Assessing the level of habitat fragmentation of the KwaZulu-Natal Sandstone Sourveld

By

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Environmental Science, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation of South Africa

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

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Signed: **Professor Onisimo Mutanga** (Co-Supervisor) Date

DECLARATION 1: PLAGIARISM

I, **Rowan Naicker**, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

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DECLARATION 2: PUBLICATIONS

Details of contribution to publications that form part of and/or include research presented in this thesis (includes publications in preparation, submitted, in press and published and give details of the contributions of each author to the experimental work and writing of each publication).

Publication 1: Naicker, R., Rouget, M. and Mutanga, O. Assessing how habitat fragmentation and low connectivity levels could affect the KwaZulu-Natal Sandstone Sourveld. **In preparation.**

Publication 2: Naicker, R., Rouget, M. and Mutanga, O. Designing landscape corridors to improve connectivity levels of the KwaZulu-Natal Sandstone Sourveld within the eThekwini Metropolitan Region**. In preparation**.

The work was done by the first author under the guidance and supervision of the second and third authors.

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ABSTRACT

Numerous processes, including habitat loss and fragmentation, contribute to ecosystem degradation, resulting in the loss of ecosystem functioning and diversity. The KwaZulu-Natal Sandstone Sourveld (KZN SS) is a grassland ecosystem type that is currently classified as endangered due to extensive habitat loss. A large percentage of this ecosystem has been converted through agriculture and development. This is due to the fact that this vegetation type occurs in a prime agricultural area for timber and sugar cane plantations. This has led to the physical fragmentation of the KZN SS, the exacerbated effects of which could diminish the biological persistence of this ecosystem. Apart from a few conserved areas (only several hundred hectares), most remnant patches of KZN SS are exposed to frequent fire and stressful levels of grazing.

Very little is known about this vegetation type and thus the current level of habitat fragmentation and connectivity of the landscape is presently unknown. Furthermore, there is currently no standard method used to quantify habitat fragmentation. The overall aim of this study was to quantify habitat fragmentation of the KZN SS using measures of structural and functional connectivity. Through the use of various measures of habitat fragmentation and connectivity, this study identified priority areas of KZN SS, and designed landscape corridors to improve landscape connectivity.

There are numerous measures that can be implemented to assess landscape and habitat connectivity, including graph theory. The Conefor Sensinode software, which employs graph theory, was chosen to aid in assessing the level of habitat fragmentation. The integral index was chosen as the best connectivity index to use in determining landscape connectivity. Once the data had been processed within Conefor, it was then imported into a Geographical information system (GIS) where the data was finally represented. A least-cost analysis was then run in ArcGIS to determine the best route for a landscape corridor to undertake within the eThekwini Metropolitan area. This analysis took into account the priority areas of KZN SS identified, the protected areas network, and the DMOSS (Durban Metropolitan Open Space System). The study ascertained that the KZN SS is a highly fragmented landscape, which has resulted in very low levels of connectivity between fragments in the eThekwini Metro. Priority areas have been identified and landscape corridors have been suggested. This situation needs to be addressed if species within the KZN SS are to persist. This study recommends that the eThekwini

Municipality can safeguard the biodiversity of this endangered ecosystem by focusing on managing the patches of KZN SS that have been identified as having a high level of importance within the landscape.

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ACRONYMS AND ABBREVIATIONS

DMOSS	Durban Metropolitan Open Space System
EPCPD	Environmental Planning and Climate Protection Department
GIS	Geographical Information System
IIC	Integral Index of Connectivity
KZN	KwaZulu-Natal
KZN SS	KwaZulu-Natal Sandstone Sourveld
PA	Protected Areas
PAN	Protected Areas Network
SANBI	South African National Biodiversity Institute
UKZN	University of KwaZulu-Natal

UNITS OF MEASUREMENT

%	Percentage
mm	Millimetres
m	Metre
ha	Hectare

CHAPTER 1: INTRODUCTION

1.1 Background

Grasslands are considered among the most degraded biomes due to the total habitat loss and degree of fragmentation (Tarboton, 1997). The South African grassland biome is of no exception and has been identified as endangered and is in need of conservation (Olsen and Dinerstein, 1998). This grassland biome is predominately located on the high central plateau of South Africa, as well as the inland regions of KwaZulu-Natal and the Eastern Cape (Schooley and Wiens, 2003; Lindenmayer and Hobbs, 2005; Mucina and Rutherford, 2006). Grasslands are unique, diverse systems that are composed of herbaceous vegetation dominated by graminoids, with high plant diversity (mostly due to forbs), as well as a wide range of fauna (Mucina and Rutherford, 2006). Grasslands often occur in some of the most fertile agricultural soils and are thus under threat from agricultural processes (Hanski, 1999; Fahrig, 2005; Lindenmayer and Hobbs, 2005; Schmiegelow, 2005; Mucina and Rutherford, 2006).

The conservation of biodiversity within urban areas faces a number of challenges, paramount amongst which is the challenge of making cities sustainable. This challenge stems from the conflict of achieving both development and environmental goals. This conflict is aggravated by the fact that development initiatives within South Africa are attributed a higher level of significance as compared to environmental concerns (Roberts, 2008). For example, in the Durban region, tension in this aspect is mounting due to the variety of development challenges facing the city, such as the housing backlog and the rate of unemployment, coupled with the increase in environmental challenges facing the city, such as the negative impact of rapid development on riverine and coastal ecosystems (Roberts, 2008). Other issues which arise within urban conservation include air and water pollution, fire and flooding (Hostetler *et al*, 2011; Shah and Haq, 2011). Effective land use and town planning probably represents one of the best ways to address these issues.

The eThekwini Municipality has a hierarchical planning structure comprised of spatial plans ranging from a strategic development framework to different town planning schemes (Roberts *et al*, 2011). The Durban (eThekwini) Metropolitan Open Space System (DMOSS) is still being represented within the higher level plans (Roberts *et al*, 2011). The different town planning schemes however, were developed with hardly any environmental consideration and as a result often collides with current environmental policy and law (Roberts *et al*, 2011). EThekwini's unique biodiversity would have been impossible to adequately conserve if the previous development schemes were initiated. The DMOSS has now been incorporated within the schemes in a number of different capacities, such as a controlled development layer (Roberts *et al*, 2011). This implementation was used as a means to ensure that biodiversity concerns could inform the development planning and assessment process (Roberts, 2008).

In consideration of this, the study forms part of the KwaZulu-Natal research programme, which is a research collaboration between the eThekwini Municipality and the University of KwaZulu-Natal (UKZN). This partnership was officially initiated in May 2011 and was developed to aid in the advancement of knowledge in biodiversity conservation and management within the context of global environmental change (Rouget and Cockburn, 2014). It is facilitated by the Environmental Planning and Climate Protection Department (EPCPD) in the eThekwini Municipality and by land use planning and management research staff at UKZN, along with researchers from various other disciplines at UKZN (Rouget and Cockburn, 2014). The programme aims to generate much needed knowledge to assist managers in the eThekwini Municipality in making biodiversity and conservation decisions. As such, institutional partnerships are essential for generating knowledge and learning and to address the gap between scientific research, policy development and management within a local government setting (Rouget and Cockburn, 2014).

1.2 Rationale for the research

There is a lack of knowledge pertaining to the KwaZulu-Natal Sandstone Sourveld (KZN SS) vegetation type as such the present landscape connectivity and fragmentation level is presently unknown. In addition, currently no standard method for the quantification of habitat fragmentation exists. The objective of this study was therefore to identify a suitable approach for quantifying habitat fragmentation and connectivity in order to inform the eThekwini Municipality on which fragments of KZN SS should conservation efforts be focused on, and thus facilitate the land use planning decision making process.

1.3 Aim

The main aim of the research was to quantify habitat fragmentation of the KwaZulu-Natal Sandstone Sourveld and to design landscape corridors using various measures of structural and functional connectivity in order to assist land use decision making in the eThekwini Metropolitan area.

1.4 Objectives

This study comprised of the following objectives:

- Review the relevant literature on habitat fragmentation, habitat connectivity and corridor design.
- Quantify the degree of habitat fragmentation of the KZN SS.
- Determine the connectivity of different fragments of KZN SS.
- Compare the effectiveness of fine-scale vs broad-scale data in quantifying habitat fragmentation.
- Design landscape corridors to facilitate movement of species indigenous to the KZN SS.
- Determine critical patches of KZN SS for species persistence and movement within the eThekwini Metro.
- Determine possible implications for biodiversity persistence conservation.
- Assess the actual importance of the PAN and DMOSS in maintaining habitat connectivity.

1.5 Study site

The KZN SS is an ecosystem type that is currently classified as endangered on a national scale, however, provincially it is considered to be critically endangered (Mucina and Rutherford, 2006). It is distributed entirely within the KZN province on elevated coastal sandstone plateaus (Mucina and Rutherford, 2006). Its distribution extends from Kranskop to the Mtwalume River in the South.

The KZN SS is a short, species-rich grassland with scattered low shrubs and geoxylic suffrutices. The grass and tree proportions varies and depends on a number of factors, especially fire. Proteaceae trees and shrubs such as: Protea, Leucospermum, and Faurea) are locally common. They can be found on flat, and sometimes rolling plateau tops and steep mountains (Mucina and Rutherford, 2006). There are 12 endemic taxon species unique to the KZN SS, amongst which are the: *Helichrysum woodi, Brachystelma modestum, Cryorkis compacta*, and *Hesperantha gracilis* (Mucina and Rutherford, 2006). According to Mucina and Rutherford (2006), the altitude of the KZN SS ranges from 500-1100m but patches can be found at lower altitudes (Scott-shaw and Escott, 2011). Although there is some controversy over the classification of this vegetation type, the KZN SS is considered part of the South African grasslands biome (but see, Mucina and Rutherford, 2006). The South African grasslands biome receives between 400-1200mm of annual rainfall (O'Connor and Bredenkamp, 1997). The KZN SS experiences mostly summer rainfall, and receives between 700-1200mm of annual rainfall (Mucina and Rutherford, 2006). This vegetation type occurs on the Ordovician Natal Group sandstones, upon which are skeletal, sandy soils that are nutrient-poor (Mucina and Rutherford, 2006).

Our knowledge of the KZN SS vegetation type is limited, the KZN SS was first described in Mucina and Rutherford (2006) and very few papers have added to that knowledge base since. As such, the fauna that inhabit the KZN SS is not very well documented (Sandy willows-Munro, pers.comm). The KZN SS vegetation type shares a number of endemic species with the Pondoland-Ugu Sandstone coastal Sourveld (Mucina and Rutherford, 2006). The KZN SS in essence forms a transitional boundary between the Moist Coast hinterland ngongoni veld and the Moist Midlands Mist-belt grassland. Traditionally the KZN Mist-belt grasslands support many grass-eating herbivores such as Zebra, Oribi, and other antelope species. Additionally, these grasslands play home to Crowned Eagles, and Raptors which hunt the many number of rodents that reside. Furthermore, other species such as Blue Swallows, the Mist-belt chirping frog (*Anhydrophryne ngongoniensis*), and the Long-toed tree frog (*Leptopelis xenodactylus*) are known to occur in the KZN Mist-belt grasslands (www.kznwildlife.com :accessed 10/08/2015).

The KZN SS is found both within and outside of the eThekwini Metropolitan area (Figure 1.1). This vegetation type occupies roughly 135,000 ha, 65,531 ha of which is located within the eThekwini Municipality (Richard Boon, pers.comm). The extant patches of KZN SS covers roughly two percent of the eThekwini Metropolitan area. Some pristine areas of KZN SS are located within the eThekwini Metropolitan area, an example of which can be seen highlighted in figure 1.2. A large percentage of this ecosystem type has been converted through agriculture and development (Mucina and Rutherford, 2006). This is predominately due to the fact that this vegetation type is a prime agricultural area for timber and sugar cane plantations. These human activities within the eThekwini Metropolitan area have led to the destruction and degradation of the KZN SS. This has led to the physical fragmentation of the ecosystem, the exacerbated effects of which could diminish the biological persistence of this vegetation type. The KZN SS is naturally fragmented and originally comprised of three predominate areas prior to any land transformation.

Apart from land-use transformation, the extant patches of KZN SS have been degraded by the altering of fire regimes, the harvesting of plants for traditional uses, and nutrient enrichment from neighbouring land-uses. This has caused a lot of the grassland to be replaced by woody vegetation (Richard Boon, pers.comm). 1.5% of the remaining 16.8% of KZN SS within the eThekwini Municipality is degraded (Richard Boon, pers.comm). To aid in the conservation of this endangered ecosystem, proper management practices must urgently be implemented.

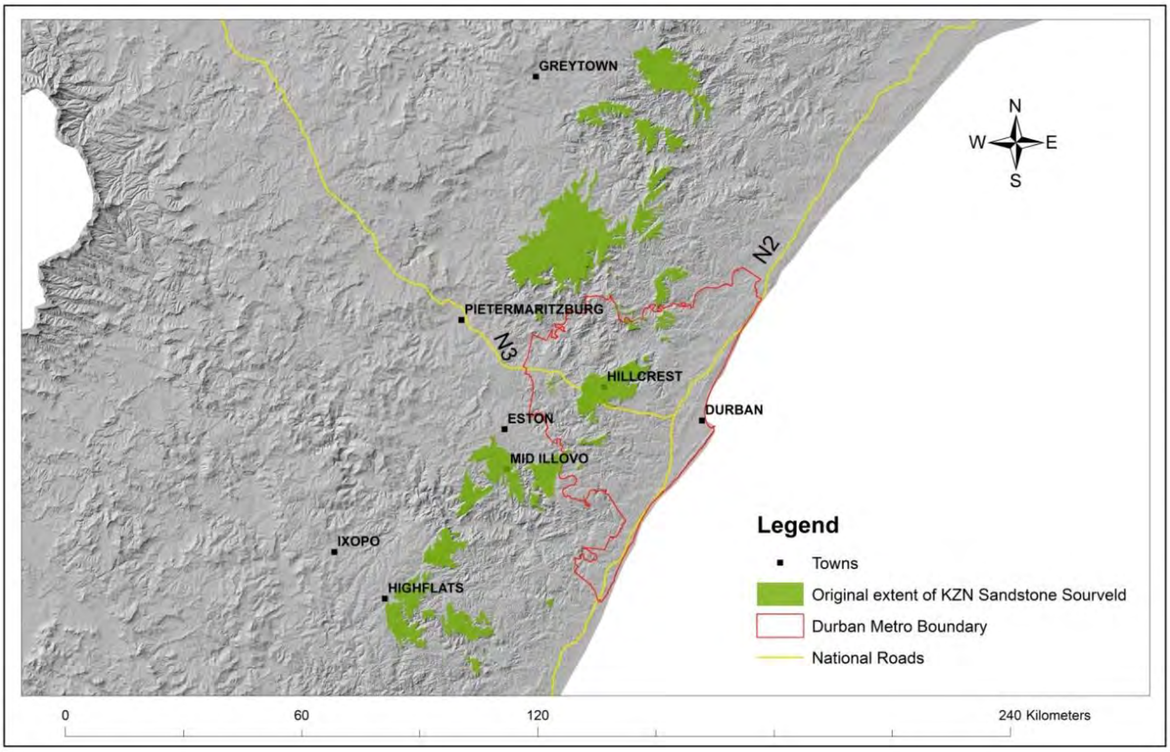

Figure 1.1 - Original extent of the KwaZulu-Natal Sandstone Sourveld in and outside the eThekwini Metro

Figure 1.2 - Aerial photo depicting pristine KZN SS with urban areas.

1.6 Outline of thesis structure

Chapter 2 sets out to review the relevant literature pertaining to the subjects of interest.

Chapter 3 introduces the first research paper that focuses on quantifying the overall degree of habitat fragmentation and connectivity both within, and outside the eThekwini Metropolitan area. Lastly, the connectivity between different fragments is established. The information gathered in this chapter aids in the generation of landscape corridors in Chapter 4.

Chapter 4 focuses on the identification of landscape corridors that comprise of patches of KZN SS. This resulted in: 1) essential patches of KZN SS to be identified; 2) the importance of the PAN and DMOSS to be assessed and; 3) possible implications for biodiversity persistence conservation to be made.

The final chapter, **Chapter 5** consolidates the findings in this study. In addition, this chapter discusses limitations and makes recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A number of different processes, including habitat loss and fragmentation, contribute towards ecosystem degradation, resulting in the loss of ecosystem functioning and diversity. Urbanisation and agricultural farming are the main human activities behind the degradation of habitats (Hanski, 1999; McGarigal and Cushman, 2002; Schooley and Wiens, 2003; Neel *et al*, 2007; Cornelisse, 2013). Habitat loss is one of the major influences leading to species loss and population decline worldwide. The term "habitat" has been used very loosely and this has led to a lot of confusion. The concept can be used in two ways. Firstly, it can be as a species-specific entity representing the environment and other conditions that are suitable for a particular fauna and flora (Bonte *et al*, 2003). Secondly, the term habitat can be used in a more general sense and normally refers to the amount of native vegetation cover (Bonte *et al*, 2003; Lindenmayer and Hobbs, 2005). Habitat loss is the process by which natural habitat is reduced to a state where it is unable to support the requirements of the present ecosystem. It is difficult to separate the effects of habitat loss from the effects of habitat fragmentation. Habitat fragmentation can however be seen as intensifying the effects of habitat loss (Whitcomb *et al*, 1981; Simberloff, 1998; Fahrig, 2003).

2.2 Habitat fragmentation

Habitat fragmentation has been the main point of interest for a considerable period of time in various ecological studies, and has thus been recognised as the reason for population and species loss from degraded ecosystems (Hanski, 1999; Fahrig, 2001; Schooley and Wiens, 2003; Fahrig, 2005; Cornelisse, 2013). Habitat fragmentation can be seen as the process whereby, the total area of habitat is reduced by a large patch of habitat being broken up into several smaller habitat patches (Robinson *et al*, 1992; Hanski, 1999; Krauss *et al*, 2003; Schooley and Wiens, 2003; Fahrig, 2005). Habitat patches are relatively homogenous non-linear areas that differ from their surroundings (Lindenmayer and Fischer, 2005; Cornelisse, 2013). They occur on different spatial and temporal scales and are considered to be dynamic, and their function differs depending on the taxon. Habitat fragmentation can result from either natural causes such as fire, or human induced causes such as urbanisation (Fahrig, 2001; Fahrig, 2003; Lindenmayer and Hobbs, 2005; Neel *et al*, 2007).

The effects of habitat loss and fragmentation when combined are considered to be the greatest threats to biological diversity worldwide (Hanski, 1999; Fahrig, 2001; Fahrig, 2002; Schooley and Wiens, 2003; Lindenmayer and Hobbs, 2005). Habitat fragmentation can have a significant impact on a species ability to disperse between habitat patches (Krauss *et al*, 2003). The effect of a reduced dispersal ability will decrease the probability of species persistence in a landscape (Young *et al*, 1996; Fahrig, 2002; Fahrig, 2005; Lindenmayer and Hobbs, 2005). Corridors can facilitate the dispersal of species between the different habitat fragments, thus placing an added importance upon the connectivity of fragmented areas (Krauss *et al*, 2003; Cornelisse, 2013).

2.2.1 Landscape connectivity

Landscape connectivity is essential to the survival of species that are faced with habitat loss and fragmentation (Keitt *et al*, 1997; Urban and Keitt, 2001). The measurement of landscape connectivity requires the species priorities to be the focal point of the approach (Hanski, 1999; Fahrig, 2005; Neel *et al*, 2007; Visconti and Elkin, 2009; Rayfield *et al*, 2011). This means that information regarding species movement responses to landscape structure is essential. The required data is often difficult to obtain, however technological and analytical advances in software and hardware has allowed for significant progress to be made (Miller, 2005; Schmiegelow, 2005; Minor and Urban, 2008; Visconti and Elkin, 2009; Rayfield *et al*, 2011).

Landscape connectivity has two major components: structural connectivity, which deals with the spatial structure of the landscape and its elements; and functional connectivity which is concerned with interactions of species with the features of the landscape (Young and Jarvis, 2001; Bonte *et al*, 2003; Rutledge, 2003; Rayfield *et al*, 2011; Rudnick *et al*, 2012). Structural connectivity is often easier to measure as opposed to functional connectivity because it can be calculated using landscape metrics which rely upon the spatial analyses of maps (Fahrig, 2001; Urban and Keitt, 2001; Fahrig, 2005; Neel *et al*, 2007; Minor and Urban, 2008). There are a number of different measures that can be used to assess landscape and habitat connectivity, namely, graph theory, network theory and circuit theory (Nikolakaki, 2004; Kindlman and Burel, 2008). These measures are increasingly being utilised to quantify multiple aspects of habitat connectivity for protected areas (Keitt *et al*, 1997; Young and Jarvis, 2001; Rutledge, 2003; Rudnick *et al*, 2012).

2.2.2 Measures of landscape connectivity

Graph theory is a well-established method used to quantify connectivity; it originates from the branch of mathematics dealing with separate objects (Schmiegelow, 2005; Pascual-Hortal and Saura, 2007; Kindlman and Burel, 2008; Minor and Urban, 2008). Graph theory metrics quantify the total length and configuration of edges required to connect all nodes in a graph or the number of edges passing through a given node (Rutledge, 2003; Urban and Keitt, 2001; Lindenmayer and Hobbs, 2005; Pascual-Hortal and Saura, 2007; Rudnick *et al*, 2012). The use of graph theory as a means of estimating habitat connectivity is rapidly escalating in popularity in ecology and conservation biology (Nikolakaki, 2004; Kindlman and Burel, 2008). This popularity can be explained by the three main strengths of the graph theory approach: Its efficiency in characterising connectivity at broad spatial scales in landscapes with many habitat patches; its capacity to balance data requirements with data content; and its flexibility to include additional data about relevant aspects of species biology into connectivity assessments (Hanski, 1999; Urban and Keitt, 2001; Fahrig, 2005; Pascual-Hortal and Saura, 2006; Rayfield *et al*, 2011).

Network theory on the other hand, applies graph theory with the main focus on the properties of real world networks and their structural dynamics (Lindenmayer and Fischer, 2005; Neel *et al*, 2007; Bodin and Saura, 2010; Baranyi *et al*, 2011). Network measures that quantify habitat connectivity are composed of topological and weighted indices. Weighted measures take into account the variation and strength of connections between different nodes by including a node and link weights in their calculations (Bodin and Saura, 2010; Baranyi *et al*, 2011). Topological network measures on the other hand, only consider the link between nodes (Lindenmayer and Hobbs, 2005; Bodin and Saura, 2010; Baranyi *et al*, 2011). Whereas circuit theory incorporates network theory to quantify connectivity in circuited systems. The circuit theory analysis makes use of the distinctive contrast between the dispersal of individuals through a landscape and movement of charge through an electrical circuit (Miller, 2005; Kindlman and Burel, 2008). Circuit theory treats cells in a landscape as electrical nodes connected to neighbouring cells (Fahrig, 2005; Miller, 2005; Neel *et al*, 2007; Minor and Urban, 2008).

Most of the metrics developed for calculating habitat connectivity are predominately concerned with the structural or physical connections between patches of a particular habitat type. Graph theory in contrast, provides a more flexible set of metrics (Lindenmayer and Fischer, 2005;

Miller, 2005; Neel *et al*, 2007; Minor and Urban, 2008). The flexibility of graph theory allows edge lengths to be defined in any way, and not just by the Euclidian distance between patches (Keitt *et al*, 1997; Young and Jarvis, 2001; Lindenmayer and Hobbs, 2005; Visconti and Elkin, 2009; Rudnick *et al*, 2012). Graph-based metrics can therefore measure functional connectivity, which accounts for species-specific habitat preferences and movement behaviours (Young and Jarvis, 2001; Rutledge, 2003; Rudnick *et al*, 2012). In order to calculate the connectivity of a landscape, graph theory and spatially clear metapopulation models that include the physical characteristics of a landscape, can be used to calculate the potential connectivity of a landscape (Nikolakaki, 2004; Lindenmayer and Fischer, 2005; Miller, 2005; Neel *et al*, 2007; Minor and Urban, 2008).

2.2.3 Analytical tools to quantify habitat fragmentation and connectivity

The management of landscape connectivity is essential to ecology and biodiversity conservation. This places an added importance on user-driven tools which assist in the integration of connectivity into landscape planning (Fahrig, 2001; Lindenmayer and Hobbs, 2005; Miller, 2005; Pascual-Hortal and Saura, 2006; Visconti and Elkin, 2009). Due to this demand for user-driven tools in landscape planning, there have been numerous different types of software and freeware derived to determine the level of fragmentation and connectivity within the landscape, amongst these are Fragstats and Conefor Sensinode (Nikolakaki, 2004; Pascual-Hortal and Saura, 2006).

Fragstats is a computer software program based on spatial pattern analysis for quantifying landscape structures. The program is designed to calculate a wide range of landscape metrics for various map patterns (Tischendorf and Fahrig, 2000, Theobald, 2006). The landscape under investigation is user-defined and can represent any spatial phenomenon. Fragstats simply quantifies the spatial heterogeneity and areal extent of patches within a landscape (Tischendorf and Fahrig, 2000, Theobald, 2006). It is up to the user to establish a sound foundation for scaling and defining the landscape. In addition, it is the user's responsibility to clearly outline and classify patches within the landscape. A useful feature of Fragstats is that it does not limit the scale of the landscape under investigation. However the fact that the distance and area based metrics calculated in Fragstats are computed in meters and hectares poses a concern (Landford *et al*, 2006). This results in landscapes of extreme extent or resolution becoming prone to rounding errors (Landford *et al*, 2006). A further limitation of Fragstats lies in the metrics, where the resolution of source images used for mapping can be affected by all of the edge indices. What this translates into, is that at coarse resolutions edges may appear as straight lines; however, with finer resolutions, these edges may then appear to be highly complex lines. This culminates in the inability to compare values of edge metrics for images with different resolutions (Landford *et al*, 2006).

The Conefor Sensinode 2.2 can be seen as an alternative. The software was developed to quantify the importance of individual habitat patches that are needed for the maintenance or improvement of the functional landscape connectivity (Pascual-Hortal and Saura, 2006; Saura and Rubio, 2010; Saura *et al*, 2011). The software is established on the foundation of graph theory, which enables the software to deal with connectivity from a functional point of view (Pascual-Hortal and Saura, 2006; Visconti and Elkin, 2009). As a result, not only does this software allow for the spatial structure of the landscape (structural connectivity) to be included into the analysis, but it caters for the dispersal distances of species and their interaction with the physical structure of the landscape (functional connectivity) as well (Tischendorf and Fahrig, 2000, Theobald, 2006; Saura and Torne, 2009).

2.3 Corridor design

The damaging effects of habitat fragmentation have been proven to diminish when fragmented patches of habitat are joined by a corridor (Bennett *et al*, 1994; Chetkiewicz *et al*, 2006). This leads into the important assumption that corridors help to facilitate interactions of organisms between previously inaccessible patches of habitat (Bennett *et al*, 1994; Doko *et al*, 2011). A considerable amount of confusion has been generated surrounding the functions of corridors due to a lack of clear and consistent terminology.

Corridors are usually conceptualised as regions of natural habitat that are attached and enable the dispersal of a particular flora or fauna which is essential for their persistence in a landscape (Bennett *et al*, 1994; Doko *et al*, 2011). The design and effectiveness of corridors are surrounded by a significant amount of controversy. The primary objective of corridors is to ensure that regional-scale ecological processes, such as pollination or animal movement, are integrated into the conservation assessment (Bennett *et al*, 1994; Chetkiewicz *et al*, 2006; Doko *et al*, 2011). Corridors are required to conserve biodiversity pattern and process, in addition to considering the opportunities and constraints surrounding their implementation. The design of landscape corridors requires taking into account issues of implementation (Chetkiewicz *et al*, 2006). Thus, in essence, corridor design should focus predominately on ensuring the long term persistence of biodiversity in the landscape (Chetkiewicz *et al*, 2006). Corridors enable the long term persistence of biodiversity in a number of ways. Firstly, it allows ecological processes, such as reproduction and dispersal, to persist. An example can be seen with riverine corridors, which allow for the migration and exchange between inland and coastal biotas (Rouget *et al*, 2003). Secondly, corridors can facilitate climate change adaptation and even contribute to evolutionary processes such as the genetic flow along major riparian corridors. Macroclimate and upland-lowland gradients are prime examples, as they allow for the geographic and ecological diversification of plant and animal lineages (Rouget *et al*, 2003). In addition, Potts *et al* (2013), highlights that drainage basins and other topographically complex landscapes, are important alternates of biodiversity and evolutionary processes.

2.3.1 Types of corridors

Corridors can be formed naturally or as the result of human induced disturbances (Townsend and Levey, 2005; Zehao *et al*, 2014). Due to these occurrences, the structures of corridors vary from very narrow lines, to wider strips of habitat, to streamside riparian vegetation (Hess and Fischer, 2001; Doko *et al*, 2011). Corridors can be seen to have originated from five commonly used categories, namely: environmental corridors, remnant corridors, introduced corridors, disturbance corridors, and regenerated corridors (Hess and Fischer, 2001; Jordan *et al*, 2003; Townsend and Levey, 2005; Doko *et al*, 2011; Zehao *et al*, 2014). Environmental corridors form due to the result of vegetation interacting with an environmental resource, such as a geological formation (Linehan *et al*, 1995; Jordan *et al*, 2003; Townsend and Levey, 2005; Zehao *et al*, 2014). Remnant corridors on the other hand form due to disturbances to the adjacent matrix, the occurrence of fragmentation in other words (Miller, 2005; Zehao *et al*, 2014). Introduced corridors are the results of regions that have been planted during prior centuries, and within agriculturally dominated landscapes (Hess and Fischer, 2001; Jordan *et al*, 2003; Miller, 2005; Townsend and Levey, 2005; Doko *et al*, 2011; Zehao *et al*, 2014). Disturbance corridors are similar to remnant corridors, but differ slightly, in that they are the result of land management activities that disturb vegetation (Linehan *et al*, 1995; Jordan *et al*, 2003; Zehao *et al*, 2014). Regenerated corridors occur when regrowth takes place in a disturbed strip of habitat. The regrowth may either be the result of planting, or natural succession (Jordan *et al*, 2003; Miller, 2005; Zehao *et al*, 2014). Engineered corridors have in recent years joined the aforementioned, as underpasses and overpasses have been developed with the sole purpose to facilitate the movement of wildlife (Hess and Fischer, 2001; Zehao *et al*, 2014).

2.3.2 The different roles of corridors

A clear and explicit understanding of a corridor's intended function is needed in order to facilitate an appropriate design and management of a corridor (Bennett *et al*, 1994; Hess and Fischer, 2001; Zehao *et al*, 2014). A corridor that is not designed to perform distinct functions may become harmful to the landscape; poorly designed corridors may act as sinks as edges may expose animals to predation. Additionally, poorly designed corridors may facilitate the spread of alien invasive plants (Bennett *et al*, 1994; Fleury and Brown, 1997; Hess and Fischer, 2001; Jordan *et al*, 2003).

The functions that corridors serve are derived from six ecological roles, namely: habitat, conduit, filter, barrier, source, and sink (Figure 2.1). In essence, a corridor that provides resources that are required for dispersal, reproduction, and survival, is supplying a habitat function (Bennett *et al*, 1994; Fleury and Brown, 1997; Jordan *et al*, 2003; Rantalainen *et al*, 2004). Conversely, a corridor that enables dispersal between habitat patches, but not reproduction, can be seen as serving a conduit function (Doko *et al*, 2011). Corridors that are serving a 'filter' function allow for some level of permeability into the corridor, and are most usually associated with riparian zones and areas with water quality issues (Linehan *et al*, 1995; Fleury and Brown, 1997; Townsend and Levey, 2005). Conversely, corridors that serve a barrier function almost completely prevent external aspects from penetrating into the corridor. An example can be perceived from the construction of roads, which serve as conduits for humans, yet can be seen as barriers to wildlife (Doko *et al*, 2011). Source and sink functions of corridors are usually applied in a demographic context. Corridors that perform a source function, allows for material or organism to emanate from within the corridor. On the contrary, a corridor that provides a 'sink' function, describes a habitat where reproduction is exceeded by mortality (Hess and Fischer, 2001; Jordan *et al*, 2003; Rantalainen *et al*, 2004; Doko *et al*, 2011).

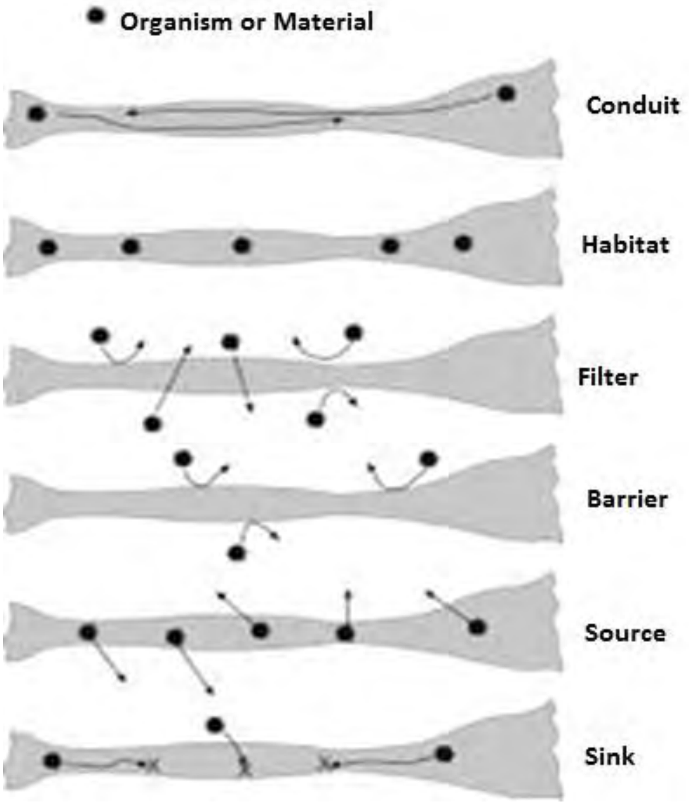

Figure 2.1 - Different corridor functions. Conduit: organisms pass from one place to another, but do not reside within the corridor. Habitat: organisms can survive and reproduce in the corridor. Filter: some organisms or material can pass through the corridor, others cannot. Barrier: organisms or material cannot cross the corridor. Source: organisms or material emanate from the corridor. Sink: organisms or material enter the corridor and are destroyed (Hess and Fischer, 2001).

It is important to note that corridors that are more structurally diverse, offer the greatest benefits to wildlife (Linehan *et al*, 1995). There are two aspects which need to be taken into consideration during corridor design; Firstly, corridor characteristics that can contribute to corridor quality needs to be included (Bennett *et al*, 1994; Fleury and Brown, 1997). Secondly, corridors need to be tailored to suit the requirements of the species it was designed to assist (Soule and Gilpin, 1991; Fleury and Brown, 1997).

2.3.3 The structure of corridors

The physical and biological characteristics of corridors are extremely important in determining how corridors function. Corridor connectivity, width, shape, and the arrangement of the plant community are viewed as the most ecological and visually important factors (Linehan *et al*, 1995; Fleury and Brown, 1997; Rantalainen *et al*, 2004; Rouget *et al*, 2006; Zehao *et al*, 2014). The connectivity within the landscape refers to the degree to which all the patches of habitat in the landscape system are connected by the corridor (Hess and Fischer, 2001; Townsend and Levey, 2005; Doko *et al*, 2011). Corridors should thus in essence minimise potential barriers to movements, such as roads. When dealing with corridors, it should be noted that, the corridor with the least number of gaps between patches have the highest level of connectivity (Linehan *et al*, 1995; Fleury and Brown, 1997; Miller, 2005; Rouget *et al*, 2006; Doko *et al*, 2011). The width of a corridor is crucial, as the corridor must cater for the needs of the species and corridor width plays a large role in this (Fleury and Brown, 1997; Hess and Fischer, 2001; McKinney, 2002; Miller, 2005; Townsend and Levey, 2005). In essence, a corridor has to be wide enough to provide shelter from predators, whilst allowing for nesting, movement, and feeding to occur. If too narrow, animals may be reluctant to enter, and if too wide, animals may make cross-directional movements which will undermine the intended function of the corridor (Linehan *et al*, 1995; Hess and Fischer, 2001; Rouget *et al*, 2006; Doko *et al*, 2011; Zehao *et al*, 2014). It is important to note that corridors will effect different species differently, depending on the intended function of the corridor. Literature indicates that a significant number of wildlife species, including: song birds, game birds, small mammals, and reptiles use corridors as a regular part of their lifestyles (Linehan *et al*, 1995; Fleury and Brown, 1997; Sieving *et al*, 2000). It is a common misconception that landscape corridors are mainly designed for use by mammals and reptiles. Birds will often use habitat patches within corridors to facilitate both travel and habitat functions (Sieving *et al*, 2000).

2.3.4 Do the benefits of corridors outweigh their limitations?

The main challenge faced by conservation corridor implementation is the limited information available pertaining to their success (Simberloff *et al*, 1991). Due to the lack in data supporting the implementation of corridors, many organisations will not allow their establishment (Simberloff *et al*, 1991; Olsen and Dinerstein, 1998; McKinney, 2002; Jepsen *et al*, 2005). Even if corridors are considered a possible solution to the problem faced, this does not essentially entail the use of them by the targeted species (Jordan *et al*, 2003). Furthermore, there is usually a limited amount of available space for corridor implementation, and thus a lack of a buffer zone leads to species becoming vulnerable to damaging external forces. Another major limiting factor to the implementation of corridors is cost (Simberloff *et al*, 1991; Olsen and Dinerstein, 1998; McKinney, 2002; Rantalainen *et al*, 2004; Jepsen *et al*, 2005). The expense generated by corridor design, implementation, and management is substantial and this is often an issue as many organisations will opt for a cheaper alternative, such as the translocation of species (Frankel and Soule, 1981; Soule and Simberloff, 1986; Simberloff *et al*, 1991; Olsen and Dinerstein, 1998). Despite some of the limitations of corridors, corridors are still an efficient way in which to increase biodiversity in a stressed landscape (Simberloff *et al*, 1991; McKinney, 2002; Jordan *et al*, 2003; Rantalainen *et al*, 2004; Rouget *et al*, 2006). Furthermore, corridors enable both humans and animals to virtually co-exist on the same regions of land (Simberloff *et al*, 1991; Olsen and Dinerstein, 1998; Jepsen *et al*, 2005; Rouget *et al*, 2006).

2.3.5 Tools for corridor design

Least cost analysis is probably the most widely used tool to aid in corridor development (e.g. Rouget *et al*, 2006). The analysis generates the least costly route an animal can take from one point to another, allowing both essential and detrimental factors to be factored in simultaneously. With the analysis, the cost is usually valued as the opposite of habitat suitability (Rouget *et al*, 2006). So essentially, unfavourable habitats are assigned a higher cost, and favourable habitats are assigned lower costs. A least cost path is simply a contiguous arrangement of cells that have the lowest cumulative cost as the path moves from one point to another (LaRue and Nielsen, 2008). Employing a GIS software is the easiest manner in which to generate this path. However, the problem associated with the least cost path is that the path generated is only one cell wide, and realistically this area is not viable for conservation purposes. A solution could lie with the use of a least cost corridor, which provides a strip of cells for a low cost route for species to transverse (Rouget *et al*, 2006; LaRue and Nielsen, 2008). There are however a few challenges associated with both the least cost corridor and the least cost path. The first obstacle lies in the assigning of cost values; this is the most problematic part of the least cost analysis, owing to difficulty in adequately assigning appropriate costs to different factors. Secondly, real world application requires a comprehensive analysis of connectivity, which conventional least cost path and least cost corridor analyses cannot provide

(Landford *et al*, 2006; LaRue and Nielsen, 2008). This is caused by their ability to only provide forecasts of connectivity between a single source and a single destination (LaRue and Nielsen, 2008). A comprehensive analysis of the connectivity of the landscape was carried out in Chapter 3, which aided in contending with some of the limitations of a least cost path analysis. A least cost path was chosen due to its ability to factor in multiple variables and as such aided in deriving the least costly route for a landscape corridor to undertake (Chapter 4).

2.4 Conclusion

Upon review of the literature, studies have highlighted the detrimental impact that habitat fragmentation has on biodiversity within grassland ecosystems. Furthermore, the review highlighted that ensuring the connectivity of the landscape is paramount in sustaining biodiversity in the region. As such, landscape corridors are viewed as the most efficient way in which to aid in increasing the connectivity and biodiversity within a fragmented landscape. In this context, the study set out to quantify the level of habitat fragmentation of the KZN SS and identify landscape corridors through the use of various measures of structural and functional connectivity. This was carried out in order to assist land use decision making in eThekwini.

CHAPTER 3: ASSESSING HOW HABITAT FRAGMENTATION AND LOW CONNECTIVITY LEVELS COULD AFFECT THE KWAZULU-NATAL SANDSTONE SOURVELD

3.1 Abstract

The KwaZulu-Natal Sandstone Sourveld (KZN SS) is an ecosystem type that is currently classified as endangered. Pressure from urbanisation has led to the remaining areas of KZN SS being physically fragmented, resulting in low connectivity levels which has diminished the biological persistence of this ecosystem. At present there is no set method employed to quantify habitat fragmentation. Furthermore, the current level of fragmentation and connectivity of the KZN SS vegetation type has not yet been determined. Due to this gap in knowledge, this chapter aimed to quantify the overall level of habitat fragmentation within, and outside the eThekwini Metropolitan area. In addition, it determined the level of connectivity within the ecosystem. Furthermore, the broad and fine-scale data sets used to conduct the analyses were compared and evaluated. The Conefor Sensinode software, which employs the bases of graph theory, was chosen to aid in assessing the level of fragmentation. The integral index was chosen as the best connectivity index to utilise in determining landscape connectivity. Once the data had been processed within Conefor, it was then imported into ArcGIS where the data was finally represented. The study has ascertained that the KZN SS is a highly fragmented landscape, which has resulted in very low connectivity between fragments in the eThekwini Metro. Moreover, the fine-scale data was found to show a more apt description of the current state of connectivity within the KZN SS. This situation needs to be addressed to ensure the persistence of biodiversity within the KZN SS.

Keywords: *connectivity measures; graph theory; grassland; habitat fragmentation, landscape connectivity; urban conservation.*

3.2 Introduction

Human activities such as urbanisation and agricultural farming are the predominant drivers behind the degradation of habitats (Hanski, 1999; Schooley and Wiens, 2003; Neel *et al*, 2007), resulting in habitat loss and fragmentation. The combined effects of habitat loss and fragmentation are considered to be the greatest threats to biological diversity worldwide (Hanski, 1999; Fahrig, 2001; Schooley and Wiens, 2003; Lindenmayer and Hobbs, 2005). Habitat fragmentation has been the focal point of extensive studies for a considerable period of time (Hanski, 1999; Fahrig, 2001; Schooley and Wiens, 2003; Lindenmayer and Hobbs, 2005; Neel *et al*, 2007).

Landscape connectivity is crucial with regards to the persistence of species that are faced with habitat loss and fragmentation (Urban and Keitt, 2001). Measuring landscape connectivity requires an approach which emphasises the persistence of species and ecosystems (Hanski, 1999; Fahrig, 2005; Neel *et al*, 2007; Visconti and Elkin, 2009; Rayfield *et al*, 2011). Structural connectivity, related to the spatial structure of the landscape, is often easier to measure than functional connectivity, associated with species interactions due to the fact that it can be calculated using landscape metrics (Hanski, 1999; Fahrig, 2001; Urban and Keitt, 2001; Minor and Urban, 2008; Rayfield *et al*, 2011). The use of graph theory as a means of estimating habitat connectivity is rapidly increasing in popularity in ecology and conservation biology (Fahrig, 2005; Neel *et al*, 2007; Minor and Urban, 2008; Rayfield *et al*, 2011).

Managing landscape connectivity is a fundamental concern in ecology and biodiversity conservation, resulting in an increasing demand for user-driven tools for integrating connectivity in landscape planning (Fahrig, 2001; Lindenmayer and Hobbs, 2005; Miller, 2005; Visconti and Elkin, 2009). The Conefor software was derived for the quantification of important habitat patches necessary to maintain the connectivity of the landscape through graph structures and habitat availability indices (Pascual-Hortal and Saura, 2006; Visconti and Elkin, 2009). The Conefor Sensinode 2.2 software is able to quantify the importance of habitat patches for maintaining or improving functional landscape connectivity and was conceived as a tool for decision-making support in landscape planning and habitat conservation. The Conefor software is based on graph structures, which have been suggested to possess the greatest benefit for conservation problems regarding landscape connectivity, as it is efficient in characterising connectivity at a broad-scale in landscapes with many habitat patches. Consequently, the software includes new connectivity metrics based on the habitat availability concept (Visconti and Elkin, 2009).

Grasslands are considered among the most devastated biomes due to total habitat loss and degree of fragmentation (Tarboton, 1997). The South African grassland biome has been identified as critically endangered and is in urgent need of conservation (Olsen and Dinerstein, 1998). The KwaZulu-Natal Sandstone Sourveld (KZN SS) ecosystem is currently classified as endangered (Mucina and Rutherford, 2006). It is distributed entirely within the sub-escarpment of the province of KwaZulu-Natal (KZN). The destruction and degradation of the KZN SS has led to its physical fragmentation, which could diminish the biological persistence of this ecosystem.

The quantification of habitat fragmentation can be used to assist land use planning, especially within an urban context. Through determining the level of habitat fragmentation of a region, certain areas which are vital for connectivity can be identified in a timely manner and properly managed. This is especially vital within an urban context, as urban regions usually have a variety of different land uses in close proximity to one another, the identification of priority conservation areas can better inform the planning of land uses in the vicinity of the priority areas. At present there is no set method employed to quantify habitat fragmentation and the choice of metrics can influence the quantified level of fragmentation. To the best of our knowledge, no studies have been undertaken to assess the current level of fragmentation and connectivity of the landscape of the KZN SS vegetation type.

Due to this lack of information, the study aimed to quantify the level of habitat fragmentation of the KZN SS utilising measures of structural and functional connectivity. This chapter is concerned with the quantification of the overall habitat fragmentation within, and outside the eThekwini Metropolitan area. In addition, it determines the overall level of connectivity within the ecosystem. Furthermore, the importance that each patch contributes towards the level of connectivity within the ecosystem is ascertained. Finally, the study assesses the extent to which habitat fragmentation measurement is influenced by the spatial scale of land-cover and vegetation data.

3.3 Materials and methods

3.3.1 Data acquisition and pre-processing

Assessing habitat fragmentation requires up to date information on the spatial extent of habitat loss, information usually derived from land cover maps. Table 3.1 displays the main data sets used to carry out the study and where the data sets were acquired from. The broad-scale data used in the analysis comprises of the 2008 landcover data set (overall accuracy of 79%) and the 2006 SANBI vegetation data set. These two datasets had to be overlaid prior to analysis as the landcover data set was used to indicate the amount of habitat that had been lost. The broad-scale data had only been classified as either natural or transformed, this offered very little information pertaining to the ecological condition of the KZN SS as the "natural" condition did not consider the degradation status of the area. The fine-scale data used in the study offered more information regarding the ecological state of the KZN SS. The fine-scale data separated the ecological state of the KZN SS into either pristine, intermediate, or degraded. The fine-scale data used in the analysis comprised of the 2011 vegetation map from the eThekwini Municipality. This dataset did not have to undergo pre-processing as it already contained the land-use data that was required. An accuracy assessment could not be conducted for the vegetation maps due to the fact that there is no accepted classification of vegetation and the extent of the KZN SS differs between the two vegetation maps. A validation of the 2011 landcover mapping accuracy was determined using statistical analysis and comparison between the 2011 vegetation map reference data and the 2011 satellite image. A total of 100 reference points were used to calculate the overall landcover mapping accuracy value, which yielded an accuracy of 84%.

Table 3.1- Data sources used to quantify habitat fragmentation at broad-scale and fine-scale

Name	Description	Year	Source	Extent	Scale	Resolution (m)
SANBI Veg	Vegetation Map	2006	Mucina and Rutherford, 2006	National	Broad - 1:250000	250
KZN_LC	Landcover	2008	Ezemvelo KZN Wildlife	Provincial	Broad - 1:100000	20
Veg2011	Vegetation Map	2011	eThekwini	eThekwini Metro	Fine - 1:20000	10

3.3.2 Quantifying habitat fragmentation

The graph theory approach has three main advantages: its efficiency in characterising connectivity at broad spatial scales in landscapes with many habitat patches; its ability to balance data requirements with information content; and its flexibility to incorporate additional information about relevant aspects of species biology into connectivity assessments (Urban and Keitt, 2001; Fahrig, 2005; Minor and Urban, 2008; Rayfield *et al*, 2011).

Many of the metrics developed for determining connectivity only address structural connectivity, or physical connections among patches of a particular habitat type. Graph theory, however, provides a more flexible set of metrics (Lindenmayer and Fischer, 2005; Miller, 2005; Neel *et al*, 2007; Minor and Urban, 2008). The flexibility of graph theory stems from the fact that edge lengths can be defined in any way, and not just by Euclidian distance between patches (Fahrig, 2005; Lindenmayer and Hobbs, 2005; Lindenmayer and Fischer, 2005; Visconti and Elkin, 2009; Rayfield *et al*, 2011). Graph-based metrics can therefore measure functional connectivity, which accounts for species-specific habitat preferences and movement behaviours. In order to quantify connectivity, graph theory and spatially explicit metapopulation models that combine the physical attributes of the landscape with limited species information can be used to provide a measure of potential connectivity (Lindenmayer and Fischer, 2005; Miller, 2005; Neel *et al*, 2007; Minor and Urban, 2008).

There has been numerous software derived to determine the level of fragmentation and connectivity within the landscape, amongst these are Fragstats and Conefor Sensinode (Pascual-Hortal and Saura, 2006; Visconti and Elkin, 2009). Conefor has been proposed to possess the greatest benefit for conservation problems regarding landscape connectivity as it includes new connectivity metrics based on the habitat availability concept (Pascaul-Hortal and Saura, 2006; Visconti and Elkin, 2009). The habitat availability concept enables a patch to be considered as a space where connectivity occurs, as a result habitat patch area and the connections between different patches can be integrated into a single measure (Pascaul-Hortal and Saura, 2006).

The Conefor Sensinode software has several connectivity indices available for use, amongst which; the integral index of connectivity (IIC) (Pascaul-Hortal and Saura, 2006) and the probability of connectivity (PC) are the most highly recommended indices (Pascaul-Hortal and

Saura, 2007). The software considers connectivity from a functional point of view. Thus not only does it take into account the spatial configuration of the landscape (structural connectivity), but it encompasses the dispersal distances of species and their interaction with the physical structure of the landscape (functional connectivity) in the analysis as well (Tischendorf and Fahrig, 2000; Theobald, 2006). The required inputs for the software are therefore both the spatial structure of the landscape and the dispersal distance of the study species.

3.3.3 Analysis

Landscape connectivity is species-specific, and different species have different levels of dispersal and movement. In order to cater for this, a range of different dispersal distances were taken into consideration for the study. Five dispersal distances were chosen, namely: 50m, 100m, 250m, 500m, and 1000m. This enabled the representation of a wide range of dispersal distances for grassland species. The study primarily focused on 50m and 1000m dispersal distances to show the impact of habitat fragmentation at minimum (50m) and maximum (1000m) dispersal range. The 50m dispersal distance represents the dispersal range of smaller mammals such as grassland mice (Kollmann and Schill, 1996), whilst the 1000m distance is more representative of larger mammals such as antelope (www.kznwildlife.com/umkhanyakude-district-municipality/168-conservation/wildlife-management/855-habitat-preference-of-game-mammals: accessed 10/08/15).

Table 3.2- Analysis conducted and criteria used

Data Set	Spatial scale	Study area	Patch condition	Dispersal distance (m)
1	Broad	In the eThekwini Metro	Natural (including degraded)	50 and 1000
2	Broad	Outside the eThekwini Metro	Natural (including degraded)	50 and 1000
3	Broad	The Entire extent of the KZN SS	Natural (including degraded)	50 and 1000
4	Fine	In the eThekwini Metro	Pristine and Intermediate status only	50 and 1000
5	Fine	In the eThekwini Metro	Pristine, Intermediate, and Degraded status	50 and 1000

Table 3.2 summarises the criteria for the analysis that was conducted thereafter. Data sets 1, 2, and 3 comprises of the broad-scale data (The 2008 landcover and 2006 SANBI vegetation map), and is only concerned with patches of KZN SS that were in a natural ecological state. The analysis for these data sets was conducted for the 50m and 1000m dispersal distance extremes. Data set 1 only dealt with patches of KZN SS that fell within the eThekwini Metro. Data set 2 focused on the patches that occurred outside the eThekwini Metro, and data set 3 looked at the entire extent of the KZN SS. Data sets 4 and 5 focused on the fine-scale data and used the 2011 vegetation map and dealt solely with patches of KZN SS that occurred within the eThekwini Metro. The analysis for these data sets took into account the 50m and 1000m dispersal distances exclusively. Additionally, Data set 4 only takes into consideration patches of KZN SS that were in a pristine and intermediate ecological condition, whilst data set 5 includes the degraded patches of KZN SS as well, into the analysis.

Thereafter, the spatial structure of the landscape and the dispersal distances of the study were derived from the ArcGIS data and then processed for use in Conefor, via the Conefor inputs GIS extension (www.jennessent.com/arcgis/conefor_inputs; accessed 06-03-2013). Once the data had been processed within the Conefor software, the outputs produced were imported back into a GIS and combined with the original data set. The number of components index was used to calculate the level of fragmentation across the different dispersal distances and the various criteria specified for each data set. The analysis took into account each patch of KZN SS larger than 1ha that fell within the specified dispersal distance. The results are displayed as graphs depicting the number of components (habitat patches) against the different dispersal distances.

3.3.4 Determining the connectivity of different fragments

Upon dealing with connectivity analysis there are two possible connection models namely: Binary, which considers each habitat patch as either connected or unconnected and doesn't factor in the strength of the connection between the patches; and secondly Probabilistic, which takes into account the movement of fauna as a means to estimate the strength of the connection between habitat patches (Pascaul-Hortal and Saura, 2007).

There are nine different types of binary indices available for use through the Conefor software, such as the number of links (NL) which determines the number of connections between different habitat patches. The integral index of connectivity (IIC) was chosen for use due to it being recommended as the best binary index for calculating landscape connectivity measurements (Pascaul-Hortal and Saura, 2007). The advantage of the IIC lies in that the formula allows for patch quality and connectivity to be integrated; this in turn enables each habitat patch to be considered as an area where connectivity takes place (Pascaul-Hortal and Saura, 2007). The IIC is calculated by the formula highlighted below, and the output values range from 0 – 1, with 1 highlighting optimal connectivity.

$$IIC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \frac{a_i . a_j}{1+nl_{ij}}}{A_L^2}$$

where n is the total number of nodes, a_i and a_j are the attributes (area) of nodes i and j, nl_{ij} is the number of links in the shortest path between patches i and j, and A_L is the maximum landscape attribute (the total landscape area, consisting of both habitat and non-habitat areas) (Pascaul-Hortal and Saura, 2007).

The analysis of the connectivity of each fragment was carried out in the Conefor program and determined through the utilisation of the IIC formula. The equation was run for each of the 5 data sets. The individual patches were then arranged and prioritised according to their overall contribution to the connectivity of the landscape, bigger and less fragmented patches would have been viewed as being better connected. The results of this analysis were displayed as GIS maps, which highlighted the contribution that each individual patch of KZN SS added with regards to the connectivity of the landscape.

3.3.5 Quantifying overall landscape connectivity

In order to determine the extent of the overall landscape connectivity of the KZN SS, two connectivity indices were used, namely; the number of components and the IIC. These specific connectivity indices were chosen due to the fact that they do not demonstrate the same problems associated with many other connectivity indices, i.e. where there is an increase in connectivity with increased fragmentation, or no connectivity predicted for a landscape occupied by one large habitat patch, or a lack of response of the index to the loss of a large isolated patch (Fahrig, 2001; Lindenmayer and Hobbs, 2005; Miller, 2005; Visconti and Elkin, 2009). As connectivity across the landscape increases, the number of components will decrease. More connected landscapes will also tend to consist of one large component in which all the habitat patches are connected. As the landscape gets more connected, the percentage of the available habitat area that is in the biggest component will also increase (Fahrig, 2001; Lindenmayer and Hobbs, 2005; Miller, 2005; Visconti and Elkin, 2009).

3.4 Results

3.4.1 The degree of habitat fragmentation

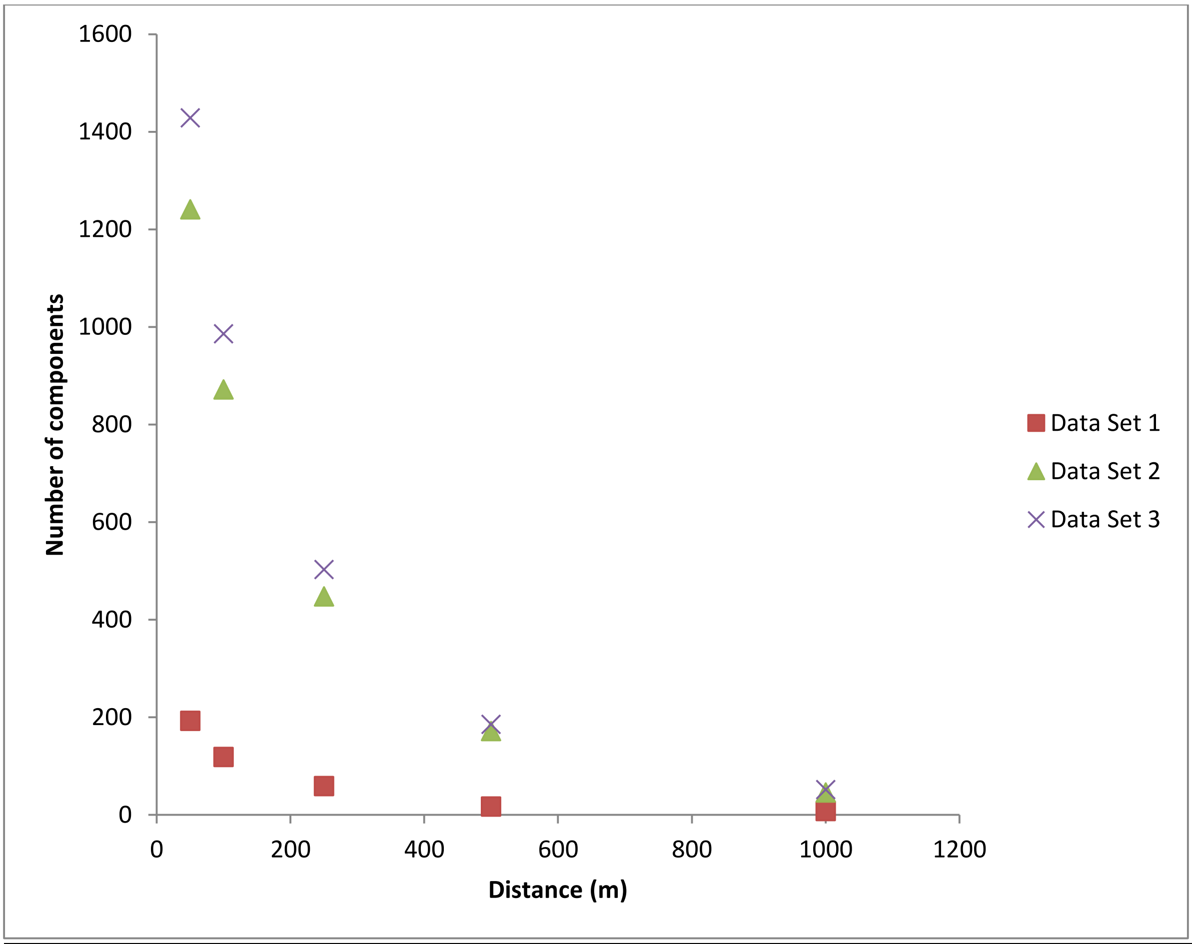

Figure 3.1- Changes in habitat fragmentation (expressed as the number of components) for KZN SS in the eThekwini Metro (data set 1, broad-scale), KZN SS outside the eThekwini Metro (data set 2, broad-scale) and for the entire KZN SS (data set 3, broad-scale) using broad-scale data.

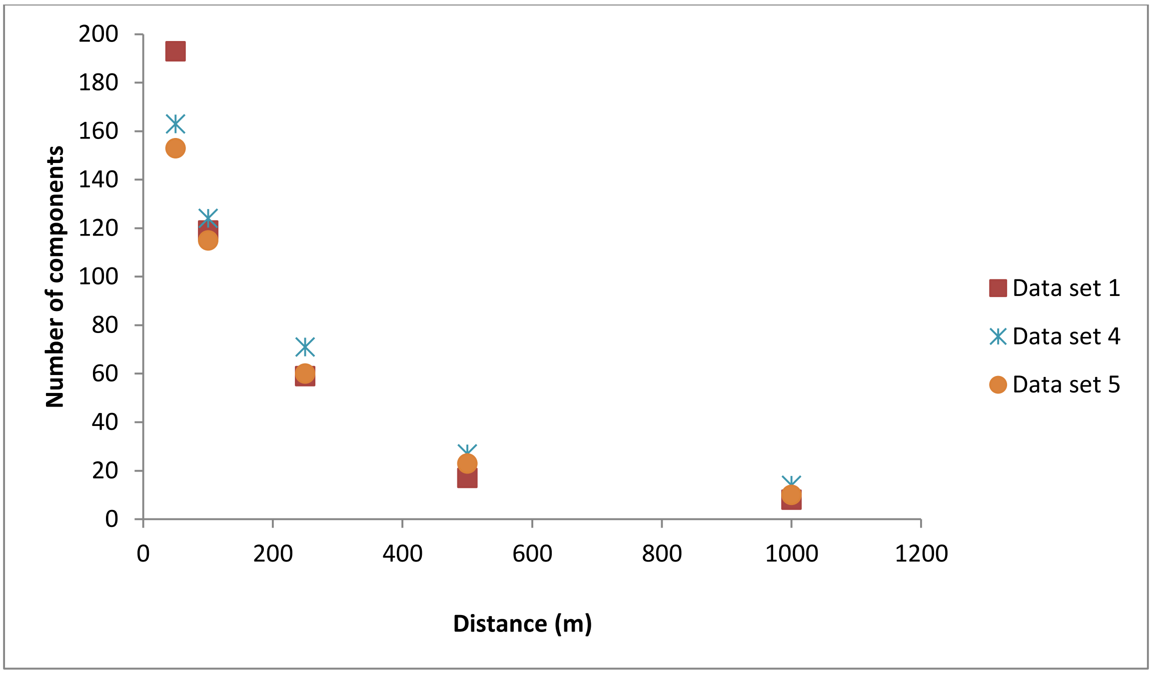

Figure 3.2 - Changes in habitat fragmentation (expressed as the number of components) for KZN SS in the eThekwini Metro (data set 1, broad-scale), KZN SS patches in a pristine ecological condition within the eThekwini Metro (data set 4, fine-scale), and patches of KZN SS in different ecological conditions within the eThekwini Metro (data set 5, fine-scale) using broad and fine-scale data.

The KZN SS is highly fragmented at a small dispersal distance and as the dispersal distance increases from 500m onwards, there is a much lower level of fragmentation. The majority of the KZN SS is located outside the eThekwini Metro, and this explains the high number of components seen in data sets 2 and 3 (Figure 3.1) which have an excess of 1200 components, in comparison to data sets 1, 4 and 5 (Figure 3.1 and 3.2), which have less than 200 components. At a dispersal distance of 1000m, the KZN SS's distance within the eThekwini Metro becomes as equally connected to the datasets that are located outside the eThekwini Metro. As a result, the number of components between the datasets at this dispersal distance has been drastically reduced and is quite similar. The number of components is considerably less when fine-scale data is used. Furthermore, the number of components can be observed to have changed substantially when small dispersal distances are used for fine-scale data. However, with the use of large distances, it can be noted that fine-scale data does not show such a major difference. The slight variation between data sets 4 and 5 in Figure 3.2, shows that the inclusion of patches, regardless of their ecological condition does not have a substantial impact upon the level of fragmentation experienced.

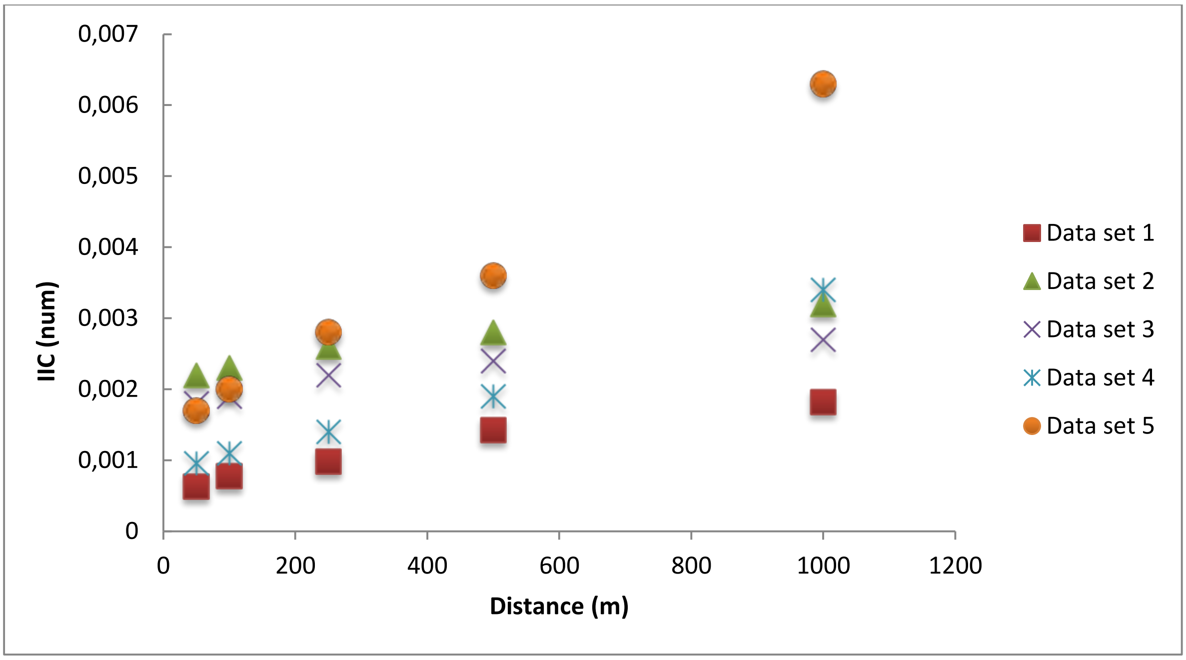

Figure 3.3 - Overall landscape connectivity (expressed as the integral index of connectivity (IIC)) for the SANBI vegetation map with patches of KZN SS within the eThekwini Metro (data set 1, broad-scale), KZN SS patches in the SANBI vegetation map outside the eThekwini Metro (data set 2, broad-scale), for the entire KZN SS in the SANBI vegetation map (data set 3, broad-scale), for KZN SS patches in the 2011 vegetation map in a pristine ecological condition within the eThekwini Metro (data set 4, fine-scale), and patches of KZN SS in the 2011 vegetation map in different ecological conditions within the eThekwini Metro (data set 5, fine-scale).

The overall landscape connectivity of the KZN SS for each of the different data sets is depicted in Figure 3.3. The general trend displayed for each data set is an increase in connectivity as the dispersal distance increases. The inclusion or exclusion of degraded patches had an important impact upon the overall landscape connectivity. Data set 5 (Figure 3.3), which took into account degraded patches, showed a considerably higher level of connectivity. This outcome was expected, and it indicates that it is possible for degraded patches to be stepping stones between more desirable habitat. In addition, degraded patches are considerably important for species with a dispersal distance in excess of 500m, evident by the higher IIC. There is an important difference between the uses of either broad or fine-scale data evident in Figure 3.3. At 1000m, both broad-scale and fine-scale data, which dealt with patches within the eThekwini Metro have a substantial difference of 85% in their connectivity levels. This is a considerable difference. The broad-scale dataset only captured large patches and did not capture many of the smaller patches. The small patches (included in the fine-scale data) increased the level of connectivity. Broad-scale data tends to underestimate levels of connectivity. The patches located within the eThekwini Metro show a higher level of connectivity, possibly owing to the smaller distance covered within the Metro as compared to the distance covered by the entire extent of the KZN SS.

Moreover, the KZN SS patches were depicted to be highly connected, with only 8 different components and 96.12% of the total habitat patch area in the main component at a dispersal distance of 1000m in data set 1 (see Appendix A, Table A1). This indicated however, that there were still 8 components which had no connections between them whatsoever, and that most habitat patches were connected in one large component. The number of components increased drastically as the dispersal distance was decreased (Figure 3.1). This can be observed with the dispersal distance of 50m whereby there were 193 different components and the proportion of patch area within the main component dropped drastically to 47.7% (Table A1). This trend is expected due to the fact that when the dispersal distance is increased, more patches become connected to one another. In comparison, data set 3, which depicts the entire extent of the KZN SS, shows an important decrease in patch area percentage (59.70%) at a 1000m dispersal distance (see Appendix A, Table A3). This result indicates that due to the smaller distances covered within the eThekwini Metro, more patches of KZN SS can form part of a larger component. This provides better connectivity as compared to the patches located out of the Metro, which have larger distances to contend with in order to form part of a larger component.

A further comparison between data sets 4 (see Appendix A, Table A4) and 5 (see Appendix A, Tables A5) indicates that when the degraded patches were excluded, the proportion of patch area in the main component increased for both the 50m and 1000m dispersal distances. Additionally, data set 4 (without degraded patches) showed a lower level of connectivity than data set 5 (with degraded patches) (Figure 3.3). These result combined is surprising, as a lower level of connectivity for data set 4, generally implies a decrease in the proportion of patch area in the main component. There is a considerable difference between the uses of broad or fine-scale data. At smaller dispersal distances the number of components of fine-scale data changes substantially, resulting in the high patch area percentage within the main component (Tables A4 and A5).

3.4.2 Determining connectivity

The individual importance of each patch with regards to the level of connectivity of the landscape can be seen depicted in Figures 3.4, 3.5, and 3.6. The importance of each patch, and therefore the loss of connectivity should this patch be lost, is shown. The regions highlighted in red are seen as being the most connected and hence are essential in ensuring the connectivity of the region. Most of the patches essential to connectivity are located outside the eThekwini Metro. There are six patches which are crucial to connectivity levels located outside the eThekwini Metro, of which, patch ‘C’ is the most crucial patch in the landscape with regards to connectivity (Figure 3.4). Patches ‘A’ and ‘B’, located in the Metro are seen as the most important with regards to connectivity (Figure 3.5A and 3.6A). However, they only hold a moderate level of importance to connectivity when placed in the broader spectrum of the landscape (Figure 3.4).

The majority of the important patches are located away from the N3, as roads have the ability to either act as conduits or as a barrier, and in so doing, inhibiting movement of mammals and reptiles. Furthermore, as the dispersal distance is increased, the level of connectivity is seen to also slightly increase. The inclusion of degraded patches has shown to increase the connectivity levels of a number of different patches within the landscape. This is evident upon examination of patches ‘1’, ‘2’, ‘3’ and ‘4’ which increase in connectivity with the inclusion of degraded patches regardless of dispersal distance (Figures 3.5B-C, 3.6B-C). In addition, this result is further strengthened by previous results gathered, which indicate a similar outcome (Figure 3.3). There are noticeable differences between the uses of broad and fine-scale data. This is evident between Figures 3.5A & 3.6A (broad-scale data) and Figures 3.5B& 3.6B (fine-scale data). One can see that patches ‘A’ & ‘B’ have been broken down into smaller fragments of KZN SS that do not hold as much importance as patches ‘A’ & ‘B’ did in Figure 3.5A & 3.6A (broad-scale). Furthermore, the group of fragments identified as ‘1’ (in the fine-scale data), which holds a relatively high importance is missing (Figure 3.5A-B).

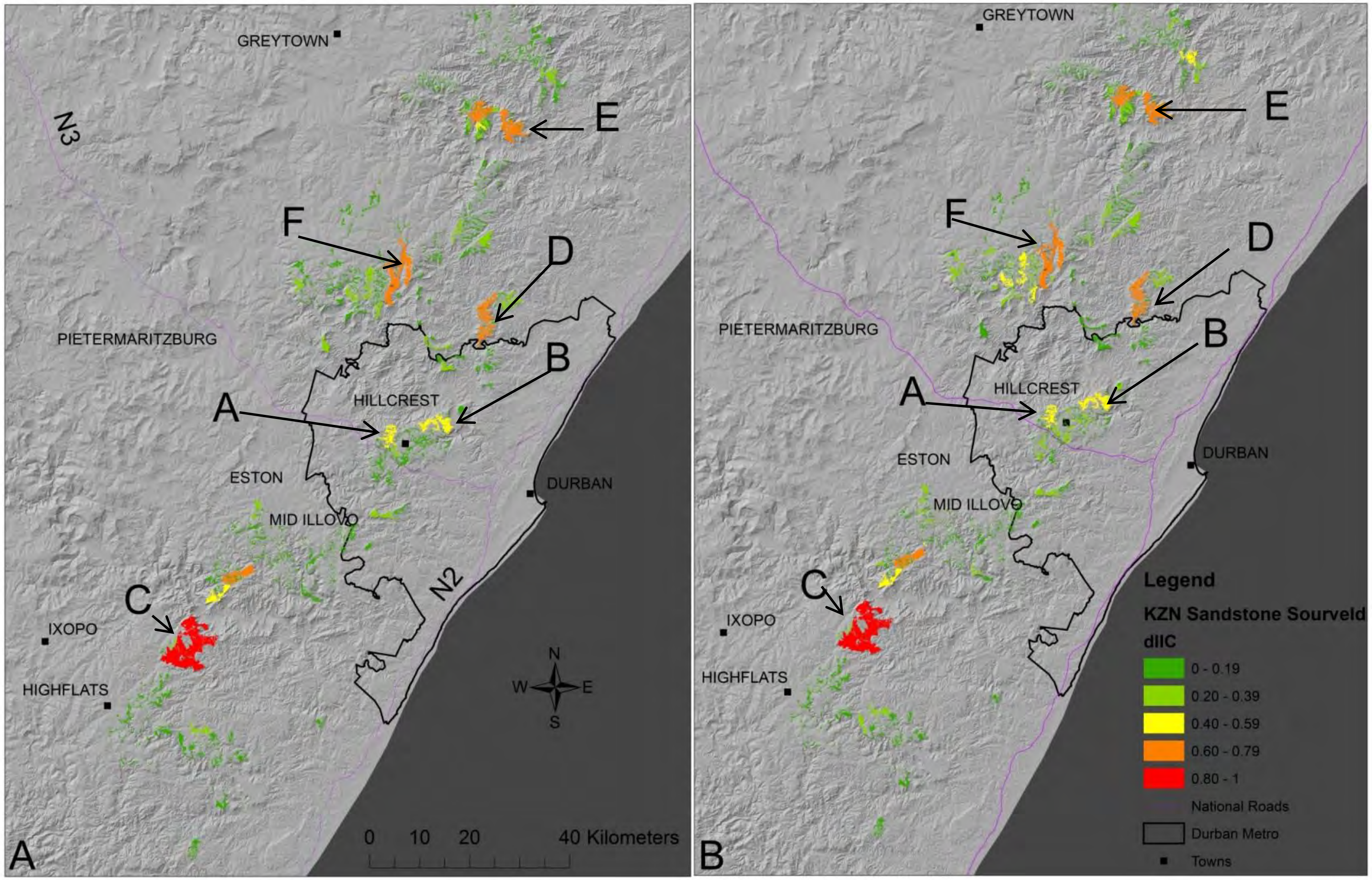

Figure 3.4 - The importance that each patch of KZN SS in a natural condition, contributes towards the connectivity (expressed as the delta integral index of connectivity, the output values range from 0 – 1, with 1 highlighting optimal connectivity) for the entire KZN SS within the SANBI vegetation map (broad-scale, data set 3), based on A) 50m dispersal and B) 1000m dispersal distance.

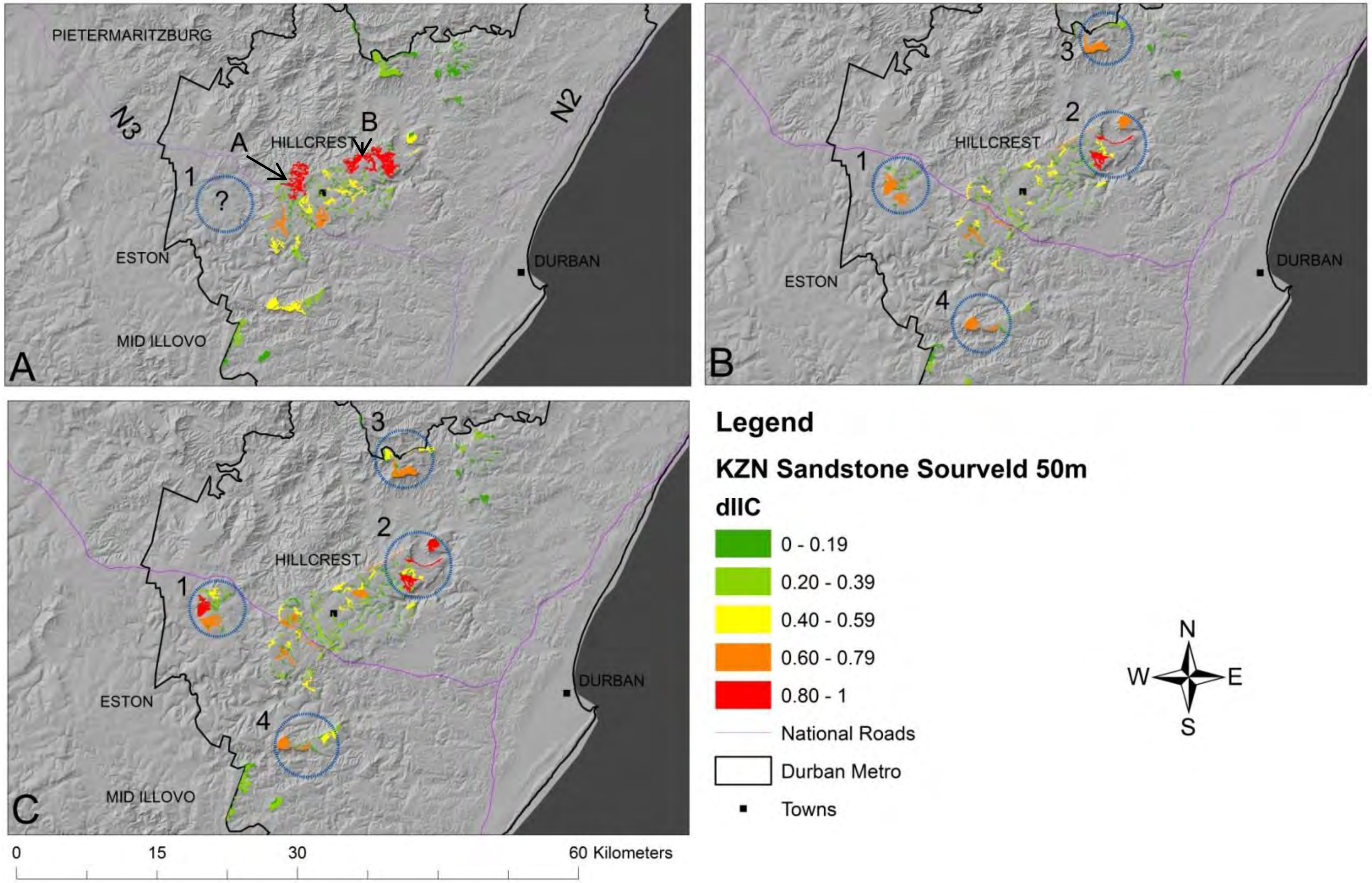

Figure 3.5 - The importance that each patch of KZN SS contributes towards the connectivity (expressed as the delta integral index of connectivity, the output values range from 0 – 1, with 1 highlighting optimal connectivity) of KZN SS patches that fall within the eThekwini Metro at a dispersal distance of 50m, based on: A) data set 1 (broad-scale), B) data set 4 (fine-scale, with patches of KZN SS in a pristine ecological condition), and C) data set 5 (fine-scale, with patches of KZN SS in different ecological conditions).

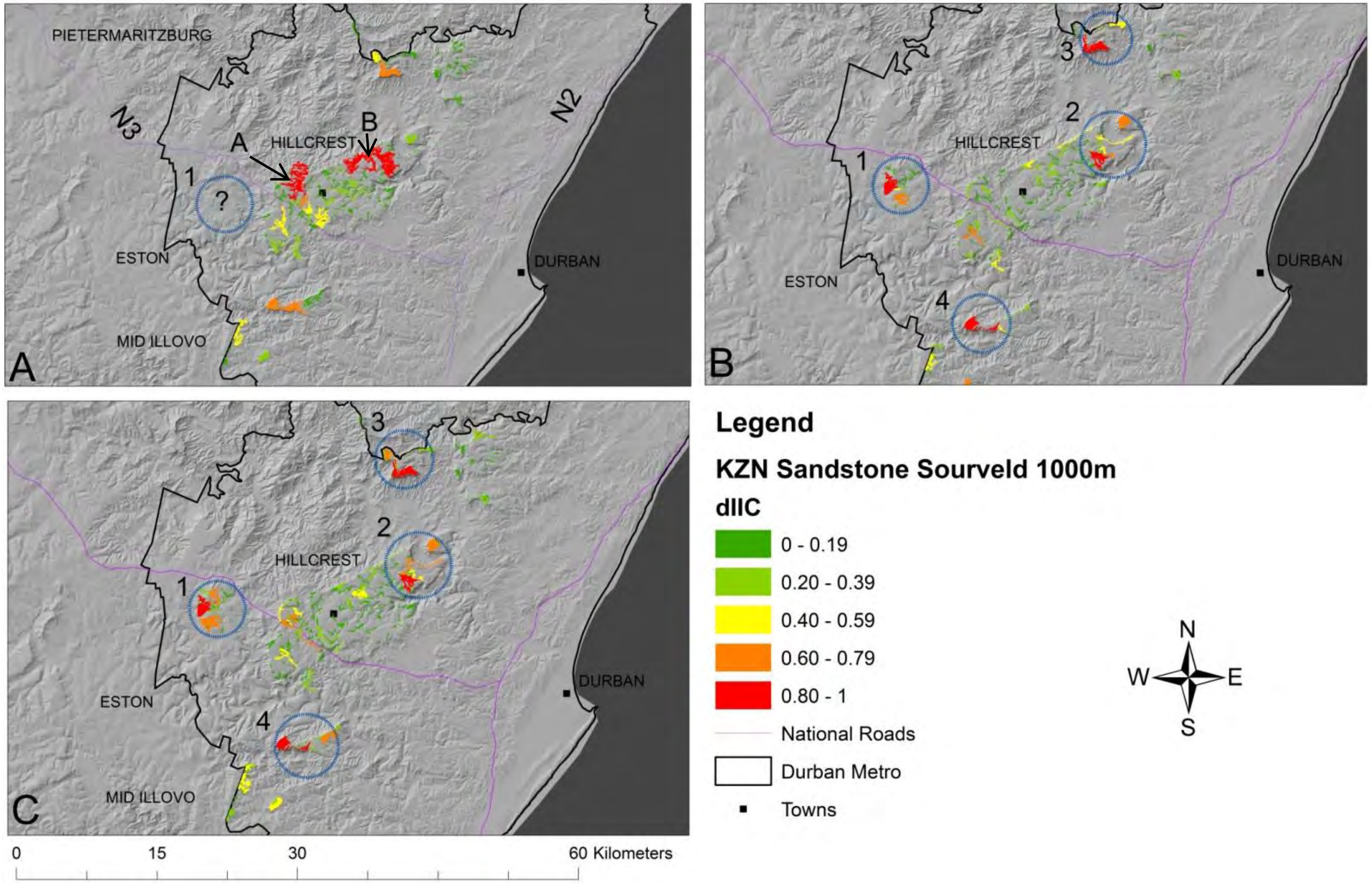

Figure 3.6 – The importance that each patch of KZN SS contributes towards the connectivity (expressed as the delta integral index of connectivity, the output values range from 0 – 1, with 1 highlighting optimal connectivity) of KZN SS patches that fall within the eThekwini Metro at a dispersal distance of 1000m, based on: A) data set 1 (broad-scale), B) data set 4 (fine-scale, with patches of KZN SS in a pristine ecological condition), and C) data set 5 (fine-scale, with patches of KZN SS in different ecological conditions).

3.5 Discussion

The study ascertained that the KZN SS is not very well connected with the highest IIC value amongst the data sets recorded at 0.0063 (data set 5) (Figure 3.3). This IIC value is considerably low in comparison to data obtained by Fourie (2015) for the Mpumalanga grasslands, where the lowest IIC value was recorded at 0.049 for a 1000m dispersal distance. The low connectivity level for the KZN SS is directly linked with the high degree of habitat loss and fragmentation currently being experienced. Garcia-Feced *et al* (2011) carried out a similar study for forests in the Mediterranean, which yielded minimum IIC values of 0.45, this outcome further stresses the detrimental state that connectivity levels for the KZN SS exist.

3.5.1 Understanding the implications of habitat fragmentation

The results obtained for the level of fragmentation of the KZN SS portrayed that the ecosystem is heavily fragmented as compared to its naturally occurring state. Figure 3.1 for data sets 2 and 3 indicates that species with a smaller dispersal distance (less than 200m, i.e. smaller mammals such as grassland mice) would be impacted dramatically by habitat fragmentation. Species with smaller dispersal distances are equally, if not more greatly affected by habitat fragmentation over longer periods (Cushman, 2006).

The result of smaller dispersal distances showing greater levels of fragmentation could dictate that food webs will begin to be affected. Species with smaller dispersal distances may not be able to move freely if patches of KZN SS aren't well connected. This in essence could lead to an extinction of the species in that particular isolated patch. The extinction of species within an isolated patch can be brought about by the resident species population depleting the resources that is sparsely available in that isolated patch. Trenham *et al* (2000), highlighted how important it is for patches to be connected, by concluding that the California Tiger Salamander population is a sink that would face extinction if substantial immigration was not to occur. Fragmentation levels for data sets 2 and 3 starts to stabilise at dispersal distance of around 500m. Predators usually have larger dispersal distances (LaRue and Nielsen, 2008). Thus a stabilization of fragmentation around 500m is preferential as a surplus of predators in isolated patches will be avoided. An example of predators can be seen with Larks, which are insectivorous birds that have a dispersal distance of around 400-600m (Wells *et al*, 2008).

A consequence of high levels of habitat fragmentation is a loss of habitat heterogeneity. This is brought about when individual fragments lack the full range of habitats that was found in the original main patch prior to fragmentation. Species in isolated patches or species that use a range of microhabitats are especially vulnerable to extinction under these conditions (Wilcove *et al,* 1991). Furthermore, high levels of fragmentation, which are being experienced outside the eThekwini Metro, could bring about a lack of connectivity between the different fragments that have now become separated from the main fragment. This result restricts the movement ability that species previously possessed when the main patch was not fragmented.

3.5.2 Dealing with the effects of connectivity

Fragmented regions that are well connected enable a corridor to form which facilitates the movement of species between the different habitat fragments (Urban and Keitt, 2001). It is important to ascertain the overall level of connectivity between different fragments of KZN SS due to the high levels of fragmentation presently being experienced by the ecosystem. The overall results from the analysis of the connectivity between patches of KZN SS showed that the level of connectivity is very low and thus species persistence is under threat.

A comparison between the broad-scale data for both in and out the eThekwini Metro showed that the habitat patches outside the eThekwini Metro had a higher level of connectivity. This outcome was induced by the majority of KZN SS patches in the Metro being located outside of the vicinity of the eThekwini Metro. In addition, the broad-scale data in the Metro depicted a much higher percentage of patch area in the main component throughout the different dispersal distances and a greater number of patches being connected and within the main component, as compared to data set 2 (Tables A1 and A2). This reiterates and supports the connectivity data and thus signifies how important the patches of KZN SS are with regards to the interaction of the grasslands biome in KZN.

The results gathered from the broad-scale data indicate that patches ‘A’ and ‘B’ (Figure 3.5A & 3.6A) are crucial with regards to the connectivity of the KZN SS. However, the fine-scale data indicates that these patches have now become fragmented and thus it is of paramount importance that patches ‘1’, ‘2’ and ‘4’ (Figure 3.5C & 3.6C) are protected and properly managed in order to facilitate species mobility and persistence. A few of the smaller fragments observed in Figures 3.5B & 3.6B (fine-scale) show a greater importance within the landscape, possibly due to the elapse of time between the data sets. This aspect solidifies the notion that fine-scale data displays a greater amount of detail and a higher level of connectivity at smaller distances. The broad-scale dataset over-estimated the level of habitat fragmentation, whilst fine-scale data showed a higher IIC, possibly due to more stepping stone patches for species to transverse. Patch ‘D’(Figure 3.4) may be of some interest to the municipality, as although it falls outside the boundary, it is still in a fairly close proximity and may be crucial for species dispersal ability into patches ‘1’ and ‘4’. It may be in the municipality’s best interest to acquire, or aid in the maintenance of this patch.

Furthermore, it was ascertained that the inclusion of degraded patches did aid in improving connectivity levels. This outcome was expected, as it was previously assumed that the degraded patches may be used as a stepping stone/ natural corridor by species with a smaller dispersal distance to gain access to pristine patches. This would have in turn increased the connectivity in this fragmented region. For example, Fourie *et al* (2015) obtained a similar outcome in their study on the connectivity of the grasslands in Mpumalanga. This particular outcome could be of use to the eThekwini municipality, as it indicates that it might be in the municipality’s best interests to rehabilitate degraded patches, in order to ensure the longevity of pristine patches as they appear to better ensure the connectivity of the landscape.

It must be taken into account that the dispersal distances used were of a general dispersal distance that could be applied to different species, and that the results produced may not necessarily reflect the movement patterns of all the organisms in the landscape. It should be noted that this study did not take species-specific data, which is important for the measurement of functional connectivity, into account. The reason that species-specific data was not taken into account was due to: the large area; various different data sets; ecological conditions of patches; and dispersal distances used. It would have been beyond the scope of the study to account for the criteria noted above, in addition to all the dispersal distances and habitat preferences of each species in the landscape. Future studies in this particular facet would be extremely valuable in ensuring the longevity of this endangered ecosystem.

3.5.3 Are landscape corridors the solution to the problem faced?

This study has ascertained that the KZN SS is highly fragmented with low levels of connectivity, which could result in habitat loss and a decrease in species persistence. As a result, measures need to be put into place to rectify the problem faced and attempt to ensure the longevity of this ecosystem within the landscape, whilst simultaneously not drastically hindering the activities that are being carried out within the eThekwini Metropolitan region.

The best way in which to ensure that the connectivity within the landscape starts to increase is to; firstly ensure the protection of the most essential patches identified within the Metro, patches '1', '2' and '4' (Figure 3.5C and 3.6C). Secondly, a route between the most essential and pristine patches is required to facilitate species dispersal, this will aid in connectivity as well as species persistence within the landscape. The most feasible manner in which to carry this out is to form a landscape corridor, which places the essential habitat patches as key regions within the corridor. A landscape corridor is simply strips of habitat that connects isolated patches of habitat; they can be seen as a lifeline for species that are unable to disperse to other patches (Bennett *et al*, 1994; Doko *et al*, 2011). Landscape corridors are considered a useful tool for conservation biodiversity.

The eThekwini Metro may be considered a difficult environment in which to design a landscape corridor due to the distribution of land uses within the Metropolitan area. As a result, various contributing aspects need to be considered prior to a landscape corridor being identified and derived. These aspects include the PAN, the DMOSS, the level of connectivity of different patches of KZN SS, and lastly the type of land-use within the areas of interest. The identification and design of possible landscape corridors for use within the eThekwini Metro will be addressed in the forthcoming Chapter.

3.5.4 The quantification of habitat fragmentation

Habitat fragmentation is a well-versed field of study, with considerable research available on the topic. With the amount of research having been carried out on habitat fragmentation, it is surprising that there is still no standardised method employed to quantify habitat fragmentation. Consequently, this study will proceed in evaluating the current methods utilised to quantify habitat fragmentation.

This was a manipulative study, which enabled the control over different aspects and thus permitted greater inferences about the fragmentation and connectivity levels of the KZN SS to be made. Moreover, the method employed aided in the pinpointing of important criteria, such as the patches' individual contribution to the connectivity of the landscape (McGarigal and Cushman, 2002). The method employed has a number of positive aspects that advocate towards its future usage. These advantages include: first, the response to changes in intensity of landscape use allows landscape trends to be identified, particularly in aspects of quality; Second, it has an intuitive interpretation, with the distinct changes in the ratios being easy to track (Young and Jarvis, 2001); Third, it is not overly sensitive to the omission or addition of very small residual areas; Fourth, it has a minimal data input, particularly relative to the more traditional complex approaches; and last, it is mathematically straight forward, allowing for the concept to be easily grasped (Nikolakaki, 2004).

Furthermore, the process applied is systematic, flexible and reproducible. Moreover, the study has demonstrated the utility and feasibility of using a GIS. The use of a GIS enhanced the capability to view habitat fragmentation within a broader landscape context and not just from individual sites (Nikolakaki, 2004). There are practical limits to the area that can be manipulated in experiments. This disqualifies many important large-scale phenomena from manipulative experiments. Fragmentation is a landscape level process and thus the study of fragmentation requires large landscapes to be dealt with, this method caters for large regions of habitat to be worked with. Moreover, Fourie *et al* (2015) employed a similar method in her study of the landscape connectivity of the grassland biome in Mpumalanga, which further advocates for the future use of this method in quantifying habitat fragmentation.

The downfall with this method is that the study is only as accurate as the data that is available. The current state of fragmentation of a landscape may not be determined if current data is not up to date. In addition, there is a lot of pre-processing that has to be done prior to the analysis being carried out. This denotes that the proposed method may be time consuming if there is a lot of data to be processed.

The two different types of data sets that were used had certain noticeable discrepancies between them. The fine-scale data depicted a more apt description of the current state of the KZN SS. This was due to the more recent 2011 vegetation map (fine-scale) showing how the different patches of KZN SS have become fragmented since 2006. In addition, the fine-scale data also included patches of KZN SS that have been completely excluded from the broad-scale data. The fine-scale data is better to use, not only because it's a newer data set and hence shows a more pertinent depiction of what the KZN SS looks like, but the smaller extent of the fine-scale adds to its level of accuracy which is evident by the broad-scale data not mapping large patches of KZN SS.

The positive applications of this method to quantify habitat fragmentation far outweigh any potential negatives. As a result, this method of quantifying habitat fragmentation could be seen as a more viable and simpler means of carrying out this process.

3.6 Conclusion

In summary, the study ascertained that the KwaZulu-Natal Sandstone Sourveld is a highly fragmented landscape, which has resulted in very low connectivity levels between fragments in the eThekwini Metropolitan area. This situation needs to be addressed if species within the KZN SS are to persist. In addition, the inclusion of degraded habitats is seen to increase landscape connectivity. It is important to note that in this instance degraded habitats will vary, depending on the manner in which they have been degraded. For example, patches that have been degraded by grazing regimes may provide a healthier stepping stone for species, as opposed to patches that have been degraded due to direct transformation. Moreover, broad-scale data overestimates habitat fragmentation but underestimates landscape connectivity, whereas fine scale data and appropriate distance thresholds are required to prioritise patches of KZN SS for conservation. Additionally, the study has identified priority areas that are essential to the landscape. Finally, it has offered a method in which to quantify habitat fragmentation which could be seen as a more viable and more convenient process as compared to circuit or network theory.

CHAPTER 4: DESIGNING LANDSCAPE CORRIDORS TO IMPROVE CONNECTIVITY LEVELS OF THE KWAZULU-NATAL SANDSTONE SOURVELD WITHIN THE ETHEKWINI METROPOLITAN REGION.

4.1 Abstract

KwaZulu-Natal Sandstone Sourveld (KZN SS) has been identified as being critically endangered, and is in urgent need of conservation due to urbanisation and agriculture pressure. The KZN SS is a highly fragmented landscape with low connectivity levels (see Chapter 3). Ensuring the connectivity of the landscape is vital with regards to sustaining the biodiversity and species persistence within the region. As such, landscape corridors are considered as the most efficient way to aid in increasing the connectivity and biodiversity within a fragmented landscape. This chapter set out to design appropriate landscape corridors within the eThekwini Metropolitan area in order to improve the connectivity levels of the KZN SS. In addition, the importance of the Protected Areas Network (PAN) and the Durban (eThekwini) Metropolitan Open Space System (DMOSS) was assessed. A least-cost analysis was conducted in ArcGIS to determine the best option for a landscape corridor within the eThekwini Metropolitan area. This analysis took into account the priority areas of KZN SS identified (see Chapter 3), the protected areas network, and the DMOSS. Two landscape corridors were created, which succeeded in adhering to the stipulated criteria. Both corridors included as much of the KZN SS and DMOSS as possible, whilst avoiding highly urbanised areas. In order to evaluate the effectiveness of the criteria used, two more corridors were created. These control corridors only used the land-use and the KZN SS layers to inform the landscape suitability for the corridors. Regardless of the DMOSS being excluded from the design of the control corridors, the corridors still proceeded through regions of the DMOSS. This indicated that important conservation regions are found within the DMOSS. Two landscape corridors have been designed to facilitate movement across the landscape for KZN SS species and thereby combat the effects being experienced by habitat fragmentation. The situation needs to be addressed soon, so that further loss in species persistence is not experienced.

Keywords: *landscape corridors, urban green spaces, corridor design, improving connectivity levels.*

4.2 Introduction

The degradation of natural habitat is a damaging occurrence, predominately brought about through human activities such as urbanisation and agriculture. A by-product of this is often experienced as habitat loss and fragmentation. The culminations of these effects are considered to be a considerable threat to global biodiversity (Hanski, 1999; Fahrig, 2001; Schooley and Wiens, 2003; Lindenmayer and Hobbs, 2005). In addition landscape connectivity, which is crucial to species persistence, is often negatively impacted due to habitat loss and fragmentation (Urban and Keitt, 2001). Consequently, the management of landscape connectivity is often a concern within ecology and biodiversity conservation (Fahrig, 2001; Lindenmayer and Hobbs, 2005; Miller, 2005; Visconti and Elkin, 2009). The grasslands biome has become one of the most devastated biomes because of habitat loss and fragmentation (Tarboton, 1997). Although there is some controversy over the classification of this vegetation type, the KwaZulu-Natal Sandstone Sourveld is considered part of the South African grasslands biome (but see, Mucina and Rutherford, 2006). It is distributed entirely within the province of KwaZulu-Natal and it has been identified as being critically endangered, and is in desperate need of conservation (Olsen and Dinerstein, 1998; Mucina and Rutherford, 2006).

The previous chapter, which quantified the levels of fragmentation and connectivity of the KZN SS, has ascertained that it is a highly fragmented landscape with very low connectivity levels between fragments in the eThekwini Metropolitan area. Ensuring the connectivity of the landscape is vital with regards to sustaining the biodiversity and species persistence within the region. As such, landscape corridors are considered as the most efficient way in which to aid in increasing the connectivity and biodiversity within a fragmented landscape.

Corridors are predominately seen as regions of habitat that are connected in a manner that enables and facilitates the movement of biota (Bennett *et al*, 1994; Doko *et al*, 2011). Studies have established that the detrimental effects which habitat fragmentation poses towards a landscape can be reduced once a landscape corridor has been created (Bennett *et al*, 1994; Chetkiewicz *et al*, 2006). Corridors have been found to facilitate the interactions of biota between previously inaccessible regions of habitat (Bennett *et al*, 1994; Doko *et al*, 2011). However, the design and implementation of corridors has been subjected to a scrupulous amount of controversy. The design of landscape corridors requires taking into account issues of implementation. The design of corridors should in essence focus predominately on ensuring the long term persistence of biodiversity in the landscape (Chetkiewicz *et al*, 2006). Corridors enable the long term persistence of biodiversity in a number of different ways (see Chapter 2). Additionally, corridors enable both humans and animals to occupy relatively the same area, which is crucial in urban green spaces (Bennett *et al*, 1994; Chetkiewicz *et al*, 2006). There are some limitations pertaining to the design and implementation of landscape corridors. One of the major limitations is the design of landscape corridors for a specific focal species (Simberloff, 1998; LaRue and Nielsen, 2008; Doko *et al*, 2011). The implementation of a single-species corridor for large carnivores is a prime example of this design flaw (LaRue and Nielsen, 2008; Doko *et al*, 2011). Often, large carnivores are seen as the keystone species to model corridors on, as they often occur at low densities and are often the first to be harmed by a loss of connectivity (Simberloff, 1998; LaRue and Nielsen, 2008; Doko *et al*, 2011). This may result in a negative umbrella effect for other species which are habitat specialists with limited mobility (Simberloff, 1998; LaRue and Nielsen, 2008; Doko *et al*, 2011). Due to this occurrence, the landscape corridors that we have designed do not rely upon a keystone species but were rather designed as a landscape feature that enables dispersal for a wide range of biota, as such the landscape corridors should improve biodiversity persistence.

The quantification of habitat fragmentation can be used to assist land-use planning, especially within an urban context. Through determining the level of habitat fragmentation of a region, certain areas which are vital for connectivity can be identified in a timely manner and properly managed. The most effective way in which to manage habitat fragmentation is through improving connectivity levels within the landscape. This chapter aims to design appropriate landscape corridors within the eThekwini Metropolitan area in order to improve the connectivity levels of the KZN SS. Furthermore, the actual importance of the PAN and the DMOSS is assessed.

4.3 Materials and methods

4.3.1 Data acquisition and pre-processing

The study area comprises of the KZN SS vegetation type, which is located in KwaZulu-Natal, both within and out of the eThekwini Metropolitan area (see Chapter 1, Figure 1.1). The development of landscape corridors within an urban environment requires up to date information on the spatial extent and the distribution of land-use activities, information usually derived from land-cover maps. Additionally, criteria used to dictate the function of the corridor need to be factored in. The purpose of the landscape corridors within this study, was to improve the connectivity levels of the KZN SS within the eThekwini Metropolitan area. In order to accomplish this, various criteria had to be considered. Firstly, the corridor had to include patches of habitat with moderate to high connectivity levels, derived in the previous chapter (Figure 4.1). Secondly, in order to facilitate the development/ implementation of the corridor, it was preferable for the corridor to fall within the PAN (Figure 4.2) or the DMOSS (Figure 4.3). Thirdly, the type of land-use the corridor is exposed to was important, as natural regions could be perceived as easy transitional barriers to transverse, however urban areas could be seen as solid barriers (Figure 4.4). Lastly, the current state of ownership of the land had to be examined, as a corridor that predominately consists of municipal land will be easier to implement as opposed to one that is comprised mostly of private land. Table 4.1 displays the main data sets used to carry out the study and where the data sets were acquired from.

Table 4.1- Data sources used in the identification of corridors

Name	Description	Year	Source	Extent
KZN_SS Connectivity	50m fine scale KZN_SS connectivity layer	2014	Chapter 3	eThekwini Metro
KZNLC	Landcover	2008	Ezemvelo KZN Wildlife	Provincial
PA	Protected Areas Network	2011	eThekwini Municipality	eThekwini Metro
DMOSS	Durban Metropolitan Open Space System	2011	eThekwini Municipality	eThekwini Metro
Ownership	Ownership of land within the eThekwini Metro	2011	eThekwini Municipality	eThekwini Metro

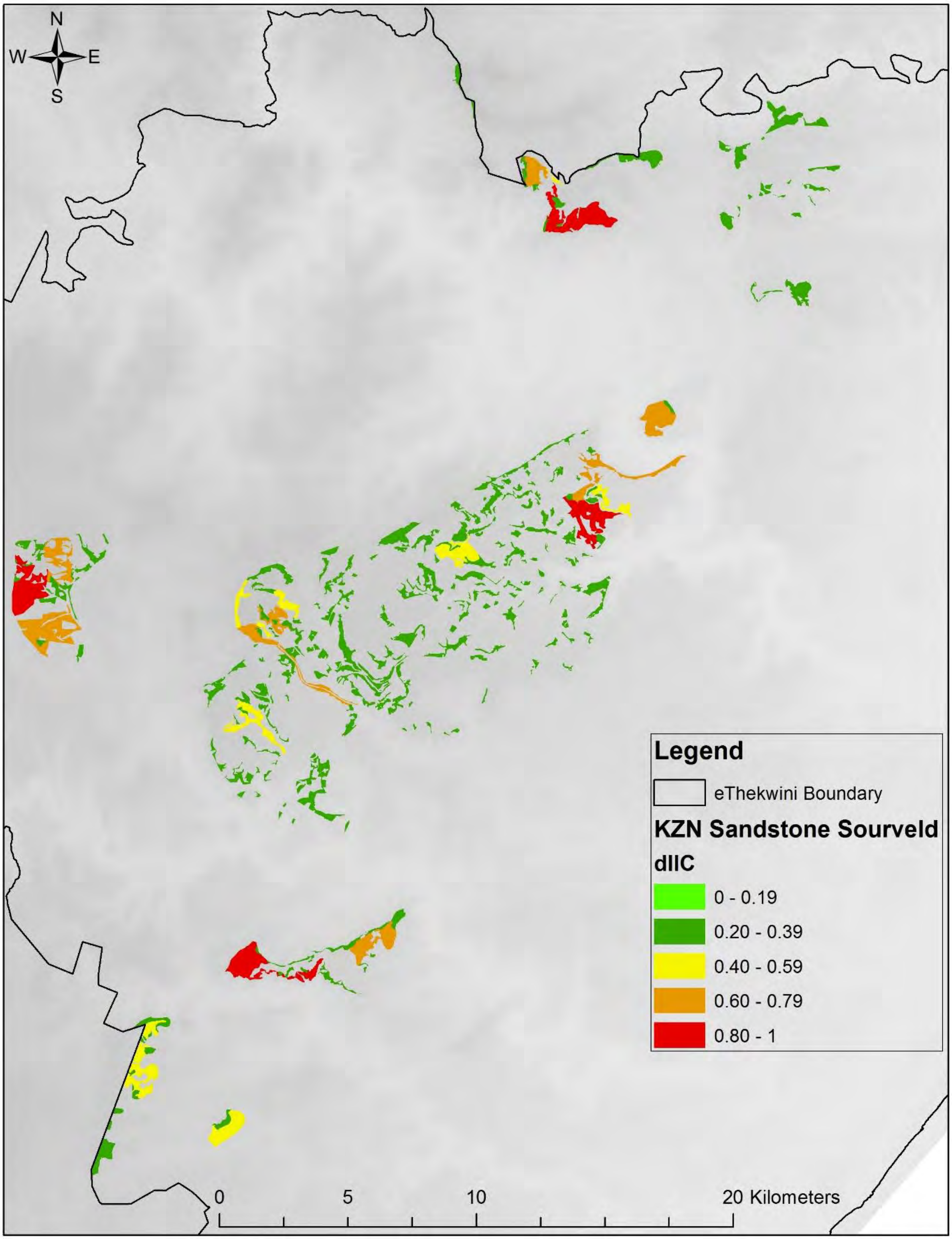

Figure 4.1 – The KZN SS connectivity layer used to conduct the corridor analysis.

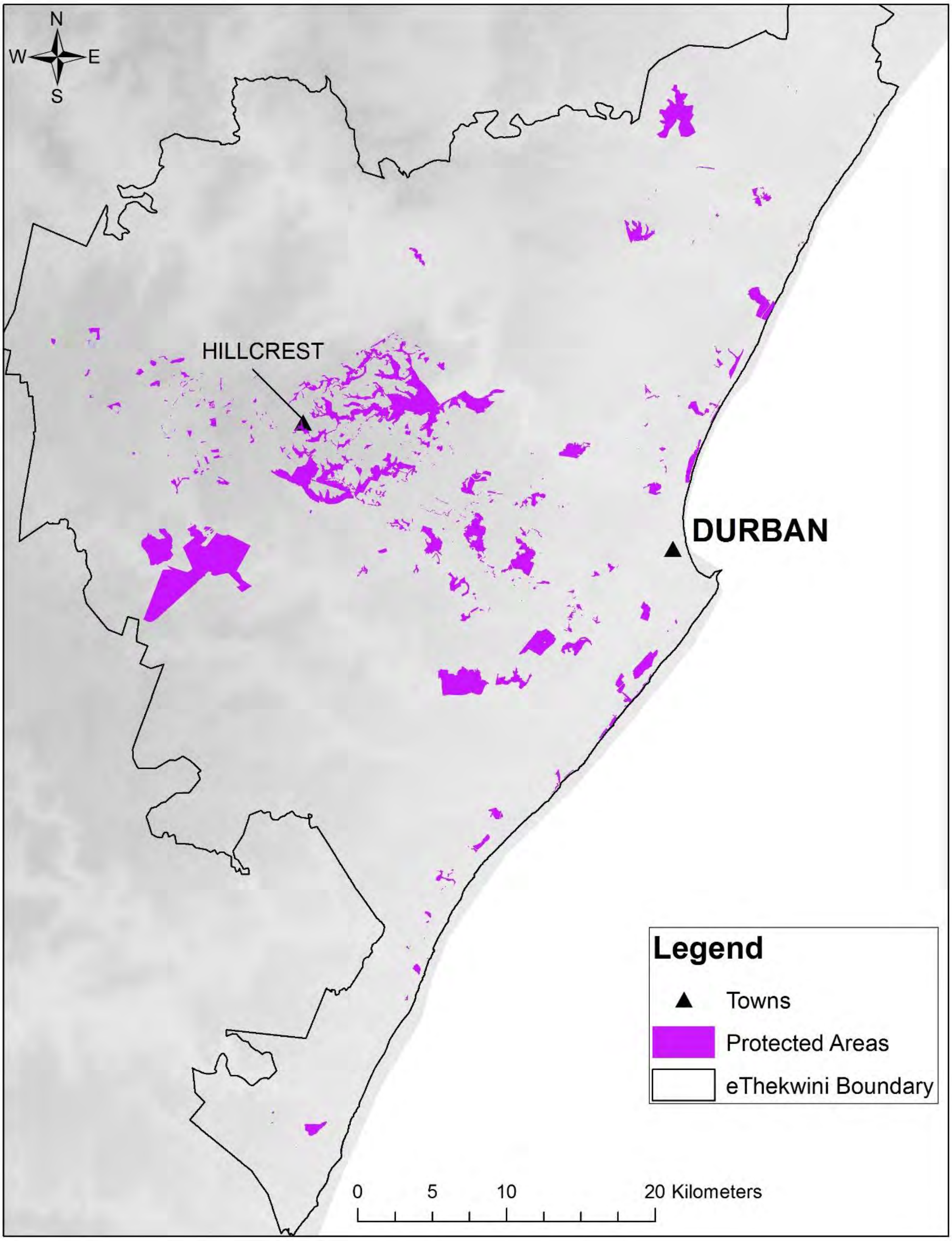

Figure 4.2 – The distribution of the PAN in the eThekwini Metro, used to conduct the corridor analysis.

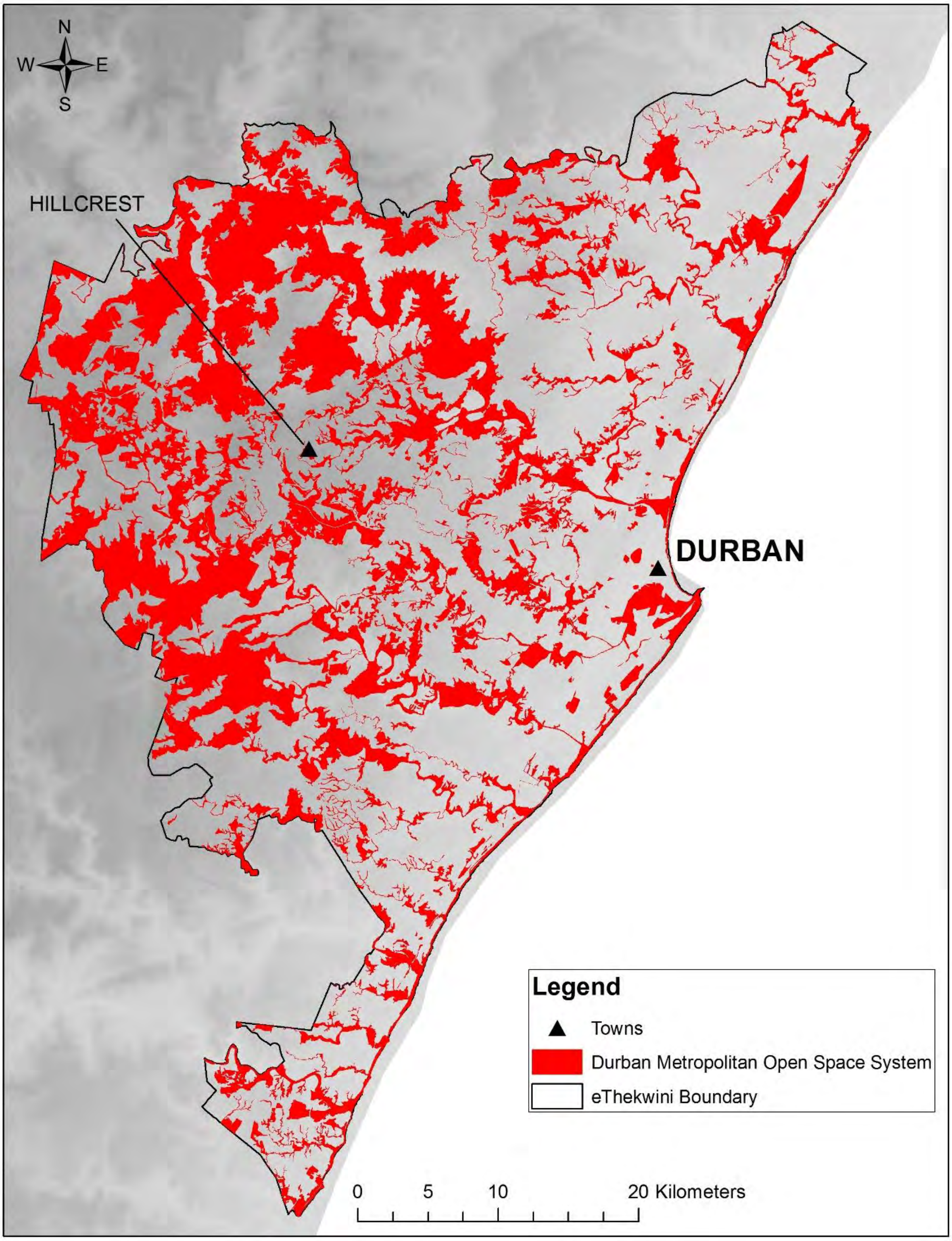

Figure 4.3 – The distribution of the DMOSS in the eThekwini Metro, used to conduct the corridor analysis.

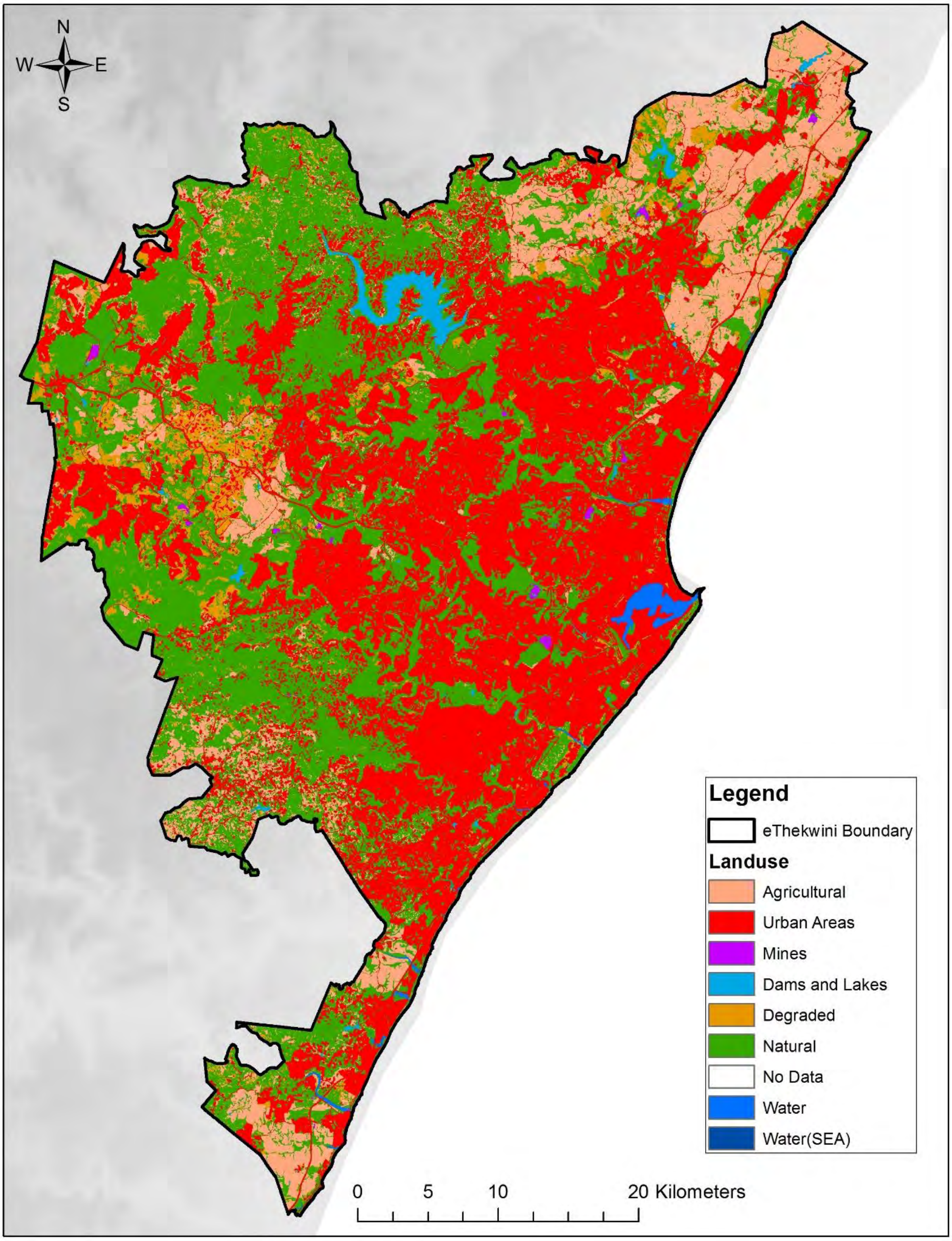

Figure 4.4 – The distribution of land uses within the eThekwini Metro, used to conduct the corridor analysis.

4.3.2 Delineating corridors

The physical and biological characteristics of corridors are essential in determining how corridors function. Corridor connectivity, width, shape, and the arrangement of the plant community are deemed as the most ecologically important factors (Linehan *et al*, 1995; Fleury and Brown, 1997; Rantalainen *et al*, 2004; Zehao *et al*, 2014). The connectivity within the landscape refers to the degree to which all the patches of habitat in the landscape system are connected by the corridor (Hess and Fischer, 2001; Townsend and Levey, 2005; Doko *et al*, 2011). Corridors should thus in essence minimise potential barriers to movements, such as roads, for mammals and reptiles.

Delineation of the landscape corridor considered four primary aspects, namely: the level of connectivity; the PAN, the DMOSS; and the land uses of the region. These attributes were included as they can contribute to persistence and better overall quality of the corridor. This is one of the main aspects that should be taken into consideration during corridor design (see Chapter 2, the different roles of corridors). The important criteria were graded and assigned costs, with the most conducive aspects being assigned lower costs (Table 4.2). The PAN, DMOSS and KZN SS were all attributed lower costs, as these were the most vital parameters for the corridor to adhere to. This will enable the landscape corridors to function as a habitat, conduit, and source for species. With regards to land-use, natural and degraded areas were ascribed a moderate cost, as they can be seen as relatively easy transitional boundaries for biota to transgress. Regions of agriculture and water bodies were attributed a moderately high cost, in the attempt to keep biota from crossing into these boundaries. Finally, all urban and commercialised regions were prescribed a very high cost, as these regions are not easy for biota to transverse and may expose species to edge effects and predation. Through the minimisation of aspects within the corridors that are unconducive to species persistence, barrier and sink functions have been avoided. Two landscape corridors were designed. Corridor 1, which runs from North to South of the eThekwini Metro, and can be seen depicted in Figure 4.5 with an origin point ‘A’ and a destination point ‘B’. Corridor 1 connects the most northerly and southerly patches of KZN SS located within the eThekwini Metro. This corridor was designed in an attempt to facilitate movement from the largest most highly connected patch of KZN SS in the landscape (see Chapter 3, Figure 3.4, Patch ‘C’), which is located South of the eThekwini Metro. It was assumed that the migration of biota from patch ‘C’ may funnel into Corridor 1’s point ‘B’. Conversely, Corridor 2 runs from East to West, and originates at the lowest altitude where KZN SS is present (point ‘C’, Figure 4.5), and then proceeds to the highest altitudinal point of KZN SS within the eThekwini Metro (point ‘D’, Figure 4.5). Corridor 2 was designed on the basis of an upland-lowland gradient, and thereby allowing for the ecological diversification of plant and animal linages, and the migration of biota. Although corridor 1 and corridor 2 serve different purposes, they have been designed to complement one another and work together to improve the overall connectivity of the landscape.

With regards to the width and general shape of the corridor, this was very difficult to dictate within an urban setting, due to the various land uses the corridor was exposed to. The corridor was however designed to progress through protected and natural regions, as much as possible. It should however be noted that corridor width should not be too vast, as a vast width allows species to become lost within the corridor (Fleury and Brown, 1997). Corridor width was not determined for these species due to the wide range of biota within the ecosystem and this corridor was modelled as a landscape feature. The general shape that the corridors undertook was controlled by the easiest and most conducive route which the criteria specified. Many approaches have been suggested to determine appropriate corridor width (Soule and Gilpin, 1991; Bennett *et al*, 1994; Fleury and Brown, 1997), including the requirements of keystone species (Simberloff, 1998). Here we develop notional corridors without explicitly considering its minimum width. Further study will be required to assess minimum corridor width based on species information, not available at the time of study.

Here, the landscape corridors will be viewed successful if they succeed in comprising of: more than 50% of the KZN SS (taking into consideration the small percentage of KZN SS present within the eThekwini Metropolitan area), 50% of the DMOSS (taking into consideration the percentage of DMOSS in the eThekwini Metro), less than 10% of urban areas (considering the large percentage of urban areas located within the eThekwini Metro).

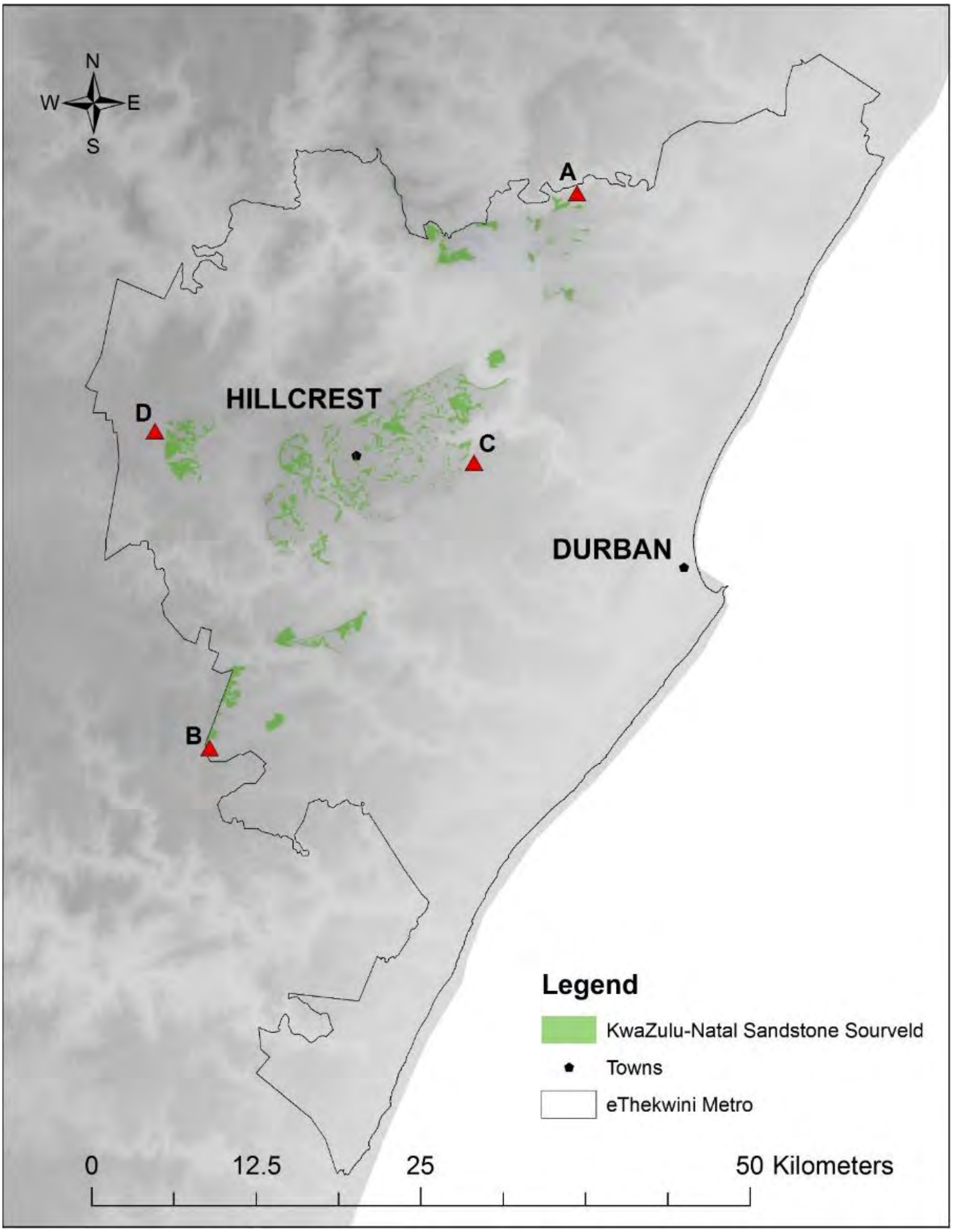

Figure 4.5 - The distribution of KZN SS within the eThekwini Metro and the origin and destination points of corridor 1 and 2. Corridor 1 originates at point 'A' and concludes at point 'B'. Corridor 2 originates at point 'C' and concludes at point 'D'.

4.3.3 The tool used to design the landscape corridor

Least cost analysis is one of the most widely used tools for corridor design and development (Store and Kangas, 2001; Adriaensen *et al*, 2003; Rouget *et al*, 2006). It creates the most conducive route an animal can undertake from one point to another, whilst factoring in both the essential and harmful factors. The analysis essentially assigns lower costs to favourable habitats and higher costs to unfavourable habitats (Store and Kangas, 2001; Adriaensen *et al*, 2003; Rouget *et al*, 2006; LaRue and Nielsen, 2008). A least cost path, which is an adjoining collection of cells that have the lowest cumulative cost as the path moves from one point to another, can be generated in order to carry out a least cost analysis (Store and Kangas, 2001; Adriaensen *et al*, 2003; Rouget *et al*, 2006; LaRue and Nielsen, 2008). This approach does however present some challenges. Assigning appropriate cost values to some of the criteria is difficult (Landford *et al*, 2006; LaRue and Nielsen, 2008). A least cost path was decided upon because it allowed multiple variables to be factored in and as such aided in deriving the least costly route for a landscape corridor to undertake within the eThekwini Metro. A comprehensive analysis of the state of connectivity levels of the KZN SS within the eThekwini Metro was carried out in Chapter 3. This allowed the least cost path analysis to be used to aid in the design and development of the KZN SS landscape corridors within the eThekwini Metro.

4.3.4 The analysis conducted

Firstly, a cost surface raster layer had to be created using the four input layers, namely: the KZN SS connectivity layer, the PAN, the DMOSS, and the landcover layer. The cost surface layer, which shows the opposite of landscape suitability (lower value of the cost surface layer indicating greater suitability) for corridor establishment, would then be inputted into the least cost analysis to inform the spatial location of the landscape corridors. The cost surface raster layer was created by firstly assigning cost values to each one of the input layers and their attributed criteria, the most favourable criteria were assigned a lower cost, and the unfavourable criteria a higher cost (Table 4.2). Costs were assigned by exponentially increasing the cost for unfavourable criteria. The level of connectivity of the KZN SS was considered the most important criteria, followed by: the protected areas network, the DMOSS, and the experienced landcover respectively. The four input layers were then combined via a spatial union to create a cost surface vector layer. Queries were then developed, which took into account every possible combination of the criteria available, and the attributed costs were then inputted into the cost surface vector layer. Once the cost surface raster was derived, the cost path analysis could be carried out in ArcGIS based on the origin and destination points shown in Figure 4.5. This produced the least costly path from point 'A' to point 'B', or corridor 1 in other words. This procedure was then carried out for corridor 2, from point "C" to "D".

Thereafter, in order to evaluate the effectiveness of the criterion used, two more corridors were created which had the same origin and destination points as their counterparts, but did not take into account the level of connectivity, the protected areas network, or the DMOSS. These control corridors (thereafter referred as control 1 and control 2) only used the land-use and the KZN SS layers to inform the landscape suitability for the corridor. Thus, ideally these corridors would run through the regions of KZN SS that are not highly impacted by human activities. This was conducted to establish the extent to which landscape connectivity, the protected areas network and the DMOSS actually influenced the design of the landscape corridor.

Table 4.2 - Corridor criteria cost allocation table

Layer	Criteria	Costs
Connectivity	High	0
	Moderate	10
	Low	20
	None	1000
PAN	Inside	30
	Outside	40
DMOSS	Inside	50
	Outside	60
Landcover	Natural (Outside KZN SS)	100
	Degraded	250
	Agricultural	500
	Water	500
	Dams and Lakes	1000
	Urban Areas	1000
	Mines	1000
	Water (SEA)	No Data

4.4 Results

Two cost surface raster layers were created in order to run the least cost path analysis and produce the final landscape (Figure 4.6A) and control (Figure 4.6B) corridors. The darker regions within the cost surface raster layers reveal the most suitable habitat for species to disperse to and thus dictated the direction of the corridors. The control corridors cost surface (Figure 4.6B) can be seen to possess a lot more regions of suitable habitat as compared to the landscape corridors cost surface (Figure 4.6A). Essentially however, the regions of KZN SS hold the greatest significance in both of the cost surface layers. There are some subtle differences between the two layers, as the landscape corridors took into account connectivity levels, thus some KZN SS patches appear more suitable than others, whereas with the control corridors they appear equally suitable.

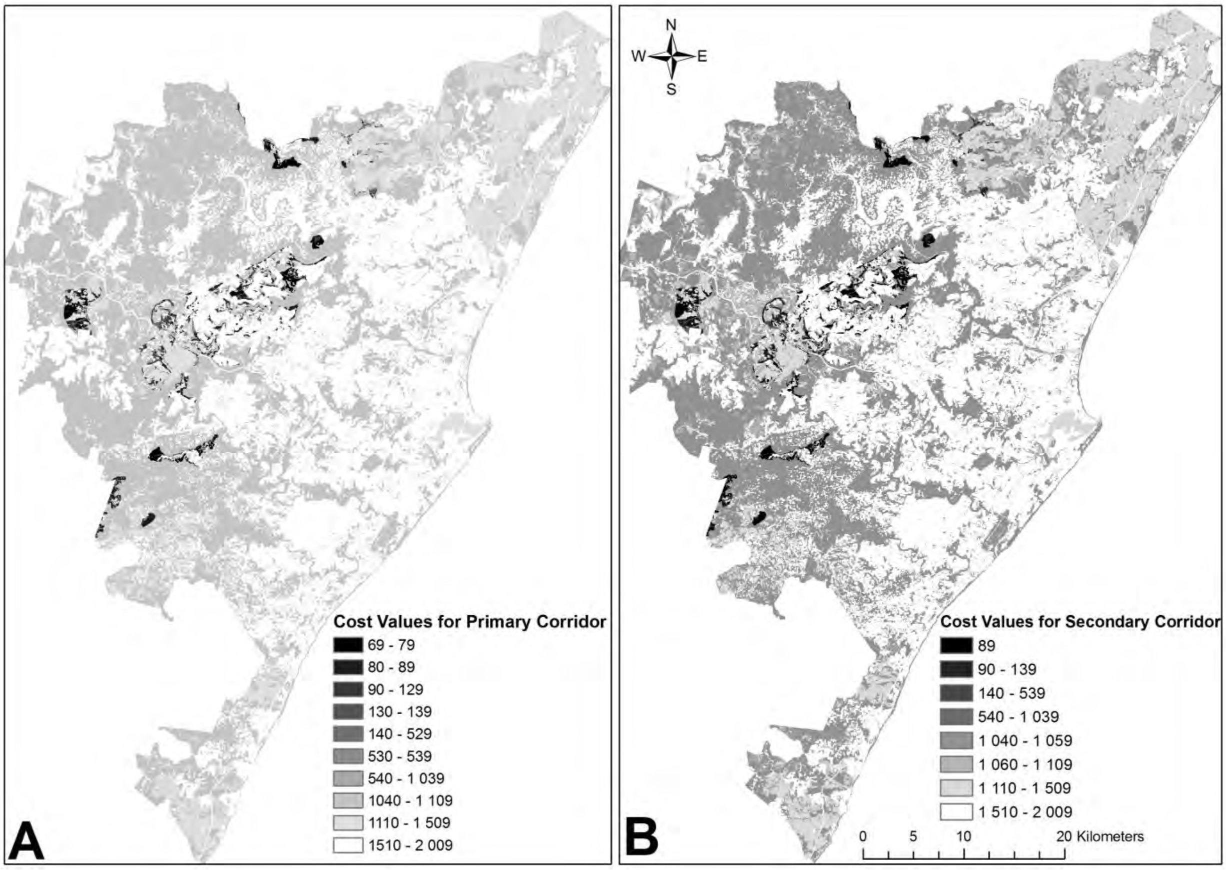

Figure 4.6 - Cost surface raster layers produced for, A) the landscape corridors, and B) the control corridors.

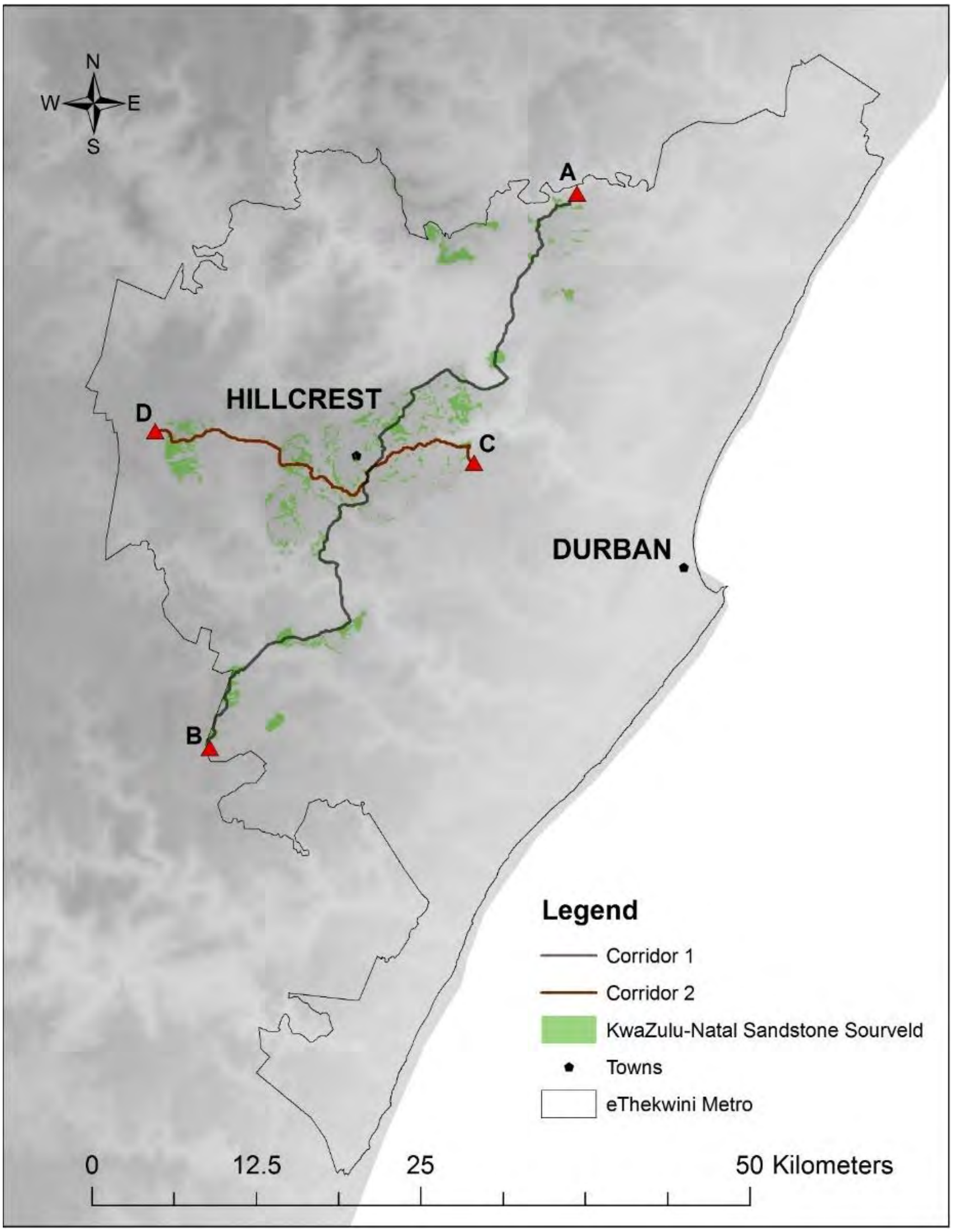

Figure 4.7 - Landscape corridors created and their distribution amongst the KwaZulu-Natal Sandstone Sourveld. Corridor 1 stretches from point ‘A’ to point ‘B’, whilst Corridor 2 stretches from point ‘C’ to point ‘D’.

The landscape corridors can be seen in Figure 4.4 and the control corridors can be seen highlighted in Appendix B (Figure B3). Both the landscape and control corridor 1’s runs from North to South, originating at point ‘A’ and concluding at point ‘B’. Corridor 1 is considerably larger than corridor 2 and extends 69.4km across the length of the eThekwini Metro, whilst corridor 2 only stretches 33.3km across the breadth of the eThekwini Metro. Corridor 2 runs from East to West, originating at point ‘C’ and concluding at point ‘D’. Corridor 2 connects the lowest altitudinal patch of KZN SS within the eThekwini Metro to the highest patch.

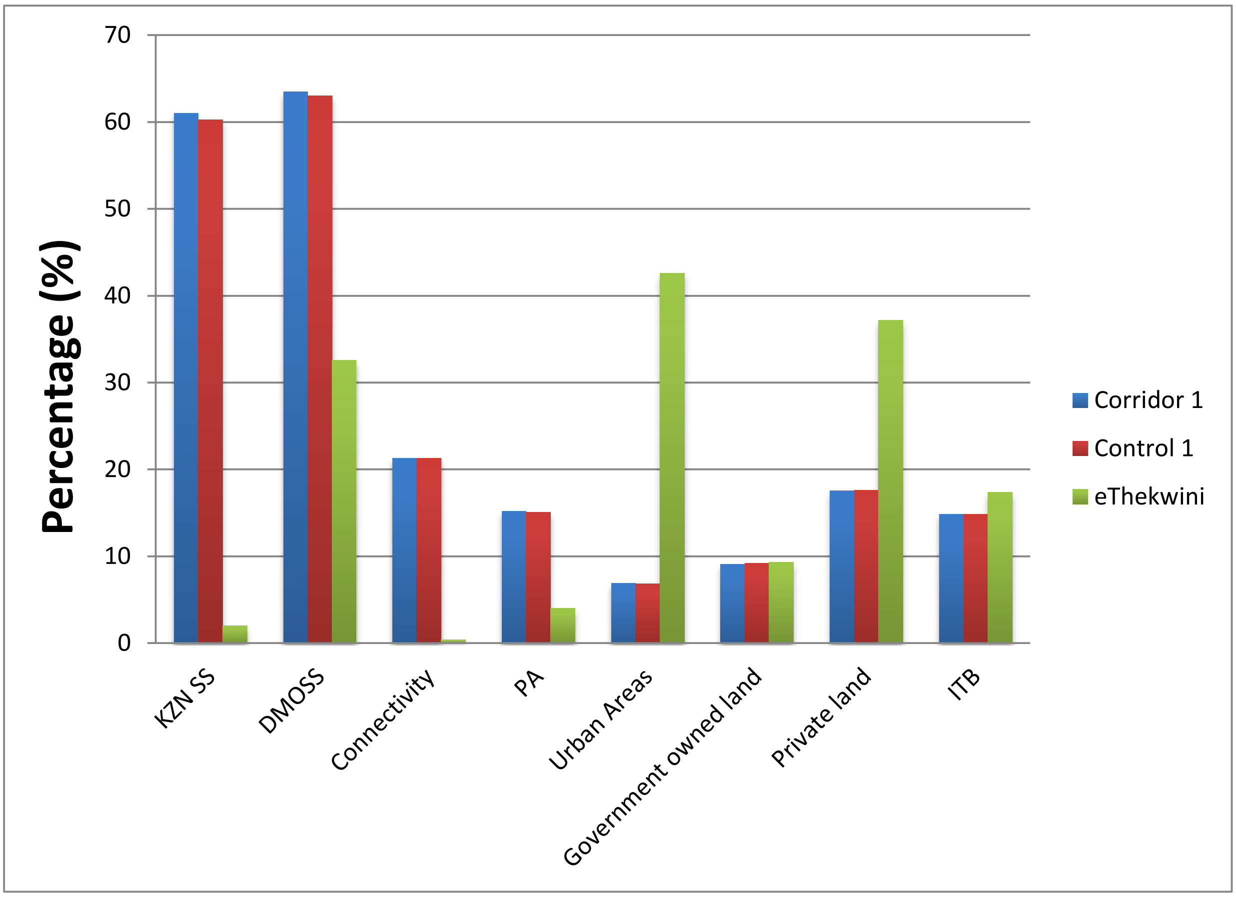

Figure 4.8 - Distribution of landscape corridor (Corridor 1) and control corridor (Control 1) in terms of criterion used to inform their design (KZN SS – KwaZulu-Natal Sandstone Sourveld, DMOSS – Durban Metropolitan Open Space System, PA – Protected areas, ITB – Ingomya Trust Board) and the percentage of each aspect within the eThekwini Metro.

Corridor 1 can be perceived to have succeeded, as 60% of the corridor is comprised of KZN SS, this is notable, as the eThekwini Metro is made up of less than 2% of KZN SS (Figure 4.8). The KZN SS is fairly evenly distributed throughout corridor 1, there are however three segments within the corridor that do not have a patch of KZN SS to facilitate movement along the corridor (see Appendix B, Figure B1A). Moreover, from the patches of KZN SS located along the corridor, 20% is of a moderate to highly connected level (Figure 4.8). Additionally, the landscape corridor is comprised of 60% DMOSS and 15% of the PAN (Figure 4.8). The DMOSS is fairly evenly distributed along corridor 1 and there are some continuous segments of the DMOSS along the corridor (see Appendix B, Figure B1B). The PAN on the other hand is isolated to the centre of the corridor (see Appendix B, Figure B2A). Furthermore, less than 10% of the corridor is comprised of urban areas (Figure 4.8), upon examination of Figure B2B (see Appendix B) it is evident that there is no continuous stretch of urban areas within the corridor. The corridor can be seen to stretch over government, private, and trust board land (Figure 4.8).

A comparison between corridor 1 and the control corridor 1, it is evident that they follow a very similar path between origin point ‘A’ and destination point ‘B’ (see Appendices, Figure B3A). There are however some subtle differences that can be noted between these corridors. The landscape corridor 1 is comprised of slightly more KZN SS, DMOSS, and protected areas as compared to the control corridor (Figure 4.8).

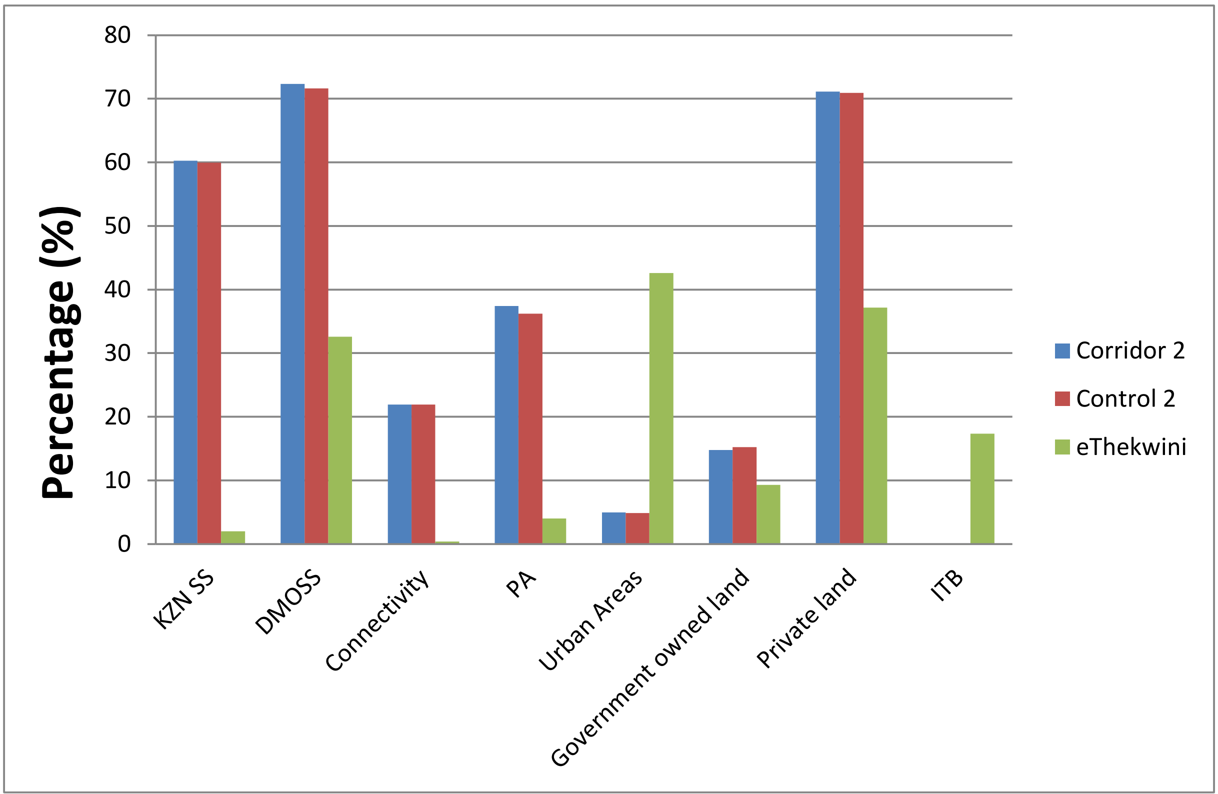

Figure 4.9 - Distribution of landscape corridor 2 (Corridor 2) and control corridor 2(Control 2) in terms of criterion used to inform their design (KZN SS – KwaZulu-Natal Sandstone Sourveld, DMOSS – Durban Metropolitan Open Space System, PA – Protected areas, ITB – Ingomya Trust Board) and the percentage of each aspect within the eThekwini Metro.

Corridor 2 can be regarded to have succeeded as well, as 60% of the corridor is comprised of KZN SS (Figure 4.9). The KZN SS is evenly distributed throughout corridor 2, there is however one segment within the corridor that does not have a patch of KZN SS to facilitate movement along the corridor (see Appendix B, Figure B1A). Similarly to corridor 1, 20% of the KZN SS present within corridor 2 is comprised of moderate to highly connected patches (Figure 4.9).

Corridor 2 is comprised of more than 70% of DMOSS and more than 35% of the PAN (Figure 4.9). The DMOSS is shown to be fairly evenly distributed, with some constant segments along corridor 2 (see Appendix B, Figure B1B). The PAN on the other hand is observably distributed solely in the beginning third of the corridor (see Appendix B, Figure B2A). Furthermore, the corridor has less than 5% of urban areas (Figure 4.9) which are sparsely distributed along the corridor (see Appendix B, Figure B2B). This corridor is distributed through both private and government owned land, with more than 70% of the corridor occurring within privately owned land (Figure 4.9).

Upon contrast of corridor 2 and the control 2 it as apparent, that like corridor 1, these corridors follow a similar route between starting point 'C' and ending point 'D' (see Appendix B, Figure B3B). Additionally, the subtle differences noted revealed that the landscape corridor contains slightly more DMOSS, and protected areas (Figure 4.9).

It is difficult to compare these two corridors, as they serve different purposes and have thus been presented together as landscape corridors to improve connectivity. Corridor 1, which runs from north to south, was designed to facilitate movement to and from patch 'C' (see Chapter 3, Figure 3.4), the largest and most highly connected patch of KZN SS in the entire ecosystem. Whereas corridor 2 extends from east to west, and was designed to connect the lowest altitudinal patch of KZN SS to that of the highest altitudinal patch of KZN SS within the eThekwini Metro.

4.5 Discussion

4.5.1 Have the landscape corridors been identified successfully?

The derived corridors set out with the purpose of improving the connectivity levels of the KZN SS. In order to achieve this, a number of criteria were stipulated to facilitate the movement of species across the landscape and thereby improve upon the connectivity levels of the ecosystem. These criteria aided the corridors in following the most conducive route that KZN SS species could undertake. Thus in essence, patches of KZN SS, which are highly connected, fall within the PAN and the DMOSS, and avoid heavily built up regions. The directionality of the corridors this induced can be seen highlighted in Figure 4.7. Upon examination of the results gathered, it is quite evident that the two landscape corridors have succeeded in adhering to the criteria stipulated, and thus the corridors should succeed in improving connectivity levels. This can be ascertained, as the results gathered, depict that the corridors attempt to go through as much of the KZN SS and DMOSS as possible, whilst avoiding highly urbanised areas. Additionally, the corridors avoid barriers, in the way of continuous stretches of urban areas, which will hinder the movement of fauna and dispersal of flora along the corridor. Moreover, the landscape corridors feed into existing conservation interventions. As such, the corridors simply prioritises existing conservation actions, such as the DMOSS and alien plant clearing, and thus does not result in any cost increase. Furthermore, corridors 1 and 2 can be integrated with buffer zones and natural preserves, which will increase connectivity further by allowing corridor networks to form (Jordan, 2000). These corridors networks are designed to work in tandem with the existing habitat connectivity to provide a dispersal gradient that will protect the biodiversity and functioning of the KZN SS.

4.5.2 Evaluation of methodology

The methodology chosen to generate the landscape corridors for the study was the least cost path analysis. The least cost analysis used to develop landscape corridors worked well and the corridors that were derived succeeded in adhering to the stipulation of the different criteria within the design. The inclusion of additional data layers to the cost surface layer could have further improved the design of the landscape corridors. A number of data layers could have been included. First, the ownership of land within the eThekwini Metro could have been included to force the corridors through government owned land. Second, proximity of patches to major roads as roads can be seen as hard transitional barriers. Third, distance to water could have been included as a data layer, as this could be a limiting factor for the migration of many species. Last, a slope layer could have been included to facilitate the movement of species. Furthermore, the analysis could have been improved by obtaining species-specific data and factoring it into the analysis. For example, the use of the DMOSS and KZN SS by crowned eagles could have been included. Moreover, an alternative method could have been employed, such as circuit theory modelling. Circuit theory is based on the theory of electrical circuits, where each cell in the landscape is treated as an electrical node (Miller, 2005; Neel *et al*, 2007; Minor and Urban, 2008) (see Chapter 2). Circuit theory models are highly useful for understanding landscape-wide patterns of connectivity and possible inhibitors to movement (Neel *et al*, 2007; Minor and Urban, 2008). Additionally, circuit theory assumes that animals only perceive the landscape within a one-cell radius of their current location, and could be a better suited tool for modelling dispersal ability (Miller, 2005; Neel *et al*, 2007).

4.5.3 Urban green space planning

The conservation of biodiversity in urban areas is faced with obstacles in the way of achieving both developmental and environmental goals, to ensure the sustainability of eThekwini. The problem is that, development initiatives within South Africa hold a higher influence as compared to environmental concerns (Roberts, 2008). Effective land use and town planning probably represents one of the best ways to address this issue. The DMOSS was incorporated in eThekwini's town planning schemes in a number of different capacities, such as a controlled development layer. This was used as a means to ensure that biodiversity concerns could inform the development planning and assessment process (Roberts *et al*, 2011).

An important aspect was raised at the start of this chapter, namely, what significance does the PAN and DMOSS actually hold, with regards to conservation. This point was evaluated in this study through the creation of an additional two control corridors, which disregarded the PA, DMOSS, and connectivity levels from their design. Upon examination of the results produced in this regard (see Appendix B, Figure B3), it is evident that the corridors follow a vastly similar route with subtle deviations. In other words, there is no alternative KZN SS habitat for the corridor to go through. This indicates that important conservation regions are found within the DMOSS, highlighting its importance in conserving biodiversity within the eThekwini Metropolitan region. The DMOSS plays a vital corridor role within the conservation of biodiversity in urban areas of the eThekwini Metro. Corridors are essential for urban planning, and the DMOSS has facilitated this.

The DMOSS can be viewed as eThekwini's green belt or greenway, although it is not fashioned in the same manner as a traditional green belt. It was implemented in an attempt to inhibit urban sprawl and protect the biodiversity within the region. A greenway can be seen as a policy for the designation of land uses, used to inform land use planning (Linehan *et al*, 1995). This is carried out in an attempt to retain regions of undeveloped, natural, or agricultural land surrounding urbanised areas. The effectiveness of greenways and green belts are often dependent upon their location and country. This is due to the fact that they can often be degraded by rural urban fringes and the need for development to expand.

The loss of Sydney's green belt is a prime example of the failure to implement a green belt. The proposed plan began in 1948 and it originally covered more than 332 square kilometres, and comprised of a ring of rural open space that surrounded the urban districts (Cumberland Country Council, 1948, 65). Thereafter, the proposed belt was to cover a mass of over 4000 square kilometres (Freestone, 1992). There are a number of reasons as to why this proposed green belt failed. Firstly, there were a number of people opposed to the green belt's implementation. Developers viewed this initiative as a means to diminish their future profits. Additionally, private property owners did not want to undergo restrictions with their land. Furthermore, coupled with this lack of support, finance was unavailable as the common wealth refused to finance the plan. Finally, the green belt had to be relinquished due to unforeseen immigration numbers into the city and subsequent need for housing (Freestone, 1992).

In contrast, Adelaide's green belt is an initiative that has worked to confine the spread of urban development (Buxton and Goodman, 2003). There are a number of lessons that can be drawn from this strategic plan to confine urban sprawl. Firstly, in order to provide green belts with continuous protection, a regional plan that comprises of a metropolitan wide focus which includes non-urban areas is required (Buxton and Goodman, 2003). Secondly, institutional integration and local decision making is needed to prevent spatial fragmentation. Thus the land-use planning of metropolitan regions should be combined with the planning for the protection of biodiversity. The design of corridors and green belts are the best way in which to implement this (Buxton and Goodman, 2003). Additionally, in order to ensure the protection of open spaces, development needs to either be contained, or accommodated elsewhere. A regional approach is thus required, to combine developmental and environmental goals (Buxton and Goodman, 2003).

Urban green spaces should strive for an integrative approach in order to achieve a sustainable environment (Shah and Haq, 2011). In the case of the corridors designed within the study, only one aspect of a sustainable environment was considered, biodiversity and nature conservation. The corridors for the study were designed with the sole purpose of improving connectivity levels within the eThekwini Metro and thereby ensuring species persistence (Shah and Haq, 2011). The landscape corridors that were designed could be made more sustainable by implementing an integrative approach, where social and economic aspects are included. The integration of all these aspects will enable the corridors to not only cater to the needs of urban biodiversity preservation, but also contribute to ecosystem services, such as recreational regions (Shah and Haq, 2011).

4.6 Conclusions

In conclusion, this study has designed appropriate landscape corridors for the eThekwini Metropolitan region that should increase connectivity levels and therefore ensuring the persistence of species within the KZN SS ecosystem. These corridors need to be implemented as the ecosystem is under considerable pressure. Furthermore, the study ascertained that the Durban (eThekwini) Metropolitan Open Space System is an essential factor in the design of these landscape corridors and a vital aspect for land-use and town planning within eThekwini.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Introduction

The main aim of the research was to quantify habitat fragmentation of the KZN SS and design landscape corridors using various measures of structural and functional connectivity in order to assist land use decision making in the eThekwini Metropolitan area. This chapter examines the aim and objectives established in Chapter One against the research undertaken. In addition, conclusions and limitations of the study will be provided and thus consolidate the findings of the study. Lastly, recommendations for future research are proposed.

The main objectives of this study were: 1) to quantify the degree of habitat fragmentation of the KZN SS, 2) to determine the connectivity of different fragments of KZN SS, 3) to compare the effectiveness of fine-scale vs broad-scale data in quantifying habitat fragmentation, 4) to design landscape corridors to facilitate movement of species indigenous to the KZN SS, 5) to assess the actual importance of the protected areas network and the Durban Metropolitan Open Space System in maintaining habitat connectivity, 6) to determine possible implications for biodiversity persistence conservation, and 7) to determine critical patches of KZN SS for species persistence and movement within the eThekwini Metro. The sections below discuss these objectives.

5.2 Major research findings

5.2.1 Quantifying the degree of habitat fragmentation of the KZN SS and determining the connectivity of different fragments of KZN SS

The study ascertained that the KZN SS is a heavily fragmented landscape, which has resulted in low connectivity levels between fragments in the eThekwini Metropolitan area. The inclusion of degraded habitats is seen to increase landscape connectivity. However, Fourie *et al* (2015) obtained a different result in their study of the landscape connectivity of the grassland biome in Mpumalanga. She found the Mpumalanga grassland biome to be well connected despite a high degree of habitat loss. Furthermore, despite habitat fragmentation being a well-versed field of study, there is no standardised method employed to quantify habitat fragmentation. The study has offered a method in which to quantify habitat fragmentation which could be seen as a more viable and convenient process to that of circuit theory. There were some associated challenges, such as the lack of clear and distinct boundaries available for the distribution of the KZN SS. In addition, the use of certain software proved to be challenging. There are many possibilities for future research within the region of investigation. Firstly, a study can be conducted to ascertain how crucial certain degraded patches of KZN SS are to connectivity. Secondly, a temporal aspect to the study could be introduced through testing the rate at which a patch of habitat becomes fragmented and thus the fragmentation history can then be inferred. This could be of value to the eThekwini municipality, as once the fragmentation history has been derived, future fragmentation implications can be extrapolated and thus aid the municipality with regards to conversation and management.

5.2.2 Comparing the effectiveness of fine-scale vs broad-scale data in quantifying habitat fragmentation

The two different spatial scales of data sets used had noticeable discrepancies between them. The fine-scale data depicted a more apt description of the current state of the KZN SS. Furthermore, broad-scale data was shown to overestimate habitat fragmentation and underestimate landscape connectivity. The greatest challenge with regard to this objective was the lack of clear distinct boundaries of the KZN SS.

5.2.3 Designing landscape corridors to facilitate movement of species indigenous to the KZN SS

This study has designed appropriate landscape corridors for the eThekwini Metropolitan region that should increase connectivity levels and thus ensure the persistence of species within the KZN SS ecosystem. The two landscape corridors created succeeded in following patches of KZN SS, which are highly connected, fall within the protected areas network and the DMOSS, whilst avoiding heavily built up regions. The major limitation to this objective was the lack of species-specific data, which would have validated the performance and functionality of the proposed landscape corridors. This highlights a region for future research. Species-specific data could be collected amongst important KZN SS patches within the corridors, to ascertain the extent of functionality of these routes.

5.2.4 Assessing the actual importance of the protected areas network and the Durban Metropolitan Open Space System in maintaining habitat connectivity

Important conservation regions are found within the DMOSS, highlighting its importance in conserving biodiversity within the eThekwini Metropolitan region. The DMOSS plays a vital corridor role within the conservation of biodiversity in the urban areas of the eThekwini Metro. Corridors are essential for urban conservation planning and the DMOSS has facilitated this. The DMOSS was used as a means to ensure that biodiversity concerns could inform the development planning and assessment process (Roberts *et al*, 2011).

5.3 Implications for the management and conservation of the KwaZulu-Natal Sandstone Sourveld

The combination of the deductions and conclusion obtained from Chapter three and four has enabled the relative importance of each patch of KZN SS within the eThekwini Metro to be calculated. This allowed for critical patches of KZN SS for species persistence and movement within the eThekwini Metro to be determined. A map which shows the calculated importance of each patch of KZN SS within the eThekwini Metro is shown in Figure 5.1. It illustrates that there are five clusters of patches within the municipality that have a high level of importance. The patches which hold a high level of importance are predominately the larger patches within the environment that are not fragmented. The smaller, more fragmented patches hold a lower level of importance. Figure 5.1 has provided valuable insight on priority conservation focus. In addition, it is able to inform the municipality as to which patches are crucial for connectivity, and which patches are most likely to be used by species during dispersal. The culmination of these aspects is vital in ensuring efficient land use decision making. The identification of crucial KZN SS patches can be used by the eThekwini municipality to manage and conserve the KZN SS in a number of different ways:

- It can inform spatial planning. This can be carried out through the inclusion of critical patches into the DMOSS framework. Additionally, critical patches can be used as important criteria for comments on development applications.
- Through agreements by government with landowners to establish good management practices of critical patches. This can be implemented though the establishment of

servitudes, where special restrictions on land use is put in place in exchange for tax rebates.

- It can be implemented through restoration efforts, such as alien plant clearing and fire management through the working for ecosystem project.

- Through the establishment of nature reserves through land acquisition. The Bartlett estate is a prime example where the municipality has purchased privately owned land and is currently converting it into a nature reserve to ensure the protection of pristine patches of KZN SS. The Bartlett estate can be seen highlighted in Figure 5.2.

5.4 Concluding Remarks

This study has made a few notable findings. Firstly, it has ascertained that the KZN SS is a highly fragmented landscape, which has resulted in very low level of connectivity between fragments in the eThekwini Metro. Secondly, connectivity and the designed corridors identify different patches of importance. Finally, the DMOSS is a crucial tool for corridors, but does not include all of the well-connected patches. Priority areas have been identified and landscape corridors have been suggested. This situation needs to be addressed if species within the KZN SS are to persist. This study recommends that the eThekwini Municipality can safeguard the biodiversity of this endangered ecosystem by focusing on managing the patches of KZN SS that have been identified as having a high level of importance within the landscape.

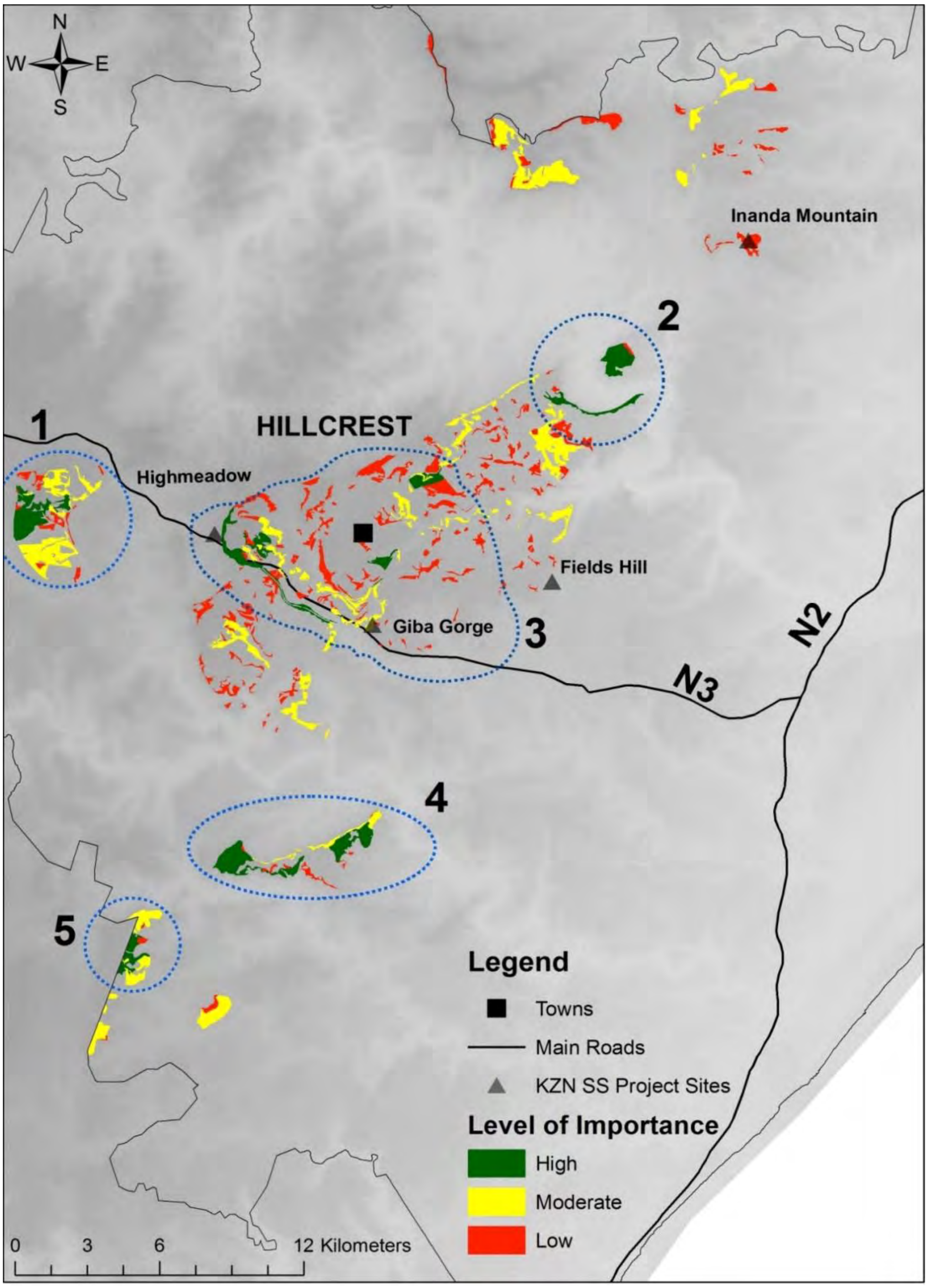

Figure 5.1 - Calculated importance of each patch of KwaZulu-Natal Sandstone Sourveld within the eThekwini Metropolitan area. Three separated layers were used to conduct the analysis, namely: the KZN SS connectivity layer (produced in Chapter 3), landscape corridor 1, and landscape corridor 2 (both produced in Chapter 4). Patches with a DIIC score above 1.8 were considered important for connectivity. Different levels of importance were then assigned to each patch within the eThekwini Metro depending on which criteria they met. Patches of 'high' importance took into account patches which were important for any 2 of the factors. Patches of 'moderate' importance took into account patches which were important for any one of the factors. Finally, patches of 'low' importance took into account all the remaining patches which did not meet the requirements of the aforementioned.

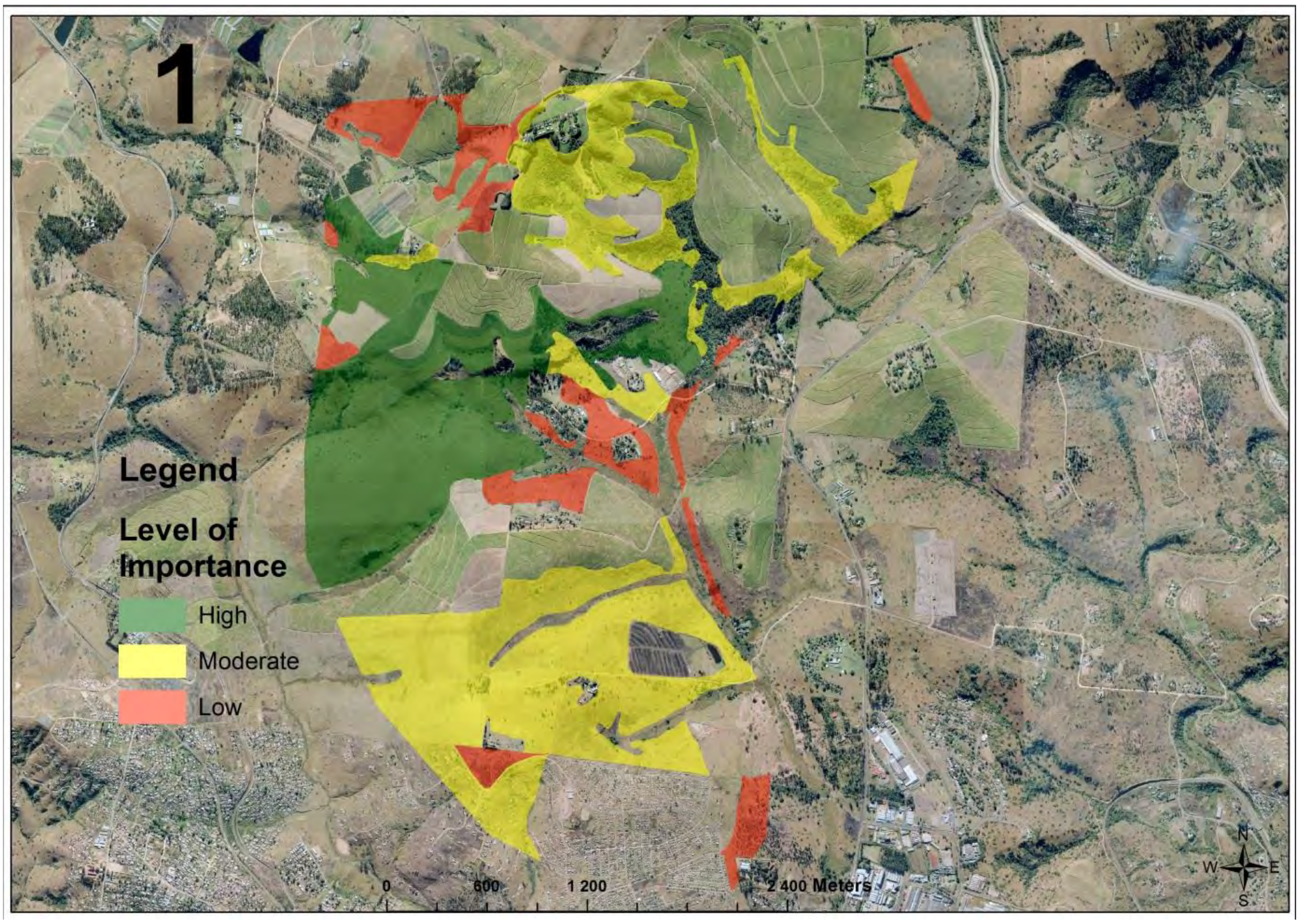

Figure 5.2 – Zoomed in region of patch cluster '1' from Figure 5.1, depicting the distribution of the level of importance within the Bartlett estate.

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APPENDIX A: Assessing how habitat fragmentation and low connectivity levels could affect the KwaZulu-Natal Sandstone Sourveld (Chapter 3)

Table A1 – Percentage of the total habitat area and the number of patches that are in the biggest component at different dispersal distances for Data set 1.

Dispersal distance (m)	Proportion of patch area in main component (%)	Proportion of number of patches in main component (%)
50	47.7	14.85
500	82.71	76.41
1000	96.12	97.7

Table A2 – Percentage of the total habitat area and the number of patches that are in the biggest component at different dispersal distances for Data set 2.

Dispersal distance (m)	Proportion of patch area in main component (%)	Proportion of number of patches in main component (%)
50	35.37	2.1
500	51.21	41.7
1000	65.68	53.96

Table A3 – Percentage of the total habitat area and the number of patches that are in the biggest component at different dispersal distances for Data set 3.

Dispersal distance (m)	Proportion of patch area in main component (%)	Proportion of number of patches in main component (%)
50	31.24	14.14
500	47.59	62.17
1000	59.70	71.5

Table A4 – Percentage of the total habitat area and the number of patches that are in the biggest component at different dispersal distances for Data set 4.

Dispersal distance (m)	Proportion of patch area in main component (%)	Proportion of number of patches in main component (%)
50	86.11	74.5
500	97.1	87.5
1000	100	100

Table A5 – Percentage of the total habitat area and the number of patches that are in the biggest component at different dispersal distances for Data set 5.

Dispersal distance (m)	Proportion of patch area in main component (%)	Proportion of number of patches in main component (%)
50	60.96	51.35
500	77.21	65.1
1000	90.17	82.4

APPENDIX B: Designing landscape corridors to improve connectivity levels of the KwaZulu-Natal Sandstone Sourveld within the eThekwini Metropolitan Region (Chapter 4)

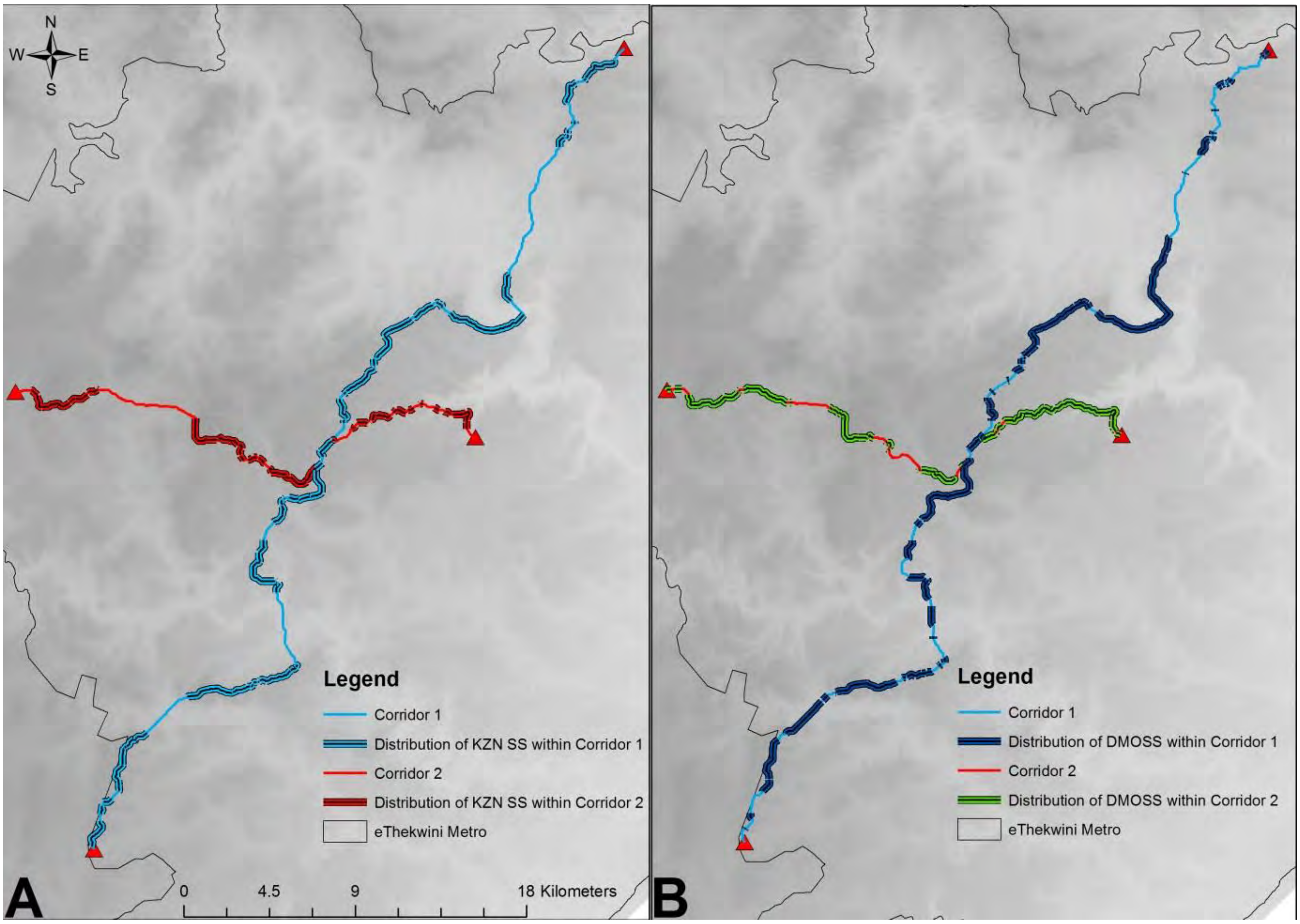

Figure B1– The distribution of A) the KwaZulu-Natal Sandstone Sourveld and B) the DMOSS along landscape corridors 1 and 2.

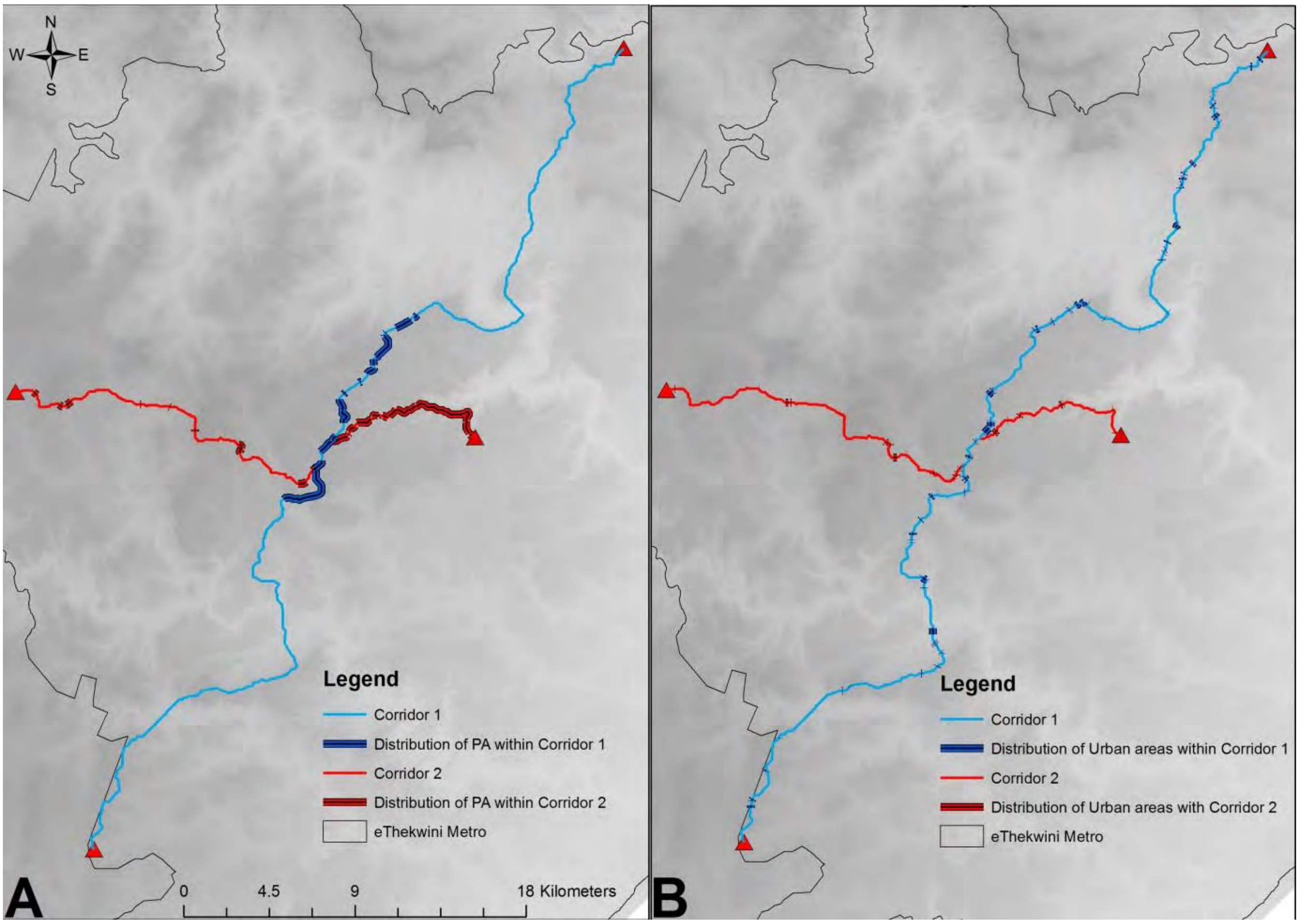

Figure B2 - The distribution of A) the protected areas network and B) the urban regions along landscape corridors 1 and 2.

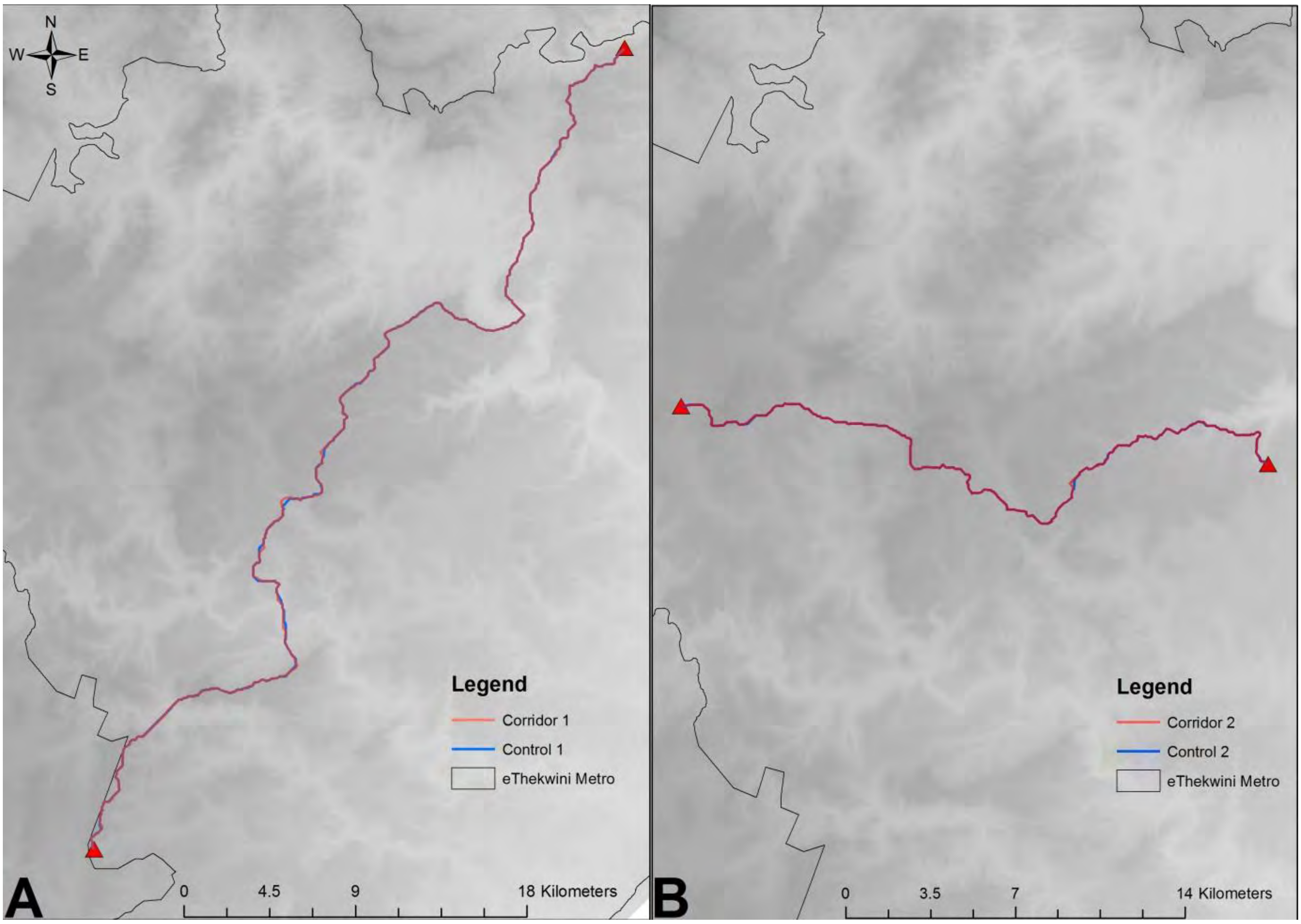

Figure B3 - The distribution and directionality of the landscape corridors against the control corridors. A) Landscape corridor 1 vs control corridor 1. B) Landscape corridor 2 vs control corridor 2.