentation, directly through need for space for physical urban expansion or indirectly as previously described. The impacts on biodiversity of this degradation are further described below.

4.4. Grassland Habitat transformation

4.4.1. Loss and fragmentation: implications for biodiversity

The endemic grassland bird threat map shows the areas where high levels of human threats and biodiversity coincide. Depending on the needs of the conservationist, the biodiversity surrogate could have been replaced by the distribution data of pre-identified vulnerable species and used to identify where they are most at risk from transformation and habitat loss (With & King 1999, Fahrig 2001). Biodiversity within the Grassland biome is under severe threat from land cover transformation. Only 56% of the entire extent of the Grassland biome is still under the natural grassland habitat land cover class. The remaining grassland patches show the impacts of habitat degradation as exhibited through habitat loss and fragmentation. Further analysis of these patches showed that the grassland patches that show low habitat loss and fragmentation make up 26.7% of the grassland habitat extent- a figure of less than 50, 000 km^2, almost the same area of grassland habitat that was lost due to land cover conversion between 1994 and 2000. These low degradation areas are concentrated in the interior of the biome, along and to the west of the escarpment and mountainous regions. There have been gains and losses in the grassland land cover class. The area of grassland losses totals to 25 % of the grasslands as they stood in the NLC1994 database, where the main agents of loss were conversion to cultivated and thicket/bushland land cover classes.

The observed trend of grassland habitat loss primarily through conversion to cultivation is familiar and a recognized global phenomenon (Meyer & Turner 1992, Lambin et al 2001, Theobald 2003), as is the increasing threat that is posed by invasive alien plants (Cronk & Fuller 1995, Richardson et al 1997, Harrison & Bruna 1999). Therefore it would appear that the unsuitability of the terrain for human exploitation over the escarpment is a likely explanation for the band of least degraded grassland patches that

occurs here. However, there is a question mark hanging over the grassland patches that are located in areas where livestock ranching is the primary land use that have also been classed as having low degradation. The biodiversity encompassed in these patches may still be facing substantial threat as a result not of habitat loss per se but from habitat modification as a result of grazing and browsing activities of the supported livestock. This may create a situation whereby the land cover is still classified as grassland but the species composition may be altered to such an extent as to impair the functioning and ability of those patches to support the native biodiversity.

Habitat loss will result in population decline proportional to the amount of habitat lost (Fahrig 1997, Bender et al 1998), considering this, we can estimate that since 1994 there may have been a decline of 25 % of Grassland biodiversity, proportional to the total amount of grassland habitat that was lost. For the most part this habitat loss is associated with the smaller grassland patches along the edges of the biome, where either the patches themselves are lost, in which case the biodiversity within is also lost but the patches themselves are also shrinking, such that the core area is decreasing creating a situation where the patch may consist almost entirely of edge. With respect to the remaining biodiversity this means that there is a strong selection pressure in favour of grassland patch edge specialists species, and a selective pressure against the resident, endemic interior specialist species in these areas in particular (Bender et al, 1997).

However, it is not only the loss of habitat that determines the effect of transformation on biodiversity but the associated degree of fragmentation in terms of patch size and edge effects (Bender et al 1997). Fragmentation effects compound the impacts of habitat loss resulting in more severe habitat degradation (Fahrig 1997) and therefore worse transformation threats to biodiversity. It has been shown that the remaining grassland vegetation has become more fragmented, on average the grassland patches are becoming smaller in size, more numerous with a corresponding increase in edge and therefore edge effects. As a result, grassland patch interior specialist species should be the most heavily impacted upon by current fragmentation trends. The observed increase in total edge makes the remaining grassland habitat ideal for edge specialists that are able to exploit

these conditions as well as for generalist grassland species that are able to thrive in most conditions. The decreasing patch sizes do not favour the survival of large-bodied specialist animal species and top-predators that of ten require large habitats (Harrison & Bruna 1999,), so there should be bias towards the survival of smaller, patch interior specialist species. So the observed pattern of fragmentation also has an impact on the food webs and pyramids in the Grassland biome.

The increasing isolation of the remaining patches and the observed decrease in connectivity between them, may lead to the creation of metapopulations that will be subject to local extirpations as these populations go into decline and are not replaced. A means of getting around this would be to improve connectivity between the patches so that there is better dispersion between the patches (Harrison & Bruna 1999, Kareiva & Wennergren 1995, Rosenberg et al 1997) but there is great debate over the effectiveness of wildlife corridors as conduits in the literature (Simberloff et al 1992, Hanson 1994, Fahrig 1997, Rosenberg et al 1997). There is little conclusive support with regards to the use of wildlife corridors by faunal species as conduits between patches (Forman & Alexander 1999) but without proof that they do not have an effect and are in fact utterly useless, it would be wise to maintain and use movement corridors as means of mitigating the effects of the grassland patch isolation observed in the Grassland biome. The use of roadside verges or corridors as "roadside reserves" between grassland patches, as done in Australia (Forman & Alexander 1999) could be considered as a means of increasing connectivity between patches, especially where the roads run across heavily transformed cultivated landscapes in the biome. "Roadside reserves" refer to strips of natural vegetation receiving little maintenance running adjacent to roads. Considering that cultivation is the leading cause of grassland land cover loss, these strips could also act as refugia for the last remnants of native grassland biodiversity (Cale & Hobbs 1991, Lamont & Blythe 1995). The proximity of these "reserves" to the roads could prove to be a challenge with regards to the effectiveness of these corridors.

The observed distribution of the remaining grassland patches whereby there is an apparent aggregation of large, relatively undisturbed grassland patches in the central

interior, coincident with the highest areas of the biome should have an influence on distributions of the remaining biodiversity with respect to habitat requirements. Those species that are associated with the areas that are severely degraded (figure 6) are likely to be lost should this trend continue and the composition of the remaining biodiversity is likely to show a high degree of alteration from the pristine state as a result of these processes of habitat loss and fragmentation and their impacts on species composition. If it were possible to compare the biodiversity within the grassland biome between the two datasets, it is most likely that not only would we find an overall decrease in the number and distribution of endemic grassland species, the variety of species and inter-specific interactions would also be much diminished with an increased abundance of smaller-bodied, widespread generalist and edge specialists (Taylor & Merriam 1995, Harrison & Bruna 1999, Gibbs & Stanton 2005, Hoekstra et al 2005

The literature tells us that habitat loss and fragmentation will cause an ultimate decrease in population abundance and occupancy and species richness and distribution. Contrarily, there have been observed instances whereby heavily fragmented landscapes have shown increased species richness in spite of intense human activity (Fairbanks 2004). This may be attributed to the creation of new, more diverse habitats as a result of fragmentation processes, thereby attracting a wider array of generalist and edge specialist species to colonise these habitats (McKinney & Lockwood 2002, Fairbanks 2004). Fairbanks (2004) found that this increase in species richness is correlated with agriculture, commercial forestry, water impoundments and urbanization. Agriculture is the major human land use causing grassland cover change across the Grassland biome today. It would be of great interest to carry out species inventories to test this assertion by Fairbanks (2004). Even if this is the current state of affairs across the biome today, Fahrig (2003) forecasts that these increases in biodiversity may occur in the short term but are not sustainable. Eventually if habitat loss and fragmentation processes continue unchecked then eventually the remaining grassland patches will be so degraded as to be severely compromised in their ability to support biodiversity and the previously mentioned effects will come into play.

Relevance of grassland land-cover gains

The apparent "gains" in grassland cover are not as easily interpreted. Globally most gains in grassland land cover can be attributed to clearing of wooded lands (Meyer & Turner 1992, Sala et al 2000) and this has occurred to some extent in South Africa through clearing of thickets, however the regeneration of grassland vegetation from cultivated lands and what were formerly classed as degraded lands also contribute to the gains observed in the results. There has been a decrease in land under active cultivation in the Grassland biome over the period of interest, 1994 – 2001 (SANBI 2004) and thus the contradiction arises- cultivation is at the same time the leading cause for grassland habitat loss and regeneration. However, these so-called gains in grassland cover do not represent a repository of the natural grassland floral and/ or faunal biodiversity and should not be interpreted as such. They are as a result of conversion from other land cover classes and will give rise to altered grassland patches that contain different species composition from the remaining semi-pristine patches, at best they will most probably contain a subset of indigenous grassland organisms that are able to colonise disturbed landscapes. Such disturbed landscapes are also prime areas for the establishment of invasive alien plants (Hobbs and Huenneke 1992, Richardson et al 1997, With 2002). In a landscape that is already at threat from spreading bush plant species, such conditions do not bode well for the future propagation of the remaining grassland biodiversity.

These apparent gains in grassland cover may have inflated the figures of the number of grassland patches, especially where they occur as a result of conversion from cultivated lands. These relatively small formerly cultivated fields, if they were left fallow to regenerate grassland vegetation would have been reclassified under the grassland land class. However, their reclassification as grassland patches does not give them the same value as representative grassland biodiversity units as virgin grassland patches that have undergone minimal human interference.

The terms land cover and land use are not synonymous, although they are often used interchangeably (Thompson, 1996). Land cover refers to the biophysical attributes over the earth's surface, whereas land use refers to the human purposes applied to these

attributes and a given land cover class may be put to numerous land uses (Thompson 1996, Fairbanks et al 1996, Lambin et al, 2001).For the most part, land cover change occurs as a direct consequence of changing land use activities (Thompson 1996, Theobald 2003). There has been grassland cover change in the biome but we are not able to elucidate the actual changes in land use aside from their impact on the land cover that results in grassland conversion. This means that some of the tracts of grassland that have been classified as such (grassland) may not be optimally functioning ecosystem units as they may be under human landuse that impairs their ability to function thus.

"Improved grasslands" were included in aggregate land cover class. As such, it is possible that there may have been an over-estimation of the actual area of semi-pristine grassland patches. So that in fact, there is less available grassland that can act as viable, ecosystem units that contribute to the maintenance and survival of threatened grassland biodiversity. This, together with the possibly misleading "gains" in land cover change suggests that the remaining biodiversity is at greater threat from habitat loss than it would appear on the surface.

4.4. Mapping Transformation threat

4.4.1. Techniques of transformation assessment & prediction

The transformation threat maps serve the purpose of identifying areas on the Grassland biome landscape that are threatened by current land use activities that are associated with human development activities (Theobald 2003). Both the Human transformation threat map and the map showing the threats in relation to biodiversity were compared against the map showing predictions to qualitatively assess the robustness of the methods used to calculate the risks of transformation by Neke & du Plessis (2004). Overall the methods used correctly predicted the incidents of grassland transformation but beyond the high rainfall areas, the predictions of the distribution of low and intermediate threat were not realised. In fact, the main discrepancies between the predictions and the representations of reality herein produced are first, the consistent over estimation of the amount of high impact degradation that was meant to occur and second the failure to provide correct descriptions of the spatial distribution and pattern of the degradation.

The fact that both maps confirmed the predictions of transformation along the eastern boundary of the biome shows that the methods used were relatively valid but there was a vital source of information that was not included that led to the restricted forecasts. However, the inability of the Neke & du Plessis model to account for grassland conversion within the biome interior suggests that not enough information about biodiversity unfriendly human land use activities in those areas. Perhaps the use of the actual spatial extent of the occurrence of those land use/cover classes extracted from NLC1994 database rather than land use suitability data would have given a more accurate reflection of transformation threats across the Grassland biome in the future. Particularly because the land use suitability models refer to the ideal pattern of exploitation as it is defined by "perfect" characteristics that would make land use of a particular type logical, As such it is hard to compare and quantitatively assess the accuracy of predictions that were extracted from the ideal state against the reality that is. Even with the incorporation of biodiversity species richness, there is not enough overlap between the areas that are under the most threat from human activities and the most species rich areas to give a distribution of high transformation threat similar to that of Neke & du Plessis (2004).
It was difficult to interpret some of the grassland changes that have been observed because there was no data available on the current land uses in those areas to give credence to the interpretations and assumptions used.

It was also difficult to interpret the composite threat scores because most of the Grasslands have undergone transformation of some degree, and perhaps this refers to comparison with a pristine state that does not exist. There was an observed difference in the proportions of the grasslands that were classed as being under threat between the maps of predicted threat and actual transformation threat. This brings forth another aspect of the model by Neke & du Plessis (2004) that may have impaired its ability to predict transformation threat accurately- it is based on the assumption that the habitat was in a pristine, undisturbed state and the reflections of transformation threat are actually based on likelihood that those areas would be chosen for non-biodiversity friendly land-uses. Although there was incorporation of some land use data accurate at the time it did not

completely account for the land cover transformation that had occurred before the NLC1994 dataset was created. This information is inherently incorporated into the Grassland change map; it only reflects change from what was Grassland in 1994. It follows therefore that one of the reasons there isn't a strict adherence to the patterns predicted grassland cover is that perhaps this pattern of change may have already occurred with the initial settlements and use of these landscapes.

A conceptual flaw with both models is that they both fail to incorporate a phenomenon that can not be ignored when one is investigating land cover transformation- global climate change, especially in light of the fact that the biome is defined by the climatic characteristics of the area (Rutherford & Westfall 1994, O'Conner & Bredenkamp 1997). Any changes in climate will exacerbate the impacts of human-induced land cover transformation and habitat loss (Noss & Cooperrider 1994, UNEP 2006). Noss & Cooperrider (1994) presented a model showing the interaction between several factors that eventually lead to land cover change; these included direct and indirect exploitation of natural resources through activities such as agriculture, mining, roads etc, disturbances through the spread of invasive alien plants, pollution and global climate change. All of which are present in the Grassland biome and all, with the exception of climate change can be observed and described with a high degree of certainty. Such information would be invaluable in identifying the actual drivers of the observed grassland land cover changes; it has been predicted that with global warming, there may be decreasing rainfall in southern Africa and this would lead to an overall contraction of the grassland biome[15]. Without such knowledge it becomes difficult to separate the causes of the observed loss of grassland cover in certain areas as either desertification or range contraction as a result of climate change or from direct impact of human activities. The ability to clearly identify the drivers causing land cover change would have major implications for land management planning in that pre-emptive courses of action to minimize the influence of these factors could be put incorporated into management plans.

[15] http://www.unep.org/aeo Accessed on-line on 20/01/2007

The decision to weight all input data in the assessment of transformation threat equally was made arbitrarily, as it would have been difficult to score or weight them in terms of the relative severity of their individual impacts on biodiversity. Thus road zone effects were given the same weighting as the impact of habitat loss in terms of threats posed to biodiversity. It is possible that a method of weighting the relative impacts on biodiversity of each input factor against the others would have produced a different threat map, showing transformation threat distributions closer to those that were predicted by Neke & du Plessis (2004)

4.4.2. Land cover change or Land cover modification?

As one speaks of land cover change one must consider that this occurs in two ways- through land cover conversion from one land cover class to another and through the modification of the land cover class (Meyer & Turner 1992). Land cover modification is not easily monitored and is more insidious. Conversion alters the structure, composition and function of that ecosystem over time but there is no outright loss of habitat. We see land cover modification in areas that are used for livestock ranching activities- where overgrazing and excessive land use pressure occur, resulting in degradation and desertification (Meyer & Turner 1992) but this is not necessarily reflected in the landcover classification, as it was reported to be difficult to identify and map degradation from the available satellite imagery used to create both NLC1994 and NLC2000. This may be the case in the Grassland biome assessment of grassland change, especially over the large grassland patches observed in the Free State plains where ranching and livestock grazing are widespread (SANBI, 2004). So in fact, there may be an over-estimation of what has been classified as grassland and the degree of degradation over this area and this is a shortcoming of the use of satellite imagery alone- the NLC database since we cannot now account for land cover modification. The degraded land cover class to some extent does try to account for this- there obviously has to be some threshold point at which the land cover is classified as degraded but not quite transformed to another land cover class. So what we may have is an overestimation of the healthy land available for conservation planning purposes that is available as viable habitat for biodiversity. Reyers et al (2004- Grassland biodiversity assessment) also picked up on the apparent

underestimation of the "degraded" land cover class in the biome as a whole. Even with the question marks hanging over the accuracy of the later NLC database, the results of this analysis still provide valid information as to the current state of the Grassland biome, especially as regards the status of the remaining grassland habitat land cover.

4.4.3. The Implications of land cover change for grassland conservation

It is not enough on our part as conservation practitioners to merely identify the presence or absence of grassland degradation or to confirm or refute predictions of transformation within the biome; it is also our part to fit this new information into the context of conservation planning. Granted, a conservation plan for the Grassland biome is beyond the scope of this project but the information that has been gathered herein may be viewed as a starting point. Indeed, as we start to talk of conservation planning the questions that need answering are, "where, and when, to start with which species"? (Bomhard et al 2005). The output from these analyses, the grassland degradation map and the biodiversity transformation threat map enable us to provide tentative answers to these questions. The time is now. There should be no further delay- over 70% of the remaining grassland patches exhibit signs of at least moderate habitat degradation. The grassland biome is already considered to be endangered (Olson & Dinerstein 1998, Rouget at al, 2004). There is no need to wait until what is left of the grassland land cover is a few patches scattered across the grassland biome, preserved in a few national parks and nature reserves. In the space of time between the collection of the two datasets, NLC1994 and NLC2000, a portion of the grassland land cover class a little smaller than the portion of "healthy" grassland that remains today was lost as a result of human-caused land cover transformations. Let us consider that there has been a lapse of approximately seven years between the collection of the last National Landcover dataset in 2000- if conservation initiatives and activities have not improved in this time period, and the developing habitat transformation trends were upheld, then it is a distinct possibility that another 25% of the remaining grassland patches has been lost. Granted, the total amount of land that could ever be assigned to conservation purposes is limited by various socio-economic and political factors (Ferrier 2002) but this only strengthens the argument for the

implementation of systematic conservation planning now, while there are still sufficient remaining untransformed grassland patches to warrant such action.

The whole idea behind collecting and analyzing all this data is to initiate a paradigm shift in conservation planning circles towards a more proactive methodology (Pressey and Margules 2000). As such, conservation efforts should aim to capture the full diversity of species within the remaining grassland patches in the Grassland biome and not just those areas that have been tagged as threatened or at risk due to heavy habitat degradation and human land use activities. In light of this, the answers to the questions of "where" and "with which species" are urgently required. The grassland degradation and transformation threat maps, showing human transformation and its relative impact on the endemic, threatened grassland bird species as a proxy for biodiversity can begin to point out the areas in need of dire conservation attention. Make no mistake, South African conservationists should realize that the Grassland biome is experiencing the symptoms of the global "biome crisis" (Hoekstra et al 2005) that is resulting in widespread species extinctions and declining population numbers. Before we can even begin to suggest means of grappling with this we require the means to identify the location where biodiversity and ecological function are most at risk from and in conflict with human land use activities (Rebelo 1997, Margules & Pressey 2000, Hoekstra et al 2005). These threat maps reflect actual transformations occurring within the Grassland biome and where they present threats to biodiversity, the usefulness of the human transformation threat map should become apparent. The surrogate biodiversity distribution map (threatened endemic grassland birds) that was used in this case could be replaced by individual species distribution information for any organism, and the output would indicate where the species is coming into direct conflict for spatial resources with anthropogenic land use activities, as well as the relative severity of the impacts of the human threats. Such information should be used to red-flag particular areas of concern where such conflict is detected and indicate where resources should be channeled. Granted, because the information is at such a coarse scale further investigations would no doubt be required before efficient and effective conservation activities are put in place in these areas but it

is a step in the right direction- a base or platform from which further investigations can be sprung.

The value of threat identification at the landscape level is that it can aid in the identification of "spatial biases in action" (Margules & Pressey 2000) by conservation agencies when incorporated into GAP analyses for conservation planning purposese (Scott et al 1998, Margules & Pressey 2000, Stoms 2000, Theobald 2003) and could be used to identify those areas in the grasslands that have been neglected in terms of conservation attention. High conservation value land is defined as "areas of outstanding and critical importance due to their environmental, socio-economic, biodiversity and/ or landscape values" (WWF, 2007). The identification of such areas of land has been carried out extensively for forests, there has been research into the how and a tool kit has been produced that allows for this identification process. This has not been carried out at the same scale for grasslands. This is surprising considering that the grasslands of the world contain the world's largest populations and have the highest incidences of conflict between conservation and development activities because of the many land uses that they can be put to- specifically because they are so resource-rich. For our purposes this was indicated by the areas that have high land use suitability for a broad array of activities and therefore were heavily impacted by human use (high threat areas) that also coincide with high biodiversity presence, particularly the high biodiversity areas in the high rainfall, mountainous regions along the eastern edge of the Grassland biome that are classed as having intermediate threat. Granted there has been widespread transformation of these areas to highly profitable, commercial forest plantations but it would be possible to create integrated management plans for such land uses so as to minimize the impacts on the regional biodiversity. High conservation value land is often the most heavily impacted upon by habitat transformation (Flather 1996, Fairbanks *et al*., 2002) and this is especially well illustrated in Lesotho within the Eastern Mountains biodiversity hotspot. The tendency for human settlements to coincide with areas of high species richness has been well documented in the literature (Fairbanks & Benn 2000; Balmford *et al*., 2001; Fairbanks *et al.,* 2002). These areas should be considered as areas of vulnerability that should be red flagged for conservation action (Ricketts and Imhoff 2003). In the

Grassland biome these high impact areas are mostly located in the vicinity of the larger urban complexes- the tendency for human settlements to occur in areas of high biodiversity is well documented in the literature (Huston 1993, Imhoff 2000, Balmford et al 2001). In the context of the threat maps, it is true that the areas of high human threats have for the most part been so degraded that it may not be of any use to concentrate conservation actions in these zones even though they are classed as being under severe stress from human transformation activities. The sustainability of any of the remaining semi-pristine grassland ecosystems in these risk areas comes into question. However, this by no means condones the continuing, unchecked exploitation of these highly degraded grassland habitats without thought of conservation and environmental management. Furthermore conservation initiatives should seek to capture the full spectra of threatened biodiversity, at all scales, and should not necessarily concentrate their efforts on heavily impacted areas that have been given critical threat status, they should look to less threatened grassland patches to ensure their longevity and sustainability (Hoekstra et al 2005).

4.4.4. Identifying Land-cover threats: Refining the methods

The information provided by this analysis is very important in that it provides information pertaining to where the transformation threats are occurring within the grassland biome today. This data can be viewed as baseline information for many other studies including those looking at climate change. Once one has a baseline description of any phenomena, the next step from there is tracing changes and trends over time. This data will also be invaluable to conservation planning, allowing for the channeling of available resources for more effective and more efficient conservation activities to areas where they will be most effective. Rouget et al., (2003) state that those areas showing less fragmentation should not be given very high priority because they have inherent protection through extreme environmental conditions that prevented transformation initially. In the Grassland biome, the grassland patches associated with the Great Escarpment exhibit this trait. On the other hand, it is more desirable to have larger, relatively contiguous grassland patches for conservation planning purposes (Pressey 1994, Margules & Pressey 2000), of which the largest remaining patches are associated

with the same area. Thus it is necessary to have a means of prioritizing the remaining patches in terms of their desirability for conservation activities. It may be better to conserve a highly fragmented area because it is facing high threat to biodiversity than to consider a more intact patch of grassland vegetation even though it is under low human threat as it will be more sustainable in the future.

One of the major short-comings of this analysis was the inability to trace the anthropogenic socio-economic drivers of the observed land cover transitions. It is highly unsatisfying to have the ability to observe change but have insufficient information to adequately explain it. This was partly due to the coarse scale at which the investigations were carried out, the specific human demands on the available resources causing these land cover transitions, especially of the remaining grassland patches, could not be discerned at this scale and to carry out a detailed analysis of said drivers for each incidence of observed change was beyond the scope of this project. Identifying and understanding the process behind the observed patterns of change ensures certainty that those factors are adequately considered and where possible mitigated in the conservation planning process so that those action plans and policies will be sustainable (McNeely et al 1997). Furthermore, the maps that were created in the process of this analysis need to undergo a process of ground truthing. The classifications of threat have been made strictly on the basis of the available spatial information and there is no description of the bio-physical characteristics associated with each threat classification, if at all this is possible. Such an exercise would be useful to validate these results, especially for the assessment of Grassland habitat degradation.

The human element can never be removed from analyses of land cover change because it is mostly human demand for ecosystem goods and services that drives it. It is acknowledged that the inability to identify and describe only patterns and not processes of change is a handicap of the land cover change analysis, as this is a major consideration in systematic conservation planning (Smith et al., 1993; Cowling et al., 1999; Margules & Pressey 2000). The proximate causes of biodiversity loss are biological but the ultimate causes are social, economic and political (Skole et al 1992, Forrester & Machlis

1996). The grasslands of South Africa they contain and support the economic heartland of this country and although the main contributors to grassland biodiversity loss have been identified (cultivation, bush encroachment, spread of invasive alien plant species and grassland degradation) it is clear that the reasons for this are solely anthropogenic. The solution to the problem of grassland habitat loss is to be found by embracing a multi-disciplinary approach to land cover change analyses and threat identification. Looking beyond the physical expression of change through grassland conversion but also at changes within the social systems associated with those areas of land cover conversion. Once all aspects of change are understood, then more efficient and pro-active conservation planning processes can be created and implemented. In terms of conservation planning action for the remaining semi-pristine grassland patches, using the information collected through this analysis of grassland habitat loss and fragmentation, we are able to answer the questions of "where and when?" (Bomhard et al, 2005). To plan appropriately for the future, there is a need to better understand the human system and economies driving those changes within the biome. It is hoped that through this project many areas of grassland degradation facing threats from human "biodiversity-unfriendly" land use practices have been red-flagged for further investigation and conservation attention.

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