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To what extent does urbanisation affect fragmented grassland functioning?

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ABSTRACT

Urbanisation creates altered environments characterised by increased human habitation, impermeable surfaces, artificial structures, landscape fragmentation, habitat loss, resulting in different resource loss pathways. The vulnerable Rand Highveld Grassland vegetation unit in the Tlokwe Municipal area, South Africa, has been extensively affected and transformed by urbanisation, agriculture, and mining. Grassland fragments in urban areas are often considered to be less species rich and less functional than in the more untransformed or “natural” exurban environments, and are therefore seldom a priority for conservation. Furthermore, urban grassland fragments are often being more intensely managed than exurban areas, such as consistent mowing in open urban areas. Four urbanisation measures acting as indicators for patterns and processes associated with urban areas were calculated for matrix areas surrounding each selected grassland fragment to quantify the position of each grassland remnant along an urbanisation gradient. The grassland fragments were objectively classified into two classes of urbanisation, namely “exurban” and “urban” based on the urbanisation measure values. Grazing was recorded in some exurban grasslands and mowing in some urban grassland fragments. Unmanaged grassland fragments were present in both urban and exurban areas. Fine-scale biophysical landscape function was determined by executing the Landscape Function Analysis (LFA) method. LFA assesses fine-scale landscape patchiness (entailing resource conserving potential and erosion resistance) and 11 soil surface indicators to produce three main LFA parameters (stability, infiltration, and nutrient cycling), which indicates how well a system is functioning in terms of fine-scale biophysical soil processes and characteristics. The aim of this study was to determine the effects of urbanisation and associated management practices on fine-scale biophysical landscape function of urban and exurban grassland fragments, as well as to determine the potential for the use of LFA in decision-making involving the conservation of grassland fragments. The results indicated that the occurrence, size and characteristics of vegetated patches, and especially the presence of litter abundances, were the main factors determining differences in the LFA indices. Furthermore, mowing resulted in the overall fine-scale biophysical indices being higher for some of the urban grassland fragments. This implied that it is not necessarily the influence of urbanisation entailing high or low resource conserving patchiness and patch quality, but rather the management practices associated with urban and exurban areas. Therefore, from a conservation point of view, the grassland fragments in the City of Potchefstroom are just as conservable (on a biophysical function level involving soil processes) than the more “natural” exurban grassland fragments.

1. Introduction

Grasslands in South Africa are considered to be extremely biologically diverse (Gibson, 2009; Henwood, 1998), and are also of economic and social importance as they are ideal landscapes for agriculture, grazing, mining, and human settlement (Fairbanks et al., 2000). These factors have subsequently contributed significantly to population increases resulting in the fragmentation, degradation, and destruction of grassland habitat throughout South Africa (Fairbanks et al., 2000). The grassland vegetation unit of importance for this study was the Rand Highveld Grassland (RHG from hereon), of which a mere 1% is currently being conserved

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(Mucina and Rutherford, 2006). Anthropogenic pressures that affect grasslands throughout South Africa have led to the transformation of 49.8%, and significant degradation of 3.2% of the RHG (NWDACERD, 2009). The RHG is considered by South African statute to be a vulnerable ecosystem which may be subject to significant ecological degradation (National Environmental Management: Biodiversity Act (10 of 2004)).

Landscape Function Analysis (LFA) is an indicator-based field method that rapidly assesses the fine-scale biophysical function of an ecological system (Tongway and Hindley, 2004a; Tongway and Ludwig, 2010). The method is concerned with soil processes such as soil surface stability, infiltration capacity and nutrient cycling potential. Furthermore, it also assesses the possible flow of resources (e.g. water and nutrients) within and out of a landscape, focussing on areas where such resources may be lost from or retained in the system (Tongway and Hindley, 2003a, 2004a). Although LFA was originally developed for, and widely applied in, arid and semi-arid areas (García-Gómez and Maestre, 2011; Holm et al., 2002; Maestre et al., 2006; Thompson et al., 2006; Tongway and Hindley, 2004a), it has also been applied in a variety of ecosystem types such as woodlands (Marchiori, 2006; Munro et al., 2012; Tongway and Hindley, 2004b), mined landscapes (Haagner, 2008; Tongway and Hindley, 2003b; Van der Walt et al., 2012) and rangelands (Bartley et al., 2006; Ludwig et al., 2004; McIntyre and Tongway, 2005; Rezaei et al., 2006; Tongway and Hindley, 2004b). However, there is only one recorded study in which this method has been used in urban areas (Green et al., 2009), indicating that there is need and opportunity to research the landscape functionality of urban areas and implementing the information in the management of urban open spaces.

Urbanisation transforms the composition and functioning of the adjacent lands through stresses and disturbances not typically encountered in the pre-urbanisation landscape (Alberti et al., 2003; Collins et al., 2000; Deng et al., 2009; Grimm et al., 2000; Niemelä, 1999; Niemelä et al., 2011; Ojima et al., 1994; Picket et al., 2011; Williams et al., 2005; Wu et al., 2011). These altered environments create novel ecosystems characterised by the effects of increased human habitation, artificial structures, exotic species, impervious surfaces, and modified energy- and resource pathways (McDonnell and Pickett, 1990; Niemelä, 1999; Pickett et al., 2001). Limited research and studies using LFA have been done in an urban context. However, research has been done in urban landscapes on the various components of landscape functionality that relate to the main LFA functionality parameters (stability, infiltration, and nutrient cycling). These components of landscape functionality were associated with soil properties and -processes, as well as fine-scale vegetation patchiness (Tongway and Hindley, 2004a, b). Vegetation removal (through e.g. mowing) in urban areas may compromise resource-conserving fine-scale heterogeneity, resulting in reduced aerial cover, exposed soil susceptible to crust formation, erosion and compaction, affecting the soil infiltration capacity (Craul, 1985). Urban soils are often compacted by human/mechanical activities and erosion, and are subsequently characterised by less permeable soil surfaces resulting in limited infiltration of rain water and depleted soil nutrient concentrations (Craul, 1985). This in turn results in increased runoff and further erosion (Sauerwein, 2011) and affects infiltration capacity and soil surface stability of urban landscapes. Zipperer and Gutenspergen (2009) found that trampling of urban woodland soils due to human activities increased erosion and reduced infiltration rates. Plant litter in urban areas is often removed as waste, which results in less available litter and disrupted or diminished nutrient cycles (Craul, 1985). McDonnell et al. (1997) studied oak forests along an urbanisation gradient and found that the leaf litter was of poorer carbon quality in urban areas, but decomposed and nitrified at quicker rates due to stresses associated with urban areas such as air pollution, the presence of heavy metals in the soil, and the urban heat island effect.

The aim of this research was to determine the effects of different management (especially mowing) on fine-scale biophysical landscape function of urban and exurban grassland fragments. Additionally the potential of LFA to provide information for rational decision-making involving the conservation of grassland fragments was explored. Conservation priorities are usually determined by the presence or absence of particular species, especially rare or endangered species. However, the information acquired by the LFA method may provide additional knowledge, such as the self-sustainability of landscapes, and thereby contribute to determining the conservation statuses of grasslands.

2. Methods

2.1. Study area

The LFA method was applied to grassland fragments which were situated in and around the City of Potchefstroom, Tlokwe Municipal area, North West Province, South Africa (Fig. 1). The climate of this region is warm-temperate, with cold, dry winters when frost is prevalent for a mean of 28 days a year (Mucina and Rutherford, 2006). Potchefstroom is situated in the RHG (Fig. 1) with and annual rainfall ranging between 570 mm and 730 mm, predominantly occurring in the summer months (October until March) (Mucina and Rutherford, 2006).

A total of 30 grassland fragments were selected (mean area = 27.56 ha, median = 4.14 ha, range = 0.59–179.41 ha) in and around Potchefstroom. Potential grassland fragments to be used as study sites were initially identified using SPOT5 satellite images (CNES, 2007). These grassland remnants were subsequently explored to ensure that they met the criteria for selection of the grassland patches. The criteria for the selection of the grassland fragments followed Van der Walt (2013) and Van der Walt et al.(2014).

2.2. Quantifying an urbanisation gradient

An urbanisation gradient was objectively quantified using SPOT5 imagery (CNES, 2007) and GIS techniques executed in ArcMap software (version 10) (ESRI, 2010). This involved the calculation of demographic- and physical variables (Du Toit, 2009; Hahs and McDonnell, 2006; Van der Walt, 2013) as well as landscape metrics (McGarigal and Marks, 1995). Four urbanisation measures (Table 1) were selected based on statistical analysis and specific research objectives. Each selected urbanisation measure reflected a different anthropogenic pattern, process or disturbance associated with urbanisation (Table 1). Edge density (ED) is an effective representation of fragmentation (Baldwin et al., 2004; Brown et al., 2000; Cifaldi et al., 2004; Hansen et al., 2001; Hargis et al., 1998; Herold et al., 2002; McAlpine and Eyre, 2002; Saura and Martinez-Millán, 2001). Density of people (DENSPEOP) reflects the extent of human habitation, and in this context related to urbanisation. Percentage grassland cover (PGRALC) acted as an indicator for RHG habitat loss, whilst Percentage urban land cover (PURBLC – percentage impervious surfaces) is the best visual and comprehensible approximation of urbanisation indicating the presence of human built landscapes (Hahs and McDonnell, 2006; Alberti, 2010). These urbanisation measures were then calculated for a 500 m radius matrix area surrounding each grassland fragment to indicate the position of each grassland fragment along an urbanisation gradient.