Tree species diversity of agro- and urban ecosystems within the Welgegund Atmospheric Measurement Station fetch region

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DECLARATION

I declare that the work presented in this Masters dissertation is my own work, that it has not been submitted for any degree or examination at any other university, and that all the sources I have used or quoted have been acknowledged by complete reference.

Signature of the Student:…………………………………………………………

Signature of the Supervisor:………………………………………………………

Signature of the Co-supervisor:……………………………………………………

ABSTRACT

Rapid worldwide urbanisation has noteworthy ecological outcomes that shape the patterns of global biodiversity. Habitat loss, fragmentation, biological invasions, climate- and land-use change, alter ecosystem functioning and contribute to the loss of biodiversity. This warrants the study of urban ecosystems and their surrounding environments since biodiversity is essential for economic success, ecosystem function and stability as well as human survival, due to the fact that it provides numerous ecosystem goods and services.

Furthermore, agroecosystems are continuously expanding to meet human needs and play a distinctive role in supplying and demanding ecosystem services, consequently impacting biodiversity. With anthropogenic impacts on ecosystems increasing exponentially, pressure on ecosystem services are intensifying and ultimately unique urban environments that are perfect for the establishment of alien species is created. The proportion of native species in urban areas has increasingly been reduced due to urbanisation, while the proportion of alien species has markedly increased. Trees are normally not considered as typical weedy plants, but many species are invasive aliens in different parts of the world. Trees are generally long-lived and easy to locate, which make trees good indicators of long-term climate conditions, physiognomy and overall vegetation structure. Knowledge of urban floras is vital to improve and maintain the services provided by these areas, as well as aiding in conservation and management practices in urban and surrounding ecosystems.

The aim of this study was to compile a detailed floristic account of the woody vegetation of agro- and urban ecosystems in a 60 km radius around the Welgegund Atmospheric Measurement Station. Bushclumps in different land-cover types were targeted, namely gardens, grasslands, hillsides, plantations, ridges, riparian areas, roadsides, sandy areas, streets and urban open spaces and included tree measurement along a belt transect. Results indicated clear differences between land-cover types as well as alien and indigenous species diversity and composition, which were indicated by means of ordinations. A total of 169 woody species were recorded, with aliens comprising 114 of these species. Tree species diversity was higher in urban areas, but mainly constituted of alien species, whereas species richness was higher in natural areas. Meaningful correlations occur between the socio-economic status of cultivated areas and the categories of alien invader trees.

DCA, NMDS, Linnear Mixed Models displaying effect sizes, diversity indices and basic statistical analyses were performed using the data. Variation in tree species composition and diversity occur between the different land-cover types.

Keywords: Agroecosystems, Tree diversity, Urban ecosystems, JB Marks Local Municipality, Woody species.

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Leandra Knoetze

SOLI DEO GLORIA

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LIST OF DEFINITIONS

Alien species - “Taxa in given areas whose presence there is due to intentional or unintentional human involvement, or which have arrived there without the help of people from an area in which they are alien.” (Richardson and Pyšek, 2004).

Anthromes - “Anthropogenic Biomes, or Human Biomes, are the globally significant ecological patterns created by sustained interactions between humans and ecosystems.” (Ellis and Ramankutty, 2008).

Biomes - “A broad ecological spatial unit representing major life zones of large natural areas, and defined mainly by vegetation structure, climate as well as major large-scale disturbance factors (such as fire).” (Mucina and Rutherford, 2006).

Biotic homogenisation - “The process of replacing localised native species with increasingly widespread non-native species, ultimately reducing the biological uniqueness of local ecosystems.” (McKinney, 2006).

Bushclump - “An association of two or more woody species with continuous canopies that were separated from other woody plants by grassland.” (O’Connor and Chamane, 2012).

BVOC - “Biogenic Volatile Organic Compounds. A specific type of VOC (collective name for a large group of organic compounds, in gas phase that participate in atmospheric photochemical reactions), which is emitted from plant surfaces, wetlands, oceans, animals, microbes, fungi and natural biomass burning (lightning).” (EPA, 2008; IAQM, 2012).

Endemic - “Pertaining to a plant or animal species which is naturally restricted to a particular, well-defined region. Often confused with indigenous.” (Mucina and Rutherford, 2006).

Indigenous (native) - “Taxa that have originated/evolved in a given area without human involvement or that have arrived there without intentional or unintentional intervention of humans from an area in which they are native.” (Richardson and Pyšek, 2004).

Invasive - “Invasive species are a subset of naturalised species that produce reproductive offspring, often in very large numbers, are capable of dispersal/movement over considerable distances from the parent populations, and thus have the potential to spread over a large area.” (Richardson and Pyšek, 2004).

Land-cover - "All the natural and human features that cover the earth's immediate surface, including vegetation (natural or planted) and human constructions (buildings, roads), water, ice, bare rock or sand surfaces. Often confused with land-use." (Fairbanks *et al*., 2000).

Land-use - "Refers to the human activity that is associated with a specific land-unit, in terms of utilisation, impacts or management practices. Land-use is based upon function, where use can be defined in terms of a series of activities undertaken to produce one or more goods or services." (Fairbanks *et al*., 2000).

Naturalised - "Alien species that sustain self-regenerating populations for a reasonable period of time, unsupported by and independent of humans." (Richardson and Pyšek, 2004).

Socio-economic status - "Socio-economic status (SES) is the social standing or class of an individual or group. It is often measured as a combination of education, income and occupation." (APA, 2017).

Vegetation unit - "A complex of plant communities ecologically and historically (both in spatial and temporal terms) occupying habitat complexes at the landscape scale." (Mucina and Rutherford, 2006).

Urbanisation - "The process whereby cities grow and societies become more urban." (Aronson *et al*., 2014).

Urban green space - "Also known as urban greening. Refers to parts of cities providing a range of services to both the people and wildlife living in urban areas which enhances the beauty and environmental quality of these areas. Includes parks, community gardens, cemeteries, playgrounds and so forth." (McConnachie *et al*., 2008).

CHAPTER 1

INTRODUCTION

1.1 Background

South Africa is considered one of the ten most biologically diverse countries in the world, containing more than 250 000 species, many of them occurring nowhere else (Wynberg, 2002). Vascular plants make up about 21 000 of these species (Groombridge, 1992), which equates to approximately 10% of the world's plant species on 2.5% of the world's land surface. This rich plant diversity is one of the main reasons why South Africa is rich in biodiversity across all lifeforms (UNEP – WCMC, 2004). The proliferation of biodiversity in South Africa can be ascribed to the nine biomes and a number of biodiversity hotspots (Mucina and Rutherford, 2006). The Savanna, Grassland and Nama-Karoo are the largest biomes, accounting for almost 80% of the total land surface (Mucina and Rutherford, 2006). Of these, the Savanna Biome is dominated by trees, in contrast to the Grassland Biome. There are 2 897 tree species recorded for South Africa (Coates-Palgrave, 2002).

In the Grassland Biome, woody plants are restricted to specialised habitats or niches. New habitats can arise through transformation and may benefit both native and exotic species. Hughes *et al*. (2014) indicated by means of land cover data that almost 60% of the South African Grassland Biome has been transformed permanently. In addition, Schoeman *et al*. (2010) indicated that this loss or transformation in the North-West province is primarily as a result of cultivation (23.8%), plantation forestry (0.4%), urbanisation (4.2%) and mining (0.5%). Transformation of natural ecosystems to agro- or urban ecosystems presents one of the most significant impacts on biodiversity (Lacher *et al*., 1999; Wessels *et al*., 2003). Furthermore, the 5th National Report of the Convention on Biological Diversity indicated that the main threats to plant species in South Africa include habitat loss, invasive alien species, habitat degradation, harvesting, demographic factors, pollution, change in species dynamics, climate change and natural disasters (CBD, 2014). Moreover, urbanisation drastically reduces natural habitats (Cilliers *et al*., 2009), destroys or fragments natural landscapes, modifies the climate and hydrology and causes the loss of biodiversity by replacing native species with exotic species, which can cause the extinction of local populations of native species and the homogenisation of biota (Barrico *et al*., 2012, Smith *et al*., 2006a).

Urban areas host approximately half of the world's population and it is expected that by 2050 two thirds of people will live in cities, increasing the urban population by approximately 84% (UN, 2009). Kowarik (2011) stated that urban areas, which cover only 3% of earth's surface, are often located on what are considered to be biodiversity hotspots. In addition, the introduction of mostly cosmopolitan exotic species to urban environments often results in cities possessing higher species richness than their natural surroundings (Kowarik, 2011). The form and function of the terrestrial biosphere has therefore fundamentally been altered due to land-cover change and human activities (Ellis *et al*., 2010). Land-cover change and different types of land uses can have a significant effect on biodiversity and, more specifically, on tree population dynamics, which involves changes in the size and age composition of tree populations, as well as the influence of environmental and biological processes on these changes (Turchin, 2003).

Another factor influencing tree populations or tree species distribution and ecological patterns is microclimate (Chen *et al*., 1999). Microclimate fosters the distribution of species and tree recruitment in localised areas. Due to their unique microclimates, urban areas therefore create and maintain a variety of habitats that do not occur elsewhere, with high species diversity and cover often found within these areas (Niemelä, 1999). Thus, tree flora of the Grassland Biome and in particular the Highveld Grassland, which this study focused on, is enhanced by land-cover change brought about by urbanisation.

Land-cover change can negatively influence the functioning of the earth's systems (Lambin *et al*., 2001) by contributing to local and regional climate change (Chase *et al*., 1999), degrading soil (Tolba *et al*., 1992), introducing non-native species (Aronson *et al*., 2015), directly impacting biotic diversity (Sala *et al*., 2000), affecting the ability of biological systems to support human needs (Vitousek *et al*., 1997) and contributing to global climate change (Houghton *et al*., 1999). Human-induced land-cover change directly impacts on the climate via emissions of greenhouse gases as well as by changing the balance of surface energies and affecting the emissions of biogenic volatile organic compounds (BVOCs).

The effects of land-cover change on emmisions of BVOCs and atmospheric chemistry relating to this subject has largely been ignored (Rosenkranz *et al*., 2015). When compared to natural ecosystems, the majority of tree species used in bioenergy plantations are strong BVOC emitters, whereas less BVOC are emitted by intensively cultivated crops (Ashworth *et al*., 2012). However, Jaars *et al*. (2016) found that woody species were the main source of BVOCs in the grassland region, while maize and sunflower crops could also be potential sources of BVOCs. It is thus important that a comprehensive study on BVOC emissions from specific tree species be performed, in order to relate the emission capacities of vegetation types to the measured atmospheric BVOCs (Jaars *et al*., 2016).

1.2 Project history

This study formed part of a larger project involving the Welgegund Atmospheric Measurement Station, which comprises a comprehensibly equipped research station situated in an agricultural landscape bordered by various urban environments (Jaars *et al*., 2016). The research station with its instrumentation was constructed in Finland during 2005–2006 with funding from the Finnish Foreign Ministry and the station was set up in South Africa in 2007. The project aim was to increase scientific knowledge of atmospheric physics and chemistry in southern Africa. From the onset of the project, the focus was on long-term measurements instead of short campaigns.

The station has been operative at Welgegund, North-West province, since June 2010 (Welgegund, 2015). The main research objectives were to observe different atmospheric parameters relevant for climate change, atmosphere-ecosystem interactions, regional pollution, aerosol chemistry and physics based on long-term measurements. The specific research topics include formation and growth of aerosol particles, aerosol optics, concentrations of aerosol particles of natural and anthropogenic origin, atmospheric trace gases, grassland-savanna carbon balance, ecosystem interactions and water balance in a water-limited ecosystem (e.g. Tiitta *et al*., 2014; Vakkari *et al*., 2014; Venter *et al*., 2016). In addition to these measurements, there have been measurements of biogenic and anthropogenic volatile organic compounds, aerosol chemical composition and column concentrations of atmospheric trace gases (e.g. Booyens *et al*., 2015; Jaars *et al*., 2016).

1.3 Study rationale

Studies on tree species in and around Potchefstroom, North-West province (the nearest town to the Welgegund Atmospheric Measurement Station), have largely been explorative and include a small number of studies on invasive alien woody plants (Henderson and Musil, 1984) and naturalised species (Henderson, 1991) as well as vegetation descriptions of spontaneous vegetation in urban open spaces and surrounding agricultural areas (Cilliers, 1998; Cilliers and Bredenkamp, 1998, 1999a, 1999b, 2000; Cilliers *et al*., 1998; Davoren *et al*., 2016; Du Toit and Cilliers, 2011; Lubbe *et al*., 2010; Lubbe *et al*., 2011; Van Wyk *et al*., 1997; Van Wyk, 1998). These studies include vegetation surveys along railways, roadsides, wetlands and urban open spaces; all forms of vegetation were recorded, but few quantitative data of woody species were captured in these studies. Furthermore, a small number of studies have been done on street trees, trees in urban areas and goods and services provided by trees in rural South Africa (Kuruneri-Chitepo and Shackleton, 2011; Paumgarten *et al*., 2005; Shackleton *et al*., 2008). However, there are no further studies in the literature specifically dealing with woody species in the Grassland Biome, urban areas and other land covers. Most studies consider urban areas as one land-use type and consequently never consider categorising urban habitats into subunits or different land-use or land-cover types according to the structure, density or function of built-up areas (Godefroid and Koedam, 2007). The relative influence of the types of built-up areas and land use on the patterns of biodiversity has only been partially studied (Cilliers *et al*., 2011; Davoren, 2009; Lubbe, 2010). Understanding the variation within urban floras and their influences on surrounding areas is therefore vital to improve and maintain the ecosystem services they provide (Cilliers *et al*., 2013; Le Maitre *et al*., 2007; Lubbe *et al*., 2011; Savard *et al*., 2000). The purpose of this study was therefore to generate current and reliable data on the tree species measurements, diversity and composition within the Welgegund Atmospheric Measurement Station (WAMS) fetch region and JB Marks Local Municipality.

Acquired data will also enable an assessment of the impact of land-cover change and topography on tree population structure and biodiversity by measuring the tree species composition turnover (β-diversity) in bushclumps within different land-cover types. The baseline data for this study can be resampled in the future to determine whether tree population structure causes long-term adaptations in BVOCs and climate change. In addition, the generated baseline data will contribute substantially to the identification, monitoring and ultimate sustainable management of tree populations and their associated BVOC emissions. Data captured will support the interpretation of atmospheric observation of VOCs, as well as secondary atmospheric species such as ozone (O_3) (for which VOCs are important precursors) and secondary aerosols (SOA) (for which oxidised VOCs contribute significantly for particle formation and growth) measured at Welgegund in future. Since Welgegund is likely the most comprehensively equipped and most productive atmospheric research station (in terms of papers published in internationally accredited journals) in the interior of South Africa, this work makes an important contribution.

Furthermore, the contribution of tree species to BVOC emissions in South Africa is still relatively unknown and few baseline data exist to compare with similar studies already done elsewhere in the world (Jaars *et al*., 2016). It is also unclear how native and alien species contribute and how different variables (leaf physiology, canopy effects, climate change, land-cover change) affect BVOC emissions. Therefore, this study acquired data on tree assemblages, diversity and population structure to give an accurate depiction of trees growing in agro- and urban ecosystems. This data will assist future studies to determine the influence or effects of tree populations together with land-cover change on BVOC emissions.

1.4 Aims and objectives

1.4.1 Wider aim

The wider aim of this study was to develop a spatial database to predict tree species occurrences and dimensions for the WAMS fetch region.

1.4.2 Immediate aim and objectives

The immediate aim of this study was to compile a detailed floristic account of the woody vegetation of agro- and urban ecosystems in a 60 km radius around the Welgegund Atmospheric Measurement Station.

The objectives included the following:

- To describe the tree floristics of the WAMS fetch region;
- To assess whether the tree flora is dominated by indigenous or alien tree species and how these diversity patterns differ among the different land-cover types; and
- To determine whether socio-economic status is linked to the categories of alien invader trees.

1.5 Hypotheses

The hypotheses formulated for this is study, based on previous studies were as follows:

(i) If a comparison is made between agro- and urban ecosystems, tree species richness and diversity would be higher in urban ecosystems.

    (a) If true, tree species richness in urban ecosystems would mainly be dominated by alien species.

(ii) If species richness of urban cultivated areas with different socio-economic statuses is compared, tree diversity and species composition would vary amongst socio-economic classes.

    (b) If true, higher socio-economic classes would have higher tree diversity – establish tree species pool, and lower classes would have lower tree diversity – maintaining the tree species pool.

1.6 Format of dissertation

This dissertation complies with standard guidelines set by the North-West University and comprises seven chapters. All references cited in the chapters are recorded in a reference list at the end of the dissertation. The results and discussion chapters (Chapters 4, 5 and 6) are presented in a manuscript format, which could be submitted to scientific journals for consideration. Therefore, duplication of certain literature, especially parts of the methodology and selected results, was unavoidable. Each chapter entails the following:

Chapter 2: Literature review

This chapter reviews literature on urban plant studies done elsewhere in the world and what is known about urban ecosystems and agroecosystems. Furthermore, the impact of urbanisation and its relevant effects on ecosystems are reviewed. Relevant literature pertaining to alien invasive plants and their effects on the environment is also addressed. The influence of trees on the environment and vice versa is also discussed.

Chapter 3: Materials and methods

The overarching methodology and experimental design are discussed in this chapter. A description of the study area, each site or land-cover type as well as sampling season and data analysis methods is also included. Global information system (GIS) maps were also used to indicate the relative location of the various land-cover types within the study area. Specific methods (pertaining to a specific chapter) are described in subsequent chapters to avoid unnecessary duplication.

Chapter 4: Woody species of the Welgegund Atmospheric Measurement Station fetch region and JB Marks Local Municipality

This chapter explores the floristic characteristics of tree flora in the WAMS fetch region. Aspects such as the number of alien and indigenous plant families, genera, most frequent species, endemic species, endangered and protected species, useful plants and regions of origin are presented and discussed to indicate the main composition of tree flora in the Highveld Grassland region surrounding the JB Marks Local Municipality.

Chapter 5: Tree species diversity patterns of land-cover types in the Welgegund Atmospheric Measurement Station fetch region and JB Marks Local Municipality

The overall tree species diversity in the WAMS fetch region was determined by means of various diversity indices. In this chapter, tree assemblages, diversity patterns, composition and distribution are discussed to show how these variables relate between the different land-cover types and whether alien or indigenous trees dominate within a given land-cover type.

Chapter 6: Cultivated urban areas as a source of alien trees along a socio-economic gradient

This chapter aims to explicate and expand the knowledge regarding alien tree invasions in urban and agroecosystems, especially pertaining to the JB Marks Local Municipality and WAMS fetch region. Possible means or pathways for the dispersal of alien invaders from urban areas are discussed and the effect of different socio-economic classes on this proliferation is considered.

Chapter 7: General conclusion and recommendations

This chapter summarises the key findings of the study by revisiting the objectives and research questions. It collates the findings regarding alien and indigenous tree species richness, diversity, assemblages and occurrences in agro-and urban ecosystems in the WAMS fetch region and also provides recommendations for further or future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

It is estimated that approximately 66% of the global population will be living in urban areas by 2050 (UN, 2014) and human activities have already changed and altered approximately 50% of the earth's ice-free land surface (Turner *et al*., 2007). The level of urbanisation in South Africa for 2014, was approximately 62%, 10% higher than the typical for developing countries (UN, 2014). These immense alterations to the global environment include enhancing the motility of biota, changing global biogeochemical cycles and ultimately transforming land (Chapin *et al*., 2000). Furthermore, Hahs and McDonnell (2006) stated the importance of understanding the impact that urbanisation have on both the environment and humans, especially considering the continual increase in the population and size of urban areas around the world.

Urban areas are frequently situated in naturally species-rich regions (Luck, 2007), where indigenous species are threatened by various anthropogenic factors, including soil contamination, habitat loss (Craul, 1992), habitat fragmentation, modification, over-exploitation (Groombridge, 1992), intentional or accidental species introductions, species extinction (Erlich and Wilson, 1991) as well as disturbances that cause or present serious challenges for conservation (McKinney, 2002). Anthropogenic impacts are among the most influential and tenacious driving forces of species richness and diversity (Aronson *et al*., 2014; Gibson *et al*., 2013) within urban areas; therefore requiring the inclusion of economic, social and cultural aspects in biodiversity conservation and urban ecology (Alberti *et al*., 2003; Goddard *et al*., 2009) as well as for understanding urban ecosystems. According to Acar *et al*. (2007), urbanisation severely affects the ecology of rapidly growing urban areas and brings about numerous environmental problems, many of which occur because ecological components and factors were not taken into consideration during planning stages.

Urban ecology can therefore be seen as an applied, practical science (Niemelä, 1999) that study or explore urban ecosystems, the associated environmental problems encountered in urban areas (Rebele, 1994), as well as the environment of people living in cities and towns. However, there is a distiction between the ecology *of* cities and the ecology *in* cities. The ecology in cities concentrates on terrestrial and aquatic areas (urban green and blue spaces) and aids in enhancing urban planning, biotic conservation, park management and design as well as urban gardening, giving urban residents access to nature, whilst also advancing human health through pollution mitigation (Pickett *et al*., 2016). However, the ecology of cities, considers the entire urban mosaic as social-ecological systems that integrates social, biological and built components and this concept was introduced to encourage scientists in ecology to think of cities, towns, suburbs and exurbs as ecosystems. In addition, land-cover change (the result of urbanisation) is a complication that needs to be considered when dealing with the ecology of cities (Pickett *et al*., 2016). Ecological research and its implementations, such as the establishment of protected areas and biodiversity conservation, would benefit from the comprehension of human actions in urban areas (Niemelä, 1999). Similarly, a better understanding of urban ecosystems would also benefit the development of residential areas that maintain and improve the quality of life, health and well-being of urban residents, with the process of urbanisation ultimately forming these urban ecosystems and also influencing the ecosystem goods and services they provide (Niemelä, 1999; Ulrich *et al*., 1991).

2.2 Ecosystem goods and services

Spontaneous vegetation, such as the types of vegetation found in urban open spaces, demonstrates the interaction between natural development and human impacts and can be used as a general measure of ecological processes and environmental conditions, which also indicate the health of urban environments (Cilliers and Bredenkamp, 1999b). Ecosystem health can therefore firstly be defined as the occurrence of normal ecosystem functions and processes (Tzoulas *et al*., 2007) and secondly as a system that is free from degradation, distress, is resilient and is capable of maintaining itself independently over time (Lu and Li, 2003). Healthy ecosystems have the ability to provide various ecosystem services, whereas increased disturbance and ecological stress levels reduce the quantity and quality of these services (Lu and Li, 2003).

According to Cilliers *et al*. (2013), ecosystem goods and services are progressively being used to describe how ecosystems, and specifically biodiversity, are linked to human well-being. Ecosystem services can be defined as the conditions and processes of natural ecosystems that assist human activities and maintain human life (Chapin *et al*., 2000), i.e. the rewards that human populations derive indirectly or directly from ecosystem functions (Constanza *et al*., 1997). These services include soil fertility, air filtering, noise reduction, microclimate regulation, natural pest control, rainwater drainage, cultural and recreational value as well as ecosystem goods such as timber, food and other provisioning services (Bolund and Hunhammar 1999; Chapin *et al*., 2000).

Furthermore, biodiversity in urban areas serves various biological and social functions and may be reckoned as one of the services provided by green spaces in these ecosystems (Alvey, 2006). Chapin *et al*. (2000) confirmed this by stating that ecosystem services are generated by the biodiversity present in natural ecosystems. Knowledge of urban environments and urban plant floras is therefore vital to improve and maintain these ecosystem services and to keep them favourable for life (Lubbe *et al*., 2010). Cilliers *et al*. (2013) underscored this by stating that the ecosystem-service approach provides a good framework for the development of sustainable science and should be placed at the centre of integrated sustainable urban development. However, an extensive four-year evaluation of the world’s ecosystem services found that 60% of these services were decreasing due to various anthropogenic factors such as habitat alteration and loss (McKinney, 2006) overexploitation and invasive alien species (Millennium Ecosystem Assessment, 2005), which can mainly be ascribed to urbanisation and its effects (Alberti, 2005). One of these effects is the continuous expansion of agricultural land (Swinton *et al*., 2007), to meet human needs.

2.3 Agroecosystems

Approximately 25% of the earth’s land area is covered by crops and rangelands, which are continually expanding (Millennium Ecosystem Assessment, 2005). These agroecosystems are governed by people mainly to meet fuel, food and fibre needs (Swinton *et al*., 2007). The clearing of local or indigenous ecosystems, such as prairies or forests, for grazing or farming represents a main disturbance of existing ecosystems (Swinton *et al*., 2007). Widespread crop farming represents a continuous disturbance; where farming has become the mainstream, ecosystems have been permanently transformed to the point that cultivated farmland is now generally recognised as a distinct kind of ecosystem (Millennium Ecosystem Assessment, 2005), namely agroecosystems.

According to Gliessman (1990), agroecosystems include the organisms and environment of an agricultural area, which together comprise an ecosystem. Agroecosystems are reliant on services supplied by nearby ecosystems, whether managed or native, and nearby ecosystems are frequently impacted by their agricultural neighbours (Swinton *et al*., 2007). Agriculture, as a managed ecosystem, plays a distinctive role in both demanding and supplying ecosystem services; categories of ecosystem services include regulating (climate systems and water), provisioning (food, fibre and fuel) and cultural services (aesthetic value) (Swinton *et al*., 2007). One of these provisioning services is supplied by trees (food – fruit trees and fuel – firewood). Trees are deliberately introduced for ornamental use in green spaces or for agroforestry (Wilson *et al*., 2014).

Savill *et al*. (1997) define agroforestry as “an intimate mixture of trees with farm crops and/or animals on the same piece of land”. Similarly, Richardson (1998) stated that agroforestry refers to the utilisation of trees in agriculture (including using trees as shelter and windbreaks and intercropping trees with arable crops). Agroforestry has the capacity to attain goals in conservation for agricultural landscapes (Harvey *et al*., 2004). However, some trees used in agro- and commercial forestry cause extensive problems as invading natural and semi-natural areas (Richardson, 1998). The fundamental reason for the expansion of problems related to invasions of tree species worldwide is the swift increase in human-mediated transport and distribution of thousands of species for a variety of purposes, especially ornamental horticulture, forestry and agroforestry (Richardson *et al*., 2014). Nevertheless, alien trees play principal roles in supplying fuel and other products to rural communities in the expansion of agroforestry fields and in land restoration (Le Maitre *et al*., 2002).

An extensive knowledge of vegetation and woody species is therefore needed for the protection of economic and threatened species as well as for managing and monitoring agroecosystems, urban ecosystems and their natural neighbours, as well as their sustainability along with the biodiversity and ecosystem goods and services they provide (Attua and Pabi, 2013; Richardson and Rejmánek, 2011).

2.4 Urban ecosystems

Studies have shown that urbanisation modifies existing ecosystems, creating unique urban environments (Niemelä *et al*., 2010; Williams *et al*., 2009). Niemelä (1999) stated that the word “urban” refers to a specific type of human community with a high population density, their habitation and other buildings or structures. Urban ecosystems can therefore be defined as intricate ecological units, with a unique set of behaviour, rules, growth and evolution (Alberti *et al*., 2003).

Pickett *et al*. (1997) indicated that the most extreme cases of human influence on ecosystem function can be seen in urban ecosystems and that these ecosystems consist of entire landscapes in which humans are the primary agents responsible for creating new and diverse plant communities (Whitney and Adams, 1980). Kowarik (1995, 1990) confirms this by indicating that impacts caused by humans have been recognised as one of the most important influences on vegetation composition in urban environments. Therefore, vegetation plays a principal role in maintaining and sustaining urban ecosystems (Colding, 2007).

These urban green spaces (Pelser, 2006) provide physical ecosystem services like flood and temperature control and removal of carbon and certain pollutants from the atmosphere as well as social ecosystem services such as community well-being and aesthetic value (Bolund and Hunhammar, 1999). Walbridge (1997) revealed that urban ecosystems differ from their “natural” counterparts exclusively in the degree of human influence. Urban habitats are usually considered to be more island-like, because they often represent early successional stages, lack integration of habitat patches, are more easily invaded by alien species and are easily disturbed; all these features result from human activities (Niemelä, 1999). In addition to species introductions and changes in the distribution of species, the quality of urban plant communities together with the global increase in urbanisation, which is a major driver in the changing patterns of life on earth, need more attention for greater understanding of these urban ecosystems and adjoining ecosystems (Aronson *et al*., 2007). Due to the uniqueness of urban ecosystems, Ellis and Ramankutty (2008) proposed “anthromes” or anthropogenic biomes to classify or describe world-wide urban or human-dominated ecosystems.

2.4.1 Anthromes

Humans have long distinguished themselves from other species by shaping ecosystem forms and processes using tools and technologies, such as fire, that are beyond the capacity of other organisms (Smith, 2007). Consequently, humans have emerged as a force of nature rivalling climatic and geologic forces in shaping the terrestrial biosphere and its processes.

Biomes are the most basic units for describing global patterns of biodiversity, ecosystem prosesses and form. Recent studies confirmed that human-dominated ecosystems, including urban ecosystems, now cover the majority of the earth’s land surface compared to natural ecosystems due to the restructuring of the terrestrial biosphere for urbanisation, agriculture, forestry and other uses. As a result, global patterns of species abundance and composition, land-surface hydrology, primary productivity and nitrogen, carbon and phosphorus biogeochemical cycles have been altered substantially (Vitousek *et al*., 1997). Standard biome systems either disregard human impacts or influence altogether or explain it using at most four classes of anthropogenic ecosystem (urban/built-up, rangeland and one or two cropland/natural vegetation mosaics) (Ellis and Ramankutty, 2008). Ellis and Ramankutty (2008) identified and classified 21 anthropogenic biomes or anthromes into six main groups (dense settlements, villages, croplands, rangelands, forested and wildlands).

2.4.2 Environmental impacts of urbanisation

Grobler *et al*. (2006) pointed out that urbanisation and its affiliated impacts pose some of the greatest threats to natural environments still present in urban areas. From an ecological point of view, urbanisation can have both beneficial and detrimental effects on biotic communities. On the one hand, the variety of human influences in urban areas creates and maintains diverse habitats that do not occur elsewhere (Niemelä, 1999). On the other hand, urbanisation threatens many natural habitats and species due to habitat destruction and species introductions (Aronson *et al*., 2007). It is therefore crucial to document changes in floras where urbanisation has occurred or is occurring, as this may reveal crucial facts or features associated with species' abilities to establish and persist in urban landscapes (Robinson *et al*., 1994).

In addition, urbanisation is one of the main causes of biological homogenisation and biodiversity loss in both developing and developed countries (Savard *et al*., 2000). Although urbanisation in certain provinces of South Africa has been less than the country's national figure of 64% (Statistics South Africa, 2016), a swift increase in urbanisation is still expected in the future as a result of fewer job opportunities and higher poverty levels (Cilliers *et al*., 2004). Nevertheless, it is important to remember that expanding urban areas are generated by humans and ultimately any problems that arise from urbanisation are thus directly or indirectly caused by anthropogenic disturbance (McKinney, 2002). Disturbances can be defined as any fairly discreet events in time that disrupt the structure of communities, ecosystems or populations and changes resources, substrate availability or the physical environment (Pickett and White, 1985; White and Jentsch, 2001).

Even though disturbances, as defined by Grime (1979), may be the outcome of natural catastrophes such as floods and windstorms, they can also be attributed to more extreme forms of human impacts such as trampling, ploughing, weeding, burning and mowing. Buhk *et al*. (2007), indicated that plant species richness is inversely correlated to the frequency of disturbance, but high levels of disturbance in urban areas can facilitate the spread and survival of introduced species (Gilbert, 1989), which can ultimately reduce native species richness (Davis, 2003). The most important problems that result from disturbances include habitat loss (Wilcove *et al*., 1998), biotic homogenisation (Aronson *et al*., 2015; McKinney, 2006), land-use change (Lambin *et al*., 2001) and ultimately human-induced climate change (Hannah *et al*., 2004; Lovejoy and Hannah, 2005), all of which are discussed in more detail in the following sections.

2.4.2.1 Habitat loss

Habitat loss and fragmentation have been identified as principal causes of global biodiversity loss (Tilman *et al*., 2001). According to McKinney (2002), there is a gradual loss of natural habitat that increases from rural areas to urban centres. Similarly, Niemelä (1999) indicated that there is a continuum of decreasing human influence away from city centres to nonurban or wilderness areas. Remaining natural areas are therefore continuously fragmented into various smaller patches (Collins *et al*., 2000). Thus, human impacts, which can result in complete loss of habitat, are recognised as some of the most important influences on the diversity and composition of vegetation in urban areas (Kowarik, 1990).

McKinney (2002) identified four types of altered habitats that usually replace lost natural habitats progressively towards urban centres. These habitats include built habitats (buildings, roads and sidewalks), managed vegetation (regularly maintained commercial and residential green spaces), ruderal vegetation (cleared, but not managed, green spaces such as abandoned farmlands and empty lots) and natural remnant vegetation (remaining islands of original vegetation) (Whitney, 1985). These land alterations or modifications are usually long-term and intensify with time.

2.4.2.2 Biotic homogenisation

Of all human activities, urbanisation, when measured by its intensity and extent, is one of the most homogenising influences on biodiversity (McKinney, 2006). Homogenisation can be defined as an increase in the similarity of the composition of species, due to the existing elimination of unique or rare native species and the increase of widespread, common species through human activities (McKinney and Lockwood, 1999). Consequently, as urban areas expand globally, biological homogenisation increases due to the same species (that have adapted to urban areas) becoming increasingly widespread and locally abundant in cities (McKinney, 2006). This is due to the fact that urban habitats and management processes tend to be similar worldwide (Clergeau *et al*., 2001). Furthermore, the continuing expansion of alien species has been outlined as one of the major causes of global biotic homogenisation (Davis, 2003).

In addition, this process of replacing native species with non-native species threatens to minimise the biological uniqueness of all local ecosystems (McKinney, 2006). Therefore, biotic homogenisation can be considered as one of the ruling processes shaping global biodiversity, while also reducing spatial diversity (Lockwood and McKinney, 2001). The growing awareness of species composition defining the extent to which biodiversity maintains ecosystem function underlines the importance of conservation biologists considering the many threats to biological diversity, including biotic homogenisation (Rooney *et al*., 2007). As a result, interest in ruderal vegetation has increased due to the escalating importance of urbanisation and urban areas, which are linked with the constant synanthropisation of vegetation due to disturbance. Synanthropisation can be defined as the changes in plant composition or cover caused indirectly or directly by human activities (Cilliers and Bredenkamp, 1999b). Furthermore, McKinney and Lockwood (1999) indicated that biotic homogenisation occurs more readily when widespread environmental changes or disturbances arise.

Disturbances associated with urbanisation can shift urban floras to species-specific assemblages, with a high diversity of exotic species and species adapted to human-induced disturbances (Niemelä, 1999; Pickett *et al*., 2011; Pyšek, 1998). These disturbances arising from urbanisation include all urban environmental circumstances, any human influences and habitat fragmentation and transformation (Van der Walt *et al*., 2015). In addition, native ecosystems are threatened by disturbances related to land-cover or land-use change, because the likelihood of plant invasions increases with these disturbances (Bradley, 2010).

2.4.2.3 Land-use change

As mentioned earlier, human activities has changed or altered more than 50% of the ice-free land surface (Turner *et al*., 2007). These transformation or alterations are referred to as land-use changes and can vary across time and space. Foster *et al*. (2003) indicated that the composition and structure of vegetation are generally simplified through land-use change at local scales, resulting in the loss and isolation of the original vegetative cover at the landscape scale. Furthermore, a decrease in the populations of many species can be a consequence of land-use change (Fischer and Lindenmayer, 2007).

Studies of subtropical areas in South Africa have confirmed that land-use change and successive plant invasions create new assemblages in vegetation, which lead to long-term changes in community structure, species composition and successional trajectories (Van der Linde *et al*., 2008). Changes in land-use may decrease plant species richness and should therefore receive more attention in urban and agricultural policies to balance conservation, urban and socio-economic considerations (Maurer *et al*., 2006).

However, land-use change can promote an increase in the populations of certain species, especially those that can utilise more attainable habitats and different land covers such as agricultural land (Haila, 2002). Land-use change has radically transformed the function and form of the terrestrial biosphere. Although changes in land use are major drivers of plant invasions in biomes and other ecosystems, increases in atmospheric carbon dioxide might be an additional global driver tipping the balance to woody invasions in particular (Bond, 2008). Land-use change has direct consequences on the climate via emissions of greenhouse gases and by affecting the emission of biogenic volatile organic compounds (BVOCs).

2.4.2.4 Climate change

Climate change is an important effect of urbanisation, mainly due to human-induced land-cover changes (Rosenkranz *et al*., 2015) and greenhouse gas emissions (Gill *et al*., 2007; Hannah *et al*., 2002). The Intergovernmental Panel on Climate Change has warned against the worldwide dangers of continuous greenhouse gas emissions to ecosystems and human populations

(IPPC, 2014). These dangers include rising sea levels, increasing numbers of heatwaves, substantial precipitation events such as storms, floods and hurricanes, elevated temperatures and increased drought affected areas (Younger *et al*., 2008).

Furthermore, climate change in itself affects species physiology and alien invasion patterns. It also changes plant species distribution or ranges, poses a threat to native species richness and is likely to expand the rate of destruction and extinctions (Bradley, 2010; Richardson and Rejmánek, 2011). According to Hannah *et al*. (2004), the ability to manage climate change will increasingly be tied to the ability to conserve biodiversity and the living resources of the planet. Therefore, given the current and imminent results of climate change, the management of suitable habitats and landscapes through suitable land-use planning will be vital in the future (Yamaura *et al*., 2009).

Although climate change, land-use change and biological invasions alter ecosystem function and structure, a general quantifiable understanding of how these drivers interact and could collaboratively influence ecosystems in the future is still lacking (Sorte *et al*., 2013). Climate change also provides an immense challenge for managing woody plant invasions (Richardson and Rejmánek, 2011), because cycles of climate change, land-use histories or altered disturbance regimes frequently modify the conditions for tree recruitment, survival and growth and can change open, treeless habitats to tree-dominated ecosystems (Rundel *et al*., 2014).

Similarly, in southern Africa, climate change was identified as an important co-driving force of bush encroachment (Ringrose *et al*., 2002) and, in combination with typical stresses induced by humans (such as waste dumping, overgrazing and alien invasive species), natural species composition are influenced (Van der Linde *et al*., 2008). In other words, in the coming century, climate change caused by increasing greenhouse gas emissions may produce dramatic shifts in the distribution of tree species, as well as the rates at which individual tree species release or sequester carbon back into the atmosphere (Scheller and Mladenoff, 2005). Consequently, with the increasing consideration of climatic effects together with air quality concerns, BVOCs are receiving growing attention because of the large amounts released from terrestrial vegetation globally (Rosenkranz *et al*., 2015).

2.5 Biogenic volatile organic compounds

More than 90% of the total volatile organic compounds entering the atmosphere are biogenic (Greenberg *et al*., 1999) and natural emissions of volatile organic compounds exceed anthropogenic emissions on a global scale (Guenther *et al*., 1996). Ecosystems emit or produce large amounts of BVOCs, which are involved in plant growth and reproduction (Jaars *et al*., 2016). A well-known characteristic of the plant world is the release of volatile substances through the aerial organs of plants (Rasmussen, 1972). Initial volatile studies included only the exchange of the metabolic gases of carbon dioxide, oxygen, water vapour and ethylene (Ivanov and Yakobson, 1965), however up to date, long-term ambient BVOCs has been studied extensively (Jaars *et al*., 2016 and references therein); furthermore, the nature of BVOC emissions in grasslands is still unknown and superficially studied (Jaars *et al*., 2016). Limited research in southern Africa has been conducted to determine the emission rates of BVOCs and their impacts (Jaars *et al*., 2014) and the effects of land-use change on BVOC emissions and related atmospheric chemistry have also been largely ignored (Rosenkranz *et al*., 2015).

BVOC emissions and production rates are conditioned by biotic and abiotic factors. Among the former, water availability, temperature and irradiance are the most important factors (Peñuelas and Llusià, 1999; Seufert, 1997). Irrespective of the exact vegetation type, much larger emission potential are possible through woody vegetation, compared to herbaceous or crop vegetation (Niinemets *et al*., 2010). However, as is true for crops, stressors in the environment modify BVOC emissions from trees to a large degree (Rosenkranz *et al*., 2015).

The emissions of BVOC can, however, be manipulated or controlled by the selection of specific cultivars or species and through field management (Rosenkranz *et al*., 2015). This may cause subsequent generations to impact less on processes in atmospheric chemistry, with lowered BVOC emission potential and, can also aid in selection for BVOCs that could enlarge plant resistance or tolerance against abiotic stresses, herbivores and pests (Loreto and Schnitzler, 2010). Furthermore, these stresses or degradation processes of plant materials might also result in significant BVOC emissions from cut trees (Rosenkranz *et al*., 2015). However, intensively cultivated crops typically emit less BVOCs compared to natural ecosystems, where tree species are strong BVOC emitters (Ashworth *et al*., 2012).

2.6 Trees

Trees are the largest plant lifeform and are normally long-lived. Therefore, trees are good measures or indicators of long-term climate conditions (O'Brien *et al*., 2000). Similarly, it is assumed that the distributions of southern African shrubs and trees are broadly in accord with present-day climatic variables and potential (O'Brien *et al*., 2000). Since trees are also the dominant lifeform under optimal edaphic and climatic conditions, are easy to locate and count and are relatively well known taxonomically (Sagar *et al*., 2003), they can be good indicators of physiognomy and vegetation structure (O'Brien *et al*., 2000). Trees have a high potential to transform landscapes, because they can dominate plant communities, with profound impacts on biodiversity and ecosystems services (Richardson and Rejmánek, 2011).

Trees are usually not deemed to be typical weedy plants, but many tree species are invasive aliens in various parts of the world (Richardson and Rouget, 2002). Adding trees to ecosystems often results in major ecological changes, particularly in ecosystems that were previously treeless or poor in tree cover (Richardson *et al*., 2014). Furthermore, special challenges are presented to ecologist when studying the dynamics of long-lived organisms such as trees, because events at various stages of a tree's lifecycle affect the likelihood of reproduction, recruitment, persistence and establishment of tree species (Richardson and Rouget, 2002). Furthermore, the information available on dimensions and relations of frequently propagated urban trees is normally based on personal observations and generally lacks substantial scientific validation (Stoffberg *et al*., 2008).

Trees are widely considered as advantageous or beneficial, because they are perceived to promote rainfall, sequester carbon, stabilise catchments or erosion and provide shade and habitat for wildlife (Van Wilgen and Richardson, 2014). On the other hand, alien invasive trees are viewed as undesirable and unwanted because of their displacement impacts on native biodiversity and ecosystem services (Van Wilgen, 2012). Apart from the ecological functions that urban trees fulfil, they are used in an architectural landscape context to derive aesthetic and spatial functions (Larsen and Kristoffersen, 2002). Resource-based niche differentiation consists of habitat specialisation in such a way that different species of trees are best suited to different habitats, where they are relatively more abundant and competitively dominant (Tilman and Pacala, 1993). A study by Van der Walt *et al*. (2015) conducted in the Grassland Biome of South Africa indicated that the mean percentage of trees found in urban areas was significantly higher than in rural areas.

In the absence of disturbances such as clearings, repeated fires or feeding by herbivores, tree cover increases until it is limited by tree-tree competition (Scholes and Archer, 1997). Furthermore, the distribution pattern of trees is affected by numerous abiotic and biotic factors and their interactions. Sankaran *et al*. (2005) indicated that mean annual precipitation limits maximum tree cover, but that other factors prevent most of the landscape mosaic (tree cover) from reaching this maximum. The main variables or factors reducing tree cover from its maximum potential are fire frequency, the density of human populations and herbivore densities. Thus, the spatial pattern of tree species distribution is largely due to local microclimates, past human disturbances and frequent natural disturbances (Basnet, 1992). For instance, topography is a major physical factor that affects the growth, composition and distribution of trees (Whitmore, 1984).

2.7 Microclimate

As mentioned above, environmental factors such as geology, topography and certain soil characteristics are important in determining the establishment of plant communities in and around urban areas (Cilliers *et al*., 2004). Climate and topography have been considered the main drivers of biodiversity at the macro-ecological scale (Yamaura *et al*., 2009). At a more localised scale, microclimate can be defined as an array of climatic conditions measured in localised areas near the earth's surface (Chen *et al*., 1999). These environmental variables normally include light, temperature, wind speed, geology and moisture. Many studies that focus on the factors that determine plant distribution use correlative methods in which environmental factors such as topography, climate and vegetation type are assumed to be important drivers of distribution (Richardson and Rouget, 2002). In addition, studies in temperate forests show that species abundance and distribution are functions of topography and exposure, which influence moisture and fertility gradients. Tree communities have also been shown to correspond to topographic features such as aspect, coves, ridges, slopes and altitude (Whittaker, 1956).

Topographical features are therefore important physical factors that create diverse microsites (Whitmore, 1984), depending on the moisture regime, soil type, altitude and geological formation (White, 1963). Topography affects sensitivity to natural disturbances and edaphic conditions and consequently influences the demographic processes of growth, mortality and tree recruitment (Gale, 2000). In addition, species-specific habitat preferences result in spatial variation in the abundance of tree and other plant species (Kubota *et al*., 2004).

2.8 Biodiversity conservation

O'Farrell *et al*. (2012) emphasised the importance of biodiversity to human well-being because of the numerous goods and services provided by natural ecosystems. Due to the fact that urbanisation rates are increasing and more of the world's human population is living in urban rather than in rural areas, extensive focus is needed on the management, planning and conservation of biodiversity, specifically for urban areas (Cilliers *et al*., 2009). Biodiversity entails much more than counting species. It is the sum total of species, genes and ecosystems in a region or the world (quantitative biodiversity), their heterogeneity, contrast or turnover (qualitative biodiversity) and functional biodiversity, including variability of ecosystem complexity or function (CBD, 2001–2005). According to Tilman (2000), biological diversity has long been a source of scientific curiosity and study, but it is also increasingly a source of concern. Therefore, the main target of environmental programmes has to be the conservation of existing species richness, habitats and overall biodiversity.

In homogeneous landscapes, where species diversity has already declined, restoration plans are a possible measure to enhance diversity (Buhk *et al*., 2007). Several studies have examined the temporal variation of biodiversity in a wide region under which land-use change has been occurring (Brook *et al*., 2003; Lambin *et al*., 2001; Lira *et al*., 2012; Yamaura *et al*., 2009; Zimmermann *et al*., 2010) and revealed that land use is an important driver of biodiversity at local, landscape, regional and macro-ecological scales. If this is the case, land-use planning at the macro-ecological scale is suggested as an effective conservation approach (Yamaura *et al*., 2009). Assessments of the composition, distribution and abundance of urban vegetation, street trees, vegetation in urban parks, remnant patches and private gardens are necessary and valuable to ensure that biodiversity is maintained and conserved in an increasingly urbanised world (Gaston *et al*., 2005).

2.8.1 Conservation strategies

Grobler *et al*. (2002) stated the importance of conservation actions and ensuring that nature conservation strategies are incorporated into land-use planning initiatives within the urban environment. Conservation strategies are being developed to expand the size and number of protected areas by incorporating communal lands and local ecosystems. Furthermore, these new policies and strategies allow communities better access to natural resources and call for citizens' participation in the management of protected areas (Daemane, 2010). South Africa has secure policies and a legislative framework for the conservation, management and sustainable use of biodiversity (CBD, 2014):

- Conservation of Agriculture Resources Act (Act 43 of 1983)
- The Constitution (Act 108 of 1996)
- White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity (1997)
- National Veld and Forest Fire Act (Act 101 of 1998)
- National Forest Act (Act 84 of 1998)
- National Environmental Management: Biodiversity Act (Act 10 of 2004)
- National Biodiversity Strategy and Action Plan (2005)
- National Biodiversity Framework (2008)
- List of Protected Tree Species under the National Forest Act (Notice 908, 2014)
- South Africa's Strategy for Plant Conservation (Target 10; Raimondo, 2015)

- Provincial biodiversity strategies, legislation and provincial protected area expansion strategies (this differs from province to province)

Furthermore, South Africa has government institutions that warrant the conservation and management of biodiversity. These include the Department of Environmental Affairs, the South African National Biodiversity Institute, South African National Parks and provincial departments of environmental affairs (CBD, 2014).

In order to estimate an area's potential for conservation or development, it is necessary to make a detailed inventory of the plant communities and their associated habitats (Grobler *et al*., 2002). Detailed knowledge of threats to biodiversity should be an essential component of conservation planning for two main reasons. Firstly, conservation planning must operate within the constraints of current and likely future LUCs. Secondly, the predicted and current spatial dimensions of land transformation have implications for setting objective targets and for implementing conservation strategies (Margules and Pressey, 2000; Myers *et al*., 2000; Pressey and Cowling, 2001). Du Toit (2015) indicated that to effectively manage urban biodiversity, all public and private green spaces in and adjacent to urban ecosystems should be managed collectively as urban green infrastructure.

2.8.2 Urban green spaces

Smith *et al*. (2006) defined urban green spaces as rudimentary land in cities and towns. Public parks, sports fields, unmaintained land, road verges, natural or semi-natural areas, railways, waterways and domestic gardens are examples of green spaces (Caula *et al*., 2009; Smith *et al*., 2005). Increasing urbanisation has intensified the interest in urban green spaces and infrastructure as well as their benefits for all urban inhabitants (Sandström, 2002). Consequently, the sustainability of cities and towns are becoming an environmental issue of increasing concern. In this regard, urban greening is of primary interest because it provides numerous ecosystem goods and services that benefit humankind (Colding *et al*., 2006) as well as contributing to improving human health (Tzoulas *et al*., 2007).

In addition to being essential for urban residents, urban green spaces have ecological value (Niemelä, 1999). The majority of urban inhabitants are dependent on managed or remnant public urban green spaces for direct contact with the natural environment (Fuller *et al*., 2007). Consequently, the preservation and enhancement of urban green spaces are key to biodiversity conservation (Miller, 2005). Furthermore, Colding (2007) emphasised the idea that "land uses in urban green areas could synergistically interact to support biodiversity when clustered together in different combinations".

2.8.2.1 Urban green space planning

Existing studies on urban green spaces in South Africa call for a new approach to the management and planning of these open spaces in urban areas (Roberts, 1993; Roberts and Poynton, 1985). Therefore, vegetation studies in urban environments are important to ensure ecologically effective open-space planning in urban areas (Roberts, 1993).

Spellerberg (1992) indicated that urban areas of European countries, landscape ecological evaluation and mapping have become essential parts of the planning process for any proposed development. This assists in restricting disturbance of areas with vulnerable species or habitats and prevents undue fragmentation of wildlife habitats (Grobler *et al*., 2006). Roberts and Poynton (1985) mentioned the possible function of areas such as vacant lots (urban open spaces) in the provision of ecological continuity throughout the urban environment.

Urban vegetation further contributes to the biological diversity in cities and some species could be used as ornamentals if vacant lots were converted into green spaces or parks (Franceschi, 1996). While the diversity of species was higher than in most developing countries, the density was lower. This means that more indigenous species can be supported in terms of nutrition, space and water resources by the combined patches of the entire urban green infrastructure, which stresses the importance of proper planning of urban development (Lubbe, 2011). Urban green spaces provide physical ecosystem services such as temperature and flood control and removal of carbon from the atmosphere as well as social ecosystem services such as increased aesthetic values and community well-being (Alberti, 2005; Bolund and Hunhammar, 1999; Hope *et al*., 2006).

2.8.2.2 Gardens

According to Gaston *et al*. (2005), gardens play a significant role in maintaining biodiversity in urban areas, because they account for a considerable proportion of green spaces and vegetated land. Cilliers and Siebert (2011, 2012) confirmed this by indicating the importance of private gardens as part of the total urban green infrastructure, which is becoming an important global realisation.

Furthermore, Savard *et al*. (2000) indicated that urban gardens have the potential or ability to provide habitats for wildlife, various ecosystem goods and services and corridors between natural and semi-natural areas. For this reason, gardens and green spaces cannot be neglected in planning and management of urban open spaces. In addition, Thompson *et al*. (2003) found that gardens consist of a much higher abundance of species than any other community type. However, Marco *et al*. (2008) confirmed that private gardens contain a high level of biodiversity strongly subjugated by alien species. Nevertheless, in recent years, ecologists have realised the importance and value of gardens for the protection of certain species (Blanckaert *et al*., 2004) and the conservation of diversity (Das and Das, 2005). Similarly, in many countries, gardens are considered traditional agroforestry systems used for the cultivation of a diverse and stable supply of socio-economic products (Blanckaert *et al*., 2004; Das and Das, 2005).

2.9 Land-cover types

Fairbanks *et al*. (2000) stated that to achieve and maintain sustainable land use planning, strategic environmental assessments and accurate predictions for global change, information regarding the spatial and characteristic distribution of South Africa's land cover is crucial. Global changes in land use and land cover are so extensive and prevalent that they significantly influence key aspects in the functioning of the earth's systems (Lambin *et al*., 2001).

The terms "land use" and "land cover" are closely related and can be confused, but they are not synonymous (Fairbanks *et al*., 2000). Knowledge of the interactions between land cover (biophysical attributes of the earth's surface) and land use (human purpose applied to these attributes) in their spatial appearances is important to comprehend land-use and land-cover change (Jansen and Gregorio, 2002; Lambin *et al*., 2001). In other words, in the broadest sense land cover can be defined as "all the natural and human features that cover the earth's immediate surface" and includes vegetation (planted or natural), human constructions (roads and buildings), ice, water, bare rock or sand surfaces (Fairbanks *et al*., 2000). Land use, however, is related to the activities, arrangements and inputs that people undertake in a certain land cover to change, produce or maintain it (Jansen and Gregorio, 2002). Land use is therefore based on function and the particular use can be defined as a series of occurrences or activities that produce an array of goods and services (Fairbanks *et al*., 2000).

Land-cover types or categories normally include the following: built-up areas, degraded areas (urban development), natural areas (forests, natural grasslands, open spaces, water bodies, wetlands), cultivated areas (plantations, fallow agricultural land, gardens, row crops) and protected areas (Gassó *et al*., 2009; Lopez and Fennessy, 2002; Van Wilgen *et al*., 2008). Furthermore, monitoring land-cover changes alone is not adequate, but it needs to be combined with land uses in order to enhance understanding of why certain trends or changes occurred (Jansen and Gregorio, 2002). Land-use and land-cover change mostly simplify vegetation composition and structure at local scales (Lambin *et al*., 2001), resulting in the loss and isolation of the original vegetative cover, consequently decreasing the populations of many species and increasing species that can exploit simplified habitats, such as invasive alien species (Yamaura *et al*., 2009).

2.10 Invasive aliens

The invasion of ecosystems by alien species and the consequent impacts have been identified as a major and growing threat to biodiversity and the delivery of ecosystem services (Van Wilgen *et al*., 2008). Furthermore, the environmental and economic effects of alien species have also increased swiftly in severity and extent over the past decades (Rouget *et al*., 2016). Alien plant species are well known to disrupt ecological services of native ecosystems, can change the structure or composition of indigenous habitats and can often cause the extinction of native fauna and flora (Aronson *et al*., 2007). An alien species will become invasive if it is capable of overcoming a series of abiotic and biotic barriers that bring about introduction, reproduction, survival, dispersal and interactions with the local environment and biota (Rouget *et al*., 2016).

Until recently, woody plants did not feature distinctively on national, regional and global lists of the most important invasive alien species (Rundel *et al*., 2014). However, alien trees have been widely planted and introduced in South Africa since the 17th century. Consequently, many parts of the semi-natural and natural vegetation of the country are infested with large, self-sown stands of alien trees (Richardson and Rouget, 2002). Various groups of alien trees possess eco-physiological and life-history characteristics that enable them to infiltrate and rapidly alter ecosystem processes (Rundel *et al*., 2014). As a result, woody aliens have a substantially larger negative impact on landscape structure and composition than herbaceous alien species (O'Connor and Kuyler, 2009). In addition, invasive alien trees outcompete indigenous vegetation and affect key ecosystem functioning (Ehrenfeld, 2003).

South Africa, possibly invaded by alien trees to a greater extent than any other part of the world, has many "natural experiments" in place to gain understanding of the many factors that drive alien tree invasions (Richardson and Rouget, 2002). Numerous alien species have taken advantage of periodical events that may give them a foothold or permit them to increase in range and numbers (Richardson and Pyšek, 2004). Native range size has emerged as an important factor influencing naturalisation and invasion success for introduced species (Lavoie *et al*., 2013). Distribution patterns of alien species are also related to land-use, climatic and topographic variables and the presence of botanical gardens, industries and horticultural trade (Gilbert, 1989; Wilson *et al*., 2007).

Furthermore, the relative number of native and alien species within a region is traditionally a good estimate of the level of invasion for that region (Stohlgren *et al*., 2011). However, every region on earth must be considered a potential donor of alien species. Certain ecological processes in towns and cities are the same as those in rural areas, but aspects such as external control of succession and invasions by alien species are more widespread or frequent in urban areas (Cilliers *et al*., 2009). Cities or urban areas serve as "immigration hubs" for alien species, as they contain abundant alien flora and act as sources of alien species for surrounding rural and suburban areas (Pyšek, 1998). Pyšek (1998) further indicated that the amount and relative contribution of alien species to the flora of urban areas increased with city size.

In addition, the number of alien species present in urban floras is related to the degree of human-induced disturbances (Aronson *et al*., 2007). Once an alien species is established in a new region or area, it is exceedingly difficult to eliminate or control and, therefore, the most successful method to minimise its impacts is to hamper its spread or establishment in the first place (Duncan *et al*., 2003). Some of these impacts include increased water use, changes to disturbance regimes and diverse effects on local biodiversity (Richardson *et al*., 2014). Consequently, impacts of biological invasions include both negative environmental effects and socio-economic costs (Rouget *et al*., 2016).

2.11 Socio-economic aspects

Several studies, from both developing and developed countries, have indicated that the socio-economic status of urban residents function as an important indicator of vegetation composition (Hope *et al*., 2003; Luck *et al*., 2009; McConnachie *et al*., 2008). Socio-economic factors have an important impact on plant species richness via land-use diversity. Furthermore, these socio-economically motivated land-use changes are serious threats to species diversity throughout the world (Maurer *et al*., 2006).

Consequently, socio-economic aspects at both local and international scales are crucial to conserve biodiversity in a human-dominated world (Yamaura *et al*., 2009). Several studies have indicated the importance of a community-based theme, including cultural and socio-economic issues, in the conservation of urban open spaces in South Africa (Graham and Ernstson, 2012; Roberts *et al*., 2012). However, in the broader context of urban greening, studies have revealed that affluent suburbs in South Africa generally have more public green spaces than poorer suburbs (McConnachie and Shackleton, 2010). Similarly, Lubbe *et al*. (2010) found that the plant species richness of urban and peri-urban domestic gardens in South Africa was higher in more affluent areas. This phenomenon was described by Hope *et al*. (2003) as the “luxury effect”.

2.12 Luxury effect vs Neef’s human-scale development model

Hope *et al*. (2003) defined the correlation between wealth and plant diversity as the “luxury effect”, i.e. as economic resources increase, humans normally inhabit urban landscapes with higher plant diversity. More specifically, the relationship between plant diversity and wealth seems to be related to the link that can be seen between species composition, socio-economic status and the physical structure of the vegetation in residential areas (Hope *et al*., 2003). Thus, higher resources (financial- or labour-related) can enable people to change their environment, while resource shortages can limit such changes.

According to Pimbert and Pretty (1997), there is an inverse relationship between human actions and the well-being of the environment. Many management plans have overlooked the importance of specific ways to provide shelter, food, health, energy and other fundamental human needs. Max-Neef *et al*. (1989) stated that fundamental human needs are universal, but their “satisfiers” vary according to region, culture and historical conditions. A working definition of environmental sustainability thus begins with a focus on human needs, if human needs are not met, ecosystems are more likely to become degraded (Hallsmith, 2003). In contrast to the “luxury effect”, Neef’s human-scale development model describes the basic human needs and to what lengths people will go to attain these needs. To put it simply, people with lower resources and income levels will overlook their environments, just as long as basic needs are met (Hallsmith, 2003).

2.12.1 Summary

The following key points were concluded and should be kept in mind for the remainder of the study:

- Urban areas are continously expanding.
- Urbanisation has various influences or effects, namely: land transformation or land-use change; habitat -loss, -destruction, -fragmentation; alien species invasion; biotic homogenisation and disturbance.
- Cities or urban areas are often located in species rich areas.
- It is therefore crucial to conserve biodiversity, in both natural and urban ecosystems. In urban areas – gardens and urban green spaces used in conservation methods. Furthermore, gardens and urban green spaces provide various ecosystem goods and services.
- However, disturbance and stres reduces species richness, as well as the quality and quantity of ecosystem goods and services (which is generated by biodiversity).
- Agroecosytems are considered to be more natural, but also have an influence on ecosystems, especially concerning trees in agroforestry (which mainly consist of alien and invasive species).
- In addition, urbanisation and disturbance causes human-induced climate change and higher greenhouse gas emissions, ultimately affecting BVOCs – the opposite is also

true, higher BVOC results in higher O_3 and SOA, both of which have climate change impacts.

- Trees are strong BVOC emitters. Trees are long-lived and good indicators of vegetation structure and physiognomy. Trees can dominate landscapes and impact ecosystem service and biodiversity. Tree distributions are influenced by microclimates (which differs in natural and urban areas).
- Many tree species are considered aliens or invasive in various parts of the world. Alien species replace native species. Alien species invasion is one of the effects of urbanisation.
- Alien invader species have an undesirable influence on biodiversity and ecosystem services.
- Socio-economic status and culture influence vegetation composition and also has an influence on biodiversity.
- Conservation and studies concerning diversity is therefore important to ensure healthy, functioning ecosystems, free from disturbance and alien invasions to ensure sustainability and continuous goods and services provided by the biodiversity contained within the ecosystems.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study area

This study focused on an area with a 60 km radius in the Highveld grasslands of South Africa, including the towns of Carletonville, Fochville, Hartbeesfontein, Klerksdorp, Potchefstroom, Stilfontein and Ventersdorp. The majority of the study area is situated in the North-West province of South Africa (Figure 3.1), but the area includes parts of Gauteng (10%) to the north-east and the Free State (11%) to the south (Figure 3.2), with Potchefstroom being the closest town to the centre of the study area, located at Welgegund Atmospheric Monitoring Station (Figure 3.1). Potchefstroom falls under the JB Marks Local Municipality, further referred to as WAMS fetch region.

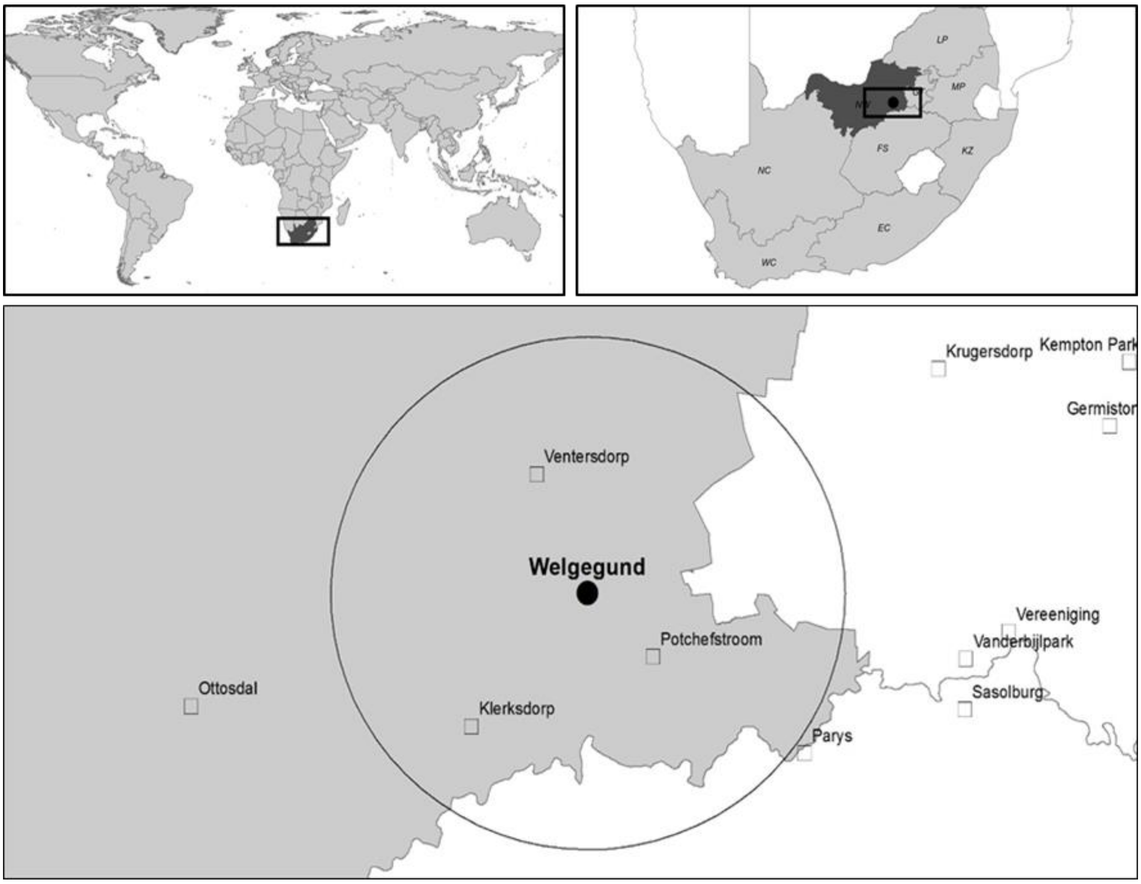
LP
MP
NW
NC
FS
KZ
EC
WC
Krugersdorp
Kempton Par
Germisto
Ventersdorp
Welgegund
Potchefstroom
Vereeniging
Vanderbijlpark
Ottosdal
Sasolburg
Klerksdorp
Parys

Figure 3.1. Location of the Welgegund Atmospheric Monitoring Station in South Africa and the 60 km radius around it. The majority of the study area is within the North-West province

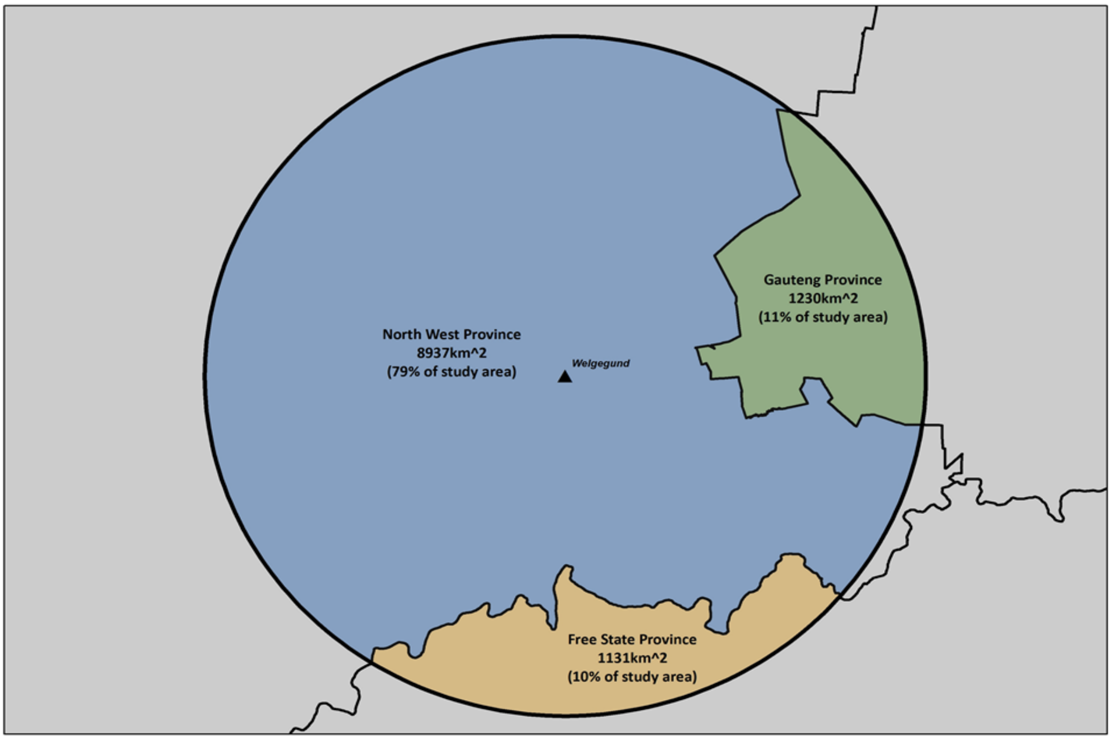

Figure 3.2. Percentage of the study area occupied by each province

The Welgegund Atmospheric Monitoring Station is located 27 km north-north-west of Potchefstroom (S26°34'11.12" and E26°56'21.35") on the property of a local maize and cattle farmer (Jaars *et al*., 2016). The study area comprised a 60 km radius around the monitoring station, this 60 km radius is centered around the Welgegund atmospheric research station (Welgegund.org). The 60 km radius was determined from BVOC reactivity (how long it takes for BVOCs to react in the atmosphere) and average wind speeds recorded at Welgegund (Jaars *et al*. 2016). This resulted in a 60 km fetch region, which was studied.

Welgegund is geographically located within the Highveld of South Africa (Jaars *et al*., 2016), but the entire study area falls within both the Grassland and Savanna Biomes (Mucina and Rutherford, 2006). The high central plateau, also known as Highveld Grassland (Mucina & Rutherford, 2006) can be defined as ‘high-altitude veld’ with mainly herbaceous vegetation of relatively simple and short structure that is dominated by grasses (graminoids). The topography includes flat to undulating plains, occasionally broken by small mountains. The Highveld’s high elevation causes cold, dry conditions and also large temperature differences between seasons with a high frequency of frost and fire in winter (Mucina & Rutherford, 2006). Woody plants are therefore rare and usually represented mostly by low-growing or medium-sized shrubs and small trees. Woody plants are often restricted to specialised habitats and niches that provide protection against winter cold, drought and fire (Mucina & Rutherford, 2006).

According to Mucina and Rutherford (2006), Highveld Grassland contains a number of habitat types with shrubland on koppies or woodlands on other substrates. Within the matrix of grassland, these shrublands form a distinctive structural vegetation type that is restricted to outcrops and rocky slopes, where surface rockiness is high and where soils are mostly stony and shallow (Table 3.1). Some of the small trees and shrubs that do occur frequently within Grassland and Savanna Biomes include species such as *Celtis africana*, *Diospyros lycioides*, *Ehretia rigida*, *Grewia flava*, *Searsia pyroides*, *Vachellia karroo* and *Ziziphus mucronata* (Mucina & Rutherford, 2006).

Furthermore, these biomes are prominent features of the South African landscape and account for nearly 60% of the total land area (Mucina and Rutherford, 2006). Each biome is subdivided into different vegetation units, which consist of the same type of biotic and physical features (Mucina and Rutherford, 2006). Thirteen vegetation units were identified for the study area (Figure 3.3), but only 10 vegetation units are discussed (see Table 3.1 for a detailed description of these units), because the Highveld Alluvial Vegetation, Eastern Temperate Freshwater Wetlands and Highveld Saltpans units were not sampled or did not contribute significantly to the study.

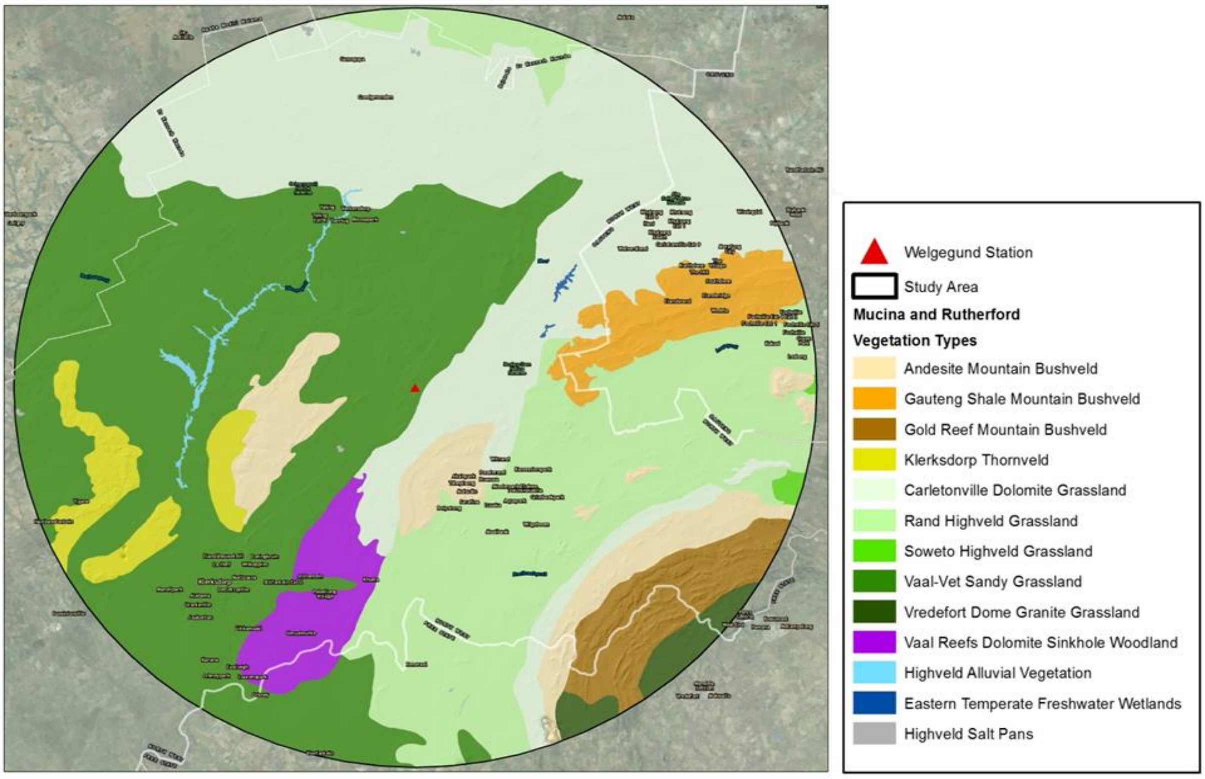
▲ Welgegund Station
☐ Study Area
Mucina and Rutherford
Vegetation Types
Andesite Mountain Bushveld
Gauteng Shale Mountain Bushveld
Gold Reef Mountain Bushveld
Klerksdorp Thornveld
Carletonville Dolomite Grassland
Rand Highveld Grassland
Soweto Highveld Grassland
Vaal-Vet Sandy Grassland
Vredefort Dome Granite Grassland
Vaal Reefs Dolomite Sinkhole Woodland
Highveld Alluvial Vegetation
Eastern Temperate Freshwater Wetlands
Highveld Salt Pans

Figure 3.3. Vegetation types occuring in the 60 km radius around the Welgegund Atmospheric Monotoring Station (Mucina *et al*., 2007)

Table 3.1. Summary of the main environmental factors for each of the 10 dominant vegetation units in the study area.

Code	Vegetation unit name	Mean annual temp (°C)	Mean annual rainfall (mm)	Mean frost days	Geology	Soil	Vegetation & landscape features	Conservation status	Relative cover of Vegetation units (km²)
Gh 10	Vaal-Vet Sandy Grassland	16.4	530	37	Sandstone, mudstone, shale, andesite & gneiss	Aeolian & colluvial sand	Plains dominated landscape, with scattered, irregular undulating plains & hills	Endangered. Only 0.3% statutorily conserved	3847.60
Gh 11	Vredefort Dome Granite Grassland	16	594	38	Granite & gneiss at the core	Hutton, mispah & avalon plinthic soils. Red soil widespread	Slightly undulating plains with mainly short grassland - often degraded & grazed. Big granite boulders conspicuous with Vaal River cutting through mountainous landscape	Endangered. Half already transformed	147.15
Gh 12	Vaal Reefs Dolomite Sinkhole Woodland	16.8	565	34	Dolomite - underground dissolution of rock causes sinkholes	Relatively shallow & rocky	Slightly undulating landscape with prominent rocky chert ridges supporting a grassland-woodland vegegtation complex	Vulnerable	346.67
Gh 13	Klerksdorp Thornveld	16.8	533	36	Shale, slate & quartzite	Shallow, rocky & red plinthic soils	Plains or slightly irregular undulating plains with open to dense bush clumps in dry grassland	Vulnerable. Only about 2.5% conserved	318.47
Gh 15	Carletonville Dolomite Grassland	16.1	593	37	Dolomite & chert	Shallow mispah, glenrosa soil & deeper red to yellow apedal soils	Slightly undulating plains with prominent rocky chert ridges	Vulnerable	3016.71
Gm 8	Soweto Highveld Grassland	14.8	662	41	Shale, sandstone or mudstone of the Madzaringwe formation	Soils are deep reddish on flat plains	Gently to moderately undulating landscape on Highveld plateau with short to medium-high dense grassland	Endangered. Only small patches statutorily conserved	22.36
Gm 11	Rand Highveld Grassland	15.8	654	28	Quartzite ridges	Shallow mispah & glenrosa soil on rocky ridges	Highly variable landscape; extensive sloping plains & a series of ridges elevated over surrounding plains	Endangered. Only 1% conserved	2220.63
SVcb 9	Gold Reef Mountain Bushveld	16.4	667	26	Quartzites, conglomerates & some shale	Shallow, gravel lithosols	Rocky hills & ridges; west-east trending with dense woody vegetation	Least Threatened	394.85
SVcb 10	Gauteng Shale Mountain Bushveld	15.6	661	33	Shale, andesite & dolomites	Shallow mispah, but deeper at foot of slopes	Low, broken ridges varying in steepness with high surface rock cover. Vegetation is semi-open short thicket	Vulnerable	390.65
SVcb 11	Andesite Mountain Bushveld	15.6	660	34	Tholeitic basalt, shale, micaceous sandstone & siltstone	Shallow rocky, clayey soils	Dense medium-tall thorny bushveld with well developed grass layer on hill slopes & some valleys	Least Threatened	654.07

Each of the vegetation units (Figure 3.3) contains similar climate, geology, soil, taxa, distribution range, vegetation and landscape features (Mucina and Rutherford, 2006). A summary of each of the dominant vegetation units is presented (Table 3.1) to differentiate vegetation cover as well as various landscape features. The code, name and climatic data of each vegetation unit is similar to the vegetation maps and units constructed by Mucina and Rutherford (2006) but at a more localised scale. Relative cover (percentage) of each of the vegetation units for the study area is also indicated. However, to comprehend the climate for the total study area, the mean annual temperature, rainfall and frost days are 16°C, 507 mm and 36 days, respectively (ARC-ISCW, 2017). Furthermore, the study area consisted of several different study sites located within different land-cover types. Ten different main sites or bushclump types were identified, namely gardens, grasslands, hillsides, plantations, ridges, riparian areas, roadsides, sandy areas, streets and urban open spaces.

3.2 Site description

Each sampling site had to meet certain criteria to qualify as a particular “bushclump”. Each bushclump was allocated to land-cover types, either urban or rangeland or both (Ellis and Ramankutty, 2008). Garden, plantation, street and urban open space bushclumps fell under the urban land-cover type (cultivated or maintained by humans), while grassland, hillside, ridge and sandy areas fell under the rangeland land-cover type (naturally occurring or derived from nature). Roadside and riparian bushclumps were classified as both urban and rangeland land-cover types (Ellis and Ramankutty, 2008). The description of each bushclump type included landscape features, topography, gradient, anthrome, dominant vegetation unit, land use and type of transformation to indicate how the bushclumps differed from one another. Figure 3.4 indicates the position of bushclumps within the various land-cover types.

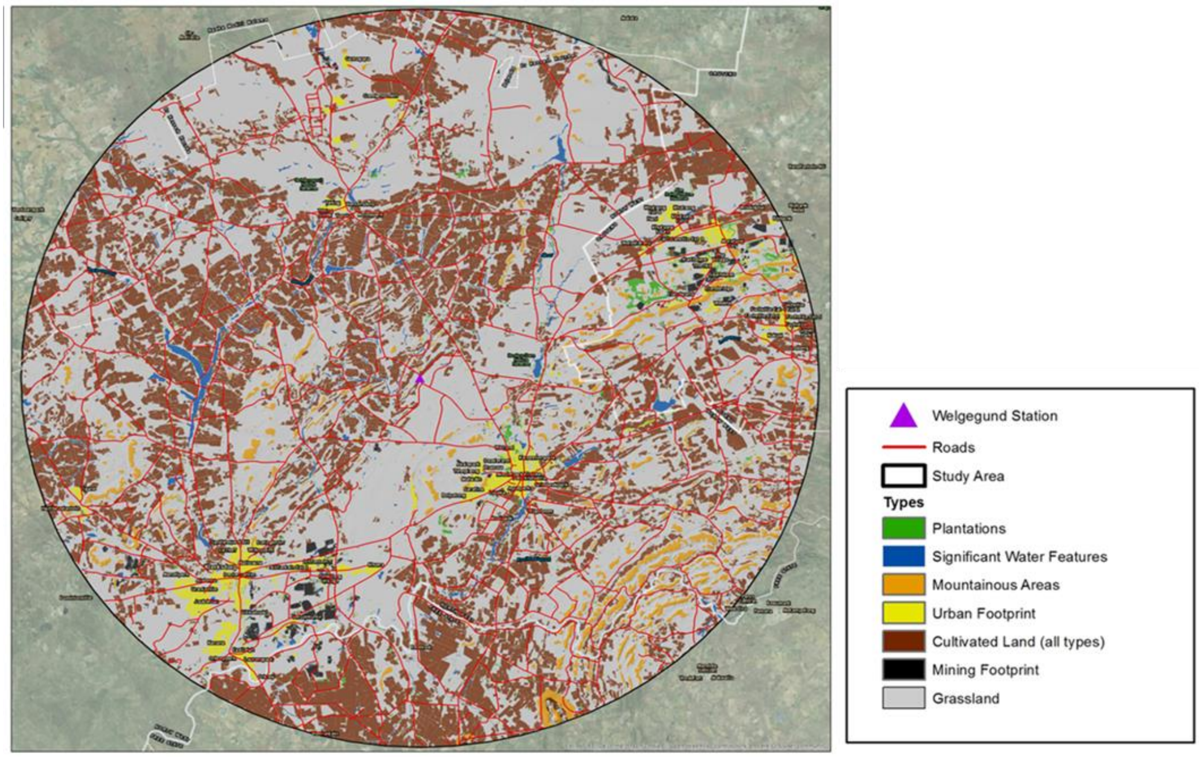
Welgegund Station
Roads
Study Area
Types
Plantations
Significant Water Features
Mountainous Areas
Urban Footprint
Cultivated Land (all types)
Mining Footprint
Grassland

Figure 3.4. Position of the dominant land-cover types: Gardens, roads and urban open spaces are located in urban areas, hillsides and ridges are included in the mountainous areas and sandy areas and grasslands are included in grasslands

3.2.1 Gardens

This land-cover type is associated with cultivated parts of residential yards (Figure 3.5). The sample comprised 32 gardens along a socio-economic gradient: 16 gardens from the higher-income Potchefstroom area and 16 from the lower-income Ikageng and Mohadin areas. Gardens were chosen randomly according to socio-economic status, representing different garden shapes, sizes, species diversity and maintenance.

Landscape features of gardens include cut lawns, relatively dense tree cover, buildings and other structures such as walls, fences and some type of water feature, e.g. pools, ponds and/or irrigation systems. The topography is mainly flat, with slight slopes or small man-made hills. Land uses include mainly residential, recreational and agricultural uses with natural areas increasingly being transformed for houses, buildings, gardens and vegetable gardens or orchards. The dominant vegetation units include Rand Highveld Grassland (Ikageng and Potchefstroom), Carletonville Dolomite Grassland (Potchefstroom) and Andesite Mountain Bushveld (Mohadin).

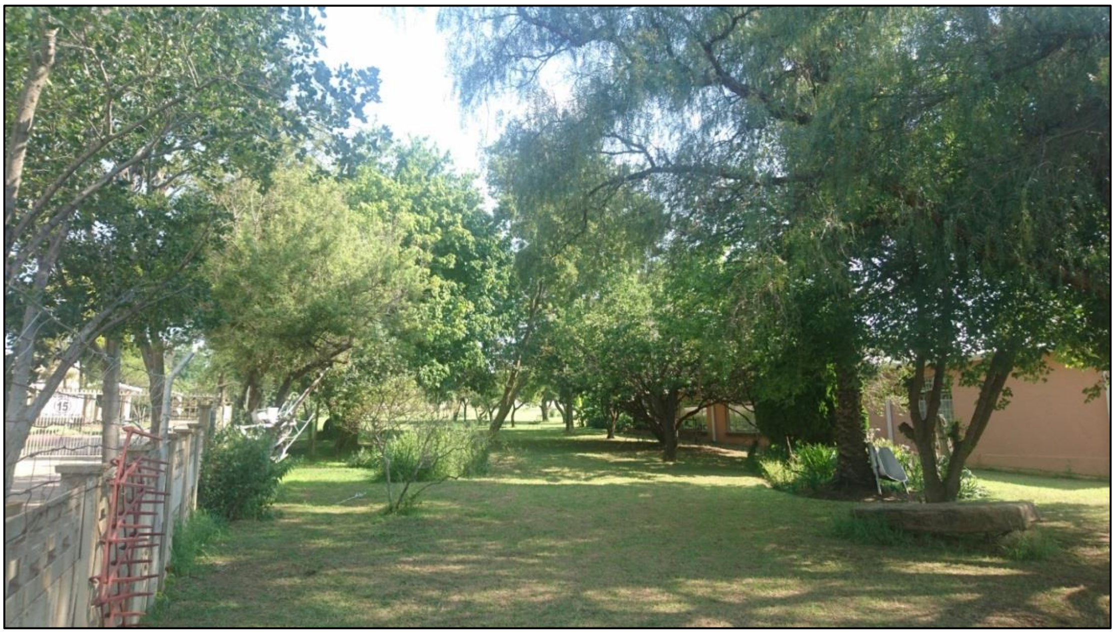

Figure 3.5. A typical higher socio-economic status garden land-cover type (Photographer: H. Wessels)

Furthermore, gardens can be classified as urban or village anthromes (Ellis and Ramankutty, 2008). The dominant vegetation unit was determined by overlying Figure 3.3 and the global positioning system (GPS) coordinates of each sampling site on Google Earth Pro. Gardens feature in both local (Davoren, 2009; High and Shackleton 2000; Lubbe *et al*., 2010; Lubbe *et al*., 2011; Molebatsi *et al*., 2010; Molebatsi *et al*., 2013; Paumgarten *et al*., 2005) and international (Das and Das, 2005; Davies *et al*., 2011; Gaston *et al*., 2005) studies.

3.2.2 Grasslands

This land-cover type is associated with natural areas. The sample comprised 16 grassland bushclumps across the study area. Sampling sites were chosen randomly within grasslands, but bushclumps were chosen as most representative of the immediate area. Bushclumps for this land-cover type consisted of a natural grove of different tree species densely grouped together in open grass plains. Grassland sampling sites were selected if this criterion was met and if these bushclumps were located away from urban areas and major human influences.

Landscape features of grasslands include open grass plains with naturally scattered trees (Figure 3.6). The topography consists mainly of flat undulating plains with gentle slopes. The main land uses include agricultural activities, forestry and mineral mining, which further increase urbanisation and other types of transformation (Mucina and Rutherford, 2006). The dominant vegetation units associated with this land-cover type is the Vaal-Vet Sandy Grassland and the Rand Highveld Grassland. Furthermore, according to Ellis and Ramankutty (2008), grasslands fall under the rangeland anthrome. Local grasslands studies include those of Bredenkamp and Bezuidenhout (1990, 1995), Cilliers *et al*. (2008), Grobler *et al*. (2006), Mills *et al*. (2013) and Van der Walt *et al*. (2015) and international studies include those of Maurer *et al*. (2006) and Groombridge (1992).

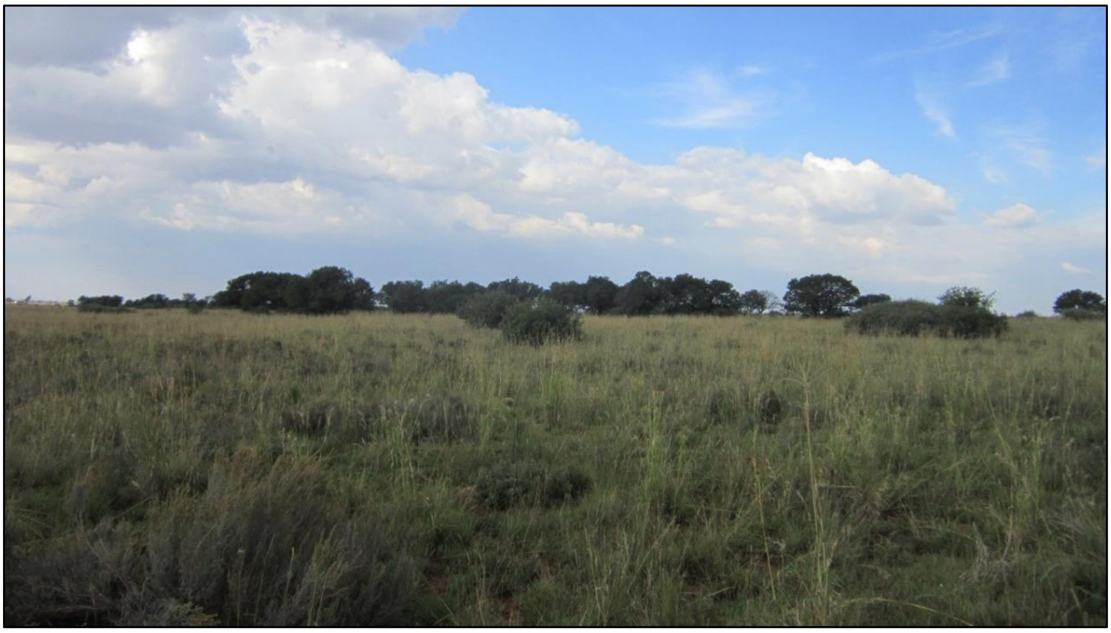

Figure 3.6. A typical grassland land-cover type (Photographer: L. Knoetze)

3.2.3 Hillsides

Hillsides are also associated with natural areas outside of urban sectors. The sample comprised 16 hillside bushclumps located across the study area. Hillside sampling sites were chosen randomly in areas where trees or bushclumps grew along a steep slope (hill). Sampling for hillside areas started at the bottom of the hill and followed in a straight line up the slope.

Landscape features of hillsides include interchanging tree- and grass-covered hills with moderate to steep slopes and intermittent rocky ridges connected to open grass plains (Mucina and Rutherford, 2006) (Figure 3.7). Trees and shrubs mainly occur on rocky ridges and are also scattered down the slope. The main land uses include agricultural and recreational uses, with hillsides being transformed for crops or rearing animals as well as parks, hiking trails or holiday locations. The Vaal-Vet Sandy Grassland and Andesite Mountain Bushveld are the dominant vegetation units associated with hillsides. Furthermore, hillsides also fall under the rangeland anthrome (Ellis and Ramankutty, 2008). Hillsides appear in both international (Famiglietti *et al*., 1998; Freitas *et al*., 2010) and local studies (Daemane *et al*., 2012; Van der Walt *et al*., 2012; Van Wyk *et al*., 1997).

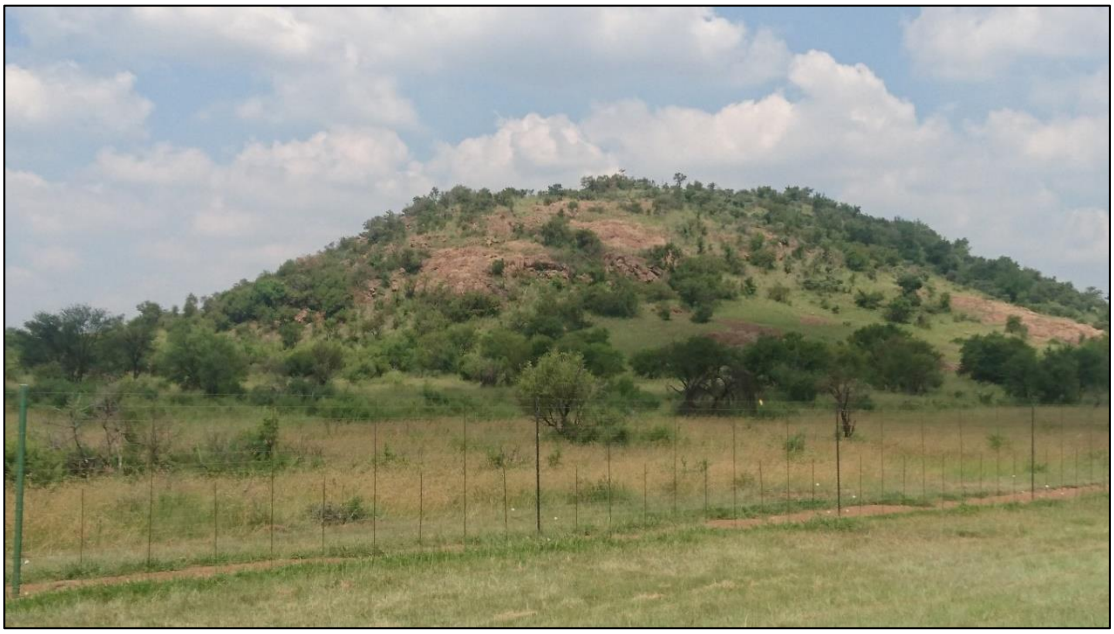

Figure 3.7. A typical hillside land-cover type (Photographer: H. Wessels)

3.2.4 Plantations

This land-cover type is associated with cultivated areas or croplands. The sample comprised 16 plantations across the study area. These bushclumps included a grove of trees of the same species densely grouped together and usually consisted of *Eucalyptus*, *Pinus* and *Populus* species (Figure 3.8). Because plantations are cultivated, they can occur in different land uses, including farms, urban open spaces, roadsides or riparian areas.

Landscape features of plantations include mainly open, flat grass plains with naturally scattered trees or bushclumps and gentle slopes. The main land uses include agricultural and residential uses with agroforestry and urbanisation being the major types of transformation. Dominant vegetation units associated with this land-cover type is the Vaal-Vet Sandy Grassland and Carletonville Dolomite Grassland. Furthermore, according to Ellis and Ramankutty (2008), plantations fall under the croplands anthrome. Plantations feature in both local (Jaars *et al*., 2016; O'Connor and Kuyler, 2009; Richardson and Petit, 2005) and international studies (Lira *et al*., 2012; Omont and Nicolas, 2006).

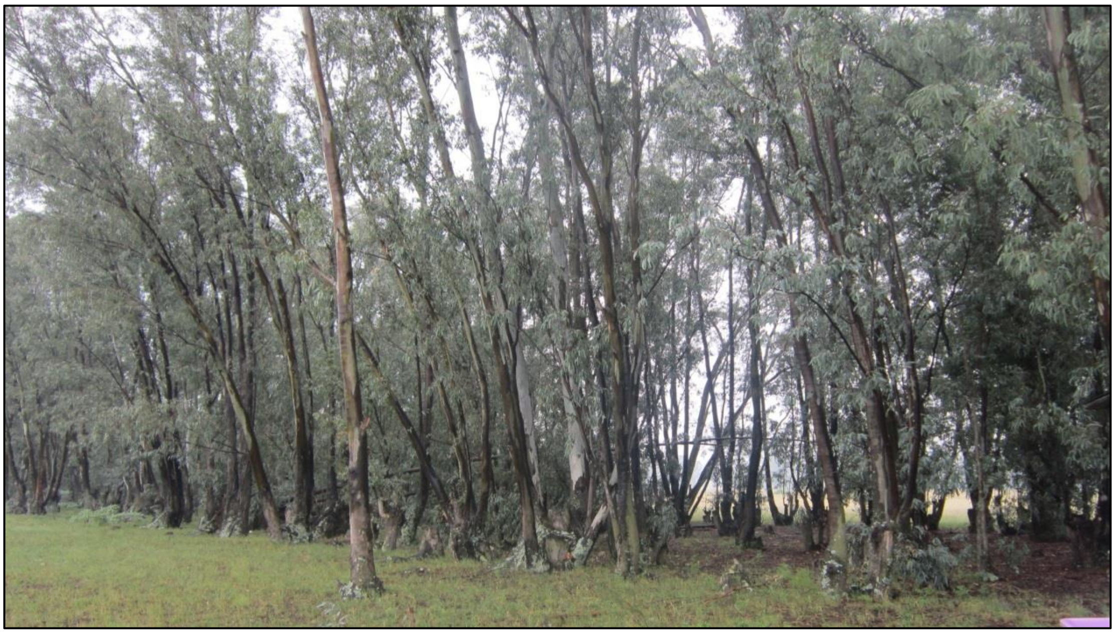

Figure 3.8. A typical plantation land-cover type. This plantation consists of *Eucalyptus* species (Photographer: L. Knoetze)

3.2.5 Ridges

This land-cover type is associated with natural areas outside urban sectors and human influences. The sample comprised 16 ridges across the study area. Sampling sites consisted of tree species growing on top of a rocky ridge (hill); transects ran in a straight line across the summit of the ridge or hill. Species composition and characteristics of ridges are similar to those of hillsides, with the only exception being that a hillside could have a ridge but a ridge cannot have a hillside.

Landscape features of this land-cover type include rocky ridges with discontinuous grass and tree cover connected to open grass plains (Figure 3.9). The topography consists of moderate to steep slopes with high surface rockiness (Mucina and Rutherford, 2006). Land uses include agricultural and recreational uses, with ridged or natural areas increasingly being transformed for the cultivation of crops or rearing of animals and recreational activities such as hiking trails and leisure. The dominant vegetation units include the Vaal-Vet Sandy Grassland and Andesite Mountain Bushveld. Furthermore, Ellis and Ramankutty (2008) classified ridges under the rangeland anthrome. Local studies on ridges include those of Bredenkamp and Bezuidenhout (1990), Du Toit (2015), Grobler *et al*. (2006) and Van Wyk *et al*. (1997). Studies by Basnet (1992), Kubota *et al*. (2004) and Sagar *et al*. (2003) comprise international studies on ridges.

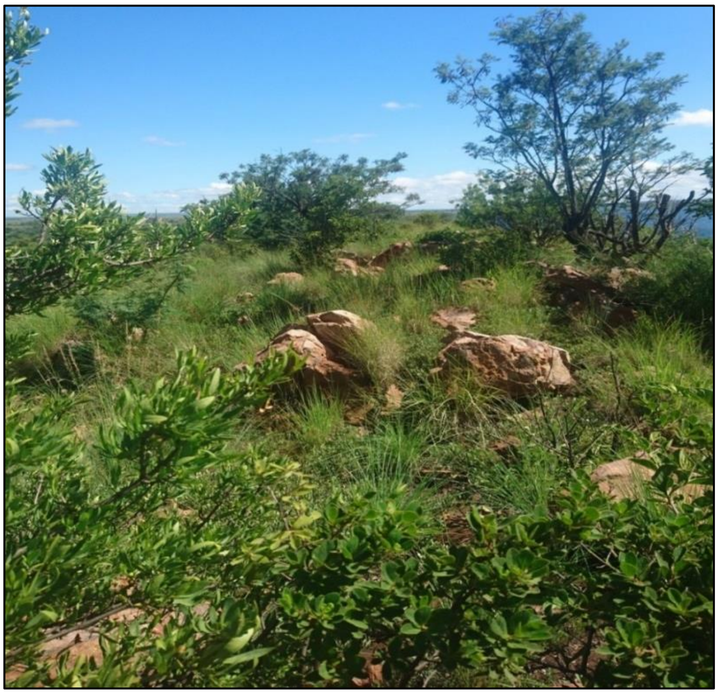

Figure 3.9. A typical ridge land-cover type (Photographer: L. Knoetze)

3.2.6 Riparian areas

This land-cover type is associated with both urban and natural areas. The sample comprised 16 riparian bushclumps across the entire study area. Bushclumps occurring on the banks of rivers or dams or on the side of a large water body were selected (Figure 3.10). Transects were chosen in a such manner that a distance of up to 2.5 m could be surveyed on both sides of the rope, with the measuring stick just touching the water's edge.

Landscape features of the riparian land-cover type included scattered or clumped trees along water bodies connected to grass plains or savanna thickets (Mucina and Rutherford, 2006) with mainly flat topography and moderate slopes. The main land uses include agricultural, recreational and residential uses, with these riparian areas being transformed for cultivating crops and rearing animals, holiday destinations, fishing locations, leisure activities or housing. Dominant vegetation units include the Vaal-Vet Sandy Grassland and Carletonville Dolomite Grassland. According to Ellis and Ramankutty (2008), riparian areas fall under both urban and rangeland anthromes. Both local (Le Maitre *et al*., 2002; O' Connor and Kuyler, 2009; Tererai *et al*., 2013; Van der Linde *et al*., 2008; Van Wilgen *et al*., 2008) and international (Turner *et al*., 2004; Zimmermann *et al*., 2010) studies have focused on riparian areas.

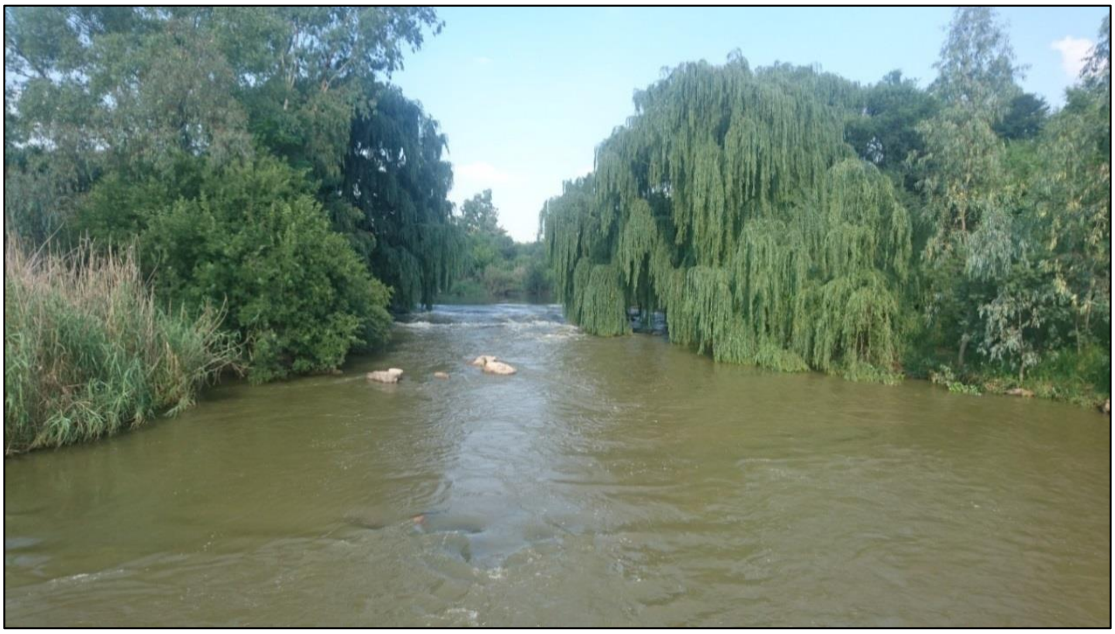

Figure 3.10. A typical riparian cover-type, where trees were sampled as close as possible to the riparian area (river, dam or other water body) (Photographer: L. Knoetze)

3.2.7 Roadsides

This land-cover type is associated with both urban and natural areas. The sample comprised 16 roadside bushclumps, consisting of groves of trees growing on road verges (Figure 3.11), i.e. only trees that occurred on the side of the road between the tar and fences were sampled. Transects were sampled 5, 10 and 20 km away from Potchefstroom, on all six major roads accessing the city. These roads include the Carletonville (R501), Klerksdorp (N12), Parys (R53), Ventersdorp (R53), Vereeniging (R54) and Viljoenskroon (R501) roads.

Landscape features of the roadside land-cover type include tarred surfaces, intensively disturbed or trampled gravel areas and scattered trees along grassy shoulders or ditches, with irregular topography and moderate slopes (Mucina and Rutherford, 2006). The main land uses include agricultural, residential and transport uses, with these areas being transformed for rearing animals, housing and transport such as roads and railways. The dominant vegetation units include Rand Highveld Grassland and Andesite Mountain Bushveld and roadsides can be classified as both urban and rangeland anthromes (Ellis and Ramankutty, 2008). Roadsides feature in both international (Deng *et al*., 2011; Freitas *et al*., 2010; Sagar *et al*., 2003) and local (Cilliers and Bredenkamp, 2000; Davoren, 2009; Du Toit, 2015; Whitmore *et al*., 2002) studies.

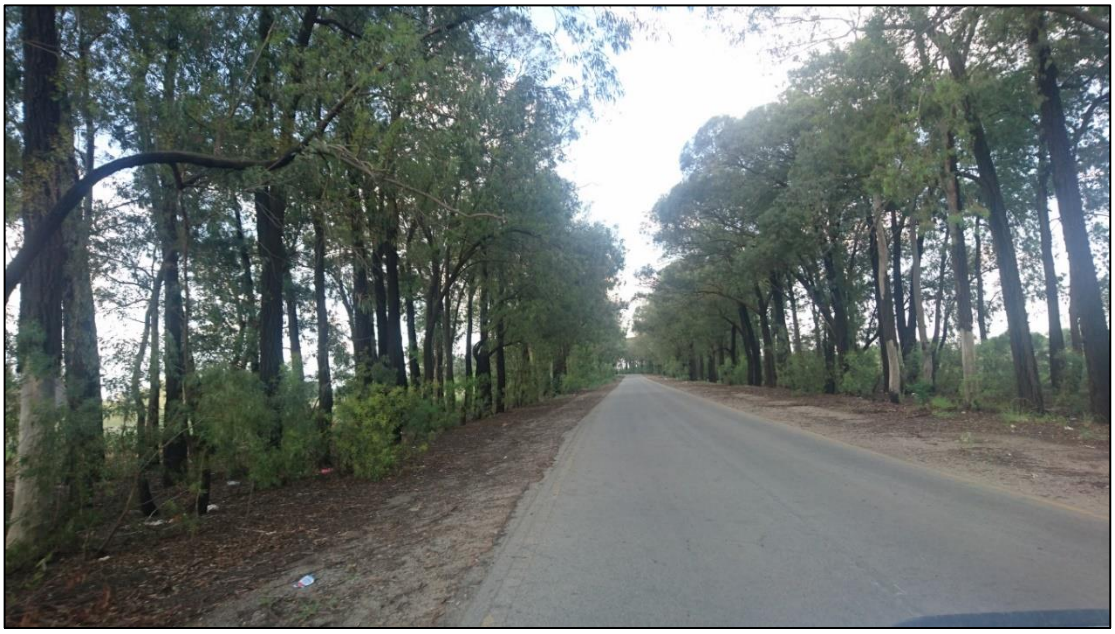

Figure 3.11. A typical roadside land-cover type (Photographer: L. Knoetze)

3.2.8 Sandy areas

This land-cover type is associated with natural areas. The sample comprised 16 sandy bushclumps across the entire study area. Bushclumps consisted of trees growing on sandy soils or in sandy areas and were similar to grassland bushclumps. *Vachellia erioloba* is known to grow on sandy soils (Seymour and Milton, 2003) and all of the sandy bushclumps were consequently sampled in or near the vicinity of *V. erioloba* trees (Figure 3.12).

Landscape features of this land-cover type included open grass plains with naturally scattered trees and the topography consisted mainly of flat undulating plains with gentle slopes. The main land uses include agricultural activities, forestry and mineral mining, which also increase urbanisation and other types of transformation (Mucina and Rutherford, 2006). The dominant vegetation units include Vaal-Vet Sandy Grassland and Carletonville Dolomite Grassland. Furthermore Ellis and Ramankutty (2008) classified sandy areas under the rangeland anthrome. Both local (Bredenkamp and Van Rooyen, 1996; Seymour, 2008; Van der Walt *et al*., 2012; Van Jaarsveld, 1987) and international (Bernhard-Reversat, 1996; Jürgens, 1997; Skarpe, 1991) studies focus on sandy areas.

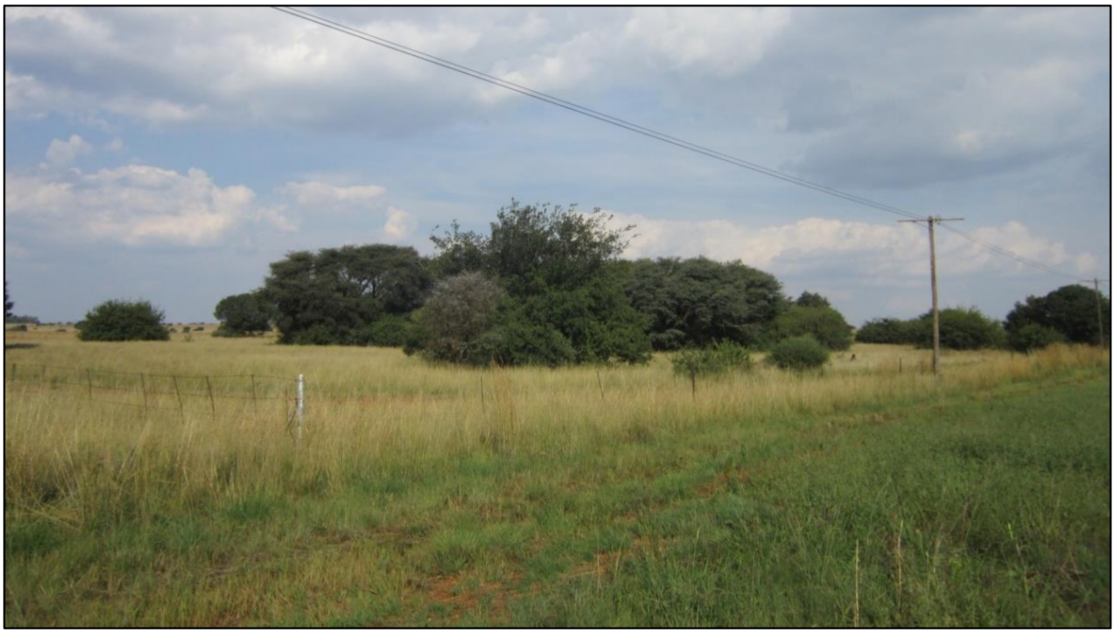

Figure 3.12. A typical sandy area, which is indicated by the presence of *Vachellia erioloba (*Photographer: L. Knoetze)

3.2.9 Streets

This land-cover type is associated with cultivated parts of urban areas and the sample comprised 21 street bushclumps sampled in the towns across the study area. The criterion for these bushclumps was that the majority of trees growing in a street should be of the same species. Observations were made as to what tree species are commonly planted along the streets in towns and streets with these species were subsequently sampled. Street bushclumps can be defined as trees planted next to streets or roads in urban areas, with more than five of the same species growing along a 50 m transect (Figure 3.13).

Landscape features include tarred surfaces and disturbed or trampled gravel areas or pavements, with scattered trees along grassy shoulders or cut sidewalks. The topography is mainly flat and irregular with moderate slopes (Mucina and Rutherford, 2006). The main land uses include commercial, residential and transport, with natural areas transformed for businesses, housing and roads. Dominant vegetation units include the Rand Highveld Grassland and Carletonville Dolomite Grassland and streets fall under the urban anthrome (Ellis and Ramankutty, 2008). Streets feature in both international (Davies *et al*., 2011; McPherson and Peper, 1995) and local (De Lacy and Shackleton, 2014; Kuruneri-Chitepo and Shackleton, 2011; McConnachie and Shackleton, 2010; Stoffberg *et al*., 2008) studies.

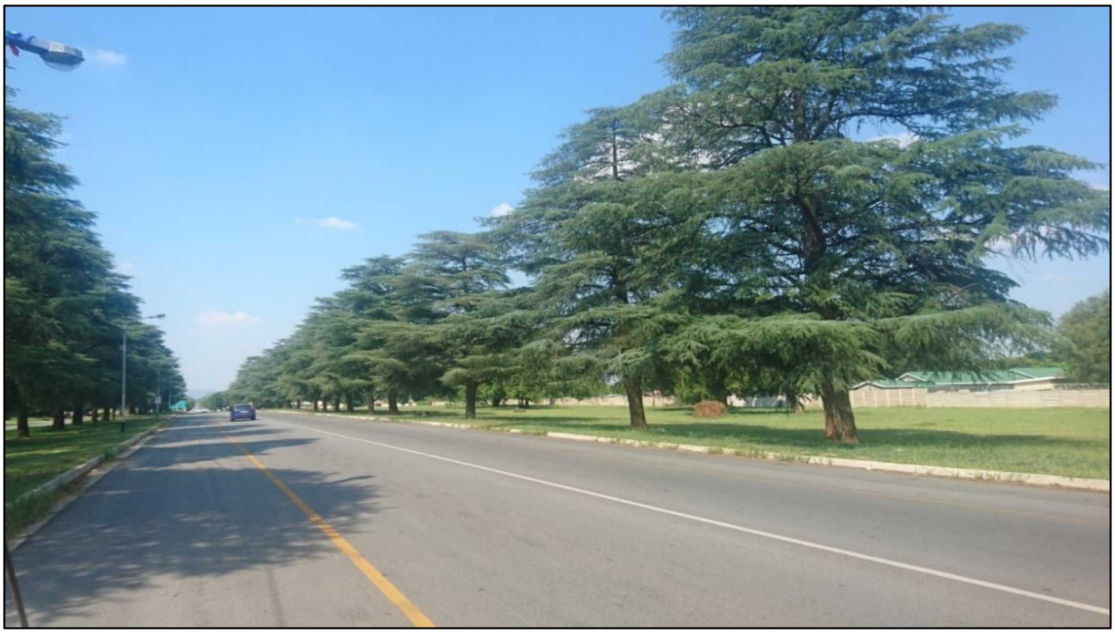

Figure 3.13. A typical street land-cover type (Photographer: L. Knoetze)

3.2.10 Urban open spaces

This land-cover type is associated with undeveloped urban areas. The sample comprised 16 urban open space bushclumps across the entire study area. Bushclumps consisted of trees growing in untransformed spaces within urban areas (Figure 3.14), in other words, spaces that were still natural, with no maintenance, grass cutting, grazing or irrigation within a town's boundaries.

Landscape features of urban open spaces include scattered trees in vacant lots with patches of grassland on irregular rocky surfaces, with moderate or extensive disturbance. The main land uses include commercial and residential uses, with these areas being transformed for housing, businesses, factories and various other types of developments. Dominant vegetation units include the Vaal-Vet Sandy and Rand Highveld Grassland and according to Ellis and Ramankutty (2008), urban open spaces fall under urban anthromes. Urban open spaces feature in both local (Cilliers, 1998; Cilliers and Bredenkamp, 1999a, 1999b; Dingaan and Du Preez, 2013; Grobler *et al*., 2006; Van der Walt *et al*., 2015) and international (Aronson *et al*., 2015; Schukoske, 1999) studies.

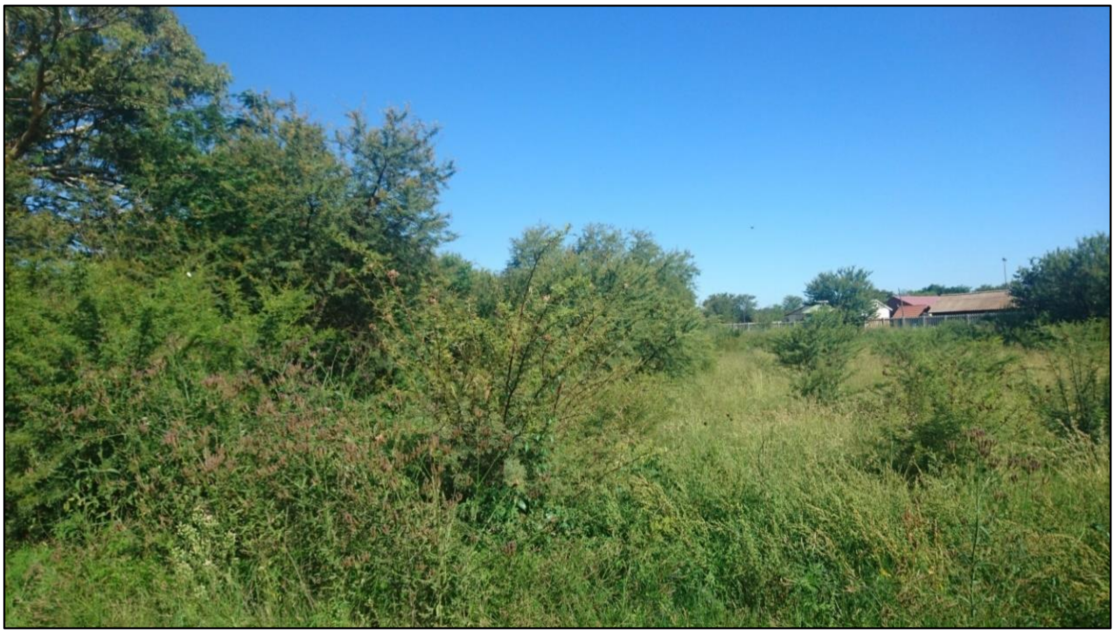

Figure 3.14. A typical urban open space (Photographer: L. Knoetze)

3.3 Study design

The 60 km radius of the study area was divided into eight segments of equal size (Figure 3.15) to enable systematic sampling. Within each eighth, each of the ten bushclump types was sampled to assess tree species diversity. Two plots per bushclump type were sampled in each eighth of the study area. Thus, 16 plots were sampled per bushclump. However, gardens and streets were exceptions, where 21 street plots and 32 gardens plots were sampled. Garden plots included 16 gardens of high socio-economic status and 16 of low socio-economic status (for the purpose of comparing tree diversity of different socio-economic statuses), thus requiring more plots than other bushclump types. These garden plots were chosen at random from the 100 sample plots surveyed by Lubbe (2011). Since the species composition of street trees is similar across towns, bushclumps were selected to be representative of street tree species, resulting in 21 street plots sampled.

Furthermore, in each of the eight areas, one plot per bushclump type was sampled close to the centre of the study area, while the other was sampled further away (if it was permitted in that area). Although bushclumps and land-cover types have separate definitions, the 10 bushclumps within the land-cover types will be referred to as “land-cover types” in the remainder of this dissertation.

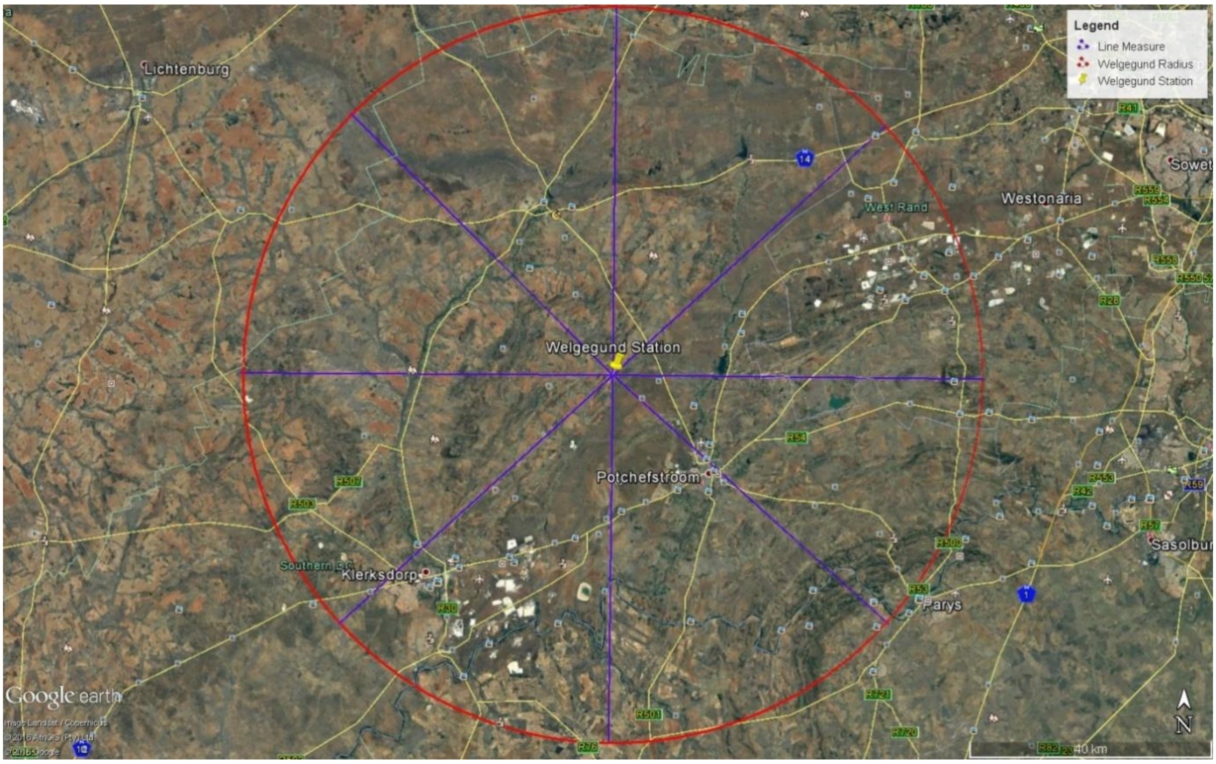
Legend
Line Measure
Welgegund Radius
Welgegund Station
Lichtenburg
West Rand
Westonaria
Welgegund Station
Potchefstroom
Klerksdorp
Parys
Sasolbu
Google earth
40 km
N

Figure 3.15. Division of the study area into eight equal segments within a 60 km radius

3.4 Data sampling

Surveys were conducted with belt transects, which can be defined as line transects where quadrats are laid out next to each other or continuously along a transect line (Kent, 2012). As mentioned, a minimum of 16 belt transects were sampled for each of the ten land-cover types. The 50 m belt transects were placed randomly. To capture the variation in the diversity of street trees, 21 transects had to be sampled and to capture the tree diversity of gardens, 16 transects were sampled in both low- and high-income areas. The transects summed to 181 in total (Addendum B).

Tree species diversity data were recorded along 50 x 5 m belt transects (Figure 3.16). Every woody species rooted in the transect was identified up to species level and counted. Identification of species were obtained from The Plant List (2013) and AP Goossens herbarium, Potchefstroom. Woody species taller than 1 m were measured. Measurements included height with a clinometer, crown diameter with a measuring stick (two directions), height of lowest crown (Figure 3.17), number of stems and stem circumference (with a measuring tape) if more than 5 cm. Global positioning system (GPS) coordinates, land-cover type, minor locality and the closest town were also recorded at every sampling site.

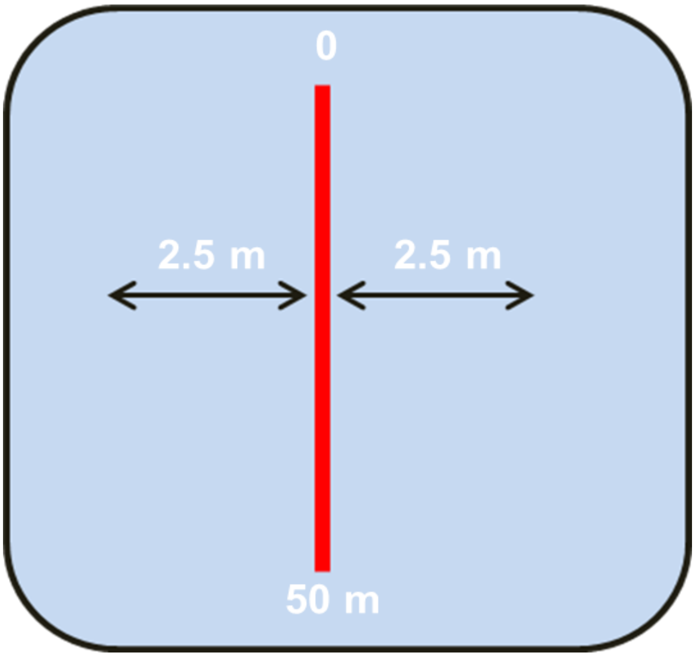

Figure 3.16. Layout of the belt transect, represented by the red line

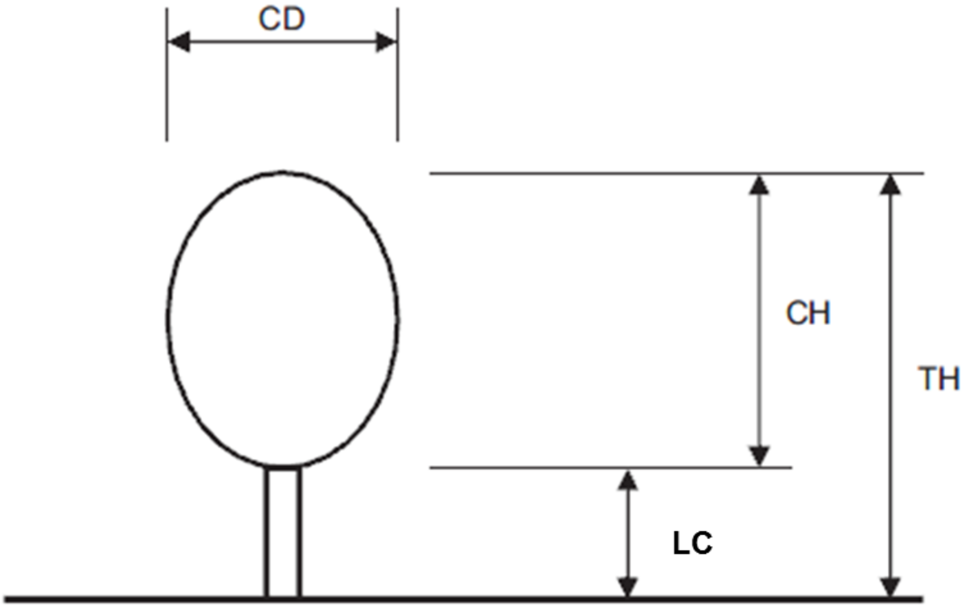

Figure 3.17. Dimensions measured for each tree: tree height (TH), height of lowest crown (LC), crown height (CH) and crown diameter (CD) (diagram adapted from Stoffberg *et al*., 2008)

3.4.1 Sampling season

Most of the trees occurring in North-West are deciduous (shedding leaves at the end of the growing season) and sampling therefore had to take place within the growing season. Considering the size of the study area and the time required to make accurate measurements, sampling had to take place over two growing seasons. Data were sampled from March 2015 to the beginning of June 2015 and continued in October 2015 to the end of April 2016.

3.5 Data analysis

Data were analysed and consolidated in Microsoft Excel spreadsheets and basic graphs, tables and lists were drawn using the same software. Specific data analysis methods, such as diversity indices and multivariate ordinations, are discussed in relevant chapters.

Geographic information system (GIS) maps were created in ArcMap to display the location of the Welgegund Atmospheric Measurement Station and the different land-cover types as well as the percentage cover of the three provinces in which the study area was located. The dominant vegetation units (Mucina and Rutherford, 2006) occurring in the study area were also indicated by means of a map. The dominant land-cover types were mapped from a 2014 land-cover product that was derived from SPOT 5 satellite imagery and refined and validated through the use of high-resolution aerial imagery.

CHAPTER 4

WOODY SPECIES OF THE WELGEGUND ATMOSPHERIC MEASUREMENT STATION FETCH REGION AND JB MARKS LOCAL MUNICIPALITY

4.1 Introduction

Global biodiversity patterns are affected by rapid urbanisation, which also has other significant ecological consequences (Aronson *et al*., 2015). For instance, in European urban environments, human impacts have been identified among the most important influences on the structure of vegetation and flora (Kowarik, 1990). Four main processes affect the floras of urban areas: habitat fragmentation, habitat transformation, habitat degradation, all as a result of urban environmental effects and the spread of alien species (Williams *et al*., 2009).

According to the United Nations (2007), rapid urbanisation will result in almost two-thirds of the world’s population living in cities or urban areas by 2030, making the sustainability of cities and towns an environmental issue of growing concern. With this in mind, urban greening is one of the main opportunities ensuring the environmental sustainability of towns, because it provides various ecosystem goods and services that benefit humanity (Colding *et al*., 2006). Biodiversity support and sustain many ecosystem goods and services (Jim and Chen, 2008) and enables urban inhabitants to connect with nature, thereby enhancing appreciation and understanding of the important ecological, psychological and social functions of green areas. These green areas or “urban forests” include vegetation in parks, along streets, woodlots, remnant sites and residential areas (Alvey, 2006). Trees, in particular, have many different functions and are essential to man’s existence (Venter and Venter, 2009). They provide food, nesting sites, shade and shelter, rendering materials for the manufacturing of goods, such as paper and furniture, and supply oxygen (Venter and Venter, 2009).

On a subcontinental scale, southern Africa has a floristic richness unequalled anywhere else in the world (Gibbs-Russel, 1985; Glen and Van Wyk, 2016). There are approximately 22 000 plant species in southern Africa (BODATSA, 2017), with 19 581 indigenous species, 2 267 genera and 349 families of vascular plants (Germishuizen *et al*., 2006). Of these species, an estimated 60% (±11 700) are endemic to South Africa, most of which (about 6 200) occur in the Cape Floristic Kingdom (Germishuizen *et al*., 2006). Furthermore, southern Africa is also considered to be rich in tree species, with approximately 2 100 indigenous tree species and over 750 aliens (Wilson *et al*., 2013) introduced from other parts of the world (Glen and Van

Wyk, 2016). However, the floristic richness and contribution of trees in the Grassland biome is much lower, with higher species richness occurring in urban areas. According to Kuruneri-Chitepo and Shackleton (2011), street trees in three different towns in the Eastern Cape Province comprised 61 species, while trees in a floristic study by Lubbe (2011) contributed 16% (131 species) of the total urban flora.

The aim of this chapter is to provide a floristic analysis of tree species in the Welgegund Atmospheric Measurement Station (WAMS) fetch region and JB Marks Local Municipality. Very few data of tree species around the municipality exist apart from a small number of studies on invasive alien woody plants (Henderson and Musil, 1984) and naturalised species (Henderson, 1991). The only vegetation analyses of spontaneous vegetation in urban open spaces and surrounding areas that occur within the study area are those in the JB Marks Local and Matlosana Municipal areas (Cilliers, 1998; Cilliers and Bredenkamp 1998, 1999a, 1999b, 2000; Davoren *et al*., 2016; Lubbe, 2011; Van Wyk *et al*., 1997; Van Wyk, 1998). These studies include vegetation surveys along railways, roadsides, wetlands and urban open spaces. All forms of vegetation were recorded, but few data of woody species were reported.

A few studies on street trees, trees in urban areas and goods and services provided by trees were conducted elsewhere in South Africa (Kuruneri-Chitepo and Shackleton, 2011; Paumgarten *et al*., 2005; Shackleton *et al*., 2008). However, no further studies specifically dealing with woody species and their ecological significance in urban areas and other land-cover types on a national level were found in the literature. The data presented here provides a snapshot of the tree flora for a South African city and its surrounding areas and provides a broad picture of the state of the tree flora of bushclumps in urban and neighbouring land-cover types in the WAMS fetch region and specifically the JB Marks Local Municipality. As there is little descriptive data of this kind available – especially for developing countries – this chapter contributes to the pool of knowledge necessary to understand urban tree flora diversity. The purpose of this study was therefore to provide a broader understanding of the contribution of trees to the floristic composition of different land-cover types in urban and agricultural areas in the WAMS fetch region. The specific objectives included to 1) determine the tree flora of the Highveld, 2) determine how the flora differs between land-cover types and 3) determine whether the tree flora of the Highveld is dominated by alien or indigenous species.

4.2 Materials and methods

4.2.1 Study area

This study was conducted in the WAMS fetch region and JB Marks Local Municipality of the North-West province of South Africa. The study area covered a 60 km radius around the Welgegund Atmospheric Measurement Station and included the towns of Carletonville, Fochville, Potchefstroom, Stilfontein, Klerksdorp, Orkney, Hartbeesfontein and Ventersdorp (Figure 4.1). The study area was located in the Grassland Biome where the Vaal Vet Sandy Grassland, Carletonville Dolomite Grassland and Rand Highveld Grassland vegetation units converge (Mucina and Rutherford, 2006). However, fragments of the Savanna Biome were also present in the study area. This biome is a grass-dominated ecosystem that contains a well-developed tree layer (Mucina and Rutherford, 2006).

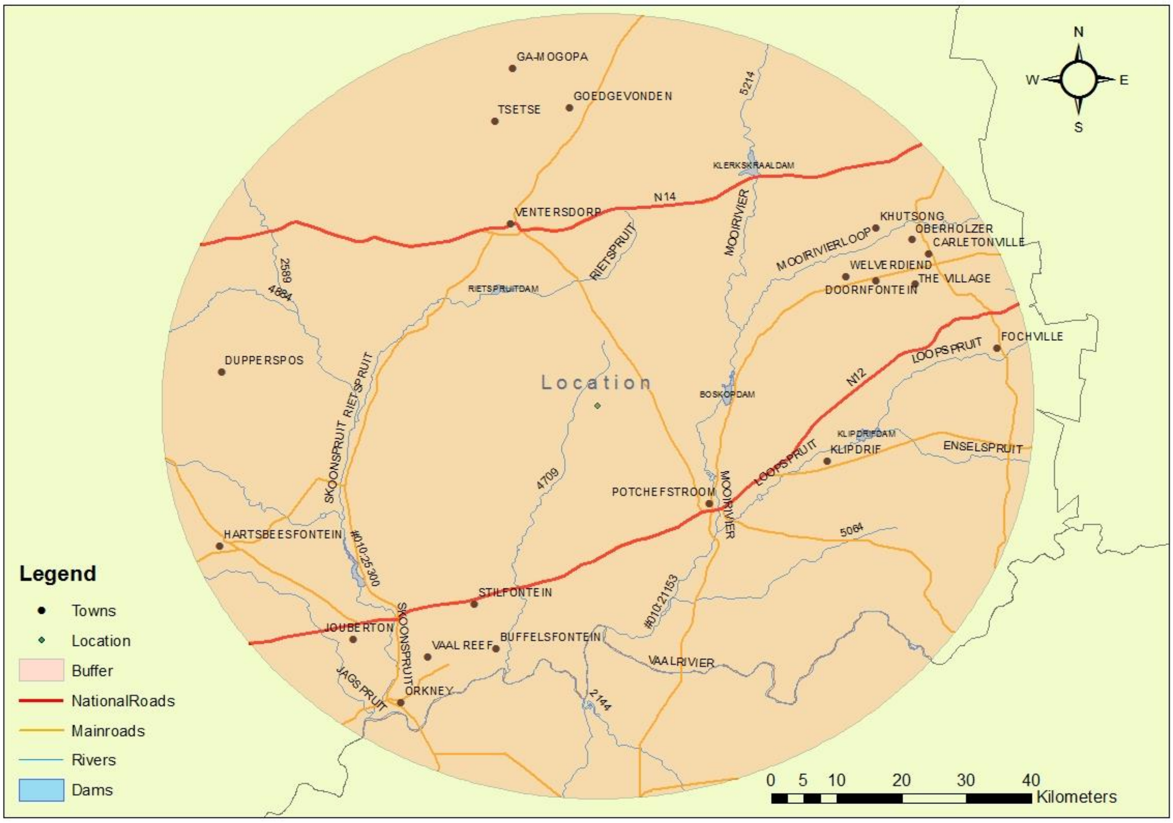
GA-MOGOPA
GOEDGEVONDEN
TSETSE
5214
KLERKSKRAALDAM
N14
VENTERSDORP
RIETSPRUIT
MOOIRIVIER
KHUTSONG
OBERHOLZER
CARLETONVILLE
MOOIRIVIERLOOP
WELVERDIEND
THE VILLAGE
DOORNFONTEIN
2589
4884
RIETSPRUITDAM
FOCHVILLE
LOOPSPRUIT
N12
DUPPERSPOS
RIETSPRUIT
SKOONSPRUIT
Location
BOSKOPDAM
KLIPDRIFDAM
KLIPDRIF
ENSELSPRUIT
LOOPSPRUIT
4709
POTCHEFSTROOM
MOOIRIVIER
5064
HARTSBEESFONTEIN
#010:25300
#010:21153
STILFONTEIN
JOUBERTON
SKOONSPRUIT
VAAL REEF
BUFFELSFONTEIN
VAALRIVIER
JAGSPRUIT
ORKNEY
2144
Legend
Towns
Location
Buffer
NationalRoads
Mainroads
Rivers
Dams
N
W
E
S
0
5
10
20
30
40
Kilometers

Figure 4.1. Study area demarcated by the 60-km buffer zone, with main towns, roads, rivers and dams indicated. Location: Welgegund Atmospheric Measurement Station

4.2.2 Plant species classification

Data sampling followed the methodology described in Chapter 3. Woody species were identified to species level and accepted species names conformed to The Plant List (2013). APG II (2003) was followed for family names. Species were classified as alien-cultivated, indigenous-cultivated, native or naturalised. This classification was adapted from Lubbe (2011) and adapted to conform to the National Environmental Management: Biodiversity Act (Act no. 10 of 2004) (NEMBA) (2014) invasive species list:

- Alien-cultivated – Not indigenous to South Africa (includes invasive aliens), cultivated in urban areas (gardens, streets and plantations), can be naturalised in the study area;
- Indigenous-cultivated – Indigenous to South Africa and cultivated in gardens and other cultivated areas, can occur naturally;
- Native – Occurring naturally (indigenous), normally not cultivated;
- Naturalised – Not indigenous to South Africa (includes invasive aliens), but occurring naturally in areas outside of cultivation, with self-replacing populations without direct intervention by humans (NEMBA, 2014).

4.2.3 Plant species categories

All species were further categorised according to endemism level, threat status, uses, origin of naturalised and cultivated species, growth forms and invasiveness. Endemic and indigenous species were identified from Germishuizen *et al*. (2006). Alien species were confirmed from Glen and Van Wyk (2016) and invasive alien species from the Conservation of Agricultural Resources Act (2001) and NEMBA (2014). Threatened species were determined from the Red List of South African Plants (SANBI, 2014) and protected species from the National Forest Act (Act 84 of 1998). The main uses of cultivated plants were identified from various sources (Van Wyk and Van Wyk, 1997; Van Wyk and Gericke, 2000; Venter and Venter, 2009). Useful plants were sorted into nine groups, namely fodder (animals), food (humans), furniture/tools, hedges, medicinal, ornamental (aesthetic), shade, weeds and windbreak according to the most distinctive uses found in Glen and Van Wyk (2016) and Van Wyk and Gericke (2000).

Indigenous-cultivated species were divided into six geographical groups according to occurrences per province (Lubbe *et al*., 2011). The origin of alien-cultivated species and invasive aliens were determined from Henderson (2001), Glen (2002), NEMBA (2014) and Van Wyk and Van Wyk (1997). Woody species were divided into different growth forms that occurred within the study area to indicate the contribution of each, namely trees, shrubs, climbers and suffrutices (Germishuizen *et al*., 2006; Van Wyk and Van Wyk, 1997).

Furthermore, trees can be defined as perennial woody plants, usually with a single main stem, which can grow to a height of 6 m or more, and a distinct upper crown (Van Wyk and Van Wyk, 1997). Shrubs are woody plants that are smaller than trees and usually have multiple stems arising at or near the ground (Venter and Venter, 2009). Pienaar (1994) defined climbers as plants that climb into trees and other tall objects; many climbers are vines with stems that twine around branches. Suffrutices are short woody plants with ground-hugging stems (or perennial woody bases) and low growth habits (White, 1976).

Where data were displayed by means of graphs or figures and variations in data compromised comparability, log transformation was applied (Higgins *et al*., 2008) to reduce the skewness of distributions or patterns and such transformations were subsequently indicated on the relevant graphs.

4.3 Results

4.3.1 Best represented families

A total of 49 plant families (with 169 species) were recorded for the WAMS fetch region and 19 families were represented by a single species. The 20 best represented families comprised 76% (129 species) of the total number of species recorded (Table 4.1). Representation, as indicated above, was determined by the number of species recorded for a given family, regardless of the occurrence or frequency of each species.

Four of the 20 best represented families in the WAMS fetch region (Table 4.1) are among the most species-rich South African plant families (Von Staden *et al*., 2013), with Asteraceae, Fabaceae and Iridaceae being the three most species-rich of these plant families. Of these three, only the Fabaceae was amongst the top three families in the study area. Asteraceae was 31st and not amongst the best represented families. Iridaceae is a non-arborescent family. The best represented families contained numerous garden genera and species that are cultivated throughout the world (e.g. Caprifoliaceae: *Abelia* spp., *Sambucus* spp., *Viburnum* spp.; Myrtaceae: *Callistemon* spp., *Melaleuca* spp., *Syzygium* spp.; Rosaceae: *Cotoneaster* spp., *Prunus* spp., *Pyracantha* spp.) as well as numerous naturalised species (e.g. Fabaceae: *Gleditsia triacanthos*, *Robinia pseudoacacia*, *Tipuana tipu*; Oleaceae: *Fraxinus angustifolia*, *Ligustrum lucidum*; Solanaceae: *Cestrum laevigatum*, *Nicotiana glauca*, *Solanum mauritianum*).

Eleven families (23% of all plant families recorded for the study area) were exclusively classified as alien plant families, as none of their constituent species were indigenous to South Africa (Table 4.2). These alien plant families were represented by fewer than 10 species, with Caprifoliaceae being the largest with six species and ranked eighth among the 20 best represented families in the study area (Table 4.1).

Table 4.1. Twenty best represented plant families in the WAMS fetch region and JB Marks Local Municipality. Superscript enumerators indicate a family's position as one of the 20 largest families in the South African Flora (Von Staden *et al*., 2013).

Position	Plant family	No. of species	Total no. of species (%)
1	Fabaceae^{2}	21	12.5
2	Rosaceae	14	8.3
3	Myrtaceae	8	4.8
4	Anacardiaceae	7	4.2
5	Cupressaceae	7	4.2
6	Rubiaceae	7	4.2
7	Salicaceae	7	4.2
8	Caprifoliaceae	6	3.6
9	Celastraceae	6	3.6
10	Oleaceae	6	3.6
11	Malvaceae^{16}	5	2.9
12	Solanaceae	5	2.9
13	Ulmaceae	5	2.9
14	Apocynaceae^{8}	4	2.4
15	Ebenaceae	4	2.4
16	Pinaceae	4	2.4
17	Rutaceae^{19}	4	2.4
18	Arecaceae	3	1.8
19	Berberidaceae	3	1.8
20	Fagaceae	3	1.8

Table 4.2. Number of species representing alien plant families recorded in the WAMS fetch region and JB Marks Local Municipality.

Alien families	No. of species
Caprifoliaceae	6
Pinaceae	4
Berberidaceae	3
Fagaceae	3
Platanaceae	2
Aquifoliaceae	1
Casuarinaceae	1
Elaeagnaceae	1
Magnoliaceae	1
Simaroubaceae	1
Theaceae	1

4.3.2 Best represented genera

In total, 113 plant genera were recorded for the study area and of these, 73% were represented by a single species. The 15 best represented genera constituted 30% of the total number of recorded species (Table 4.3). All of the best represented genera belong to families on the list of the 20 best represented families in the study area. Seven genera that belong to the 15 best represented genera in the WAMS fetch region (23 of the 52 species) are alien to South Africa.

Table 4.3. Number of species representing the 15 best represented genera in the WAMS fetch region and JB Marks Local Municipality. Superscript enumerators indicate alien genera (*).

Genera	Family	No. of species
Searsia	Anacardiaceae	6
Acacia*	Fabaceae	4
Celtis	Ulmaceae	4
Populus*	Salicaceae	4
Prunus	Rosaceae	4
Citrus*	Rutaceae	3
Pavetta	Rubiaceae	3
Pinus*	Pinaceae	3
Pyracantha*	Rosaceae	3
Quercus*	Fagaceae	3
Salix	Salicaceae	3
Senegalia	Fabaceae	3
Vachellia	Fabaceae	3

4.3.3 Most frequent species

A total of 169 species was recorded for the WAMS fetch region and surrounding areas. However, 59 of these species were recorded only once. In addition, 114 of the 169 species were alien (67%) and 21 species (12%) belonged to a single family (Fabaceae).

The species that occurred most frequently were all present in more than 10% of the plots (Table 4.4) and all but four species represented the 20 best represented families in the study area. The two species that occurred most frequently, *Asparagus laricinus* and *A. suaveolens*, are both indigenous scrambling shrubs (Hyde *et al*., 2016) and were included in the study because of their encroaching nature. The majority of the 20 most frequently occurring tree species were indigenous to South Africa (65%), whereas only seven species were aliens (Henderson, 2001). *Cestrum laevigatum*, *Eucalyptus camaldulensis*, *Ligustrum lucidum* and *Melia azedarach* are all declared weeds or invader plants, whereas *Celtis australis*, *C. sinensis* and *Ulmus parvifolia* are proposed invaders (Henderson, 2001). The best represented families among the most frequently occurring species was Ulmaceae (four species), Anacardiaceae, Asparagaceae, Ebenaceae and Fabaceae (two species each).

Table 4.4. Twenty most frequently recorded species (alphabetically) for the WAMS fetch region and JB Marks Local Municipality. Superscript enumerators indicate shrubs (1) and alien species (*).

Species	Families	% plots in which species occur
Asparagus laricinus[1]	Asparagaceae	72
Asparagus suaveolens[1]	Asparagaceae	54
Searsia pyroides	Anacardiaceae	49
Vachellia karroo	Fabaceae	41
Celtis africana	Ulmaceae	39
Diospyros lycioides subsp. *guerkei*[1]	Ebenaceae	34
*Melia azedarach**	Meliaceae	32
Searsia lancea	Anacardiaceae	27
Gymnosporia buxifolia	Celastraceae	25
Diospyros lycioides subsp. *lycioides*[1]	Ebenaceae	23
*Celtis sinensis**	Ulmaceae	22
Ziziphus mucronata	Rhamnaceae	20
Ehretia rigida	Boraginaceae	19
*Ligustrum lucidum**	Oleaceae	18
Zanthoxylum capense	Rutaceae	18
Senegalia caffra	Fabaceae	17
*Cestrum laevigatum**[1]	Solanaceae	17

*Eucalyptus camaldulensis**	Myrtaceae	15
Vangueria infausta	Rubiaceae	12
*Ulmus parvifolia**	Ulmaceae	12
*Celtis australis**	Ulmaceae	11
Grewia flava[1]	Malvaceae	11

4.3.4 Growth forms

Most of the woody species found in the study area were trees (117 species) (Figure 4.2). *Searsia pyroides* and *Vachellia karroo* were the most frequent tree species, occurring in 49 and 41% of the sample plots, respectively. The second most frequent growth form was shrubs (46 species) with frequent species such as *Asparagus laricinus*, *Asparagus suaveolens* and *Diospyros lycioides* subsp. *guerkei*. Climbers and suffrutices were both represented by the same number of species and were the smallest groups, each consisting of only 2% of the total number of species.

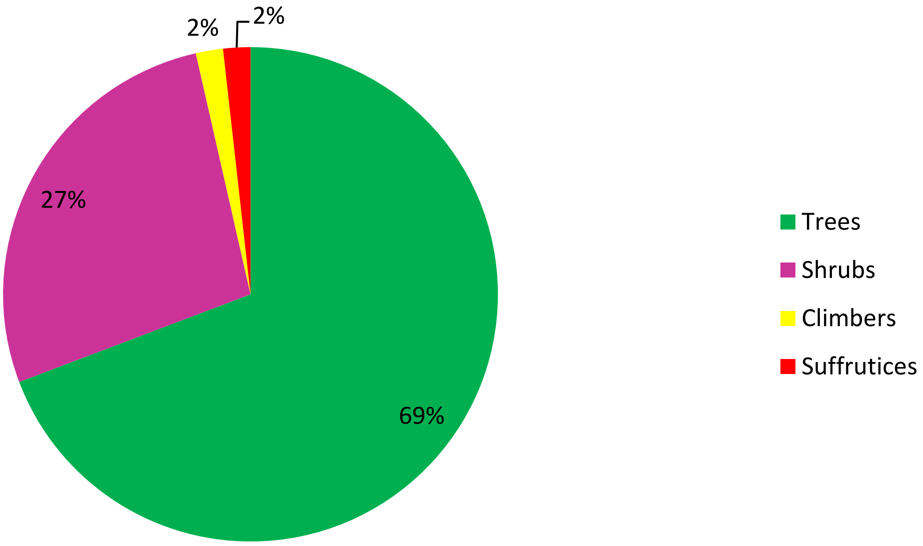

Figure 4.2. Dominant growth forms in the WAMS fetch region and JB Marks Local Municipality

4.3.5 Endemic and indigenous species

Of the 55 recorded indigenous species in the WAMS fetch region, four are regarded as endemic to South Africa and only 10 occurred in more than 20% of the plots (Table 4.5). *Gymnosporia polyacantha*, *Mystroxylon aethiopicum*, *Searsia rigida* and *Triumfetta sonderi* are endemic. *Gymnosporia polyacantha* occurred the most frequently but with the least number of individuals

(11) and *T. sonderi* was recorded only once, with the highest number of individuals (52) compared to other endemic species.

4.3.6 Threatened and protected species

None of the tree species recorded for the WAMS fetch region were listed as threatened. According to the South African National Red Data List (SANBI, 2014), all the species recorded during the survey were considered Least Concern (Raimondo *et al*., 2009). However, two species, *Vachellia erioloba* and *Boscia albitrunca* are listed as protected species according to the National Forest Act (1998).

Table 4.5. South African indigenous woody species recorded in the WAMS fetch region and JB Marks Local Municipality. Superscript enumerators indicate endemic (E) and protected (P) species. Percentage plots indicate the % of plots the species occurred in.

Species	% plots	Species	% plots
Asparagus laricinus	72	*Dombeya rotundifolia*	3
Asparagus suaveolens	54	*Elephantorrhiza elephantina*	3
Searsia pyroides	49	*Gymnosporia polyacantha*^{E}	3
Vachellia karroo	41	*Maytenus tenuispina*	3
Celtis africana	39	*Carissa bispinosa*	2
Diospyros lycioides subsp. *guerkei*	34	*Combretum molle*	2
Searsia lancea	27	*Gnidia burchellii*	2
Gymnosporia buxifolia	25	*Grewia occidentalis*	2
Diospyros lycioides subsp. *lycioides*	23	*Salix mucronata*	2
Ziziphus mucronata	20	*Searsia rigida*^{E}	2
Ehretia rigida	19	*Senegalia hereroensis*	2
Zanthoxylum capense	18	*Ancylobotrys capensis*	1
Senegalia caffra	17	*Boscia albitrunca*^{P}	1
Vangueria infausta	12	*Brachylaena rotundata*	1
Grewia flava	11	*Buddleja saligna*	1
Euclea undulata	9	*Canthium gilfillanii*	1
Pavetta zeyheri	9	*Clerodendrum glabrum*	1
Searsia magalismontana	9	*Mystroxylon aethiopicum*^{E}	1
Vachellia erioloba^{P}	9	*Pavetta gardeniifolia*	1
Ziziphus zeyheriana	9	*Pavetta harborii*	1
Vangueria parvifolia	8	*Protea caffra*	1
Searsia leptodictya	7	*Senegalia hebeclada*	1
Pappea capensis	5	*Sphedamnocarpus pruriens*	1
Combretum erythrophyllum	4	*Triumfetta sonderi*^{E}	1

Euclea crispa	4	*Vachellia robusta*	1
Mundulea sericea	4	*Vangueria cyanescens*	1
Olea europaea subsp. *africana*	4	*Widdringtonia nodiflora*	1
Searsia pendulina	4		

4.3.7 Useful plants

Most of the plant species recorded in the study area (24%) were classified as ornamental plants (Glen and Van Wyk, 2016; Van Wyk and Gericke, 2000), suggesting that they were originally cultivated solely for their aesthetic value (Figure 4.3). Some of the species in this group included the indigenous trees *Combretum erythrophyllum* and *Vachellia karroo* and the alien shrubs *Nandina domestica* and *Viburnum sinensis*. The second-largest group consisted of plants that are used for making tools (Glen and Van Wyk, 2016; Van Wyk and Gericke, 2000), furniture, firewood, timber and carvings (19%), which included species such as *Celtis africana*, *Searsia lancea* and *Pinus pinea*. A further 13 and 14% were respectively classified as medicinal and food plants on account of their edible leaves, fruits, tubers or seeds and the fact that their parts can be used for herbal remedies and healing value (Venter and Venter, 2009). Plants used as fodder or browsed by game and livestock (Glen and Van Wyk, 2016; Van Wyk and Gericke, 2000) accounted for 11% of all the species, while 10% were regarded as living hedges. Shade trees (4%), weeds (3%) and windbreaks (2%) did not contribute considerably to species richness.

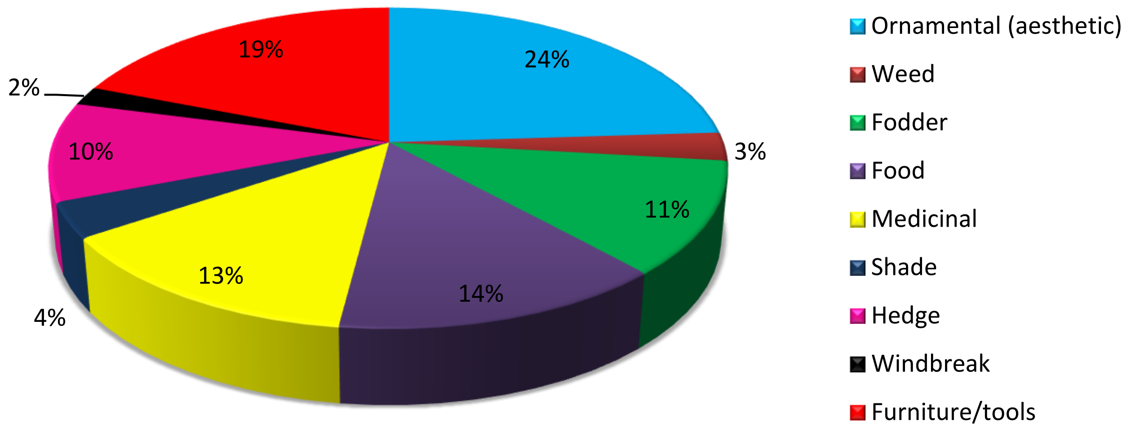

Figure 4.3. Contribution of trees in the WAMS fetch region and JB Marks Local Municipality towards nine plant use and non-use categories

4.3.8 Origin of cultivated indigenous species

Of the 55 indigenous species, 20 (36.4%) were indigenous-cultivated species. To accurately depict the origin of these cultivated native species, South Africa was divided into six geographical regions based on the study by Lubbe (2011), namely widespread, north-eastern (Mpumalanga, Gauteng, Swaziland), south-eastern (KwaZulu-Natal, Eastern Cape), western (Western Cape, Northern Cape, Namibia), north-central (North-West, Limpopo, Botswana) and south-central (Free State, Lesotho).

Widespread species contributed the most (64%) towards the origin of indigenous trees found within the study area (Figure 4.4). These species have fewer specific environmental preferences and were classified as widespread if they occurred in eight or more of the 13 regions specified in Germishuizen *et al*. (2006). Other tree species originated from the northern parts of South Africa, with the north-central and north-eastern regions contributing 35 and 31%, respectively. The south-central and south-eastern geographical regions contributed 18 and 16%, respectively, to the cultivated indigenous tree flora of the WAMS fetch region, whereas the western region contributed the least with only 7%.

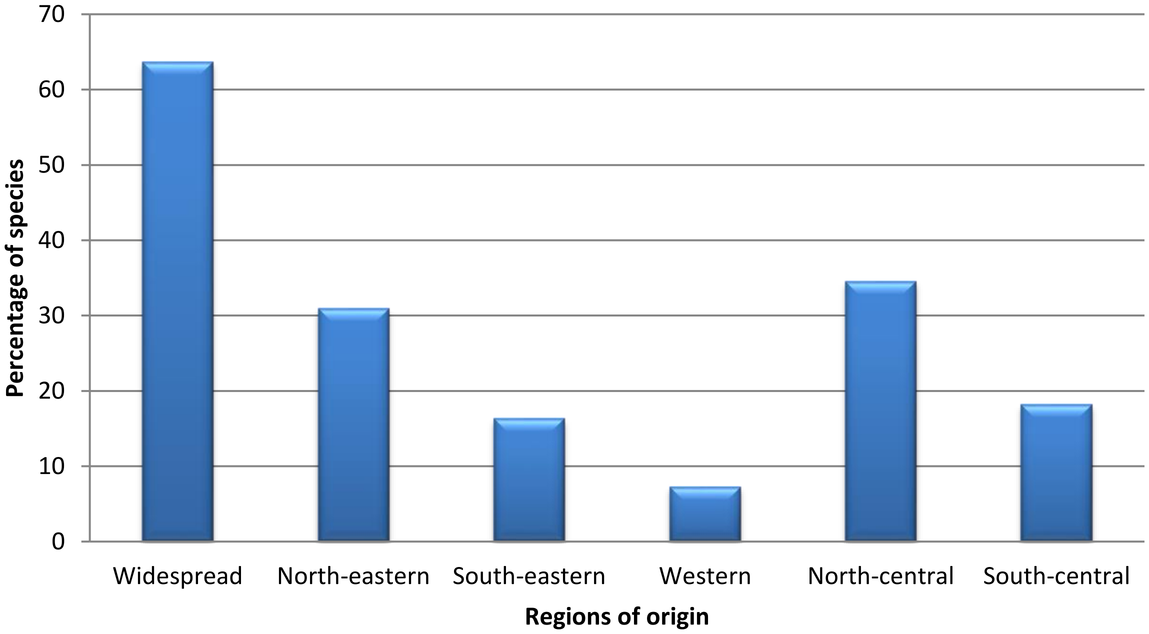

Figure 4.4. Regions of origin of indigenous-cultivated species recorded in the WAMS fetch region and JB Marks Local Municipality

4.3.9 Origin of cultivated and naturalised alien species

The majority of tree species recorded in the WAMS fetch region and JB Marks Local Municipality were alien species (67.5%). These 114 species did not originate in (i.e. are not native to) South Africa and were introduced from other parts of the world (Glen and Van Wyk, 2016).

The possible origins of the alien species were divided into seven regions (Figure 4.5). Almost half (40.4%) of the species were originally introduced from Asia, whereas the Americas (North, Central and South America) contributed 26.3% of the alien trees. The third-largest contributor was Australasia (13.2%). The rest of the groups each contributed less than 10% of the aliens found within the study area. Europe contributed the least to the percentage of aliens recorded (5.3%).

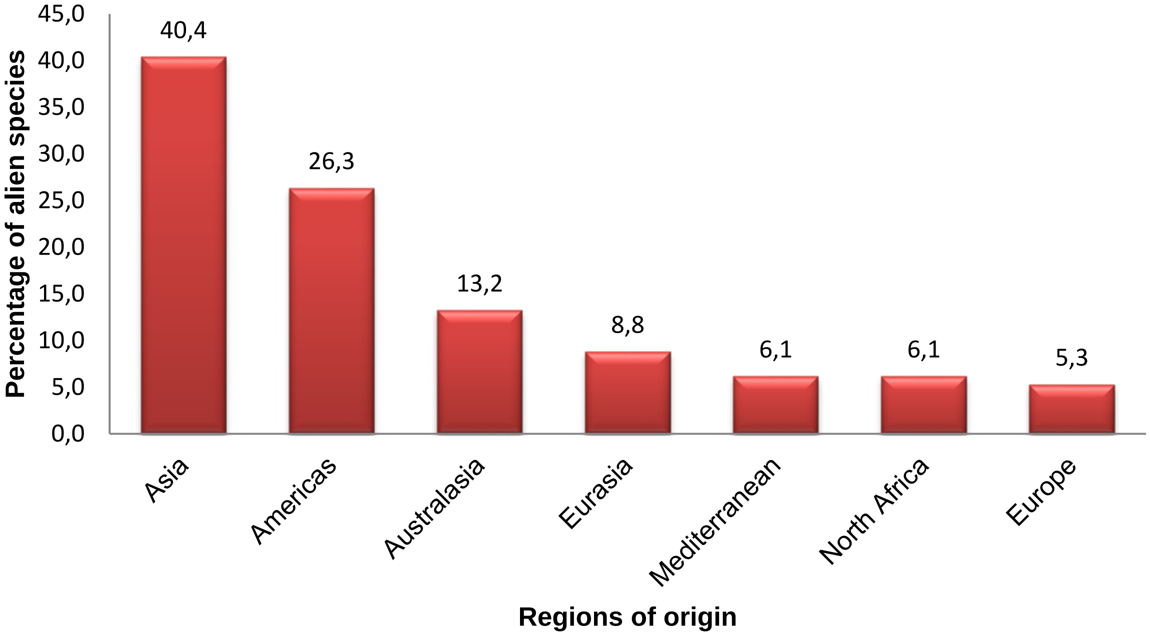

Figure 4.5. Seven regions of origin of alien-cultivated and naturalised species recorded in the WAMS fetch region and JB Marks Local Municipality

4.3.10 Species diversity of land-cover types

The total number of species and the number of alien and indigenous species within the different land-cover types of the study area were compared (Figure 4.6). A few distinct floristic differences were evident regarding species diversity within the different land-cover types. Firstly, gardens had a substantially higher total number of species (gamma diversity) than other land-cover types and hosted 89% of the alien species. Hillsides and ridges had the highest diversity of indigenous species (93 and 91%, respectively), whereas roadsides had the lowest overall diversity (25 species). Although the total species richness was lower in the natural areas, the number of indigenous species within these areas was higher than that in cultivated areas. The opposite was also true, i.e. in cultivated areas; the number of alien species was substantially higher than that of indigenous species.

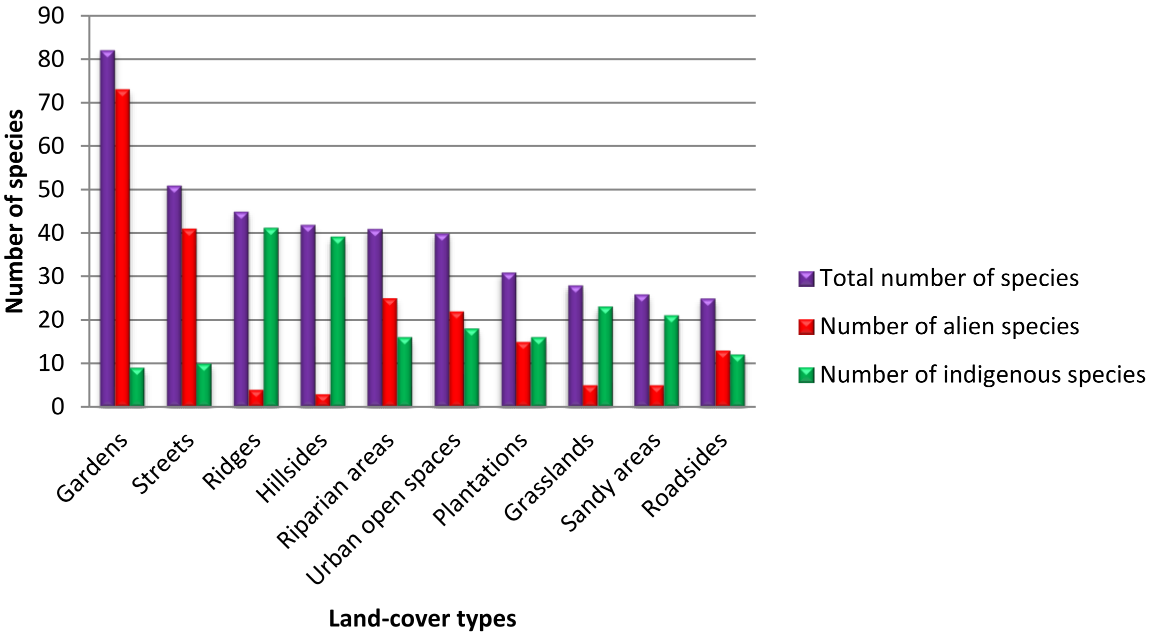

Figure 4.6. Comparison of the number of total species, indigenous species and alien species for woody plants in different land-cover types of the WAMS fetch region and JB Marks Local Municipality (gamma diversity)

4.3.11 Invasive aliens

The number of indigenous species and individuals were compared to the number of naturalised alien species and individuals for all the land-cover types (Figure 4.7). Consequently, a number of distinct floristic differences were evident between the different cultivated land-cover types. The first was the higher number of naturalised species in gardens and other cultivated areas compared to the number of indigenous species in natural areas. The second was that the total number of indigenous individuals was much higher than that of naturalised individuals in the natural areas. Furthermore, the number of naturalised individuals was the same or higher in cultivated and disturbed areas such as gardens, streets, roadsides, plantations and urban open spaces.

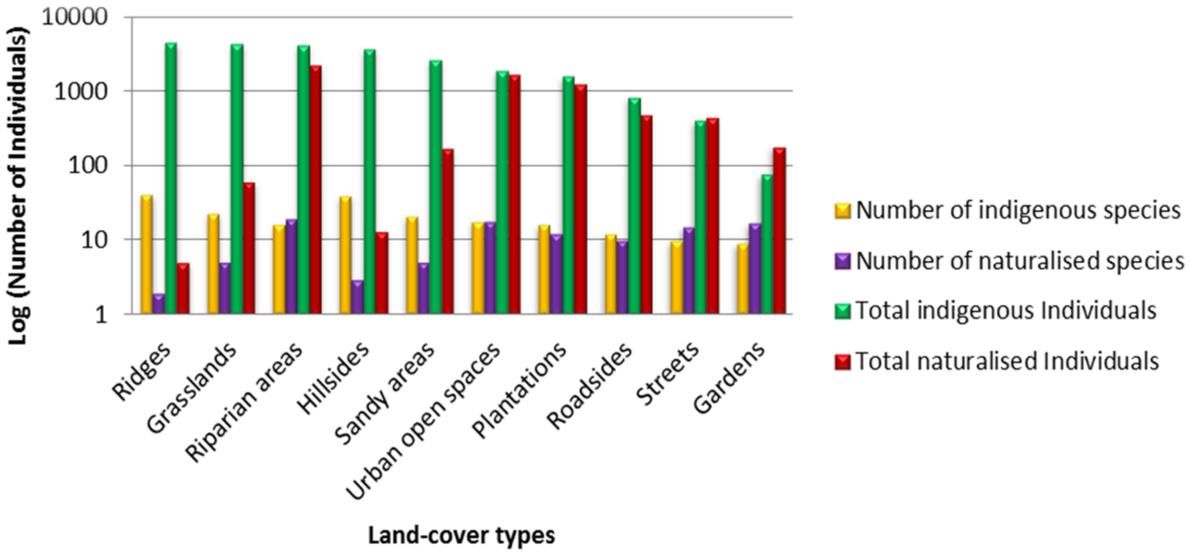

Figure 4.7. Comparison of the total number (log) of indigenous and naturalised species richness and total number of woody individuals in different land-cover types of the WAMS fetch region and JB Marks Local Municipality

As mentioned, 114 alien species occurred within the WAMS fetch region. However, only 45 of these species were declared invasive aliens (CARA, 2001; NEMBA, 2014). The high diversity found in cultivated areas (Figure 4.5), can be attributed to the high number of aliens found in these cultivated areas (Figure 4.9). A comparison between the number of indigenous- and alien-cultivated individuals in gardens, plantations and streets of the study area revealed that plantations had the highest number of individuals (Figure 4.8, Figure 4.9). Cultivated areas had a higher number of alien than indigenous species, especially in gardens and streets (Table 4.6). Of the indigenous-cultivated species, only 36.4% (20 out of 55) were present in cultivated areas, whereas 89.5% (102 out of 114) of alien species were present in cultivated areas. Table 4.6 indicates that the number of indigenous-cultivated species was lower than that of alien-cultivated species. The number of individuals per species (abundance) was lowest for gardens, higher for streets and highest for plantations (Table 4.6). However, the richness of alien-cultivated species was higher than that of indigenous-cultivated species, i.e. species diversity was highest in gardens containing aliens.

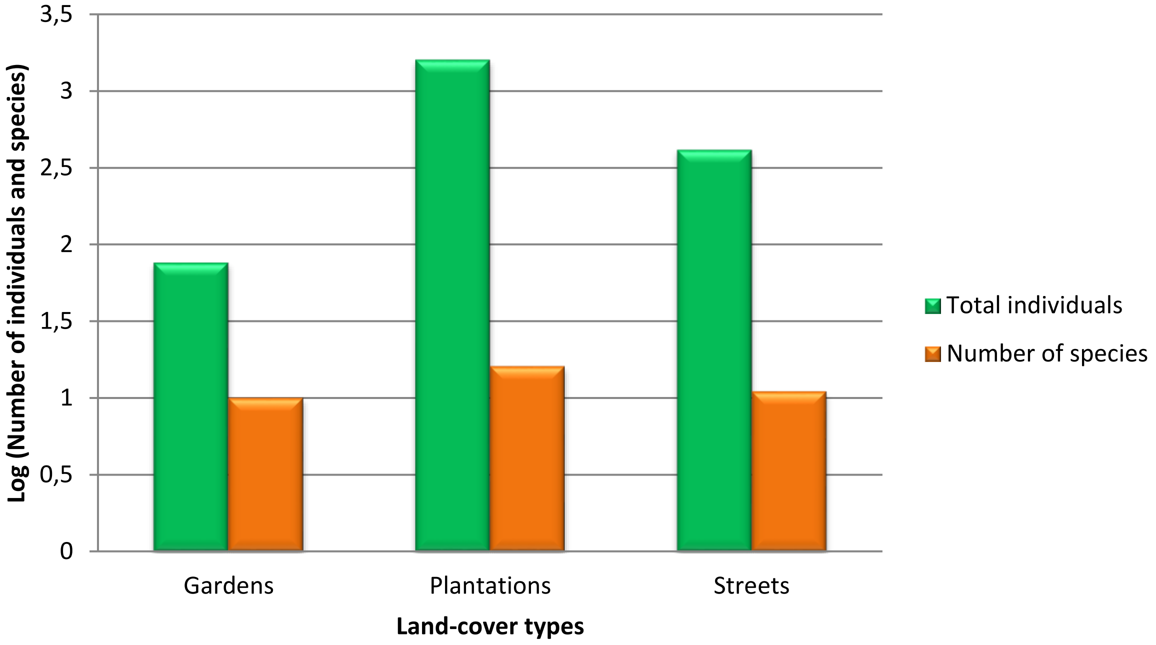

Figure 4.8. Log number of indigenous cultivated individuals and species within the cultivated land-cover types of the WAMS fetch region and JB Marks Local Municipality

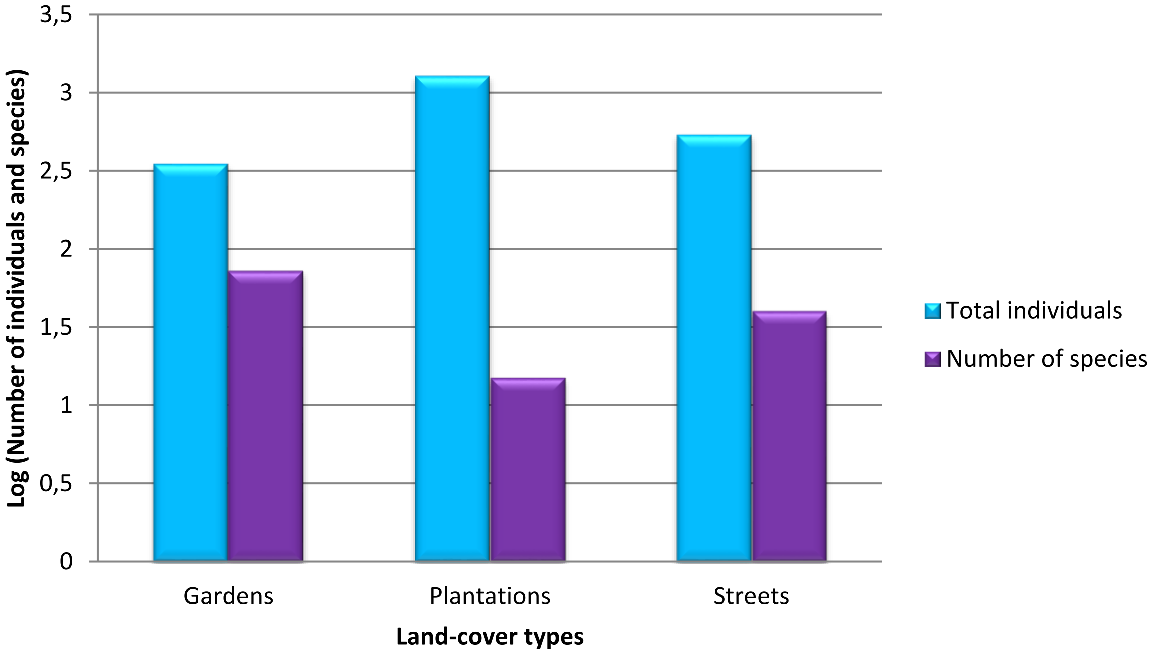

Figure 4.9. Log number of alien-cultivated individuals and species in the cultivated land-cover types of the WAMS fetch region and JB Marks Local Municipality

Table 4.6. Number of indigenous- and alien-cultivated species in the WAMS fetch region and JB Marks Local Municipality as well as the number of individuals.

	Land-cover types	Total no. of individuals	No. of species	Mean no. of individuals per species
Indigenous-cultivated species	Gardens	77	10	7.7
	Plantations	1591	16	99.4
	Streets	414	11	37.6
	Total	**2082**	**20**	**104.1**
Alien-cultivated species	Gardens	350	72	4.9
	Plantations	1272	15	84.8
	Streets	536	40	13.4
	Total	**2158**	**102**	**21.2**

4.4 Discussion

4.4.1 Most common taxa

The three largest families in the study area, Fabaceae, Rosaceae and Myrtaceae, consisted of species mostly cultivated as ornamentals and harvested for food (consumption) and timber purposes (*Acacia melanoxylon*, *Tipuana tipu*, *Vachellia karroo*; *Cotoneaster franchetti*, *Prunus persica*, *Pyracantha coccinea*; *Acca sellowiana*, *Calistemon citrinus*, *Eucalyptus camaldulensis*). Twenty-nine of the 49 plant families consisted of mainly cultivated species (found in gardens, plantations and along streets). The majority of the 49 plant families had multifunctional purposes. Furthermore, of the three most species rich plant families in South Africa – Asteraceae, Fabaceae and Iridaceae (Von Staden *et al*., 2013), only Fabaceae occurred among the top woody families for WAMS fetch region. As mentioned, Iridaceae is a non-arborescent family and tree growth forms are not well developed in the Asteraceae (Coates-Palgrave, 2002).

The gamma diversity (169 species and 49 plant families) found in WAMS fetch region was in accordance with results from other studies, e.g. 55 families consisting of 159 woody species in Santa Rosa, Costa Rica (Kalacska *et al*., 2004) and 516 species consisting of 106 plant families (all vegetation types) in Ganyesa rural settlement, North-West province, South Africa (Davoren, 2009). This indicates that urban landscapes have a high species or floristic diversity (82 species in gardens compared to 45 species in ridges), even though the majority of the species in these areas are alien or non-native.

4.4.2 Endemic and protected species

South African endemic species represent only a small proportion of the tree flora in the WAMS fetch region. This was also found in other local studies, e.g. 61 endemic species from a total of 835 plant species in Potchefstroom (Lubbe, 2011) and 22 endemics from a total of 387 plant species in Ganyesa (Davoren, 2009). In these studies, all forms of vegetation were recorded, but only a small number of the endemic species were woody plants.

The small number of endemic and protected woody species (mainly in sandy areas and ridges) can be attributed to the natural lack of indigenous woody species found in Highveld grasslands (Bond, 2008; Mucina and Rutherford, 2006). Indigenous tree species that do occur here are hardy, widespread species (e.g. *Celtis africana* and *Vachellia karroo*). Moreover, invasive alien species change the structure and composition of native ecosystems and can displace indigenous woody species diversity (Davis, 2003; Gaertner *et al*., 2009). This is evident in the alien species (*Eucalyptus camaldulensis*, *Gleditsia triacanthos*, *Melia azedarach*) found in the natural (grassland) land-cover type. Furthermore, Aronson *et al*. (2015) stated that urbanisation causes a loss of overall indigenous woody plant species diversity and also causes an increase in non-native species diversity. Therefore, the number of endemic and protected species present in urban and surrounding areas can change and be replaced by alien-cultivated species. Keeping this in mind, conservation strategies that already exist (Conservation of Agricultural Resources Act, National Environmental Management Biodiversity Act) can be utilised to better protect endemic and protected species.

4.4.3 Useful plants

Plants provide essential resources for human well-being (Bown, 1995). Ornamentals, furniture/tools, food and medicinal plants were the main uses of woody plant species in the WAMS fetch region. This trend was also evident in a study of Blanckaert *et al*. (2004), where 60% of plants were cultivated for ornamental purposes, 29% for food and 6.5% for medicinal value in the Tehuacán-Cuicatlán valley, Mexico. Furthermore, Das and Das (2005) showed that the dominant uses of plants in India included fruit (for consumption), followed by timber, which was also the second most common plant use in the WAMS fetch region. The most dominant growth forms in the WAMS fetch region, trees and shrubs, coincided with the major plant uses for the study area. Trees are also popular for aesthetical purposes in urban or cultivated areas. Nagendra and Gopal (2010) found that street trees are considered to provide aesthetic value as well as social and economic benefits. Similarly, Wezel and Bender (2003) found that fruit trees and medicinal plants were dominant in the cultivated flora as these plants generate an income or are consumed by the household.

4.4.4 Species origin

According to Mucina and Rutherford (2006), climatic conditions such as temperature, rainfall and fire largely determine the distribution of tree species. Commonalities between climatic conditions of the South African Highveld grasslands and those of Asia and the Americas could be the reason for these two regions being the origins of most of the alien flora in the WAMS fetch region and surrounding areas (Table 4.4). Many of these Asian and American species flourish under South African conditions and can even be hardier than indigenous species. They are usually introduced for their multiple uses such as food, income and ornamentals (Lubbe, 2011). A study by Thompson *et al*. (2003) also found that the majority of cultivated aliens in the United Kingdom originated from Europe, Asia, North and South America.

Species that are widespread and occur naturally in South Africa (indigenous-cultivated and native) were the most common in the study area and included tree species such as *Celtis africana*, *Olea europaea* subsp. *africana*, *Searsia lancea*, *Vachellia karroo* and *Ziziphus mucronata*. The widespread nature of native species in South Africa is usually because they are tolerant to drought, disturbance, wide temperature ranges and relatively dry conditions. A similar study by Lubbe (2011) found that the majority of indigenous-cultivated or native plants in a city in the Highveld region were also widespread in South Africa.

4.4.5 Invasive species

Urbanisation has been indicated as one of the factors influencing biotic homogenisation (Kühn and Klotz, 2006; McKinney, 2006; Olden *et al*., 2006). More alien than indigenous species are cultivated in urban areas, because cultivation practices promote the planting of aesthetic and hardy alien species that can be imported from all over the globe (Thompson *et al*., 2003). Moreover, the study of woody species in particular offer an important perspective on the effect of urbanisation on invasions in that the larger part of alien woody species are intentionally introduced by the horticultural trade (Reichard and Hamilton, 1997). The introduction of these alien species can increase the biodiversity in urban habitats (e.g. gardens), but can simultaneously reduce the biological uniqueness (through homogenisation) of natural environments (McKinney, 2006; Marco *et al*., 2008).

Accordingly, the gamma diversity of gardens was substantially higher than that of the other land-cover types and was mainly dominated by alien species. Marco *et al*. (2008) further mentioned that the development of gardens near natural areas holds a possible threat for the native vegetation, which is subsequently exposed to genetically transformed species and potential hubs or reservoirs of invasive plants, which can lead to the development of hybrid species and higher invasion rates. In total, 82 woody species were recorded in gardens in the

WAMS fetch region, of which 73 were aliens. Other urban areas such as streets and urban open spaces also had high gamma diversity, with the majority of these species also consisting of aliens. These alien species could threaten native species diversity by invading surrounding natural areas from cultivated urban areas, consequently decreasing the natural biodiversity by out-competing native species (Marco *et al*., 2008).

Natural land-cover types, namely grasslands, hillsides and ridges, had moderate diversity, with about half of the total number of species found in gardens. However, the natural areas had higher numbers of indigenous species. Overall, the total diversity of woody species in the WAMS fetch region and surrounding areas was made up of 67.5% alien species and 32.5% indigenous species. Similar results were found by Tererai *et al*. (2013) and Davoren (2009). A total of 75 woody species were recorded in the Western Cape, with alien and indigenous species contributing 57.3 and 42.7%, respectively, to the total species pool (Tererai *et al*., 2013). In Ganyesa, 51% of plant species were characterised as alien and 49% as indigenous species (Davoren, 2009).

4.5 Conclusions

Analysing the floristic composition of an area is a good indicator of the health, structure and main ecological processes, which can aid in beter planning, management and conservation for that area. Determining the tree flora of the Highveld, how tree flora differs between land-cover types and whether tree flora of the Highveld is dominated by alien or indigenous species formed the main objectives of this study.

Tree cover in the Grassland biome is much lower than other areas, which is supported by this study. A total of 169 species for WAMS fetch region was recorded from the approximately 2900 tree species found in South Africa. There was also great variation in the floristic composition of trees between land-cover types, with gardens being floristically more diverse than the other land-cover types and roadsides having the lowest tree flora. Furthermore, the tree flora of the Highveld is mainly dominated by alien species (114 alien species from a total of 169 tree species). The floristic diversity will be discussed in detail in Chapter 5, while the influences of alien species are covered in Chapter 6.

CHAPTER 5

TREE SPECIES DIVERSITY PATTERNS OF LAND-COVER TYPES IN THE WELGEGUND ATMOSPHERIC MEASUREMENT STATION FETCH REGION AND JB MARKS LOCAL MUNICIPALITY

5.1 Introduction

Rapid worldwide urbanisation has noteworthy ecological outcomes that shape the patterns of global biodiversity (Aronson *et al*., 2015). Furthermore, biological invasions, climate change, land-use change, habitat loss and fragmentation alters ecosystem functioning and contributes to the loss of biodiversity (Aronson *et al*., 2014; Fennell *et al*., 2013; Tilman *et al*., 2001). This warrants the study of urban ecosystems or environments, because biodiversity is essential for human survival, economic success and for ecosystem stability and function (Singh, 2002). Sheil (1999) stated that different kinds of environmental changes determine or influence processes that can both elevate or erode diversity. Human impacts on ecosystems are increasing exponentially, consequently intensifying stress on ecosystem goods and services, and adding to the necessity of finding ways to properly conserve biodiversity. One of the most persistent and dominant driving forces of species diversity and richness within urban areas, is anthropogenic influences (Davoren, 2017; Gibson *et al*., 2013). Studies have indicated that cities have richer plant species diversity, than the surrounding areas (Hope *et al*., 2003; McKinney, 2002), which could in part be attributed to the intrusion of alien species from both intentional and unintentional introductions (Miller, 2005; Wilcove *et al*., 1998), but can also be due to natural factors, seeing that in some regions cities were developed in areas of natural heterogeneity which naturally supports high levels of biodiversity (Kühn and Klotz, 2006).

The proportion of non-native species in urban areas is a useful indicator of the intensity of disturbance caused by human activities (Sukopp *et al*., 1979). Kent *et al*. (1999) indicated that the proportion of native species in urban areas have been increasingly reduced due to urbanisation, while the proportion of alien species has markedly increased. Furthermore, Godefroid (2001) states that the influence humans have on ecosystems in urban areas can create the ideal environment for the establishment and formation of alien species.

Aronson *et al*. (2016) introduced a conceptual framework for comprehending the filtering processes that mould diversity of urban floras and faunas, consisting of hierarchically imposed filters through which species with appropriate traits can colonise or persist in a community. Consequently, the biota of cities are shaped by anthropogenic and biotic filters, as well as a hierarchical series of environmental filters that determine species composition at different spatial scales (Aronson *et al*., 2016); the direction and strength of the influences of these filters is different across taxonomic groups. These hierarchical series of filters, which influence species distributions in cities include: land use, regional climate, and biogeography; human mediated biotic interchange; the history of urban development and form; cultural and socio-economic influences; local human facilitation; and, the interactions of species. Aside from these filters, an important factor determining community assembly is the functional and life history traits of species (Morin, 2011).

Alberti *et al*. (2003) stated that urban areas are treated as homogenous entities by many ecological studies, which combine all anthropogenic factors into a single aggregated variable, despite urbanisation being multidimensional and highly unstable across space and time. Most studies consider urban areas as one land use type and consequently never consider categorising urban habitats into subunits or different land-use or land-cover types according to the structure, function or density of built-up areas (Godefroid and Koedam, 2007). Godefroid and Koedam (2007) further stated that very little attempts have been made to assess the relative influence of the types of built-up areas and land use on the patterns of biodiversity. In addition, trees have a high possibility of transforming landscapes with intense impacts on biodiversity and ecosystems services and can also dominate plant communities (Richardson and Rejmánek, 2011). Understanding the variation within urban floras is therefore vital to improve and maintain the ecosystem services they provide (Cilliers *et al*., 2013; Le Maitre *et al*., 2007; Lubbe *et al*., 2011; Savard *et al*., 2000).

The aim of this study was to determine tree species diversity patterns between several land-cover types in the WAMS fetch region and assess the influence of these land-cover types on tree diversity. This study set out specifically to (i) determine the Alpha, Beta and Gamma diversity (diversity quantification) of native and alien species of land-cover types, (ii) determine the tree species composition, as well as a possible distribution gradient of tree communities and (iii) compare the land-cover types in terms of indices based on tree counts and measurements. From this, it will be possible to make various recommendations regarding the appropriate and responsible management of urban and agricultural green spaces.

Materials and methods

5.1.1 Vegetation survey

As explained in detail in Chapter 3, the belt transect method (Kent, 2012) was used to sample the vegetation data. This method was chosen to accurately depict the size and abundance of tree species in a certain area (Table 5.1). In total 181 plots were sampled within the different land-cover types. Plant surveys were completed along a 50 x 5 m transect in each sample area (Chapter 3, Section 3.4). Species were classified as adults or saplings. All trees were measured to determine their crown diameter and basal area. Species were also classified as native or alien based on Germishuizen *et al*. (2006) and Glen and Van Wyk (2016).

5.1.2 Diversity quantification

Alpha (α) diversity is the local species pool of a land-cover type and is calculated as the mean number of species per transect:

$$\boldsymbol{\alpha = \frac{S}{C}}$$

Where, S is the total number of species in the land-cover type and C is the number of plots in the land-cover type.

Gamma (γ) diversity is the diversity of the regional species pool of the land-cover type and is expressed as the total number of species recorded for the land-cover type (Primack, 2002). Gamma diversity can be expressed as:

$$\boldsymbol{\gamma = \alpha \times \beta}$$

Beta diversity is a transition (acts as a bridge) from alpha (local) to gamma (regional) scale and can be interpret as a type of metric turnover or dissimilarity among sites. Beta (β) diversity represents the differences in species composition among the land-cover types (species turnover) and can be calculated as (Anderson *et al*., 2011):

$$\boldsymbol{\beta = \frac{\gamma}{\alpha}}$$

5.1.3 Species composition

5.1.3.1 Non-metric multidimensional scaling

The tree composition of each transect or plot within the different land-cover types were compared using non-metric multidimensional scaling (NMDS) with Primer 6 software (Clarke and Gorley, 2006). Tree frequency data was used to perform ordinations for adult and saplings combined, and adults only. Basal area and crown diameter were also considered in separate ordinations for adults to compare composition of tree densities and volume. Samples clustered based on Bray–Curtis dissimilarity depicting differences between sampling points in the ordination space, in terms of plant assemblages.

The stress value of an ordination is a measure of how well two points match or fit (Clarke and Gorley, 2006). For 2-dimensional ordinations, the stress value increases with decreasing dimensionality and increasing quantity of data. In the interpretation of these stress values, Clarke (1993) suggested that the following rule is used; (1) stress ≤0.05 represents an excellent depiction with no likelihood of misinterpretation, (2) stress value smaller than ≤0.1 represents a good ordination, (3) stress value smaller than ≤0.2 still provides an adequate ordination, but cross-checks with other techniques are recommended. Stress values that are larger than 0.2 are placed randomly and bear very little relation to the original similarity ranks. Simper (analysis of similarity) was also done in PAST 3 (Hammer *et al*., 2001) to indicate the contribution of each species towards the similarity or dissimilarity between samples (Addendum D).

5.1.3.2 Detrended Correspondence Analysis

Detrended Correspondence Analysis (DCA), with default settings, in Canoco version 5 (Ter Braak and Šmilaurer, 2012) was applied to the dataset to determine species distributions in tree communities. DCA is an indirect ordination method, due to the fact that only the variability among species data is analyzed, without using any environmental data (Kent and Coker, 1992). For the DCA ordination, only the species containing more than five individuals were included during the analysis, to obtain a clear depiction of the species composition based on common species.

5.1.4 Diversity assessment

5.1.4.1 Diversity indices

Species diversity can be divided into three main categories; (1) species abundance models, (2) species richness indices and (3) indices build on the proportional abundance of species (Magurran, 1988; Magurran, 2004). The species abundance models illustrates the distribution of species abundances (in other words, how evenly the species are distributed), for example Pielou's evenness, while the species richness indices evaluate the number of species in a sampling unit, for example Menhinick's or Margalef's species richness indices, and diversity indices based on the proportional abundance of species include the Simpson and Shannon-Wiener diversity indices (Magurran, 1988).

Frequency data was used to calculate diversity indices with Primer 6 software (Clarke and Gorley, 2006). The various diversity variables and indices used in this study included species richness (S), total individuals (N), and the indices Margalef's species richness (d), Pielou's evenness (J'), Shannon-Wiener (H) and Simpson's diversity (D) (Clarke and Gorley, 2006).

Both Margalef's species richness and Pielou's evenness is highly sensitive to sample size (Warwick and Clarke, 1995); whereas Shannon's index is sensitive to both the number of individuals per species and species richness (Keller, 2002). This index also makes the assumption that individuals are randomly sampled from an extensive or large population and that all species are included in the sample (Kent and Coker, 1992). Simpson's index takes into account both species richness and evenness. Values range between zero and one for this index. A more diverse community is indicated by a higher value (Clarke and Gorley, 2006).

5.1.4.2 Tree dimensions

Tree measurements were included in the study to determine the size and relative age of trees. These measurements can be used to calculate tree volume and densities, as well as establish population structure of tree species. Height and crown diameter normally depict tree size, while girth or circumference can be used to estimate age. Basal area was calculated by converting the stem circumference to area. This was calculated as:

$$\mathbf{A} = \mathbf{C}^2/(4\,\boldsymbol{\pi})$$

Where A is the area, C the circumference of the measured stem and $\boldsymbol{\pi}$ is 3.1416.

Crown diameter or average crown spread was determined using the cross-method:

$$\frac{(\boldsymbol{longest\ spread} + \boldsymbol{longest\ crossspread})}{\mathbf{2}}$$

5.1.5 Statistical analysis

The species data collected for each of the ten land-cover types were analysed in terms of total (adult and sapling), adult (sapling data excluded), indigenous (adult and sapling), adult indigenous, alien (adult and sapling) and adult alien species. Adult data included crown diameter and basal area measurements for all adult tree species. The data showed relation or dependence, and did not show a normal distribution, which is normal for data obtained through counting. Therefore, a linear mixed model (LMM) was applied (Bolker *et al*., 2009; Noël *et al*., 2011). LLMs were performed on the dataset in SPSS version 21 (IBM, 2012) software package (Hancock and Mueller, 2010), using PostHoc Tukey B settings, to test for overall significant differences in index values between land-cover types.

The data set is quite extensive and d-values (effect size) instead of p-values are reported. Ellis and Steyn (2003) found that as data sets accumulate, various significant statistical tests are likely to display smaller p-values; for this reason, this study reports effect size (Cohen's d-values). Consequently, effect size can report practically significant relationships between variables and indicates the difference between two means, independent of unit and sample size, because effect size relates to the distribution of the data (Ellis and Steyn, 2003). Cohen (1988) gives the following guidelines for the interpretation of the effect size: (a) small effect: $d>0.2$, (b) medium effect: $d>0.5$ and (c) large effect: $d>0.8$.

Therefore, data with $d \geq 0.8$ is considered as practically significant difference between two means, since it is the result of a difference having a large effect (see Addendum C for effect sizes). A scoring system was devised to compare land-cover types in terms of the significant differences of their tree diversity and dimensional measures due to the extensive statistical tests. For each specific measure, every land-cover type was compared with every other land-cover type to determine whether it had higher or lower values that were significantly different at $d \geq 0.8$. A land-cover type was scored based on the number of times it showed significantly higher or lower values than other land-cover types (example Table 5.2). In the case of alien species diversity, a significantly lower means was considered ideal, seeing that high numbers of alien species are normally considered undesirable.

5.2 Results

5.2.1 Species diversity and composition

A comparison of land-cover types (Table 5.1) revealed that gardens have the highest total tree diversity (gamma-diversity). Gardens also had the highest number of alien tree species and the lowest number of indigenous species. Whereas, ridges (considered as natural area) had the highest number of indigenous species and the lowest number of alien species (Table 5.1). Furthermore, the overall alien species diversity is higher in urban or cultivated areas than more natural areas, where the indigenous species diversity is much higher.

Table 5.1. Gamma diversity of total species, alien species and indigenous species for land-cover types.

Land-cover type	Total number of species	Number of alien species	Number of indigenous species
Gardens	82	73	9
Streets	51	41	10
Ridges	45	4	41
Hillsides	42	3	39
Riparian areas	41	25	16
Urban open spaces	40	22	18
Plantations	31	15	16
Grasslands	28	5	23
Sandy areas	26	5	21
Roadsides	25	13	12
Total for WAMS fetch region	**169**	**114**	**55**

Hillsides had the highest alpha-diversity (a mean of approximately 13 species per transect), followed by ridges (a mean of 11 species per plot) (Figure 5.1). In addition, grasslands and sandy areas had a relatively high alpha-diversity, but low gamma-diversity; indicating that even though fairly high numbers of species may occur per sample plot, the cumulative richness was low. This suggests low turnover and therefore low beta diversity (Figure 5.2). In contrast, gardens had low alpha-diversity (a mean of approximately seven species per plot), but had a high gamma-diversity (a total species diversity of 82 species), which suggests a high-turnover of species between different gardens, resulting in a high beta diversity (Figure 5.2). Hillsides had a high alpha-diversity, but a lower gamma-diversity (a total species diversity of approximately 42 species) and beta diversity (Figure 5.2).

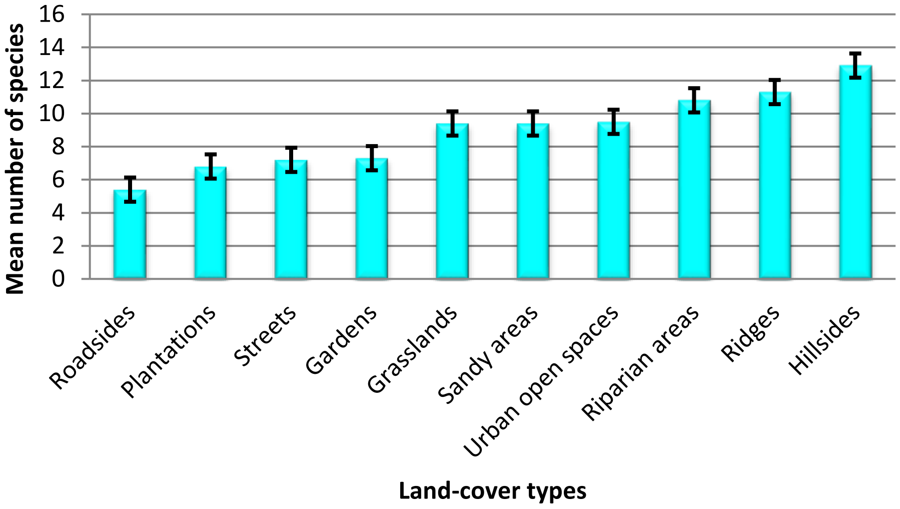

Figure 5.1. Alpha diversity, indicated as the mean number of species per transect for each of the land-cover types in WAMS fetch region

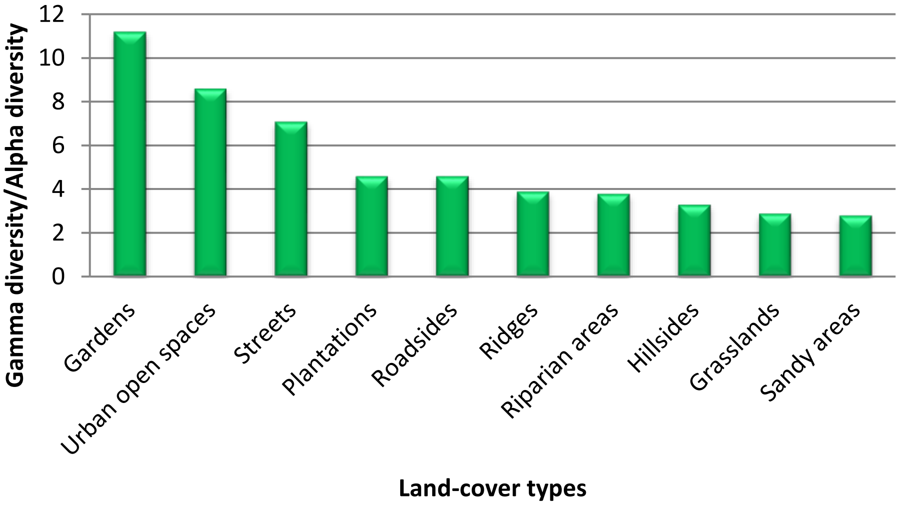

Figure 5.2. Beta diversity for each of the land-cover types in WAMS fetch region

Gardens and urban areas had much higher beta diversity than the more natural areas (grasslands, hillsides, ridges and sandy areas) (Figure 5.2). This was further supported by a comparison of the species composition between the different land-cover types, by means of NMDS ordination (Figure 5.3 A). The stress value of the ordination was lower than 0.2, meaning that the ordination was satisfactory, but that certain groupings were less clear. From the ordination it is deduced that the more natural areas (Group 1 – small circle) had a lower beta-diversity as opposed to urban areas like gardens and streets (Group 2 – big circle). This is evidenced by natural areas forming denser clusters, while the urban area plots appeared more dispersed due to a significant variation ($p=0.0078$; $p<0.05$) in the species composition per sample plot (Figure 5.3 A). Furthermore, the NMDS ordination also indicated a similarity in species composition of those land-cover types grouped close together (Figure 5.3 A). In the two groupings (Figure 5.3 A), the extremes in assemblages are formed by gardens (urban areas) and ridges. In gardens the species *Cestrum laevigatum*, *Ligustrum lucidum* and *Melia azedarach* is responsible for these differences, while *Diospyros lyciodes*, *Pavetta zeyheri* and *Vangueria infausta* contribute the most in ridges. Figure 5.3 B indicated that there is a similarity in the species composition regarding basal area of gardens and streets, ridges and hillsides, as well as the remaining land-cover types – three groups can be distinguished. This is also true for Figure 5.3 D, the total species composition, however in Figure 5.3 C groupings are not clearly visible.

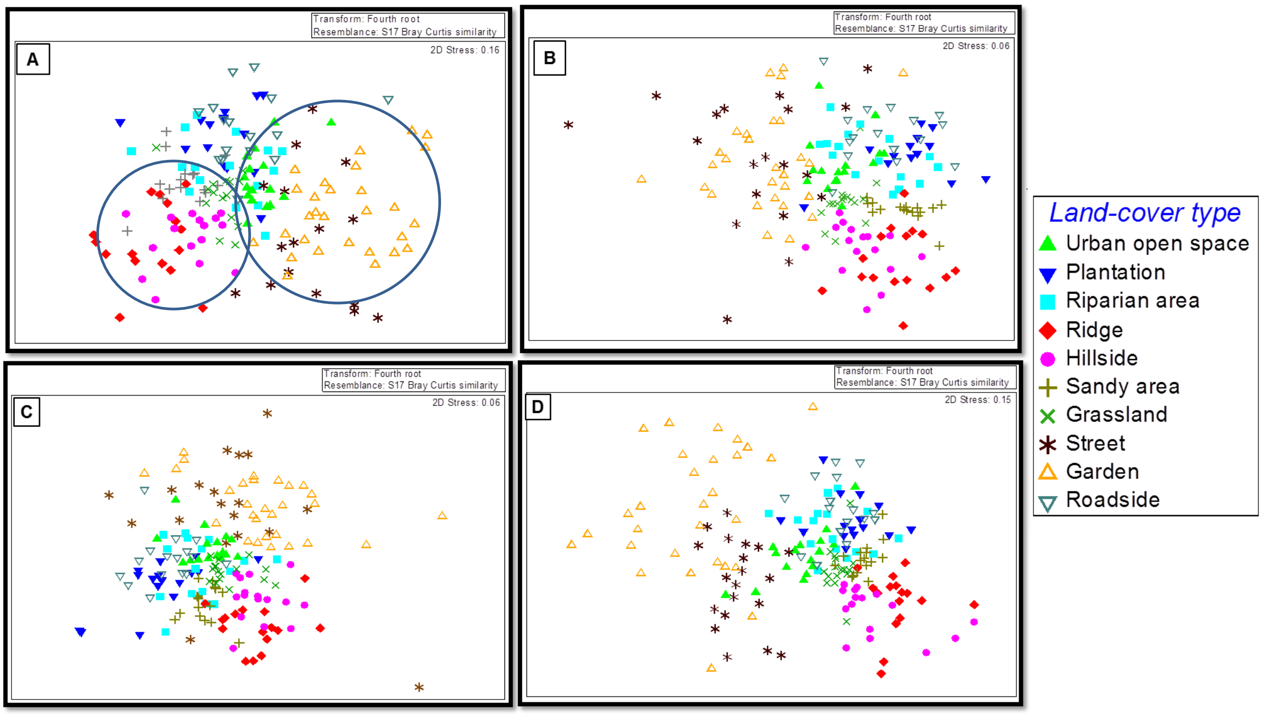

Figure 5.3. NMDS ordination of the species composition (A – adult trees, B – basal area, C – crown diameter, D – adult and sapling) for transects of all the land-cover types in WAMS fetch region

In the DCA symbols represents specific species or transects of similar land-cover types (Figure 5.4). The distances between points on the graph are an estimation of the degree of similarity between plots and subsequent species.

The graph indicates that indigenous species such as *Grewia flava*, *Searsia pyroides* and *Vangueria infausta* are associated with ridges, hillsides, grasslands and sandy areas, while alien species such as *Celtis australis*, *Melia azedarach* and *Ligustrum lucidum* are associated with streets, gardens, plantations and riparian areas. Furthermore, there is a clear relationship in the species distribution of plantations, riparian areas and roadsides, while urban open spaces and streets have similar types of distributions. In addition, grasslands, sandy areas, hillsides and ridges (all considered as natural areas) have a similar type of species distribution, while gardens have a unique type of distribution. Five types of species assemblages can be recognised: gardens (with their own unique type of species as a result of horticulture), grasslands (flat topography), hills (includes ridges with undulating topography), invasive (streets and urban open spaces) and urban (plantations, riparian, roadside).

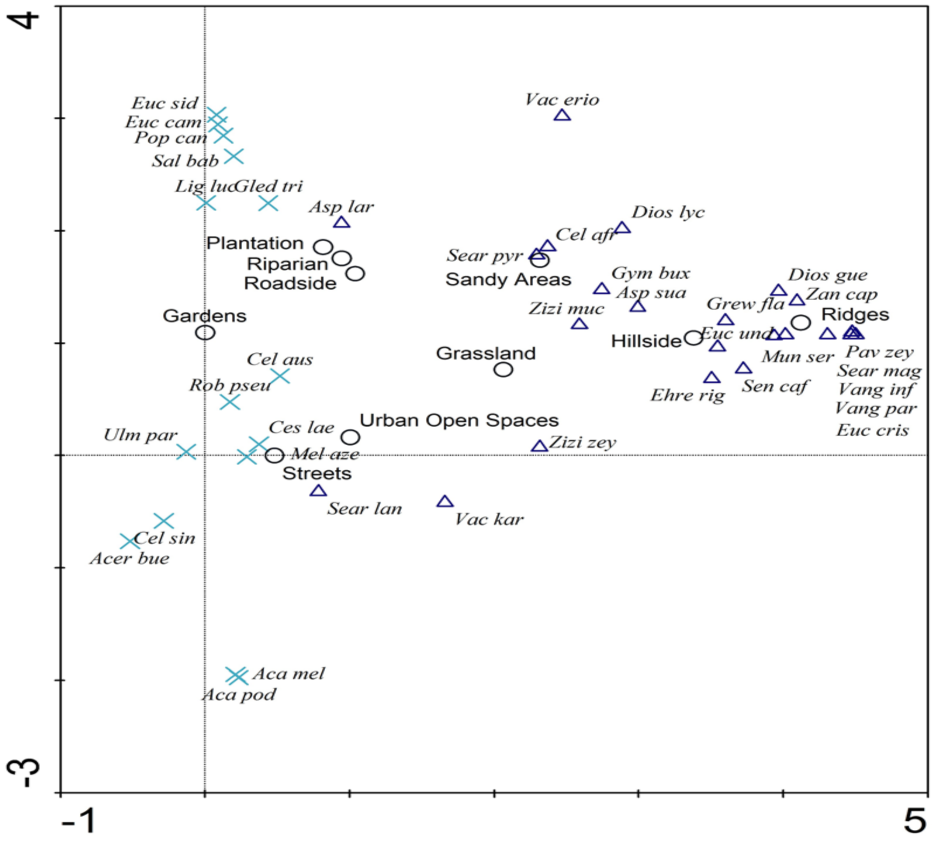

Figure 5.4. Detrended Correspondence Analysis groupings of all the different land-cover types of WAMS fetch region. Triangles indicate indigenous species, while crosses indicate alien species. Land-cover types are indicated by circles (Aca mel, *Acacia melanoxylon*; Aca pod, *Acacia podalyriifolia*; Acer bue, *Acer buergerianum*; Asp lar, *Asparagus laricinus*; Asp sua, *Asparagus suaveolens*; Cel afr, *Celtis africana*; Cel aus, *Celtis australis*; Cel sin, *Celtis sinensis*; Ces lae, *Cestrum laevigatum*; Dios gue, *Diospyros lycioides* subsp. *guerkei*; Dios lyc, *Diospyros lycioides* subsp. *lycioides*; Ehre rig, *Ehretia rigida*; Euc cam, *Eucalyptus camaldulensis*; Euc sid, *Eucalyptus sideroxylon*; Euc cris, *Euclea crispa*; Euc und, *Euclea undulata*; Gle tri, *Gleditsia triacanthos*; Grew fla, *Grewia flava*; Gym bux, *Gymnosporia buxifolia*; Lig luc, *Ligustrum lucidum*; Mel aze, *Melia azedarach*; Mun ser, *Mundulea sericea*; Pav zey, *Pavetta zeyheri*; Pop can, *Populus canescens*; Rob pseu, *Robinia pseudoacacia*; Sal bab, *Salix babylonica*; Sear lan, *Searsia lancea*; Sear mag, *Searsia magalismontana*; Sear pyr, *Searsia pyroides*; Sen caf, *Senegalia caffra*; Ulm par, *Ulmus parvifolia*; Vac erio, *Vachellia erioloba*; Vac kar, *Vachellia karroo*; Vang inf, *Vangueria infausta*; Vang par, *Vangueria parvifolia*; Zan cap, *Zanthoxylum capense*; Zizi muc, *Ziziphus mucronata*; Zizi zey, *Ziziphus zeyheriana*)

5.2.2 Diversity indices

Margalef’s species richness index indicated that gardens and hillsides had the highest species richness, while roadsides and plantations had the lowest (Figure 5.5 A). Furthermore, the majority of species in gardens were alien species, whereas hillsides comprised mostly of indigenous species. Pielou’s evenness did not show great variation between the different land-cover types (Figure 5.5 B), with gardens having the greatest evenness in comparison with the unevenness of riparian areas. Thus gardens are considered to have a more evenly distributed species composition. Shannon-Wiener’s diversity index varied considerably among the different land-cover types (Figure 5.5 C), hillsides, sandy areas and gardens had the highest diversity, while plantations and roadsides had the lowest diversity. The Simpson’s diversity index also showed noteworthy differences among the land-cover types (40% variation between gardens and plantations) (Figure 5.5 D).

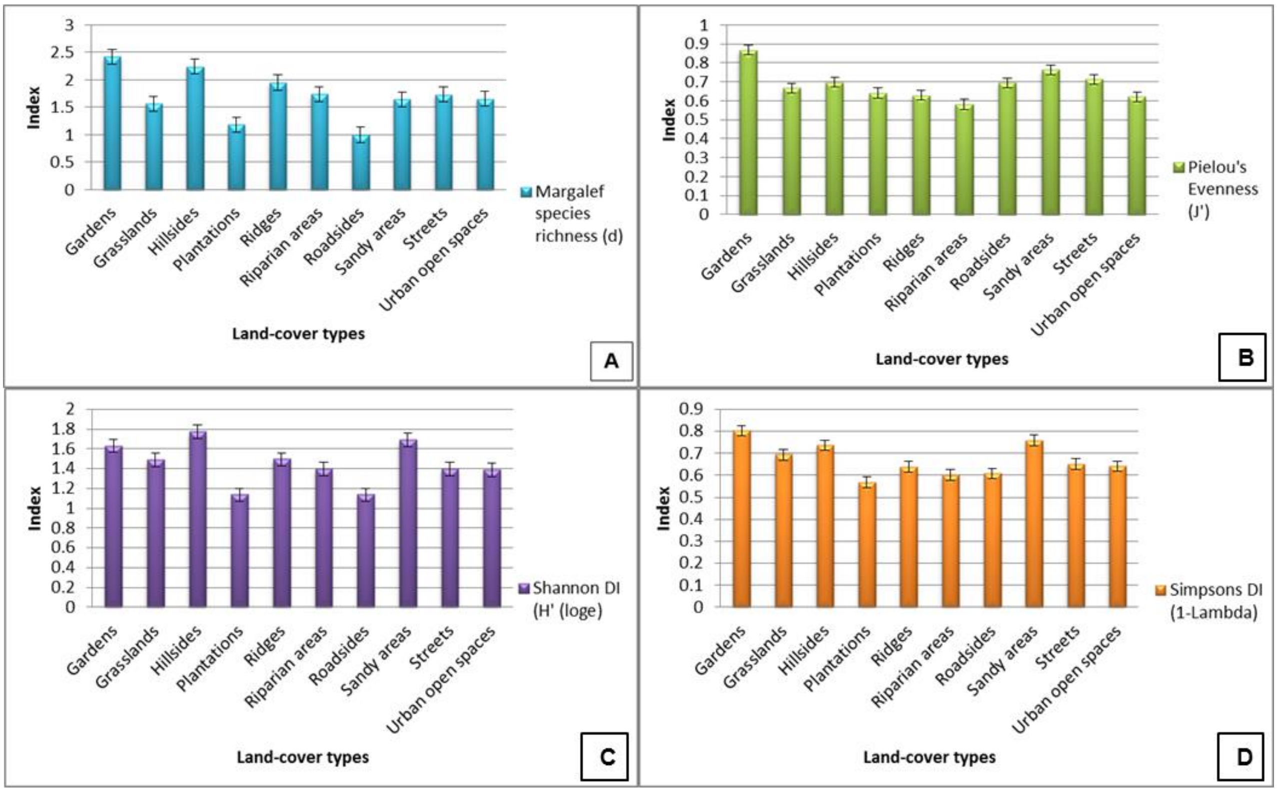

Figure 5.5. Comparative mean values of Margalef’s species richness index (A), Pielou’s evenness index (B), Shannon-Wiener species diversity index (C) and Simpson’s diversity index (D) for land-cover types

5.2.3 Performance scores

5.2.3.1 Total species

When adult and sapling data is considered, hillsides had significantly more species (d>0.8) than seven of the other nine land-cover types (Table 5.2). Overall it performed the best in terms of tree diversity indices compared to the other land-cover types. It is therefore the most divers, followed by ridges and sandy areas. Gardens and streets underperformed significantly (d>0.8) in the density of trees (number of individuals), but gardens had significantly higher evenness than the other eight land-cover types. Overall, roadsides had the poorest diversity, followed by plantations and streets.

Table 5.2. Total (adult and sapling) tree species diversity performance scores for land-cover types based on large effect sizes (d>0.8). Number of instances where a land-cover type performed significantly poorer (<) or better (>) than other land-cover types.

Diversity Index	Gardens	Grasslands	Hillsides	Plantations	Ridges	Riparian areas	Roadsides	Sandy areas	Streets	Urban open spaces
Species richness (S)	<3	<1 ; >2	>7	<6	>4	>4	<6	<1 ; >2	<4	<1 ; >3
Performance rating	-3	1	7	-6	4	4	-6	1	-4	2
Number of individuals (N)	<9	>3	>3	>2 ; <1	>3	<5	<6 ; >2	>1 ; >3	<8 ; >7	>3
Performance rating	-9	3	3	1	3	-5	-4	2	-7	3
Margalef species richness (d)	>3	<2 ; >1	>6	<6	>2	<1 ; >2	<8	<1 ; >2	>1	>1 ; >2
Performance rating	3	-1	6	-6	2	1	-8	1	1	1
Pielou's Evenness (J')	>8	<2	<1	<1	<1	<2	<1	<1 ; >3		<2
Performance rating	8	-2	-1	-1	-1	-2	-1	2	0	-2
Shannon Index (H)	>2	>2	>3	<4	-	-	<4	>3	-	<2
Performance rating	2	2	3	-4	0	0	-4	3	0	-2
Overall performance	**1**	**3**	**18**	**-16**	**8**	**-2**	**-23**	**9**	**-10**	**2**

5.2.3.2 Adult species

When only adult tree data were considered, hillsides, riparian areas and urban open spaces had significantly more species (d>0.8) than four of the other nine land-cover types (Table 5.3). Plantations and riparian areas had tree dimensions significantly greater than six and four of the other land-cover types respectively. Overall, riparian areas and urban open space performed best in terms of adult tree diversity and dimensions. These two land-cover types therefore have the most divers and best developed tree layer, followed by sandy areas. Gardens and streets underperformed significantly (d>0.8) in the density of trees (number of individuals), and plantations and street had significantly lower species richness and diversity than six of the other land-cover types. Overall, roadsides and street performed the poorest diversity in terms of adult tree diversity and dimensions.

Table 5.3. Adult tree species diversity performance scores for land-cover types based on large effect sizes (d>0.8). Number of instances where a land-cover type performed significantly poorer (<) or better (>) than other land-cover types.

Diversity Index	Gardens	Grasslands	Hillsides	Plantations	Ridges	Riparian areas	Roadsides	Sandy areas	Streets	Urban open spaces
Species richness (S)	-	<3	>4	<5	>2	>4	<5	>3	<4	>4
Performance rating	0	-3	4	-5	2	4	-5	3	-4	4
Number of individuals (N)	<8	>2	>3	>3	>2	>3	>2 ; <3	>2	<8	>2
Performance rating	-8	2	3	3	2	3	-1	2	-8	2
Margalef species richness (d)	>4	<4	>5	<6	>2	>3	<6	<1 ; >2	<2	>3
Performance rating	4	-4	5	-6	2	3	-6	1	-2	3
Pielou's Evenness (J')	>1	-	>1	<5	-	>1	-	>1	-	>1
Performance rating	1	0	1	-5	0	1	0	1	0	1
Shannon Index (H)	>2	<2	>4	<6	>2	>4	<6	>3	<4	>3
Performance rating	2	-2	4	-6	2	4	-6	3	-4	3
Basal Area	>2 ; <2	>2 ; <2	<7	>4	<6	>3	>4 ; <2	>3 ; <3	>3	>1
Performance rating	0	0	-7	4	-6	3	2	0	3	1
Crown Diameter	<4	>3 ; <1	>1 ; <5	>6	>1 ; <5	>4	<3	>2 ; <3	>3 ; <1	>2
Performance rating	-4	2	-4	6	4	4	-3	-1	2	2
Overall performance	**-5**	**-5**	**6**	**-9**	**6**	**22**	**-19**	**9**	**-13**	**16**

5.2.3.3 Total indigenous species

When adult and sapling data of indigenous tree species is considered, hillsides had significantly more species (d>0.8) than six of the other nine land-cover types (Table 5.4). Overall it performed the best in terms of tree diversity indices compared to the other land-cover types. It is therefore the most divers, closely followed by ridges, sandy areas and grasslands. Gardens and streets underperformed significantly (d>0.8) in the density of trees (number of individuals), but streets had similar evenness to five other land-cover types. Overall, gardens had the poorest indigenous diversity, followed by streets, roadsides and plantations.

Table 5.4. Total (adult and sapling) indigenous tree species diversity performance scores for land-cover types based on large effect sizes (d>0.8). Number of instances where a land-cover type performed significantly poorer (<) or better (>) than other land-cover types.

Diversity Index	Gardens	Grasslands	Hillsides	Plantations	Ridges	Riparian areas	Roadsides	Sandy areas	Streets	Urban open spaces
Species richness (S)	<9	>6 ; <1	>8	>1 ; <5	>6	>3 ; <4	>1 ; <6	>6 ; <1	>1 ; <7	>3 ; <4
Performance rating	-9	5	8	-4	6	-1	-5	5	-6	-1
Number of individuals (N)	<8	>5	>5	>1 ; <3	>4	>3	>2 ; <5	>3	<7	>2 ; <2
Performance rating	-8	5	5	-2	4	3	-3	3	-7	0
Margalef species richness (d)	<9	>6 ; <1	>8	>1 ; <4	>6	>2 ; <4	>1 ; <6	>6 ; <1	>1 ; <4	>2 ;<4
Performance rating	-9	5	8	-3	6	-2	-5	5	-3	-2
Pielou's Evenness (J')	<9	>1	>1	>1 ; <1	>1	>1	>1	>3	>1	>1 ; <1
Performance rating	-9	1	1	0	1	1	1	3	1	0
Shannon Index (H)	<9	>6	>6	>1 ; <4	>6	>1 ; <4	>1 ; <4	>6	>1 ; <4	>1 ; <4
Performance rating	-9	6	6	-3	6	-3	-3	6	-3	-3
Overall performance	**-44**	**22**	**28**	**-12**	**23**	**-2**	**-15**	**22**	**-18**	**-6**

5.2.3.4 Indigenous adult species

When only indigenous adult tree data is considered, hillsides, ridges, sandy areas and grasslands had significantly more species (d>0.8) than four of the remaining nine land-cover types (Table 5.5). Sandy areas had tree dimensions significantly more than six other land-cover types. Overall, sandy areas and hillsides performed best in terms of indigenous adult tree diversity and dimensions. These two land-cover types therefore have the most divers and best developed tree layer, followed by ridges and grasslands. Gardens, roadsides and streets underperformed significantly (d>0.8) in the density of trees (number of individuals), and gardens, roadsides and streets had significantly lower species richness and diversity than up to six other land-cover types. Overall, gardens, roadsides and plantations performed the poorest in terms of indigenous adult tree diversity and dimensions.

Table 5.5. Indigenous adult tree species diversity performance scores for land-cover types based on large effect sizes (d>0.8). Number of instances where a land-cover type performed significantly poorer (<) or better (>) than other land-cover types.

Diversity Index	Gardens	Grasslands	Hillsides	Plantations	Ridges	Riparian areas	Roadsides	Sandy areas	Streets	Urban open spaces
Species richness (S)	<6	>4 ; <1	>7	<5	>6	>3 ; <3	<6	>6	<6	>4 ; <3
Performance rating	-6	3	7	-5	6	0	-6	6	-6	1
Number of individuals (N)	<7	>6	>6	>1 ; <4	>6	>2 ; <4	<6	>6	<6	>3 ; <4
Performance rating	-7	6	6	-3	6	-2	-6	6	-6	-1
Margalef species richness (d)	<6	>4 ; <1	>8	<6	>6	>4 ; <2	<6	>5 ; <1	<6	>4 ; <3
Performance rating	-6	3	8	-6	6	2	-6	4	-6	1
Pielou's Evenness (J')	<6	>3	>4	<6	>4	>3	<3	>4	<6	>3
Performance rating	-6	3	4	-6	4	3	-3	4	-6	3
Shannon Index (H)	<6	>4 ; <1	>7	<6	>6	>4 ; <3	<6	>6	<6	>4 ; <3
Performance rating	-6	3	7	-6	6	1	-6	6	-6	1
Basal Area	<2	>2 ; <1	>2 ; <1	<3	<1	<1	<3	>8	-	<1
Performance rating	-2	1	1	-3	-1	-1	-3	8	0	-1
Crown Diameter	<6	>5 ; <1	>5 ; <1	<5	>3 ; <1	>1 ; <1	<5	>9	<3	>3 ; <3
Performance rating	-6	4	4	-5	2	0	-5	9	-3	0
Overall performance	**-39**	**23**	**37**	**-34**	**29**	**3**	**-35**	**43**	**-33**	**4**

5.2.3.5 Total alien species

When adult and sapling data of alien tree species is considered, hillsides, grasslands, ridges and sandy areas had significantly less alien species (d>0.8) than five of the other land-cover types (Table 5.6). Overall, gardens performed the best in terms of tree diversity indices compared to the other land-cover types, seeing that high alien diversity is regarded as bad thing. It is therefore the most divers, closely followed by streets, urban open spaces and riparian areas. Roadsides and urban open spaces underperformed significantly (d>0.8) in the density of trees (number of individuals). Overall, hillsides had the poorest alien diversity, followed by grasslands, ridges and sandy areas.

Table 5.6. Total (adult and sapling) alien tree species diversity performance scores for land-cover types based on large effect sizes (d>0.8). Number of instances where a land-cover type performed significantly poorer (>) or better (<) than other land-cover types.

Diversity Index	**Gardens**	**Grasslands**	**Hillsides**	**Plantations**	**Ridges**	**Riparian areas**	**Roadsides**	**Sandy areas**	**Streets**	**Urban open spaces**
Species richness (S)	<6	>6	>6	<4 ; >4	>6	<6	>4 ; <4	>6	<6	<6
Performance rating	-6	6	6	0	6	-6	0	6	-6	-6
Number of individuals (N)	<3 ; >2	>4	>6	<2	>6	<2	<5	>2	<3	<5
Performance rating	-1	4	6	-2	6	-2	-5	2	-3	-5
Margalef species richness (d)	<8	>6	>6	>4 ; <3	>4	>1 ; <6	>4 ; <3	>6	<6	>1 ; <6
Performance rating	-8	6	6	1	4	-5	1	6	-6	-5
Pielou's Evenness (J')	<8	>6	>6	>1 ; <4	>5	>1 ; <5	>4 ; <2	>5	<5	>1 ; <5
Performance rating	-8	6	6	-3	5	-4	2	5	-5	-4
Shannon Index (H)	<7	>6	>6	>2 ; <4	<5	<5	>4 ; <2	>5	<6	>1 ; <5
Performance rating	-7	6	6	-2	5	-5	2	5	-6	-4
Overall performance	**-30**	**28**	**30**	**-6**	**26**	**-22**	**0**	**24**	**-26**	**-24**

5.2.3.6 Adult alien species

When only alien adult tree data is considered, grasslands, hillsides, ridges and sandy areas had significantly less alien species (d>0.8) compared to six of the other land-cover types (Table 5.7). Plantations and riparian areas had tree dimensions significantly more than the other land-cover types. Overall, riparian areas and streets performed best in terms of alien adult tree diversity and dimensions. These two land-cover types therefore have the most divers and best developed alien tree layer, followed by gardens, urban open spaces and plantations. Grasslands, hillsides, ridges and sandy areas underperformed significantly (d>0.8) in the density of trees (number of individuals), and had significantly lower alien species richness and diversity than the other land-cover types. Overall, hillsides, ridges and sandy areas performed the poorest in terms of adult alien tree diversity and dimensions, closely followed by grasslands.

Table 5.7. Adult alien tree species diversity performance scores for land-cover types based on large effect sizes (d>0.8). Number of instances where a land-cover type performed significantly poorer (>) or better (<) than other land-cover types.

Diversity Index	Gardens	Grasslands	Hillsides	Plantations	Ridges	Riparian areas	Roadsides	Sandy areas	Streets	Urban open spaces
Species richness (S)	<6	>6	>6	>4 ; <4	>6	<6	>3 ; <4	>6	<5	<6
Performance rating	-6	6	6	0	6	-6	-1	6	-5	-6
Number of individuals (N)	>2 ; <4	>6	>6	<8	>6	<5	>1 ; <4	>6	>1 ; <4	>1 ; <4
Performance rating	-2	6	6	-8	6	-5	-3	6	-3	-3
Margalef species richness (d)	<7	>6	>6	>4 ; <4	>6	>1 ; <5	>2 ; <4	>6	<5	<6
Performance rating	-7	6	6	0	6	-4	-2	6	-5	-6
Pielou's Evenness (J')	<6	>6	>6	>2 ; <4	>6	<4	>1 ; <4	>6	<4	<5
Performance rating	-6	6	6	-2	6	-4	-3	6	-4	-5
Shannon Index (H)	<6	>6	>6	>4 ; <4	>6	<5	>3 ; <4	>6	<6	<6
Performance rating	-6	6	6	0	6	-5	-1	6	-6	-6
Basal Area	>3 ; <4	>4	>5	<7	>5	<7	>2 ; <3	>5	<5	>2
Performance rating	-1	4	5	-7	5	-7	-1	5	-5	2
Crown Diameter	>4 ; <4	>6	>6	<7	>6	<7	>3 ; <5	>6	<7	>3 ; <4
Performance rating	0	6	6	-7	6	-7	-2	6	-7	-1
Overall performance	**-28**	**40**	**41**	**-24**	**41**	**-38**	**-13**	**41**	**-35**	**-25**

5.2.3.7 Overall diversity performance

This was determined by adding up the performance rating of each of the total, indigenous and alien species. A score higher than 20 (purple) was considered meaningful and below -20 (green) unsatisfactory in terms of diversity (Table 5.8). Considering the sum of the overall diversity performance scores, hillsides, sandy areas and ridges had the highest diversity, with grasslands following close behind. Urban open spaces and riparian areas had moderate diversity performance scores, with only two unsatisfactory scores. Roadsides and plantations had more negative performance scores, with only two unsatisfactory scores. Streets and gardens had the lowest overall diversity scores, with gardens having the most unsatisfactory scores.

Table 5.8. Overall performance score of the different land-cover types.

	Gardens	Grasslands	Hillsides	Plantations	Ridges	Riparian areas	Roadsides	Sandy areas	Streets	Urban open spaces
Total	1	3	18	-16	8	-2	-23	9	-10	2
Adults	-5	-5	6	-9	6	22	-19	9	-13	16
Indigenous Total	-44	22	28	-12	23	-2	-15	22	-18	-6
Indigenous Adults	-39	23	37	-34	29	3	-35	43	-33	4
Alien Total	-30	28	30	-6	26	-22	0	24	-26	-24
Alien Adults	-28	40	41	-24	41	-38	-13	41	-35	-25

5.3 Discussion

The main theme of this chapter was to determine diversity patterns, as well as quantification of the differences in alpha, beta and gamma diversity between the different land-cover types, especially the differences between urban and natural areas. Tree species diversity varied considerably among the land-cover types of the WAMS fetch region, with gardens (urban areas) having the highest gamma diversity. This was substantiated in a study by Davoren (2009), who found that homegardens had the highest gamma diversity in Ganyesa, a rural settlement. Similarly, a study by Knapp *et al*. (2008) in Germany, found that species richness was significantly higher in urbanised, than in agricultural or semi-natural areas. However, gardens (in this study) had the third lowest alpha diversity; even though gardens had the highest gamma diversity. This suggests that gardens had high species turn-over or beta diversity (Figure 5.2), whereas the fairly high gamma diversity in natural areas can be ascribed to South Africa's rich indigenous flora (Germishuizen *et al*., 2006).

Alpha diversity was higher in the more natural land-cover types (rangelands) outside urban areas, while gardens had a lower alpha diversity. In contrast, a study conducted by Smith *et al*. (2006) indicated that the alpha diversity of gardens and natural areas are similar, while a study by Kent *et al*. (1999) found that residential areas tend to have a higher alpha diversity than natural areas. The lower alpha diversity in urban areas can be explained by the high number of alien species, since alien species are one of the main causes behind biological homogenization and biodiversity loss due to urbanization, within urban areas (Savard *et al*., 2000). As would be expected, the natural areas were mostly dominated by indigenous and native species, while the flora inside urban areas is attributed to a high number of alien and naturalized species.

However, Kühn and Klotz (2006) found that urban areas are capable of supporting a high native, as well as high alien species richness. The opposite was true for this study, as most of the land-cover types in urban areas contained high number of alien species and relative low native diversity levels (Table 5.1). Kent *et al*. (1999) stated that different land-cover types in urban areas influence plant species composition and distribution patterns. This correspond with this study, since NMDS analysis revealed two distinct groups (Figure 5.3 A) regarding species composition; DCA analysis reveal species distribution patterns along a gradient, with more alien species distributed in urban areas and gradually more native species towards natural land-cover types. A study by Aronson *et al*., (2015) indicated this trend, where indigenous plant species decreased and alien species increased with increasing urban land cover.

The effect size of the various diversity indices clearly show that indigenous diversity or diversity characterized by indigenous species, has a much higher or better performance than alien diversity or urban areas and their diversity. A study by Omoro *et al*. (2010) substantiated this, where tree species diversity, richness and similarity of exotic and indigenous species in a Kenyan forest was analysed. The indigenous forests showed higher diversity than the exotic or alien forests, which was true in this study, where indigenous diversity performed better in the more natural areas. Higher diversity performance scores for indigenous species are beneficial for the environment, seeing that Pimm *et al*. (1995) found that all components of biodiversity are negatively affected by invasive alien plants.

5.4 Conclusion

This chapter provides a snapshot of tree species diversity in urban and agroecosystems. Determining alpha, beta and gamma diversity, tree species composition or distribution as well as a comparison between the different land-cover types in terms of diversity indices based on tree count and measurements included the main objectives for this study. Different land-cover types have an influence on tree species diversity, with urban land-cover types having higher alien tree diversity and natural land-cover types a higher indigenous diversity. Urban areas are controlled by human intervention and urban residents or municipalities who select species to be introduced, planted or maintained in these areas, while natural areas have less or no human intervention. These contrasting species pools are responsible for the variation in alpha, beta and gamma diversity among the various land-cover types – with gardens having a higher gamma diversity and natural areas higher alpha diversity. Urban areas have a seemingly high diversity; however this is mainly characterised by alien species; which can have a long-term negative effect on entire landscapes. This study contributes to our knowledge of tree diversity in various land-covers and can aid in the better management of these areas, specifically pertaining to the invasion of alien species. This will be discussed in more detail in Chapter 6.

CHAPTER 6

CULTIVATED URBAN AREAS AS A SOURCE OF ALIEN TREES ALONG A SOCIO-ECONOMIC GRADIENT

6.1 Introduction

Urbanisation and its associated effects have an immense impact on biodiversity through the modification of existing ecosystems, ultimately creating unique urban environments (Niemelä *et al*., 2010; Williams *et al*., 2009). However, invasive alien organisms are considered as one of the major threats to global biodiversity and all components of biodiversity are negatively affected by invasive alien plants (Pimm *et al*., 1995).

According to Levine and D'Antonio (2003), the accidental or intentional movement of species by humans has accelerated drastically these past few decades. These movements have become more frequent and global, with species far removed from their natural ranges. However, in the last few decades, tree invasions especially have increased in importance because of larger areas being invaded, more invasive tree species, different types of environmental impacts and major management challenges (Richardson *et al*., 2014). Since the 17th century, alien trees have been widely introduced and planted in South Africa (Richardson and Rouget, 2002). Even though invasive trees have an increasing and substantial impact on biodiversity, human livelihoods and the functioning of ecosystems (Richardson *et al*., 2014); many species are still useful and is usually the reason why these species were originally introduced and distributed. Some of the main reasons for introductions include: ornamental horticulture, agroforestry, urban greening, food production and especially forestry - due to this there is vast areas and plantations of alien trees dominating many regions of the world (Richardson *et al*., 2014).

Ornamental plants, also known as floriculture, is plants that are grown for their decorative purposes (Foxcroft *et al*., 2008) and are often used in gardens and urban landscape design. These plants are easy to obtain (Donaldson *et al*., 2014b; Rundel *et al*., 2014) and have been widely planted across the globe, as well as in South Africa for their decorative and ecosystem services. Services provided by ornamentals include dune stabilisation (Donaldson *et al*., 2014b), agroforestry, erosion control and aesthetic value (Rundel *et al*., 2014). The majority of ornamental plants are selected for their easy cultivation characteristics and reproductive traits – early flowering age, high seed sets and long flowering times (Anderson *et al*., 2006; Donaldson *et al*., 2014a). However, some ornamental plants have the ability to rapidly become invasive, such as *Acacia elata*, *Robinia pseudoacacia*, *Campiloclium* (Pompom weed) and various other species like Pine trees (Donaldson *et al*., 2014b; NEMBA, 2014; Rundel *et al*., 2014).

Invasive species can be defined as a subset of naturalised species, which produce very large numbers of reproductive offspring and are capable to spread over a large area due to dispersal or movement methods (Richardson and Pyšek, 2004). Introduced species, either intentional or unintentionally, that have become naturalised have the ability to displace other species from ecosystems (Aronson *et al*., 2007; Erlich and Wilson, 1991). Furthermore, naturalised species are capable to reproduce and spread over vast areas, without the direct assistance of humans (Richardson and Pyšek, 2004). These invasive species are a serious threat to biodiversity and ecosystem services, due to the fact that they displace native species and penetrate various landscapes (Aronson *et al*., 2007; Donaldson *et al*., 2014a). Invasive species are regulated by the Alien and Invasive Species Regulations of the National Environmental Management Biodiversity Act (No. 10 of 2004), also known as NEMBA. The NEMBA list contains 1124 invader species in four categories, of which plant species contribute 381 of the invasive species (NEMBA, 2014).

Henderson (2001) suggested a proposed list of invasives to illustrate why alien trees should be monitored in cities, seeing that naturalised species are capable of reproducing and spreading without the assistance of humans (Richardson and Pyšek, 2004). Hence gardens are a major source or place of origin for naturalised species and possibly invasion (Davoren, 2009; Lubbe *et al*., 2011). Masses of seeds are produced in gardens and through there efficient seed distribution mechanisms can spread beyond the yard boundary into neighbouring yards or open spaces (Aronson *et al*., 2007; Faulkner *et al*., 2016). We don’t want to reach a point were weed and aliens take over, because all components of biodiversity are negatively affected by invasive alien plants (Pimm *et al*., 1995). Furthermore, socio-economic status (SES) influences diversity; with the luxury effect (Hope *et al*., 2003) increasing the diversity of gardens in higher SES groups (Cilliers *et al*., 2012). Studies in the WAMS fetch region indicated that diversity is enhanced by exotic species in Potchefstroom (Davoren, 2009; Lubbe *et al*., 2010, 2011). Cilliers *et al*., (2012) also indicated that diversity is an important ecosystems service in poor areas. So the question arises whether SES hampers the current regulation processes of alien invasive species?

This chapter investigates alien tree species, more specifically alien tree species composition of various urban cultivated and agricultural land-cover types. The main aim was to determine the alien tree species diversity and composition along a socio-economic gradient, as well as establish the main source of alien trees within the different land-cover types. Furthermore, this study set out to: (i) determine the alien tree species composition for each of the land-cover types; (ii) determine whether these alien tree species are cultivated or naturalized, as well as which land-cover type act as main source of alien trees; (iii) compare alien species along a socio-economic gradient; and (iv) determine or compare tree population dynamics of alien and indigenous tree species.

6.2 Materials and methods

6.2.1 Vegetation survey

The belt transect method (Kent, 2012) was used to gather floristic and structural data (Chapter 3, section 3.4). This method was chosen to generate data to investigate the structure and composition of alien woody species in land-cover types (Table 6.1). In total 181 plots were sampled within the different land-cover types. Plant surveys were completed along a 50 x 5 m transect in each sample area (Chapter 3, Section 3.4). Species were classified as adults or saplings, all adult trees were measured to determine their density. Species were also classified as alien or invasive alien based on Glen and Van Wyk (2016) and NEMBA (2014).

6.2.2 Data selection

6.2.2.1 Alien data

The original database was considered to extract the alien woody species occurring in each of the land-cover types. A complete list of alien species (Addendum A) was compiled and this list was refined to indicate the number of individuals occurring in cultivated and natural areas and whether these alien species are considered invasive or not for South Africa (CARA, 2001 and NEMBA, 2014). The "flagged" alien species were further reduced to only the aliens that had high number of individuals in both cultivated and natural areas (Figure 6.1).

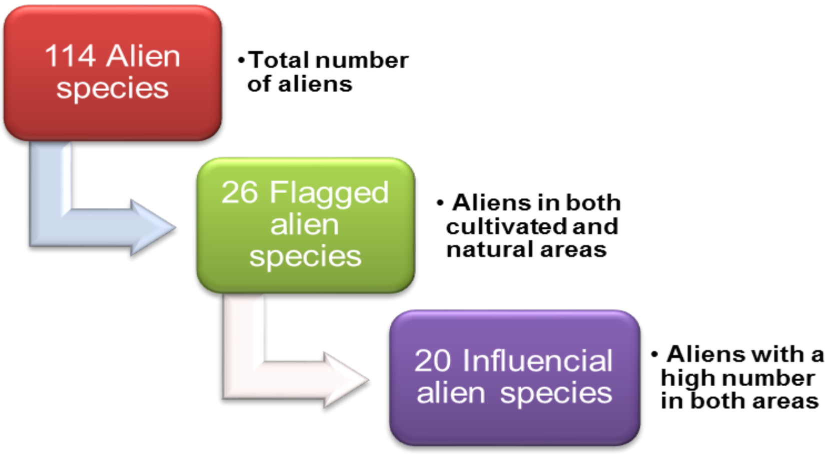
114 Alien species
•Total number of aliens
26 Flagged alien species
• Aliens in both cultivated and natural areas
20 Influencial alien species
• Aliens with a high number in both areas

Figure 6.1. Selection process to determine which alien species to use in analysis

For the purpose of this study, a cultivated area is considered as a land-cover type where alien trees are planted (gardens, plantations and streets), in contrast to areas where alien plants occur naturally (rangelands, riparian areas, roadsides and urban open spaces). Grasslands, hillsides, ridges and sandy areas contained five or less alien species per land-cover type and were grouped together as rangelands for this chapter.

Species occurring in both cultivated and non-cultivated areas were flagged; these 26 species were sorted into adults and sapling individuals per land-cover type. Species which had high richness in both cultivated and non-cultivated areas (more than five individuals in an area) were selected for further analyses. The main methods of dispersal and type of seed for these species were identified from Henderson (2001), Bromilow (2010) and Encyclopedia of Life (2016).

6.2.2.2 Garden data

Garden plant data (32 plots), each belonging to a different socio-economic status (SES) class, were randomly selected of a 100 separate garden plots, from Lubbe *et al*. (2011). Alien species were divided into four different groups, namely declared invasives, partially declared invasives, naturalised (not declared invasives) and cultivated (not declared invasives). Various definitions for these terms are found in the literature (Henderson, 2001; Richardson and Pyšek, 2004; Richardson *et al*., 2000), but for the purpose of this study declared invasive aliens are listed on the CARA and NEMBA lists of invasive species. Partially declared aliens are those species that occurred on either CARA or NEMBA lists, naturalised aliens are those species that occurred in both cultivated and natural areas, but are not listed on the invasive list, whereas cultivated aliens are all the non-native species that are grown in gardens.

Determination of socio-economic status (SES) classes was based on a study by Lubbe *et al*. (2010), where the percentage unemployment (per household), household size (five or more people per household), number of rooms (two or less rooms per household), schooling status (percentage of people above 18 years with no schooling per household) , access to basic services (no access to pipe water in household) and monthly income were combined to determine socio-economic status (Table 6.1). Class 1 was defined as the economically most stressed household (lowest SES), class 3 would have average SES and class 5 would have the highest SES (Lubbe *et al*., 2010).

Table 6.1. Principle Component 1 loadings considered in the demarcation of SES classes for WAMS fetch region (bold values show largest weights for interpretation of principle component scores) (Davoren, 2017).

	Component 1
Unemployment (% unemployed household members)	**0.891169**
Household size (% households with 5 or more persons)	**0.945434**
Number rooms (% households with 1 or 2 rooms only)	0.522844
Basic services (% households with piped water > 200 m away)	0.093692
Schooling Status (% individuals with no schooling per household)	0.399193
Monthly Income	-0.858129

6.2.3 Data analysis

Non-metric multidimensional scaling (NMDS) graphs were constructed with Primer 6 software (Clarke and Gorley, 2006) to indicate the total alien species composition across land-cover types. NMDS multivariate ordinations were also used to indicate the alien species composition of the four different groups of aliens (declared, partially declared, naturalised and cultivated) and also to indicate the species composition within each of the different SES classes. Simper (analysis of similarity) was also done in PAST 3 (Hammer *et al*., 2001) to indicate the contribution of each species towards the similarity or dissimilarity between samples (Addendum D).

6.2.4 Population structure

To assess the population structure of the alien tree species, seven species with the largest populations were selected. These species were selected after removing all species that do not occur in 10 % or more of the sample plots and has more than a hundred adult individuals. To compare the alien species population dynamics with that of native species, seven indigenous tree species populations were also selected. Two variables for every species was analysed, namely height and basal area.

To determine the size-class distribution (SCD) as well as the frequency intervals for the population graphs of each species, Sturge's rule (Equation 6.1) was applied (Scott, 2009):

$$K = 1 + 3.322(log_n)$$

Equation 6.1

Where K is the number of classes and n is the size of the data set (number of individuals or observations).

The size of each class was determined by dividing the range of the SCD by K. The stability of tree populations between successive size-classes was calculated using quotient analysis (Meyer, 1952). Graphically displayed quotients were interpreted according to Botha *et al*. (2004) and Shackleton (1993), where stable populations are indicated by constant quotients and fluctuating quotients were interpreted as instability within the specific population.

The likelihood that any two trees within a population originate from the same size-class was investigated by Simpson's index of dominance (SDI) (Equation 6.2); in other words, SDI measures the evenness of occupation of size classes (Botha *et al*., 2004). Values below 0.1 shows that size classes are more evenly distributed, while values above 0.1 reveal that size frequency is steeper than would be expected from an exponentially declining population.

$$C = \frac{1}{N(N-1)} \sum_{i=1}^{k} N_i \, (N_i - 1)$$

Equation 6.2

N is the total number of plants per year, Ni is the number of plants in class i, and k is the number of size-classes (Botha *et al*., 2004).

Wiegand *et al*. (2000) reported that various indices did not sufficiently describe asymmetrical size distributions. Consequently they developed the Permutation Index (PI), which calculates the degree of deviation from a monotonic decline or from an inverse-J curve SCD. The combination of SDI and PI could better describe size distribution within a population and was based on the assumption that an "ideal" undisturbed population should represent a monotonic decline. In the case of the Permutation Index (Equation 6.3), rank is equivalent to enumerating size-classes from the smallest class, which should show the highest frequency, to the largest class, which should show the lowest frequency. In a monotonically declining population PI is equal to zero (P=0), while in a discontinuous population, where larger individuals show a higher frequency than a previous size-class, the rank of that size-class has deviated from enumeration and PI is greater than zero (P>0) (Botha *et al*., 2004; Venter and Witkowski, 2010).

$$P = \sum_{i=1}^{k} |J_i - i| ; J_i = 1, 2, \dots \dots, k$$

Equation 6.3

Ji is the rank of size-class i (i = 1 for the plants occupying the smallest size-class), with the highest rank (Ji = 1) given to the most frequent size-class, and k is the number of size-classes (Wiegand *et al*., 2000).

6.2.5 Statistical analyses

The alien species data from the 32 gardens were analysed in terms of the different SES classes. As the data showed relation or dependence, and did not show a normal distribution, which is normal for data obtained through counting, a linear mixed model (LMM) was applied (Bolker *et al*., 2009; Noël *et al*., 2011). LLM were performed on the dataset in SPSS version 21 (IBM, 2012) software package (Hancock and Mueller, 2010), using PostHoc Tukey B settings, to test for overall significant differences in index values between SES classes.

Effect size (d-values) instead of p-values are reported, because Ellis and Steyn (2003) found that as data sets accumulate, various significant statistical tests are likely to display smaller p-values; for this reason this study reports effect size (Cohen’s d-values). Consequently, effect size can report practically significant relationships between variables and indicates the difference between two means, independent of units and sample size, because effect size relates to the distribution of the data (Ellis and Steyn, 2003). Cohen (1988) gives the following guidelines for the interpretation of the effect size: (a) small effect: $d>0.2$, (b) medium effect: $d>0.5$ and (c) large effect: $d>0.8$.

Therefore, data with $d \geq 0.8$ is considered as practically significant difference between two means, since it is the result of a difference having a large effect (see Addendum C for effect sizes). A scoring system was devised to compare SES classes in terms of the significant differences of their alien tree diversity and number of individuals. For each specific measure, every SES class was compared with every other SES class to determine whether it had higher or lower values that were significantly different at $d \geq 0.8$. A SES class was scored based on the number of times it showed significantly higher or lower values than other SES classes (example Table 6.5).

6.3 Results

6.3.1 Flagged alien species

A total of 114 woody alien species were recorded for the study area and 45 (39.5%) were classified as invasive aliens (NEMBA, 2014 and CARA, 2001). The 114 species consisted of a total of 8021 individuals, whereas the invasive species contributed 86.8% (6959) of these individuals. Furthermore, the woody alien species that occurred in both cultivated and natural areas comprised 26 species and a total of 7450 individuals – 2137 adults and 5313 saplings – which contributed 92.8% of the individuals of all the woody species. These 26 flagged alien species occurred most frequently in gardens, riparian areas and in streets (Table 6.2).

Table 6.2. Number of individuals for each of the 26 flagged alien species.

Species	Family	Adults	Saplings	Total	Most frequent land-cover type
Acacia melanoxylon[1,2]	Fabaceae	17	68	85	Urban open spaces
Acer buergerianum[2]	Sapindaceae	62	64	126	Streets
Ailanthus altissima[1,2]	Simaroubaceae	17	22	39	Riparian areas
Brachychiton populneus	Malvaceae	11	0	11	Gardens; Streets
Callistemon citrinus[2]	Myrtaceae	27	0	27	Gardens
Celtis australis[2]	Ulmaceae	28	86	114	Streets
Celtis occidentalis[2]	Ulmaceae	1	32	33	Rangelands
Celtis sinensis	Ulmaceae	186	160	346	Gardens
Cestrum laevigatum[1,2]	Solanaceae	41	356	397	Riparian areas
Eucalyptus camaldulensis[1,2]	Myrtaceae	299	129	428	Plantations
Eucalyptus sideroxylon[1]	Myrtaceae	138	87	225	Plantations
Ficus carica	Moraceae	67	25	92	Gardens
Gleditsia triacanthos[1,2]	Fabaceae	63	157	220	Roadsides
Grevillea robusta[1,2]	Proteaceae	2	3	5	Rangelands
Ligustrum ibota	Oleaceae	20	3	23	Gardens
Ligustrum lucidum[1,2]	Oleaceae	311	592	903	Riparian areas
Melia azedarach[1,2]	Meliaceae	241	2536	2777	Urban open spaces
Morus alba[1,2]	Moraceae	75	17	92	Gardens
Populus canescens[1,2]	Salicaceae	132	750	882	Riparian areas
Prunus persica	Rosaceae	81	13	94	Gardens
Punica granatum	Lythraceae	28	3	31	Gardens
Pyracantha coccinea[2]	Rosaceae	12	32	44	Riparian
Robinia pseudoacacia[1,2]	Fabaceae	70	63	133	Roadsides
Salix babylonica[1]	Salicaceae	75	19	94	Riparian areas
Schinus molle	Anacardiaceae	54	0	54	Gardens
Ulmus parvifolia	Ulmaceae	79	96	175	Roadsides; Streets

Superscript enumerators indicates the Invasive species lists of the Conservation of Agricultural Resources Act (CARA) [1] and National Environmental Management Biodiversity Act (NEMBA) [2] respectively

The majority of the 26 alien species (69%) occurred on either one or both of the invasive alien lists. However only 11 of the 26 species occurred on both lists, while eight species did not occur on either of the lists. Furthermore, of these eight species only four species had a significant amount of individuals in naturalised areas. The four species include *Celtis sinensis*, *Ficus carica*, *Prunus persica* and *Ulmus parvifolia*, and these species can be considered as naturalised species of the North-West Province.

6.3.2 Alien species composition and occurrence of the 20 influential species within the different land-cover types

The total number of individuals for the 20 alien species within each of the land-cover types varied considerably (Figure 6.2). Urban cultivated areas had the highest number of adult alien trees (1432), while rangelands had the lowest number of adult alien trees (18). On the other hand, the highest number of woody alien saplings occurred in riparian areas (2090) and the lowest also occurred in rangelands (234). In most of the land-cover types the number of saplings exceeded the number of alien adults, however urban cultivated areas and roadsides was an exception – sapling numbers were either fewer than or relatively similar to adult numbers.

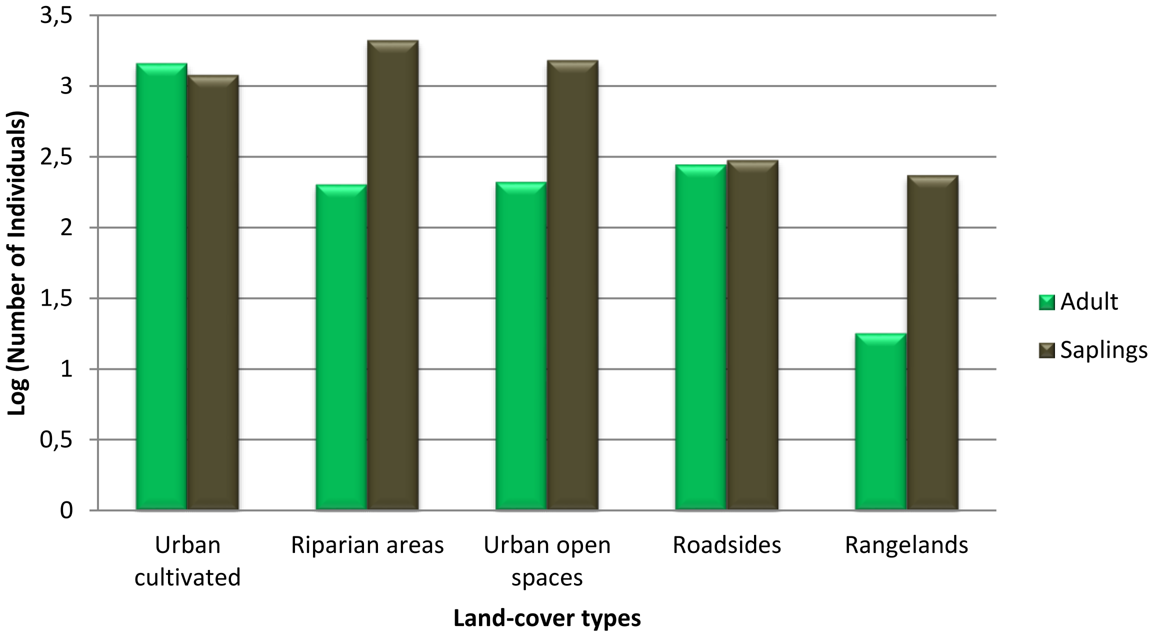

Figure 6.2. Total number of individuals (adults and saplings) of woody alien species within the different land-cover types

In cultivated areas, gardens had the highest number of individual adult alien trees (865), whereas streets had the lowest number of adult alien trees (107). The number of saplings of cultivated areas was the highest in plantations (784) and the lowest in gardens (70) (Figure 6.3). Urban cultivated areas and more specifically gardens are the only land-cover type where the number of individual adult trees exceeds the saplings.

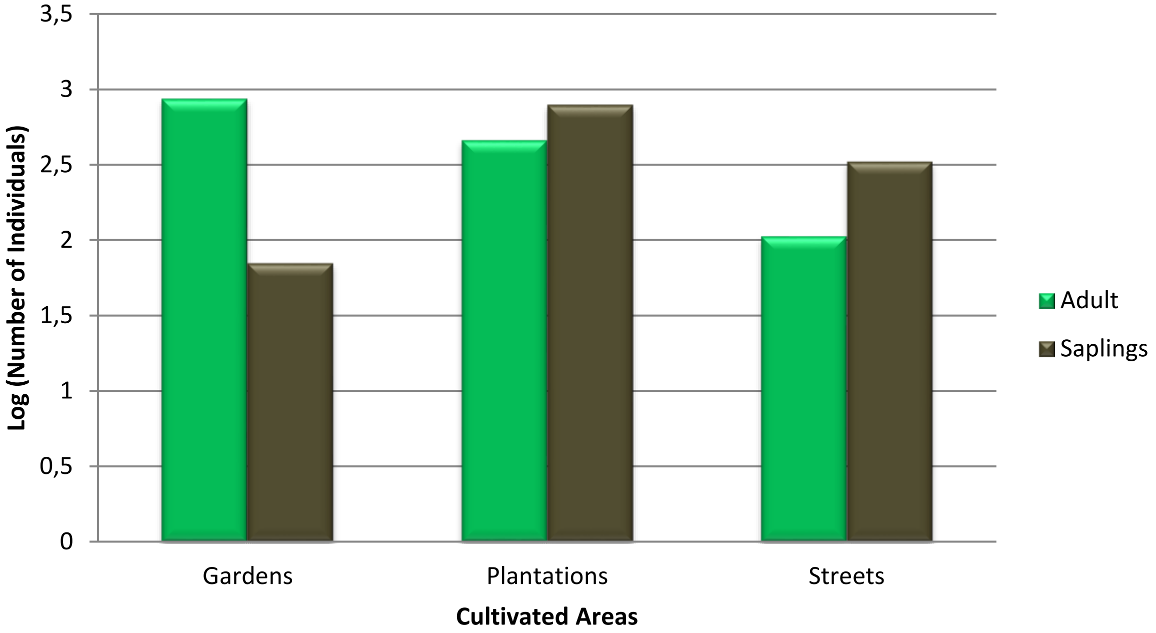

Figure 6.3. Total number of individuals (adults and saplings) for the respective land-cover types within urban cultivated areas

Considering the 20 influential alien species, gardens, urban open spaces and riparian areas had the highest numbers (Figure 6.4). Furthermore, in two of the land-cover types the number of sapling species exceeded that of the adult trees. However, the opposite was found in gardens, roadsides, streets and urban open spaces. This is mainly due to these areas (gardens and streets) being cultivated and maintained, with regular clearing or mowing, which can influence these numbers within the data. Figure 6.4 clearly indicates that cultivated urban areas have much higher numbers of alien species, than the surrounding rangelands.

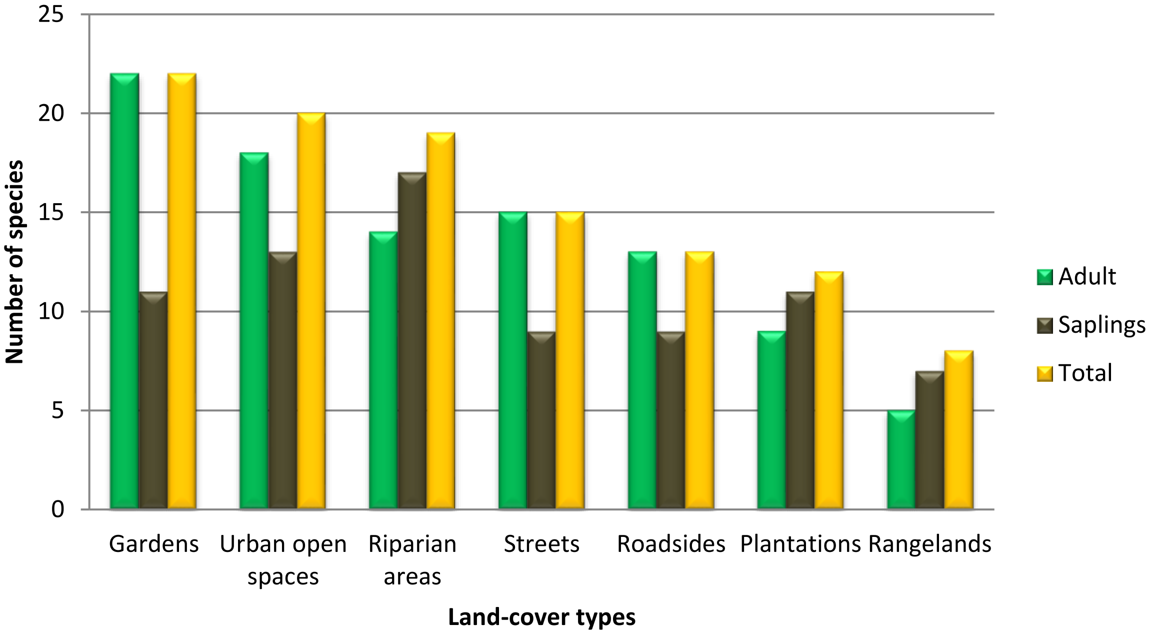

Figure 6.4. Total number of alien species (adults and saplings) for the respective land-cover types

An ordination revealed similarities in alien species composition of land-cover types (Figure 6.5). If the adult alien species (Figure 6.5 A) and saplings (Figure 6.5 B) are considered, no clear groupings can be identified. However, on the extremes are the assemblages of plantations and roadsides with *Populus canescens*, *Melia azedarach*, *Eucalyptus camaldulensis*, *Gleditsia triacanthos* and *Robinia pseudoacacia* mainly responsible for these assemblages. However, when total (adult and sapling) data (Figure 6.5 C) are considered, two groupings are visible, showing that combined species numbers or assemblages varied more across the different land-cover types. These two groups mainly consist of garden and streets and the rest of the land-cover types (urban open space, plantations, riparian areas and rangelands). The species mainly responsible for this distinction in tree assemblages between gardens and streets and the rest of the land-cover types are: *Acer buergerianum*, *Celtis sinensis*, *Cestrum laevigatum*, *Ligustrum lucidum*, *Melia azedarach* and *Ulmus parvifolia*.

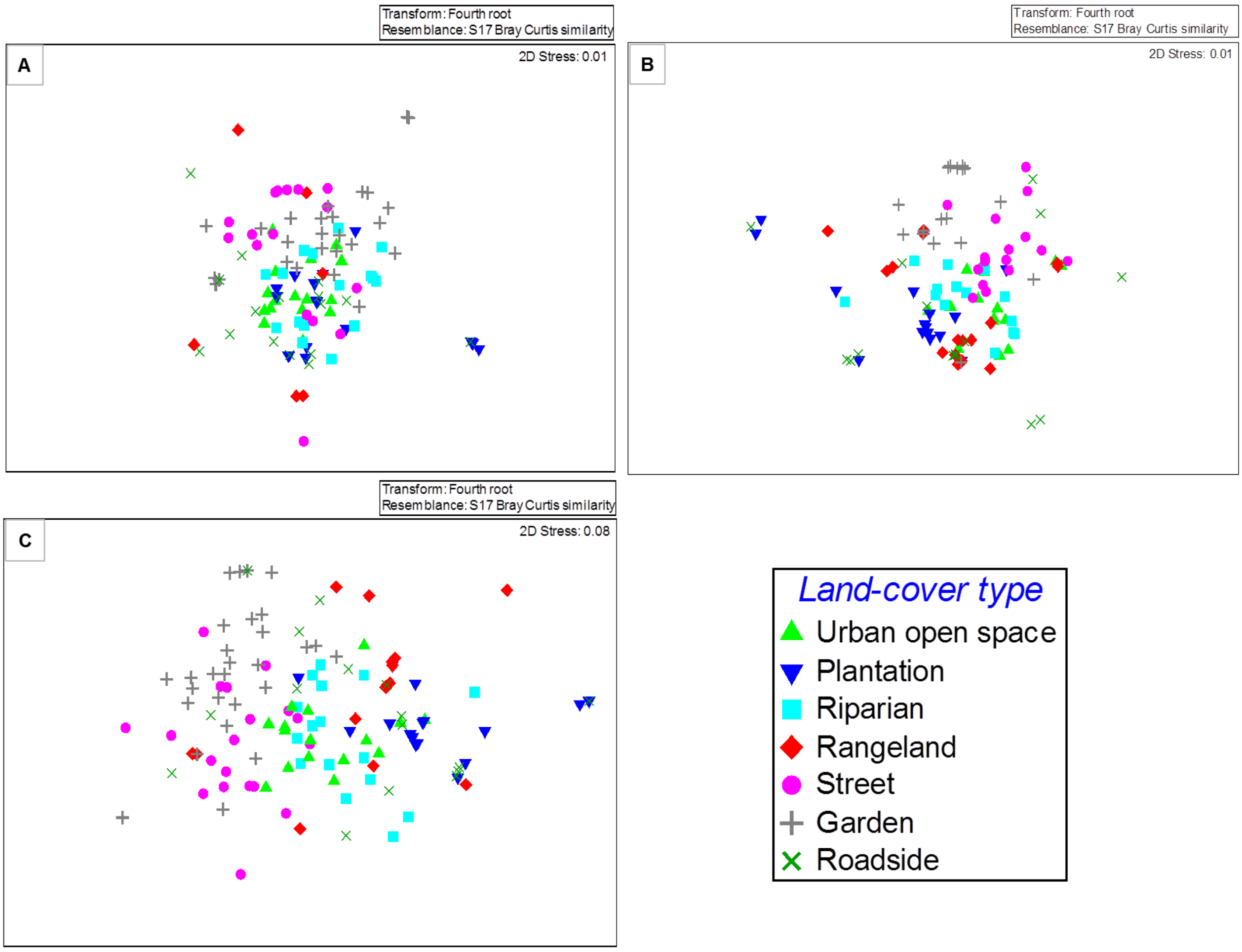

Figure 6.5. NMDS ordination indicating species assemblages for the 20 adult (A), sapling (B) and combined adult and sapling (C) alien tree species

6.3.3 Main dispersal methods of the 20 influential alien species

To gain a better understanding of how alien species migrate from urban cultivated areas to surrounding urban and agricultural areas the type of seed and main dispersal mechanisms of the most influential alien species in both cultivated and naturalised areas were assessed (Table 6.3). Furthermore, the percentage of the main dispersal mechanisms was also indicated (Figure 6.6), with the majority of seeds being dispersed by birds (26 %) and animals (24 %), while wind and suckering was the least utilised dispersal mechanism (10 and 11 % respectively). Water and resprout or reseeding was responsible for the remaining type of dispersal methods for these alien species.

Table 6.3. Main dispersal methods of alien species.

Species	Type of seed	Dispersal method
Acacia melanoxylon	Seed-containing pods	Insects, animals, particularly birds, also dispersed in dumped garden waste and contaminated soil
Acer buergerianum	Winged samara, 4-7mm in diameter, 15mm wing often overlapping	Seeds dispersed by wind, water
Ailanthus altissima	Flat, twisted, single-seeded winged fruits or samaras	Seeds dispersed by wind, water. Resprout vigorously when cut, also spreads by suckering
Celtis australis	Fruits: berry-like "drupes", yellow, purple or black, fleshy with one white seed	Seeds are dispersed by birds and other wildlife. Can also propagated by cutting and layering
Celtis sinensis	Fleshy, berry-like fruit: dark orange, with hard, round seeds	Seeds are distributed by birds, bats and running water
Cestrum laevigatum	Fruit/seeds: Green 10mm long berries which turn purple-black	Berries/seeds are dispersed by birds
Eucalyptus camaldulensis	Distinguished seeds which are cuboid, yellow to brownish yellow and have two seed coats	Insects, birds, and small mammals help in pollination of flowers; seeds are shed from a tree, most fall onto ground below crown, with some seed carried by wind and water
Eucalyptus sideroxylon	Woody fruits or capsules, with valves at end which open to release seeds. Seeds are waxy, rod-shaped, about 1 mm in length, and yellow-brown in colour	Seeds are shed from tree, most fall onto ground below crown, with some seed carried by wind and water
Ficus carica	Commonly referred to as fruit, figs are actually infructescence or scion of the tree, known as a false fruit or multiple fruit, in which flowers and seeds are borne	Dispersed by birds, mammals that scatter seeds in droppings. Important food source; trees owe expansions to those that feed on its fruit. Also sprouts from root and stolon issues
Gleditsia triacanthos	Very distinctive, long, flattened, red-brown, leathery pod that becomes dry and twisted; pod contains many oval, dark brown, shiny seeds	Seeds dispersed by grazing herbivores (cattle & horses), which eat pod pulp and excrete seeds in droppings; animal's digestive system assists in breaking down hard seed coats, making germination easier
Ligustrum lucidum	Oblong, blue/black fruit is a drupe containing 1 to 4 seeds	Grows readily from seed or root and stump sprouts. Wildlife and birds can aid in dispersal of seed, often relocating plant over long distances
Melia azedarach	Flowers followed by yellow clusters of fruit (poisonous if eaten by humans and animals although many birds seem partial to them and are not affected)	Large numbers of bird-dispersed seed. Seeds maintain viability for up to two years. Regenerates rapidly from seed and by suckering
Morus alba	Fruits are multiple-seeded berries (wind pollinated)	Fruit ripens and drops off the tree; water, birds, jackals and human beings often disperse it
Populus canescens	Flowers are catkins, female catkins lengthen after pollination, with several green seed capsules	Fruits spread by wind; also spreading via suckers in damp woodland (spread vegetatively by root suckers)
Prunus persica	Single, large seed, red-brown, oval shaped. Approximately 1.3–2 cm long, and surrounded by a wood-like husk	Fruit ripens and drops off the tree; water, birds, jackals and human beings often disperse it
Pyracantha coccinea	Berries (scarlet fruits) produced in large numbers with up to 1000 seeds/m2 of soil surface recorded	Birds readily eat berries and disperse seeds. Seeds are dispersed by animals, water, gravity, soil movement and dumped vegetation
Robinia pseudoacacia	Fruit: legume two-valved, smooth, usually four to eight seeded. Seeds dark orange brown with irregular markings in elongated and flattened pods	In South Africa, regarded as a weed because it produces large numbers of suckers from its root system, eventually forming dense thickets. Seeds will re-spout vigorously from stumps that have been cut or damaged by fire
Salix babylonica	Flowers are arranged in catkins produced early in spring; dioecious, with male and female catkins on separate trees	Plants propagated vegetatively, and capable of hybridizing with various other kinds of willows, but not breeding true from seed
Schinus molle	Fruit are 5–7 mm diameter round drupes, with woody seeds that turn from green to red, pink or purplish. Carried in dense clusters of hundreds of berries that can be present year-round	Tree reproduces through seed, suckers and cuttings. Seeds have a particularly hard coat, germination rates are greatly improved after they have passed through the gut of birds or other animals
Ulmus parvifolia	Fruit: elliptic samara. Samara mostly glabrous, with seed at centre or towards apex	Wind. Chinese elm trees are prodigious reseeders, can be messy with lots of fruit falling and causing seedling growth

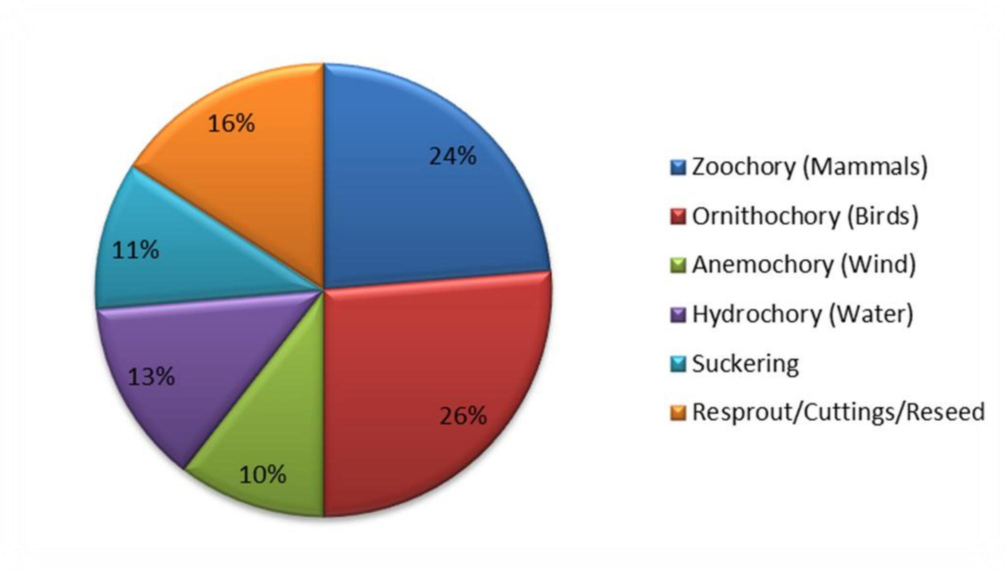

Figure 6.6. Main dispersal methods of the 20 selected alien species

6.3.4 Socio-economic status – species composition and diversity

The Non-metric multidimensional scaling (NMDS) analysis revealed significant variation between the four different groups used to classify the SES alien species (Figure 6.7). The lower SES classes had the least amount of declared (Figure 6.7 A) and partially declared (Figure 6.7 C) alien species, compared to the other groups. However, considering cultivated (Figure 6.7 B) and naturalised (Figure 6.7 D) alien species, the lower SES classes featured more prominently. Furthermore, if the total alien species composition (Figure 6.7 E) for the SES classes is considered, a clear distinction can be made between the higher (SES 4 and SES 5) and lower SES classes, which indicate that the different SES classes each comprise certain alien species.

SES class 4 had the highest number of individuals for all the different alien groups (Figure 6.8); the partially declared group, which had the lowest number of individuals for SES 4, was higher than the number of individuals for any of the other groups within the lower SES classes (Table 6.4). Furthermore, SES 5 was the class following closest behind SES 4, concerning the number of individuals for each alien group; however the lower SES classes had significant lower number of individuals for each group. Nevertheless, the declared and naturalised number of alien individuals was fairly high for the lower SES classes, while the partially declared number of individuals was the lowest in all three of the lower SES classes.

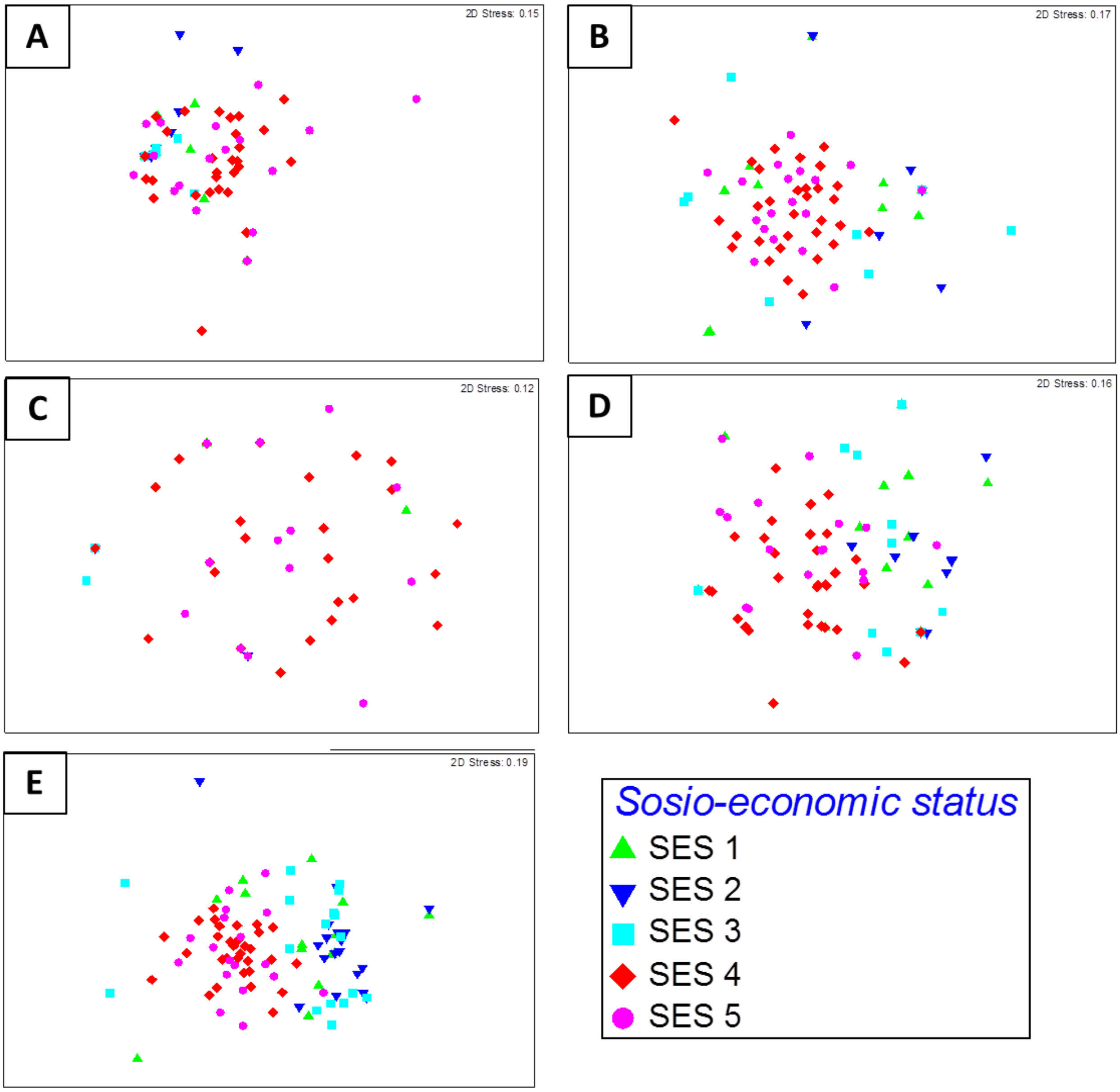

Figure 6.7. NMDS ordinations of declared alien (A), cultivated alien (B), partially declared alien (C), naturalised alien (D) and combined total alien (E) species composition

Table 6.4. Summary of the total number of individuals for each of the four alien groups.

SES Group	Cultivated Aliens	Declared Aliens	Partially declared	Naturalised
1	51	50	4	34
2	12	60	2	52
3	17	46	3	34
4	370	182	80	167
5	194	79	43	85

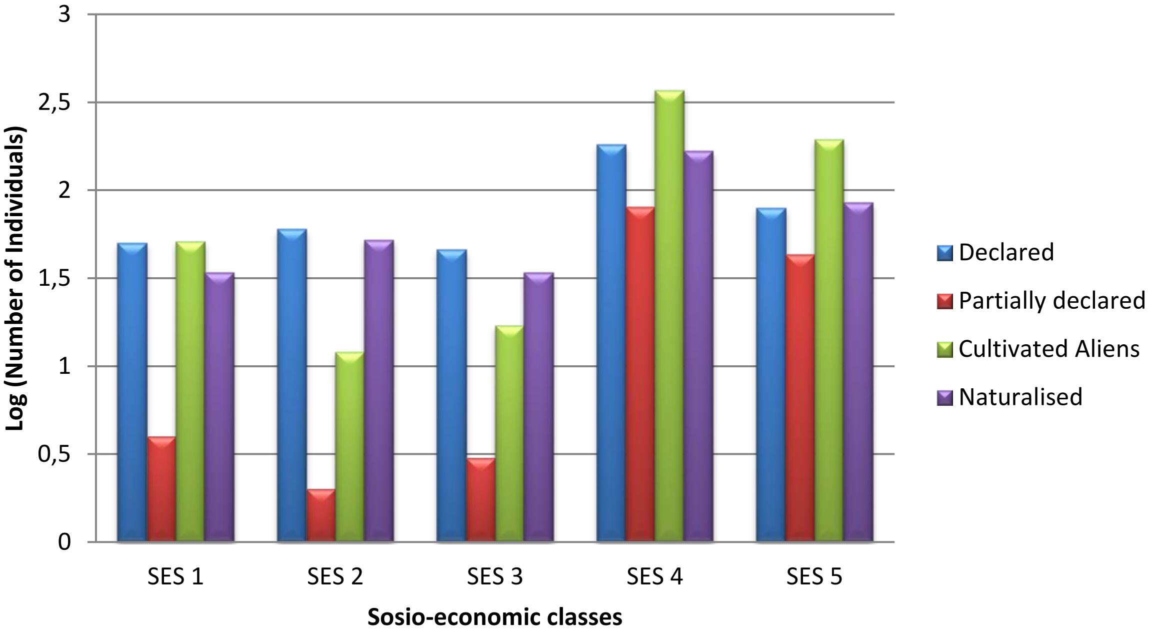

Figure 6.8. Total number of individuals for each of the different alien groups within each of the SES classes

6.3.4.1 SES performance score

When SES data is considered, SES 4 and SES 5 had significantly more species (d>0.8) than three of the other SES groups (Table 6.5). Overall SES 4 and SES 5 performed the best in terms of tree diversity indices compared to the other SES groups. It is therefore the most divers, followed by lower SES (class 1 and 2). SES 3 underperformed significantly (d>0.8) in the evenness of species, however SES 1 and SES 2 had no effect regarding evenness. Overall, SES 3 had the poorest diversity, followed by SES 1 and SES 2.

Table 6.5. Alien species performance scores for SES based on large effect sizes (d>0.8). Number of instances where a land-cover type performed significantly poorer (<) or better (>) than other SES.

Diversity Index	SES 1	SES 2	SES 3	SES 4	SES 5
Species richness (S)	<2	<2	<2	>3	>3
Performance rating	-2	-2	-2	3	3
Number of individuals (N)	<2	<2	<2	>3	>3
Performance rating	-2	-2	-2	3	3
Margalef species richness (d)	<2	<2	<2	>3	>3
Performance rating	-2	-2	-2	3	3
Pielou's Evenness (J')	-	-	<2	>1	>1
Performance rating	0	0	-2	1	1
Shannon Index (H)	<2	<2	<2	>3	>3
Performance rating	-2	-2	-2	3	3
Overall performance	**-8**	**-8**	**-10**	**13**	**13**

6.3.5 Population dynamics and structure

The results of the size class distribution (SCD) indicated variation between the population structure of indigenous and alien species. Height SCD indicated that the majority of indigenous trees had a lower PI value, while alien species had higher PI values indicating a discontinuous SCD. PI values closer to zero indicate a monotonically declining population. SDI for height size classes indicated that the majority of species (alien and indigenous) have exponentially declining populations (SDI > 0.1). However *Salix babylonica* and *Eucalyptus camaldulensis* was an exception, with values closer to zero, indicating even distributions of size-classes.

Table 6.6. Summary of size-class distributions for selected alien and indigenous tree species populations. Permutation Index (PI) and Simpson's Index of Dominance (SDI) values are given. PI* and SDI* represents height size-class distribution, whereas PI and SDI represents the basal area size-class distributions.

Species	PI*	SDI*	PI	SDI
Celtis africana	4	0.67	4	0.41
Celtis sinensis	10	0.53	18	0.23
Eucalyptus camdulensis	6	0.16	12	0.18
Gleditsia triacanthos	7	0.54	4	0.20
Ligustrum lucidum	6	0.75	13	0.18
Melia azedarach	10	0.86	0	0.34
Robinia pseudoacacia	5	0.39	4	0.39
Salix babylonica	21	0.14	17	0.48
Searsia lancea	4	0.61	12	0.16
Searsia pyroides	9	0.50	2	0.39
Senegalia caffra	5	0.38	8	0.24
Vachellia karroo	7	0.73	0	0.22
Zanthoxylym capense	3	0.58	0	0.56
Ziziphus mucronata	4	0.41	6	0.21

SCD for basal area indicated that the majority of species had discontinuous size-class distributions, with PI values higher than zero. However, *Melia azedarach*, *Vachellia karroo* and *Zanthoxylum capense* was an exception with PI=0. This indicates that these populations are in monotonic decline, or that SCD are more continuous for these species, which indicates healthy populations. SDI is higher than 0.1 for all the species, which indicates uneven size-class distributions.

Quotient analysis (Figure 6.9 – Figure 6.12) for the selected indigenous and alien species indicated that the majority of indigenous species had a stable distribution, while the most alien species were unstable. *Vachellia karroo* and *Searsia lancea* had typical quotients for indigenous species; the "spike" at the end of the SCD indicates instability between size-classes. Stable SCD are beneficial, because it indicates that populations are healthy. However, stable quotients in the case of *Ligustrum lucidum* (Figure 6.10 A) and *Melia azedarach* (Figure 6.10 A en B) is considered undesirable, because this indicates that these species are healthy, stable and has naturalised.

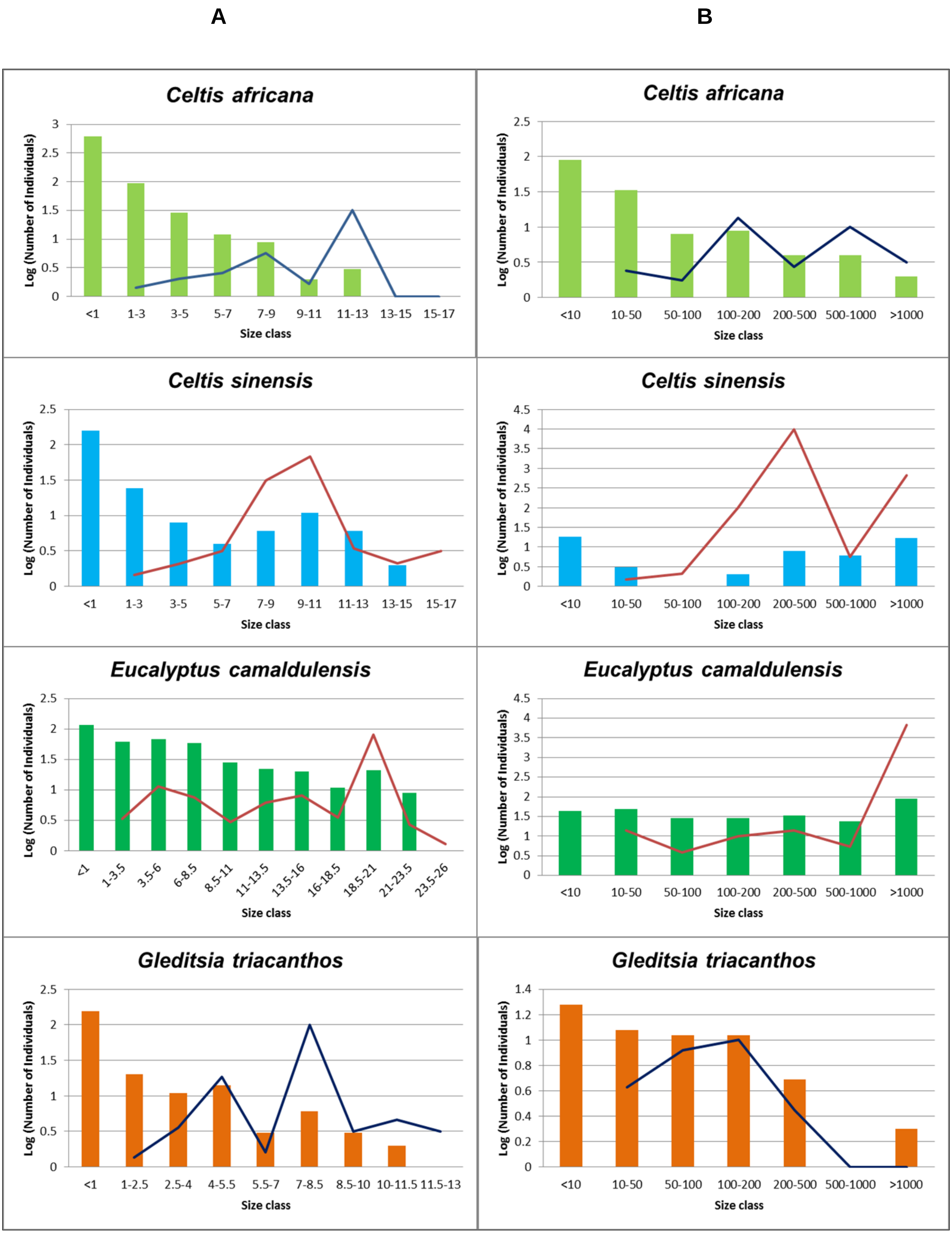

Figure 6.9. Size class distributions of height (A) and basal area (B) for selected indigenous and alien tree species and their respective quotients

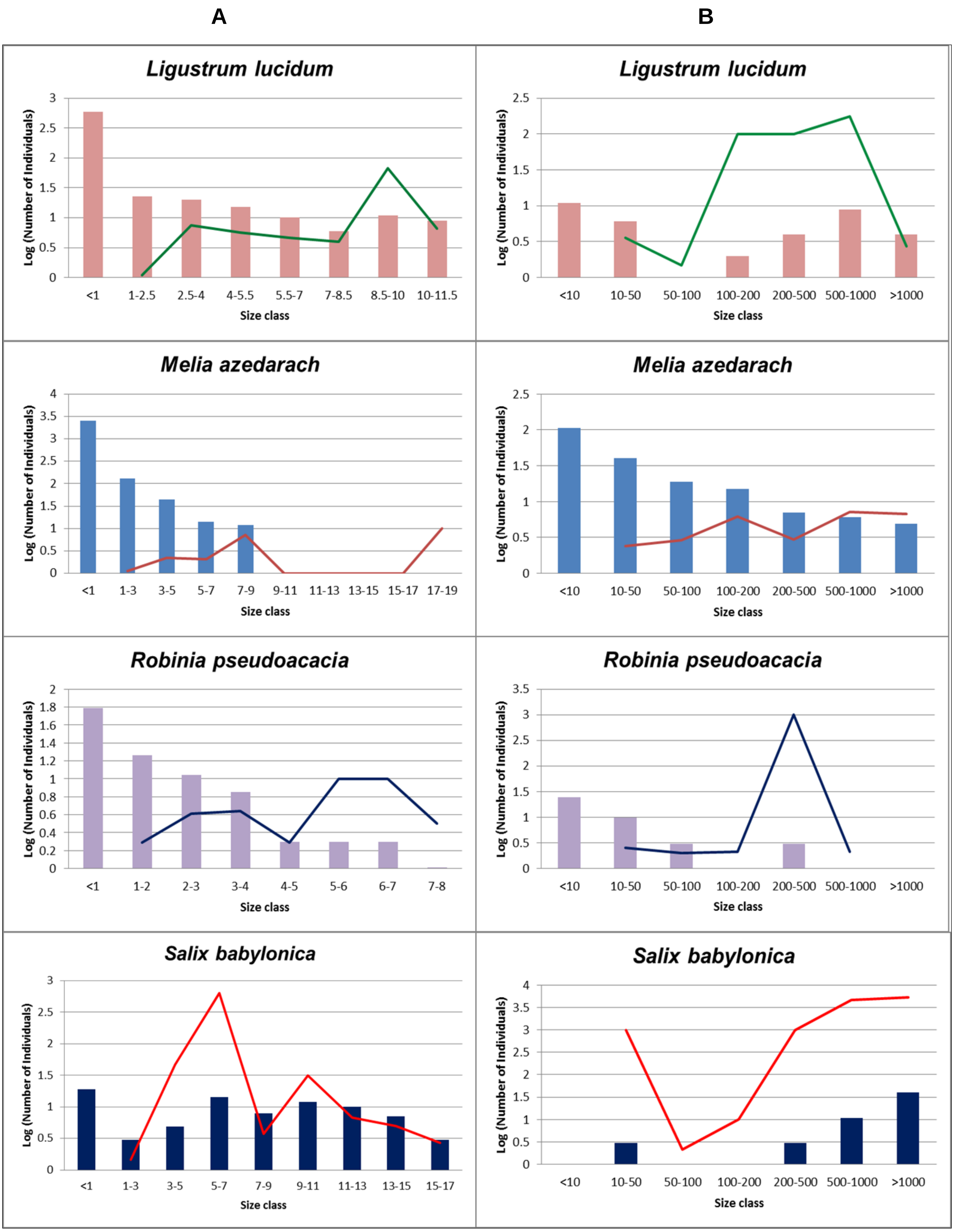

Figure 6.10. Size class distributions of height (A) and basal area (B) for selected indigenous and alien tree species and their respective quotients

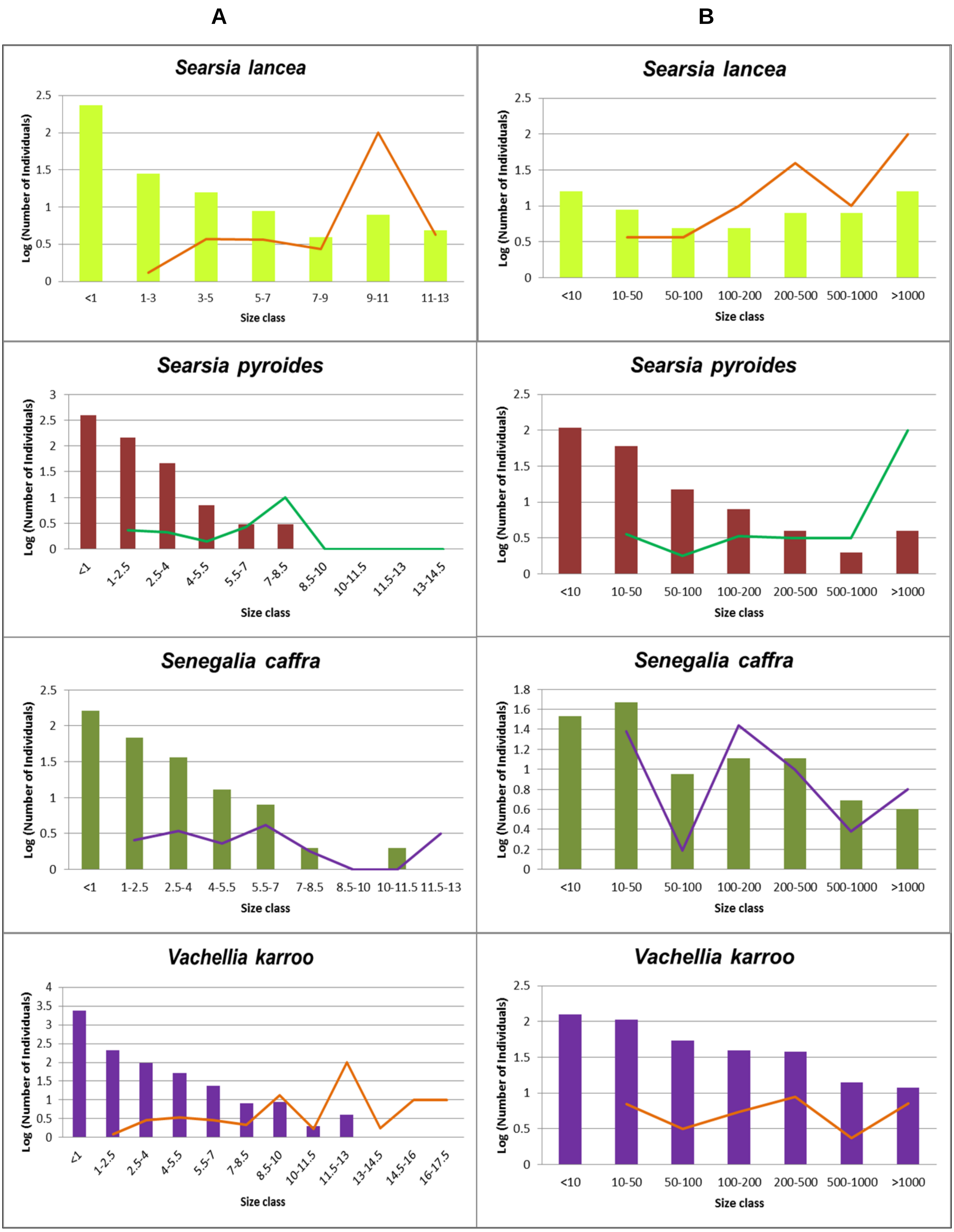

Figure 6.11. Size class distributions of height (A) and basal area (B) for selected indigenous and alien tree species and their respective quotients

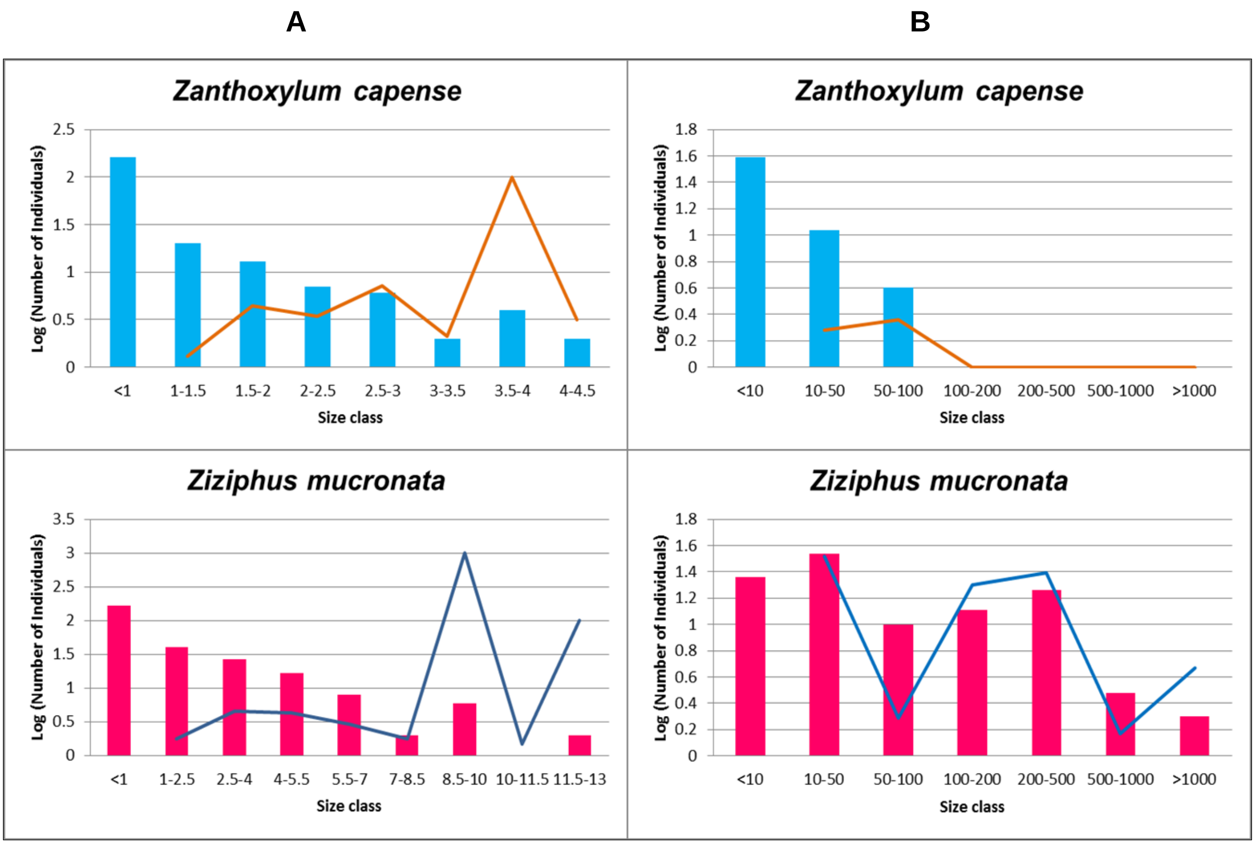

Figure 6.12. Size class distributions of height (A) and basal area (B) for selected indigenous and alien tree species and their respective quotients

6.4 Discussion

According to Richardson and Pyšek (2004) the rampant spread of certain alien species has wreaked havoc in ecosystems around the world. This chapter confirms that cultivated urban areas have a rich biodiversity, mainly dominated by alien species; with aliens accounting for 114 species from a total of 169 tree species. Similarly, the study of Loram *et al*. (2008) recorded 29% British native species and 71% alien species across five cities in the UK. Therefore, it is acceptable to say that the majority of species that have been introduced into urban habitats are alien and can have both a negative and a positive effect on the natural environment (Marco *et al*., 2008). Furthermore, Marco *et al*. (2008) stated that the development of gardens near natural areas holds a possible threat for the native vegetation, which is exposed to reservoirs of potentially invasive plants and genetically transformed species which can lead to development of hybrid species or ‘super’ weeds. This can confirm why urban cultivated areas can act as a source or mechanism for the spread of alien species.

Furthermore, studies by Richardson and Rouget (2002), Davoren (2009) and Lubbe *et al*. (2010) also found high numbers of invasive and declared alien species, however it is important to remember that various definitions for the terms alien, invasive alien, declared alien and naturalized alien species exist in the literature. However, these studies also confirmed or took into account that there is a difference in alien species composition along a socio-economic gradient (Lubbe *et al*., 2010; Davoren *et al*., 2016). The studies of Hope *et al*. (2003) and Martin *et al*. (2004) also confirmed this and found that the plant diversity in urban areas increased across a gradient of low to high SES, with the most variation explained by median family income.

Hope *et al*. (2003) defined the positive relationship that exists between plant diversity and wealth, as the 'luxury effect'. This luxury effect is mainly caused by an abundance of human resources and higher levels of residential involvement in urban greening efforts in areas with a higher socioeconomic status (Hope *et al*., 2003). The study of Martin *et al*. (2004) also found that residents who live in areas with a low SES are less likely to enjoy rich assemblages of vegetation in their neighbourhoods than residents who live in neighbourhoods with a high SES. This selection for certain hardy alien species is a problematic outcome of urban cultivated areas, since these urban adaptable species tend to become more widespread and abundant due to human activities (McKinney, 2006).

6.5 Conclusions

This study confirms that socio-economic factors and not only ecological factors have an influence on vegetation patterns and species distributions. It can also conclude that the higher SES classes introduce new alien species into an area, while the lower SES classes maintain these species. In other words, poverty (Neef's Human Development Model) sustains alien invasive genebanks, while wealth ('luxury effect') expands pool of invasive plant species. Furthermore, this chapter also indicates that urban areas aid in the distribution or dispersal of alien species and therefore careful planning is necessary in urban ecology and management, since many alien taxa that are not currently considered as aliens, naturalised species or invasive species, may become such in the future.

CHAPTER 7

GENERAL CONCLUSION AND RECOMMENDATIONS

Describing the tree floristics for WAMS fetch region, determining diversity patterns between land-cover types and whether the diversity is dominated by alien or indigenous species, as well as whether SES classes is linked to categories of alien invader trees formed the main themes of this dissertation. The themes were addressed in three main parts, namely floristic composition (Chapter 4) the patterns of tree diversity (Chapter 5), relationship between SES and categories of invasive trees (Chapter 6). Concluding remarks on each of these sections are given below, with the major findings on each of these sections.

7.1 Floristic characteristics of woody species

- A total of 169 tree species were recorded for the study area.
- Floristic composition of woody species for the WAMS fetch region indicates that the majority of trees are alien species (114) and only 55 indigenous species were recorded.
- Woody species are mostly cultivated for the ecosystem goods and services they provide.
- The relative low tree species diversity or composition of the WAMS fetch region is expected, because this area is situated in the Grassland Biome, with trees restricted to certain habitats.
- This floristic analysis ensure a better understanding of trees in urban and agroecosystems, as well as the reason why floristic composition of trees in and around urban areas consist of the species they do.

7.2 Diversity patterns

- Diversity varied considerably among the land-cover types. Overall the tree species diversity was higher in urban areas (high gamma diversity in gardens), than the surrounding natural areas.
- Species richness was higher in natural areas, with higher number of individuals per species in these areas.
- Tree species diversity in the WAMS fetch region is dominated by alien tree flora.
- Diversity patterns vary considerably among the different land-cover types, with certain species associated with certain land-cover types – due to topography, microclimate, location (distance from urban areas).

Based on these results the hypothesis, which proposed that tree species richness and diversity would be higher in urban areas, is partially accepted, since only tree species diversity was higher in urban areas. Furthermore, the sub-hypothesis, which proposed that tree species diversity in urban ecosystems would be mainly dominated by alien species, is accepted.

7.3 Cultivated aliens and socio-economic status

- Invasive aliens contribute 45 species of the 114 alien species found in the WAMS fetch region.
- Twenty of these species were identified to have an effect in both cultivated and natural areas.
- Four of these species are newly naturalised or need special attention in regards to proposed invaders namely: *Celtis sinensis*, *Ficus carica*, *Prunus persica* and *Ulmus parvifolia*.
- Mammals and birds acts as the main vectors for dispersal.
- Alien tree diversity varies among different SES classes, with higher SES classes having higher alien tree diversity than the lower SES classes.

Based on these results the hypothesis and sub-hypothesis, which proposed that tree diversity would vary among SES classes and that higher SES classes would have higher tree diversity – establish species pool, than lower SES classes, which maintains the species pool is accepted.

7.4 Recommendations for future research

This dissertation provides a snapshot of tree species diversity and composition in the WAMS fetch region, however further studies are necessary to give a better understanding of tree species diversity patterns on a global scale and to assess whether these findings correlates with urban and agroecosystems in or near other urban areas in South Africa.

The effect and continual increase of alien invader trees and more species becoming naturalised calls for urgent attention in this regard. The following recommendations in this regard can be made:

- Firstly, educational programmes to inform the general public (from all the different SES classes) as well as municipalities and stakeholders which plant and specifically tree species are considered as weeds or invasive.
- Secondly, better regulations of the horticultural trade and political will to enforce these regulations.

- Participation from various groups to combat and eradicate species that has already been identified as invasives.
- Ecologist and officials working together to first assess species and possible outcomes of the species selected for planting in urban areas and gardens.

Future studies should also assess the “use value” of alien invasive trees and plants, especially to plants that provides ecosystem services such as windbreak, timber, fuel, fruit and so forth to replace these species with indigenous alternatives.

Practical outcomes of this study

This study acts as a baseline database for a comprehensive study on tree species diversity in urban and agroecosystems in the Grassland Biome. Furthermore, the data generated by this study will assist in future research regarding BVOCs and to determine which tree species or land-cover types are responsible for what type of BVOCs to better manage air pollution and future climate change. Practical outcomes include:

- Baseline data for this study, which can be resampled in the future to determine whether tree population structure causes long-term adaptations in BVOCs and climate change.
- Generated baseline data which will contribute substantially to the identification, monitoring and ultimate sustainable management of tree populations and their associated BVOC emissions. Captured data will support the interpretation of atmospheric observation of VOCs, as well as secondary atmospheric species such as ozone (O_3) (for which VOCs are important precursors) and secondary aerosols (SOA) (for which oxidised VOCs contribute significantly for particle formation and growth) measured at Welgegund in the future.
- Furthermore, the contribution of tree species to BVOC emissions in South Africa is still relatively unknown and few baseline data exist to compare with similar studies already done elsewhere in the world. It is also unclear how native and alien species contribute and how different variables (leaf physiology, canopy effects, climate change, land-cover change) affect BVOC emissions.
- This data will assist future atmospheric research studies at Welgegund, to determine the influence or effects of tree populations together with land-cover change on BVOC emissions.

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ADDENDUM A

Total species list of Welgegund Atmospheric Measurement Station fetch region

- **Alien - Purple**
- **Invasive - Red**
- **Indigenous - Green**

🟪 *Abelia floribunda*	🟪 *Codiaeum variegatum* (L.) A.Juss.*	🟪 *Mahonia lomariifolia*	🟪 *Rhaphiolepis indica* (L.) Lindl.*
🟪 *Abelia grandiflora* (André) Rehd.*	🟩 *Combretum erythrophyllum* (Burch.) Sond.*	🟩 *Maytenus tenuispina* (Sond.) Marais*	🟥 *Robinia pseudoacacia* L.*
🟥 *Acacia baileyana* F.Meull.*	🟩 *Combretum molle* R.Br. ex G.Don*	🟪 *Melaleuca armillaris* (Sol. ex Gaertn.) Sm.*	🟩 *Searsia lancea* L.f.*
🟩 *Acacia caffra* (Thunb.) Willd.* (*Senegalia caffra*)	🟪 *Cordyline australis* (G.Forst.) Endl.*	🟥 *Melia azedarach* L.*	🟩 *Searsia leptodictya* Diels*
🟩 *Acacia erioloba* E.Mey.* (*Vachellia erioloba*)	🟥 *Cotoneaster franchetii* Bois.*	🟪 *Myrtus communis* L.*	🟩 *Searsia magalismontana* Sond.*
🟩 *Acacia hebeclada* DC.* (*Vachellia hebeclada*)	🟥 *Cotoneaster pannosus* Franch.*	🟥 *Morus alba* L. var. *alba**	🟩 *Searsia pendulina* Jacq.*
🟩 *Acacia hereroensis* Engl.* (*Senegalia hereroensis*)	🟪 *Cryptomeria japonica* (L.f.) D.Don*	🟩 *Mundulea sericea* (Willd.) A.Chev.*	🟩 *Searsia pyroides* Burch.*
🟩 *Acacia karroo* Hayne* (*Vachellia karroo)*	🟪 *Cupressus sempervirens* L. var. *sempervirens**	🟪 *Musa* x *paradisiaca* L.*	🟩 *Searsia rigida* Mill.*
🟥 *Acacia mearnsii* De Wild.*	🟪 *Cydonia oblonga* Mill.*	🟩 *Mystroxylon aethiopicum* (Thunb.) Loes.*	🟥 *Salix babylonica* L.*
🟥 *Acacia melanoxylon* R.Br.*	🟩 *Diospyros lycioides* Desf. subsp. *guerkei* (Kuntze)	🟪 *Nandina domestica* Thunb.*	🟥 *Salix fragilis* L. var. *fragilis**
🟥 *Acacia podalyriifolia*	🟩 *Diospyros lycioides* Desf. subsp. *lycioides*	🟥 *Nerium oleander* L.*	🟩 *Salix mucronata* Thunb.*
🟩 *Acacia robusta* Burch.* (*Vachellia robusta*)	🟩 *Dombeya rotundifolia* (Hochst.) Planch.*	🟥 *Nicotiana glauca* Graham*	🟥 *Sambucus nigra* L.*
🟪 *Acca sellowiana* (O. Berg) Burret*	🟩 *Elephantorrhiza elephantina* (Burch.) Skeels*	🟩 *Olea europaea* L. subsp. *africana* (Mill.) P.S.Green*	🟪 *Schinus molle* L.*
🟥 *Acer buergerianum* Miq.*	🟩 *Ehretia rigida* (Thunb.) Druce*	🟩 *Pappea capensis* Eckl. & Zeyh.*	🟪 *Senna corymbosa* (Lam.) Irwin & Barneby*
🟥 *Ailanthus altissima* (Mill.) Swingle*	🟪 *Elaeagnus pungens* Thunb.*	🟥 *Parkinsonia aculeata* L.*	🟥 *Sesbania punicea* (Cav.) Benth.*
🟪 *Aloysia triphylla* (L'Hér.) Britt.*	🟥 *Eriobotrya japonica* (Thunb.) Lindl.*	🟪 *Parthenocissus quinquefolia* (L.) Planch.*	🟥 *Solanum mauritianum* Scop.*
🟩 *Ancylobotrys capensis* (Oliv.) Pichon*	🟥 *Eucalyptus camaldulensis* Dehnh.*	🟩 *Pavetta gardeniifolia* A.Rich.*	🟪 *Solanum rantonnetii* Carriere*
🟩 *Asparagus laricinus* Burch.*	🟥 *Eucalyptus sideroxylon* A.Cunn.*	🟩 *Pavetta harborii* S.Moore*	🟩 *Sphedamnocarpus pruriens* (A.Juss.) Szyszyl.*

Asparagus suaveolens Burch.*	*Euclea crispa* (Thunb.) Gürke*	*Pavetta zeyheri* Sond.*	*Spiraea arguta* Zabel*
Berberis thunbergii DC.*	*Euclea undulata* Thunb.*	*Phoenix canariensis* Hort. ex Chabaud*	*Styphnolobium japonicum* (L.) Schott*
Boscia albitrunca (Burch.) Gilg & Gilg-Ben.*	*Euonymus fortunei* (Turcz.) Hand.-Maz.*	*Photinia glabra* (Thunb.) Maxim.*	*Syzygium paniculatum* Gaertn.*
Brachychiton populneus (Schott & Endl.) R.Br.*	*Euonymus japonicus* Thunb.*	*Pinus halepensis* Mill.*	*Tamarix ramosissima* Ledeb.*
Brachylaena rotundata S.Moore*	*Ficus carica* L.*	*Pinus roxburghii* Sarg.*	*Thuja occidentalis* L.*
Brunfelsia pauciflora (Cham. & Schltdl.) Benth.*	*Fraxinus angustifolia* Vahl*	*Pinus pinea* L.*	*Thuja orientalis*
Buddleja saligna Willd.*	*Fraxinus pennsylvanica* Marshall*	*Platanus occidentalis* L.*	*Tipuana tipu* (Benth.)Kuntze*
Callistemon citrinus (Curtis) Skeels*	*Gleditsia triacanthos* L.*	*Platanus wrightii* S. Wats.*	*Trachycarpus fortunei* (Hook.) H.Wendl.*
Callistemon viminalis (Gaertn.) G.Don*	*Gnidia burchellii* (Meisn.) Gilg*	*Plumeria rubra* L.*	*Triumfetta sonderi* Ficalho & Hiern*
Camellia japonica L.*	*Grevillea robusta* Cunn. ex R.Br.*	*Populus* x *canescens* (Aiton) Sm.*	*Ulmus parvifolia* Jacq.*
Canthium gilfillanii (N.E.Br.) O.B.Mill.*	*Grewia flava* DC.*	*Populus deltoides* W.Bartram ex Marshall*	*Vangueria cyanescens* Robyns*
Carissa bispinosa (L.) Desf. ex Brenan*	*Grewia occidentalis* L.*	*Populus nigra* L.*	*Vangueria infausta* Burch. *
Casuarina cunninghamiana Miq*	*Gymnosporia buxifolia* (L.) Szyszyl.*	*Populus simonii* Carrière*	*Vangueria parvifolia* Sond.*
Cedrus deodara (Roxb. ex D.Don) G.Don*	*Gymnosporia polyacanthus* (Sond.) Szyszyl.*	*Protea caffra* Meisn.*	*Viburnum odoratissimum* Ker Gawl.*
Celtis africana Burm.f.*	*Ilex crenata* Thunb.*	*Prunus armeniaca* L.*	*Viburnum sinensis*
Celtis australis L.*	*Jacaranda mimosifolia* D.Don*	*Prunus domestica* L.*	*Viburnum tinus* L.*
Celtis sinensis Pers.*	*Jasminum humile*	*Prunus laurocerasus* L.*	*Washingtonia filifera* (Linden. ex André) H.Wendl.*
Celtis occidentalis L.*	*Jatropha multifida* L.*	*Prunus persica* (L.) Batsch*	*Widdringtonia nodiflora* (L.) Powrie*
Cestrum laevigatum Schltdl.*	*Juniperus scopulorum* Sarg.*	*Punica granatum* L.*	*Wisteria sinensis* (Sims) DC.*
Chamaecyparis lawsoniana (A.Murray bis) Parl.*	*Lagerstroemia indica* L.*	*Pyracantha angustifolia* (Franch.) C.K.Schneid.*	*Zanthoxylum capense* (Thunb.) Harv.*
Cinnamomum camphora (L.) T.Nees & C.H.Eberm.*	*Leucaena leucocephala* (Lam.) de Wit*	*Pyracantha coccinea* M.Roem.*	*Ziziphus mucronata* Willd.*
Citrus limon (L.) Burm.f.*	*Ligustrum ibota* Siebold ex Siebold & Zucc.*	*Pyracantha crenulata* (D.Don) M.Roem.*	*Ziziphus zeyheriana* Sond.*
Citrus reticulata Blanco*	*Ligustrum lucidum* W.T.Aiton*	*Quercus palustris* Münchh.*	
Citrus sinensis (L.) Osbeck*	*Litsea glutinosa* (Lour.) C.B.Rob.*	*Quercus robur* L.*	
Clerodendrum glabrum	*Magnolia* x *soulangeana* Soul.–Bod.*	*Quercus suber* L.*	

ADDENDUM B

Fieldwork – Plot information

Plot	Land-cover type	GPS	Nearest town	Minor locality	No of trees	Saplings	Total	No of species
1	Urban open space	S 26º 40' 43.12" E 27º 05' 42.17"	Potchefstroom	NWU Ingenieurs Campus	49	43	92	9
2	Plantation	S 26º 42' 06.50" E 27º 04' 41.61"	Potchefstroom	Louis le Grange Street	58	88	146	8
3	Riparian area	S 26º 46.728' E 27º 17.778'	Potchefstroom	Orepass Mining Technologies	37	118	155	11
4	Ridge	S 26º 44.587' E 27º 17.751'	Potchefstroom	Orepass Mining Technologies	75	127	202	13
5	Plantation	S 26º 44.285' E 27º 17.791'	Potchefstroom	Orepass Mining Technologies	77	189	266	7
6	Ridge	S 26º 39.954' E 27º 02.494'	Potchefstroom	Eleazer Road	24	34	58	9
7	Riparian area	S 26º 51.843' E 27º 17.792'	Parys	Thabela Thabeng	20	46	66	8
8	Hillside	S 26º 51.422' E 27º 16.970'	Parys	Thabela Thabeng	18	74	92	17
9	Sandy area	S 26º 34.147' E 26º 56.376'	Potchefstroom	Welgegund Station	26	109	135	7
10	Plantation	S 26º 50.570' E 26º 42.662'	Klerksdorp	Matlosana Mall	49	21	70	1
11	Plantation	S 26º 33.052' E 27º 06.836'	Potchefstroom	Boskop Dam	32	48	80	8
12	Grassland	S 26º 25.204' E 27º 13.782'	Potchefstroom	Blaauwbank Piggery	31	37	68	8
13	Plantation	S 26º 19.498' E 26º 49.915'	Ventersdorp	Bikers Got Soul	113	459	572	16
14	Ridge	S 26º 26.978' E 26º 52.190'	Ventersdorp	Naleloudi Lodge	7	291	298	11
15	Sandy area	S 26º 35.559' E 27º 01.877'	Potchefstroom	10 km Potch signboard	75	202	277	10
16	Ridge	S 26º 41.850' E 27º 16.201'	Potchefstroom	Hekplaas - Modderdam	23	417	440	14
17	Riparian area	S 26º 44.396' E 27º 06.378'	Potchefstroom	Prozesky - Mooirivier	34	117	151	9
18	Ridge	S 26º 56.322' E 27º 02.006'	Potchefstroom	Vaalriver - Vermont	22	195	217	12
19	Ridge	S 26º 33.506' E 26º 56.333'	Potchefstroom	Welgegund Station	26	263	289	14
20	Urban open space	S 26º 44.297' E 27º 04.931'	Potchefstroom	Abraham Kriel	33	124	157	7
21	Street	S 26º 41.741' E 27º 04.542'	Potchefstroom	Vegkoppie Dassierand (Hlobi)	11	38	49	11
22	Street	S 26º 41.891' E 27º 04.543'	Potchefstroom	Bats Dassierand (Hlobi)	15	10	25	5
23	Street	S 26º 43.240' E 27º 05.646'	Potchefstroom	Smit street (Hlobi)	13	28	41	10
24	Riparian area	S 26º 58.139' E 27º 12.569'	Parys	Schoemansdrift - Vaalkop	24	255	279	12

25	Street	S 26º 50.070' E 26º 47.511'	Stilfontein	Miners College	19	29	48	12
26	Riparian area	S 26º 50.670' E 26º 46.978'	Stilfontein	Stilfontein Pan	24	41	65	13
27	Riparian area	S 26º 54.878' E 27º 23.880'	Parys	Rocky Ridge	39	656	695	15
28	Riparian area	S 26º 37.142' E 27º 17.836'	Potchefstroom	Klipdrift	16	1018	1034	5
29	Ridge	S 26º 37.746' E 26º 54.936'	Potchefstroom	Rietkuil - Wildebeestlaagte	32	12	44	6
30	Sandy area	S 26º 35.059' E 26º 51.090'	Potchefstroom	Rooikraal (Welgegund)	22	106	128	10
31	Ridge	S 26º 46.419' E 26º 41.812'	Klerksdorp	Rheeboksfontein Campsite	41	42	83	13
32	Sandy area	S 26º 48.210' E 26º 39.776'	Klerksdorp	North Hill Country House	40	306	346	10
33	Grassland	S 26º 35.405' E 27º 06.191'	Potchefstroom	Oudedorp	28	345	373	10
34	Grassland	S 26º 49.542' E 27º 08.641'	Potchefstroom	Haaskraal (Schoemansdrif)	52	552	604	10
35	Plantation	S 26º 15.142' E 27º 09.143'	Ventersdorp	Klerkskraal Dam	47	400	447	8
36	Street	S 26º 29.226' E 26º 29.308'	Fochville	Agtste street	10	0	10	4
37	Street	S 26º 29.941' E 27º 29.460'	Fochville	Potchefstroom Street - LS Losberg	10	19	29	6
38	Street	S 26º 22.118' E 27º 24.408'	Carletonville	Heath Place	10	6	16	7
39	Street	S 26º 44.309' E 27º 05.122'	Potchefstroom	Bloem street	10	108	118	4
40	Street	S 26º 40.982' E 27º 05.737'	Potchefstroom	Botanical Garden street	9	21	30	9
41	Street	S 26º 41.178' E 27º 05.970'	Potchefstroom	Gimmies Back yard	11	13	24	7
42	Street	S 26º 42.100' E 27º 06.791'	Potchefstroom	Rosini Street	12	79	91	8
43	Street	S 26º 41.804' E 27º 06.702'	Potchefstroom	PnP Duet	14	41	55	3
44	Street	S 26º 41.757' E 27º 05.352'	Potchefstroom	Campus Gate	9	38	47	3
45	Street	S 26º 41.711' E 27º 05.464'	Potchefstroom	Campus gate 4 - President Str	12	74	86	6
46	Street	S 26º 44.575' E 27º 05.052'	Potchefstroom	Louw Street	11	23	34	5
47	Street	S 26º 42.955' E 27º 06.786'	Potchefstroom	Suid Street	11	32	43	9
48	Street	S 26º 43.049' E 27º 07.038'	Potchefstroom	Republiek Street	12	27	39	8
49	Street	S 26º 42.665' E 27º 06.833'	Potchefstroom	Piet Cronje Street	11	3	14	3
50	Street	S 26º 43.622' E 27º 04.640'	Potchefstroom	Oranjerivier Avenue; Dep of Water	17	90	107	14
51	Street	S 26º 41.200' E 27º 05.765'	Potchefstroom	Venter Str - Gimmies	8	16	24	10
52	Street	S 26º 23.186' E 27º 16.929'	Carletonville	6de Street - Welverdiend	14	6	20	8
53	Hillside	S 26º 44.449' E 26º 28.837'	Hartbeesfontein	Thaba Tswene Game Lodge	47	190	237	11

54	Sandy area	S 26º 49.833' E 26º 32.863'	Hartbeesfontein	Rietkuil - Tussenin	15	69	84	5
55	Ridge	S 26º 23.271' E 27º 24.275'	Carletonville	Blyvoor - Driefontein Mine	8	136	144	5
56	Urban open space	S 26º 29.031' E 27º 29.163'	Fochville	Du Preez Str	28	162	190	7
57	Grassland	S 26º 30.853' E 26º 51.498'	Ventersdorp	Witrandsfontein	35	258	293	11
58	Ridge	S 26º 35.326' E 26º 49.842'	Potchefstroom	Doornfontein	24	827	851	13
59	Riparian area	S 26º 49.086' E 26º 36.958'	Klerksdorp	Klerksdorp Dam	35	652	687	14
60	Plantation	S 26º 39.800' E 26º 50.558'	Klerksdorp	Eleazar Road	26	42	68	6
61	Ridge	S 26º 30.349' E 26º 56.812'	Ventersdorp	Syferfontein	30	217	247	15
62	Sandy area	S 26º 28.250' E 26º 59.370'	Ventersdorp	Witpoort	27	111	138	9
63	Hillside	S 26º 21.863' E 27º 05.702'	Ventersdorp		38	150	188	13
64	Grassland	S 26º 19.063' E 27º 08.774'	Carletonville	De Beerskraal	14	200	214	5
65	Riparian area	S 26º 25.408' E 27º 06.906'	Potchefstroom	Muiskraal	17	308	325	11
66	Urban open space	S 26º 19.573' E 26º 49.205'	Ventersdorp	Roscher Str	25	72	97	7
67	Urban open space	S 26º 50.588' E 26º 40.001'	Klerksdorp	Dr Yusuf Dadoo Ave	25	158	183	14
68	Ridge	S 26º 31.150' E 26º 47.767'	Ventersdorp	Rooipoort - Klipplaatdrift	22	109	131	9
69	Riparian area	S 26º 25.330' E 26º 43.859'	Ventersdorp	Schoonrivier - Rietspruitdam road	29	132	161	10
70	Riparian area	S 26º 28.790' E 27º 09.096'	Carletonville	Oog - Gerhardminnebronne	45	313	358	12
71	Hillside	S 26º 28.222' E 27º 24.957'	Carletonville	Turnstone Drilling - Elandsfontein	32	163	195	12
72	Grassland	S 26º 55.679' E 26º 42.993'	Orkney	Vaal Reefs Mine	27	92	119	11
73	Hillside	S 26º 53.607' E 26º 38.824'	Klerksdorp	Best Street	21	104	125	13
74	Urban open space	S 26º 45.479' E 26º 25.365'	Hartbeesfontein	Eenheidstreet	24	60	84	9
75	Grassland	S 26º 40.808' E 26º 32.208'	Hartbeesfontein	Arizona Farm	20	319	339	7
76	Plantation	S 26º 42.648' E 26º 34.868'	Hartbeesfontein	Top Lay Kleinplaas - Brakspruit	35	266	301	5
77	Grassland	S 26º 14.149' E 26º 53.023'	Ventersdorp	Appeldraai (10km Ventersdorp)	72	395	467	9
78	Riparian area	S 26º 18.690' E 26º 50.211'	Ventersdorp	Mosaic B&B	31	784	815	13
79	Hillside	S 26º 29.180' E 26º 42.370'	Ventersdorp	Sterkspruit	16	483	499	10
80	Plantation	S 26º 27.067' E 26º 41.964'	Ventersdorp	Pretty Little Things / Boerbokstoet	15	26	41	4
81	Plantation	S 26º 08.402' E 26º 43.550'	Ventersdorp	Grootbosch - Trompie	13	9	22	5
82	Hillside	S 26º 13.212' E 26º 38.721'	Ventersdorp	Boschkop	29	183	212	11

83	Plantation	S 26º 57.075' E 27º 03.062'	Potchefstroom	S714 - Skandinawiedrif	36	103	139	8
84	Hillside	S 26º 56.616' E 27º 08.821'	Potchefstroom	Hanzet	37	127	164	11
85	Urban open space	S 26º 42.252' E 27º 07.090'	Potchefstroom	MC Roode avenue	21	140	161	11
86	Hillside	S 26º 47.936' E 27º 22.239'	Parys	Mooiplaas	18	172	190	13
87	Urban open space	S 26º 50.734' E 26º 47.170'	Stilfontein	Buffelsfontein Road	32	64	96	11
88	Urban open space	S 26º 59.443' E 26º 40.117'	Orkney	Sheridan way	30	140	170	10
89	Urban open space	S 26º 22.037' E 27º 23.063'	Carletonville	Klaserie & Vaal street	21	250	271	8
90	Hillside	S 26º 24.442' E 27º 27.129'	Carletonville	Western Deep Levels	22	170	192	15
91	Sandy area	S 26º 37.903' E 27º 21.776'	Potchefstroom	Palmietfontein	20	181	201	12
92	Sandy area	S 26º 34.068' E 26º 56.649'	Potchefstroom	Welgegund Station	35	157	192	11
93	Plantation	S 26º 33.902' E 26º 54.827'	Potchefstroom	Kromdraai	23	35	58	7
94	Grassland	S 26º 39.831' E 26º 59.146'	Potchefstroom	Eleazer road	17	80	97	11
95	Sandy area	S 26º 34.530' E 26º 56.301'	Potchefstroom	Welgegund Station	29	88	117	9
96	Ridge	S 26º 34.027' E 26º 56.293'	Potchefstroom	Welgegund Station	26	422	448	14
97	Urban open space	S 26º 28.127' E 27º 29.112'	Fochville	Jakaranda avenue	8	208	216	9
98	Plantation	S 26º 20.021' E 27º 25.451'	Carletonville	Crane Street Wissingdal	18	205	223	4
99	Ridge	S 26º 34.208' E 27º 06.726'	Potchefstroom	Boskop Yacht Club	22	641	663	6
100	Grassland	S 26º 26.617' E 27º 03.150'	Ventersdorp	Herman Fouche Farm	36	454	490	9
101	Riparian area	S 26º 20.497' E 26º 59.232'	Ventersdorp	Uitkyk	24	414	438	8
102	Sandy area	S 26º 33.807' E 26º 55.981'	Potchefstroom	Welgegund Station	13	35	48	7
103	Ridge	S 26º 33.759' E 26º 55.158'	Potchefstroom	Kromdraai	16	276	292	10
104	Sandy area	S 26º 39.743' E 26º 56.250'	Potchefstroom	Highveld National Park	46	248	294	11
105	Hillside	S 26º 38.862' E 26º 45.259'	Klerksdorp	Sterkstroom - Goedgevonden	20	249	269	17
106	Grassland	S 26º 36.066' E 26º 42.142'	Klerksdorp	Doornfontein	22	158	180	13
107	Urban open space	S 26º 45.677' E 26º 25.605'	Hartbeesfontein		18	497	515	10
108	Urban open space	S 26º 19.182' E 26º 49.671'	Ventersdorp	Graaf Street	14	373	387	12
109	Sandy area	S 26º 26.325' E 26º 52.898'	Ventersdorp	Leeufontein Road	25	208	233	10
110	Urban open space	S 26º 24.174' E 27º 22.947'	Carletonville	7th Avenue - Rockland Primary	31	400	431	8
111	Grassland	S 26º 23.921' E 27º 27.266'	Carletonville	Driefontein Mine	10	128	138	11

112	Riparian area	S 26º 56.164' E 26º 51.102'	Stilfontein	Vaalrivier - Wawielpark	15	553	568	11
113	Urban open space	S 26º 59.017' E 26º 41.234'	Orkney	Stevenson Road	47	442	489	14
114	Hillside	S 26º 10.825' E 26º 45.299'	Ventersdorp	Cecilias House	22	213	235	13
115	Riparian area	S 26º 20.452' E 26º 51.900'	Ventersdorp	Moosa Park - R53	11	351	362	6
116	Urban open space	S 26º 50.136' E 26º 39.736'	Klerksdorp	Scott Street	22	261	283	10
117	Grassland	S 26º 42.212' E 26º 48.705'	Klerksdorp	Rietfontein	33	266	299	10
118	Sandy area	S 26º 33.819' E 27º 00.633'	Potchefstroom	SAPD Mounted Academy	18	166	184	8
119	Plantation	S 26º 30.863' E 26º 59.790'	Potchefstroom	Rock valley	42	22	64	6
120	Sandy area	S 26º 34.281' E 26º 56.416'	Potchefstroom	Welgegund Station	34	128	162	11
121	Hillside	S 26º 34.848' E 26º 55.690'	Potchefstroom	Welgegund Station	36	405	441	16
122	Grassland	S 26º 30.966' E 26º 52.857'	Ventersdorp	Leeufontein	19	192	211	9
123	Riparian area	S 26º 35.252' E 26º 54.910'	Potchefstroom		34	390	424	14
124	Plantation	S 26º 36.790' E 26º 51.679'	Potchefstroom	Rooipoort - Soetvelde Farm	22	67	89	7
125	Ridge	S 26º 47.849' E 26º 37.348'	Klerksdorp	Across Panar	23	140	163	17
126	Grassland	S 26º 20.547' E 26º 26.348'	Coligny	Bodenstein	19	442	461	8
127	Hillside	S 26º 32.307' E 26º 24.057'	Hartbeesfontein	Brakpan	26	232	258	15
128	Sandy area	S 26º 34.145' E 26º 54.869'	Potchefstroom	Kromdraai	52	176	228	12
129	Sandy area	S 26º 33.496' E 26º 56.509'	Potchefstroom	Welgegund Station	12	51	63	8
130	Hillside	S 26º 19.261' E 27º 05.480'	Ventersdorp	Witkoppies	21	340	361	11
131	Grassland	S 26º 40.353' E 27º 28.324'	Fochville	Nuutbegin - Enslinspruit	12	87	99	8
132	Hillside	S 26º 45.038' E 27º 12.021'	Potchefstroom	Rooipoortjie	38	59	97	9
133	Plantation	S 26º 39.616' E 27º 04.358'	Potchefstroom	Mayor's Lapa	59	234	293	9
134	Garden R1	S26 43 24.8 E27 00 58.0	Ikageng	11955 Extention 7 - Ikageng	9	3	12	4
135	Garden R2	S26 43 25.5 E27 01 13.1	Ikageng	12046 Extention 7 - Ikageng	8	7	15	6
136	Garden R24	S26 43 05.9 E27 01 30.3	Ikageng	14330 Extention 7 - Ikageng	5	1	6	4
137	Garden R25	S26 43 06.4 E27 01 50.1	Mohadin	1st Avenue 4 - Mohadin	10	8	18	9
138	Garden R51	S26 42 50.8 E27 03 38.5	Ikageng	6048 Lerothodi Street - Ikageng	6	1	7	5
139	Garden R53	S26 42 44.8 E27 05 44.7	Potchefstroom		17	14	31	7

140	Garden R62	S26 42 38.5 E27 01 16.7	Ikageng	11020 Vuiswa Street - Ikageng	3	3	6	2
141	Garden R84	S26 42 19.5 E27 02 04.4	Promosa	1 Timmerman Street - Promosa	19	6	25	7
142	Garden R100	S26 42 00.7 E27 01 54.0	Promosa	15 Catherina Street - Promosa	10	4	14	7
143	Garden R102	S26 42 05.7 E27 02 18.4	Promosa	10 Paulsen Street - Promosa	5	3	8	6
144	Garden R17	S26 43 25.1 E27 06 38.9	Potchefstroom	Japonika 5 - Grimbeek Park	14	10	24	14
145	Garden R19	S26 43 24.1 E27 07 14.4	Potchefstroom		11	6	17	9
146	Garden R32	S26 43 12.5 E27 05 08.0	Potchefstroom	Smit Street 107 - Potch Sentraal	7	5	12	7
147	Garden R35	S26 43 09.3 E27 06 02.5	Potchefstroom	Rivier Street - Potch Sentraal	17	3	20	13
148	Garden R39	S26 43 04.5 E27 07 14.2	Potchefstroom	Strydom Street 110 - Bailie Park	15	4	19	12
149	Garden R56	S26 42 47.6 E27 06 37.8	Potchefstroom	Paryslaan - Grimbeek Park	9	3	12	9
150	Garden R71	S26 42 37.1 E27 05 23.2	Potchefstroom	Boys High School - Potch Central	12	6	18	13
151	Garden R72	S26 42 32.7 E27 05 44.3	Potchefstroom	Luke St 12 - Potch central (PnP)	10	2	12	8
152	Garden R73	S26 42 32.8 E27 06 01.9	Potchefstroom	Short Street 4 - Potch Central	14	1	15	12
153	Garden R74	S26 42 32.9 E27 06 25.1	Potchefstroom	Bremner Street 36 - Bailie Park	13	6	19	10
154	Garden R75	S26 42 34.9 E27 06 39.5	Potchefstroom	Kleyn Street 8 - Van Der Hoff Park	14	6	20	14
155	Garden R11		Potchefstroom	Witstinkhoutlaan 9	6	2	8	
156	Garden R12		Potchefstroom	Kruisstreet 19	8	8	16	
157	Garden R14		Potchefstroom	Susannastreet 13	6	6	12	
158	Garden R37		Potchefstroom	Lupinestreet 4 - Grimbeek Park	4	18	22	
159	Garden R26		Mohadin	Casimstreet 37 - Mohadin	2	3	5	
160	Garden R43		Ikageng	11204 Extention 7 - Ikageng	2	5	7	
161	Garden R45		Mohadin	22 Haffejee Street - Mohadin	3	1	4	
162	Garden R64		Promosa	15 Robert drive - Promosa	3	3	6	
163	Garden R83		Promosa	67 McDonald Street - Promosa	2	1	3	
164	Garden R125		Ikageng		3	4	7	
165	Garden R142		Ikageng		4	2	6	
166	Roadsides	S 26º 37' 39.5" E 27º 02' 53.4"	Potchefstroom	Ventersdorp Road - 5 km	10	41	51	4
167	Roadsides	S 26º 34.892' E 27º 01.566'	Potchefstroom	Ventersdorp Road - 10 km	5	44	49	5
168	Roadsides		Potchefstroom	Ventersdorp Road - 20 km	14	21	35	5

169	Roadsides	S 26º 31.522' E 27º 08.127'	Potchefstroom	Carletonville Road - 20 km	7	117	124	4
170	Roadsides	S 26º 35.929' E 27º 06.883'	Potchefstroom	Carletonville Road - 10 km	18	30	48	5
171	Roadsides	S 26º 39.909' E 27º 11.613'	Potchefstroom	Vanderbijlpark Road - 5 km	20	98	118	5
172	Roadsides	S 26º 38.099' E 27º 19.429'	Potchefstroom	Vanderbijlpark Road - 10 km	27	109	136	5
173	Roadsides	S 26º 37.273' E 27º 21.896'	Potchefstroom	Vanderbijlpark Road - 20 km	25	51	76	4
174	Roadsides	S 26º 45.496' E 27º 17.344'	Potchefstroom	Parys Road - 20 km	16	54	70	7
175	Roadsides	S 26º 45.115' E 27º 12.621'	Potchefstroom	Parys Road - 10 km	23	100	123	10
176	Roadsides	S 26º 56.759' E 27º 03.427'	Potchefstroom	Viljoenskroon Road - 20 km	29	62	91	6
177	Roadsides	S 26º 50.171' E 27º 04.607'	Potchefstroom	Viljoenskroon Road - 10 km	10	67	77	5
178	Roadsides	S 26º 46.715' E 27º 07.831'	Potchefstroom	Viljoenskroon Road - 5 km	22	45	67	7
179	Roadsides	S 26º 52.772' E 26º 58.974'	Potchefstroom	Kromdraai/Klerksdorp - 20 km	28	83	111	3
180	Roadsides	S 26º 51.626' E 27º 01.062'	Potchefstroom	Kromdraai/Klerksdorp - 10 km	25	84	109	8
181	Roadsides	S 26º 47.206' E 27º 03.622'	Potchefstroom	Kromdraai/Klerksdorp - 5 km	27	44	71	3

ADDENDUM C

Linear mixed model – Effect sizes

A	All total	B	Adults total
C	Indigenous total	D	Indigenous adults
E	Aliens total	F	Alien adults

	Land-cover type	Geometric Mean	Std Error	Garden	Grassland	Hillside	Plantation	Ridge	Riparian area	Roadside	Sandy area	Street
						A						
S (Species Richness)	Garden	7.25	0.64									
	Grassland	9.38	0.48	0.59								
	Hillside	12.94	0.59	1.57	1.5							
	Plantation	6.81	0.80	0.12	0.8	1.92						
	Ridge	11.38	0.90	1.14	0.56	0.43	1.27					
	Riparian area	10.81	0.75	0.98	0.48	0.70	1.25	0.16				
	Roadside	5.38	0.46	0.52	2.07	3.18	0.45	1.67	1.80			
	Sandy area	9.38	0.49	0.59	0.00	1.5	0.80	0.56	0.48	2.04		
	Street	7.24	0.68	0.00	0.69	1.83	0.13	1.15	1.15	0.60	0.69	
	Urban open spaces	9.75	0.56	0.69	0.17	1.34	0.92	0.45	0.35	1.96	0.17	0.81
N (Total number of Individuals)	Garden	13.34	1.24									
	Grassland	278.25	41.12	1.61								
	Hillside	234.69	28.47	1.94	0.26							
	Plantation	178.94	39.73	1.04	0.60	0.35						
	Ridge	281.81	55.89	1.20	0.02	0.21	0.46					
	Riparian area	411.06	70.75	1.41	0.47	0.62	0.82	0.46				
	Roadside	84.75	7.95	2.25	1.18	1.32	0.59	0.88	1.15			
	Sandy area	176.88	21.08	1.94	0.62	0.51	0.01	0.47	0.83	1.09		

	Street	45.24	6.67	1.04	1.42	1.66	0.84	1.06	1.29	1.24	1.56	
	Urban open spaces	238.50	36.06	1.56	0.24	0.03	0.37	0.19	0.61	1.07	0.43	1.34
d (Margalef species Richness)	Garden	2.42	0.19									
	Grassland	1.57	0.11	0.80								
	Hillside	2.24	0.12	0.17	1.39							
	Plantation	1.19	0.13	1.16	0.73	2.04						
	Ridge	1.95	0.16	0.44	0.59	0.45	1.17					
	Riparian area	1.74	0.14	0.64	0.32	0.92	1.01	0.32				
	Roadside	1.00	0.10	1.33	1.31	2.55	0.36	1.45	1.35			
	Sandy area	1.65	0.08	0.73	0.19	1.23	0.89	0.46	0.17	1.63		
	Street	1.74	0.17	0.64	0.22	0.65	0.70	0.28	0.00	0.94	0.11	
	Urban open spaces	1.66	0.10	0.72	0.21	1.21	0.91	0.45	0.15	1.61	0.02	0.10
J (Pielou's Eveness)	Garden	0.87	0.02									
	Grassland	0.67	0.03	1.63								
	Hillside	0.70	0.05	0.93	0.17							
	Plantation	0.60	0.06	1.12	0.27	0.40						
	Ridge	0.63	0.05	1.19	0.19	0.34	0.11					
	Riparian area	0.58	0.05	1.39	0.41	0.56	0.08	0.22				
	Roadside	0.70	0.04	1.07	0.18	0.01	0.39	0.33	0.55			
	Sandy area	0.76	0.02	0.84	0.80	0.36	0.68	0.67	0.88	0.43		
	Street	0.71	0.05	0.73	0.21	0.07	0.47	0.39	0.61	0.08	0.24	
	Urban open spaces	0.62	0.03	1.79	0.33	0.41	0.08	0.04	0.19	0.45	1.03	0.42
H (Shannon Index)	Garden	1.63	0.11									
	Grassland	1.49	0.09	0.23								
	Hillside	1.77	0.11	0.24	0.63							
	Plantation	1.14	0.11	0.83	0.81	1.42						
	Ridge	1.50	0.14	0.23	0.01	0.51	0.66					
	Riparian area	1.40	0.14	0.39	0.17	0.67	0.47	0.18				
	Roadside	1.14	0.09	0.83	1.00	1.42	0.00	0.66	0.46			

	Sandy area	1.69	0.06	0.10	0.59	0.18	1.27	0.36	0.53	1.57		
	Street	1.40	0.13	0.38	0.15	0.62	0.44	0.16	0.01	0.43	0.48	
	Urban open spaces	1.39	0.07	0.41	0.30	0.86	0.58	0.20	0.02	0.71	1.04	0.02
B												
S **(Species Richness)**	Garden	6.16	0.67									
	Grassland	4.94	0.53	0.32								
	Hillside	7.44	0.34	0.34	1.18							
	Plantation	3.81	0.61	0.62	0.46	1.49						
	Ridge	5.94	0.60	0.06	0.42	0.62	0.88					
	Riparian area	6.81	0.59	0.17	0.80	0.27	1.24	0.36				
	Roadside	3.44	0.49	0.71	0.71	2.04	0.15	1.04	1.44			
	Sandy area	6.06	0.52	0.02	0.53	0.66	0.93	0.05	0.32	1.26		
	Street	4.10	0.47	0.54	0.39	1.54	0.12	0.77	1.16	0.30	0.91	
	Urban open spaces	6.81	0.50	0.17	0.89	0.31	1.24	0.36	0.00	1.68	0.36	1.25
N **(Total number of Individuals)**	Garden	8.47	0.88									
	Grassland	27.94	3.99	1.22								
	Hillside	27.56	2.33	2.05	0.02							
	Plantation	40.56	6.27	1.28	0.50	0.52						
	Ridge	22.50	2.13	1.65	0.34	0.54	0.72					
	Riparian area	26.81	2.38	1.92	0.07	0.08	0.55	0.45				
	Roadside	19.13	1.98	1.34	0.55	0.91	0.85	0.40	0.81			
	Sandy area	30.56	4.13	1.34	0.16	0.18	0.40	0.49	0.23	0.69		
	Street	11.86	0.59	0.68	1.01	1.69	1.14	1.25	1.57	0.92	1.13	
	Urban open spaces	26.38	2.47	1.81	0.10	0.12	0.57	0.39	0.04	0.73	0.25	1.47
d **(Margalef species Richness)**	Garden	2.32	0.23									
	Grassland	1.18	0.13	0.86								
	Hillside	1.98	0.10	0.26	1.54							
	Plantation	0.75	0.14	1.19	0.77	2.19						
	Ridge	1.59	0.18	0.55	0.57	0.53	1.16					

	Riparian area	1.75	0.15	0.43	0.97	0.38	1.70	0.22				
	Roadside	0.85	0.16	1.11	0.53	1.81	0.15	1.03	1.45			
	Sandy area	1.51	0.13	0.61	0.63	0.89	1.36	0.12	0.41	1.06		
	Street	1.24	0.19	0.81	0.08	0.86	0.58	0.41	0.60	0.47	0.31	
	Urban open spaces	1.82	0.15	0.38	1.07	0.26	1.78	0.32	0.12	1.56	0.52	0.68
J (Pielou's Eveness)	Garden	0.85	0.05									
	Grassland	0.76	0.04	0.31								
	Hillside	0.84	0.02	0.03	0.53							
	Plantation	0.55	0.08	0.99	0.69	0.96						
	Ridge	0.75	0.06	0.35	0.04	0.37	0.66					
	Riparian area	0.83	0.03	0.04	0.51	0.03	0.95	0.36				
	Roadside	0.68	0.06	0.57	0.31	0.64	0.44	0.27	0.63			
	Sandy area	0.84	0.02	0.02	0.55	0.03	0.97	0.38	0.05	0.65		
	Street	0.67	0.07	0.56	0.27	0.53	0.41	0.24	0.52	0.02	0.54	
	Urban open spaces	0.79	0.04	0.18	0.24	0.29	0.81	0.19	0.27	0.46	0.31	0.39
H (Shannon Index)	Garden	1.47	0.14									
	Grassland	1.14	0.11	0.43								
	Hillside	1.66	0.06	0.25	1.17							
	Plantation	0.74	0.13	0.94	0.78	1.82						
	Ridge	1.34	0.13	0.17	0.38	0.61	1.12					
	Riparian area	1.56	0.11	0.11	0.93	0.24	1.61	0.41				
	Roadside	0.81	0.12	0.86	0.71	1.83	0.12	1.00	1.60			
	Sandy area	1.47	0.08	0.01	0.73	0.60	1.43	0.24	0.21	1.41		
	Street	1.00	0.13	0.61	0.23	1.14	0.45	0.58	0.96	0.34	0.80	
	Urban open spaces	1.49	0.10	0.03	0.79	0.44	1.49	0.29	0.14	1.47	0.07	0.85
Basal Area	Garden	3040.14	426.85									
	Grassland	2660.59	650.09	0.34								
	Hillside	1786.20	227.71	1.28	1.32							
	Plantation	33517.60	6007.50	0.27	0.07	1.31						

	Ridge	1960.22	593.19	1.19	1.24	0.32	1.23					
	Riparian area	25728.70	4846.07	0.44	0.58	1.18	0.56	1.06				
	Roadside	5240.83	1477.68	1.2	1.39	1.05	1.36	0.90	0.50			
	Sandy area	8203.68	1151.86	1.12	1.17	0.47	1.16	0.19	0.97	0.80		
	Street	22142.22	3793.45	0.58	0.68	1.07	0.66	0.93	0.28	0.06	0.83	
	Urban open spaces	7711.66	2190.94	0.52	0.58	0.95	0.57	0.77	0.36	0.17	0.65	0.20
Crown Diameter	Garden	25.09	2.76									
	Grassland	61.16	5.76	0.38								
	Hillside	52.40	3.37	1.23	1.44							
	Plantation	110.97	10.15	0.82	0.45	1.69						
	Ridge	42.22	5.60	1.42	1.68	0.05	1.98					
	Riparian area	108.93	8.43	0.32	0.07	1.41	0.52	1.63				
	Roadside	53.82	5.03	0.76	0.96	0.37	1.19	0.32	0.93			
	Sandy area	94.75	11.02	0.97	1.22	0.39	1.51	0.39	1.18	0.01		
	Street	95.31	7.67	0.23	0.68	1.10	1.08	1.26	0.61	0.64	0.82	
	Urban open spaces	66.52	5.22	0.16	0.38	1.07	0.63	1.02	0.34	0.61	0.68	0.03
C												
S (Species Richness)	Garden	1.03	0.17									
	Grassland	8.81	0.57	3.40								
	Hillside	12.75	0.55	5.31	1.72							
	Plantation	4.06	0.46	1.64	2.08	3.94						
	Ridge	11.13	0.88	2.88	0.66	0.46	2.02					
	Riparian area	6.00	0.66	1.87	1.06	2.54	0.73	1.46				
	Roadside	3.31	0.41	1.41	2.41	4.28	0.41	2.23	1.01			
	Sandy area	8.75	0.45	4.27	0.03	1.81	2.54	0.68	1.03	3.01		
	Street	2.57	0.34	1.00	2.73	4.61	0.81	2.44	1.29	0.46	3.42	
	Urban open spaces	5.25	0.37	2.84	1.56	3.40	0.64	1.68	0.28	1.19	1.94	1.74
N (Total number of Individuals)	Garden	2.41	0.58									
	Grassland	274.38	41.58	1.64								

	Hillside	233.88	28.58	2.02	0.24							
	Plantation	99.44	29.51	0.82	1.05	1.14						
	Ridge	281.38	55.92	1.25	0.03	0.21	0.81					
	Riparian area	264.31	61.51	1.06	0.04	0.12	0.67	0.07				
	Roadside	53.00	7.69	1.64	1.33	1.58	0.39	1.02	0.86			
	Sandy area	166.13	20.09	2.04	0.65	0.59	0.56	0.52	0.40	1.41		
	Street	19.71	5.63	0.67	1.53	1.87	0.68	1.17	0.99	1.08	1.82	
	Urban open spaces	121.31	21.95	1.35	0.92	0.98	0.19	0.72	0.58	0.78	0.51	1.16
d **(Margalef species Richness)**	Garden	0.19	0.07									
	Grassland	1.47	0.13	2.54								
	Hillside	2.21	0.11	4.55	1.47							
	Plantation	0.78	0.10	1.48	1.38	3.23						
	Ridge	1.91	0.16	2.70	0.68	0.48	1.78					
	Riparian area	1.00	0.13	1.59	0.95	2.41	0.43	1.43				
	Roadside	0.60	0.09	1.02	1.75	3.64	0.46	2.06	0.80			
	Sandy area	1.54	0.07	3.42	0.14	1.50	1.95	0.57	1.09	2.67		
	Street	0.67	0.12	0.85	1.41	2.71	0.18	1.94	0.57	0.14	1.53	
	Urban open spaces	0.94	0.06	1.89	1.06	2.86	0.41	1.52	0.11	0.97	2.11	0.47
J **(Pielou's Eveness)**	Garden	0.16	0.06									
	Grassland	0.66	0.04	1.57								
	Hillside	0.70	0.05	1.67	0.17							
	Plantation	0.50	0.08	1.06	0.54	0.65						
	Ridge	0.63	0.05	1.47	0.16	0.33	0.43					
	Riparian area	0.51	0.07	1.08	0.59	0.71	0.02	0.47				
	Roadside	0.56	0.07	1.25	0.37	0.48	0.20	0.25	0.19			
	Sandy area	0.76	0.02	1.88	0.66	0.35	0.87	0.65	0.96	0.71		
	Street	0.57	0.09	0.98	0.23	0.31	0.17	0.15	0.15	0.02	0.47	
	Urban open spaces	0.61	0.04	1.41	0.31	0.45	0.37	0.09	0.40	0.18	0.89	0.11
H	Garden	0.15	0.05									

(Shannon Index)	Grassland	1.45	0.10	3.21								
	Hillside	1.76	0.11	3.52	0.68							
	Plantation	0.71	0.10	1.35	1.74	2.28						
	Ridge	1.49	0.13	2.48	0.08	0.50	1.43					
	Riparian area	0.94	0.15	1.33	0.86	1.39	0.38	0.93				
	Roadside	0.70	0.11	1.24	1.67	2.31	0.03	1.45	0.40			
	Sandy area	1.63	0.06	5.01	0.46	0.28	2.18	0.27	1.17	2.09		
	Street	0.62	0.11	0.91	1.61	2.21	0.18	1.61	0.54	0.16	1.96	
	Urban open spaces	0.96	0.06	2.76	1.19	1.74	0.60	0.97	0.05	0.59	2.76	0.67
						D						
S (Species Richness)	Garden	0.72	0.16									
	Grassland	4.75	0.52	1.94								
	Hillside	7.38	0.34	4.89	1.26							
	Plantation	1.94	0.41	0.74	1.35	3.29						
	Ridge	5.94	0.60	2.17	0.49	0.60	1.66					
	Riparian area	3.56	0.52	1.36	0.57	1.82	0.78	0.99				
	Roadside	1.56	0.39	0.55	1.53	3.76	0.23	1.82	0.95			
	Sandy area	5.94	0.50	2.63	0.57	0.73	2.02	0.00	1.13	2.21		
	Street	0.86	0.22	0.14	1.87	4.79	0.65	2.11	1.29	0.46	2.56	
	Urban open spaces	3.56	0.39	1.84	0.57	2.46	0.98	0.99	0.00	1.29	1.20	1.75
N (Total number of Individuals)	Garden	1.00	0.26									
	Grassland	27.13	4.02	1.63								
	Hillside	27.50	2.35	2.82	0.02							
	Plantation	10.06	2.75	0.82	1.06	1.59						
	Ridge	22.50	2.13	2.53	0.29	0.53	1.13					
	Riparian area	12.19	2.37	1.18	0.93	1.62	0.19	1.09				
	Roadside	6.50	1.87	0.74	1.28	2.24	0.32	1.88	0.60			
	Sandy area	30.31	4.13	1.78	0.19	0.17	1.23	0.47	1.10	1.44		
	Street	2.48	0.78	0.41	1.53	2.67	0.69	2.36	1.03	0.54	1.69	

	Urban open spaces	13.94	1.93	1.67	0.82	1.44	0.35	1.01	0.18	0.96	0.99	1.48
d **(Margalef species Richness)**	Garden	0.19	0.08									
	Grassland	1.12	0.14	1.73								
	Hillside	1.96	0.09	3.74	1.54							
	Plantation	0.44	0.13	0.51	1.26	3.03						
	Ridge	1.59	0.18	1.93	0.65	0.50	1.58					
	Riparian area	1.01	0.16	1.29	0.17	1.47	0.89	0.80				
	Roadside	0.34	0.12	0.32	1.45	3.40	0.20	1.72	1.05			
	Sandy area	1.48	0.13	2.56	0.66	0.95	2.06	0.16	0.73	2.26		
	Street	0.18	0.09	0.00	1.74	4.09	0.51	1.94	1.29	0.33	2.57	
	Urban open spaces	0.97	0.14	1.37	0.26	1.71	0.92	0.85	0.06	1.10	0.88	1.37
J **(Pielou's Eveness)**	Garden	0.14	0.06									
	Grassland	0.70	0.06	1.65								
	Hillside	0.84	0.02	2.05	0.58							
	Plantation	0.32	0.09	0.51	1.10	1.49						
	Ridge	0.75	0.06	1.79	0.19	0.37	1.23					
	Riparian area	0.70	0.08	1.66	0.01	0.44	1.10	0.15				
	Roadside	0.38	0.11	0.52	0.72	1.02	0.13	0.82	0.72			
	Sandy area	0.84	0.01	2.06	0.60	0.03	1.50	0.38	0.45	1.02		
	Street	0.15	0.07	0.02	1.70	2.12	0.49	1.85	1.71	0.50	2.13	
	Urban open spaces	0.67	0.08	1.56	0.09	0.53	1.01	0.24	0.10	0.65	0.54	1.61
H **(Shannon Index)**	Garden	0.12	0.05									
	Grassland	1.09	0.13	1.90								
	Hillside	1.66	0.06	4.99	1.12							
	Plantation	0.38	0.11	0.60	1.40	3.02						
	Ridge	1.34	0.13	2.28	0.48	0.59	1.81					
	Riparian area	0.88	0.14	1.32	0.35	1.34	0.88	0.80				
	Roadside	0.35	0.12	0.50	1.45	2.83	0.05	1.86	0.93			
	Sandy area	1.45	0.08	4.21	0.72	0.65	2.54	0.21	0.99	2.39		

	Street	0.13	0.07	0.02	1.88	4.95	0.58	2.27	1.31	0.48	4.19	
	Urban open spaces	0.90	0.12	1.56	0.37	1.52	1.05	0.83	0.03	1.10	1.11	1.54
Basal Area	Garden	477.94	193.66									
	Grassland	2476.05	668.87	0.75								
	Hillside	1786.16	227.71	1.19	0.26							
	Plantation	155.39	127.58	0.29	0.87	1.79						
	Ridge	1960.22	593.19	0.62	0.19	0.07	0.76					
	Riparian area	3028.91	1308.27	0.49	0.11	0.24	0.55	0.20				
	Roadside	304.43	187.58	0.16	0.81	1.63	0.20	0.70	0.52			
	Sandy area	8202.66	1151.72	1.68	1.24	1.39	1.75	1.36	0.99	1.71		
	Street	4774.54	2080.76	0.45	0.24	0.31	0.48	0.30	0.18	0.47	0.36	
	Urban open spaces	2514.67	1188.31	0.43	0.01	0.15	0.50	0.12	0.10	0.46	1.20	0.24
Crown Diameter	Garden	4.78	1.49									
	Grassland	58.48	6.07	2.21								
	Hillside	52.34	3.39	3.50	0.25							
	Plantation	14.66	4.19	0.59	1.80	2.25						
	Ridge	42.22	5.60	1.67	0.67	0.45	1.23					
	Riparian area	37.18	8.51	0.95	0.63	0.45	0.66	0.15				
	Roadside	16.18	4.95	0.58	1.74	1.83	0.08	1.16	0.62			
	Sandy area	94.51	11.01	2.04	0.82	0.96	1.81	1.19	1.30	1.78		
	Street	19.21	7.28	0.43	1.18	0.99	0.14	0.69	0.53	0.09	1.71	
	Urban open spaces	33.44	4.48	1.60	1.03	1.06	1.05	0.39	0.11	0.87	1.39	0.43
E												
S (Species Richness)	Garden	6.22	0.67									
	Grassland	0.56	0.16	1.48								
	Hillside	0.19	0.10	1.58	0.60							
	Plantation	2.75	0.54	0.91	1.02	1.19						
	Ridge	0.25	0.17	1.56	0.46	0.09	1.17					
	Riparian area	4.81	0.59	0.37	1.81	1.97	0.88	1.95				

	Roadside	2.06	0.27	1.09	1.41	1.76	0.32	1.71	1.17			
	Sandy area	0.63	0.18	1.47	0.09	0.61	0.99	0.52	1.79	1.35		
	Street	4.67	0.46	0.41	1.93	2.10	0.89	2.07	0.06	1.22	1.90	
	Urban open spaces	4.50	0.50	0.45	1.97	2.16	0.82	2.13	0.13	1.22	1.94	0.08
N (Total number of Individuals)	Garden	10.94	1.16									
	Grassland	3.88	2.18	0.81								
	Hillside	0.81	0.63	1.55	0.35							
	Plantation	79.50	24.58	0.70	0.77	0.80						
	Ridge	0.44	0.30	1.61	0.39	0.15	0.80					
	Riparian area	146.75	45.37	0.75	0.79	0.80	0.37	0.81				
	Roadside	31.75	5.11	1.02	1.36	1.51	0.49	1.53	0.63			
	Sandy area	10.75	4.70	0.01	0.37	0.53	0.70	0.55	0.75	1.03		
	Street	25.52	4.99	0.64	0.95	1.08	0.55	1.10	0.67	0.27	0.65	
	Urban open spaces	117.19	33.09	0.80	0.86	0.88	0.28	0.88	0.16	0.65	0.80	0.69
d (Margalef species Richness)	Garden	2.17	0.21									
	Grassland	0.02	0.02	1.83								
	Hillside	0.00	0.00	1.84	0.25							
	Plantation	0.40	0.10	1.50	1.01	1.06						
	Ridge	0.10	0.07	1.76	0.30	0.36	0.79					
	Riparian area	0.86	0.13	1.11	1.58	1.61	0.86	1.42				
	Roadside	0.34	0.08	1.55	0.96	1.02	0.17	0.71	0.98			
	Sandy area	0.03	0.02	1.82	0.15	0.37	0.98	0.25	1.55	0.92		
	Street	1.26	0.16	0.77	1.74	1.76	1.20	1.62	0.56	1.29	1.72	
	Urban open spaces	0.84	0.10	1.13	2.02	2.07	1.07	1.82	0.04	1.23	1.99	0.59
J (Pielou's Eveness)	Garden	0.83	0.04									
	Grassland	0.04	0.04	3.17								
	Hillside	0.00	0.00	3.32	0.25							
	Plantation	0.48	0.09	1.00	1.28	1.38						
	Ridge	0.11	0.07	2.45	0.24	0.37	1.07					

	Riparian area	0.56	0.07	0.92	1.79	1.92	0.23	1.54				
	Roadside	0.30	0.08	1.68	0.83	0.95	0.52	0.61	0.83			
	Sandy area	0.07	0.06	3.05	0.13	0.28	1.19	0.14	1.69	0.73		
	Street	0.71	0.06	0.46	2.49	2.63	0.65	2.03	0.50	1.29	2.37	
	Urban open spaces	0.57	0.07	0.99	1.97	2.11	0.24	1.55	0.01	0.84	1.86	0.53
H **(Shannon Index)**	Garden	1.45	0.12									
	Grassland	0.03	0.03	2.05								
	Hillside	0.00	0.00	2.09	0.25							
	Plantation	0.48	0.08	1.39	1.38	1.45						
	Ridge	0.07	0.05	1.98	0.24	0.37	1.23					
	Riparian area	0.91	0.15	0.78	1.43	1.47	0.69	1.35				
	Roadside	0.28	0.08	1.69	0.82	0.90	0.62	0.66	1.02			
	Sandy area	0.05	0.04	2.02	0.13	0.28	1.31	0.14	1.39	0.75		
	Street	1.10	0.12	0.50	1.91	1.96	1.10	1.82	0.31	1.47	1.87	
	Urban open spaces	0.77	0.10	0.98	1.88	1.94	0.73	1.75	0.22	1.25	1.82	0.59
F												
S **(Species Richness)**	Garden	5.44	0.69									
	Grassland	0.19	0.10	1.34								
	Hillside	0.06	0.06	1.37	0.31							
	Plantation	1.88	0.29	0.91	1.47	1.58						
	Ridge	0.00	0.00	1.39	0.47	0.25	1.63					
	Riparian area	3.25	0.41	0.56	1.85	1.93	0.83	1.97				
	Roadside	1.88	0.27	0.91	1.55	1.67	0.00	1.72	0.83			
	Sandy area	0.13	0.09	1.36	0.16	0.18	1.53	0.37	1.89	1.61		
	Street	3.24	0.38	0.56	1.74	1.81	0.78	1.84	0.01	0.78	1.77	
	Urban open spaces	3.25	0.30	0.56	2.59	2.69	1.16	2.75	0.00	1.16	2.64	0.01
N **(Total number of Individuals)**	Garden	7.47	0.90									
	Grassland	0.81	0.58	1.31								
	Hillside	0.06	0.06	1.46	0.32							

	Plantation	30.50	5.18	1.11	1.43	1.47						
	Ridge	0.00	0.00	1.47	0.35	0.25	1.47					
	Riparian area	14.63	1.82	0.99	1.90	2.00	0.77	2.01				
	Roadside	12.63	1.94	0.67	1.53	1.62	0.86	1.63	0.26			
	Sandy area	0.25	0.19	1.42	0.24	0.24	1.46	0.32	1.98	1.60		
	Street	9.38	0.82	0.38	2.27	2.47	1.02	2.49	0.72	0.42	2.42	
	Urban open spaces	12.44	2.48	0.50	1.17	1.25	0.87	1.25	0.22	0.02	1.23	0.31
d (Margalef Species Richness)	Garden	2.09	0.25									
	Grassland	0.00	0.00	1.50								
	Hillside	0.00	0.00	1.50	0.00							
	Plantation	0.25	0.07	1.33	0.86	0.86						
	Ridge	0.00	0.00	1.50	0.00	0.00	0.86					
	Riparian area	0.79	0.13	0.94	1.47	1.47	1.01	1.47				
	Roadside	0.49	0.14	1.15	0.87	0.87	0.44	0.87	0.51			
	Sandy area	0.00	0.00	1.50	0.00	0.00	0.86	0.00	1.47	0.87		
	Street	1.01	0.16	0.78	1.34	1.34	1.02	1.34	0.30	0.69	1.34	
	Urban open spaces	1.03	0.14	0.76	1.87	1.87	1.43	1.87	0.45	0.95	1.87	0.03
J (Pielou's Eveness)	Garden	0.79	0.06									
	Grassland	0.00	0.00	2.20								
	Hillside	0.00	0.00	2.20	0.00							
	Plantation	0.33	0.10	1.17	0.85	0.85						
	Ridge	0.00	0.00	2.20	0.00	0.00	0.85					
	Riparian area	0.60	0.09	0.54	1.69	1.69	0.68	1.69				
	Roadside	0.43	0.11	0.82	0.97	0.97	0.22	0.97	0.38			
	Sandy area	0.00	0.00	2.20	0.00	0.00	0.85	0.00	1.69	0.97		
	Street	0.63	0.07	0.44	1.84	1.84	0.77	1.84	0.10	0.46	1.84	
	Urban open spaces	0.78	0.08	0.03	2.53	2.53	1.14	2.53	0.51	0.79	2.53	0.43
H (Shannon Index)	Garden	1.32	0.15									
	Grassland	0.00	0.00	1.61								

	Hillside	0.00	0.00	1.61	0.00							
	Plantation	0.30	0.09	1.24	0.86	0.86						
	Ridge	0.00	0.00	1.61	0.00	0.00	0.86					
	Riparian area	0.79	0.15	0.64	1.36	1.36	0.84	1.36				
	Roadside	0.38	0.10	1.15	0.92	0.92	0.19	0.92	0.71			
	Sandy area	0.00	0.00	1.61	0.00	0.00	0.86	0.00	1.36	0.92		
	Street	0.82	0.12	0.61	1.55	1.55	0.98	1.55	0.04	0.83	1.55	
	Urban open spaces	0.90	0.10	0.52	2.20	2.20	1.46	2.20	0.17	1.25	2.20	0.14
Basal Area	Garden	2562.20	391.01									
	Grassland	184.54	126.97	1.07								
	Hillside	0.04	0.04	1.16	0.36							
	Plantation	33362.22	6023.25	1.28	1.38	1.38						
	Ridge	0.00	0.00	1.16	0.36	0.25	1.38					
	Riparian area	22699.79	5047.57	1.00	1.12	1.12	0.44	1.12				
	Roadside	4936.40	1509.43	0.39	0.79	0.82	1.18	0.82	0.88			
	Sandy area	1.02	0.85	1.16	0.36	0.29	1.38	0.30	1.12	0.82		
	Street	17367.68	3918.60	0.82	0.96	0.97	0.66	0.97	0.26	0.69	0.97	
	Urban open spaces	5196.99	2141.16	0.31	0.59	0.61	1.17	0.61	0.87	0.03	0.61	0.68
Crown Diameter	Garden	20.31	2.63									
	Grassland	2.68	2.00	1.18								
	Hillside	0.06	0.06	1.36	0.33							
	Plantation	96.30	8.54	2.22	2.74	2.82						
	Ridge	0.00	0.00	1.36	0.34	0.25	2.82					
	Riparian area	71.76	9.37	1.37	1.84	1.91	0.66	1.92				
	Roadside	37.64	5.17	0.84	1.69	1.82	1.72	1.82	0.91			
	Sandy area	0.24	0.21	1.35	0.31	0.21	2.81	0.29	1.91	1.81		
	Street	76.10	9.62	1.27	1.67	1.72	0.46	1.73	0.10	0.87	1.72	
	Urban open spaces	33.08	6.10	0.52	1.25	1.35	1.85	1.35	1.03	0.19	1.35	0.98

ADDENDUM D

Simper Analysis

- Alien species
- Socio economic-status

Urban open space
Plantation
Riparian
Range

Street
Garden
Road
Rangelands

Alien Species	Percentage
Urban open space vs Plantation	**70.41%**
Melia azedarach	38.87%
Populus canescens	14.98%
Eucalyptus camaldulensis	11.83%
Acacia podalyriifolia	7.92%
Eucalyptus sideroxylon	6.39%
Cestrum laevigatum	6.07%
Acacia melanoxylon	3.46%
Urban open space vs Range	**80.17%**
Melia azedarach	67.17%
Acacia podalyriifolia	10.32%
Cestrum laevigatum	5.57%
Acacia melanoxylon	4.51%
Robinia pseudoacacia	2.29%
Urban open space vs Garden	**93.89%**
Melia azedarach	61.00%
Acacia podalyriifolia	8.42%
Cestrum laevigatum	6.41%
Acacia melanoxylon	3.68%
Plantation vs Riparian	**53.88%**
Ligustrum lucidum	25.09%
Melia azedarach	18.25%
Eucalyptus camaldulensis	13.04%
Populus canescens	10.38%
Eucalyptus sideroxylon	7.77%
Cestrum laevigatum	7.62%
Salix babylonica	4.09%
Plantation vs Street	**89.02%**
Melia azedarach	22.58%
Populus canescens	20.54%
Eucalyptus camaldulensis	17.33%

Eucalyptus sideroxylon	9.38%
Celtis sinensis	7.84%
Acer buergerianum	4.38%
Riparian vs Rangelands	**81.85%**
Melia azedarach	30.01%
Populus canescens	25.18%
Ligustrum lucidum	24.66%
Cestrum laevigatum	5.12%
Riparian vs Garden	**90.37%**
Melia azedarach	30.01%
Populus canescens	25.18%
Ligustrum lucidum	24.66%
Cestrum laevigatum	5.12%
Rangelands vs Street	**68.94%**
Celtis sinensis	23.26%
Melia azedarach	15.38%
Acer buergerianum	13.00%
Ulmus parvifolia	8.97%
Ligustrum lucidum	5.31%
Gleditsia triacanthos	4.03%
Rangeland vs Road	**67.67%**
Gleditsia triacanthos	20.39%
Eucalyptus camaldulensis	17.28%
Eucalyptus sideroxylon	12.23%
Robinia pseudoacacia	10.29%
Melia azedarach	8.35%
Ulmus parvifolia	7.57%
Cestrum laevigatum	6.99%
Celtis australis	4.66%
Acacia mearnsii	4.08%
Garden vs Road	**93.02%**
Gleditsia triacanthos	16.15%
Eucalyptus camaldulensis	11.51%
Melia azedarach	10.76%
Ligustrum lucidum	10.76%
Eucalyptus sideroxylon	7.88%
Robinia pseudoacacia	6.63%
Urban open space vs Riparian	**52.4%**
Populus canescens	24.22%
Ligustrum lucidum	23.23%
Melia azedarach	22.91%
Acacia podalyriifolia	7.95%
Salix babylonica	3.62%
Urban open space vs Street	**83.51%**
Melia azedarach	61.01%
Acacia podalyriifolia	8.73%

Celtis sinensis	4.66%
Cestrum laevigatum	4.66%
Acacia melanoxylon	3.72%
Urban open space vs Road	**81.2%**
Melia azedarach	61.45%
Acacia podalyriifolia	9.10%
Cestrum laevigatum	6.77%
Gleditsia triacanthos	5.17%
Acacia melanoxylon	3.98%
Plantation vs Range	**80.2%**
Populus canescens	27.05%
Melia azedarach	22.91%
Eucalyptus camaldulensis	22.58%
Eucalyptus sideroxylon	12.35%
Plantation vs Garden	**93.39%**
Melia azedarach	26.95%
Populus canescens	21.84%
Eucalyptus camaldulensis	18.43%
Eucalyptus sideroxylon	9.97%
Plantation vs Road	**72.18%**
Populus canescens	25.77%
Melia azedarach	25.15%
Eucalyptus camaldulensis	14.63%
Gleditsia triacanthos	9.99%
Eucalyptus sideroxylon	6.89%
Robinia pseudoacacia	4.03%
Riparian vs Street	**88.36%**
Melia azedarach	28.34%
Populus canescens	21.01%
Ligustrum lucidum	19.44%
Celtis sinensis	4.51%
Cestrum laevigatum	4.23%
Riparian vs Road	**87.82%**
Melia azedarach	30.01%
Populus canescens	25.18%
Ligustrum lucidum	24.66%
Cestrum laevigatum	5.12%
Rangeland vs Garden	**95.03%**
Melia azedarach	22.47%
Ligustrum lucidum	14.98%
Cestrum laevigatum	6.79%
Gleditsia triacanthos	4.18%
Street vs Garden	**78.65%**
Celtis sinensis	15.14%
Acer buergerianum	9.57%
Ligustrum lucidum	8.14%

Melia azedarach	6.43%
Cestrum laevigatum	5.71%
Ulmus parvifolia	5.57%
Celtis australis	4.14%
Street vs Road	**79.37%**
Celtis sinensis	15.88%
Gleditsia triacanthos	15.28%
Eucalyptus camaldulensis	11.07%
Acer buergerianum	8.54%
Eucalyptus sideroxylon	7.58%
Robinia pseudoacacia	5.05%
Melia azedarach	4.93%
Cestrum laevigatum	4.45%
Pooled Groups	**80.06%**
Melia azedarach	29.83%
Populus canescens	11.04%
Ligustrum lucidum	8.82%
Eucalyptus camaldulensis	7.09%
Cestrum laevigatum	4.27%
Gleditsia triacanthos	4.26%
Celtis sinensis	4.23%
Eucalyptus sideroxylon	4.09%

Simper Analysis – Socio-economic Status

SES 1
SES 2
SES 3
SES 4
SES 5

Species	Percentage
1 Socio-economic status - 2 Socio-economic status	**46.42%**
Schinus molle	14.63%
Ligustrum lucidum	13.82%
Prunus persica	8.13%
Chamaecyparis lawsoniana	5.69%
Fraxinus pennsylvanica ; Ulmus parvifolia ; Viburnum tinus	4.07%
Phoenix canariensis	3.25%
1 Socio-economic status - 3 Socio-economic status	**41.42%**
Ficus carica	10.1%
Schinus molle	9.09%
Phoenix canariensis ; Ulmus parvifolia ; Melia azedarach ; Viburnum tinus	5.05%
Chamaecyparis lawsoniana ; Ligustrum lucidum ; Fraxinus pennsylvanica	4.04%
Euonymus japonicus ; Populus simonsii ; Trachycarpus fortunei ; Cydonia oblonga	3.03%
1 Socio-economic status - 4 Socio-economic status	**72.28%**
Celtis sinensis	10.47%
Lagerstroemia indica	4.57%
Ligustrum lucidum	3.84%
Morus alba	3.69%
Nandina domestica	3.54%
Chamaecyparis lawsoniana	3.39%
1 Socio-economic status - 5 Socio-economic status	**58.89%**
Chamaecyparis lawsoniana	7.23%
Celtis sinensis	5.97%
Ulmus parvifolia	5.31%
Nandina domestica	4.72%
Acer buergerianum	3.46%
Melaleuca armillaris	3.15%
2 Socio-economic status - 3 Socio-economic status	**45.13%**
Schinus molle	26.47%
Ligustrum lucidum	12.75%
Ficus carica	9.80%
Prunus persica	7.84%
Nerium oleander	3.92%
2 Socio-economic status - 4 Socio-economic status	***77.95%***
Celtis sinensis	9.99%
Lagerstroemia indica	4.58%

Chamaecyparis lawsoniana	4.16%
Nandina domestica ; Morus alba	3.61%
Schinus molle ; Cordyline australis	3.33%
2 Socio-economic status - 5 Socio-economic status	**75.33%**
Chamaecyparis lawsoniana	7.56%
Ligustrum lucidum	6.80%
Schinus molle	6.30%
Ulmus parvifolia	5.29%
Celtis sinensis	5.04%
Nandina domestica	4.28%
3 Socio-economic status - 4 Socio-economic status	**78.64%**
Celtis sinensis	10.33%
Lagerstroemia indica	4.24%
Chamaecyparis lawsoniana	3.82%
Morus alba	3.68%
Nandina domestica ; Cordyline australis	3.40%
Ligustrum lucidum	3.11%
3 Socio-economic status - 5 Socio-economic status	**68.06%**
Chamaecyparis lawsoniana	7.92%
Celtis sinensis	6.16%
Nandina domestica	4.40%
Ligustrum lucidum	4.11%
Acer buergerianum ; Phoenix canariensis	3.23%
4 Socio-economic status - 5 Socio-economic status	**38.83%**
Celtis sinensis	11.16%
Ligustrum lucidum	7.73%
Lagerstroemia indica	4.72%
Cordyline australis	3.86%
Morus alba	3.65%
Fraxinus pennsylvanica	3.43%
Ulmus parvifolia	3.00%
Pooled - Groups	**60.3%**
Celtis sinensis	6.80%
Ligustrum lucidum	5.44%
Schinus molle	5.41%
Chamaecyparis lawsoniana	4.92%
Lagerstroemia indica	3.30%
Nandina domestica	3.22%
Ulmus parvifolia	2.99%