

## CHAPTER FOUR: QUANTIFYING AN URBANISATION GRADIENT

---

### 4.1 Introduction

*“Urban ecological systems present multiple challenges to ecologists— pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory”* (Grimm *et al.*, 2000)

The use of an urbanisation gradient approach has improved our understanding of how organisms respond to the continuous process of urbanisation with humans as an integral part of urban ecosystems (McDonnell & Pickett, 1990). Urban-rural gradients in studies have predominantly been quantified using concentric zones from the urban core outwards (Kroll *et al.*, 2012; Pillsbury & Miller, 2008; Sadler *et al.* 2006), and objective quantification using GIS methods (Hahs & McDonnell, 2006; Hunt *et al.*, 2013; Lockaby *et al.*, 2005; Luck & Wu, 2002; Williams *et al.*, 2005). Furthermore, the use of spatial metrics to quantify landscape-level structure and pattern has become an increasingly useful tool, and if used in conjunction with remote sensing, may provide detailed spatial information about urban structural dynamics (Herold *et al.*, 2005). The demand for measurement of landscape pattern and process are motivated by the concept that ecological processes are possibly connected to, and driven by coarse-scale ecological patterns (Gustafson, 1998). Pattern and process are widely accepted as being interactional where “*process creates, modifies, and maintains pattern*” and “*pattern constrains, promotes, or neutralizes process*” (Li & Wu, 2004). Landscape metrics (spatial metrics) are widely used to quantify vegetation structure and pattern in natural landscapes (Gustafson, 1998; Hargis *et al.*, 1998; O’Neill *et al.*, 1988) and are used to describe the spatial heterogeneity of individual patches belonging to a common land cover class or the entire landscape as a collection of patches (Herold *et al.*, 2005).

Luck and Wu (2002) studied the landscape pattern dynamics of the Phoenix metropolitan area (Arizona, USA) along an urban-rural gradient using gradient analysis in combination with landscape metrics. They concluded that different land use types were characterised by distinct spatial signatures and correlated with certain spatial metrics. This accentuated the importance of urbanisation gradient quantification for associating pattern and process in urban ecological research (Luck & Wu, 2002). Hahs & McDonnell (2006) quantified an urban-rural gradient for Melbourne using a combination of landscape metrics and demographic- and physical variables for a more complete expression of ecological responses to urbanisation. Du Toit (2009) tested these urbanisation measures for Klerksdorp, a South African city, and confirmed the usefulness of using landscape metrics in association with demographic- and physical variables. However, Du Toit & Cilliers (2011) identified

several aspects that must be taken into account when using urbanisation measures to quantify an urban-rural gradient, namely analysis scale, spatial resolution, classification typology, input data accuracy, measure equations, statistical analysis type, and habitat context.

#### 4.1.1 Objectives

The specific objectives of this chapter are as follows:

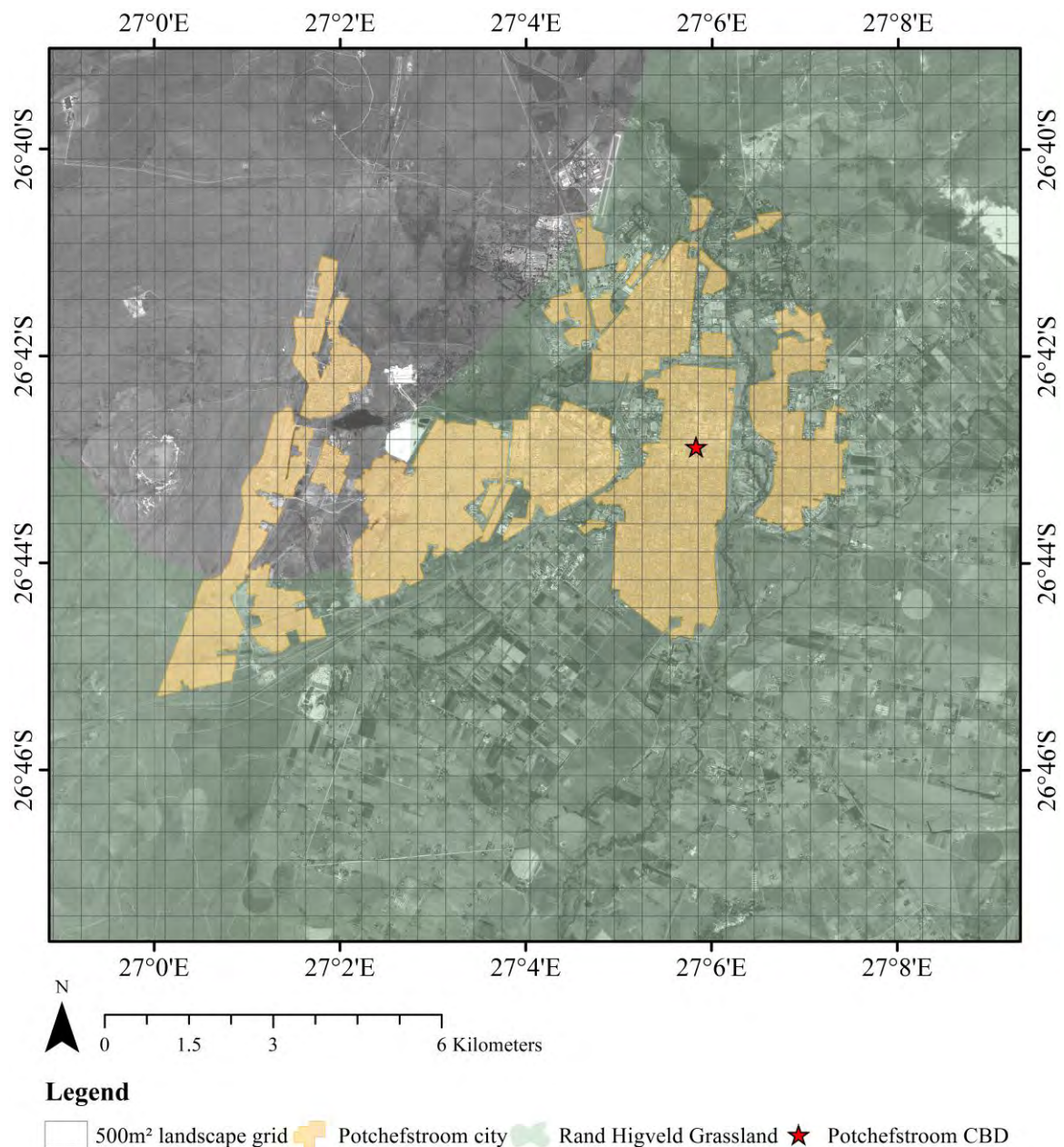
1. Test and select applicable urbanisation measures used by Du Toit (2009) for each 500 m<sup>2</sup> grid cell of the land cover map (created in *Chapter 3*) using GIS techniques.
2. Select urbanisation measures to further describe an entire landscape urban-rural gradient within the study area.
3. Use the selected urbanisation measures as indicators for anthropogenic influences within the study area.
4. Calculate the selected urbanisation measures for the matrix within 500 m from the edge of all selected grassland fragments.
5. Classify the selected grassland fragments into urbanisation classes based on selected urbanisation measures using objective statistical methods to determine the position of the selected grassland fragments along the urbanisation gradient.

The successful quantification of an urbanisation gradient and the classification of the selected grassland fragments into urbanisation classes will enable the determination of the effects of urbanisation intensity on plant species diversity and plant functional diversity (*Chapter 5*), as well as biogeochemical landscape function (*Chapter 6*).

#### 4.2 Methods

A landscape grid, consisting of 5846 500 m<sup>2</sup> cells, was created for the 1461.5 km<sup>2</sup> study area in the Tlokwe Municipal area (Figure 4.1). Hahs & McDonnell (2006) & Du Toit (2009) used 1 km<sup>2</sup> grid cells, which for the purpose of this study were too coarse, especially for testing possible correlations with fine-scale landscape functionality. The use of landscape grids has been applied for whole landscape pattern investigation and more accurate description of complex, non-linear urbanisation gradients (Abdullah & Nakagoshi, 2006; Du Toit, 2009; Du Toit & Cilliers, 2011; Hahs & McDonnell, 2006; Honnay *et al.*, 2003; McDonnell & Hahs, 2008; Yeh & Huang, 2009). To determine the urbanisation degree of a specific landscape patch in context with the landscape grid, and because the landscape patches do not necessarily fit in a single grid cell, Hahs & McDonnell (2006) and Du Toit (2009) created 1 km<sup>2</sup> circles around the centres of the patches. If the size of the

grid cells in this study were to be practically brought into context, 500 m<sup>2</sup> circles would have sufficed for calculating urbanisation measures for each grassland fragment. However, because the size range of the selected grassland fragments in the Tlokwe Municipal area is so variable (size range = 0.59 ha – 179.41 ha), a 500 m<sup>2</sup> circle would be encapsulated by some of the larger fragments, not providing any information about the position of the patch along an urbanisation gradient. Therefore, buffers around the edges of the selected grassland fragments, instead of circles with a fixed radius, were created to determine the urban-rural gradient position of the grassland remnants based on its matrix characteristics.



**Figure 4.1:** Map of a section of the study area indicating the 500 m<sup>2</sup> landscape grid. There are a total of 5846 500 m<sup>2</sup> cells in the 1756.25 km<sup>2</sup> study area. Urban areas are indicated in orange, and the Rand Higveld Grassland vegetation type in green. The Potchefstroom CBD is also indicated.

#### 4.2.1 Determining matrix size

*“...the landscape surrounding remnant patches, as well as the quality of the habitat maintained within the remnant, may be more important drivers of fragmentation effects on plant species than spatial attributes of patches...”* (Williams *et al.*, 2006)

The matrix (most encompassing landscape component (Forman & Godron, 1986)) surrounding a landscape patch plays an important role in determining the intra-patch characteristics (August *et al.*, 2002; Collinge, 2009; Wiens, 2002). Several studies observing the effects of the landscape matrix on plant species were reviewed in order to determine the most appropriate buffer distance from the edge of each selected grassland fragment that would represent the matrix area that has an influence on intra-patch characteristics (Table 4.1). The specific research questions of the studies determined buffer distances and whether the study sites were included or excluded from the buffer area. For instance Mitchley & Xofis (2005) selected 200 m buffers based on a “connectivity threshold” for calcareous grassland habitat suitability as proposed by Burnside *et al.* (2002). Their aim was to explore landscape connectivity and fragmentation effects *between* grassland sites, and therefore excluded the sites from the buffers. For the purpose of this study a 500 m radius buffer area surrounding the edges of each grassland fragment was consequently selected due to its previous use and applicability on grassland plant species (Klimek, 2006; Tschardtke *et al.*, 2005). The grassland fragments were excluded because one of the main objectives for this study was to determine the position of grassland fragments along an urbanisation gradient (i.e. does the plant species diversity and landscape function of grassland fragments in urban and rural matrices differ?). Landscape metrics were, therefore, calculated for only the matrix area surrounding the sites.

#### 4.2.2 The selection of relevant urbanisation measures

Hahs and McDonnell (2006) selected seventeen urbanisation measures (landscape metrics) to quantify an urban-rural gradient in Melbourne, Australia. Du Toit (2009) used thirteen of these measures in Klerksdorp, South Africa. The same land cover classification and urbanisation quantification methodology as described by Du Toit (2009) was used in this study and therefore the same metrics were tested. Table 4.2 provides the landscape metrics that were found to effectively describe the landscape structure and demographic- and physical attributes of the Klerksdorp area (Du Toit, 2009). Du Toit (2009) calculated the metrics for a fixed 1km<sup>2</sup> circle around the centroid of all the study patches. However, in this study the landscape metrics will be calculated for matrix areas of varying size and shape (500 m around the edge of selected grassland fragments of varying sizes (0.59 ha – 179.41 ha). Therefore, the limitations of landscape metrics need to be considered in order to determine which measures will be the most suitable for the specific research methodology and objectives of this study.

Table 4.1: Review of studies observing the effects of the landscape matrix on plant species.

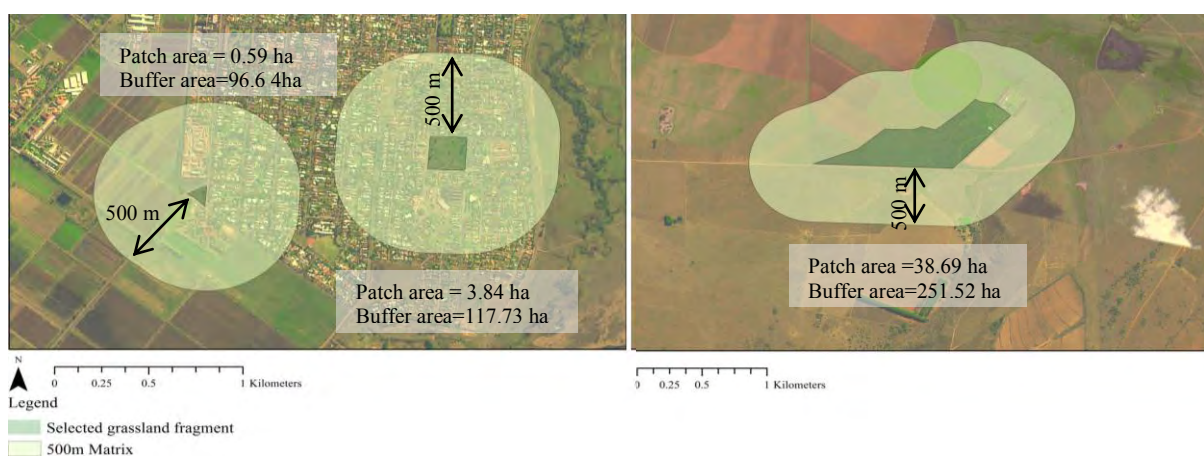
| Author                          | Buffer size                            | Matrix variable                     | Intra-patch variable                                                                                                   | "Best" buffer size | Patch included or excluded? |
|---------------------------------|----------------------------------------|-------------------------------------|------------------------------------------------------------------------------------------------------------------------|--------------------|-----------------------------|
| Aggenmyr & Cousins (2012)       | 200m                                   | Connectivity metrics                | Temporal plant species data                                                                                            | 200m               | Included                    |
| Brady <i>et al.</i> (2009)      | 500m radius around point on patch edge | Landscape metrics                   | Habitat structures and floristics                                                                                      | 500m               | Partially included          |
| Butaye <i>et al.</i> (2001)     | 100m, 500m, 1000m                      | Shared species                      | Forest plant community                                                                                                 | N/A                | Excluded                    |
| Dauber <i>et al.</i> (2003)     | 50m & 200m                             | Land cover                          | Influence of the matrix surrounding managed grassland sites on species richness of ants, wild bees and vascular plants | N/A                | Excluded                    |
| Gaba <i>et al.</i> (2010)       | 100m, 200m, 300m, 500m, 1000m radii    | Landscape metrics                   | Effect of landscape heterogeneity on weed richness                                                                     | 200m               | Included                    |
| Gabriel <i>et al.</i> (2005)    | 1km, 2km, 3km, 4km and 5km diameter    | Landscape metrics                   | Effect of landscape complexity on weed richness                                                                        | 2km                | Included                    |
| Grashof-Bokdam (1997)           | 100m, 500m, 1000m                      | Isolation metrics                   | Forest plant species dispersal method                                                                                  | N/A                | Excluded                    |
| Jacquemyn <i>et al.</i> (2003)  | 100m                                   | Isolation metrics                   | Plant species in forests                                                                                               | 100m               | Excluded                    |
| Klimek (2006)                   | 250m, 500m                             | Landscape metrics                   | Grassland plant species                                                                                                | 500m               | Excluded                    |
| Krauss <i>et al.</i> (2004)     | 0.25-5km radius                        | Landscape metrics                   | Plant species richness in calcareous grasslands                                                                        | 250m               | Excluded                    |
| Marini <i>et al.</i> (2008)     | 500m radius                            | Landscape metrics                   | Patterns of plant species richness in Alpine hay meadows                                                               | 500m               | Included                    |
| Michley & Xofis (2005)          | 200m radius                            | Landscape metrics                   | Calcareous grasslands                                                                                                  | 200m               | Excluded                    |
| Purschke <i>et al.</i> (2012)   | 300m                                   | Landscape metrics                   | Landscape history and dispersal traits in grassland plant communities                                                  | 300m               | Excluded                    |
| Roschewitz <i>et al.</i> (2005) | 1km                                    | Landscape complexity                | Weed species diversity                                                                                                 | 1km                | Excluded                    |
| Ruprecht (2006)                 | 500m                                   | Relative areas of propagule sources | Natural recovery of grasslands                                                                                         | 500m               | Included                    |
| Söderström <i>et al.</i> (2005) | 1km radius                             | Land cover                          | Vascular plants, butterflies, bumble bees, ground beetles, dung beetles and birds                                      | 1km radius         | Included                    |
| Tschamtké <i>et al.</i> (2005)  | 500 - 6000m radius                     | Landscape complexity                | Various organisms                                                                                                      | 500m for plants    | Included                    |

**Table 4.2: Urbanisation measures used in the study of Du Toit (2009) that were considered for use in this study.**

| Landscape metrics                    | Demographic- and physical variables          |
|--------------------------------------|----------------------------------------------|
| Largest patch index (LPI)            | Density of people (DENSPEOP)                 |
| Landscape shape index (LSI)          | Distance to central business district (CBDm) |
| Land cover richness (LCR)            | Road network density (RND)                   |
| Percentage urban land cover (PURBLC) |                                              |
| Number of patches (NP)               |                                              |
| Simpsons diversity index (SIDI)      |                                              |

Although landscape metrics may be widely applied to quantify pattern and process, it is not without limitations (McGarigal & Marks, 1995; Li & Wu, 2004). To successfully interpret landscape metrics one must be aware of its restrictions and the possible dynamics of achievable landscape metric values when applied to landscapes characterised by different morphological properties and extents (Hargis *et al.*, 1998).

A challenge in this study is that applicable urbanisation measures is aimed to be selected in a statistically sound manner which is of relevance to the entire study area (landscape grid). However, an objective for this study was to quantify the human impacts provided by only the matrix within 500 m of the edge of the 30 selected grassland fragments, and subsequently classify grassland remnants under observation into urbanisation classes to allow for comparative statistics. This entailed that the urbanisation measures were selected based on the 500 m<sup>2</sup> grid values for eligible landscape metrics and demographic- and physical variables, and that the selected landscape metrics were then re-calculated for the matrix 500 m surrounding the grassland fragment. The selected grassland fragments in the study area vary in shape and size resulting in different matrix area sizes and shapes thus different extents (Figure 4.2). This implies that area and shape sensitive landscape metrics could not be used for this study.



**Figure 4.2: Three of the selected grassland fragments within the study area are shown to indicate their variability in size and shape, resulting in subsequent matrix area differences for which to calculate landscape metrics.**

Landscape metrics that are proportional to size were still applicable, representing the percentage of matrix area consisting of a land cover type (e.g. percentage urban land cover (PURBLC)). Diversity and richness metrics which include Land Cover Richness (LCR) and Simpson's Diversity Index (SIDI) were not included in this study as they are closely related to scale (McGarigal & Marks, 1995; McGarigal, 2013). Based on the island biogeography theory of MacArthur and Wilson (1967) larger areas will be more rich (be it species or patches) and heterogeneous than smaller areas. The matrix areas for the 30 grassland fragments vary (mean area = 165.02 ha, median = 132.97, range 96.64–356.3 ha) indicating that smaller and larger grassland remnants will not be directly comparable. Consequently the SIDI and LCR diversity metrics, that were used by Du Toit (2009) and Hahs & McDonnell (2006), were also excluded from this study.

Number of patches (NP) is also subject to the extent of the landscape (McGarigal & Marks, 1995) and was therefore also excluded. This limits the type of measures appropriate / available to reflect landscape fragmentation. Landscape metrics which are more robust against changes in extent were therefore also considered. Edge Density (ED) and Patch Density (PD) were consequently added to the study to indicate landscape fragmentation. PD is size normalised (McGarigal, 2013) and substituted NP in order to reflect the patchiness of the landscape matrix surrounding the selected grassland fragments. ED has been used in a number of studies to reflect landscape fragmentation (Hargis *et al.*, 1998; Brown *et al.*, 2000; Hansen *et al.*, 2001; Saura & Martinez-Millán, 2001; Herold *et al.*, 2002; McAlpine & Eyre, 2002; Baldwin *et al.*, 2004; Cifaldi *et al.*, 2004). The studies of Saura & Martinez-Millán (2001) and Baldwin *et al.* (2004) indicated that ED showed the least deviation between landscapes of varying extent. Edge density is calculated in much the same way as Landscape Shape Index (LSI) and will therefore replace LSI for the purpose of this study based on the calculation simplicity and comprehensibility of the ED metric and its success in reflecting landscape fragmentation. Since grasslands, and specifically the Rand Highveld Grassland, is the main research subject it was decided to also calculate a landscape metric which will allow determining the extent of grassland habitat loss in the study area. The landscape metric Percentage Grass Land Cover (PGRALC) was therefore added for the above mentioned purpose (Table 4.3).

Ideally the aim was to select both a landscape metric and a demographic- and physical variable to quantify the urbanisation gradient (Du Toit & Cilliers, 2011). Measures that will address key aspects of this study, that is, the effect of urbanisation on the species composition, landscape – and species function within selected grassland fragments, was also selected (Table 4.3).

**Table 4.3: Description of the final eight selected urbanisation measures that will be used to describe the landscape structure and demographic- and physical properties and quantify an urbanisation gradient for the study area. Formulae are according to McGarigal and Marks (1995).**

| Measure                               | Description |                                                                                                                                                                                                                                                                                      | Formula                                        |
|---------------------------------------|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| Landscape metrics                     |             |                                                                                                                                                                                                                                                                                      |                                                |
| Edge density*                         | ED          | ED is the sum of the lengths (m) of all edge segments within the landscape per hectare (McGarigal & Marks, 1995). The landscape edge was not included.                                                                                                                               | $ED = \frac{E}{A} (10\ 000)$                   |
| Largest patch index                   | LPI         | The LPI landscape metric calculates the percentage area of the largest patch in the landscape (McGarigal & Marks, 1995). The area of the largest patch is divided by the total landscape area and then converted to percentage (McGarigal & Marks, 1995).                            | $LPI = \frac{i_{j=1}^n \max(a_{ij})}{A} (100)$ |
| Patch density*                        | PD          | PD is the total number of patches present in the landscape, divided by the landscape area and converted to 100ha (McGarigal & Marks, 1995).                                                                                                                                          | $PD = \frac{N}{A} (10\ 000)(100)$              |
| Percent urban land cover              | PURBLC      | PURBLC measure calculates the percentage of the landscape consisting of urban areas (Hahs & McDonnell, 2006), thus the percent impervious surfaces within each 500m <sup>2</sup> grid cell.                                                                                          | $PURBLC = \frac{\sum_{j=1}^n a_{ij}}{A} (100)$ |
| Percent grassland land cover*         | PGRALC      | PGRALC is the percentage of the landscape consisting of the grass land cover class. (As per PURBLC method – Hahs & McDonnell, 2006).                                                                                                                                                 | $PGRALC = \frac{\sum_{j=1}^n a_{ij}}{A} (100)$ |
| Demographic and physical variables    |             |                                                                                                                                                                                                                                                                                      |                                                |
| Density of people                     | DENSPEOP    | DENSPEOP represents the total number of people per 500 square m (500m <sup>2</sup> ) (Hahs & McDonnell, 2006). The source in this instance was the census small area statistics (Statistics South Africa, 2005).                                                                     |                                                |
| Distance to central business district | CBDm        | CBDm is the linear distance (m) to the central business district (Hahs & McDonnell, 2006). The Central Business District (CBD) of Potchefstroom is located on the corner of James Moroka Street and Walter Sisulu Lane (Department of Constitutional Development and Planning, 1986) |                                                |
| Road network density                  | RND         | RND is the total length of public roads (m) per 500m <sup>2</sup> (extent of our grid cells).                                                                                                                                                                                        |                                                |

*\*Not used in the studies of Hahs & McDonnell (2006) or Du Toit (2000).*

\*Not used in the studies of Hahs & McDonnell (2006) or Du Toit (2009)

### 4.2.3 Calculation of urbanisation measures

Considering the limitations, comprehensibility, and applicability of landscape metrics in the context of this study, eight urbanisation measures (refer to Table 4.3) were calculated for each 500 m<sup>2</sup> grid cell (refer to Figure 4.1). Appendix A lists the definitions of the specific notation used in urbanisation measures equations. Methods followed for the calculation of urbanisation measures were, where applicable, similar to Du Toit (2009) using formulae presented in McGarigal & Marks (1995). Various measures of urbanisation were calculated for each 500 m<sup>2</sup> grid cell in the entire study area using ArcView 10 (ESRI, 2010) and Hawth's analysis tools 3.27 (Beyer, 2007). In order to calculate the urbanisation measures, the raster land cover map created in *Chapter 3* had to be converted to a vector shapefile. This process creates polygons of the class classifications. Hawth's Analysis Tools (Beyer, 2007) were used to create the landscape grid with the Create Vector Grid tool.

LPI, PURBLC, CBDm, and RND urbanisation measures were calculated according to the methods used by Du Toit (2009). DENSPEOP was determined through using the Census Small Area Statistics (Statistics South Africa, 2005) and the Calculate Demographics Tool (Muzslay, 2006). PD was calculated using the number of patches (method for determining number of patches as per Du Toit (2009)) per 500 m<sup>2</sup> grid cell, divided by the grid cell area (250 000m<sup>2</sup>) and multiplied by 10 000 and 100 to convert the final PD value to patches per 100ha (McGarigal & Marks, 1995). ED was calculated by converting the polygons of the vector land cover map (of which the land cover classes have been merged) to lines (polygon to lines function of Data Management Tools, ArcMap 10 (ESRI, 2010)). The lines represent patch edges in the landscape. The length of the edges were calculated for each 500 m<sup>2</sup> grid cell using the Sum Line Lengths function of Hawth's Tools (Beyer, 2007), divided by the area of each grid cell (250 000 m<sup>2</sup>) and multiplied with 10 000 to convert the final ED value to meters per hectare (m/ha) (McGarigal & Marks, 1995). PGRALC was calculated using the same method used by Hahs & McDonnell (2006) and Du Toit (2009) to calculate Percentage Urban Land Cover (PURBLC), only using the grass land cover class, extracted from the 2006 North West Land Covers Map (GeoTerraImage, 2008), instead of the urban land cover class from the land cover map created in *Chapter 3*.

### 4.2.4 Data analysis

#### 4.2.4.1 Factor analysis

Selecting the appropriate landscape metrics for this study required values of the eight urbanisation measures for each of the 500 m<sup>2</sup> grid cells and was used as input for a Factor Analysis (FA). "Skew" data influences the results of the FA (Steyn, 2012), and therefore the urbanisation measures were transformed using Box-Cox transformation (Box and Cox, 1964) in the STATISTICA data analysis software (version 10) (StatSoft, Inc., 2011a) to enhance the normality of the samples. The formulae

used to transform each urbanisation measure as well as “before and after” distribution plots are provided in Appendix B. FA is applied as a data reduction process or to explore structure within the data (StatSoft, 2011b). The main goals for executing FA on data are thus to reduce the number of variables and to classify variables (StatSoft, 2011b). Usually only variables characterised by loadings exceeding 0.32 are interpreted, and greater loadings indicate that a variable is a strong measure of a specific factor (Tabachnick & Fidell, 2007). Loadings exceeding 0.7 are considered outstanding (Comrey & Lee, 1992), and were used as the FA cut-off point for the purpose of this study. The urbanisation measure variables used as input for the FA were rotated using the varimax raw rotation which maximises the variances of the squared raw factor loadings across variables for each factor (StatSoft, 2011b).

The results of the FA, the simplicity of the landscape metric, and the key research questions will aid in the selection of measures that will be used during this study to quantify the entire landscape gradient as well as the 500 m radius matrix areas around each selected grassland fragment.

#### 4.2.4.2 Cluster analysis for determining urbanisation classes

To compare grassland fragments of varying urbanisation intensities, the aim was to categorise the selected grassland fragments into natural clusters based on the selected urbanisation measures which were used to describe the urbanisation gradient within the study area. These urbanisation classes allowed for comparative statistics (such as ANOVA) between species diversity and functional diversity, and landscape functionality of selected grassland fragments, situated in areas of varying urbanisation, in subsequent chapters. The classification of selected grassland fragments into urbanisation classes was achieved by performing a cluster analysis which was executed in PRIMER software (PRIMER-E, 2012) using the Bray Curtis similarity index and Complete Linkage cluster mode. Cluster analysis is a multivariate method which enables classification of variables into clusters or groups using numerical techniques (Romesburg, 1984).

### 4.3 Results and discussion

#### 4.3.1 The selection of landscape metrics

The minimum, maximum, median and mean values for each urbanisation measure are listed in Table 4.4. These values indicate the range of the urbanisation measures calculated for the study area.

**Table 4.4: Range of values for the various urbanisation measures of the 500 m<sup>2</sup> grid cells within the study area.**

| Urbanisation measure     | Minimum | Maximum | Median | Mean |
|--------------------------|---------|---------|--------|------|
| <b>Landscape metrics</b> |         |         |        |      |
| ED                       | 0       | 694     | 173    | 192  |
| LPI                      | 12      | 100     | 81     | 76   |
| PD                       | 4       | 3884    | 500    | 631  |

|                                            |     |       |       |       |
|--------------------------------------------|-----|-------|-------|-------|
| PGRALC                                     | 0   | 100   | 68    | 59.6  |
| PURBLC                                     | 0   | 93.7  | 0.9   | 4.9   |
| <b>Demographic- and physical variables</b> |     |       |       |       |
| CBDm                                       | 250 | 27560 | 15260 | 14667 |
| DENSPEOP                                   | 0   | 3147  | 1     | 21    |
| RNDm                                       | 0   | 5527  | 107   | 375   |

The FA results for the urbanisation measures are listed in Table 4.5. Variables with high loadings on the same factor in the FA results directly or indirectly correlate with each other, measuring similar underlying characteristics (Warner, 2008). Factor 1 accounts for 42.9% of the variance, and Factor 2 for 65.12%. LPI, PD, and ED are highly correlated with Factor 1, whilst DENSPEOP and PGRALC correlated strongly with Factor 2. The correlation matrix of the landscape metric variables, used as input for the FA, is provided in Appendix C.

**Table 4.5: Factor Analysis results for the first two components of the calculated urbanisation measures (varimax raw rotated). The factor loadings for each variable per component are indicated. The Eigenvalues for each factor are also indicated (E). Values >0.7 are listed in red.**

|          | Factor 1<br>E = 3.43209 | Factor 2<br>E = 1.77774 |
|----------|-------------------------|-------------------------|
| LPI      | <b>-0.822053</b>        | 0.070050                |
| CBDm     | -0.047390               | 0.663800                |
| RNDm     | 0.486143                | -0.322470               |
| PGRALC   | -0.031752               | <b>0.743356</b>         |
| DENSPEOP | 0.032455                | <b>-0.852063</b>        |
| PURBLC   | 0.674748                | -0.465741               |
| PD       | <b>0.937815</b>         | -0.017189               |
| ED       | <b>0.955488</b>         | 0.018801                |
| Expl.Var | 3.164151                | 2.045678                |
| Prp.Totl | 0.395519                | 0.255710                |

In this study the aim was to examine the influences of urbanisation on the Rand Highveld Grassland vegetation unit. Therefore, certain differences in spatial characteristics and human impacts (and the effects thereof on plant species diversity, plant functional diversity and landscape function) between urban areas and more “natural” areas had to be included. Keeping the research questions in mind, the following landscape metrics were selected:

- **Density of people (DENSPEOP – demographic variable):** this variable had the highest score on Factor 2 and reflects the extent of human inhabitation, and thus urbanisation.
- **Edge density (ED – landscape metric):** ED had the highest score on Factor 1 and for the purpose of this study will reflect the degree of fragmentation (also a key aspect in this study).

Edge density is an effective measure of fragmentation (Hargis *et al.*, 1998; Brown *et al.*, 2000; Hansen *et al.*, 2001; Saura & Martinez-Millán, 2001; Herold *et al.*, 2002; McAlpine & Eyre, 2002; Baldwin *et al.*, 2004; Cifaldi *et al.*, 2004).

- **Percentage grass land cover (PGRALC – landscape metric):** PGRALC also loaded high with Factor 2. The central concept of the study is the effect of urbanisation on the Rand Highveld Grassland vegetation unit. Low percentage grassland cover may indicate grassland habitat loss, and therefore it was decided to be included in quantifying urbanisation effects within the study area.
- **Percentage urban land cover (PURBLC – landscape metric):** PURBLC represents the percentage impervious surfaces and is the best visual and comprehensible approximation of urbanisation indicating the presence of human built landscapes (Hahs & McDonnell, 2006; Alberti, 2010). As an important part of the research question PURBLC was retained as a direct estimate of urbanisation, although it did not load high with any of the two factors for the FA.

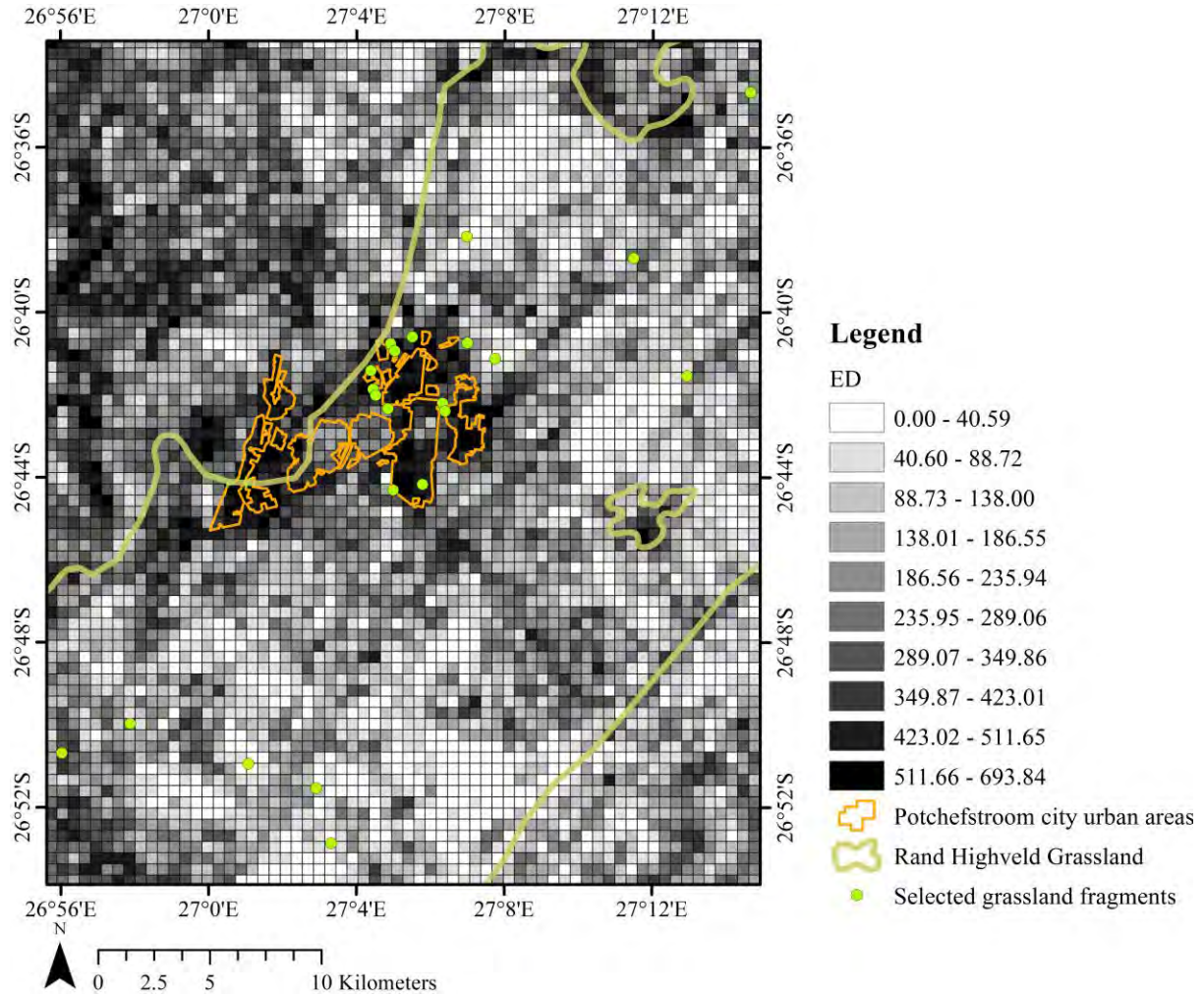
#### 4.3.2 Quantification of entire landscape urbanisation gradient

We have thus determined that ED, PGRALC, PURBLC and DENSPEOP will be used as the urbanisation measures to describe the entire landscape urbanisation gradient in the Tlokwe Municipal area (Figures 4.3-4.6), and to act as indicators for certain anthropogenic influences (i.e. urbanisation, habitat loss and fragmentation) in the following chapters. These measures are easy to understand and interpret, and will address the research question regarding the effects of anthropogenic influences, as brought about by human activity, on species composition and species– and landscape function of Rand Highveld Grassland fragments.

##### 1. Edge Density (ED)

The ED physical variable is an indicator for the degree of landscape fragmentation (Hargis *et al.*, 1998; Brown *et al.*, 2000; Hansen *et al.*, 2001; Saura & Martinez-Millán, 2001; Herold *et al.*, 2002; McAlpine & Eyre, 2002; Baldwin *et al.*, 2004; Cifaldi *et al.*, 2004). The ED landscape metric represents the total length of edge segments (m) per hectare (McGarigal & Marks, 1995) in each 500 m<sup>2</sup> grid cell. A high ED value for a grid cell / matrix area of the landscape indicates that many edge segments are present in that specific area, consequently reflecting a fragmented landscape. Thus grid cells with high ED (black) contains more patch edge than grid cells with low ED, and is thus more fragmented. The city is characterised by a much more fragmented environment and certain areas

outside the city edges were also characterised by fragmentation due to agricultural land uses (Figure 4.3).

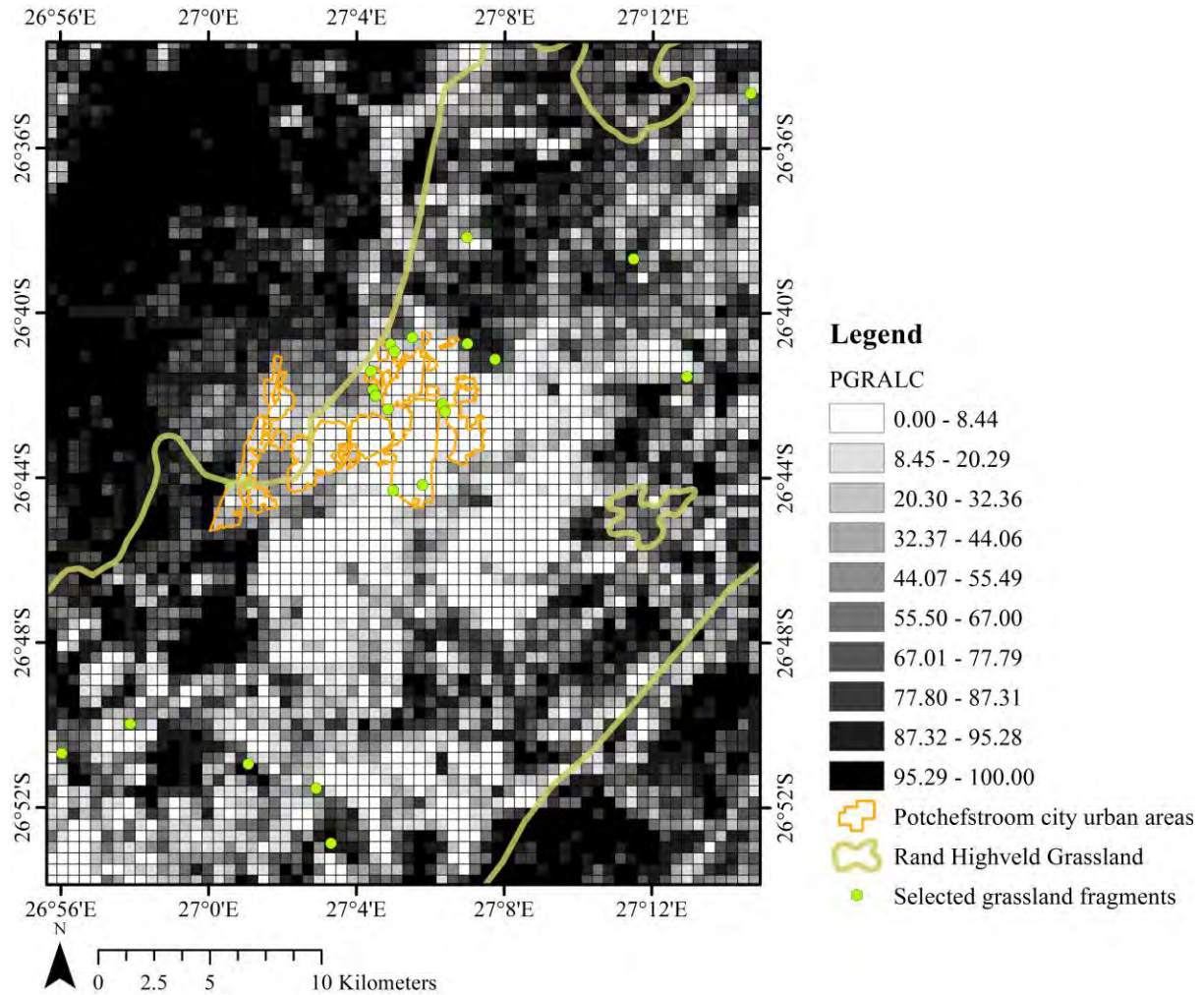


**Figure 4.3:** Landscape grid exhibiting the ED values for the study area in the Tlokwe Municipality. The selected grassland fragments (green dots), as well as the outlines of the city of Potchefstroom (yellow outline) and the Rand Highveld Grassland vegetation unit are also indicated.

## 2. *Percentage grass land cover (PGRALC)*

PGRALC indicates the percentage of each grid cell that consists of the grass land cover class and is an indicator for Rand Highveld Grassland habitat loss. The assumption is made that before any human impact the study area consisted of “natural” Rand Highveld Grassland. If a large proportion of the grid cell / matrix area of the landscape still consist of „natural” grasslands then those areas have not undergone a lot of habitat loss, on the other hand low percentage grassland cover may indicate that some degree of habitat loss has taken place. Grid cells with a high PGRALC value (black) consists of mainly grass cover, and lower values indicate that a smaller fraction of the grid cell consists of

grasslands (Figure 4.4). It is apparent that the land cover within the city border consists of less than 27% grass land cover within each 500 m<sup>2</sup> grid cell, indicating the loss of grassland habitat due to human urban development and inhabitation. The areas South and East of Potchefstroom are utilised for agriculture and therefore also have low grassland cover (Figure 4.4). Other land cover types (such as trees) may also attribute to lower grassland cover.

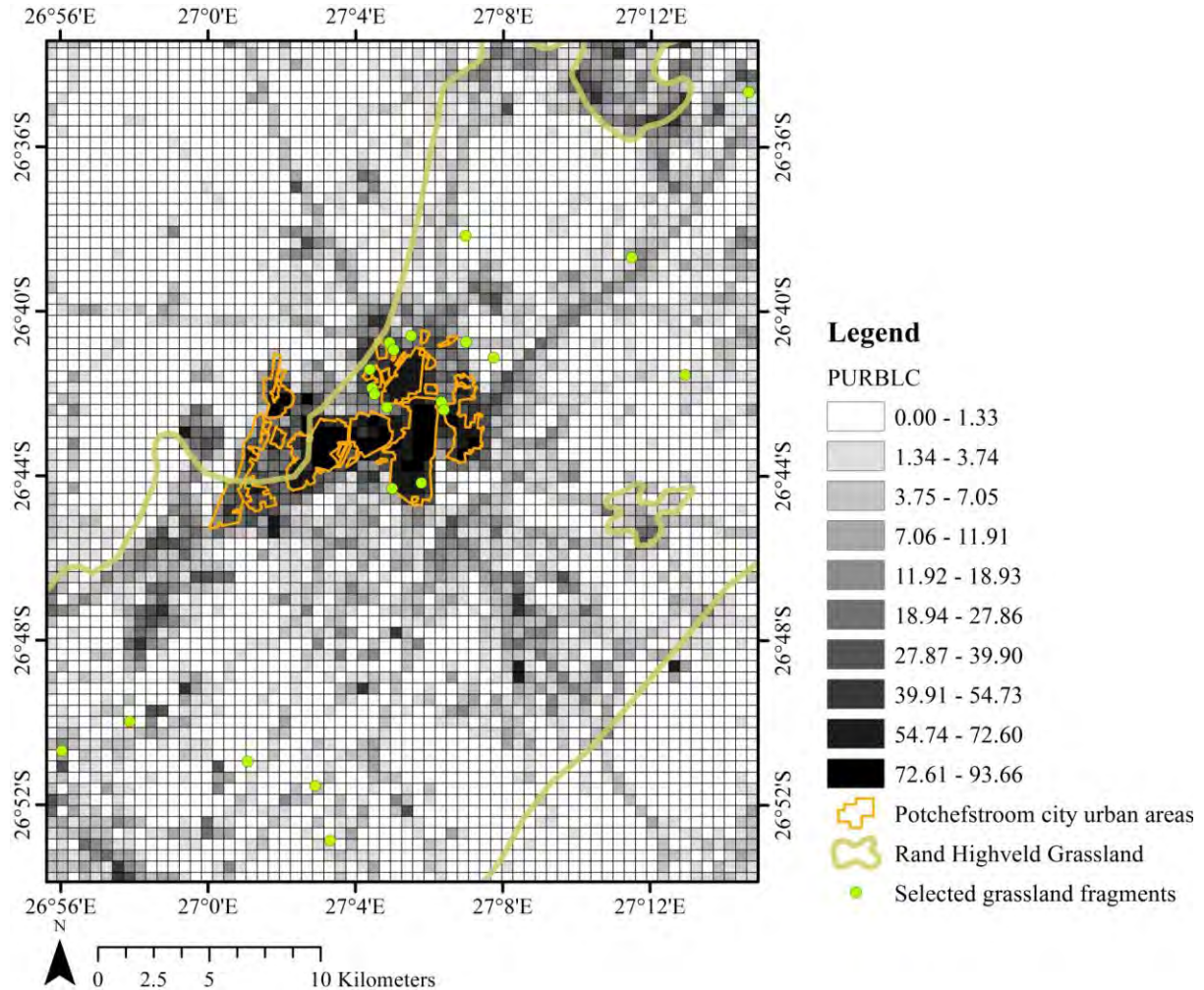


**Figure 4.4:** Landscape grid exhibiting the PGRALC values for the study area in the Tlokwe Municipality. The selected grassland fragments (green dots), as well as the outlines of the city of Potchefstroom (yellow outline) and the Rand Highveld Grassland vegetation unit are also indicated.

### 3. *Percentage urban land cover (PURBLC)*

PURBLC indicates the percentage of each grid cell that consists of impervious surfaces (e.g. roads, pavements, buildings, farmsteads), and is the most accurate view of urban built-up areas. Impervious surfaces are always associated with urbanised areas (e.g. buildings, roads, pavements) (Hahs & McDonnell, 2006; Alberti, 2010), or human presence in more rural areas (e.g. farmsteads). Grid cells with a high PURBLC value (black – as may be observed within the city of Potchefstroom) consists of

mainly urban cover (72-94% per 500 m<sup>2</sup>). Lower values indicate that a smaller fraction of the grid cell consists of urban impermeable structures (Figure 4.5). However, because this landscape metric is based on a land cover map some misclassifications might have occurred and the percentage impervious surfaces values of some grid cells might be slightly inaccurate (*Chapter 3*).

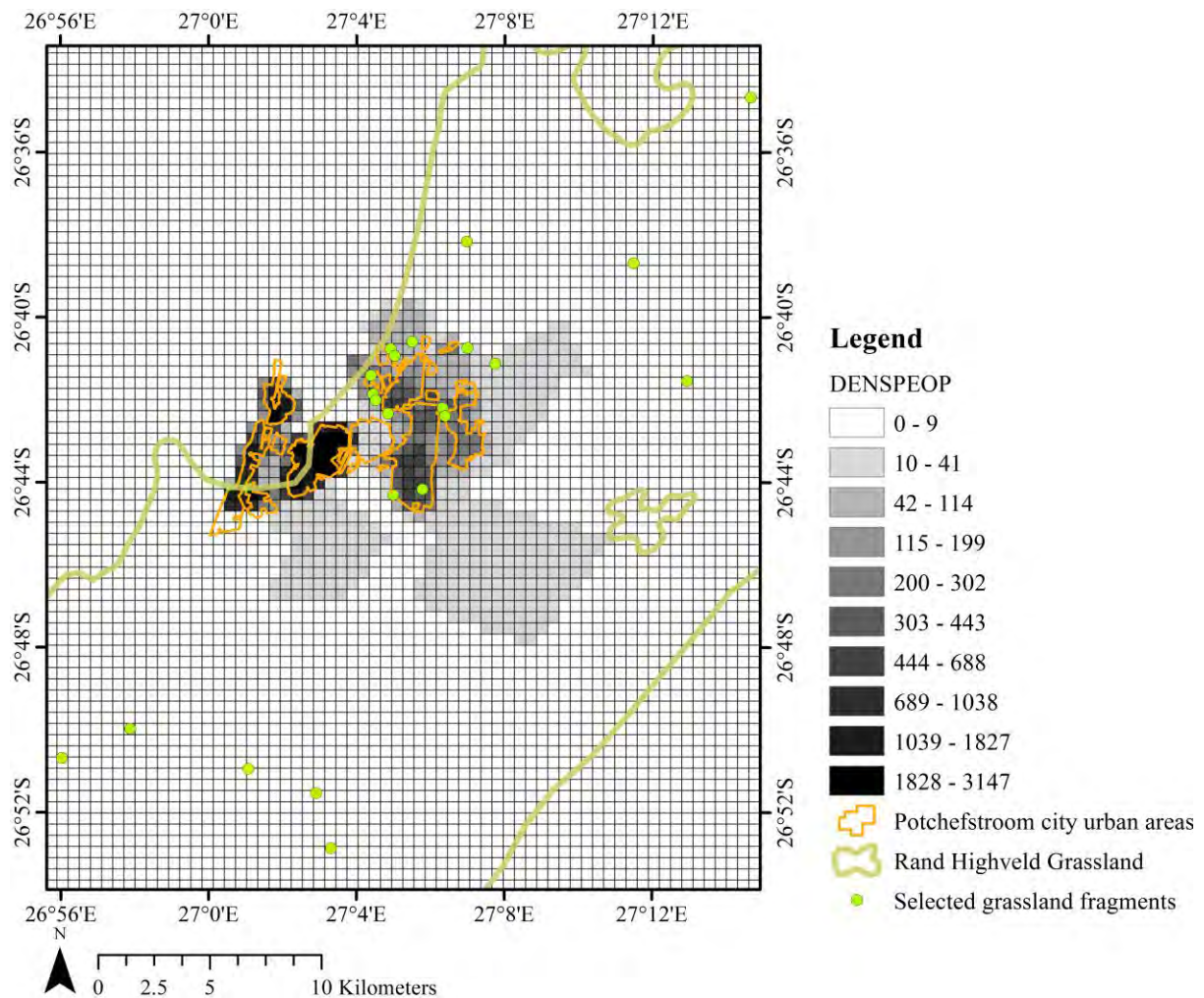


**Figure 4.5:** Landscape grid exhibiting the PURBLC values for the study area in the Tlokwe Municipality. The selected grassland fragments (green dots), as well as the outlines of the city of Potchefstroom (yellow outline) and the Rand Highveld Grassland vegetation unit are also indicated.

#### 4. *Density of people (DENSPEOP)*

DENSPEOP represents the total number of people per 500 m<sup>2</sup> (Figure 4.6), and is an indicator for the degree of urbanisation. The DENSPEOP demographic variable does not clearly reflect urban boundaries because it is supplied in ward format which covers the entire municipal area, thus grid cells may have a value even if no people occupy it. The source of the census data used in this study was the census small area statistics (Statistics South Africa, 2005). The political ward boundaries are

clearly visible (Figure 4.6) as a legacy of the source data. However this is currently the most accurate data for density of people in the Tlokwe Municipal area.



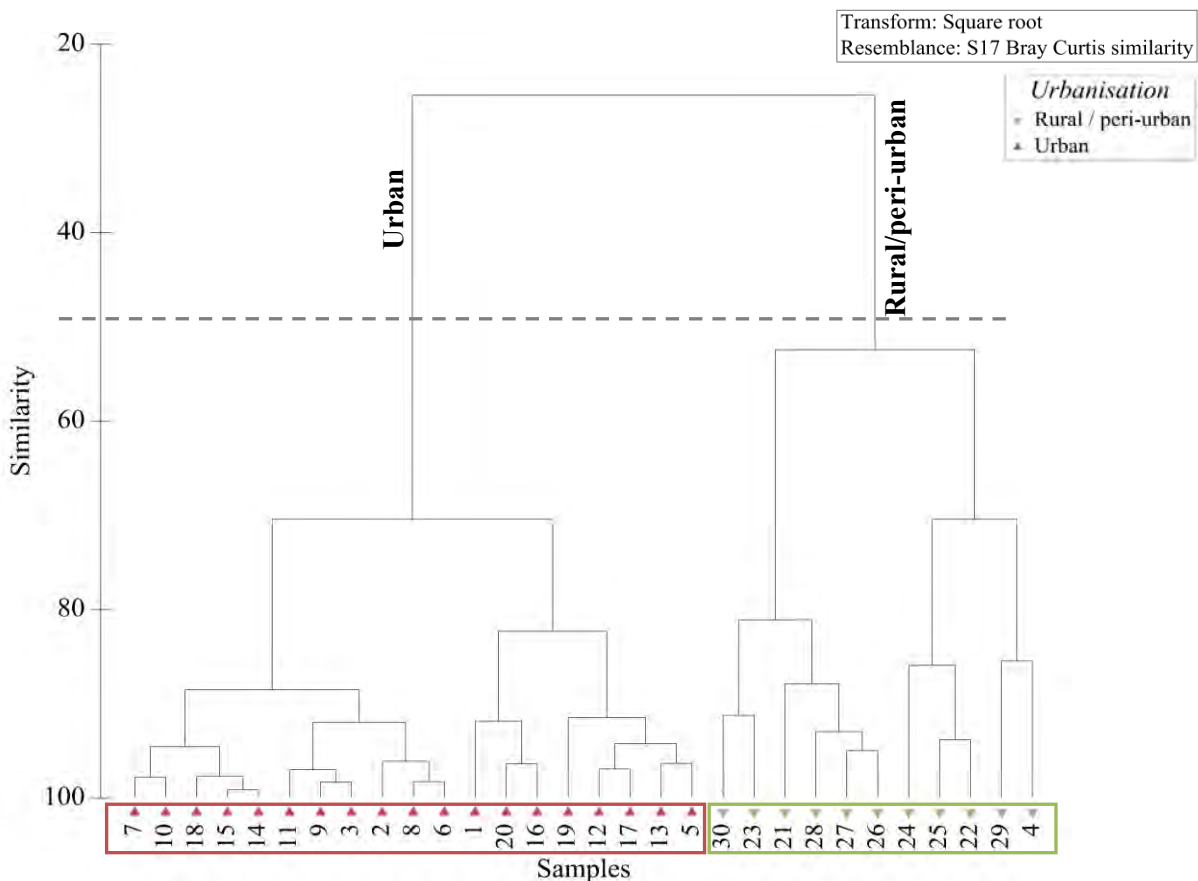
**Figure 4.6: Landscape grid exhibiting the DENSPEOP values for the study area in the Tlokwe Municipality. The selected grassland fragments (green dots) , as well as the outlines of the city of Potchefstroom (yellow outline) and the Rand Highveld Grassland vegetation unit are also indicated.**

#### 4.3.4 Position of grassland fragments along an urbanisation gradient

The ED, PGRALC, PURBLC and DENSPEOP urbanisation measures were subsequently calculated for the 500 m radius buffer zones around the selected grassland fragments in order to determine the position of the grassland remnants along an urbanisation gradient for the Tlokwe Municipal area.

In order to determine whether grassland fragments exposed to different degrees of anthropogenic disturbances differed from each other in statistically significant ways (i.e. does grassland fragments situated in areas of varying urbanisation degrees differ significantly from each other based on their species composition and species– and landscape function?), the urbanisation measures selected for this study (ED, PGRALC, PURBLC, and DENSPEOP) were used as input for a cluster analysis to

objectively classify the selected grassland fragments according to increasing urbanisation / human impacts. This allowed for analysis of variance (ANOVA) in subsequent chapters between the means of intra-patch variables (i.e. species richness between grassland fragments in rural/peri-urban and urban areas). From the results of the cluster analysis presented in Figure 4.7 two urbanisation classes namely “rural/peri-urban” and “urban” have been identified at an arbitrary cut-off point of 50% Bray-Curtis similarity.



**Figure 4.7:** Cluster analysis results (dendrogram – complete linkage) for the urbanisation measure values of the selected grassland fragments (based on Bray-Curtis similarity index). Grassland fragments were classified into two classes, namely rural/peri-urban and urban, at a 50% Bray-Curtis similarity (grey dashed line).

Table 4.6 provides the specific urbanisation measure values for each selected grassland fragment, categorised as rural/peri-urban or urban based on the urbanisation measure values. Rural/peri-urban grassland fragments are all situated in matrix areas that have less than 10% impervious surfaces (thus less urbanised), and an ED value of more than 300 (thus less fragmented) per 500 m matrix buffer area (Table 4.6). Urban grassland fragments are all situated in matrix areas that have less than 26% Rand Highveld Grassland habitat, and a density of people exceeding 269 per hectare. Because of the political ward census data used sites 4 and 29 (rural/peri-urban, situated just outside Potchefstroom) had higher DENSPEOP values of 348 and 168 respectively, which does not reflect the immediate

surroundings of the sites accurately. For the purpose of confirming the rural/peri-urban and urban classification of selected grassland fragments and confirming in which class sites 4 and 29 should belong, two NMDS ordinations were created (Figure 4.8). In Figure 4.8a all the urbanisation measure values were used as presented in Table 4.6, indicating sites 4 and 29 as outliers. However, in Figure 4.8b the DENSPEOP values of sites 4 and 29 were arbitrarily substituted for lower values (DENSPEOP = 40), and therefore they grouped with the rural/peri-urban class. These grassland fragments were situated outside the urban edge, but are closest to the city of Potchefstroom of all the rural/peri-urban grassland fragments (Figure 4.9).

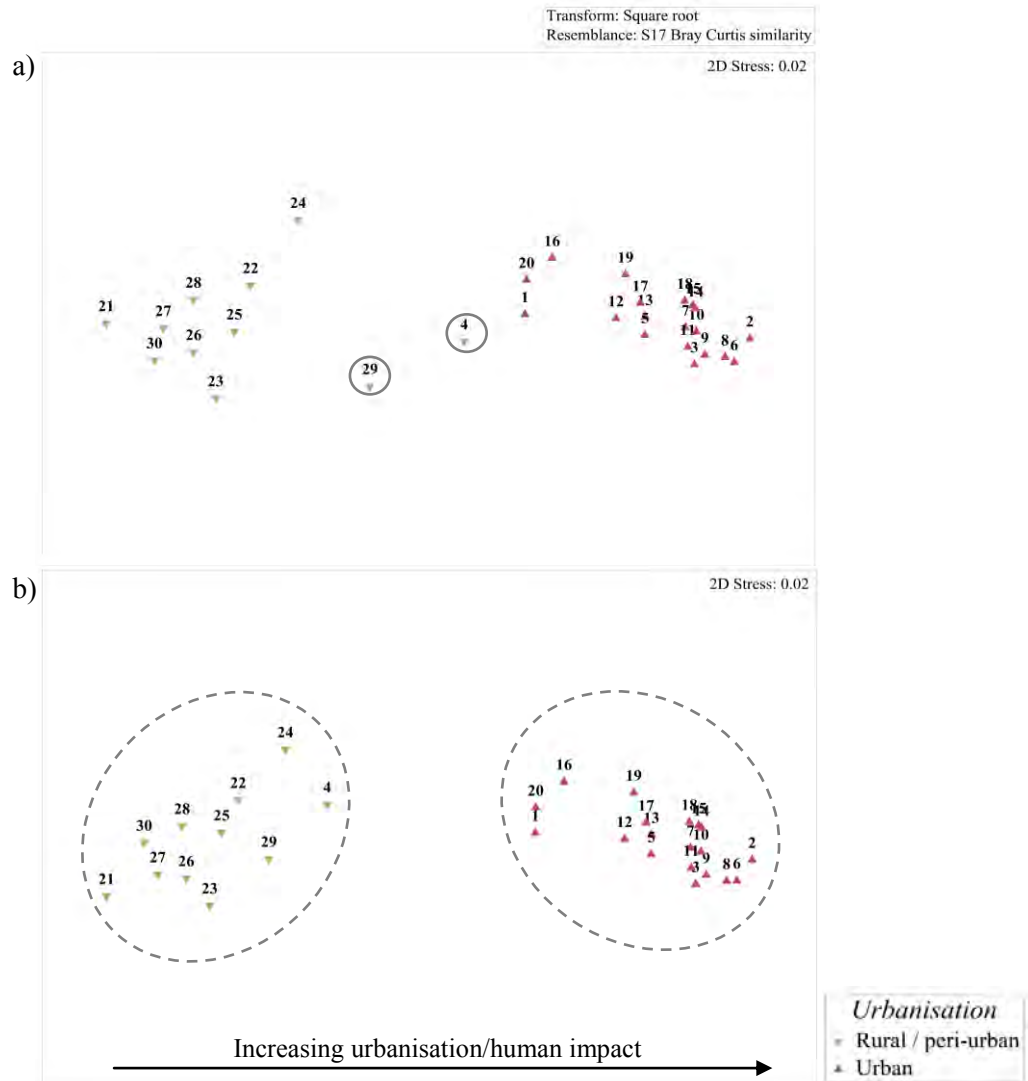
**Table 4.6: The specific urbanisation measures scores (acting as indicators for certain anthropogenic disturbances) for the 30 selected grassland fragments along the urbanisation gradient as determined by the selected urbanisation measures. The selected grassland fragments were classified as rural/peri-urban or urban based on the cluster analysis, and are arranged in the direction of increasing percentage impervious surfaces.**

| Selected grassland fragment | Fragment size (ha) | Buffer size (ha) | % Impervious surfaces (PURBLC) | Fragmentation (ED) | Habitat loss (PGRALC) | Population density (DENSPEOP) |
|-----------------------------|--------------------|------------------|--------------------------------|--------------------|-----------------------|-------------------------------|
| Rural/peri-urban            | 21                 | 11.54            | 160.14                         | 0.61               | 64.75                 | 25.02                         |
|                             | 30                 | 38.69            | 251.52                         | 0.93               | 86.43                 | 44.27                         |
|                             | 28                 | 19.85            | 209.45                         | 1.59               | 130.17                | 23.63                         |
|                             | 27                 | 10.77            | 154.82                         | 2.29               | 96.06                 | 28.21                         |
|                             | 23                 | 116.3            | 325.13                         | 2.81               | 92.14                 | 50.08                         |
|                             | 26                 | 172.83           | 344.47                         | 3.33               | 99.49                 | 23.43                         |
|                             | 25                 | 179.41           | 356.3                          | 5.46               | 137.71                | 49.32                         |
|                             | 29                 | 169.26           | 346.09                         | 5.98               | 139.12                | 42.78                         |
|                             | 22                 | 9.49             | 179.49                         | 6.33               | 178.64                | 40.95                         |
|                             | 4                  | 26.17            | 194.49                         | 8.78               | 254.89                | 58.18                         |
| Urban                       | 24                 | 3.76             | 123.54                         | 9.80               | 274.68                | 56.29                         |
|                             | 1                  | 5.52             | 130.47                         | 17.23              | 434.97                | 26.8                          |
|                             | 20                 | 2.99             | 115.55                         | 27.79              | 452.78                | 19.81                         |
|                             | 7                  | 2.36             | 124.92                         | 30.64              | 412.32                | 2.19                          |
|                             | 19                 | 0.59             | 96.64                          | 34.28              | 377.48                | 2.17                          |
|                             | 16                 | 3.42             | 116.5                          | 36.27              | 499.63                | 8.43                          |
|                             | 13                 | 0.82             | 115.06                         | 38.01              | 469.65                | 7.74                          |
|                             | 9                  | 7.27             | 140.89                         | 38.33              | 423.59                | 2.63                          |
|                             | 5                  | 4.43             | 135.46                         | 41.64              | 394.35                | 12.17                         |
|                             | 8                  | 3.03             | 145.75                         | 41.69              | 422.24                | 2.26                          |
|                             | 3                  | 18.13            | 165.24                         | 44.43              | 386.14                | 6.15                          |
|                             | 11                 | 2.29             | 114.49                         | 44.57              | 440.01                | 7.14                          |
|                             | 10                 | 1.63             | 113.7                          | 44.87              | 424.15                | 1.49                          |
|                             | 6                  | 6.26             | 152.51                         | 44.89              | 419.87                | 1.93                          |
|                             | 12                 | 2.13             | 116.09                         | 46.67              | 457.41                | 18.77                         |
|                             | 17                 | 1.03             | 101.63                         | 52.03              | 512.2                 | 10.6                          |
|                             | 15                 | 1.74             | 108.46                         | 61.7               | 496.71                | 2.08                          |
|                             | 14                 | 0.74             | 96.85                          | 64.18              | 505.93                | 2.34                          |
|                             | 18                 | 0.65             | 97.07                          | 64.18              | 475.58                | 1.96                          |
|                             | 2                  | 3.84             | 117.73                         | 66.19              | 523.8                 | 0.53                          |

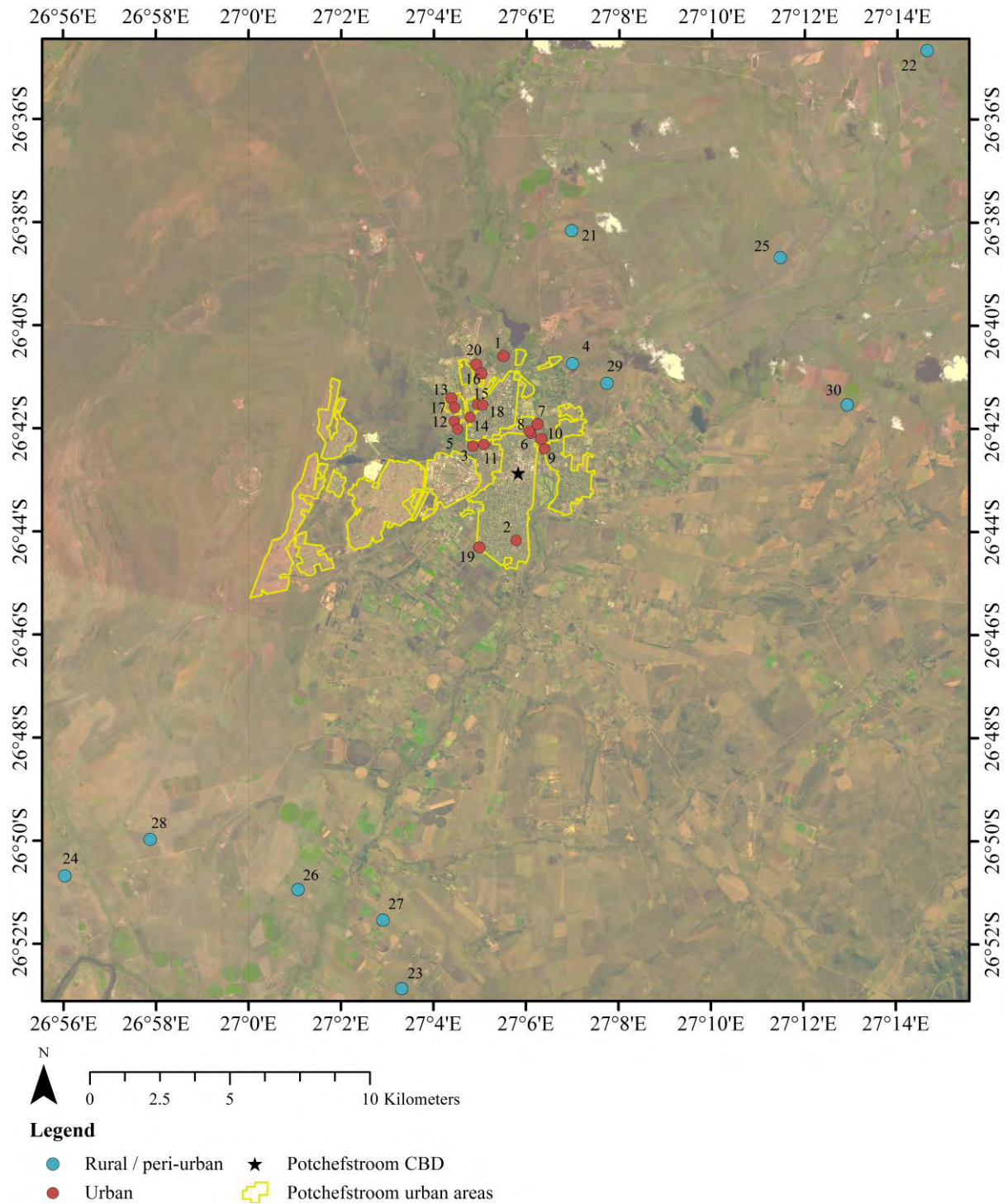
Increasing urbanisation / human impact ↓

Figure 4.9 indicates the position of each selected grassland fragment (rural/peri-urban and urban) within the study area. From the map it is obvious that the city of Potchefstroom does not conform to the conventional urban morphology theory of concentric zones of different land use types radiating outwards from the CBD (Burgess, 1925), which may be the reason rural/peri-urban grassland fragments are situated closer to the urban fringe (i.e. sites 4 and 29), and well beyond the urban edge (i.e. sites 22, 24 and 25) (Figure 4.9). Old towns in South Africa were mostly designed using a simple grid layout (Floyd, 1960). South African cities also conform to the sector model of urban land use (Davies, 1981) as a legacy of colonialism and Apartheid. Recent planning development reflects multi-nuclei urban land use planning (Pacione, 2005). Additionally, the first farms that were allocated in the

region directly surrounded the Potchefstroom settlement area (Van den Bergh, 1990). Subsequent farm owner decisions and personal economic conditions determined much of the urban fringe character. The result is that zoning around the urban fringe is not consistent and there is no gradual transition between urban and rural – some urban areas end abruptly in “natural” areas. This explains the peculiar urban morphology found in the study area, as well as the “rural” nature of some sites situated alongside the urban areas.

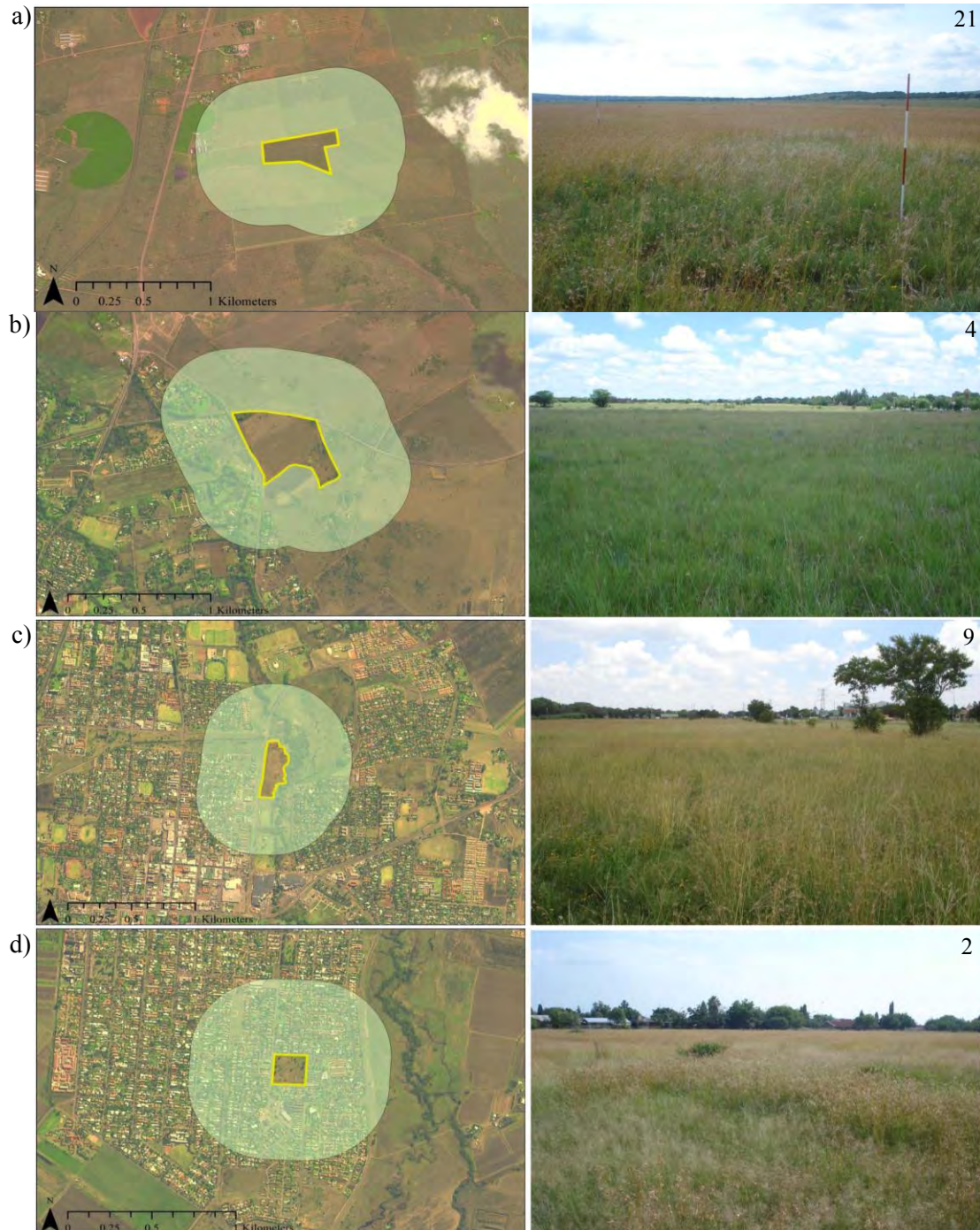


**Figure 4.8: NMDS ordinations to express the selected grassland fragments classified as rural/peri-urban based on the values of the four main urbanisation measures. Sites 4 and 29 (indicated with grey circles) are not grouped closely with rural/peri-urban or urban because of outlier DENSPEOP values (a). Rural/peri-urban and urban selected grassland fragments form two distinct clusters (indicated by dashed grey circles) when the DENSPEOP values of sites 4 and 29 are arbitrarily lowered (b).**



**Figure 4.9: SPOT 5 satellite image of the study area indicating the rural/peri-urban and urban selected grassland fragments. The urban outline (yellow) and the CBD (black star) are also indicated.**

Figure 4.10 indicates images of rural/peri-urban and urban grassland fragments. See Appendix D for SPOT satellite- and in-field images, as well as corresponding fragment- and matrix sizes and specific urbanisation measures for all 30 selected grassland fragments.



**Figure 4.10: SPOT 5 satellite image and in-field photograph of a & b) rural/peri-urban, and c & d) urban selected grassland fragments. Yellow indicates the patch boundary which is surrounded by 500 m radius matrix area (green). The selected grassland fragments are arranged according to increasing percentage impervious surfaces.**

Site 21 (Figure 4.10a) was categorised as rural/peri-urban. The 500 m radius matrix area surrounding this grassland remnant was not very fragmented ( $ED = 64.75 \text{ m/ha}$ ), and 25.02% consisted of Rand Highveld Grassland. Site 4 (Figure 4.10b) is surrounded by an intermediately fragmented ( $ED = 254.89 \text{ m/ha}$ ) environment, intermediate population density ( $DENSPEOP = 16 \text{ per } 500 \text{ m}^2$ ), consisted of 58.18% Rand Highveld Grassland cover, and classified as rural/peri-urban.

Site 9 (Figure 4.10c) classified as urban and was situated in a more fragmented ( $ED = 423.59$  m/ha) matrix. It was also characterised by a population density of 359 people per 500 m<sup>2</sup>, and contained only 2.63% Rand Highveld Grassland cover. Site 2 (Figure 4.10d) classified as urban. It was situated in a highly fragmented ( $ED = 523.8$  m/ha) environment with a population density of 187 per 500 m<sup>2</sup>. Only 0.53% of the matrix area was covered by Rand Highveld Grassland.

## 4.4 Summary

The aim of this chapter was to:

1. Test and select applicable urbanisation measures used by Du Toit (2009) for each 500 m<sup>2</sup> grid cell of the land cover map (created in *Chapter 3*) using GIS techniques.
2. Select urbanisation measures to further describe an entire landscape urban-rural gradient within the study area.
3. Calculate the selected urbanisation measures for 500 m radius matrix areas surrounding the boundaries of the selected grassland fragments.
4. Use the selected urbanisation measures as indicators for anthropogenic influences within the study area.
5. Classify the selected grassland fragments into urbanisation classes based on the selected urbanisation measures using objective statistical methods to determine the position of the selected grassland fragments along the urbanisation gradient.

We have successfully accomplished all these objectives.

Eight landscape metrics (based on Du Toit (2009)) and the specific research questions and experimental design of this study were calculated for each 500 m<sup>2</sup> grid cell of the land cover map, as an initial step to quantify the urbanisation gradient characterising the study area. A Factor Analysis (FA) was executed in order to reduce and explore possible structure within the data (StatSoft, 2011b).

Based on the FA results, the simplicity and comprehensibility of these measures, and keeping the research objectives in mind the following landscape metrics were selected:

- ED (landscape metric) acting as an indicator for fragmentation
- DENSPEOP (demographic variable) acting as an indicator for urbanisation (human inhabitation)
- PGRALC (landscape metric) acting as an indicator for Rand Highveld Grassland habitat loss

- PURBLC (landscape metric) acting as an indicator for the percentage impervious surfaces and thus urbanisation (through development of human infrastructure)

The selected four urbanisation measures were subsequently calculated for the 500 m radius matrix area surrounding the boundary of each selected grassland fragment.

Based on the four selected urbanisation measures (ED, DENSPEOP, PGRALC, and PURBLC) the 30 selected grassland fragments were classified into two classes of increasing urbanisation, namely rural/peri-urban and urban, which will allow for comparisons between landscape function, plant diversity and plant functional diversity of the grassland fragments exposed to different urbanisation degrees using statistical methods in subsequent chapters. All intra-patch variables associated with plant species– and functional diversity and fine-scale biogeochemical landscape function will be correlated with the main urbanisation measures, namely: density of people, edge density, percentage urban land cover, and percentage grass land cover, in order to explore relationships between species– and functional properties and aspects of urbanisation of grassland fragments in the Tlokwe Municipal area.

## 4.5 References

- Abdullah, S.A. & Nakagoshi, N. 2006. Changes in spatial pattern in the highly developing state of Selangor, peninsular Malaysia. *Landscape and Urban Planning*, 77: 263-275.
- Alberti, M. 2010. Maintaining ecological integrity and sustaining ecosystem function in urban areas. *Current Opinion in Environmental Sustainability*, 2: 178-184.
- August, P., Iverson, L. & Nugranad, J. 2002. Human conversion of terrestrial habitats. (In Gutzwiller, K.J., ed. *Applying landscape ecology in biological conservation*. Springer. p. 198-224).
- Baldwin, D.J.B., Weaver, K., Schneckeburger, F. & Perera, A.H. 2004. Sensitivity of landscape pattern indices to input data characteristics on real landscapes: implications for their use in natural disturbance emulation. *Landscape Ecology*, 19: 255-271.
- Beyer, H. 2007. Hawth's analysis tools 3.27. [Web:] <http://www.spatial ecology.com/htools/index/php>. Date of access: 18 Nov. 2011.
- Box G.E.P. & Cox, D.R. 1964. An analysis of transformations. *Journal of the Royal Statistical Society. Series B (Methodological)*, 26(2): 211-252.

- Brady, M.J., McAlpine, C.A., Miller, C.J., Possingham, H.P. & Baxter, G.S. 2009. Habitat attributes of landscape mosaics along a gradient of matrix development intensity: matrix management matters. *Landscape Ecology*, 24: 879-891.
- Brown, D.G., Duh, J.-D. & Drzyzga, S.A. 2000. Estimating error in an analysis of forest fragmentation change using North American Landscape Characterisation (NALC) data. *Remote Sensing of Environment*, 71: 106-117.
- Burgess, E.W. 1925. The growth of the city: an introduction to a research project. (In Park R.E *et al.*, eds. *The City*. Chicago: University of Chicago Press. pp. 47– 62).
- Burnside, N. G., Smith, R. F., & Waite, S. 2002. Habitat suitability modelling for calcareous grassland restoration on the South Downs, United Kingdom. *Journal of Environmental Management*, 65: 209–221.
- Butaye, J., Jacquemyn, H., Honnay, O. & Hermy, M. 2001. The species pool concept applied to forests in a fragmented landscape: dispersal limitation versus habitat limitation. *Journal of Vegetation Science*, 13: 27-34.
- Cifaldi, R.L., Allan, J.D., Duh, J.-D. & Brown, D.G. 2004. Spatial patterns in land cover of exurbanising watersheds in southeastern Michigan. *Landscape and Urban Planning*, 66: 107-123.
- Collinge, S.K. 1996. Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. *Landscape and Urban Planning*, 36: 59- 77.
- Collinge, S.K. 2009. Ecology of fragmented landscapes. The John Hopkins University Press.
- Comrey, A.L. & Lee, H.B. 1992. A first course in factor analysis. 2<sup>nd</sup> ed. NJ: Lawrence Erlbaum Associates.
- Dauber, J., Hirsch, M., Simmering, D., Waldhardt, R., Otte, A. & Wolters, V. 2003. Landscape structure as an indicator of biodiversity: matrix effects on species. *Agriculture, Ecosystems and Environment*, 98: 321-329.
- Davies, R.J. 1981. The spatial formation of the South African city. *GeoJournal*, 2(Supplement 2): 9-72.
- Department of Constitutional Development and Planning. 1986. Potchefstroom - Draft Guide Plan. Pretoria: Government Printer.
- Du Toit, M.J. 2009. Grassland ecology along an urban-rural gradient using GIS techniques in

- Klerksdorp, South Africa. Potchefstroom: NWU. (Thesis – MSc). <http://hdl.handle.net/10394/4197>.
- Du Toit, M.J. & Cilliers, S.S. 2011. Aspects influencing the selection of representative urbanisation measures to quantify urban-rural gradients. *Landscape Ecology*, 26: 169-181.
- Dunford, W. & Freemark, K. 2004. Matrix matters: effects of surrounding land uses on forest birds near Ottawa, Canada. *Landscape Ecology*, 20: 497-511
- ESRI (Environmental Systems Research Institute). 2010. ArcView 10. [www.esri.com](http://www.esri.com) Redlands, CA: USA.
- Fairbanks, D.H.K., Thompson, M.W., Vink, D.E., Newby, T.S., Van Den Berg, H.M. & Everard, D.M. 2000. The South African Land-cover Characteristics Database: a synopsis of the landscape. *South African Journal of Science*, 96: 69-82.
- Floyd, T.B. 1960. Town planning in South Africa. Pietermaritzburg: Shuter and Shooter.
- Forman, R.T.T. & Godron, M. 1986. Landscape ecology. NY: John Wiley and Sons.
- Gaba, S., Chauvel, B., Dessaint, F., Bretagnolle, V. & Petit, S. 2010. Weed species richness in winter wheat increases with landscape heterogeneity. *Agriculture, Ecosystems and Environment*, 138: 318-323.
- Gabriel, D., Thies, C. & Tschardtke, T. 2005. Local diversity of arable weeds increases with landscape complexity. *Perspectives in Plant Ecology, Evolution and Systematics*, 7: 85-93.
- GeoTerraImage. 2008. Final Report: North West Province 2006 Land-Cover Project. Report for North West Province Department of Agriculture, Conservation and Environment (DACE - Environmental Policy and Coordination) by GeoTerraImage (Pty) Ltd. Pretoria, South Africa. [www.geoterraimage.com](http://www.geoterraimage.com).
- Grimm, N.B., Grove, J.M., Pickett, S.T.A. & Redman, C.L. 2000. Integrated approaches to long-term studies of urban ecological systems. *BioScience*, 50(7): 571-584.
- Grobler, C.H., Bredenkamp, G.J. & Brown, L.R. 2006. Primary grassland communities of urban open spaces in Gauteng, South Africa. *South African Journal of Botany*, 72: 367-377.
- Gustafson, E.J. 1998. Quantifying landscape spatial pattern: what is the state of the art? *Ecosystems*, 1: 14-156.

- Hahs, A.K. & McDonnell, M.J. 2006. Selecting independent measures to quantify Melbourne's urban-rural gradient. *Landscape and Urban Planning*, 78: 435-448.
- Hamer, T.L., Flather, C.H. & Noon, B.R. 2006. Factors associated with grassland bird species richness: the relative roles of grassland area, landscape structure, and prey. *Landscape Ecology*, 21: 569-583.
- Hansen, M.J., Franklin, S.E., Woudsma, C.G. & Peterson, M. 2001. Caribou habitat mapping and fragmentation analysis using Landsat MSS, TM, and GIS data in the North Columbia Mountains, British Columbia, Canada. *Remote Sensing of Environment*, 77: 50-65.
- Hargis, D.D., Bissonette, J.A. & David, J.L. 1998. The behaviour of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology*, 13: 167-186.
- Herold, M., Couclelis, H. & Clarke, K.C. 2005. The role of spatial metrics in the analysis and modelling of urban land use change. *Computers, Environment and Urban Systems*, 29: 369-399.
- Hersperger, A.M. & Forman, R.T.T. 2003. Adjacency arrangement effects on plant diversity a composition in woodland patches. *Oikos*, 101(2): 279-290.
- Honnay, O., Piessens, K., Van Landuyt, W., Hermy, M. & Gulinck, H. 2003. Satellite based land use and landscape complexity indices as predictors for regional plant species diversity. *Landscape and Urban Planning*, 63: 241-250.
- Hunt, S.D., Guzy, J.C., Price, S.J., Halstead, B.J., Eskew, E.A. & Dorcas, M.E. 2013. Responses of riparian reptile communities to damming and urbanisation. *Biological Conservation*, 157: 277-284.
- Klimek, S. 2006. Effects of local and landscape factors on grassland plant diversity. Göttingen: Georg-August-Universität . (Thesis - PhD).
- Krauss, J., Klein, A., Steffan-Dewenter, I. & Tschardtke, T. 2004. Effect if habitat area, isolation, and landscape diversity on plant species richness of calcareous grasslands. *Biodiversity and Conservation*, 13: 1427-1439.
- Kroll, F., Müller, F., Haase, D. & Fohrer, N. 2012. Rural-urban gradient analysis of ecosystem services supply and demand dynamics. *Land Use Policy*, 29: 521-535.

- Kuroe, M., Yamaguchi, N., Kadoya, T. & Miyashita, T. 2011. Matrix heterogeneity affects population size of harvest mice: Bayesian estimation of matrix resistance and model validation. *Oikos*, 120: 271-279.
- Li, H. & Wu, J. 2004. Use and misuse of landscape indices. *Landscape Ecology*, 19: 389-399.
- Litteral, J. & Wu, J. 2012. Urban landscape matrix affects avian diversity in remnant vegetation fragments: evidence from the Phoenix metropolitan region, USA. *Urban Ecosystems*, 15: 939-959.
- Lockaby, B.G., Zhang, D., McDaniel, J., Tian, H. & Pan, S. 2005. Interdisciplinary research at the urban-rural interface: the WestGa project. *Urban Ecosystems*, 8: 7-21.
- Luck, M. & Wu, J. 2002. A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA. *Landscape Ecology*, 17: 327-339.
- MacArthur, R.H.; Wilson, E.O. 1967. The theory of island biogeography. Princeton University Press. p. 203.
- Marini, L., Scotton, M., Klimek, S. & Pecile, A. 2008. Patterns of plant species richness in Alpine hay meadows: local vs. landscape controls. *Basic and Applied Ecology*, 9: 365-372.
- Matsika, R. 2007. Land-cover change: threats to the Grassland Biome of South Africa. Johannesburg: University of the Witwatersrand. (Thesis – MSc).
- McAlpine, C.A. & Eyre, T.J. 2002. Testing landscape metrics as indicators of habitat loss and fragmentation in continuous eucalypt forests (Queensland, Australia). *Landscape Ecology*, 17: 711-728.
- McDonnell, M.J. & Hahs, A.K. 2008. The use of gradient analysis studies in advancing our understanding of the ecology of urbanising landscapes: current status and future directions. *Landscape Ecology*, 23: 1143-1155.
- McDonnell, M.J. & Pickett, S.T.A. 1990. Ecosystem structure and function along urban-rural gradients: an unexploited opportunity for ecology. *Ecology*, 71(4): 1232-1237.
- McGarigal, K. 2013. Specific enquiry about the use of landscape metrics for the quantification of a gradient [e-mail]. 22 Feb. 2013.

- McGarigal, K. & Marks, B. J. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Mitchley, J. & Xofis, P. 2005. Landscape structure and management regime as indicators of calcareous grassland habitat condition and species diversity. *Journal for Nature Conservation*, 13: 171-183.
- Muzslay, J. 2006. Calculate demographics. [Web:] <http://arcscrips.esri.com/details.asp?dbid=13866> [Date of use: 14 March 2013].
- Niemelä, J. 1999. Is there a need for a theory of urban ecology? *Urban Ecosystems*, 3: 57-65.
- O'Neill, R. V., Krummel, J. R., Gardner, R. H., Sugihara, G., Jackson, B., Deangelis, D. L., Milne, B. T., Turner, M. G., Zygmunt, B., Christensen, S. W., Dale, V. H., & Graham, R. L. 1988. Indices of landscape pattern. *Landscape Ecology*, 1: 153-162.
- Pacione, M. 2005. Urban geography: a global perspective. 2<sup>nd</sup> ed. NY: Routledge.
- Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Boone, C.G., Groffman, P.M., Irwin, E., Kaushal, S.S., Mashall, V., McGrath, B.P., Nilon, C.H., Pouyat, R.V., Szlavecz, K., Troy, A. & Page, W. 2011. Urban ecological systems: scientific foundations and a decade of progress. *Journal of Environmental Management*, 92: 331-362.
- Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Nilon, C.H., Pouyat, R.V., Zipperer, W.C. & Costanza, R. 2001. Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecological Systems*, 32: 127-157.
- Pillsbury, F.C. & Miller, J.R. 2008. Habitat and Landscape Characteristics Underlying Anuran Community Structure along an urban-rural gradient. *Ecological applications*, 18(5): 1107-1118.
- PRIMER-E. 2012. PRIMER software v6. PRIMER-E ltd.
- Purschke, O., Sykes, M.T., Reitalu, T., Poschlod, P. & Prentice, H.C. 2012. Linking landscape history and dispersal traits in grassland plant communities. *Oecologia*, 168: 773-783.
- Rebele, F. 1994. Urban ecology and special features of urban ecosystems. *Global Ecology and Biogeography letters*, 4(6): 173-187.
- Romesburg, H.C. 1984. Cluster analysis for researchers. North Carolina: Lulu Press.

- Roschewitz, I., Gabriel, D., Tschardtke, T. & Thies, C. 2005. The effects of landscape complexity on arable weed species diversity in organic and conventional farming. *Journal of Applied Ecology*, 42: 873-882.
- Sadler, J.P., Small, E.C., Fiszpan, H., Telfer, M.G. & Niemelä, J. 2006. Investigating environmental variation and landscape characteristics of an urban-rural gradient using woodland carabid assemblages. *Journal of Biogeography*, 33: 1126-1138.
- Saunders, S.C., Mislivets, M.R., Chen, J. & Cleland, D.T. 2002. Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region, USA. *Biological Conservation*, 130: 209-225.
- Saura, S. & Martinez-Millán, J. 2001. Sensitivity of landscape pattern metrics to map spatial extent. *Photogrammetric Engineering & Remote Sensing*, 67(9): 1027-1036.
- Savard, J.-P. L., Clergeau, P. & Mennechez, G. 2000. Biodiversity concepts and urban ecosystems. *Landscape and Urban Planning*, 48: 131-142.
- Scholes, R.J. & Biggs, R. 2005. A biodiversity intactness index. *Nature*, 434: 45-49.
- Statistics South Africa. 2005. Census 2001: census small area statistics. Pretoria: Statistics South Africa. [CD].
- StatSoft, Inc. 2011a. STATISTICA (data analysis software system). Version 10. Tulsa: USA.
- StatSoft, Inc. 2011b. STATISTICA 10: electronic manual. StatSoft Inc., Tulsa: USA.
- Steyn, F. 2012. Normal distribution, scale and transformations for FA data input [e-mail]. *NWU Statistical Consultation Service*. 1 Oct. 2012.
- Tabachnick, B.G. & Fidell, L.S. 2007. Using multivariate statistics. 5<sup>th</sup> ed. USA: Pearson Education, Inc.
- Tschardtke, T., Klein, A.M., Kreuss, A., Steffan-Dewenter, I. & Thies, C. 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters*, 8: 857-874.
- United Nations Population Fund. 2011. State of the world population 2011. NY: United Nations Populations Fund.
- Van den Bergh, G. 1990. Voortrekker plaasbesetting op die Transvaalse Hoëveld: „n versteurde beeld. *South African Journal of Surveying and Mapping*, 20(7): 301-311.

- Warner, R.M. 2008. Applied statistics: from bivariate through multivariate techniques. Los Angeles: Sage Publications.
- Watling, J.I., Nowakowski, A.J., Donnelly, M.A. & Orrock, J.L. 2011. Meta-analysis reveals the importance of matrix composition for animals in fragmented habitat. *Global Ecology and Biogeography*, 20: 209-217.
- Wiens, J.A. 2002. Central concepts and issues of landscape ecology. (In Gutzwiller, K.J., ed. Applying landscape ecology in biological conservation. Springer. p. 3-21).
- Williams, N.S.G., McDonnell, M.J. & Seager, E.J. 2005. Factors influencing the loss of an endangered ecosystem in an urbanising landscape: a case study of native grasslands from Melbourne, Australia. *Landscape and Urban Planning*, 71: 35-49.
- Williams, N.S.G., Morgan, J.W., McCarthy, M.A. & McDonnell, M.J. 2006. Local extinction of grassland plants: the landscape matrix is more important than patch attributes. *Ecology*, 87(12): 3000-3006.
- Yeh, C.-T. & Huang, S.-L. 2009. Investigating spatiotemporal patterns of landscape diversity in response to urbanization. *Landscape and Urban Planning*, 93: 151-162.
- Zhu, M., Xu, J., Jiang, N., Li, J. & Fan, Y. 2006. Impacts of road corridors on urban landscape pattern: a gradient analysis with changing grain size in Shanghai, China. *Landscape Ecology*, 21: 723-734.
- Zipperer, W.C., Wu, J., Pouyat, R.V. & Pickett, S.T.A. 2000. The application of ecological principles to urban and urbanising landscapes. *Ecological Applications*, 10(3): 658-688.