

Plant- and arthropod diversity of vegetable gardens along a socio- economic gradient within the Tlokwe Municipal Area

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Abstract

Globally urbanization has increased to such an extent that more than half of the human population currently resides in cities. In the years to come, urban expansion will especially take place in developing countries through efforts to improve economic growth and poverty alleviation. This may have a negative effect on native biodiversity within and surrounding urban environments. However, residential areas with a high proportion of gardens form a significantly large part of urban environments and these domestic gardens contribute to the maintenance and preservation of biodiversity in cities. Although the preservation of biodiversity in these gardens is important in the overall conservation of urban green spaces, little is known about how these gardens can possibly contribute to conservation purposes in urban areas.

Bearing in mind that anthropogenic activities are possible drivers of urban biodiversity, it is vital to quantify socio-economic aspects within urban ecological research. In developing countries, such as South Africa, the inclusion of socio-economic aspects are especially important because there is a wider gap between poor and wealthy households. There are also a larger number of people that are dependent on their gardens for subsistence purposes, such as vegetable gardening. In the Municipal Area of Tlokwe, South Africa, there exists a definite socio-economic gradient from the poorer western to the more affluent eastern part of the city. Five socio-economic status (SES) classes, primarily based on % unemployment, were used in this study.

The ultimate aim of this study was therefore to determine the plant- and arthropod diversity within urban domestic gardens along a socio-economic gradient. Vegetable gardens within domestic gardens were selected to quantify plant- and arthropod biodiversity. Biodiversity of adjacent lawns were also sampled for comparative purposes. The study also attempted to determine to what extent socio-economic aspects of city residents may be possible drivers of biodiversity within the gardens. Various other factors that might have an effect on the plant and/or arthropod diversity were included such as soil characteristics, specific management factors of the gardens and other land-uses surrounding domestic gardens.

Arthropod diversity was surveyed by means of pitfall traps and suction sampling in eight 0.25 m² squares along an 8 m transect in each representative garden. Arthropods were identified up to morphospecies level. Vegetation was surveyed along the same transect and total species composition was determined. Plants were identified up to species level. The plant and arthropod surveys were conducted in both the vegetable gardens and lawns of all SES classes. For the soil samples a 1:2.5 water analysis was conducted. A social survey was conducted in all representative gardens by means of a questionnaire and a SPOT 5 satellite imagery was used to determine the

land-use types in the areas surrounding the participating gardens. All the above mentioned factors were compared between the different SES classes.

Diversity indices for the arthropods, multivariate statistical analyses and ANOVA analyses were applied to test for meaningful variables between socio-economic status classes as well as vegetable gardens and lawns.

From the results it was evident that the more affluent SES classes had significantly higher arthropod diversity values, whilst the lower income classes had higher plant diversity. The factor analysis between the plants and arthropods with the surrounding land-uses revealed two significant factors. Firstly, arthropod diversity was influenced by domestic gardens in the surrounding landscape and there was a positive correlation between these two variables. This indicates that a high percentage of surrounding domestic gardens were possible drivers of arthropod diversity. No correlations were evident between plant and arthropod diversity. Secondly, the other significant factor showed that one SES class had a significantly higher percentage of woodlands and grasslands as opposed to two of the other classes that had a significantly higher percentage of built structures within the surrounding area. Differences were also apparent between the SES classes concerning management regimes, financial stability and level of education. The two more affluent SES classes had obtained a higher level of education and income and had management practices that were uncommon in the three poorer SES classes.

This study proposes that domestic gardens are a means to conserve biodiversity in cities. Vegetable gardens in domestic gardens will also be able to harbour a larger diversity of plants and arthropods than the lawns. The socio-economic status of residents also had a significant effect on biodiversity and therefore it should be included in studies on urban domestic gardens. This study also provides additional knowledge to the fundamentals of the field of urban ecology and the importance of using domestic gardens as an urban green space for conservation purposes.

Keywords: urban ecology, domestic gardens, socio-economic status, morphospecies, vegetable gardens, lawns

Opsomming

Verstedeliking het wêreldwyd so toegeneem dat meer as die helfte van die menslike bevolking huidiglik in stede woon. In toekomstige jare sal stedelike uitbreiding veral plaasvind in ontwikkelende lande om sodoende ekonomiese groei en die teenkamping van armoede te bevorder. Dit kan moontlik 'n negatiewe effek hê op inheemse biodiversiteit in die stedelike en omliggende gebiede. Stedelike omgewings bestaan grootliks uit woongebiede waarvan huistuine 'n groot gedeelte daarvan is. Hierdie huistuine mag dus gebruik word om biodiversiteit in stedelike omgewings te bestuur en te bewaar. Alhoewel, ten spyte van die belangrikheid van hierdie tuine vir die bewaring van biodiversiteit in stedelike groen gebiede, is daar min kennis oor hoe hierdie huistuine moontlik kan bydrae tot bewaringsdoeleindes in stedelike gebiede.

Deur in ag te neem dat menslike aktiwiteit 'n moontlike dryfkrag van biodiversiteit is, is dit dus noodsaaklik om sosio-ekonomiese aspekte te kwantifiseer tydens ekologiese navorsing van stede. In ontwikkelende lande, soos Suid-Afrika, is dit veral belangrik om hierdie sosio-ekonomiese aspekte in te sluit omdat daar 'n groter gaping is tussen arm en welgestelde huishoudings. Daar is ook 'n groter hoeveelheid mense wat afhanklik is van hul huistuine, soos in die geval van groentetuine. In die Munisipale gebied van Tlokwe, Suid-Afrika bestaan daar 'n duidelike sosio-ekonomiese gradiënt van die westelike armer na die oostelike welgestelde gedeelte van die stad. Vyf sosio-ekonomiese status (SES) klasse, hoofsaaklik gebaseer op die % werkloosheid, was gebruik in hierdie studie.

Die uiteindelige doel van hierdie studie was dus om die plant- en artropood diversiteit te bepaal binne-in huistuine langs 'n sosio-ekonomiese gradiënt. Groentetuine binne-in hierdie huistuine was uitgekies om die plant- en artropood biodiversiteit te kwantifiseer. Die biodiversiteit van die aangrensende grasperke was ook bepaal vir vergelykende doeleindes. Dit was ook belangrik vir hierdie studie om te bepaal tot watter mate sosio-ekonomiese aspekte van stedelike inwoners 'n moontlike dryfkrag van biodiversiteit in huistuine is. Verskeie ander faktore wat moontlik 'n invloed kan hê op die plant en/of artropood diversiteit was ook ingesluit soos grondeienskappe, spesifieke bestuurspraktyke van die tuine en ander grondgebruike in die omliggende gebiede van die huistuine.

Artropood diversiteit was opgeneem deur wyse van putvalle en 'n suigopnametegniek in agt 0.25 m² vierkante langs 'n 8 m transek in elk van die bestudeerde huistuine. Die artropode was tot by morfospesiesvlak geïdentifiseer. Die plantopname was ook langs dieselfde transek gedoen en die totale spesiesamestelling is bepaal. Plante was geïdentifiseer tot by spesiesvlak. Die plant-en artropood opnames was in beide die groentetuine en die grasperke uitgevoer van al die SES

klasse. 'n 1:2.5 wateranalise was uitgevoer vir die grondmonsters. 'n Sosiale opname was voltooi in al die verteenwoordigende huistuine deur gebruik te maak van 'n vraelys en 'n SPOT 5 satellietbeeld was gebruik om te bepaal watter grondgebruike voorkom in die gebiede rondom die deelnemende huistuine. Al die bogenoemde faktore was tussen die verskillende SES klasse vergelyk.

Diversiteitsindekse vir die artropode, meerveranderlike statistiese analises en ANOVA analises was toepas om betekenisvolle veranderlikes te toets tussen die sosio-ekonomiese status klasse sowel as die groentetuine en grasperke.

Vanuit die resultate was dit duidelik dat die meer welgestelde SES klasse betekenisvolle hoër artropod diversiteitswaardes gehad het, terwyl die plant diversiteit hoër was by die laer-inkomste klasse. Twee faktore was betekenisvol vanaf die faktoranalise tussen die plante en artropode met die omliggende grondgebruike. Eerstens, artropod diversiteit was beïnvloed deur huistuine in die omliggende landskap en daar was 'n positiewe korrelasie tussen hierdie twee veranderlikes. Dit dui dus aan dat 'n hoër persentasie van die omliggende huistuine positiewe drywers was van artropod diversiteit. Geen korrelasies was egter duidelik tussen die plant- en artropod diversiteit nie. Tweedens, die ander betekenisvolle faktor het bewys dat een SES klas 'n betekenisvolle hoër persentasie van boslande en grasvelde gehad het in teenstelling met twee van die ander klasse wat 'n betekenisvolle hoër persentasie van opgeboude strukture in die omliggende gebiede gehad het. Verskille was ook duidelik tussen die SES klasse met verwysing na hul bestuurspraktyke, finansiële stabiliteit en vlak van onderrig. Die twee meer welgestelde SES klasse het 'n hoër vlak van onderrig en inkomste behaal en het bestuurspraktyke beoefen wat ongewoon was in die drie armer SES klasse.

Hierdie studie stel voor dat huistuine 'n manier is om biodiversiteit in stede te bewaar. Groentetuine in huistuine is ook daartoe in staat om 'n groter diversiteit van plante en artropode te huisves as die grasperke. Die sosio-ekonomiese status van inwoners het ook 'n betekenisvolle effek op biodiversiteit gehad en moet dus ingesluit word in studies van stedelike huistuine. Hierdie studie verskaf ook verdere basiese kennis vir die veld van stedelike ekologie en die belangrikheid van die gebruik van huistuine as 'n stedelike groen gebied vir bewaringsdoeleindes.

Sleutelwoorde: stedelike ekologie, huistuine, sosio-ekonomiese status, morfospesies, groentetuine, grasperke

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List of Abbreviations

BUGS =	Biodiversity of Urban Gardens Sheffield
EC =	Electrical conductivity
L =	Lawn
ORP=	Oxidation-reduction potential
SES =	Socio-economic status
TDS =	Total dissolved solids
UHI =	Urban Heat Island
UNDP =	United Nations Development Program
UNFPA =	United Nations Population Fund
VG =	Vegetable garden

Chapter 1: Introduction

1.1. Introduction

According to the United Nations Population Fund (UNFPA, 2007), more than 50% of the global human population currently resides in cities. These numbers are predicted to increase to 80% in the next 20 years, with developing countries being the greatest contributors to urban expansion (McIntyre *et al.*, 2001; Cilliers *et al.*, 2004; Kaye *et al.*, 2006; Tzoulas *et al.*, 2007; UNFPA, 2007; Goddard *et al.*, 2010).

Urbanization is regarded as one of the most severe human impacts on the environment because it transforms the local natural environment completely and leads to fragmentation and ultimately the loss of native biodiversity (Cilliers *et al.*, 2004; Smith *et al.*, 2005). Anthropogenic activities are therefore considered to be one of the main drivers of biodiversity in urban environments (Cilliers, 2010). The effects of fragmentation, as a result of urban development, emphasizes the importance of conserving biodiversity in cities (Smith *et al.*, 2005; Goddard *et al.*, 2010).

According to Gaston *et al.* (2005a), the solution to this effect of fragmentation on biodiversity in cities may lie within the protection of urban green spaces. These urban green spaces include public parks and school gardens, as well as domestic gardens (JNCC, 2005). Considering that a large part of an urban environment consists of domestic gardens (21.8% to 26.8% of cities in the UK and up to 36% of Dunedin, New Zealand), these gardens may act as a refuge for biodiversity (Thompson *et al.*, 2003; Loram *et al.*, 2007; Mathieu *et al.*, 2007; Goddard *et al.*, 2010). In addition, domestic gardens are able to form the most interconnected green spaces within the urban matrix (Smith *et al.*, 2005).

Since anthropogenic activities are important drivers of urban biodiversity, it is becoming vital to include socio-economic aspects within urban ecological research (Cilliers, 2010; Lubbe *et al.*, 2010). This is because social aspects and individualism influence the types of ecological preferences that urban residents have, whilst their economic status determines the possibility to realize those preferences (Loram *et al.*, 2007; Cilliers, 2010). It is also crucial to understand that the perceptions regarding biodiversity are not only realized at an individual level, but forms part of different social and cultural groups (Head & Muir, 2004).

In a developing country, such as South Africa, there are many different needs associated with different social groups. For example, many households do not have an adequate supply of food, which emphasizes the necessity to promote urban agriculture within urban communities (Cilliers, 2010). Cilliers (2010) stated further that ecological urban agriculture contributes greatly to increase liveability and equity in developing cities, whilst simultaneously conserving biodiversity through sustainable use.

1.2. Motivation

Urban ecology is a novel scientific discipline that is imperative to the development and management of sustainable cities (Cadenasso & Pickett, 2008). However, even though urban ecology has received more attention during the past few years, there remains a void when it comes to constructing a mature theory for the ecological science of urban systems (Cadenasso & Pickett, 2008; Lubbe *et al.*, 2010).

Developing countries in particular are understudied when it comes to urban ecological theory, in spite of these countries being prone to extensive urban growth in years to come (Lubbe *et al.*, 2010; Cilliers *et al.*, 2012). More importantly, it is difficult to apply general urban ecological theory and practice of the developed Western countries to the African or Eastern countries because climates, cultures and the natural environment are different (Cilliers *et al.*, 2012). Even though it can be argued that basic ecological principles will operate similarly in various countries, the sociological situations will differ extensively, especially between developed and developing countries. It is therefore of the utmost importance to increase ecological research of urban environments within these developing countries.

Vegetation is a fundamental aspect of the urban ecosystem because not only does it provide vital ecosystem services such as, carbon sequestration and heat mitigation, but it also determines the biodiversity of other organisms within that system (Cilliers & Siebert, 2011). In urban environments, humans have a profound effect on the vegetation, especially within their private domestic gardens (Smith *et al.*, 2006c) and investigating these gardens will therefore give an insight to the plant management decisions of the residents (Blanckaert *et al.*, 2004). According to Cai *et al.* (2010) arthropod diversity will increase with an increase in plant diversity. Arthropods are the most diverse and abundant animals in the terrestrial habitats of the world (Gaspar *et al.*, 2010) and a diversity of these arthropods are indicators for environmental quality (Duelli *et al.*, 1999). This is because they play vital roles in the ecosystem and they also provide valuable ecosystem services for example acting as pollinators for plants and decomposers of

organic material (McIntyre & Rango, 2009). Unfortunately, urbanization is considered to decrease arthropod diversity and abundance and more knowledge is needed to determine what effect urbanization may have on arthropod communities in cities (McIntyre *et al.*, 2001).

Lawns are included within the study because not only are they one of the most understudied aspects of urban flora (Thompson *et al.*, 2004), they are also highly abundant in cities (Ignatieva & Stewart, 2009). They are common in parks and school gardens, domestic gardens, along streets and roads and certain recreation facilities such as golf courses (Ignatieva & Stewart, 2009). Lawns originated as a representation of meadows that naturally occurred within Europe and Britain (Ignatieva & Stewart, 2009). During British colonization, this practice of having and maintaining lawns spread to various parts of the world (Ignatieva & Stewart, 2009). The lawns, which represent meadows, gave them a sense of familiarity in their new countries. However, the use of lawns in domestic gardens became very popular, especially in the United States, and because of the United States' political and economic influence in the world lawns became a global phenomenon (Ignatieva & Stewart, 2009). Today it is a symbol of Western Civilization (Ignatieva & Stewart, 2009) and is highly common in many domestic gardens of South Africa.

South Africa is a rapidly growing developing country that has a variety of different cultures and social groups, which may influence biodiversity patterns extensively (Lubbe *et al.*, 2010). This study therefore aims to follow an interdisciplinary approach to determine what are the main drivers of biodiversity (plants and arthropods) in vegetable gardens in cities.

1.3. Aims of the study

The main objective of the study was to determine plant-and arthropod diversity within urban vegetable gardens and to compare them with lawns adjacent to those gardens. They were compared within this study because vegetable gardens are highly beneficial for residents, especially the poorer groups, while lawns are one of the most abundant landscapes in residential areas of cities. This study also aims to determine how the socio-economic component and other environmental factors influence plant- and arthropod diversity in urban domestic gardens.

The specific objectives of the study were to:

- I. Determine plant- and arthropod diversity of urban vegetable gardens.
- II. Compare the plant- and arthropod diversity of urban vegetable gardens with lawns adjacent to the gardens.

- III. Determine plant-and arthropod diversity patterns associated with different socio-economic status classes.
- IV. Determine which environmental variables are associated with specific plant- and arthropod diversity patterns of vegetable gardens.

1.4. Hypotheses

The hypotheses of this study based on previous knowledge (as will be discussed in Chapter 2) are that:

- Socio-economic status is a driver of plant- and arthropod diversity. Socio-economic status will influence the plant diversity preferences in gardens. The composition of plants will in turn determine arthropod diversity. The generalist arthropod species will be less affected than those arthropods that are considered to be specialist species.
- Vegetable gardens will have higher plant- and arthropod diversity than their associated lawns. Lawns will have mainly one dominant species with few other species.
- The surrounding land-uses and socio-economic status of residents determine the plant- and arthropod diversity of the different SES classes. The surrounding land-uses will have an influence on many of the plant species in domestic gardens. This will be especially true for many of the weeds that proliferate. Also, many arthropods do not have an extensive distribution range and species found in domestic gardens would have derived from those gardens or the adjacent areas.

1.5. Dissertation structure and content

- Chapter 1 provides a brief introduction of the importance and motivation of the study, as well as the aims, objectives and hypotheses.
- Chapter 2 is a literature review and provides a broad overview of some of the theoretical aspects of urban ecology.
- Chapter 3 gives a description of the study area, which focuses on the location, vegetation, topography, geology and climate of the area. It also describes the grouping of the socio-economic status classes and highlights the history of Potchefstroom.
- Chapter 4 focuses on the different sampling methods and data analyses that were used.

The results are provided in chapters 5 – 7. Each of these chapters is divided into subsections consisting of a short introduction, results and discussion and a brief summary.

The conclusion of this dissertation will be summarized in Chapter 8 and future research possibilities will be highlighted.

- Chapter 5 determines the species and functional diversity of arthropods collected along a described socio-economic gradient. The arthropods sampled in the vegetable gardens were compared to those in lawns. Arthropod diversity was also compared between the different socio-economic status classes and it also determined whether urban domestic gardens form a suitable green space for the conservation of arthropods in cities.
- Chapter 6 addresses the biodiversity of the plants surveyed along the socio-economic gradient. It also determines how the species composition of the plants differ between the vegetable gardens and lawns. Vegetable species composition between the SES classes were also verified. This chapter also provides a brief description of the soil analyses from the vegetable gardens.
- Chapter 7 presents results from the social survey, which includes management practices and socio-economic factors. This chapter also includes the percentage cover of the surrounding land-uses in the vicinity of the gardens and whether there are any correlations between plant- and arthropod diversity.
- Chapter 8 gives a short summary of the conclusions of each results chapter as well as a discussion of the hypotheses and recommendations for future studies.

Chapter 2: Literature Review

2.1. Introduction

This chapter is divided into six themes. The first theme is the scientific field of urban ecology. In this section the rapid increase in urbanization, reasons why an urban environment is regarded as an ecosystem and differences between an urban and a natural ecosystem will be discussed. The history and importance of urban ecological research will also be highlighted. The second part of the chapter is based on the concept of urban agriculture and the importance and advantages thereof. The focus is then shifted from cities as a whole to homegardens, after which it is narrowed down even further in the fourth part of the chapter to include the socio-economic aspects of urban residents and to emphasize the importance of social aspects in urban ecological research. This section will also discuss human perceptions of homegardens and how they differ between developed and developing countries. The fifth part will focus on arthropods and gives an overview of arthropod studies in urban environments. Lastly, a brief outline is given of previous studies in urban areas of the North-West Province, South Africa.

2.2. Urban Ecology

2.2.1. Urbanization and the term “urban”

Urbanization is increasing globally at high rates. Urbanization has increased to such an extent that since 2008, for the first time in history, more than half of the human population (3.3 billion people) was established within cities (UNFPA, 2007). It is also predicted that by the year 2030, this number will have greatly escalated, with developing countries being the greatest contributors to urban expansion (UNFPA, 2007). As a result of this expansion, the human impact on the surrounding environment is increasing and consequently leads to fragmentation and ultimate loss of biodiversity (Smith *et al.*, 2005). Many cities are also overpopulated, which puts enormous pressure on urban green spaces (Lehvävirta & Kotze, 2009). It is therefore becoming increasingly important to conserve biodiversity within urban environments (Smith *et al.*, 2005; Goddard *et al.*, 2010).

According to Wittig (2009), urban ecology can be defined in both a narrow and a broader sense. In the narrow sense urban ecology is the part of ecology that focuses mainly on urban biocenoses, biotopes and ecosystems. It also takes into account the organisms that occur in those areas, as well as the structure, function and history of urban ecosystems (Wittig, 2009). In a broader sense urban ecology is an integrated field of research, which includes different areas

of science and planning in order to improve living conditions in urban environments. It also ensures an environmentally sound city that will be sustainable over long-term development (Wittig, 2009).

Unfortunately, “urban” is an extremely broad concept that does not have one single definition (McIntyre *et al.*, 2000). According to Wittig (2009), “urban” is defined as an area that has a high concentration of human activity, production and use. It includes high housing density and trafficking areas, as well as industrial buildings. When comparing ecological sciences with social sciences, it is apparent that there are distinct differences in the way they perceive the term “urban”. Social sciences are far more descriptive in their definition for “urban”. Sociologists differentiate between varieties of “urban” aspects such as whether it is part of a metropolitan area or the centre of the city, whilst ecologists use the term to describe areas under intense human influence (McIntyre *et al.*, 2000; Cilliers *et al.*, 2004). Collaborations between the social and ecological sciences with regards to the definition of “urban” have benefits for both disciplines. Therefore, it is recommended to link social perspectives within the ecological study, not only to have a more definite description for “urban”, but also to improve the level of research within that specific study (McIntyre *et al.*, 2000).

It is also vital to distinguish the difference between the terms ‘ecology in cities’ and ‘ecology of cities’. Even though both are useful in understanding ecosystems within metropolitan areas, they follow different approaches and have different outcomes (Cadenasso *et al.*, 2006). ‘Ecology in cities’ follows a traditional approach to ecological research, but is conducted within or near cities. Thus, it focuses on ecologically familiar places, including parks and other open green spaces and it is conducted in a similar way than studies in non-urban areas (Cadenasso *et al.*, 2006; McDonnell *et al.*, 2009). Within many of these focused studies the distribution and abundance of native and exotic species are determined or the rate of decomposition within and outside of the city is compared to one another (McDonnell *et al.*, 2009). The second approach, ‘ecology of cities’, has developed more recently and is less studied than the first (Cadenasso *et al.*, 2006; McDonnell *et al.*, 2009; Cilliers, 2010). This approach is more inclusive and follows an interdisciplinary approach, which gives an ecological perspective on the entire metropolitan area of the city. According to Cadenasso *et al.* (2006), there are three advantages of using the ‘ecology of cities’ approach. Firstly, it addresses and includes all types of habitats in cities, not only open green spaces. Secondly, it takes the spatial heterogeneity of the metropolitan area into account, which can be used to explain and predict environmental changes within the city. And lastly, the human impact is considered in urban landscapes (Cadenasso *et al.*, 2006;

Niemelä *et al.*, 2009). Humans of all different social levels and at all scales, from individuals, to households and even complex agencies are included and linked to the biogeophysical aspects of the city (Cadenasso *et al.*, 2006). To have a better understanding of urban planning and management, as well as challenges associated with it, it is compulsory to integrate social, biological and other sciences (Tzoulas *et al.*, 2007). Through using all these aspects, it gives a more comprehensive understanding of the urban ecosystem as a whole.

2.2.2. The urban environment as an ecosystem

In the past, the study of ecology only took place in natural ecosystems that were far removed from any form of human civilization (Collins *et al.*, 2000). Until recently, ecologists were reluctant to search for scientific answers in urbanized areas and preferred “pristine” environments for their scientific research (Collins *et al.*, 2000; McIntyre *et al.*, 2000). However, according to Niemelä (1999), cities have intrinsic value when it comes to ecological research. Firstly, urban nature is important for not only ensuring a healthy environment for its residents, but it also offers recreation activities for them. Secondly, urbanized areas have a variety of habitats, ranging from natural to highly altered environments. Cities also act as a laboratory where ecological changes can be observed and ecological differences between urban and rural areas can be determined (McDonnell & Pickett, 1990; Collins *et al.*, 2000). Urban ecological study therefore also broadens the knowledge humans have of the natural environment and how it reacts to development. This in turn can be used when conducting urban planning.

It is possible to regard an urban environment as an ecosystem with a diversity of processes and functions that work together as a system. An ecosystem is based on the interaction between a biotic and a physical complex (Cadenasso & Pickett, 2008). Using this principle, it is also possible to define a city as an ecosystem. The reason for this is that cities also include biological and physical complexes. However, they contain additional characteristics within both of these complexes that are not found within natural ecosystems. These biological complexes include humans (with their social systems) and institutions, whilst physical complexes of cities include modified soils, building structures, roads and pavements, as well as other human infrastructure (Cadenasso & Pickett, 2008). Thus, even though cities have some additional properties, they are interlinked with one another and hold true to the definition of an ecosystem.

The urban green spaces are able to support a large part of the biodiversity within an urban environment (JNCC, 2005). Urban green spaces are defined as vegetated lands within or adjacent to urban areas (Caula *et al.*, 2009). These vegetated lands include all green areas

found within cities, such as man-made parks and gardens, as well as natural and semi-natural areas. According to Thompson *et al.* (2003), private domestic gardens contribute a large part of these urban green spaces (23% in Sheffield, UK). Thus, through increasing the biodiversity of these domestic gardens, the biodiversity of the ecosystem as a whole will be significantly increased (Thompson *et al.*, 2003).

2.2.3. Differences between a natural and an urban ecosystem

There are distinct differences between natural and urban ecosystems. These differences can be the result of many different features of which four will be summarized. These four aspects include the Urban Heat Island (UHI) Effect, the ecological footprint and mass balance approach, urban patch dynamics and the human ecosystem model.

2.2.3.1. Urban Heat Island effect

Urban ecosystems are the most altered ecosystems on earth (Collins *et al.*, 2000). They are energy intensive, unbalanced and have characteristics that differ extensively from natural systems. The Urban Heat Island (UHI) effect is one of these differentiating characteristics. According to Memon *et al.* (2008), this UHI, which is caused solely by urbanization and industrialization, is a cause of great concern in the 21st century. It is primarily caused by the replacement of vegetation with impervious surfaces, which reduces the evapotranspiration of plants in cities (Wu, 2008). As a result, solar radiation energy that is normally used for evapotranspiration is now available for heating the urban surfaces leading to an increase in urban temperatures. Thermal radiation that transcends from these urban surfaces, are usually absorbed and reflected several times within the city structures before escaping into the atmosphere (Gilbert, 1989; Memon *et al.*, 2000; Wu, 2008). Consequently, urban environments are able to have an annual mean air temperature that is 0.5°C – 1.5°C warmer than the surrounding natural areas (Gilbert, 1989). This alteration in temperature has various consequences for the urban biota. Plants tend to have longer growth and flower seasons and leaf formation takes place much earlier than in natural areas (Sukopp, 1989). It has also been observed that warmer temperatures extend the macrofungi fruiting season in the southern parts of England (Newbound *et al.*, 2010). It is therefore apparent that alterations in the temperature changes the natural cycles of biota in urban environments. According to Imhoff *et al.* (2010), the UHI also increases as the city expands, with the inner-city parts having higher temperatures than the outer areas of the city.

2.2.3.2. The ecological footprint and mass balance approach

Urbanized ecosystems are dependant on the surrounding natural areas for their energy inputs (Collins *et al.*, 2000). The dependability of a city can be measured through calculating and comparing energy inputs and outputs of the city. The energy budget would then give a valid indication of the energy required from the surrounding natural systems for the urban ecosystem. The energy budget also signifies the ecological footprint of the city or town (Collins *et al.*, 2000).

An appropriate definition for urban ecological footprints is the total area of land and water surfaces that are needed to support urban populations (Forman, 2008). The ecological footprint is therefore the area of land that is required to produce a quantity of resources that are equivalent to the amount consumed by the city (inputs), as well as the area of land that is able to receive all the wastes from that specific city. This usually results in extremely large ecological footprints. In many cases the land necessary for the ecological footprint far exceeds that of the city itself (Collins *et al.*, 2000). According to Forman (2008), many of the Canadian cities require a land area that is at least 300 times larger than that specific city to sustain its population.

The concept of the urban ecological footprint has received much criticism. According to Kaye *et al.* (2006) this is mainly because the biophysical setting, the population size and the per capita consumption rate are not included. Fiala (2008) also stated that it is difficult to compare ecological footprints between different nations, considering that the average consumption of one nation is multiplied by the world population which in turn is compared to the resource capacity of the earth. As a result many scientists rather prefer the mass-balance approach of urban biogeochemical cycles (Kaye *et al.*, 2006). The mass balance approach determines whether a city is a source or a sink of a specific material or element. This is done by quantifying the inputs and outputs of the element or material (Kaye *et al.*, 2006). This approach does not only make use of urban population sizes, but also includes urban structure, biophysical and social factors that all affects the per capita consumption in cities and gives a better understanding of material use in cities (Kaye *et al.*, 2006). Therefore, even though the ecological footprint concept does have potential, it does not give a valid representation of urban biogeochemical cycles as the mass balance approach does (Kaye *et al.*, 2006).

2.2.3.3. Urban patch dynamics

One of the most significant ecological features of urban areas is their spatial heterogeneity (Cadenasso & Pickett, 2008). This concept is based on the idea that there are individual

patches within an urban landscape that all interact with one another to form the urban matrix. According to Band *et al.* (2005), heterogeneity in urban areas consists of both natural and structural elements. Urban patches are only partly influenced by the ecological and geophysical components. However, these urban patches are for the most part influenced by the institutional, economic and social factors of the urban environment (Band *et al.*, 2005). The inclusion of these urban factors gives a better understanding of how individuals are organized into larger groups.

Urban institutions (or patches) can either be grouped as households, community groups or religious congregations, as well as businesses or government agencies (Band *et al.*, 2005). Economic factors include income and public/private businesses, whilst the social factors include cultural heritage and racial factors, as well as neighbourhood cohesion. According to Band *et al.* (2005), it is the neighbourhood subdivisions that are the most effective measurement to use for spatial variation in land cover and social groups. The types of neighbourhoods in an urban setting can be distinguished from each other on factors such as density of buildings, presence or type of vegetation and transportation frameworks (Band *et al.*, 2005). Changes within all of these factors, both biophysical and anthropogenic, give a valid representation over time of how the dynamics of the urban system works.

2.2.3.4 The human ecosystem model

The presence of humans is an important factor that distinguishes urban and natural ecosystems from one another. Humans have a large effect on the urban ecosystem and it is important to understand how their presence influences the natural ecosystem concept (Pickett *et al.*, 1997). The natural ecosystem concept is based on the linkages that exist between organisms and the physical environment within a specified spatial area. The spatial boundaries of the ecosystem can be adjusted to any size regardless of whether it is large or small (Cadenasso & Pickett, 2008). This concept can be used as a scientific tool to quantify different physical aspects of the natural environment and to determine how it affects the organisms within those areas (Pickett *et al.*, 1997). These physical aspects are the most important factors that influence the natural ecosystem. It can also be used to quantify the energy fluxes within the specified ecosystem.

The human ecosystem model differs largely from the natural ecosystem concept. This model aims at recognizing that there are linkages that exist between organisms and the physical environment, but that humans are included as part of the ecosystem. Consequently, humans (with their different social systems) have a great influence in the urban ecosystem (Pickett *et al.*, 1997; Wu, 2008).

2.2.4. The importance of urban ecological research

With urbanization increasing at an unprecedented rate, there have been extreme changes in land use, accompanied by an invasion of exotic species and a global loss of native biodiversity (McDonnell *et al.*, 2009). This is especially of great concern in developing countries. It is vital to attain a comprehensive understanding of the functioning of urban ecosystems so that sustainable cities can be developed and effects of global climate change can be mitigated (McDonnell *et al.*, 2009).

A sustainable city is one that utilizes the functional benefits of the natural environment. These benefits or ecosystem services include processes such as pollination and decomposition, as well as an improvement of fertility of urban soils (Cilliers, 2010). If urban green space is implemented successfully it can also alleviate stormwater runoff and negative effects of the Urban Heat Island effect (Cilliers, 2010; Kotze *et al.*, 2011). Moreover, urban ecological research can add to conservation initiatives through ongoing projects within cities (Kotze *et al.*, 2011). These initiatives can be supported through improving environmental awareness and education of urban residents. An increase in biodiversity of cities will also increase the aesthetic value of those cities (Kotze *et al.*, 2011). These aspects should therefore be taken into consideration when conducting urban ecological research.

Over the past 20 years, urban ecological research has developed significantly. However, there is still a great demand for comparative information between cities that might serve as general principles in urban ecology. These baseline principles are important, because it enables planners to use ecological knowledge in urban planning (Niemelä *et al.*, 2009). It is therefore becoming more important to conduct research in urban settings (McDonnell *et al.*, 2009).

2.2.5. The history of urban ecological research

Urban ecology is characterized by multiple research approaches that were integrated during different time periods in the past. Weiland & Richter (2009) investigated these time periods and established five lines of development, dating back to the 16th century, which led to the scientific discipline of urban ecological research used today. Each of these lines of development had different objectives and approaches, depending on the environmental requirements and prior knowledge to that date. Similarly, Wu (2008) also recognized five urban ecological perspectives that have originated from three traditions known as the ecology in cities (EIC), ecology of cities as socio-economic structures (EOC-S) and ecology of cities as ecosystems (EOC-E).

According to Weiland & Richter (2009), the first of the five lines was rooted in natural history during the 16th century. This line followed a descriptive approach of nature in cities without broad habitat characterizations. For example, during 1597, John Gerard observed that certain plant species were growing spontaneously on stonewalls, castles and remnants of old buildings (Weiland & Richter, 2009). However, there was no term or definition issued to these observations and they were not investigated any further. It was only later on during the 17th and 18th centuries that nature in cities received more attention. This was however for the most part caused by the exploration of foreign countries, which led to the discovery and import of plants, especially herbs, that had possible economic or medicinal use (Weiland & Richter, 2009).

The second line, known as the sociological and human ecology tradition, started during the 1920's in Chicago, USA (Weiland & Richter, 2009). Chicago, like many other North-American and European towns during that time, was in the middle of an industrial revolution and in only a few decades the city expanded from a small provincial town to an industrial city. As a consequence, the human population had also escalated rapidly in only a short period of time (Weiland & Richter, 2009). Unfortunately, the industrial expansion and population increase led to various environmental health problems. There were high levels of gas emissions, which resulted in poor air quality and light conditions, insufficient water supply, sewage and waste disposal (Weiland & Richter, 2009). As a result of these harsh living conditions, industrial workers were unhealthy and struggled to survive. These circumstances inspired Robert Ezra Park to start socio-ecological studies, where interrelations between city and society were determined. This approach focussed on how the processes of urban development influenced social groups (Weiland & Richter, 2009). This was done through using existing aspects of plant and animal ecology (such as succession, symbiosis and competition) and applying them to human interactions. This is the same as the ecology of cities as socio-economic structures (EOC-S) approach that was distinguished by Wu (2008). However, these studies mentioned above focussed only on human social systems and did not include the environment.

According to Weiland & Richter (2009), the third line of development started in 1965 and is known as the bio-ecological tradition. During this period the study focus shifted from humans to the urban environment. Herbert Sukopp and his colleagues from Berlin analyzed ecological sites of natural areas within urban environments (Sukopp, 2002; Weiland & Richter, 2009). Therefore, the focus was placed on plant and animal species, urban soil, water bodies and the urban climate, whilst humans and human social systems were excluded (Sukopp, 2002; Weiland & Richter, 2009). This line of development also correlates to a great extent with the first

line of natural history, which was previously mentioned and, according to Wu (2008), it follows an 'ecology in cities' approach.

The (eco)system-related tradition of urban ecology was greatly influenced by landscape ecology and systems theory. Two basic approaches can be distinguished. The first approach focused on the ecological analyses of urban landscapes (Wu, 2008; Weiland & Richter, 2009). The objective of this type of approach was to identify ecological patterns and processes, which included aspects such as the analysis of urban-rural gradients (McDonnell & Pickett, 1990; Weiland & Richter, 2009). The second approach analyzes urban material and energy flows. This type of approach uses energy flow systems to explain chemical and physical processes in urban environments (Weiland & Richter, 2009). As a result, a comprehensive understanding was obtained of how substances accumulate and transfers via food chains in urban environments. It also gave a better understanding of cities as a whole. However, once again the human component was not included.

It was not until the 1990's that urban ecological research, as it is known today, started to develop. According to Weiland & Richter (2009), the last line is referred to as an applied urban ecology which strives to develop sustainable urban environments. Urban ecological research should therefore try to plan and develop sustainable cities by following an integrative approach (McIntyre *et al.*, 2000; Cilliers *et al.*, 2004; Wu, 2008; Weiland & Richter, 2009). This is possible through combining all the aspects that influence a city as an environment into urban ecological research. These aspects include material fluxes, all organisms (including humans), as well as humans' socio-economic and governance aspects. Through including these aspects within the study, it is possible to not only determine the impact humans have on the urban environment, but to ensure that many of the urban residents and planners will be able to understand more basic concepts regarding urban ecosystems (Niemelä, 1999). Only then is it possible to develop cities that are sustainable and where the residents, as well as the environment, are able to benefit.

Consequently, urban ecological research should follow an integrative approach including different stakeholders within the city, as well as other sciences to ensure that a holistic view is obtained and that further urban development is carried out in a sustainable manner.

2.3. Urban Agriculture

2.3.1. Introduction to urban agriculture

In many ways, agriculture and urbanization are two different concepts that seem to contradict one another (Madaleno, 2000). However, urban agriculture has great potential to assist urban citizens to become self-sustainable and independent. In fact, the main purpose of urban agriculture is to create food security and increase health (Redwood, 2009).

Urban agriculture is a global concept and takes place in every city. According to the UNDP (1996), it is estimated that 14.3% of the earth's food supply is cultivated within cities, by a total of about 800 million urban farmers. Agricultural activities in urban areas are also growing because of local markets increasing their prices on basic goods (Redwood, 1999). Urban agriculture is especially important for the urban poor who annually spend 40% to 60% of their income on food (UNDP, 1996). The urban poor are also the group that suffers the most from increasing food product prices (Zezza & Tasciotti, 2010). These agricultural practices therefore ensure the availability of food and assists in poverty alleviation.

According to Madaleno (2000), urban agriculture takes place in open green spaces within the central parts of the city (intra-urban) or in peri-urban areas. These open green spaces include private and public open spaces such as homegardens, non-residential areas, public lands (parks) or semi-public areas, including schools, churches or hospitals (RUAF, 2009). All food products are included within urban agriculture, for example crops (fruits, vegetables and grains) and animals (poultry, cattle, fish), as well as non-food products (aromatic and medicinal herbs).

Urban agriculture follows an integrated approach, which takes the social, cultural and economic aspects of urban residents into account and it forms part of the urban economic and ecological system. Urban agriculture is therefore not only within urban areas, but also interacts with all other aspects of the urban ecosystem (RUAF, 2009). This form of agriculture includes the use of urban residents as labourers, makes use of urban resources, competes for land with other urban functions and has a direct impact on the ecology of urban areas (RUAF, 2009). Evidently, urban agriculture is not something that will fade away, it increases as the city expands and it is an integral part of the urban ecosystem (RUAF, 2009). The development of urban agriculture is important and it is vital to acquire more knowledge to improve this form of agriculture and to ensure food security for urban residents.

2.3.2. The importance and advantages of urban agriculture

Urban agriculture is able to ensure food security and increases health. It can also be used to alleviate poverty to some extent, thus having possible economic value and it may even be able to increase and conserve biodiversity in certain areas (Cilliers, 2010; Zezza & Tasciotti, 2010). This holds true for developing countries in particular and can be used within these countries to develop healthy and sustainable cities.

Urban agriculture has multiple benefits (see Fig. 2.1), which also include an increase in livability, equity and sustainability of the people involved (Cilliers, 2010). All of these different spheres are linked to one another making it an effective way to increase human health in cities (Fig.2.1).

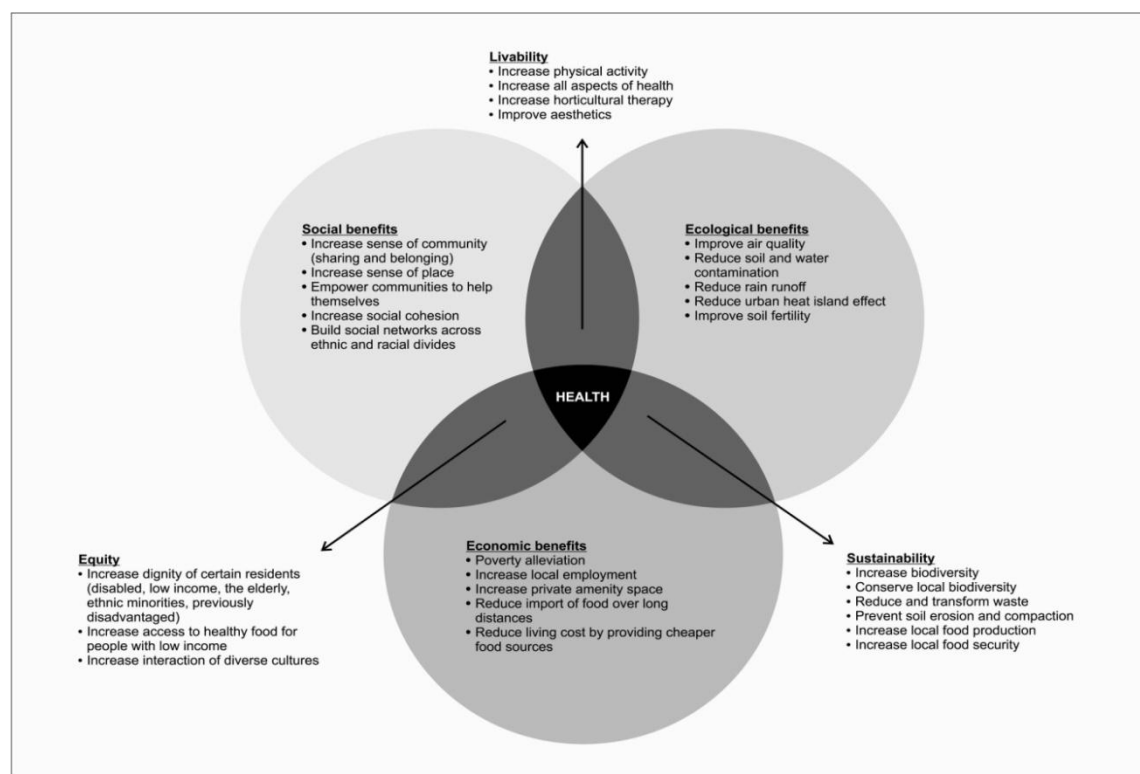


Figure 2.1: Multiple benefits of urban agriculture as a model of a healthy community (Cilliers, 2010).

One of the most important socio-economic benefits concerning the people of the community is that urban agriculture directly addresses socio-economic issues such as poverty, health and unemployment (Cilliers, 2010). Through implementing urban agriculture, people are empowered to live with assurance and increased wellbeing, whilst conserving the urban green spaces in a sustainable way. Additional environmental advantages are an improvement of air quality and

soil fertility, reduction of rain runoff, as well as a reduction in the Urban Heat Island Effect (Trowbridge, 1998; Cilliers, 2010; Zezza & Tasciotti, 2010)

A study was conducted by Zezza and Tasciotti (2010) to determine to what extent urban agriculture is able to alleviate poverty and ensure food security. It was found that especially urban residents from African countries (e.g. Ghana, Madagascar, Malawi and Nigeria) are able to benefit from urban agriculture for own consumption (Zezza & Tasciotti, 2010). However, in Latin America it was found that many households sell their produce on the market and ultimately alleviates poverty to a great extent (Zezza & Tasciotti, 2010).

It was further determined that the greatest contribution of urban agriculture was provision of a nutritionally rich diet that would not have otherwise been possible to attain by these households (Zezza & Tasciotti, 2010). Urban agriculture is therefore able to thoroughly increase dietary nutrition and ultimately ensure a healthy community on many levels.

2.3.3. Various types of urban agriculture

There is a variety of methods available to practice urban agriculture. This is important because many people make use of a specific method, depending on the specific environmental conditions they live in. The availability of water, time and space influences the appropriate method to use (RUAF, 2009). For example, the use of group gardening is an effective method of agriculture, but if the necessary space and labour is not readily available, this method will not succeed.

Urban agricultural gardening can be practiced in mainly two areas, i.e. homegardens or community gardens. Homegardens are practiced in private residential areas, whilst community gardening is done in more public open green spaces. There are, however other agricultural methods that can be used apart from traditional homegardens or community gardens. These methods may range from multi-storey gardens to micro-gardens (Cilliers, 2010). Each method has its own functions, advantages and disadvantages. Evidently homegardens are the most common form of gardening, which many people practice for household consumption.

Community gardening has many benefits for the community. Firstly, it improves the quality of urban green spaces, whilst simultaneously providing sanctuaries for urban wildlife (CAHN, 2009). Secondly it provides a community meeting place and helps the people of the community to grow nutritious food within the city. It also ensures that local people of the neighbourhood take an active responsibility for their surrounding environment and make sure that they work in

partnership to improve their own livelihoods (CAHN, 2009; Thornton, 2009). One example of community gardens is the Masizame Community Garden Project (MCGP) in Peddie, South Africa (Thornton, 2009). This community garden is based in a previous homeland town established during the apartheid era and aids in alleviating the poverty and lack of food in this area (Thornton, 2009). Community gardens are mostly led by the women of the community and they empower the community to sustain themselves (Thornton, 2009).

Multi-storey gardening is an effective method to use in areas where limited space is available and where there is a shortage of water (Corbett, 2009). This method focuses on using vertical arrangements for gardening in areas where space is severely limited. One of these methods includes the use of bags for planting. If the seedlings become overcrowded, it is possible to remove them and place them at the top or side of the bags, thus resulting in an effective use of limited space (Corbett, 2009). However, this is not the only method of its type. Many methods follow the same principles of multi-storey gardening with only a few slight differences depending on the materials that are available.

The eco-circle method can also be applied in areas with limited space, and it is an effective method to use for both group gardening and homegardens. The eco-circle operates with its own water irrigation system (Trowbridge, 1998). This is usually done with the use of pierced tin cans or plastic bottles that are buried at the centre of the circle, underneath the ground surface. These tin cans create a similar effect as a sponge, ensuring that the water retention is maintained beneath the surface and that the roots of crops have an adequate supply of water (Trowbridge, 1998). The tin can is exposed above the ground surface and is filled with water but is also able to accumulate rainwater, which will then be directly transported to the roots. As a result, the water is not wasted unnecessarily, considering that it not only decreases the water run-off on the surface, but also ensures that the roots have enough moisture for plant growth.

It is important to note that these are not the only methods of urban agriculture. Urban agricultural practices are extremely diverse with different methods for specific environmental conditions and it also depends on the availability of space and water. New methods are consistently being developed to ensure that people are able to have a sense of food security and that urban green spaces have productive uses. Therefore, it is vital to develop agriculture in urban environments for both present and future use.

2.4. Homegardens

2.4.1. Introduction to homegardens

According to Vogl & Vogl-Lukasser (2003), a homegarden is a small-scale garden that is adjacent to the residential housing of a farmer. It is used by the farmer for own consumption and is not generally used for market-orientated purposes. There are however different definitions for the term 'homegarden', depending on the geographical location and purpose of the garden. For example, a general definition for homegardens in tropic and sub-tropic climate states that a homegarden consists of multipurpose trees and shrubs that are in close association with agricultural crops and livestock (Fernandes & Nair, 1986). These gardens are within the vicinity of the residential area of the farmer and are actively managed by the household. Homegardens within urban environments are often referred to as 'domestic gardens' and have been defined by Gaston *et al.* (2005a) as any private green space that is adjacent to a residence and may include lawns, ornamental and vegetable plots, ponds, paths, patios and temporary buildings such as sheds and greenhouses. For the purposes of this study, a definition for a homegarden is any green space adjacent to a residence, which is used for cultivating ornamental and especially agricultural plants for both own consumption or economic benefit (Davoren, 2010).

Homegardens, with edible plants, are important for a variety of reasons and is especially prominent in developing countries. According to Pandey *et al.* (2007), homegardens cover 63% of the arable land in India. This implies that developing countries are extremely dependant on homegardens for food production and nutritional improvement (Trinh *et al.*, 2003).

Traditional homegardens make a significant contribution to biodiversity in residential areas and it enhances food security for both the rural and the urban poor (Trinh *et al.*, 2003). In Vietnam, households on average receive 50% of their edible products from their gardens (Trinh *et al.*, 2003). These products include vegetables, fruits, herbs and medicinal plants (Trinh *et al.*, 2003). From a study in Mexico, it was determined that the average homegarden has a total of 29.6% edible plants and 8.6% medicinal plants (Blanckaert *et al.*, 2004).

According to Trinh *et al.* (2003), traditional homegardens are extremely important when it comes to conserving and increasing biodiversity and it was suggested that these types of gardens should be included within national conservation strategies. In fact, traditional homegardens are ideal for in situ conservation of crop genes (Trinh *et al.*, 2003; Blanckaert *et al.*, 2004; Pandey *et al.*, 2007). However, species composition of homegardens are influenced by unrestrained factors such as specific preferences of the household individuals, food culture, government

agricultural policies and even religious ceremonies (Trinh *et al.*, 2003). Only when these social and cultural preferences of the people are understood, will it be possible to implement conservation plans within gardens.

Further research is needed in several fields of homegardens such as agriculture, ecology, socio-economics and nutrition (Trinh *et al.*, 2003). According to Madaleno (2000), this is especially important within the urban municipal boundaries where some of the main purposes are to increase food security, nutrition and health and to ensure economic stability for the urban residents. It is also vital to note that research of homegardens in arid and semi-arid areas are lacking, with the most research being done in tropic and sub-tropic regions (Blanckaert *et al.*, 2004). Homegardens seem to represent a useful strategy that will enhance food security, improve economic independency and possibly be used in conservation strategies.

2.4.2. Previous studies of homegardens

In urban ecological research, it is important to include social aspects that influence biodiversity (McIntyre *et al.*, 2000; Cilliers *et al.* 2004). The 'Biodiversity in Urban Gardens in Sheffield' study (BUGS) in the United Kingdom acknowledged the importance thereof and obtained various social data within their homegardens study (James, 2010).

One of the studies in the BUGS project focused on five cities in the UK (Edinburgh, Belfast, Leicester, Oxford and Cardiff). It was established that homegardens within all the cities comprised between 21.8% and 26.8% of the total urban environment (Loram *et al.*, 2007; James, 2010). It was also determined that these gardens were positively correlated with the variation in human population density and housing density (Loram *et al.*, 2007). This indicated that not only do domestic gardens constitute a large part of the urban environment, but that it also increase the heterogeneity of urban green spaces that harbours a large diversity of plants and animals.

Two former studies of the BUGS project also investigated the roles of domestic gardens for maintaining high levels of biodiversity in cities (Gaston *et al.*, 2005a; Smith *et al.*, 2006a). One research project determined the effectiveness of manipulation techniques such as ponds, artificial nest sites and dead wood that can be used to increase biodiversity (Gaston *et al.*, 2005b), whilst another was performed on soil seed banks from these domestic gardens (Thompson *et al.*, 2005). According to Gaston *et al.* (2005a) these studies indicated the importance of empirical data and how it can be used to understand the roles of domestic

gardens in urban environments with regards to biodiversity. Nevertheless, even though there has been an in-depth study within Sheffield, it is vital to attain knowledge of domestic gardens in other parts of the world, which can be used as comparative data for urban ecological study.

Homegarden research in developing countries is of the utmost importance (Trinh *et al.*, 2003). Many studies that have been done in developing countries focus on a variety of aspects, both ecological and social. This includes garden size (Trinh *et al.*, 2003), species diversity within gardens and whether species are native or invasive (Trinh *et al.*, 2003; Blanckaert *et al.*, 2004) as well as the division of labour within gardens based on gender (Trinh *et al.*, 2003; Blanckaert *et al.*, 2004; Pandey *et al.*, 2007). Commercial produce is also included within some studies to emphasize the use of homegardens for own economic benefit (Pandey *et al.*, 2007). In the islands of Andaman, India, it was established that 70% of the coconut and 98% of the arecanut production is sold to local merchants (Pandey *et al.*, 2007). It is therefore necessary to develop a further understanding of homegardens and try to determine the biophysical and socio-cultural characteristics that influence the biodiversity of these gardens.

2.5. Socio-economic aspects in urban areas

2.5.1. The importance of social values in urban ecological research

An urban ecosystem is a complex social-ecological system consisting of strongly interacting spheres, which are all linked to the anthroposphere (Marzluff *et al.*, 2008; Cilliers, 2010). According to Marzluff *et al.* (2008), the anthroposphere is considered to be the socio-economic world of people. This indicates that all the other spheres, such as the biosphere, lithosphere and hydrosphere, interacts with and is influenced by the human sociological component.

Ecosystem services in urban areas are largely determined by the biodiversity patterns of the city (Cilliers, 2010). Biodiversity patterns derive from socio-economic aspects of cities. People's cultural and social perceptions influence their appeal for specific ecological features while their economic status determines whether they are able to attain those characteristics they desire (Bhatti & Church, 2001; Cilliers, 2010). These perceptions of people are highly variable and will differ between cities depending on various ethnic backgrounds, economic standings, age, education and familiarity with nature (Swanwick, 2009; Cilliers *et al.*, 2012).

With human social systems as the driving force of biodiversity in cities and domestic gardens representing a large part of the urban landscape, it is vital to assess social perceptions regarding biodiversity within urban domestic gardens (Loram *et al.*, 2007; Cilliers, 2010).

According to Barthel *et al.* (2010), social groups can be distinguished when it comes to gardening based on their collective or social memory from the past. This social memory of people forms the basis of the social framework and is constructed from individuals that share common aspects such as language, symbols and cultural heritage (Barthel *et al.*, 2010). These common aspects were shaped in the past and transferred to the next generation that share similar social ideologies.

Barthel *et al.* (2010) used a new term to specifically define the perceptions of social groups with regards to ecological features namely the *social-ecological memory*. This states that different cultural and socio-economic groups have different perceptions and management practices in gardening. Bhatti & Church (2001) also emphasizes the importance of studying domestic gardens to comprehend how urban dwellers influence the biodiversity patterns within a city. For example, a study conducted in Auckland, New Zealand, emphasized that the main social factors that influence urban vegetation are the residents' environmental education and social beliefs (Meurk *et al.*, 2009). A master's study from the North-West Province, South Africa also showed that cultural and social differences in people lead to different plant diversity patterns in urban domestic gardens (Lubbe *et al.*, 2010). Two other master's studies from the North-West Province also highlighted how social systems and cultural preferences influence biodiversity in domestic gardens. For example, in the one study, the majority of residents from a specific rural settlement perceived gardens as a place of food production (Davoren, 2010). Similarly, the other study, which focused solely on the Batswana people, showed that people living in deep rural areas, regarded domestic gardens as places of food production and emphasized the importance of the medicinal value of gardens (Molebatsi *et al.*, 2010). Therefore, the manner in which humans interpret nature is also the way they will interpret their urban environment (Swanwick, 2009; Cilliers, 2010). This, together with the benefits of ecosystem services, highlights the need for integrating social values in urban ecological studies.

2.5.2. Human perceptions of homegardens in developed countries

A variety of urban ecological studies have been conducted in developed countries around the globe. These studies have provided fundamental data regarding human perceptions of nature in cities. One such study focussed on determining the effect that cultural heritage and community influence has on gardens (Head *et al.*, 2004). Urban residents that were selected for this specific study were all migrants to Australia from Macedonia, Vietnam and Britain. There was also another group of first-generation Australians with both the parents that originated from an

overseas country (Head *et al.*, 2004). According to Head *et al.* (2004), the generation of people that migrated kept their own cultural perspectives of gardens, whereas the first-generation Australians have altered their gardens, adapting to their new society. Distinct garden differences were apparent between people from different nationalities. Macedonian and Vietnamese gardens had highly productive gardens, producing edible produce, whilst British gardens were more aesthetically orientated (Head *et al.*, 2004). This study indicated the strong ethnic backgrounds that influence biodiversity in gardens and the adaptability of people's perceptions depending on their surrounding social influence.

In gardens between suburbs of Hobart, Australia, it was determined that socio-economic status was responsible for the variation between gardens (Kirkpatrick *et al.*, 2007). Tree cover was positively correlated with people having higher incomes and vegetable and native gardens were associated with people that completed tertiary education (Kirkpatrick *et al.*, 2007). The greater tree cover in households with high income may be the result of these households having proportionally larger gardens, or other factors such as better physical environmental conditions, home ownership, ethnicity and education. Either way, it was determined that different social groups have different outcomes when it comes to garden management and biodiversity.

Allotment gardens in Central European cities are regarded as important green spaces. These gardens are situated within or on the outskirts of cities and according to regulation should be mainly used for vegetable and fruit production. With densely built-up residential properties, these allotment gardens give a sense of escape and recreation to urban dwellers (Breuste, 2010). According to Breuste (2010), Germany has 1 million registered allotment gardeners (covering a total area of 466.4 km²), which constitute a large part of the urban population. Several studies, including socio-economic questionnaires, were conducted within these gardens and it was determined that allotment gardeners form part of a distinct social group (Breuste, 2010). This group was determined to be the lower middle income-class, especially older people, who has similar ideologies regarding biodiversity, agricultural gardening and social lifestyles (Breuste, 2010). According to Swanwick (2009), allotment gardens are also becoming more popular in the UK, with 300 000 gardens that are already registered and a waiting list of 76 330 in 2009. Allotment gardens are associated with high levels of biodiversity in comparison with other parts of the city, therefore not only providing enjoyable green space for urban dwellers, but ultimately increasing and conserving biodiversity (Swanwick, 2009; Breuste, 2010).

2.5.3. Human perceptions of homegardens in developing countries

The integration of social values in urban ecological studies has focussed mostly on developed countries and important aspects such as human health and welfare are often neglected within these studies (Cilliers, 2010; Cilliers *et al.*, 2012). In developing countries, such as South Africa, there are many health and wealth issues associated with socio-economic aspects, with many people being unemployed and unable to provide for themselves or their households. This indicates the importance of studying the social aspects of domestic gardens in developing countries especially, where products from these gardens can increase livelihoods for people and possibly ensure an income (Cilliers, 2010; Cilliers *et al.*, 2012).

The inclusion of social aspects within urban ecological studies can be conducted on various levels. One of these studies determined the social drivers for homegarden biodiversity within a settlement in the North-West Province, South Africa (Davoren, 2010). The social aspects were determined based on a questionnaire that was divided into four different sections focusing on the perceptions of the residents with regards to their gardens, the level of garden activity, socio-economic status and the emotional well-being and satisfaction with life of the urban residents (Davoren, 2010). Within this study it was determined that 89% of the residents perceived a garden to be a place where food production should take place, even though 53% of the people have a high regard for ornamental plants in gardens. It was also determined that the level of education is influenced by the socio-economic status of the people. In the settlement, 28% of the participants did not have any formal education (Davoren, 2010). It was concluded within this study that, with the majority of the residents being poor, homegardens are essential for ensuring food security and increasing health.

A study conducted within Harare, Zimbabwe, also focussed on determining the importance of homegardens for ensuring food security. In this study the minimum required intake of 2100 kcal per day was used as a benchmark for accepted daily energy requirements (Mutonodzo, 2009). It was determined that 26.3% of the households that practiced in urban agriculture were considered to be food secure, whilst only 13.5 % that did not practice urban agriculture had an adequate supply of food. It was also determined in this study that the socio-economic status of people are influenced by their extent of education, household size, age and gender (Mutonodzo, 2009). However, there are cases where it is becoming increasingly important to attain economic benefit from homegardens. One such example is homegardens in Kerala, India, where gardens

are not only solely used for subsistence purposes, but also for generating income and providing economic stability (Mohan, 2004).

Two other studies were conducted in the North-West Province, South Africa, one of which described the total floral diversity of urban domestic gardens in a typical medium-sized city (Lubbe *et al.*, 2011). The study done in Potchefstroom recorded a total number of 835 plant species that consisted of 501 genera that were part of 145 plant families (Lubbe *et al.*, 2011). This study also determined how the plant diversity patterns differed along an indirect socio-economic gradient (Lubbe *et al.*, 2010). The city of Potchefstroom is culturally very heterogeneous, mainly because of the former segregation laws of the apartheid era and the socio-economic gradient was established by combining socio-economic factors of the residents into classes (Lubbe *et al.*, 2010). Results showed that these socio-economic factors had an effect on the plant diversity patterns with more affluent, white-dominant suburbs obtaining the highest plant species richness (Lubbe *et al.*, 2010).

The other study of the North-West Province focussed solely on one specific ethnic group, the Batswana people. This study determined the diversity of useful plants in homegardens, or otherwise known as tshimo gardens, in deep rural, rural and peri-urban regions (Molebatsi *et al.*, 2010). Deep rural areas was defined as a community that is under tribal rule and of which the majority of residents are subsistence farmers. This study found that deep rural and rural homegardens had a more specific and similar garden layout that consisted of six types of micro-gardens with many useful species for example, medicinal and food gardens (Molebatsi *et al.*, 2010). In contrast, the peri-urban homegardens resembled typical European gardens which contained a higher number of alien and ornamental species (Molebatsi *et al.*, 2010). This study also suggested that urbanization has a distinct influence on the plant use categories in these tshimo gardens. From these abovementioned studies it is evident that social factors influence plant diversity patterns in homegardens, and that homegardens are important for sustaining households in developing countries.

It is important to integrate the biological and physical components with socio-economic aspects, such as human perceptions, education and age, within urban ecological studies (Niemelä, 1999; Pickett *et al.*, 2009).

2.6. Studies on arthropods within urban environments

2.6.1. The importance of arthropod studies in cities

Arthropods are vital components of biodiversity of urban ecosystems and the interactions they partake in are crucial for the ecological integrity of these systems (Hochuli *et al.*, 2009). They provide essential ecosystem services through playing important roles in nutrient cycles, organic matter decomposition, pollination, and soil aeration and are also fundamental organisms in foodweb interactions (McIntyre *et al.*, 2001; Kotze *et al.*, 2011). Therefore, through enhancing the biodiversity of arthropods in cities, the sustainability of the urban ecosystem is increased by maintaining ecosystem services (Kazemi *et al.*, 2009). Arthropods are to a large extent underrepresented in urban ecological studies even though alterations of their habitats, as a result of urbanization, is considered to be one of the major causes for a decline in arthropod diversity and abundance worldwide (McIntyre *et al.*, 2001). Arthropods are also threatened by human preferences. Many adults, has a distinct dislike in arthropods or “bugs” as they are referred to and this can have a negative influence on arthropods in households (Kotze *et al.*, 2011). This negative connotation will only be removed through educating residents in urban environments (Kotze *et al.*, 2011). It is therefore necessary to include arthropods within urban studies and to determine to what extent arthropod communities are affected by urbanization (Hochuli *et al.*, 2009; McIntyre & Rango, 2009).

Arthropods are especially valuable for studying how urbanization impacts the biotic environment of urban ecosystems (McIntyre *et al.*, 2001). Apart from the important roles they play, arthropods are extremely abundant and ensure that large samples are obtained in arthropod studies (McIntyre *et al.*, 2001; McIntyre & Rango, 2009). They are also easy to sample and because of their relatively short generation times these arthropods are able to respond rapidly to urban expansion (McIntyre *et al.*, 2001; Kotze *et al.*, 2011). As a result of these factors they can also be used for cross-city comparative studies in urban ecology (McIntyre & Rango, 2009). Arthropods are also regularly used as biodiversity indicators (Zapparoli, 1997; Whitmore *et al.*, 2002; Kazemi *et al.*, 2009) of environmental changes such as air and water pollution (Zapparoli, 1997) and they therefore reflect ecosystem quality (Kotze *et al.*, 2011) which can all be applied to urban planning and management (Zapparoli, 1997). With many arthropods perceived as pests in urban areas, they are considered to be economically and socially important, while simultaneously having possible health risks considering that many of them are vectors of diseases (McIntyre & Rango, 2009). This is especially important in areas where there is a large population of people living in close proximity to one another. However, apart from their important

roles in providing ecosystem services they are also vectors for disease making the study of arthropods in urban environments a high priority.

2.6.2. Effects of urbanization on arthropods

Urbanization affects arthropod diversity and abundance because of habitat loss and fragmentation (Connor *et al.*, 2002). Fragmentation of the natural habitat of arthropods is a major cause for the decline in arthropod numbers (McIntyre *et al.*, 2001) because it leads to changes in the quality of habitats (Connor *et al.*, 2002). However, it has been shown that the effects of habitat fragmentation are not similar for all groups of arthropods and will differ as a result of their specific needs from their surrounding environment, as well as life history and morphological traits (Kotze *et al.*, 2011). Those species that are considered to be habitat specialists will decrease in numbers because of the severity of habitat alterations (Kotze *et al.*, 2011). However, many species tend to become dominant in urban environments, especially those species that are considered to have generalist feeding requirements, high dispersive abilities, are thermophilic (as a result of the Urban Heat Island Effect) and those which are regarded as invasive species (Kotze *et al.*, 2011).

A study in small and large fragmented heath and woodlands in Sydney, Australia found that arthropod assemblages are greatly affected by urban fragmentation (Gibb & Hochuli, 2002). Even though there were no differences between species richness in small and large fragmented areas, there were compositional differences (Gibb & Hochuli, 2002). For example, there was a completely different composition of wasp fauna between the smaller disturbed and larger less disturbed fragments (Gibb & Hochuli, 2002). Also, smaller fragments seemed to have more generalized species (Gibb & Hochuli, 2002) indicating that these highly altered environments were unable to provide for the more specialist species. A study conducted in different cities in New Zealand aimed to determine the distribution of dominant ants and what factors may influence these species' dominance (Stringer *et al.*, 2009). Latitude and temperature seemed to influence ant abundance with native species more commonly found in areas with higher latitude and colder temperatures in the southern island and more invasive species found at higher latitudes and warmer temperatures in the northern island (Stringer *et al.*, 2009). This study also showed the dominance of one specific invasive species namely *Linepithema humile* (the Argentine ant) whose presence seemed to result in a decrease in the number of native ant species (Stringer *et al.*, 2009).

Another factor that seemed to influence arthropod diversity in cities is habitat complexity. A study on traffic islands in Durban, South Africa, found that structurally enhanced islands had significantly higher species richness than those of grassed traffic islands (Whitmore *et al.*, 2002). Similarly, McIntyre *et al.* (2001) found that arthropod assemblages differed between different land-use types in Phoenix, Arizona in the USA. However, these differences were not necessarily ascribed to the specific land-use types but rather the habitat structure present within land-use types were the driving forces behind arthropod communities (McIntyre *et al.*, 2001). Arthropod abundance is also influenced by the surrounding green space of an area. For example, Smith *et al.* (2006b) conducted a study in domestic gardens of Sheffield, UK and the abundance of most arthropods sampled, especially ground beetles, was higher in gardens that had a larger area of green space surrounding the garden.

The abovementioned factors seemed to influence arthropod diversity, even though not all arthropods are equally affected. Therefore it is necessary to study these factors in urban environments so that more knowledge can be obtained of arthropod communities and how they respond to their surrounding urban environment, which can then be used to conduct urban planning and conservation in an appropriate manner.

2.6.3. Conservation of arthropods in cities

Arthropod diversity around the world is threatened as a result of land transformation brought on by human development (McGeoch, 2002). These transformations include overgrazing by livestock, soil erosion, deforestation, invasive species introductions and urban expansion (McGeoch, 2002). The conservation of arthropods in all these areas are vital, however, only the importance and possibility of arthropod conservation in urban settings will be highlighted.

According to Connor *et al.* (2002), the San Francisco Bay Area in the USA is a biodiversity hotspot that is situated within a large urban environment and as a result there are many species that are threatened, some of which have already become extinct. Fortunately, many arthropod species still live in gardens, along roadside verges, in remnant natural habitats and other areas in and around the city despite the magnification of the urban development that has taken place over the years (Connor *et al.*, 2002). Therefore, arthropod conservation in urban environments will be possible if natural areas in cities are reserved and urban green spaces are continually managed to their optimal potential (Kotze *et al.*, 2011). Another possibility is to integrate arthropod habitats within designs of urban development (Connor *et al.*, 2002; Kotze *et al.*, 2011). Through educating urban residents in terms of the ecological value of arthropods

(Zapparoli, 1997; McGeoch, 2002, Kotze *et al.*, 2011) and ensuring ready access to areas such as urban parks or botanical gardens will improve the understanding and support for conserving arthropod diversity in cities (McGeoch, 2002).

The use of natural habitat remnants is vital for the conservation of arthropods in urban settings because they contain naturally occurring species (Gibb & Hochuli, 2002; Whitmore *et al.*, 2002). However, other areas of urban green space can also be used effectively to maintain viable arthropod communities. For example, a study in the city of Rome, Italy, found that despite of the extensive urban development that had taken place over the last 100 years, Rome still has a considerable high level of arthropod diversity. The areas responsible for supporting these arthropods are the parks and historical villas, urban and semi-natural green spaces and archaeological sites (Zapparoli, 1997). The BUGS program that was conducted in Sheffield, UK also observed the importance of domestic gardens as a form of urban green space that has the ability to minimize the effects of urbanization on arthropods through providing and preserving suitable habitat (Smith *et al.*, 2006a; Smith *et al.*, 2006b). According to McGeoch (2002), only a small fraction of South Africa's land area is protected which emphasizes the importance of conserving arthropods outside of protected areas and highlights the possibility of using urban areas for conservation objectives in this country. Urban environments should therefore be used for the conservation of arthropods in cities.

2.7. The importance of lawns in urban environmental studies

Lawns are one of the most abundant landscapes in cities and are common in parks and school gardens, domestic gardens, along streets and roads and certain recreation facilities such as golf courses (Ignatieva & Stewart, 2009). In Christchurch, New Zealand, lawns cover approximately 75% of parks and 50-60% of domestic gardens (Ignatieva & Stewart, 2009).

The use of lawns in gardens became very popular, especially in the United States (where 27.6 million acres of land is covered by lawns) and because of the United States' political and economic influence in the world, lawns became a global phenomenon (Ignatieva & Stewart, 2009).

2.8. Previous studies in urban areas of the North-West Province

A limited number of urban studies in South Africa have been done in the past, with most studies conducted in natural and semi-natural areas that have a small human component. Only recently the focus has shifted towards urbanized environments. According to Cilliers *et al.* (2004), there

is a lack of ecological data in urban areas of the country, which makes conservation-orientated policies in urban planning and management difficult to implement.

However, in the North-West Province, there is currently an expansion of studies in urban open spaces that focus on the ecology of cities and the influence of human social factors (Cilliers *et al.*, 2004; Du Toit, 2009). These studies are conducted with interdisciplinary perspectives and include the cost-efficiency of greenhouse gas reductions and how both the environment and the city's economy are able to benefit (Nel, 2006). Other examples are projects in which the effectiveness of local municipalities' efforts to alleviate poverty is determined (Malefane, 2004) and in which birds are used as indicators to determine the effect of urbanization (Smith, 2004).

Several studies were also conducted along an urban-rural gradient. These studies included phytosociological studies that determined the vegetation of road verges (Cilliers & Bredenkamp, 2000) as well as species diversity of epigeal arthropods in grasslands along this gradient (Jonas, 2007). GIS techniques have been used to quantify urbanization and vegetation and soil surveys have also been used to determine the influence of human impacts on grassland ecology (Du Toit, 2009). Another study focussed on one specific ethnic group, the Batswana people (Molebatsi *et al.*, 2010). This study investigated the cultivation of useful plants and the layout of the Tswana tshimo gardens from deep rural to peri-urban areas (Molebatsi *et al.*, 2010). According to Malefane (2004), the majority of South African households are either extremely poor or have a continual vulnerability to becoming poor. The distribution of income and wealth in South Africa are considered to be the most unequal in the world. This indicates the importance of including social and economic aspects in urban studies by doing surveys along a socio-economic gradient. Some of the surveys that used a socio-economic gradient focussed on identifying patterns of plant diversity in a rural settlement (Davoren, 2010) and in domestic gardens of a medium-sized city (Lubbe *et al.*, 2010; Lubbe *et al.*, 2011). Further studies are however needed in this regard to establish the effect socio-economic gradients have on urban biodiversity and to include the participation of all stakeholders in urban planning and conservation (Cilliers *et al.*, 2012).

2.9. Summary

The majority of the world's population lives in urban areas and have an effect on biodiversity (Müller *et al.*, 2010). Even though urbanization is responsible for a great loss of biodiversity globally, cities are able to provide a mosaic of habitats that can harbour a vast spectrum of

plant- and animal species. It is therefore important to study these urban habitats to develop general principles of biodiversity and how it is affected by the human component.

Within urban ecological studies it is also necessary to follow an interdisciplinary approach for a comprehensive understanding of cities and it is vital to include social factors, because these are the most important drivers for biodiversity in urban environments. Social preferences of people, with regards to biodiversity, are apparent within their homegardens, and considering that these private domestic gardens constitute a large part of the urban environment, urban ecological studies should also be extended to these open spaces.

In developing countries, such as South Africa, there are however many social aspects associated with people living in cities and vegetable gardening is a means of alleviating poverty and increasing health to a large extent. It is therefore, important to determine the dependability of people on vegetable gardens, whilst simultaneously understanding how biodiversity is affected by people with different social preferences. Conserving these urban environments will become imperative in the development of sustainable cities.

Chapter 3: Study Area

3.1. Location and previous survey

The study was conducted in the municipal area of Tlokwe (Potchefstroom), which is located in the North-West Province, South Africa between latitude of 26°40' and 26°44'S and longitude of 27°00' and 27°07'E (Figure 3.1). The green polygon on the inset map indicates the boundary of the municipal area in the North-West Province, whilst the different subdivisions indicate the election wards (numbers within this area) on the satellite image.

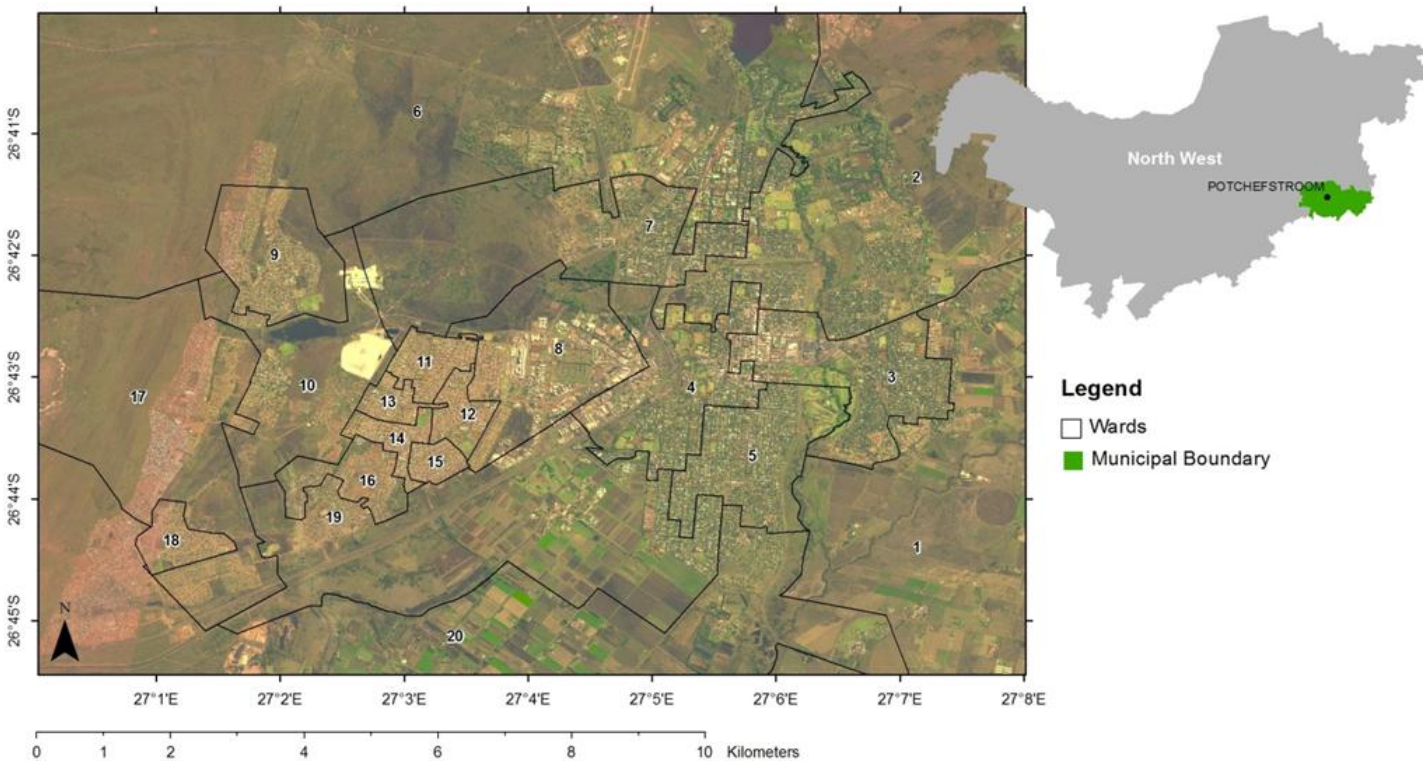


Figure 3.1: Map of the study area in the Tlokwe Municipal area, North-West Province, South Africa.

Potchefstroom is culturally diverse and there exists a definite socio-economic gradient from the eastern to the western part of the city (Cilliers *et al.*, 2012). A previous study described this socio-economic gradient through grouping the different wards into 5 distinct socio-economic status (SES) classes (Lubbe *et al.*, 2010). This was done with a survey that focused on specific aspects that influenced the financial stability of the urban residents in the Tlokwe Municipal Area.

This previous survey was predominantly based on the average % unemployment of households within the different wards. However, Lubbe *et al.* (2010) obtained additional information such as household size (% households with 5 or more persons), number of rooms (% with 2 or less rooms), schooling status (% of persons with no schooling) and access to basic services (% households with pipe water \geq 200 m away). This information, provided in Table 3.1, was then used to group the different wards into socio-economic classes.

Table 3.1: Five parameters examined to define the five socio-economic status classes of the Tlokwe City Municipality (Lubbe *et al.*, 2010).

SES (class)	Unemployment ¹	Household size ²	Number of rooms ³	Access to basic services ⁴	Schooling status ⁵
1	46 \pm 5	28 \pm 8	44 \pm 18	7 \pm 9	14 \pm 4
2	33 \pm 2	27 \pm 9	40 \pm 10	11 \pm 17	24 \pm 10
3	25 \pm 3	38 \pm 5	27 \pm 14	5 \pm 9	9 \pm 5
4	15 \pm 2	23 \pm 17	23 \pm 12	2 \pm 1	10 \pm 8
5	4 \pm 1	13 \pm 1	10 \pm 1	1 \pm 0	2 \pm

¹ % unemployed household members, ² % households with five or more persons, ³ % households with one or two rooms only, ⁴ % households with pipe water \geq 200 m away, ⁵ % individuals with no schooling per household

According to Lubbe *et al.* (2010), a higher percentage in any of the categories indicates a lower socio-economic status (SES). From Table 3.1 it is evident that households in SES 1 are the economically most stressed households, whilst SES class 5 are the households with the most economic stability. Evidently, there is a wide gap between the different classes when it comes to financial stability. An important question that needs to be asked is whether these different socio-economic status classes are the drivers behind biodiversity in urban environments (Cilliers *et al.*, 2012).

3.2. History of Potchefstroom

Potchefstroom was founded by the Voortrekkers in November 1838, under the leadership of Andries Hendrik Potgieter, in Oudedorp which is approximately 10 km upstream from where the city is situated today (Anon, 2010). This was the first settlement north of the Vaal River and was chosen because of features such as proximity to permanent water (the Mooi River) and fertile soil for agriculture. In 1841 Potchefstroom became the capital of the former Transvaal and by 1866 it was regarded as the largest town in Transvaal with a population of 1 200 (Anon, 2010).

It played an important part in South Africa's constitutional, cultural and religious development. Today Potchefstroom is mainly known for its educational role, sport facilities and recreation (Anon, 2010). It has a population of approximately 128 345 people which is made up of four distinct areas namely Potchefstroom City, Ikageng, Promosa and Mohadin. Each of these areas is former residential areas of people with different racial ethnicities dating back to the time of Apartheid (Anon, 2010).

3.3. Vegetation, topography and geology

Potchefstroom is situated within two biomes namely, the Grassland and Savanna Biomes (Mucina & Rutherford, 2006). The Grassland Biome in this area is further divided into two vegetation units, the Rand Highveld Grassland and the Carletonville Dolomite Grassland. There is only one vegetation unit of the Savanna Biome represented within Potchefstroom, namely the Andesite Mountain Bushveld (Mucina & Rutherford, 2006).

3.3.1. Carletonville dolomite grassland

The Carletonville Dolomite Grassland has an altitude of 1 360 – 1 620 m and is characterized by its slightly undulating plains and rocky chert ridges (Mucina & Rutherford, 2006). This is a species-rich grassland, which forms a complex mosaic pattern that is dominated by many species. The geology of this region is mostly dominated by dolomite and chert of the Malmani Subgroup (Transvaal Supergroup). Glenrosa soils are abundant in the area, although deeper red to yellow apedal soils (Hutton & Clovelly soil forms) also occur sporadically (Mucina & Rutherford, 2006).

3.3.2. Rand Highveld grassland

The Rand Highveld Grassland has an altitude of 1 300 – 1 635 m and is associated with an extremely variable landscape, from extensive sloping plains to a series of ridges surrounding these plains (Mucina & Rutherford, 2006). The most common species on these plains belong to the grass genera *Themeda*, *Eragrostis*, *Heteropogon* and *Elionurus*. The geology of this vegetation unit is associated with quartzite ridges of the Witwatersrand Supergroup and the Pretoria Group. This vegetation unit is able to support a variety of soil types including Glenrosa and Mispah forms (Mucina & Rutherford, 2006).

3.3.3. Andesite mountain bushveld

The Andesite Mountain Bushveld is characterised by a medium-tall thorny bushveld and a well-developed grass layer. The geology is dominated by Tholeitic basalt of the Kliprivierberg Group (Randian Ventersdorp Supergroup). Other geological characteristics include dark shale, micaceous sandstone and siltstone, as well as thin coal seams. The most common soil types in this region are the Mispah and Glenrosa forms (Mucina & Rutherford, 2006).

3.4. Climate

Potchefstroom is situated in a warm-temperate region with summer rainfall and the variance of temperature between the summer and winter seasons are quite distinct (De Villiers & Mangold, 2002; Mucina & Rutherford, 2006). Potchefstroom also has a mean annual humidity (%) that varies between 71% in January (summer) and 36% in June (winter) (De Villiers & Mangold, 2002).

The Carletonville Dolomite Grassland has an over-all Mean Annual Precipitation (MAP) of 593 mm. It is also associated with high summer temperatures and severe frost during the winter season (Mucina & Rutherford, 2006).

The Rand Highveld Grassland has a MAP of 654 mm. However, the MAP is slightly lower in the Potchefstroom area which is part of the western region (570 mm) than in the eastern region (730 mm). This vegetation unit also has a higher incidence of frost in the western region (Mucina & Rutherford, 2006).

The Andesite Mountain Bushveld is associated with having a very dry winter season and has a MAP that ranges between 550 mm (southwest, Potchefstroom area) and 750 mm (northeast) (Mucina & Rutherford, 2006). This vegetation unit is also associated with having frequent frost, however, to a lesser extent in the ridges and hills.

Chapter 4: Material & Methods

4.1. Introduction

In this study the five socio-economic status (SES) classes described by Lubbe *et al.* (2010), as discussed in Chapter 3, were used. The wards are divided into these SES classes in the city of Tlokwe (Figure 4.1).

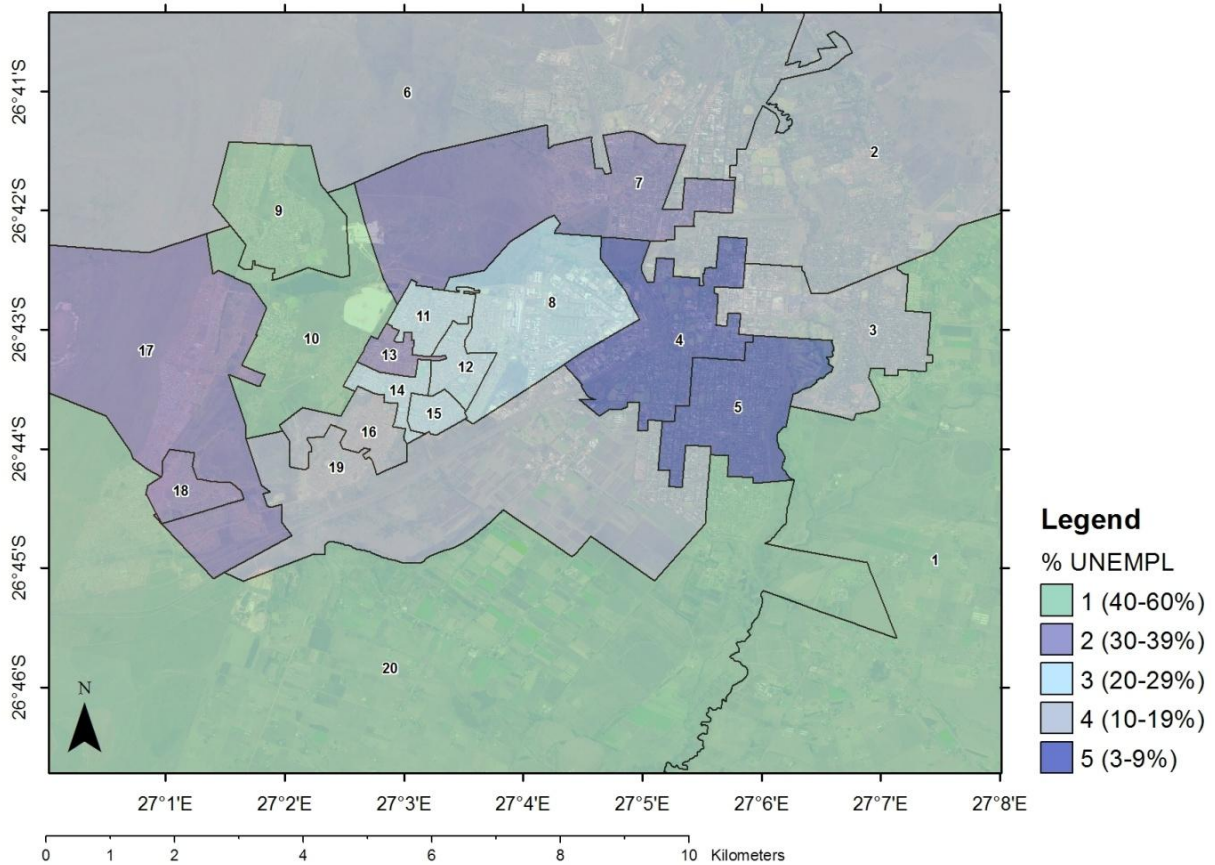


Figure 4.1: Wards divided into the previously described socio-economic status classes within the Tlokwe Municipal Area, North-West Province, South Africa (Lubbe *et al.*, 2010).

UNEMPL = Unemployment

A total of 44 domestic gardens, which included vegetable gardens, were selected to conduct the study. The gardens in SES classes 1 to 3 each had ten representative gardens, whilst SES classes 4 and 5 only had seven representative gardens each. The reason for the lower number of representative gardens in the higher SES classes is due to the lack of vegetable gardens

within the higher income groups. Also, only domestic gardens that had both a lawn and a vegetable garden could be used for data collection to compare plant- and arthropod diversity. Apartment blocks, which generally lack any garden areas, were excluded from the study (Smith *et al.*, 2005). The 44 representative gardens were plotted within the city of Potchefstroom (Figure 4.2).

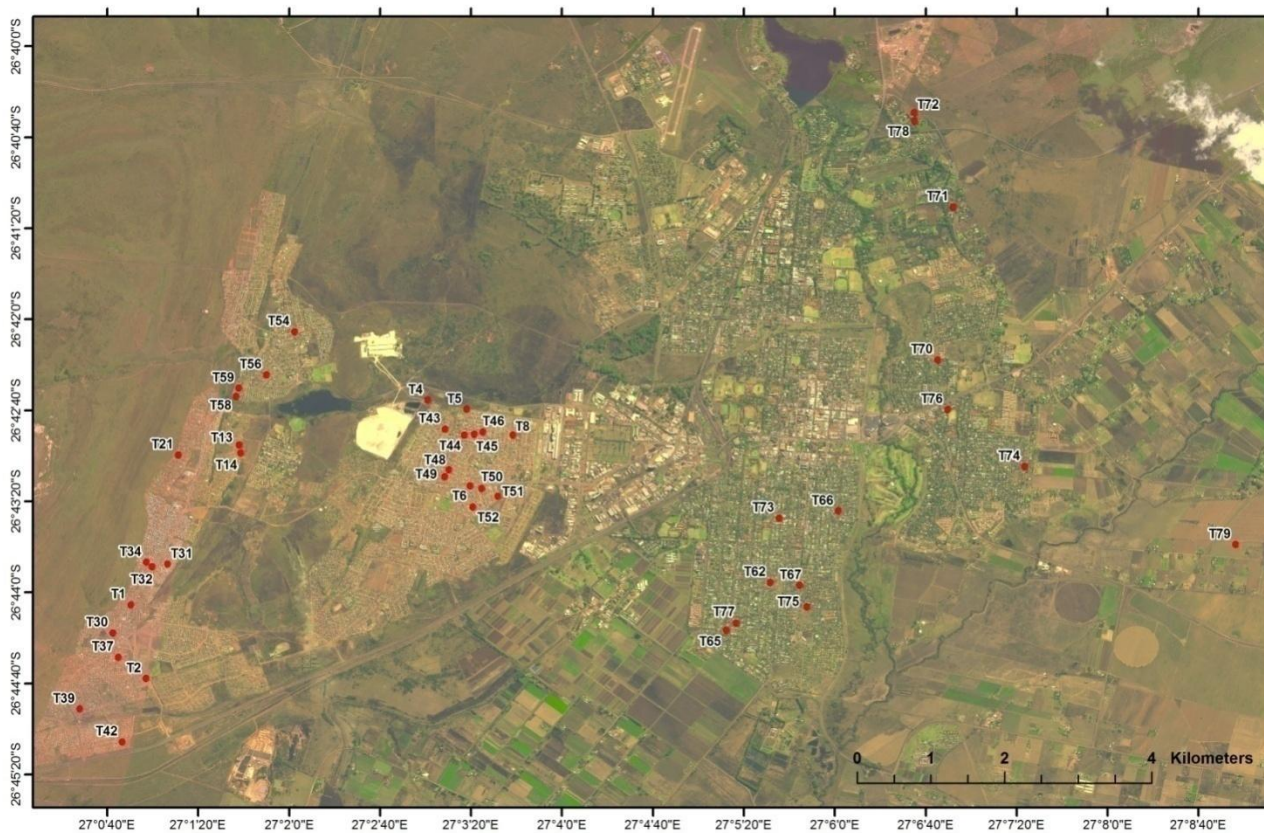


Figure 4.2: Vegetable gardens and lawns surveyed (red dots) in the Tlokwe Municipal Area, North-West Province, South Africa.

All surveys were conducted during summer (February-March 2010). Soil samples were collected in each vegetable patch, and a socio-economic questionnaire was completed for every domestic garden.

4.2. Arthropod sampling

Arthropod diversity was determined by means of pitfall trapping and suction sampling. These two methods were also used in other similar studies on arthropod diversity mainly because each method samples different types of arthropods (Thomas & Marshall, 1999; Pryke & Samways, 2009). Pitfall traps were used for sampling ground-dwelling arthropods, whilst suction sampling

is a useful method in trapping a wider array of arthropod taxa (Thomas & Marshall, 1999). The sampling was conducted within the vegetable garden and lawn of each of the selected domestic gardens for the study. As indicated earlier, lawns were included because they are a highly dominant landscape in cities (Ignatieva & Stewart, 2009) and covered a high proportion of the land area in all the domestic gardens that were surveyed.

4.2.1. Pitfall traps

Pitfall traps are useful to collect a diversity of arthropods that are active on the ground surface (White *et al.*, 1990; Thomas & Marshall, 1999; McIntyre *et al.*, 2001). The pitfalls used in this study were 300 ml honey jars with an opening diameter of 60 mm and were half-filled with water and a 50% alcohol solution, and placed into the soil (Wakefield & Cogan, 2007). Three pitfall traps were placed in the vegetable garden and three in the lawn of each study site. The pitfall traps were left in the vegetable gardens and lawns for a 48-hour period before they were collected. Although the 48 hour period is shorter than the normal pitfall period, it was used because of the small sizes of the gardens. The three pitfall traps were kept separately and was analyzed independently because they were repetitive samples.

4.2.2. Suction sampling

Suction sampling was done with a D-vac portable suction sampler. Sampling in the vegetable garden was conducted along an 8 m transect with eight subsamples being taken at every 0.25 m along the line (Kruess & Tschardtke, 2002).

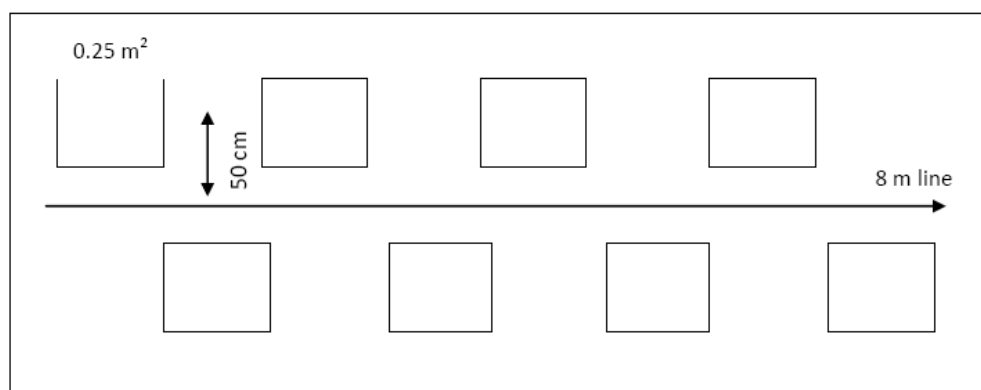


Figure 4.3: Layout of the 8 m transect and approximate position for the suction sampling. Four subsamples were taken at opposite sides of the transect. A maximum deviation of 50 cm was allowed away from the transect.

This transect was placed inside the vegetable garden in such a way that it included the highest diversity of vegetable species possible in that garden. The subsamples were squares that covered a surface area of 0.25 m² (Fig 4.3). Deviation of 50 cm was allowed at every 0.25 m² to ensure that the most dense vegetation units were sampled. The same method was used in lawns and vegetable gardens.

All arthropods collected from the suction sampling, was frozen at -25°C. Each of the eight samples per vegetable garden and lawn were kept separately. The suction sampling bags were sorted by firstly separating them from the soil particles and secondly by identifying and placing them in morphospecies. Different domestic gardens' morphospecies were kept separate for both vegetable garden and lawn data.

During the pitfall- and suction sampling process a total of 264 samples and 704 samples were collected respectively. After sorting and dividing the individuals from each sample into different morphospecies, there were 3600 subsamples.

4.3. Vegetation survey

The vegetation survey was conducted at the 44 gardens along the same 8 m transect in which the arthropods were sampled. Vegetation sampling was conducted immediately after the suction sampling in both the vegetable gardens and lawns. This was done to ensure that the arthropods that were sampled correlated with the plants species that were present at that time. A vegetation survey was conducted (both vegetable garden and lawn) within each of the 0.25 m² subsample squares that were used for arthropod sampling. Total species composition was noted as well as the abundance of each species in terms of the percentage crown cover. Plants were identified to species level with native species being identified according to Germishuizen *et al.* (2006) and alien species according to Glen (2002). A few species was only recorded up to genus level. However, 13 specimens were not identified because they were seedlings but only contributed a small amount to the total vegetation cover. These species were all grouped together as seedlings and were taken into account during the analyses. The vegetation survey data sheet used is given in the Appendix (A).

4.4. Soil sampling and analysis

Soil samples were taken at all 44 vegetable gardens. The lawns were not sampled due to the destructive nature of the sampling. In each vegetable garden a composite sample was taken from three areas within the garden to reduce the effects of microvariations on the soil analysis

(Jim, 1998; Biasioli *et al.*, 2006). These samples were used to determine certain aspects regarding the soil, such as texture, structure, electric conductivity (EC), pH, oxidation-reduction potential (ORP) and total dissolved solids parts per million (tdsppm). Soil samples were dried in an oven for 48 hours (not exceeding 40°C) as preparation for analysis (The Non-Affiliated Soil Analysis Work Committee, 1990). After drying the samples were crushed to pass through a 2 mm stainless steel sieve. A 1:2.5 water analysis was conducted to determine all the variables (excluding soil texture). During the water analysis an amount of 20 ml soil of every sample was mixed with 50 ml distilled water and calibrated for one hour (The Non-Affiliated Soil Analysis Work Committee, 1990). The solution of every soil sample was measured individually using the Multiparameter Water Quality Portable Meter (HI9828, Hanna Instruments). The particle size distribution was determined by EcoAnalytica soil laboratory in the School for Environmental Sciences and Development, North-West University, Potchefstroom.

4.5. Social survey

The social survey was conducted with the use of a questionnaire (Appendix B), with two sections. The first section considered specific garden management practices followed in vegetable gardens and the second the socio-economic status of the participant (Davoren, 2010; Lubbe *et al.*, 2010). Participants were assured that the questionnaire was confidential, anonymous and voluntary (Davoren, 2010). All questions were straightforward and based on a yes/no option. This ensured that the participants were not overwhelmed and did not have to elaborate on any of their answers. The social survey was only conducted after the sampling visits to the garden when the participants were already familiar and comfortable enough with the project. The first section focused on the use of chemicals, watering frequency and age of the vegetable garden. The socio-economic status section focused on the purpose of the vegetable garden, number of people per household, level of education and financial stability. A Tswana-speaking fieldworker (with previous social survey experience) acted as interpreter for the Tswana-speaking gardeners.

4.6. Surrounding land-uses

The percentage cover of land-uses in the vicinity of the surveyed domestic gardens were estimated to determine the possible influence these land-uses may have on biodiversity and how biodiversity differs between the different socio-economic status classes in Potchefstroom. This method used was proposed by Colding (2007) and is commonly referred to as 'Ecological Land-use Complementation' (ELC). This method identifies how gardens interact with other

urban green patches within the vicinity of those gardens. It also determines how these green patches and gardens when clustered together within an area, are able to increase the necessary habitat for biodiversity (Colding, 2007). This is done especially for those species that require larger areas for movement, and to determine how it is able to facilitate in essential ecosystem services within cities (Colding, 2007). The 'Ecological Land-use Complementation' factors were estimated through the use of ArcGIS. GIS (Geographic Information Systems) is useful for processing spatial data into information that can be used to answer questions and to make decisions about some section of the earth's landscape (DeMers, 2005). A radius of 200 m surrounding each of the studied gardens were used for these estimations. A Global Positioning System (GPS) was used to identify specific gardens on the map of the Tlokwe City Municipality. In our study we estimated both the percentage cover of green spaces and infrastructure within the 200 m radius on satellite images (Appendix G). The urban green spaces that were estimated included surrounding domestic gardens, public gardens such as parks and schools and natural areas such as grasslands or woodlands. The percentage cover of agricultural land was also noted. The infrastructural areas that were identified included the percentage buildings (i.e. houses), roads and/or pavements (Smith *et al.*, 2005). A SPOT 5 satellite image with 2 m resolution (captured in 2008) was used in ArcGis ver. 9 (ArcMap ver. 9.2) to estimate the surrounding areas (see Appendix G).

4.7. Data analysis

4.7.1. Arthropod diversity

The data analyses of the diversity indices and the functional groups of the arthropods (results in Chapter 5) are discussed.

4.7.1.1. Diversity indices

Measurements of diversity consists of two essential components (Magurran, 1988) namely, the variety of species present and the relative abundance or evenness of each species. Considering that there are two vital components involved, and the fact that there exists a wide array of indices and models, this can make the measurement of diversity quite complex (Magurran, 1988). Species diversity measurements are divided into three categories which are: species richness indices, species abundance models and indices that are based on the proportional abundances of species (Magurran, 1988).

The Primer 5 software program (Clarke & Gorley, 2001) was used to calculate the diversity indices of the pitfall and suction sampling data. The Margalef index was used to calculate

species richness, whilst the Pielou's evenness index was used to calculate relative abundances of each. Both the Shannon and Simpson indices were used to calculate the proportional abundances of species present.

The STATISTICA 10 (StatSoft, 2005) software program was used to determine significant differences of the indices between the lawns and vegetable gardens, as well as the SES classes. A two-way Analysis of Variance (two-way ANOVA) was conducted.

A two-way ANOVA can be used to analyze the effect of two independent variable as well as the interaction between the two (StatSoft, 2005). One of the aims of this study was to compare the diversity of arthropods between the socio-economic status (SES) classes, as well as between the lawn and vegetable garden (variable designated "Place"). Therefore, the two independent variables were: SES and Place. An interesting component of this type of ANOVA is that it simultaneously determines the effect these two independent variables have on a dependent variable (Valiela, 2009). This dependent variable is referred to as the *interaction of independent variables*. It follows the approach that there will be an interaction if the effect of one variable differs depending on the level of another variable (StatSoft, 2005). For this study the dependent variable was SES*Place.

4.7.1.2. Functional groups

The entire assemblage of arthropods was classified into functional groups according to trophic position (herbivores, predators, parasitoids, decomposers/detritivores, pollinators and visitors). These functional groups were then compared between different SES classes. If differences were observed in functional composition between the SES classes, it would indicate a difference in ecosystem functioning. It would therefore be important to include functional groups within this study as suggested by McIntyre *et al.*, 2001.

Even though an arthropod order or family may host a variety of functional groups, they were assigned to only one specific group depending on whether the majority of that taxon was considered to be herbivores, predators, parasitoids, decomposers/detritivores or pollinators (McIntyre *et al.*, 2001; Wenninger & Inouye, 2008). The functional group "visitors" was assigned to those few taxa that could not be assigned to any of the other groups. All juvenile stages were however excluded from the functional group analysis.

4.7.2. Plant diversity and soil analysis

The ordination methods that were used during the plant diversity and soil analyses (see Chapter 6) are given below.

4.7.2.1. Ordination methods

The CANOCO 4.5 for Windows program (Ter Braak & Šmilauer, 2002) was used to conduct multivariate statistical analyses of the vegetation data along a socio-economic gradient and was used to compare the lawn and vegetable garden species composition. Even though there exists a wide array of statistical methods for studying biotic communities, ordination methods can be used to thoroughly determine gradients of species compositional change and can link these changes to specific environmental factors (Lepš & Šmilauer, 2003). According to Lepš & Šmilauer (2003), the ultimate goal of an ordination is to determine the axis that leads to the greatest variability in the species community composition.

A Detrended Correspondence Analysis (DCA), which is an indirect gradient analysis (Kent & Coker, 1992), was used to illustrate possible differences in the total plant species composition in the vegetable gardens and lawns, as well as vegetable species compositional differences, between the SES classes. The Canonical Correspondence Analysis (CCA) is a direct gradient analysis that uses environmental variables to determine variability in species composition that is due to the measured environmental factors (Kent & Coker, 1992). A CCA was conducted to determine to what extent soil as a factor influences vegetable species composition between the SES classes.

4.7.3. Surrounding land-uses and integration of plant- and arthropod diversity

The results from the following data analyses that were conducted are provided in Chapter 7.

The 'Ecological Land-use Complementation' or surrounding land-use factors (as outlined in section 4.6) were estimated through the use of ArcGIS. From these estimations a Detrended Correspondence Analysis (DCA) was conducted (Kent & Coker, 1992) within the CANOCO 4.5 for Windows software program. With this ordination the different land-use types that were identified were compared between the five socio-economic status classes.

One of the aims of this study was to determine how the plant and arthropod diversity are related and how they differ between the SES classes as well as between vegetable gardens and lawns. Through the use of the STATISTICA 10 software program, a two-way ANOVA of the plant and

arthropod data sets was conducted individually using a Wilks lambda test to identify any significant differences between SES classes and vegetable gardens and lawns. Similar to those analyses conducted for the arthropods (see section 4.7.1.1), the two independent variables were: SES and Place.

It was also important in this study to determine how the surrounding GIS land-use types affect plant and arthropod diversity. For this purpose, a principal component analysis (PCA) was conducted in the STATISTICA 10 software program. A PCA gives a linear response model that is used in an indirect gradient analysis (Kent & Coker, 1992). From the PCA the factors that explained the most variability within the data was further analyzed against the plant and arthropod diversity using a one-way ANOVA for each. A one-way ANOVA is one of the simplest types of analysis of variance and it tests whether the differences amongst groups are more significant than the variances that are found within those specific groups (Valiela, 2009).

Spearman's rank order correlations, which are nonparametric tests, were also conducted for the total plant and arthropod data as well as how plants and arthropods correlate with all the variables from the surrounding land-uses. This was done for all the SES classes collectively as well as each SES class individually. It is important to understand that correlation differs from regression because correlation measures how two variables vary together as opposed to regression where the one variable is expressed as a function to the other (Valiela, 2009).

Chapter 5: Arthropod diversity of vegetable gardens and lawns along a socio-economic gradient

5.1. Introduction

5.1.1. Arthropods in urban areas

Urbanization is considered to be one of the major causes for a decline in arthropod diversity and abundance worldwide (McIntyre *et al.*, 2001). This is especially true in developing countries, such as South Africa (McGeoch, 2002). Only a few studies have focused on how arthropods actually respond to urbanization. Most studies of arthropods in cities focused largely on specific taxa and not on entire arthropod assemblages (McIntyre *et al.*, 2001). Urban fragmentation have been reported to alter the composition of arthropod assemblages, especially that of predators and parasitoids (Gibb & Hochuli, 2002). Urban domestic gardens are not considered to be isolated fragments, but are rather interconnected areas of urban green space (Smith *et al.*, 2006b). The management of urban green space should be improved to achieve insect conservation objectives in cities (Kotze *et al.*, 2011). Domestic gardens, especially, has the potential for conserving arthropod diversity.

Invertebrate species richness and diversity are not only used in conservation, but also to evaluate ecosystem fitness within the community (Burel *et al.*, 1998). This can also be applied within urban environments where invertebrates fulfill specific functions which reflect the environmental quality of the urban ecosystem (Kotze *et al.*, 2011). Several studies however indicated that the sole use of species richness to determine diversity is a too simplistic measurement (Gibb & Hochuli, 2002; Moonen & Bàrberi, 2008). In conservation studies, it is generally believed that a high biodiversity value inevitably reflects a high level of sustainability; however, this is not necessarily the case (Moonen & Bàrberi, 2008). Functional groups, which reflect ecosystem functioning and provide essential ecosystem services such as pollination and decomposition, should also be included within biodiversity studies (Moonen & Bàrberi, 2008). In fact Moonen & Bàrberi (2008) argued that a high diversity within functional groups, increase the functional integrity of the ecosystem and is therefore considered to be more sustainable.

5.1.2. Layout of the chapter

This chapter focuses on arthropod diversity in lawns and vegetable gardens. The pitfall and suction sampling data were analyzed separately. Data were separated during the analyses mainly because these two collection methods differ greatly, usually trapping different arthropod

groups. Arthropods collected from the vegetable gardens were also compared to the lawns adjacent to these gardens. In this chapter lawn and vegetable garden data collected using the different methods were also compared to one another for the five socio-economic status (SES) classes (as described within Chapter 4).

Results from this study were also compared to those from previous studies describing arthropod diversity in agroecosystems. Agroecosystems were used for comparison firstly, because there are few comparable studies on arthropods in urban ecosystems (McIntyre *et al.*, 2001) and secondly, agroecosystems have certain characteristics in common with urban ecosystems. These similar characteristics were highlighted by Moonen & Bàrberi (2008) who indicated that an agroecosystem has three distinct and strongly interacting systems namely; 1) the productive system, 2) the semi-natural or natural areas surrounding the productive system and 3) the human sub-system that consists of settlements and infrastructure. In this study the productive system was domestic gardens (vegetable gardens and lawns), whilst the human sub-system was the housing and management tendencies which influenced the productive system. The surrounding semi-natural/natural areas were also included.

The specific objectives were to determine the:

- Arthropod morphospecies and functional diversity in domestic vegetable gardens and comparison with lawns.
- Arthropod diversity turn-over between different socio-economic status classes.

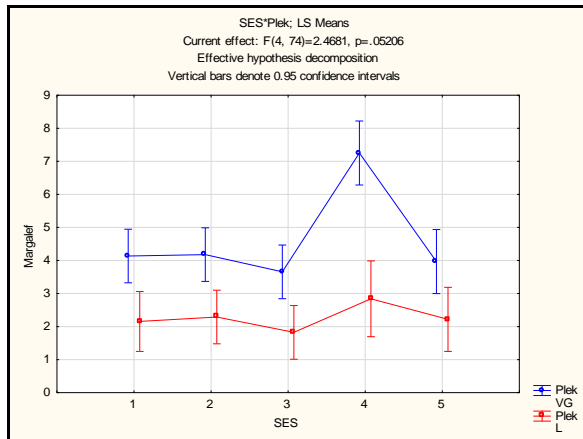
5.2. Results and discussion

5.2.1. Taxa numbers

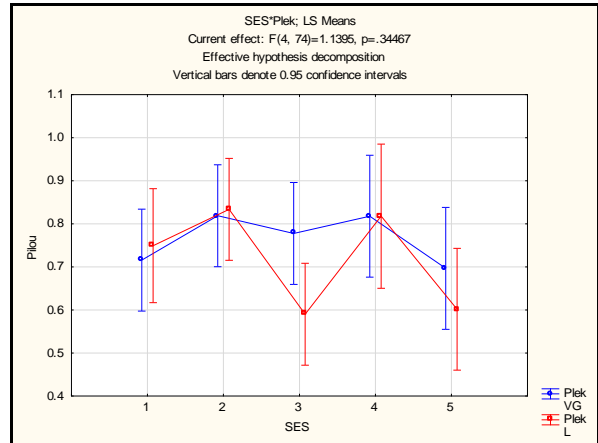
A total of 21 437 arthropod individuals were collected comprising 18 orders and 66 families belonging to 495 morphospecies (See Appendix C for details). A few individuals from other taxa (i.e. Mollusca and Chordata) were also sampled. Arthropod orders containing the highest number of morphospecies were Coleoptera (132), Hymenoptera (110), Diptera (70), Araneae (68) and Hemiptera (44). From the total number of individuals 72.7% was collected in pitfalls, whilst suction sampling accounted for 27.3%. When the total number of individuals from lawns and vegetable gardens were compared for pitfall traps, the lawns contributed 55.5% of all the individuals. However, comparing the total number of individuals between lawns and vegetable gardens captured by means of suction sampling, the lawns contributed only 36.5% of all individuals.

5.2.2. Diversity indices

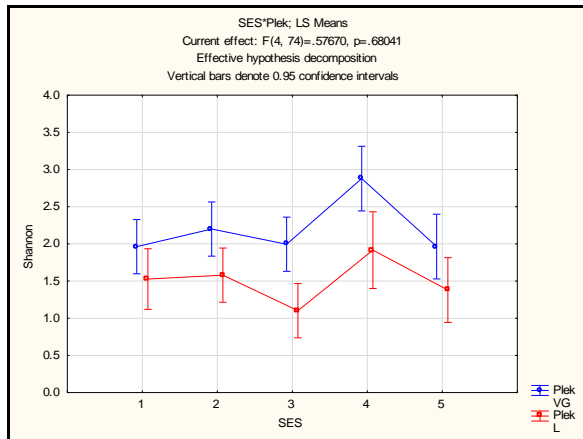
Diversity indices for the suction sampling data are provided in Figure 5.1. Significantly higher index values were observed for the vegetable gardens than lawns, except for Pielou's evenness index which showed no significant differences between them ($p = 0.27$) (Fig. 5.1).



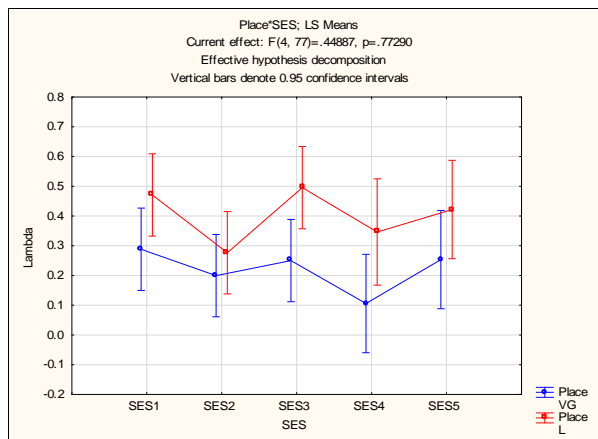
A)



B)



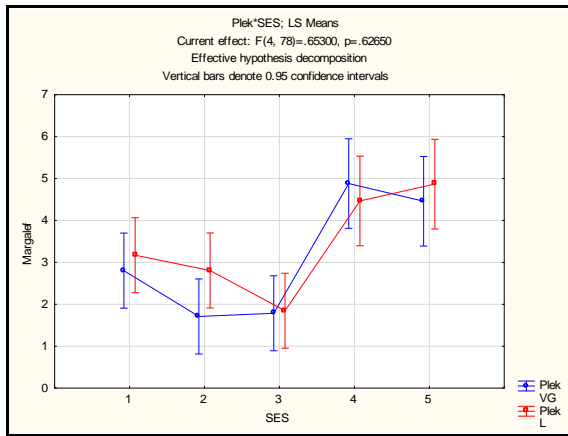
C)



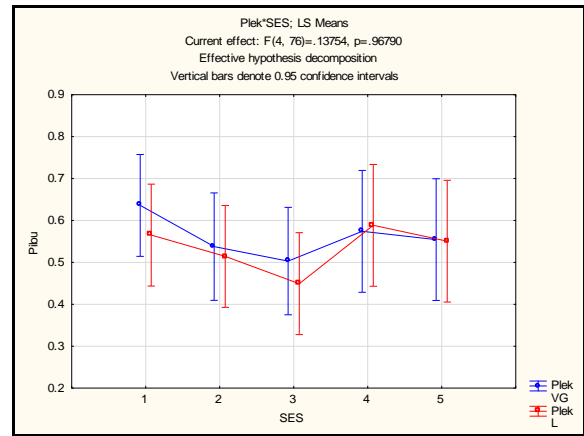
D)

Figure 5.1: Comparative values of species diversity indices between both the SES classes and vegetable gardens and lawns for arthropods collected by means of suction sampling. (A) Margalef's species richness index. (B) Pielou's evenness index. (C) Shannon-Wiener diversity index. (D) Simpson's diversity index.

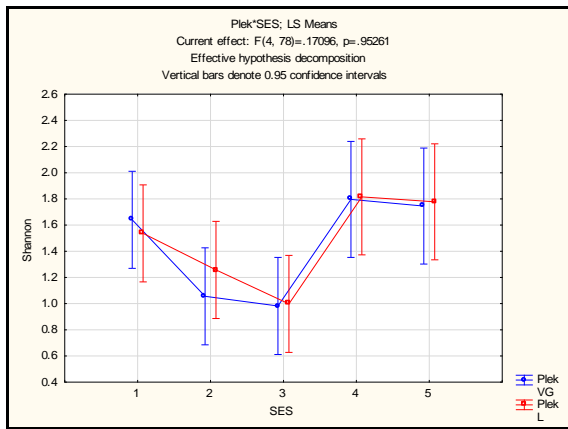
Blue line (VG) indicate Vegetable garden, Red Line (L) indicate Lawn.



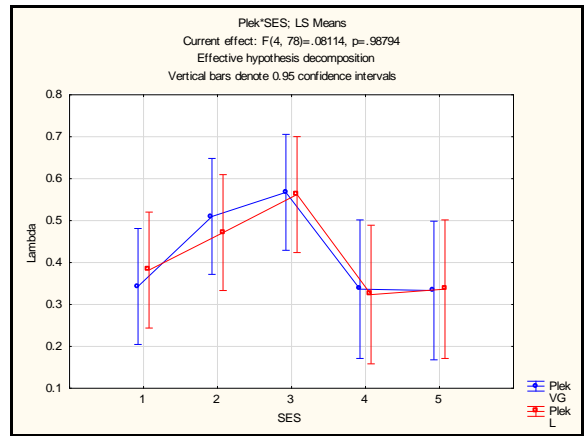
A)



B)



C)



D)

Figure 5.2: Comparative values of species diversity indices between both the SES classes and the vegetable gardens and lawns for the arthropods collected by means of pitfall sampling. (A) Margalef's species richness index. (B) Pielou's evenness index. (C) Shannon-Wiener diversity index. (D) Simpson's diversity index.

Blue line (VG) indicate Vegetable garden, Red Line (L) indicate Lawn.

From Pielou's evenness index, Margalef's species richness as well as Shannon and Simpson's indices (Fig. 5.1 A-D) no overall pattern of diversity was noted along the SES classes. In some cases diversity values either increased or decreased but, this was not ascribed to specific SES classes for the suction sampling. It did seem however that vegetable gardens from SES class 4 had higher Margalef species richness values and higher Shannon and Simpsons' diversity indices than any of the other classes in both vegetable gardens and lawns. No significant interaction between SES with Place (vegetable garden and lawn) was observed with regard to

any of the diversity indices (Fig.5.1). The p-values for this interaction were: Margalef's species richness (0.05); Pielou's evenness index (0.34); Shannon's diversity index (0.68); Simpson's diversity index (0.77).

Figure 5.2 illustrates the diversity indices derived from the pitfall sampling data. There were no significant differences between vegetable gardens and lawns for any of the diversity indices. However, significant differences were observed between Margalef index values of the different SES classes (Fig.5.2A).

Margalef's species richness index (Fig. 5.2A) showed that SES classes 4 and 5 had significantly ($p < 0.05$) higher species richness values than the three lower income classes. The two-way ANOVA results for Pielou's evenness index (Fig.5.2B) revealed no significant differences between any SES classes for the pitfall data ($p = 0.32$). Thus, indicates that the relative abundance of all species were similar. The Shannon and Simpson's diversity indices (Fig. 5.2 C & D) showed that SES class 4 had the highest diversity which was also significantly ($p < 0.05$) higher than the diversity of SES class 3. There was no significant interaction between SES and Place ($p > 0.05$). The p-values for the interaction were: Margalef's species richness (0.63); Pielou's evenness (0.97); Shannon's diversity (0.95); Simpson's diversity (0.99).

The mean values of the indices from the suction sampling analysis are provided in Table 5.1. These values include both vegetable gardens and lawns. The higher Margalef species richness index and Shannon diversity index values for SES class 4 were evident (Table 5.1). It also showed that SES class 3 had the lowest scores for Margalef and Shannon-Wiener indices (Table 5.1). SES classes 1 and 2 had similar results for these indices.

Table 5.1: The weighted mean values and diversity indices of arthropods collected by means of suction sampling in vegetable gardens and lawns for all SES classes.

	SES1	SES2	SES3	SES4	SES5
Variable			Mean		
Margalef	3.2551	3.2341	2.7403	5.4136	3.0935
Pielou	0.7306	0.8263	0.6839	0.8178	0.6491
Shannon-Wiener	1.7693	1.8897	1.5485	2.4776	1.6715
Simpson	0.3794	0.2381	0.3728	0.2168	0.3377
Species richness	12.60	12.45	11.40	23.23	14.29
Abundance	85.80	40.75	59.65	78.00	87.90

It is also apparent that all SES classes had similar relative abundance of species as indicated by Pielou's evenness index values, as well as similar values for Simpson's diversity index. Even

though SES class 4 had the highest species richness (Table 5.1), it did not have the highest abundance (number of individuals). SES class 5 had the highest mean abundance (87.9, Std. dev = 83.51) and SES class 2 the lowest (Table 5.1).

Table 5.2 provides the mean values of the diversity indices from the pitfall sampling. The more affluent SES classes (4 and 5) had higher values for both Margalef species richness index and Shannon-Wiener diversity index (Table 5.2). SES class 3 had the lowest values for these two indices (Table 5.2). Once more Margalef and Shannon-Wiener values for SES classes 1 and 2 are quite similar. Pielou’s evenness index values illustrates that all the SES classes had similar abundance of species, regardless of the number of species present (Table 5.2). SES classes 4 and 5 also had the highest species richness and abundance and there was quite a distinct difference in the mean number of species between these two classes and SES classes 1, 2 and 3 (Table 5.2). Through comparing the mean values between the suction (Table 5.1) and pitfall sampling (Table 5.2) it showed that the pitfall traps overall sampled a higher abundance and richness of species.

Table 5.2: The weighted mean values and diversity indices of arthropods collected by means of pitfall sampling in the vegetable gardens and lawns for all SES classes.

	SES1	SES2	SES3	SES4	SES5
Variable			Mean		
Margalef	2.9875	2.2578	1.8153	4.6727	4.6633
Pielou	0.6006	0.5253	0.4747	0.5812	0.5525
Shannon-Wiener	1.5885	1.1566	0.99	1.8059	1.7615
Simpson	0.3625	0.4906	0.5647	0.33	0.3348
Species richness	14.50	11.30	9.40	25.57	27.21
Abundance	156.10	145.95	111.90	248.50	293.43

Except for Margalef index values (suction sampling) results of all the diversity measurements showed that there was no significant interaction between SES status and Place. Therefore, these variables were independent from each and each had their own effect on arthropod diversity. This is an interesting finding since similar studies in urban areas showed that socio-economic status influenced plant diversity. These studies indicated that plant diversity in urban areas increases across a socio-economic gradient (Martin *et al.*, 2004; Lubbe *et al.*, 2010; Cilliers *et al.*, 2012) or have higher species richness with increasing SES status (Kirkpatrick *et al.*, 2007). Martin *et al.* (2004) referred to this phenomenon as the “luxury effect”. This study also showed that habitat type (vegetable garden or lawn) had an influence on the arthropod diversity in the different SES classes. Arthropod diversity in urban residential areas are

therefore possibly influenced by other factors that are only indirectly effected by SES status. These other factors, as found in other studies, may include surrounding habitat and landscape (Burel *et al.*, 1998; Duelli *et al.*, 1999; Santos *et al.*, 2007; Cai *et al.*, 2010), plant structural heterogeneity (Procheş & Cowling, 2006; Sperling & Lortie, 2010), plant species richness and diversity (Thomas & Marshall, 1999; Biaggini *et al.*, 2007; Cai *et al.*, 2010; Sperling & Lortie, 2010) and management regimes (Samways *et al.*, 1996; Duelli *et al.*, 1999; Santos *et al.*, 2007; Noordijk *et al.*, 2010). A few of these factors were investigated within our study, such as surrounding landscape (see Chapter 7) and plant species diversity (results in Chapter 6). Management regimes of the residents are also highlighted in Chapter 7.

The Margalef, Shannon and Simpson indices showed that diversity was higher in the more affluent urban areas (SES classes 4 and 5). Diversity index values reported in our study cannot be directly compared to those reported in other agro-ecosystem studies. However, such comparisons between urban and agro-ecosystems could provide insight regarding general tendencies of diversity. Diversity index values in our study were lower than those reported in agroecosystems. For example, a study conducted by Burel *et al.* (1998) reported comparatively high Shannon-Wiener index values (1.68 - 3.69) for arthropod diversity along a gradient of agricultural intensification. These values were all higher than the Shannon values derived from our domestic gardens (1.42 - 2.36). Higher diversity was also reported in a study that determined the effects of intercropping on arthropod diversity in vegetable fields (Cai *et al.*, 2010). It therefore seems that arthropod diversity in agroecosystems is higher than in urban domestic gardens. However, when taking into account that these studies were conducted in larger plots (Cai *et al.*, 2010) and over longer periods (Burel *et al.*, 1998; Cai *et al.*, 2010), results from our study indicate that urban domestic gardens may actually harbor a high diversity of arthropods. For example, Santos *et al.* (2007) determined arthropod diversity, using different pitfall trap types in small plots, which unveiled substantially lower Shannon-values than in our studies. Even though the diversity values obtained in our study was low in comparison with those of large agroecosystems, diversity measurements in urban domestic gardens have been reported to be much higher than those in smaller farmholdings (Santos *et al.*, 2007). Considering that arthropod assemblage composition changes and declines with an increase in fragmentation (McIntyre *et al.*, 2001; Gibb & Hochuli, 2002), urban domestic gardens could contribute to an increase and conservation of biodiversity within cities (Goddard *et al.*, 2010) since domestic gardens are generally linked to each other (Smith *et al.*, 2006b).

The Margalef species richness index indicated significant differences between vegetable gardens and lawns for the suction trap data. Simpson and Shannon indices only showed significant differences for the suction data and only for SES class 4. There were no differences in Shannon and Simpson diversity indices between vegetable gardens and lawns for the pitfall data. In terms of the Pielou's evenness index there were no differences between different SES classes or between vegetable gardens and lawns. This indicated that regardless of the differences in the number of species present within vegetable gardens, lawns or SES classes, the relative abundance of those species were similar.

A previous study conducted in the city of Durban, South Africa, also determined species richness, evenness and diversity of arthropods between traffic islands that were subjected to two different management regimes (Whitmore *et al.*, 2002). The one type of traffic island consisted of lawns that were subjected to extensive mowing and therefore had a low structural diversity. The other type was enhanced with indigenous and exotic vegetation to give it more structural diversity. This study obtained similar results to our study, reporting that species richness was lower on grassed (lawn) island types (Whitmore *et al.*, 2002). Evenness was also unaffected by the type of island (Whitmore *et al.*, 2002), which corresponds to results from our study where no significant differences in evenness were observed between vegetable gardens and lawns for both the sampling methods.

Our study also showed that high species richness of urban domestic gardens was associated with high abundance values. These results are similar to those reported from urban domestic gardens in Sheffield, UK (Smith *et al.*, 2006b). According to Smith *et al.* (2006b), if both the species richness and abundance within a domestic garden was high, it indicates that the high values was not caused by a small number of species that contributed a disproportionate number of individuals, but rather to high numbers of individuals of many species (Smith *et al.*, 2006b).

5.2.3. Functional groups

The morphospecies were divided into six distinct functional groups and compared between vegetable gardens and lawns of the SES classes. These functional groups are Herbivores, Predators, Parasitoids, Decomposers/Detritivores, Pollinators and Visitors. The functional groups from the suction sampling are provided in Table 5.3.

In vegetable gardens the arthropod complex was dominated by herbivores and predators (Table 5.3). In lawns, predators were the most abundant (Table 5.3).

Table 5.3: Number of individuals of each functional group for both the vegetable gardens and lawns of all SES classes collected by means of suction sampling.

SES	VG/L*	Functional groups					
		Herbivore	Predator	Parasitoid	Decomposer/Detritivore	Pollinator	Visitor
SES1	VG	941	149	158	103	2	8
SES2	VG	213	173	38	33	1	2
SES3	VG	166	274	22	13	1	2
SES4	VG	411	129	93	17	3	66
SES5	VG	238	164	35	229	3	6
Total		1969	889	346	395	10	84
SES1	Lawn	197	49	16	43	0	5
SES2	Lawn	160	133	19	19	0	2
SES3	Lawn	150	422	17	14	1	2
SES4	Lawn	88	76	15	23	0	7
SES5	Lawn	128	274	23	87	0	2
Total		723	954	90	186	1	18

*VG = Vegetable garden, *L = Lawn

Pollinator numbers were low but evenly distributed between the SES classes. The numbers of parasitoids were higher in vegetable gardens than lawns (Table 5.3). Only 0.2%, 1.8% and 10.3% of individuals on vegetable gardens and lawns were pollinators, visitors and decomposers respectively.

High numbers of herbivores were collected in vegetable gardens and lawns of SES class 1. SES class 1 also had a dominance of parasitoid numbers in vegetable gardens (Table 5.3). The highest numbers of predators were located in vegetable gardens and lawns of SES class 3 and the lowest in lawns of SES class 1. Also, low abundance of predators and herbivores were found on lawns of SES class 4 (Table 5.3). SES class 5 had a high number of decomposers for both vegetable gardens and lawns in comparison with the other SES classes (Table 5.3).

The functional groups collected by means of pitfall sampling, showed completely different results from those obtained by suction sampling (Table 5.4). The two most affluent classes (SES 4 and 5) had the highest number of herbivores, parasitoids and visitors in vegetable gardens and lawns, as well as the highest number of predators and decomposers for vegetable gardens (Table 5.4). As with the suction sampling, an evenly distributed number of pollinators were recorded in vegetable gardens and lawns of the different SES classes (Table 5.4). Only 0.15%, 1.25% and 1.43% of individuals that were identified in vegetable gardens and lawns were pollinators, parasitoids and visitors respectively. From the high number of predators collected in lawns, SES class 1 obtained the majority of individuals (Table 5.4).

Table 5.4: Number of individuals of each functional group for both the vegetable gardens and lawns of all SES classes collected by means of pitfall sampling.

SES	VG/L*	Functional groups					
		Herbivore	Predator	Parasitoid	Decomposer/Detritivore	Pollinator	Visitor
SES1	VG	106	645	9	136	4	8
SES2	VG	68	907	15	496	0	0
SES3	VG	54	802	8	60	1	4
SES4	VG	171	928	30	639	3	35
SES5	VG	134	940	52	675	2	28
Total		533	4222	114	2006	10	75
SES1	Lawn	92	1515	6	498	1	10
SES2	Lawn	69	1079	11	236	2	20
SES3	Lawn	67	1118	2	37	1	15
SES4	Lawn	119	732	18	703	5	45
SES5	Lawn	156	1413	44	565	5	58
Total		503	5857	81	2039	14	148

*VG = Vegetable garden, *L = Lawn

Also, SES class 1 had a higher number of decomposers in lawns than in vegetable gardens. In vegetable gardens the highest number of both herbivores and predators were collected in SES class 4 (Table 5.4).

Results from this section of the chapter showed overall that predators were the most abundant group in vegetable gardens and lawns. Lawns also had higher number of predator individuals than any of their associated vegetable gardens for both sampling methods (Table 5.3 & 5.4). This correlates with other studies within urban areas and agroecosystems where predators were also the most abundant group (Cai *et al.*, 2010). This could be ascribed to various aspects such as the availability of resources on a temporal and spatial scale (Cai *et al.*, 2010).

Jonas (2007) reported that the higher number of predators in disturbed urban environments may be the result of predators not having such specific feeding requirements. According to Duelli *et al.* (1999), the higher total numbers of predatory individuals are of utmost importance since it enhances the ecological resilience of an ecosystem and increases its ability to counteract sudden environmental changes. Predator numbers were largely evenly distributed between all SES classes.

The total number of herbivores was larger in vegetable gardens than lawns (Table 5.3 & 5.4) indicating that vegetable gardens had the capacity to accommodate a wider range of herbivores. This could be a result of vegetable gardens having higher plant species diversity than lawns (Procheş & Cowling, 2006) or more diverse structural microhabitats (Moonen & Bàrberi, 2008) which attracts more herbivores. It could however also be that herbivores have

more specific feeding requirements (Jonas, 2007), which are provided for within vegetable gardens. These aspects will be addressed later in this dissertation, as the plant diversity will only be analyzed and discussed within Chapter 6 and the plant-arthropod relationships in Chapter 7.

Decomposers are beneficial and play an important role in nutrient cycling within the soil (Alvarez *et al.*, 2001). The pitfall sampling showed that the two most affluent SES classes (4 & 5) had the highest number of decomposers/detritivores (Table 5.4). SES class 5 also had the highest number as indicated by the suction sampling data (Table 5.3). SES class 3 had the lowest number of decomposer/detritivore individuals. Parasitoids, together with predators, are good indicators for ecological resilience of an ecosystem (Duelli *et al.*, 1999). The number of individuals varied extensively between the different classes. The only consistently high values were obtained from SES class 4, which had high numbers of individuals in vegetable gardens (Tables 5.3 – 5.4). Fenoglio *et al.* (2009) investigated the effect urbanization has on the parasitoid community of arthropods and showed that the species richness of parasitoids were homogenous regardless of the level of urbanization. In this study the number of parasitoid species was positively correlated with the number of plant species present (Fenoglio *et al.*, 2009). It could therefore be that the higher numbers of parasitoids in SES class 4 was a result of a higher abundance of plants in this SES class. This will also be tested in Chapter 6 of this dissertation.

Pollinators play a vital role in most terrestrial ecosystems and maintain both wild plant communities and agricultural productivity (Potts *et al.*, 2010). Unfortunately, there has been a global decline in pollinators, which are caused by numerous environmental changes of which habitat loss and/or fragmentation are the greatest contributors (McFrederick & LeBuhn, 2006; Potts *et al.*, 2010). In this study pollinators were the functional group with the overall lowest abundance in vegetable gardens and lawns (Tables 5.3 – 5.4). A possible reason for this is that the collection techniques that were used is unsuitable for pollinators and therefore they are underrepresented in the samples. It is however also possible that morphospecies from other functional groups (i.e. herbivores) may act as pollinators.

A DCA-biplot of the functional groups were constructed to give an indication of the differences between vegetable gardens and lawns (Fig. 5.3). The Eigen-values for the first axis was 0.689 and the second axis was 0.425. For the most part vegetable gardens and lawns shared similar arthropod species with three lawns and nine vegetable gardens which can be regarded as

outliers (Fig. 5.3). These outliers have resulted in the presence of several additional species occurring in only lawns or only vegetable gardens (Fig. 5.3). This DCA-biplot also provides an indication of the dominance of herbivores and predators from the arthropod sampling (Fig. 5.3).

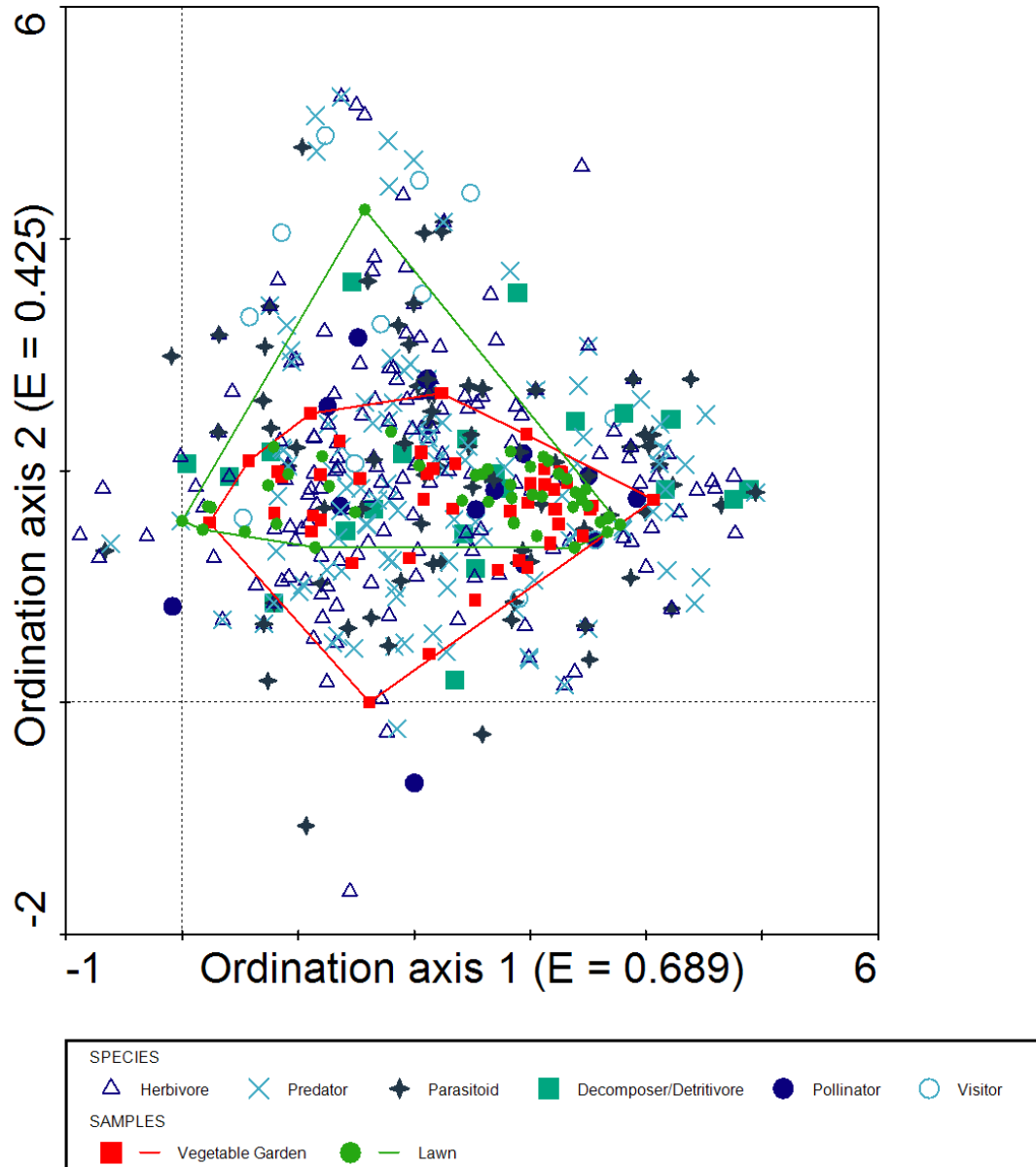


Figure 5.3: DCA-biplot indicating the functional group distribution and beta-diversity between the vegetable gardens and lawns.

5.3. Summary

The two highest socio-economic status classes obtained the highest diversity measurements as well as the highest number of individuals from the different functional groups. However, as

previously stated, differences in arthropod diversity are not necessarily driven directly by SES status, but could be the result of other factors which is an indirect effect of SES status. Other factors, which may influence the diversity measurements, are surrounding habitat and landscape, plant structural heterogeneity, plant species richness and diversity and management regimes. These factors will be discussed further in Chapters 6 and 7.

Another interesting finding was that vegetable gardens of all the SES classes had higher diversity values than their associated lawns. However, Pielou's evenness was similar for vegetable gardens and lawns, regardless of SES status. SES classes 4 and 5 had the highest mean abundance and species richness, whilst SES class 3, which also obtained the lowest diversity index values, had the lowest.

In terms of functionality, predators were dominant within both lawns and vegetable gardens. Herbivore numbers were higher in vegetable gardens than in lawns. The predator group had an even distribution of individuals in vegetable gardens and lawns, whilst herbivores had an even distribution within lawns but not vegetable gardens of the different SES classes. This further indicates that vegetable gardens have specific attributes within each SES class which attract herbivores, for example, some SES classes may have higher plant species diversity.

This study showed that urban domestic gardens differ in arthropod diversity and functionality between SES classes. Nevertheless, it also signifies that urban vegetable gardens are appropriate green spaces that can be used to conserve arthropod diversity within cities. Also, considering that residential areas are not isolated fragments (Smith *et al.*, 2006b), but are interconnected with one another and make up a substantial proportion of a city, it implies that vegetable gardens can be used to increase the urban arthropod diversity of the city as a whole (Thompson *et al.*, 2003).

Chapter 6: Plant diversity of vegetable gardens and lawns along a socio-economic gradient

6.1. Introduction

6.1.1. Domestic gardens

According to Cilliers & Siebert (2011), vegetation is considered to be a representation of the ecosystem functioning it is part of and it inevitably determines the composition and abundance of other organisms within that system. This can also be applied onto an urban ecosystem, where urban vegetation ultimately influences the system. However, only a few studies of urban vegetation have been undertaken within developing countries in the southern hemisphere (Cilliers & Siebert, 2011). Furthermore, it is especially domestic gardens together with their assembly of garden floras that have been neglected when it comes to urban ecological research (Smith *et al.*, 2006c).

Domestic gardens constitute a large part of the urban environment with up to 21 – 26% coverage of cities in the UK (Loram *et al.*, 2007). The few studies that have been conducted within these gardens proposed that they have immense potential for maintaining biodiversity within cities (Gaston *et al.*, 2005a). Domestic gardens are complex environments that have the ability to support a variety of microhabitats and are also considered to form interconnected areas of urban green space rather than isolated fragments (Smith *et al.*, 2005). Loram *et al.* (2007) has also stated that the importance of domestic gardens increase with an increase in urbanization. However, despite the potential benefits these gardens have for biodiversity in cities, only a few studies have been conducted globally (Thompson *et al.*, 2003). In Potchefstroom, North-West Province, South Africa, 13.27% of the threatened natural grasslands have been transformed as a result of urbanization in the last 25 years, of which 84.02% was for residential purposes (Cilliers & Siebert, 2011). Similarly, 26.18% of grasslands surrounding the city of Klerksdorp, North-West Province, have been altered of which 81.9% was converted into residential areas (Cilliers & Siebert, 2011). This emphasizes the necessity to study private urban green areas such as domestic gardens and to determine whether they are able to harbor a large plant diversity and counteract the sudden environmental changes caused by urbanization. If so, domestic gardens can contribute ultimately to maintain a sustainable urban environment.

Urban sustainability is only possible if its four underlying fundamental dimensions are in equilibrium with one another. These dimensions include the economic, social, environmental

and political factors of the city (Aguilar, 2008). Moreover, it is considered that the social and ecological resilience of a city is closely linked to each other (Adger, 2000; Madaleno, 2000). It is important for urban ecologists to understand the relationship between the social composition and vegetation in urban areas so that sustainable management plans can be created for urban green spaces within cities (Cilliers & Siebert, 2011). Socio-economic aspects within urban domestic gardens influence plant diversity. In fact, it has been shown that plant diversity increase across an urban socio-economic gradient, which is referred to as the “luxury effect” (Martin *et al.*, 2004; Lubbe *et al.*, 2010; Cilliers *et al.*, 2012). It can therefore be stated that urban residents’ social perceptions influence their plant diversity preferences within their gardens, whilst their economic status determines whether they are able to realize those preferences (Bhatti & Church, 2001; Cilliers, 2010).

In many developing countries around the world, homegardens with edible plants are used for subsistence purposes (Blanckaert *et al.*, 2004). These homegardens can become sustainable food systems and is considered to have social and environmental benefits (Blanckaert *et al.*, 2004). A homegarden is a small-scale organic garden that is adjacent to the residential housing of a farmer and the products derived from these homegardens are used for own consumption (Vogl & Vogl-Lukasser, 2003). These homegardens are often located in rural areas, but, they can also be situated within urban areas where they form part of the urban agriculture system within a city. According to the UNDP (1996) it is estimated that one-seventh of the earth’s food supply is cultivated within cities, by a total of about 800 million urban farmers. In Africa, 68% of the population in six Tanzanian cities, 45% in Lusaka (Zambia) and 37% in Maputo (Mozambique) are involved in urban agriculture (De Bon *et al.*, 2010). This emphasizes the importance of homegardens in cities and highlights the possible benefits they may have for developing countries. Likewise, De Bon *et al.* (2010) stated that even a continuing increase in the population growth of cities in developing countries will not affect the economic and social importance of urban agriculture for food security. Even though urban agriculture on its own is not able to provide completely self-reliant human communities, it is able to fulfill the increasing demand for fruits and vegetables (Madaleno, 2000). Vegetables especially are typical urban crops, mainly because they have such short cycles (De Bon *et al.*, 2010). Nevertheless, despite all the potential benefits (as discussed in Chapter 2) urban agriculture may have on the social, economic or ecological level (De Bon *et al.*, 2010; Cilliers, 2010), there is a need for reliable data for homegardens in arid and semi-arid regions that reveals the successful integration of

urban agriculture within cities (Blanckaert *et al.*, 2004; De Bon *et al.*, 2010; Zezza & Tasciotti, 2010).

The most understudied aspects of domestic gardens are the lawns associated with those gardens (Thompson *et al.*, 2004). A domestic lawn is defined as the grass within a domestic garden that is subjected to mowing more than once a month during the growing season (Smith *et al.*, 2006c). Lawns also constitute a large part of the domestic garden. Gaston *et al.* (2005) revealed from a study in Sheffield, UK, that $\pm 60\%$ of domestic gardens are comprised of lawns, which is calculated as 13.7% of the total area of the city. Similarly, a study in Franklin County, Ohio, USA revealed that lawns had a total coverage of 23% of the city, which covers 90 618 ha of land (Robbins & Birkenholtz, 2003). Moreover, domestic lawns are usually considered to be sterile environments, which have a high intensity of disturbance and an increased use of chemicals, when compared to other types of vegetation within urban domestic gardens (Robbins & Birkenholtz, 2003; Thompson *et al.*, 2004; Gaston *et al.*, 2005). However, urban ecologists have paid very little attention to these lawns, even though they constitute such a large part of gardens and have a high disturbance level (Thompson *et al.*, 2004).

In our study, we therefore try to determine the diversity of plants in vegetable gardens, especially with regards to socio-economic status, considering that a large part of the urban human population in developing countries lives in poverty (De Bon *et al.*, 2010) and to compare these vegetable gardens with lawns adjacent to those gardens. Lawns are included in the study because it is a global phenomenon that is the most dominant garden landscape that started during the British and European colonization (Ignatieva & Stewart, 2009). Lawns were considered to be a green “carpet” that was an extension of the interior of households and were therefore expected to be neat within domestic gardens (Ignatieva & Stewart, 2009). Lawns are supposed to be homogenous not only in its appearance but also in its species composition (Ignatieva & Stewart, 2009). This cultural belief of the domesticated lawn still reigns today and it is therefore important to include within urban biodiversity studies. Results from this study will also shed additional light on the importance of urban agriculture, especially in developing countries.

6.1.2. Urban soils

Urban soils form an important aspect for plant life in cities (Sauerwein, 2011). Soils are considered to be the life basis of many organisms and are responsible for many major roles and ecosystem services including nutrient and water cycles and they act as both material sources

and sinks within ecosystems (Coleman *et al.*, 2004; Wall *et al.*, 2004; Sauerwein, 2011). Soils are, however, easily disturbed by human activities and are considered to be a non-renewable resource (Wall *et al.*, 2004; Sauerwein, 2011). As a result of anthropogenic activities, urban soils are markedly different from the more natural and undisturbed soils. Construction work in cities influence the soil structure, leading to compaction and a decrease in the bare soil surface area (Sauerwein, 2011). Consequently, the aeration in the soil is reduced, which decreases the water storage capacity and infiltration rate, and results in impermeable surfaces (Sauerwein, 2011). This in turn does not only reduce the available water and nutrients for plants and other biota, but increases the water run-off on the surface. Urban soils are also different from natural functioning geo-systems because there is an increased probability of contamination from acid rain, or the possible accumulation of heavy metals and organic compounds that are common wastes within urban-industrial areas (Sauerwein, 2011). In our study we aimed to include various aspects of soil in urban domestic gardens (as discussed in Chapter 4) to determine what effect these soils may have on the vegetation within gardens and how they vary between socio-economic status classes.

6.1.3. Layout of the chapter

In this chapter the main objective is to determine and compare the plant diversity of vegetable gardens and lawns between the socio-economic status (SES) classes (as described in Chapter 4). Results from this study will be discussed in the context of previous studies in urban domestic gardens and homegardens, in both developed and developing countries.

The ultimate aim of this chapter was to determine the plant diversity in vegetable gardens of urban domestic gardens along a socio-economic gradient.

The specific objectives were to:

- Determine the plant diversity patterns in vegetable gardens and comparing it to adjacent lawns. It is expected that vegetable gardens will have higher plant diversity than lawns, because lawns tend to be more homogenous.
- Compare the vegetable diversity in urban domestic gardens.
- Compare plant diversity patterns across different socio-economic status classes.
- Determine the specific soil characteristics associated with vegetable gardens and whether there are any differences in soil factors between socio-economic status classes.
-

6.2. Results and discussion

6.2.1. Taxa numbers

During the vegetation survey in the 44 urban domestic gardens along a socio-economic gradient (as outlined in Chapter 4), a total of 88 plant species from 27 families were recorded. Of the 88 species identified within this study, the vegetable gardens accounted for 80 of those species, with the most species occurring in SES classes 1 (46 species) and 2 (42 species). However, the high number of species in these two classes is because of weeds that were either not removed within the gardens or removed on an irregular basis. SES classes 3, 4 and 5 had 34, 33 and 35 species respectively. The two most frequent plant families were Poaceae and Asteraceae. Other families that were also highly represented were Malvaceae, Solanaceae, Fabaceae and Chenopodiaceae. A complete species list is given in the Appendix (D). The number of exotic and native annuals, perennials and biennials for each SES class are provided in Figure 6.1.

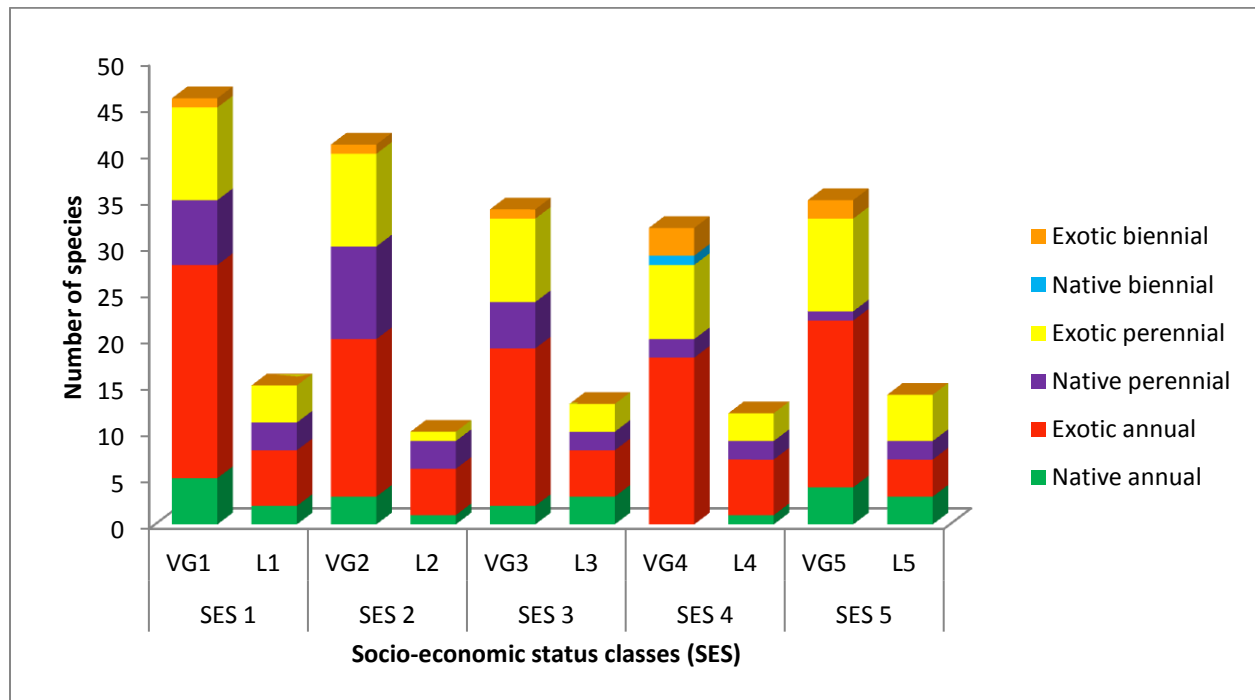


Figure 6.1: The number of species of each SES class that were exotic or native as annuals, perennials and biennials. A distinction was also made between the vegetable gardens (VG) and lawns (L) of each SES class.

A high number of exotic species (75.4%), especially exotic annuals (47.2%), were found in the vegetable gardens and lawns of all SES classes. There seems to be no distinct differences between the SES classes in this regard, although vegetable gardens had a significantly higher number of species than lawns (Fig. 6.1). Also, there were more native perennial species within

vegetable gardens of the three lower income classes (SES classes 1, 2 and 3) than in the two higher income classes (SES classes 4 and 5). This could be ascribed to the households of the three lower income classes being more closely situated to natural areas and where many households (informal settlements) were only constructed in recent times (Lubbe *et al.*, 2010).

6.2.2. Species composition of vegetable gardens and lawns

Lawns often consist of monocultures that are subjected to a high intensity of disturbance and maintenance (Robbins & Birkenholtz, 2003; Thompson *et al.*, 2004, Gaston *et al.*, 2005). On the contrary, homegardens are considered to have high species diversity (Zaldivar *et al.*, 2002), they do not require such high energy inputs (Blanckaert *et al.*, 2004) and can be used by households for food security or to increase income (Rugalema *et al.*, 1994; Blanckaert *et al.*, 2004). Furthermore, homegardens' species composition reveals much about the ethnicity of the household (Zaldivar *et al.*, 2002; Akinnifesi *et al.*, 2010). Therefore, this part of the chapter will compare the total species composition of vegetable gardens and lawns. The total species composition includes all the plant species that occurred in vegetable gardens or lawns during the survey, regardless of whether they were edible species or unwanted weeds. This part of the chapter also determines what edible crops were most common within vegetable gardens in the different SES classes.

The total species composition of vegetable gardens were determined and compared between SES classes (Fig. 6.2). The Eigen-values showed a variability between the species composition of the vegetable gardens (1st axis = 0.665, 2nd axis = 0.479). From Fig. 6.2 it is clear that the SES classes do not form clear groups in terms of plant species composition. Outliers in each of the SES classes do however indicate differences in species composition within each SES class. All the species that will be discussed, are given in the ordination. However, even though the vegetable species were included in the ordination, they will only be discussed later on in this chapter. Many species had a low occurrence in all the SES classes and these are evident as the outliers in the DCA-biplot. These species included a small proportion of native perennials such as *Tulbaghia simmleri* and exotic annuals such as *Bidens pilosa* and *Bidens bipinnata*. There were also a few species that seemed to be very prominent within vegetable gardens of all the socio-economic status classes. They however included mainly exotic annual weed species namely *Oxalis corniculata*, *Amaranthus hybridus*, *Euphorbia hirta*, *Euphorbia prostrata* and *Eragrostis tef* (Fig. 6.2). All these species seemed to have had a high occurrence within the gardens, possibly indicating that they were not removed during weeding or were removed on an

irregular basis. One common species of native origin included the perennial species *Eragrostis lehmanniana*.

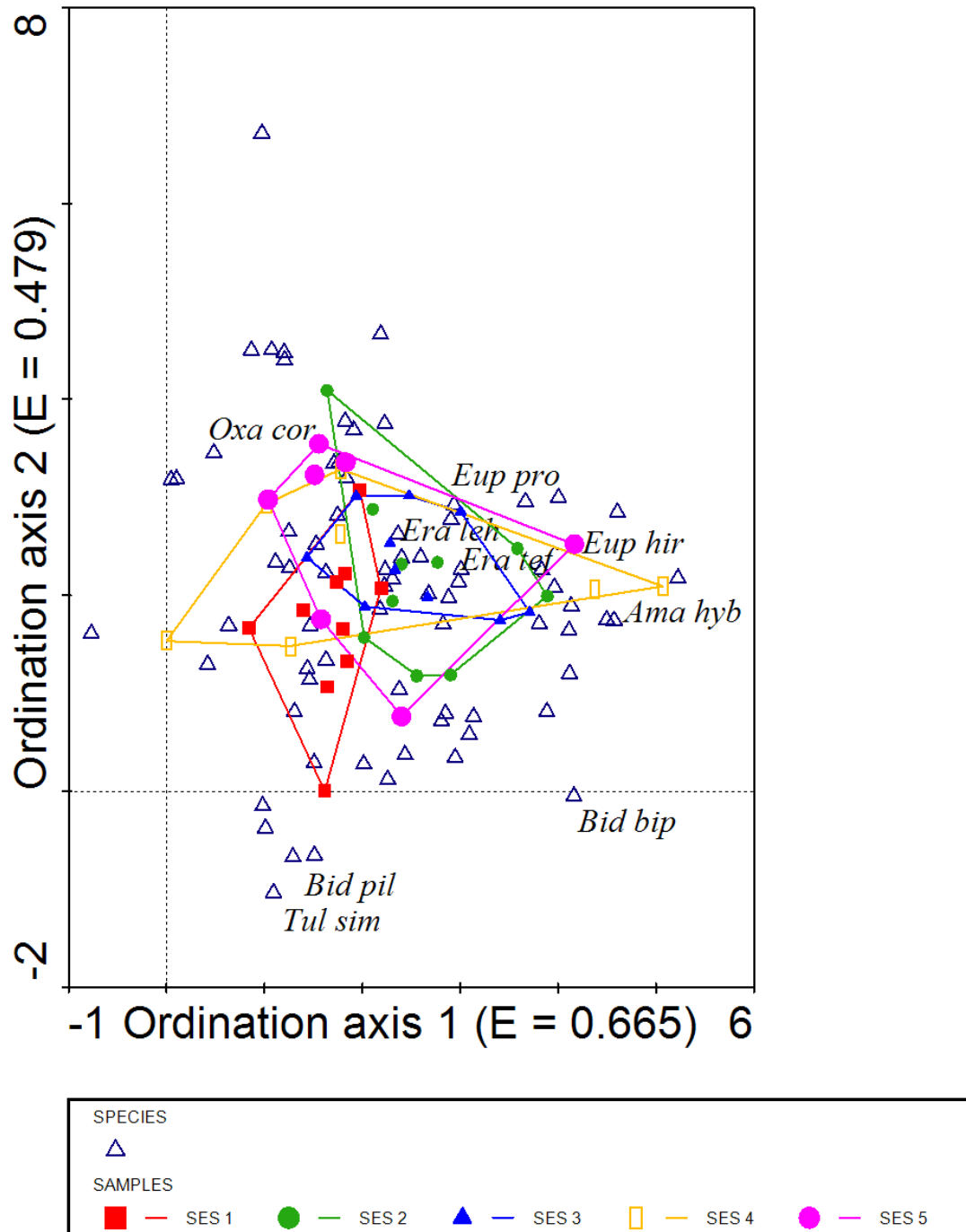


Figure 6.2: DCA-biplot of the total species composition in the vegetable gardens between the five socio-economic status classes. Abbreviations of species are given in Table 6.1

Table 6.1: Abbreviations of species in the DCA-biplot from Figure 6.2.

Abbreviation	Species Name	Annual/ Perennial
Ama hyb	<i>Amaranthus hybridus</i> L.*	Annual
Bid bip	<i>Bidens bipinnata</i> L.*	Annual
Bid pil	<i>Bidens pilosa</i> L.*	Annual
Era leh	<i>Eragrostis lehmanniana</i> Nees.	Perennial
Era tef	<i>Eragrostis tef</i> (Zucc.)Trotter*	Annual
Eup hir	<i>Euphorbia hirta</i> L.*	Annual
Eup pro	<i>Euphorbia prostrata</i> Aiton*	Annual
Oxa cor	<i>Oxalis corniculata</i> L.*	Annual
Tul sim	<i>Tulbaghia simmleri</i> P.Beauv.	Perennial

* indicates exotic species

Lawns had a much lower occurrence of species than vegetable gardens, with a total number of 34 species. The species composition of lawns in the different SES classes is provided in Figure 6.3.

There was a high variability between the total species composition in lawns (Fig. 6.3) as indicated by the Eigen-values (1st axis = 0.857, 2nd axis = 0.566). However, these differences could rather be ascribed to the infrequent species within the data than the SES classes. The first axis explained 29.2% of the variability in the data and the second axis explained 19.3%. As indicated in Fig. 6.3 all the SES classes shared common species whilst the other species occurred infrequently within some domestic lawns.

Undoubtedly, the most common lawn species in all the SES classes was *Pennisetum clandestinum* that is an exotic grass species, generally used for domestic lawns. Similar to a previous study that was conducted in Potchefstroom (Lubbe *et al.*, 2011), *Pennisetum clandestinum* was the species that occurred in all but one of the domestic gardens. In that domestic garden *Eleusine coracana* was the dominant lawn species. The species that occurred in most lawns were weeds such as *Euphorbia prostrata* and *Gomphrena celosioides* (Fig. 6.3). The outliers of SES classes 3, 4, and 5 indicates the presence of other species such as *Cynodon dactylon* and *Setaria verticillata* that are both native species (Fig. 6.3). The outliers of these three classes that were exotics include *Chenopodium carinatum*, *Cestrum aurantiacum* and *Alternanthera pungens* (Fig. 6.3).

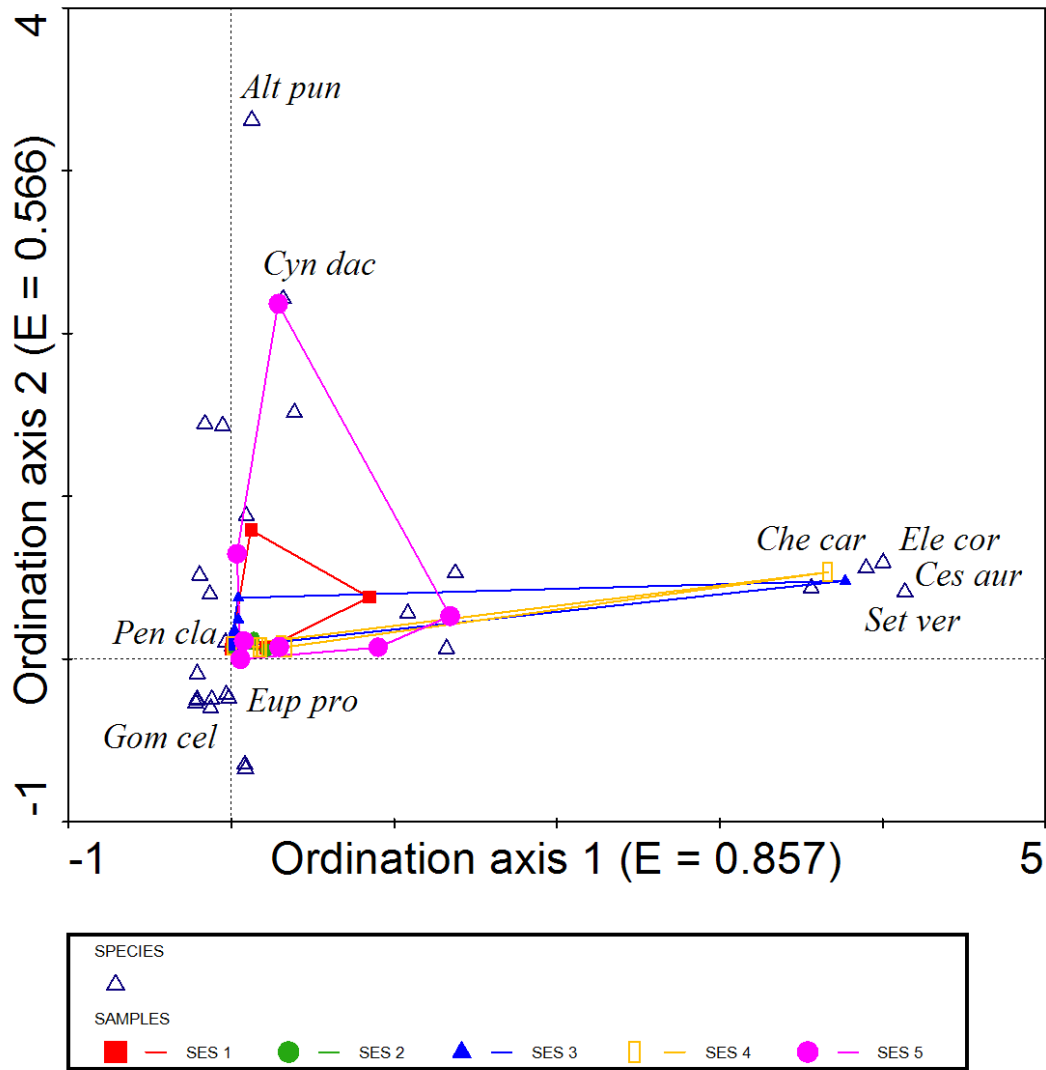


Figure 6.3: DCA-biplot of the total species composition in the lawns between the five socio-economic status classes. Abbreviations of species are given in Table 6.2.

Table 6.2: Abbreviations of species in the DCA-biplot from Figure 6.3.

Abbreviation	Species name	Annual/ Perennial
Alt pun	<i>Alternanthera pungens</i> Kunth.*	Perennial
Ces aur	<i>Cestrum aurantiacum</i> Lindl.*	Perennial
Che car	<i>Chenopodium carinatum</i> R.Br.*	Annual
Cyn dac	<i>Cynodon dactylon</i> (L.)Pers.	Perennial
Ele cor	<i>Eleusine coracana</i> (L.)Gaertn.	Annual
Eup pro	<i>Euphorbia prostrata</i> Aiton*	Annual
Gom cel	<i>Gomphrena celosioides</i> Mart.*	Perennial
Pen cla	<i>Pennisetum clandestinum</i> Hochst. ex. Chiov.*	Perennial
Set ver	<i>Setaria verticillata</i> (L.)P.Beauv.	Annual

* indicates exotic species

For the purposes of this study, it is important to compare the total species composition between vegetable gardens and lawns, regardless of SES. This was done through a DCA-biplot which is illustrated in Fig. 6.4.

The abbreviations of the species are given in Table 6.3. It is evident that there were distinct differences between the species composition of lawns and vegetable gardens and the Eigenvalues for the first and second axis were 0.933 and 0.649 respectively (Fig. 6.4). For the most part, lawns were dominated by *Pennisetum clandestinum* (Fig. 6.4) but other species that also had a high occurrence in lawns include *Eleusine coracana* and *Oxalis corniculata*. The vegetable gardens were dominated by edible crop species but also other species such as the native perennials *Tribulus terrestris* and *Eragrostis lehmanniana*, as well as the exotic annual *Eragrostis tef*. Some species were common in both vegetable gardens and lawns which included *Euphorbia prostrata*, *Conyza podocephala*, *Verbena tenuisecta* and *Urochloa mosambicensis* (Fig. 6.4). The beta-diversity between the vegetable gardens was much higher (plots more dispersed in the ordination) than that of the lawns.

It has been shown in previous research that socio-economic status has an influence on the plant species composition and diversity in cities (Martin *et al.*, 2004; Lubbe *et al.*, 2010). However, according to Cilliers & Siebert (2011), it is important to determine to what extent socio-economic status can be a driver of plant diversity in urban environments, especially in those cities that are culturally diverse. It is also vital to refine the knowledge that currently exists with regards to vegetation diversity as a result of social factors.

From our study it was determined that the most plant species were found in vegetable gardens of SES classes 1 and 2. This differs from a previous study of vegetation patterns that was conducted along the same socio-economic gradient in Potchefstroom (Lubbe *et al.*, 2010). From the previous study it was found that the more affluent classes (SES classes 4 and 5) had higher species richness in the entire garden (Lubbe *et al.*, 2010). The reason for differences between our study and the previous study is that our study only determined the species composition in vegetable gardens and lawns, while the previous study examined the total species composition and diversity of domestic gardens as a whole (Lubbe *et al.*, 2010).

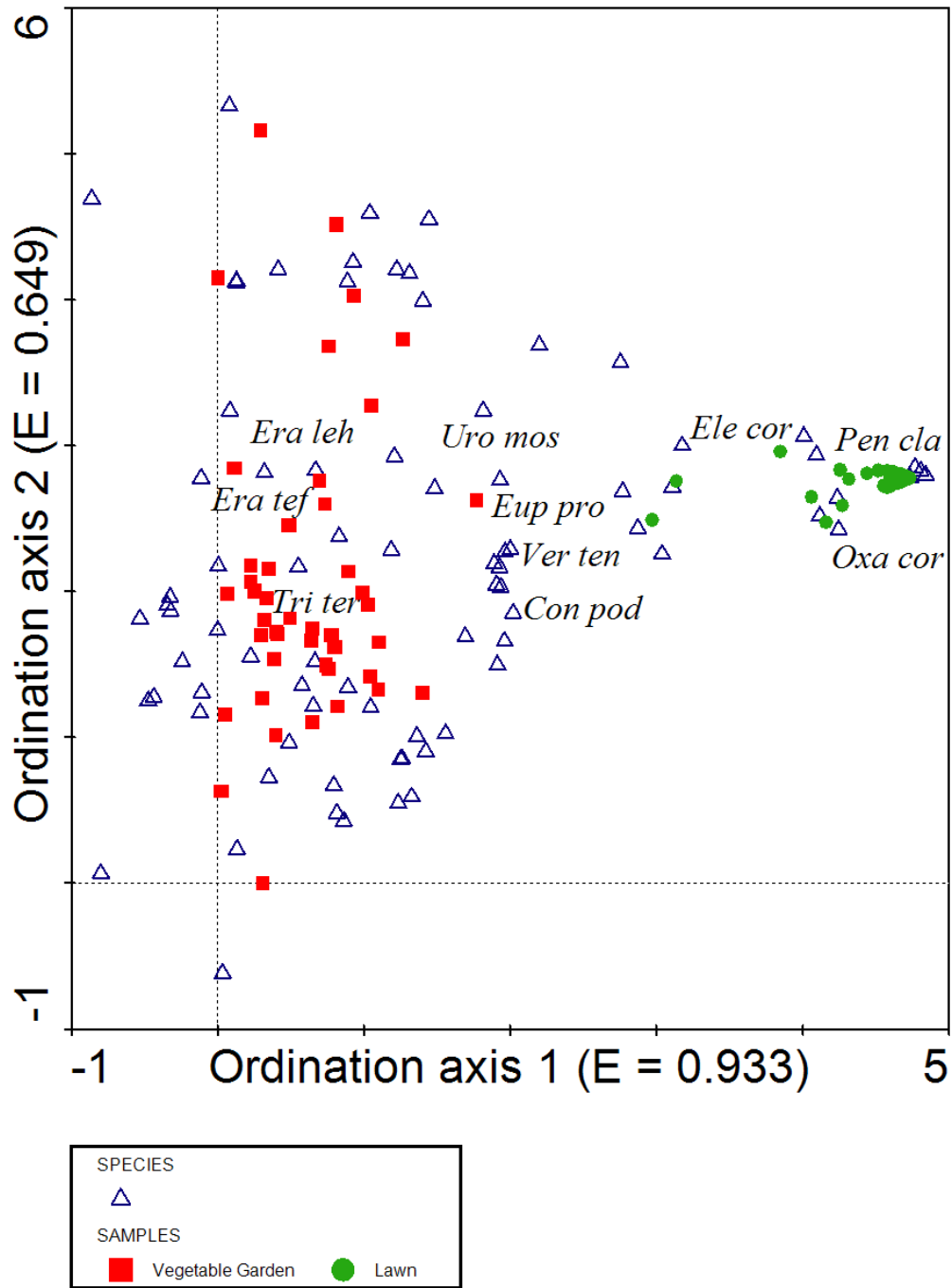


Figure 6.4: DCA-biplot indicating differences in plant species composition and beta-diversity between the vegetable gardens and lawns of different socio-economic status classes. Abbreviations of species are given in Table 6.3.

Table 6.3: Abbreviations of species in the DCA-biplot from Figure 6.4

Abbreviation	Species name	Annual/ Perennial
Con pod	<i>Conyza podocephala</i> DC.	Perennial
Cyn dac	<i>Cynodon dactylon</i> (L.)Pers.	Perennial
Ele cor	<i>Eleusine coracana</i> (L.)Gaertn.	Annual
Era leh	<i>Eragrostis lehmanniana</i> Nees.	Perennial
Era tef	<i>Eragrostis tef</i> (Zucc.)Trotter*	Annual
Eup pro	<i>Euphorbia prostrata</i> Aiton*	Annual
Oxa cor	<i>Oxalis corniculata</i> L.*	Annual
Pen cla	<i>Pennisetum clandestinum</i> Hochst. ex. Chiov.*	Perennial
Tri ter	<i>Tribulus terrestris</i> L.	Annual
Uro mos	<i>Urochloa mosambicensis</i> (Hack.)Dandy	Perennial
Verb ten	<i>Verbena tenuisecta</i> Briq.*	Perennial

* indicates exotic species

In our study both vegetable gardens and lawns had several exotic species, of which many occurred at low frequencies. This is understandable because it is possible for the surrounding natural and exotic woody species to invade the gardens (Blanckaert *et al.*, 2004). It was also found that the exotic and/or less frequent species are usually removed from the domestic gardens before they can become mature or established in the plant communities of gardens (Thompson *et al.*, 2004). However, it is also possible in domestic gardens that some species have the ability to become highly established because of the garden owners' management practices (Thompson *et al.*, 2003). One exotic grass species was common in lawns of all the SES classes, which corresponds with previous studies where lawns were considerably dominated by monocultural species (Robbins & Birkenholtz, 2003; Thompson *et al.*, 2004). In our study, this exotic lawn species is *Pennisetum clandestinum*. The low beta-diversity of lawns indicates a similar species composition of all the SES classes. This possibly indicates that all manicured lawns have a similar species composition regardless of socio-economic factors and/or cultural preferences.

Of the 88 identified species only 32% was indigenous. This is lower than that of a study on urban homegardens in Northeastern Brazil (Akinnifesi *et al.*, 2010) that had much higher percentage of native species (58%) than our study. From our study it was also found that vegetable gardens did not only have a higher number of species than the lawns, but it also had a higher beta-diversity between the different domestic gardens of all the SES classes. This may possibly have implications for the diversity of other organisms, such as arthropods (Blanckaert *et al.*, 2004). This important aspect will be discussed more thoroughly in Chapter 7.

6.2.3. Edible species composition of vegetable gardens in different SES classes

A DCA-biplot was constructed to compare the species composition of vegetable gardens between the different SES classes to determine whether SES classes had certain preferences for specific vegetables (Fig 6.5). For the purposes of this study, herbs that are used for seasoning (*Allium sativum* and *Mentha* sp.) and fruits (*Ananas comosus*, *Prunus persica* and *Pyrus communis*) were excluded from the DCA-biplot. *Capsicum frutescens* was also given twice in the ordination to compare the preferences for either green or red peppers between the SES classes. The Eigen-values of Fig. 6.5 was 0.591(1st axis) and 0.400 (2nd axis). This indicates that there is variability between the SES classes with regards to vegetable species diversity. The first axis is by far the longest, explaining 13.7% of the variability.

As mentioned previously there was a total number of 20 edible crop species (excluding fruit trees). Of these species, 19 were exotic (as indicated in Table 6.4). The edible crop species comprised of 22.7% of the total number of species identified within our study. The most common edible species in all the SES classes was the tomato (*Lycopersicon esculentum*). Other species that were also highly represented was the potato (*Solanum tuberosum*) and spinach (*Spinacia oleracea*). From Fig. 6.5 it is evident that all SES classes shared common vegetable species, but with many of them in low frequencies. This is similar to the total species composition in vegetable gardens and lawns. It does however seem that certain SES classes have preferences for specific vegetables. For example, some of the gardens in SES class 2 was associated with planting maize (*Zea mays*), red peppers (*Capsicum frutescens*) and chilli peppers (*Capsicum annuum*) (Fig. 6.5). Similarly, some of the residents of SES class 4 planted pumpkins (*Cucurbita pepo*) and sweet potatoes (*Ipomoea batatas*) which were not common garden vegetables for the other SES classes. Nevertheless, SES class 4 has a slightly larger variety of vegetables in their gardens than gardens of SES classes 2 and 3. SES classes 2 and 3 also form closer groups with regards to edible species diversity, which is an interesting concept considering that they form part of the same ethnic group. It therefore implies that certain preferential trends do exist within households of the same cultural backgrounds.

The percentage of edible crop species (22.7%) from our study corresponds with other studies that were conducted in homegardens of developing countries. For example, studies that were conducted in San Rafael, Mexico (Blanckaert *et al.*, 2004) and São Luís, Northeastern Brazil (Akinnifesi *et al.*, 2010) had edible species that made up 29.6% and 16.7% of the total species composition respectively.

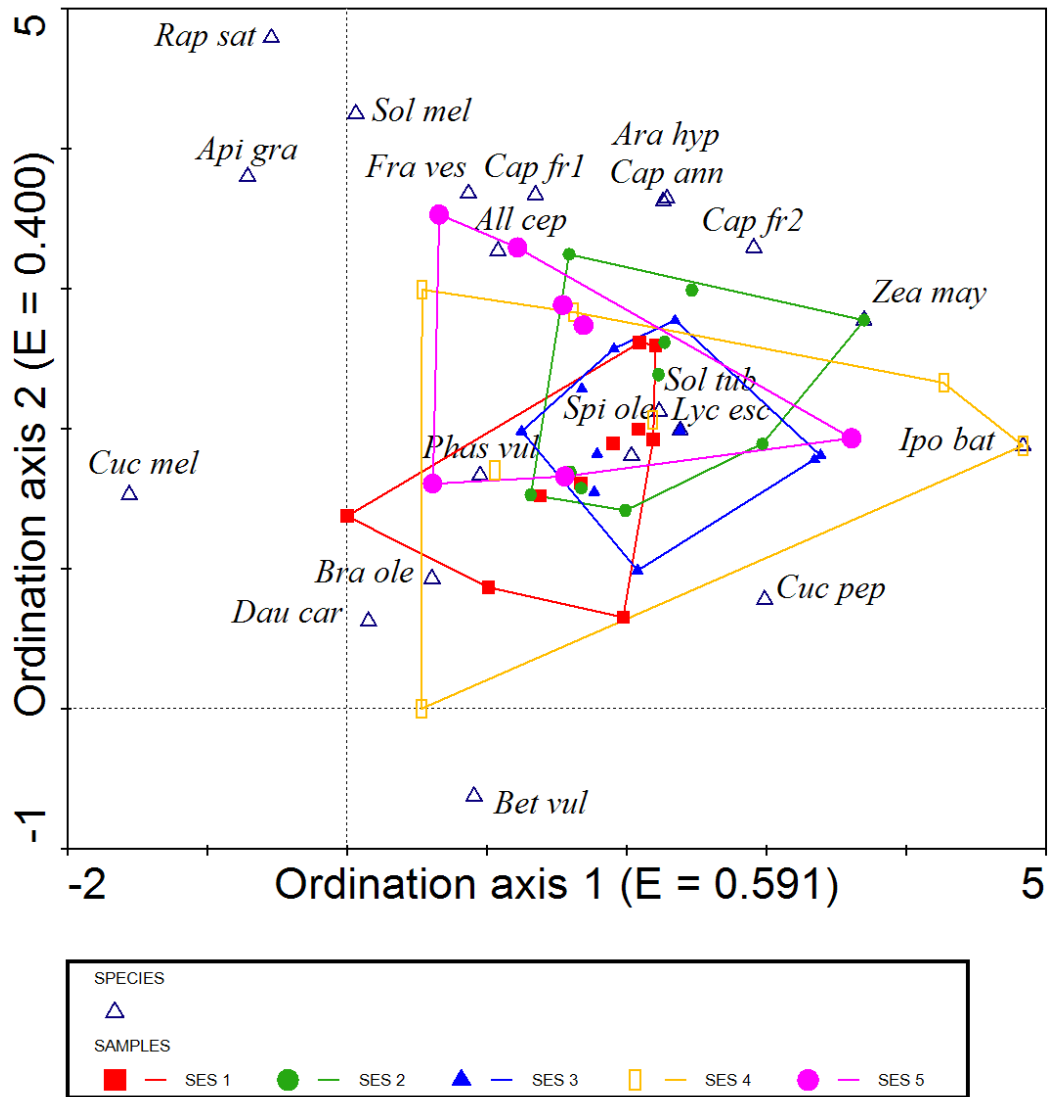


Figure 6.5: DCA-biplot illustrating differences in vegetable species diversity between the five socio-economic status classes. Abbreviations of species are given in Table 6.4.

In Mexico, the homegardens of members of the same family and/or neighborhood were found to have similar species composition (Blanckaert *et al.*, 2004). This may possibly be a comparable situation from our study, where people living in the same neighborhoods or deriving from the same ethnic groups (such as SES classes 2 and 3 in Fig. 6.5) may have similar vegetable species composition. Even though SES classes 1, 2 and 3 are from African origin, SES classes 2 and 3 are from a different ethnic group than SES class 1. This may be because they could have preferences for specific vegetables or they may share vegetable seeds or seedlings with their neighbors or a combination of both. Studies from homegardens on the Indian islands

showed similar responses of strong neighborhood cohesion (Pandey *et al.*, 2007). For example, a study on two of the islands in the archipelago of India showed that homegardens of the same island had similar edible species composition (82 - 92%) but that homegardens between the two islands differed extensively and only had a similarity of 12 -18% (Pandey *et al.*, 2007).

Table 6.4: A list of the edible crop species from the domestic gardens in the SES classes.

Symbol	Scientific name	Common name
All cep	<i>Allium cepa</i> L.*	Onion
Api gra	<i>Apium graveolens</i> L.*	Celery
Ara hyp	<i>Arachis hypogaea</i> L.*	Peanut
Bet vul	<i>Beta vulgaris</i> L. subsp. <i>vulgaris</i> *	Beetroot
Bra ole	<i>Brassica oleracea</i> L.*	Cabbage
Cap ann	<i>Capsicum annuum</i> L. var. <i>glabrusculum</i> (Dunal) Heiser & Pickersgill*	Chilli pepper
Cap fr1	<i>Capsicum frutescens</i> L.*	Green pepper
Cap fr2	<i>Capsicum frutescens</i> L.*	Red Pepper
Cuc mel	<i>Cucumis melo</i> L. subsp. <i>agrestis</i> (Naudin) Pangalo	Cantaloupe
Cuc pep	<i>Cucurbita pepo</i> L.*	Pumpkin
Dau car	<i>Daucus carota</i> L.*	Carrot
Fra ves	<i>Fragaria vesca</i> L.*	Strawberry
Ipo bat	<i>Ipomoea batatas</i> (L.) Lam.*	Sweet potato
Lyc esc	<i>Lycopersicon esculentum</i> Mill. var. <i>esculentum</i> *	Tomato
Phas vul	<i>Phaseolus vulgaris</i> L.*	Beans
Rap sat	<i>Raphanus sativus</i> L.*	Radish
Sol mel	<i>Solanum melongea</i> L.*	Eggplant
Sol tub	<i>Solanum tuberosum</i> L.*	Potato
Spi ole	<i>Spinacia oleracea</i> L.*	Spinach
Zea may	<i>Zea mays</i> L.*	Maize

* indicates exotic species

6.2.4. Soil as an environmental factor

Soil is a non-renewable resource that is a vital component for any type of ecosystem, including human systems where it provides essential goods and services to humans on various levels (Wall *et al.*, 2004) and is therefore vulnerable to exploitation by humans. This exploitation and change of natural soils by the human population is nowhere more evident than in urban areas (Douglas, 2011). In urban areas soil is mainly seen as a foundation for buildings and is used as a landfill for the disposal of solid and liquid wastes, which differ from domestic gardens and parks where it is still managed and used as a means to ensure nutrients for plants and to provide a healthy habitat for other organisms (Sauerwein, 2011). Soil in parks and domestic gardens may have layers of material such as rubble that covers the natural soil or rock material, which inevitably affects the natural soil processes (Douglas, 2011). These soil processes in turn influence the vegetation emphasizing the importance of including certain soil aspects within the study and to determine how they are affected by management regimes of the different socio-

economic status classes. A CCA-ordination was conducted to determine whether the soil has an influence as an environmental factor on the vegetable species and how the soil characteristics differ between the SES classes (Fig. 6.6).

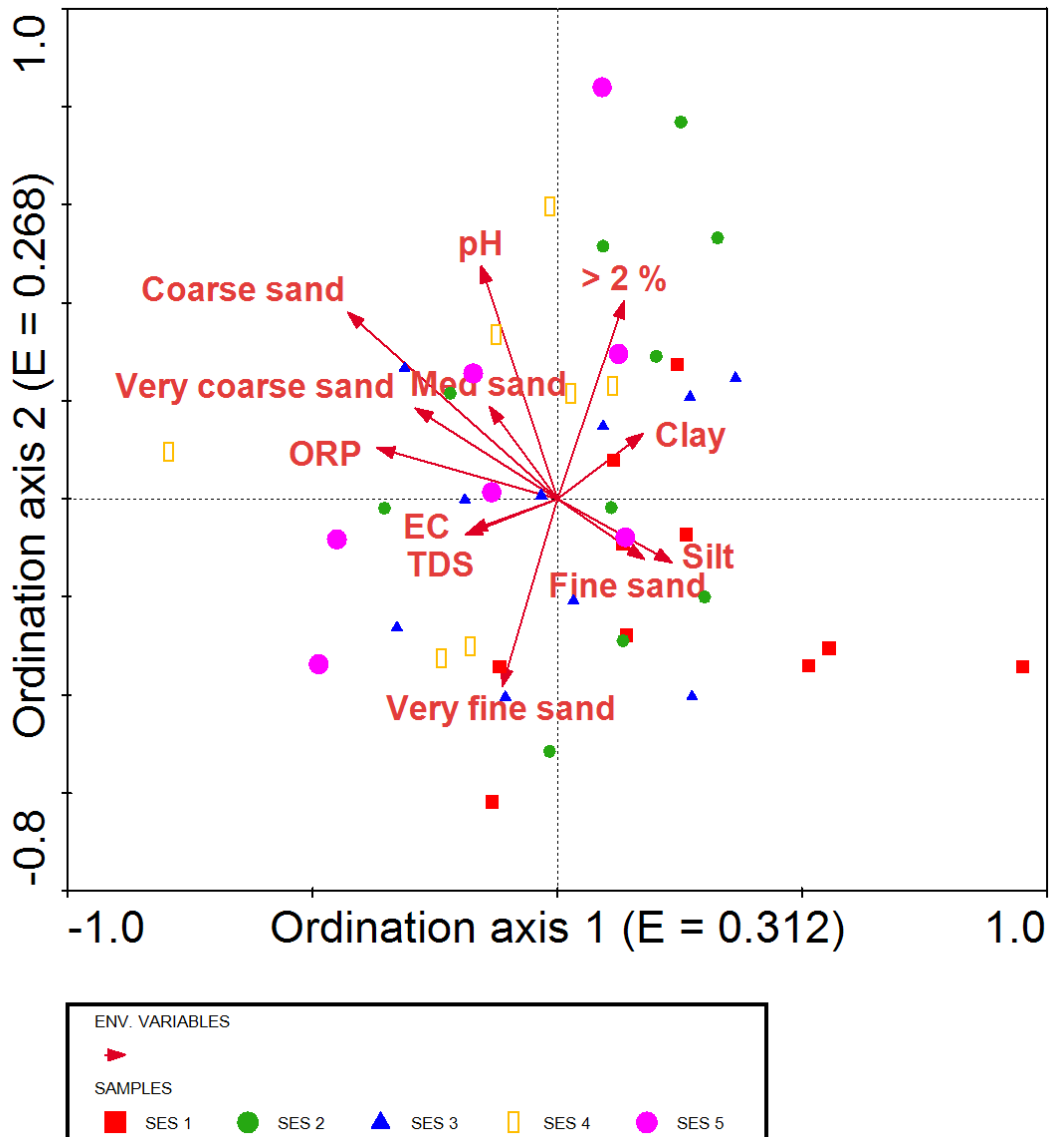


Figure 6.6: CCA-ordination determining the extent of soil as an environmental factor affecting vegetable species diversity between the socio-economic status classes. (EC = electrical conductivity, TDS = total dissolved solids parts per million, ORP = oxidation-reduction potential).

Various factors of the soil was determined including, the oxidation-reduction potential, pH, electrical conductivity, total dissolved solids parts per million and the particle size distribution within the soil (methods described in Chapter 4). A complete list of the soil results are given in

the Appendix (E). As indicated by the Eigen-values (1st axis = 0.312, 2nd axis = 0.268), the variability between the SES classes with regards to the soil factors were reasonably low (Fig. 6.6). This possibly indicates that soil attributes of domestic vegetable gardens are relatively similar regardless of the area of the city or the type of management within gardens.

In Fig. 6.6 it is evident that there is not a large variability in the data and that there is no distinct environmental factor that could explain the variability in the vegetable data. The total dissolved solids (TDS) parts per million (tdspmm) and oxidation-reduction potential (ORP) are closely correlated with the electrical conductivity (EC) with correlation coefficients of 0.997 and 0.829 respectively. Also, no distinct differences were evident between the different SES classes, indicating that the soil factors differed from one household to the next and not as a result of any distinct environmental gradient or specific management practice.

The mean values of some of the soil factors are given in Table 6.5. The pH-values of the soil was very similar between the SES classes and had a mean value of 7.45 (Std. dev. = 0.4), (Table 6.5). The electrical conductivity (EC) and the total dissolved solids parts per million (TDS) are closely correlated (Fig. 6.6). According to Atekwana this is because the electrical conductivity is used as an estimate of the total dissolved solids content. The EC and TDS values from our study varied greatly between the domestic gardens of the same SES classes with means of 297.21 us/cm (Std. dev. = 156.99) and 147.62 mg/L (Std. dev. = 78.51) respectively (Table 6.5). This implies that the salt content (dissolved solids and ions) of the soil differs between domestic gardens and was not ascribed to specific SES classes.

Table 6.5: Table of the weighted mean values of the electrical conductivity, total dissolved solids, oxidation-reduction potential and pH.

Soil variable	Mean	Standard deviation
Electrical conductivity (EC) measured in us/cm	297.21	156.99
Total dissolved solids (TDS) parts per million (mg/L)	147.62	78.51
Oxidation-reduction potential (ORP) measured in mV	-110.47	7.75
pH	7.45	0.4

**Definitions provided in Appendix E*

In our study, the soil had neutral to alkaline pH and a large proportion of sand within the soil. This corresponds with previous studies conducted on soil in urban environments. A study from Torino, Italy compared the urban soils with those in rural surroundings. This study showed that the pH and the sand fraction were the soil attributes that was most affected by the urban

environment with both of these showing much higher values than in the surrounding rural areas (Biasioli *et al.*, 2006). In the study in Italy, the mean pH was 7.2 (Biasioli *et al.*, 2006), which is very close to the values obtained from our study. Similarly, studies from Hong Kong (Jim, 1998) and Nanjing (Zhao *et al.*, 2007) in China showed that urban areas had higher pH values and sand fractions. Moreover, more than half of the soil samples from the study in Hong Kong, had pH values that can be classified as either strongly alkaline or very strongly alkaline (Jim, 1998). These values far exceed those in rural areas. The high pH and sand fractions can be ascribed to the calcareous construction materials that release carbonate which ultimately increases the pH and the inclusion of extraneous materials, which are coarser, leading to more sand particles within the soil (Jim, 1998; Biasioli *et al.*, 2006; Zhao *et al.*, 2007). The high pH-values raise concern for the plants within these urban soils, because it induces micronutrient (such as iron, copper, zinc and cobalt) and phosphorus deficiency (Jim, 1998).

Our study showed low redox potential (Eh) values (Table 6.5). This is an important factor because it has an influence on the functioning and growth of plants (Pezeshki & DeLaune, 1998). For example, a study that was conducted on seedlings of four woody species at different levels of redox potential showed that the Eh values of soil higher than +400 mV increased plant growth and photosynthesis, indicating a well-aerated soil (Pezeshki & DeLaune, 1998.) However, the soils that had Eh values under -70 mV and under -160 mV showed a reduction in plant growth and survival, with survival rates of some species as low as 10% (Eh = -160 mV) (Pezeshki & DeLaune, 1998). It was the lowest Eh value (-160 mV) that had a significantly reduced plant growth performance. These low Eh values have an immense effect on the nutrient uptake of plants in various ways (Pezeshki & DeLaune, 1998). It firstly leads to root growth inhibition, decreasing the ability of roots to absorb vital nutrients, especially phosphorus (Pezeshki & DeLaune, 1998), whilst the low Eh conditions simultaneously increases the availability of iron and manganese in the soil for uptake (Pezeshki & DeLaune, 1998; Li *et al.*, 2010). If these micronutrients are taken up in excess within the plants, it may lead to toxicity (Li *et al.*, 2010). The redox potential values in vegetable gardens from our study were much lower (-110.58) than the ideal well-aerated conditions (+ 400 mV) and this raises concerns for the influence it may have on plant growth and the possibility of toxicity in the vegetable gardens. It is therefore necessary to thoroughly examine the soil of urban vegetable gardens in the future.

6.3. Summary

Of the 88 plant species identified in our study, 80 of those species occurred in the vegetable gardens. Our study also suggests that social and cultural factors may have an influence on the total species composition of vegetable gardens. For example, SES classes 2 and 3, which include residents of the same ethnic group, have similar species composition, indicating similar plant preferences or management regimes (e.g. in terms of weeding) or a combination of both.

The vegetable gardens had much higher plant species diversity than lawns. All the lawns from our study had a low beta-diversity regardless of socio-economic status, with the dominating species being the exotic lawn species *Pennisetum clandestinum* and with most of the other species occurring infrequently. The vegetable gardens also had much higher beta-diversity than the lawns. This may also possibly have certain implications for the arthropod diversity. In Chapter 5 of our study it was found that vegetable gardens from all the SES classes had higher arthropod diversity than any of their associated lawns. This implies that higher plant diversity (in the vegetable gardens as opposed to the lawns) is able to accommodate a higher diversity of arthropods. The relationship between the arthropod and plant diversity will be discussed in Chapter 7.

The most frequently planted edible species was the tomato (*Lycopersicon esculentum*). Similar to the total species composition, SES classes 2 and 3 (from the same ethnic group) also had the most similar edible species composition, which is a different ethnic group than SES class 1, even though they are both from African origin. SES classes 4 and 5 consisted of individuals from European origin.

Primarily, the soil analysis from our study showed that there is no distinct environmental gradient from any of the soil factors that was responsible for the variability in the data. Also, no apparent differences were found between the SES classes. The pH was neutral to alkaline and there was a large fraction of sand particles in the soil that is common in urban environments. However, there are some aspects of these soils (such as redox potential values) that need to be assessed more thoroughly to determine to what extent the influence of domestic gardens, or the city as a whole, have on the soil.

The management tendencies of the residents from the SES classes, the correlation between the arthropod and plant species diversity and the influence of the surrounding land-uses will be discussed in Chapter 7.

Chapter 7: Integration of plant- and arthropod diversity and various other variables

7.1. Introduction

As the global human population increases, urbanization and fragmentation of natural landscapes increase, which have profoundly negative effects for native biodiversity worldwide. However, it is possible that urban green spaces may give refuge to a diversity of organisms (Goddard *et al.*, 2010). For example, in urban and suburban parks in Belgium it was found that urban green spaces are not only capable of harboring biodiversity but that they can be considered to be biodiversity “hotspots” within cities (Cornelis & Hermy, 2004). Despite the importance of parks as urban green space, an alternative solution for biodiversity conservation in cities would be domestic gardens (Goddard *et al.*, 2010). Domestic gardens are however the least understood green spaces within urban environments (Mathieu *et al.*, 2007) in spite of these gardens having immense potential for conserving biodiversity (Gaston *et al.*, 2005a; Goddard *et al.*, 2010). This is mostly because domestic gardens have high percentage coverage in comparison with other urban landscapes (Loram *et al.*, 2007; Gaston & Gaston, 2011) and because they are interconnected within the urban matrix (Smith *et al.*, 2006b). Conserving and increasing biodiversity within domestic gardens, may ultimately conserve biodiversity of the city as a whole (Thompson *et al.*, 2003).

Biodiversity in urban domestic gardens are greatly influenced by human management caused by social and economic components (Goddard *et al.*, 2010; Cilliers *et al.*, 2012). These human components give an additional aspect to urban environments uncommon in natural areas. As a result of the human component playing such an active role within the urban environment, the human ecosystem framework was established (Pickett *et al.*, 2004). This framework proposes that within cities the ecological and social systems are integrated and that the processes within these two systems form part of an interactive network (Pickett *et al.*, 2004). The individual households especially can increase the heterogeneity even further through parcelization (Cadenasso & Pickett, 2008). This implies that each household within the urban matrix is considered to be an individual parcel and can differ from the surrounding areas as a result of tenant property boundaries (Cadenasso & Pickett, 2008). However, it has been found that individual households form part of larger socio-economic groups that have similar perceptions and management tendencies within their individual households (Cilliers, 2010). It means therefore, that biodiversity research in urban environments should shift focus from individual

households to groups of domestic gardens that function as patches in the urban environment (Goddard *et al.*, 2010).

For this type of research on biodiversity in cities to be possible, it is necessary to follow an integrated approach, where different scientific disciplines are combined and a greater understanding of the sociological component is found and the landscape factors are determined (Savard *et al.*, 2000; Pickett *et al.*, 2004; Musacchio *et al.*, 2005; Cadenasso & Pickett, 2008; Petts *et al.*, 2008; Wu, 2008; Goddard *et al.*, 2010; Cilliers, 2010; Cilliers *et al.*, 2012). Landscape design and management greatly affects the ecological components of the city (Zipperer *et al.*, 2011) and patches can be characterized as the biophysical, social or built structures or by a combination of all three of them (Cadenasso *et al.*, 2006). Urban systems can be viewed either from a local (patches) or a landscape (urban matrix) level and the interactions between them will give a more comprehensive understanding of how landscapes affects biodiversity in cities (Angold *et al.*, 2006; Goddard *et al.*, 2010). In fact, according to Gaston and Gaston (2011), the biodiversity within an individual garden is greatly affected by other green spaces within the surrounding environment. Marco *et al.* (2008) also highlights the importance of including social and economic aspects and how it impacts the management of gardens. This emphasizes that these aspects should be included within studies on urban domestic gardens.

In biodiversity studies within urban environments, it may be valuable to even follow an integrated approach when it comes to the living organisms itself. Numerous studies have shown that socio-economic aspects does determine to a great extent the plant diversity within domestic gardens (Lubbe *et al.*, 2010; Cilliers *et al.*, 2012). Similarly, many studies have indicated that plant diversity may significantly influence arthropod diversity (Thomas & Marshall, 1999; Biaggini *et al.*, 2007; Cai *et al.*, 2010, Sperling & Lortie, 2010). However, there is a necessity to determine whether the relationship between plants and arthropods in urban environments are significant and how they differ between domestic gardens because of the human socio-economic component, as well as to what extent they are influenced by the surrounding landscape. Therefore, in this chapter we aim to incorporate all these aspects of domestic gardens to have a more comprehensive view of the drivers of biodiversity in cities.

7.2. Layout of the chapter

The ultimate aim of this chapter was to determine whether the plant and arthropod diversity in domestic gardens correlate and how they were influenced by features such as surrounding

land-uses, socio-economic aspects and management regimes along the described socio-economic gradient.

The specific objectives were:

- To determine the specific socio-economic aspects and management activities within the different SES classes and determine to what extent they differ from each other.
- To determine the percentage cover of other land-uses surrounding the surveyed domestic gardens and comparing them between the SES classes.
- To determine whether the plant and arthropod diversity are correlated and how they differ between the SES classes.
- To determine whether the surrounding land-uses influences arthropod and plant diversity within urban domestic gardens.

7.3. Results and discussion

7.3.1. Garden management survey

The survey that was conducted in the respective SES classes consisted of two sections namely, the management practices and socio-economic characteristics. The management section of the survey determined aspects such as the chemical and organic use, maintenance of weeds, frequency of watering and age of the vegetable garden. The specific socio-economic aspects that were determined include the use of the vegetable garden, the distance of the nearest water tap, the number of people and accessible rooms per household, educational status, monthly income and the specific income generating activities. These aspects were then compared between the different socio-economic status (SES) classes.

7.3.1.1. Management practices

The use of fertilizers and/or insecticides, as well as the form of compost that was used, within each SES class are provided in Fig 7.1 & 7.2. In terms of fertilizers and insecticides, the results were contradictory (Fig. 7.1). Firstly, SES classes 2 and 3, which forms part of the poorer households had the highest use of fertilizers. Likewise, residents of SES class 2 also used insecticides (Fig. 7.1). A possible explanation for the high frequency of fertilizer use in SES classes 2 and 3 could be that these two classes required the use of a Tswana-speaking interpreter during the questionnaire, and the respondents most likely misinterpreted the questions.



Figure 7.1: An illustration of the percentage participants of the different socio-economic status classes that use fertilizers and insecticides in their vegetable gardens.

This could possibly be true because many of these participants also struggled to understand the difference between fertilizer use and the use of compost. SES class 1 did not use either fertilizers or insecticides mostly because of a lack of financial capital to obtain these products. However, the same proportion of residents from SES class 4 used both of these products in their vegetable gardens. Compost use is illustrated in Fig. 7.2.

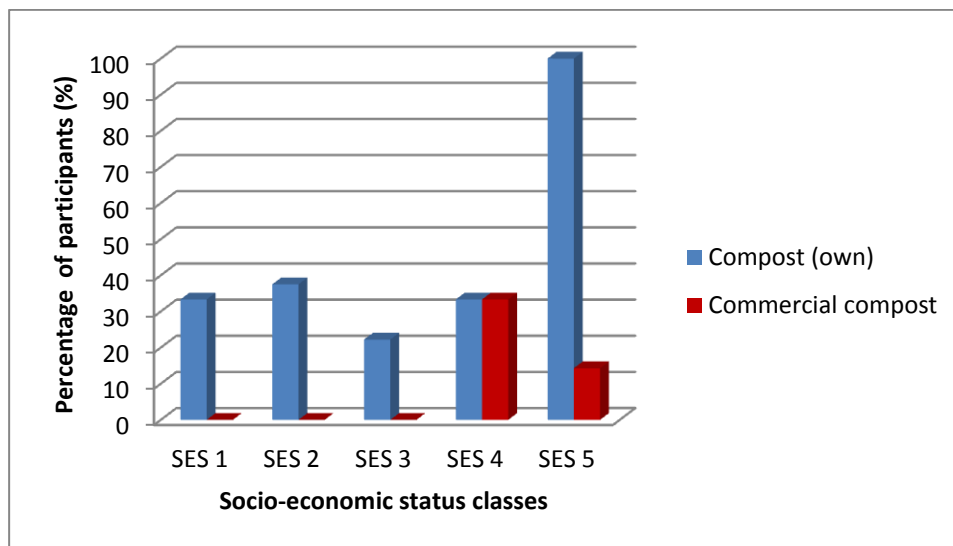


Figure 7.2: An illustration of the percentage participants of the different socio-economic status classes that use their own or commercially produced compost.

During the survey a distinction was made between the households which used their own compost in the garden and those who buy commercially produced compost (Fig. 7.2). In our study all the SES classes used compost that derived from their own organic household waste. SES class 5 had the highest use of this organic compost. None of the participants from the lower income classes (SES classes 1, 2 & 3) used commercially produced compost (Fig. 7.2). SES class 4 once again had an equal number of participants that used both forms of compost for their vegetables (Fig. 7.2).

Three types of weed maintenance practices were recorded (Fig. 7.3). The first and most prominent type of maintenance was the manual removal of weeds (Fig. 7.3). The second type was the use of chemicals (herbicides) and lastly, the sweeping of the garden, which can be regarded as indirect removal of weeds. This last management practice forms part of the cultural beliefs of some ethnic groups in South Africa that is referred to as the 'lebala concept' (Cilliers, 2010). Through this concept it is believed that the vegetation surrounding the residents' houses should be removed leaving large areas of bare ground (Cilliers, 2010). This gives an indication of the tidiness of the household in the community.

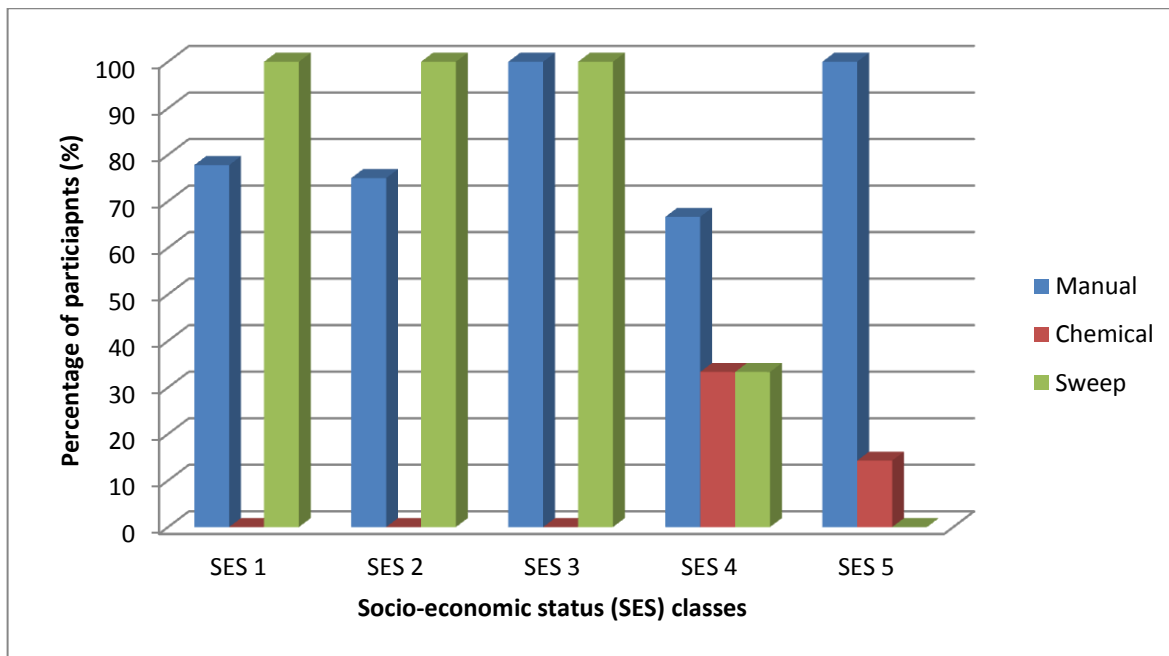


Figure 7.3: The percentage of participants that practice manual and chemical removal of weeds and the percentage of residents that sweep their gardens.

Members of all the SES classes removed weeds manually from their vegetable gardens (Fig. 7.3) and there were no major differences between the SES classes in this regard. SES class 4

had the lowest number of participants that actively removed weeds, but had the highest percentage of participants that used chemicals for weed removal (Fig. 7.3). Moreover, only SES classes 4 and 5 (higher income classes) made use of chemicals in their vegetable gardens. All the participants from SES classes 1, 2 and 3 sweep the soil in the areas surrounding their vegetable gardens (Fig. 7.3). A small proportion of members of SES class 4 also sweep their gardens even though the owners do not belong to that ethnic group. It is however very likely that the Tswana workers of the households from SES class 4 sweep parts of the large garden area.

No differences were apparent between the various SES classes with regards to the watering frequency of their vegetable gardens (Table 7.1). This gives an indication that the watering of the vegetable gardens possibly differs from one household to the next regardless of strong social influences (Table 7.1). Nevertheless, some tendencies were noticeable. For example, all the participating residents from SES class 3 watered their vegetable gardens between 2 to 4 times per week (Table 7.1). Likewise, all the residents from SES class 4 had a watering frequency in their vegetable gardens of 4 or more times per week (Table 7.1).

Table 7.1: Table showing the frequency of watering and the percentage (%) of residents from each SES class that participated in this management practice.

	Once	2 Times	3 Times	4 Times	>4 Times
SES 1	11.1	11.1	22.22	0	55.56
SES 2	0	25	50	0	25
SES 3	0	33.33	44.44	22.22	0
SES 4	0	0	0	33.33	66.67
SES 5	0	14.29	57.14	0	28.57

The ages of the vegetable gardens were also determined by means of the questionnaire (Fig. 7.4). Garden age may have a significant influence on the biodiversity within those gardens and may play a vital role in their contribution as habitats for biodiversity in the urban ecosystem (Thompson *et al.*, 2004; Smith *et al.*, 2006c). As indicated in Fig. 7.4 most of the vegetable gardens were older than 4 years. This was the most evident in SES class 5. Similarly, all the participating residents from SES class 4 also had vegetable gardens of 4 or more years old (Fig. 7.4). It is the lower income classes that had the younger vegetable gardens, which can be ascribed to these households (mainly from informal settlements) being established more

recently than those from the affluent classes (Lubbe *et al.*, 2010). This may have a definite influence on plant and arthropod diversity in vegetable gardens.

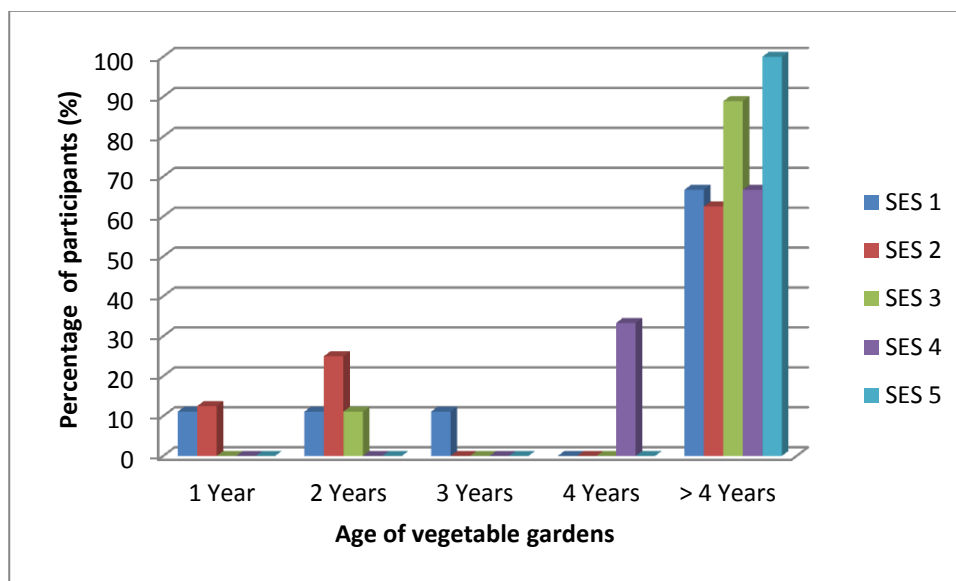


Figure 7.4: The average age of the vegetable gardens between the different socio-economic status (SES) classes.

Since urban environments are so highly populated, the management tendencies and perceptions of the urban residents must form an integral part of the management of biodiversity in cities (Savard *et al.*, 2000). Likewise, according to Gaston *et al.* (2005b), the time that is spent on management activities in urban domestic gardens resulted in that they are the most intensively managed areas of land. Loram *et al.* (2007) also stated that an increase in urbanization proportionately increases the importance of management tendencies within domestic gardens from an ecological perspective. This emphasizes the importance of understanding these management practices and determining how they may influence diversity and differ between various socio-economic groups.

7.3.1.2. Socio-economic aspects

Numerous studies have indicated that the management in homegardens may vary because of factors such as number of family members, level of income and level of education (Rugalema *et al.*, 1994; Adger, 2000; Madaleno, 2000; Kirkpatrick *et al.*, 2007). Therefore, my study included these aspects to determine how they may possibly differ between the SES classes. A few of the factors such as percentage unemployment, access to basic services, level of education, household size and number of rooms per household, from which these socio-economic status

classes were identified by Lubbe *et al.* (2012) are provided in Table 3.1 of Chapter 3. However, a more specific summary of the answers obtained during our survey is provided in Appendix F.

The specific purposes (i.e. medicinal) of the vegetable gardens were determined along the socio-economic gradient (Fig. 7.5).

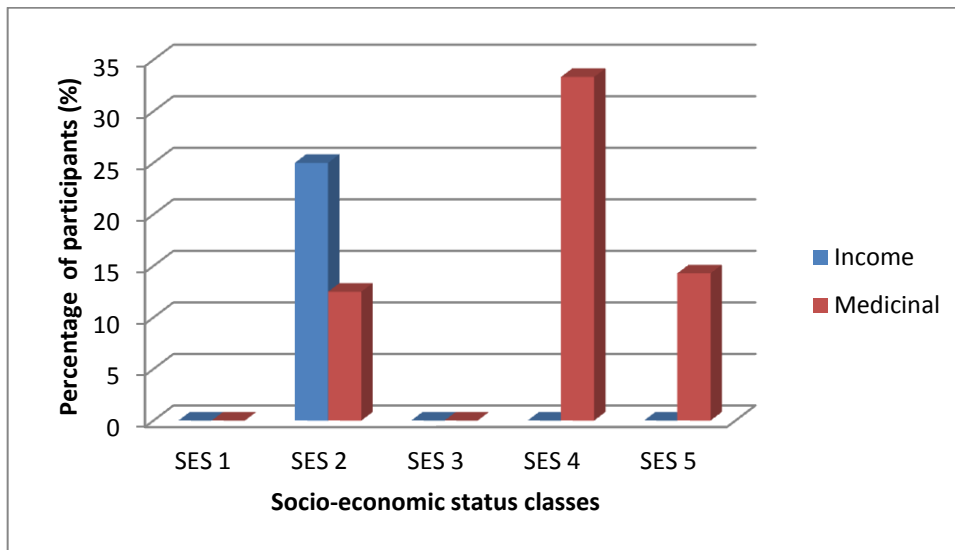


Figure 7.5: The major uses of the vegetable gardens for either income or medicinal purposes within the socio-economic status classes.

All the participants from the social survey predominantly harvested vegetables for their own consumption and food security (not indicated in Fig. 7.5). However, a small proportion of the two most affluent classes and SES class 2 did make use of vegetable gardens for medicinal purposes and/or to improve their health through organic products (Fig. 7.5). Moreover, a few of the residents in SES class 2 also sold their vegetables for an additional income (Fig. 7.5).

An economic factor that was taken into consideration was the monthly income of the participants. As discussed in Chapter 4, these residents were told that this survey was anonymous and confidential. They were also told that if they felt uncomfortable answering these questions that it could be passed. The results from the survey indicates that all the residents from SES class 1 and 3 had a monthly income of less than R 5 000 (Fig. 7.6). A few respondents of SES classes 4 and 5 also received less than R 5 000 monthly (Fig. 7.6). However, these individuals (SES classes 4 and 5) were all retired and received their monthly pension from the government. What is remarkable is that there was quite a gap between the lower and higher SES classes (Fig. 7.6). In the affluent classes the largest part of the residents

received more than R 20 000 and some even more than R 30 000 monthly, which was substantially larger than those of lower SES classes.

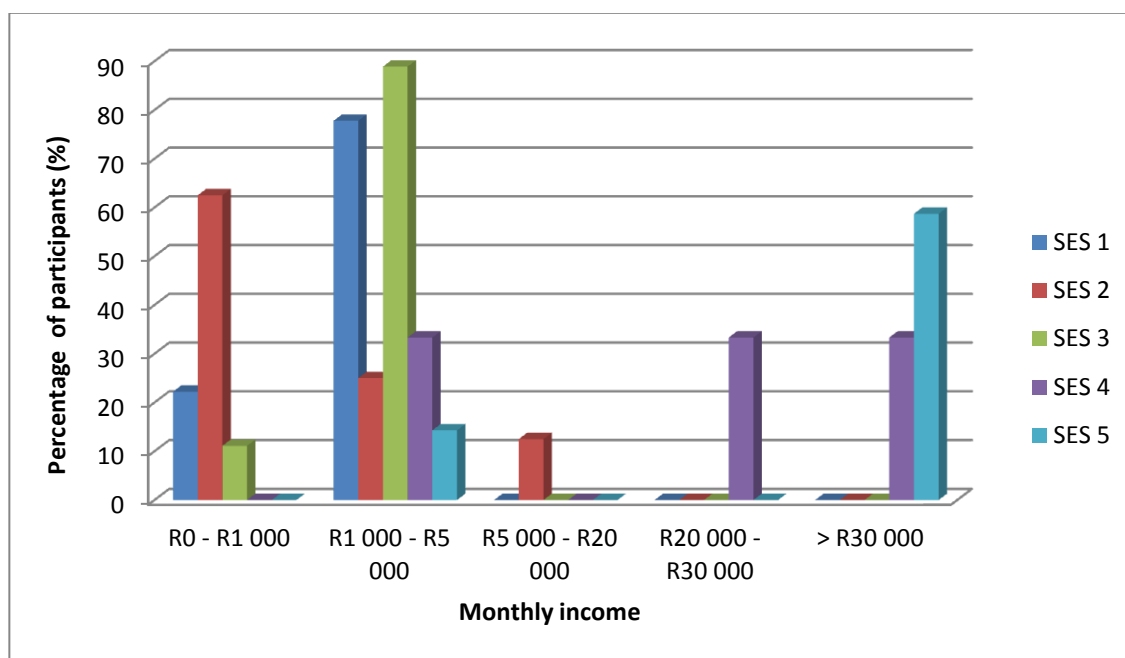


Figure 7.6: The average monthly income of the participants and comparisons between the socio-economic status classes.

From our study some differences were evident between the socio-economic status classes for both management and socio-economic factors (see Chapter 3 and Appendix F). SES class 4 had the highest use of chemical products in their gardens because they applied large amounts of fertilizer, insecticides and commercially produced compost (Fig. 7.1 & 7.2). This class was also associated with using the highest number of chemicals for weed control in vegetable gardens (Fig. 7.3). This may explain the lower number of plants species that were obtained in vegetable gardens of SES class 4 (see Chapter 6). Members of all the socio-economic status classes manually removed weeds from their gardens and additionally used their own produced compost, which indicates that these were general management methods employed by all groups.

It has been stated that garden age may have an important influence on the biodiversity that is found within the gardens (Thompson *et al.*, 2004; Smith *et al.*, 2006). A study conducted in Mexico found no correlation between the age of the garden and a higher plant diversity (Blanckaert *et al.*, 2004), which is also the case in our study. Similar to our study, previous studies also reported that the use of organic waste as compost and the manual removal of

weeds are globally applied methods in homegardens (Rugalema *et al.*, 1994; Vogl & Vogl-Lukasser, 2003; Smith *et al.*, 2006; De Bon *et al.*, 2010). The studies that have focused on the use of insecticides, fertilizers and herbicides found contrasting results. A study in Tanzania indicated that none of the residents made use of any type of fertilizers, herbicides or insecticides (Rugalema *et al.*, 1994), whilst those of the Alpine regions in Austria did apply fertilizers to their soil but did not use any herbicides or insecticides (Vogl & Vogl-Lukasser, 2003). In contrast to this, homegardens in India frequently used both insecticides and fertilizers (Pandey *et al.*, 2007). Our results showed that some households did use chemicals whilst others did not, which differs from these previous studies where specific tendencies were noted. It therefore indicates that the use of these products within homegardens will depend on the specific community that the study was conducted in.

In the studies in Tanzania and India it was found that homegardens were a great means of income for households (Rugalema *et al.*, 1994; Pandey *et al.*, 2007). Remarkably, most other studies showed that only a small proportion of the residents used their homegardens to generate income however, all the residents mainly used it for own consumption (Madaleno, 2000; Trinh *et al.*, 2003; Zezza & Tasciotti, 2010) which is similar to the results of our study. As previously mentioned, there is a great distinction in the monthly income between the higher and lower SES classes. A study that was conducted in a settlement in Ganyesa in the North-West Province, South Africa, revealed that 40% of the residents from the study did not receive more than R 1 000 per month, whilst only 4% earned a monthly income that was higher than R 5 000 (Davoren, 2010). Similar trends were evident in our study. Approximately 22% of the residents did not earn a monthly income higher than R 1 000 and roughly 52% of the residents surveyed did not receive more than R 5 000 per month. In direct contrast, almost 20% of the people from the wealthier classes in Potchefstroom received a monthly salary of more than R 30 000.

7.3.2. Surrounding land-uses

The method proposed by Colding (2007) to identify the surrounding green spaces and to establish how they complement each other in supporting biodiversity was used in this study. This method is referred to as 'Ecological Land-use Complementation' (ELC) and was discussed in Chapter 4. The percentage cover of the surrounding land-use areas was estimated in a 200 m radius surrounding each garden surveyed. This was done with the use of a SPOT 5 satellite image using ArcGIS ver. 9 (ArcMap ver. 9.2) and an example of these satellite images are given in the Appendix (G). A list of the estimated percentages are also given in the Appendix G.

A DCA-biplot (Fig. 7.7) was constructed to determine what the majority of land-uses are surrounding domestic gardens of the different socio-economic status classes. The eigen-values for the first and second ordination axes were 0.350 and 0.180 respectively. The first axis explained 37.5% of the variability, whilst the second axis explained only 19.3%.

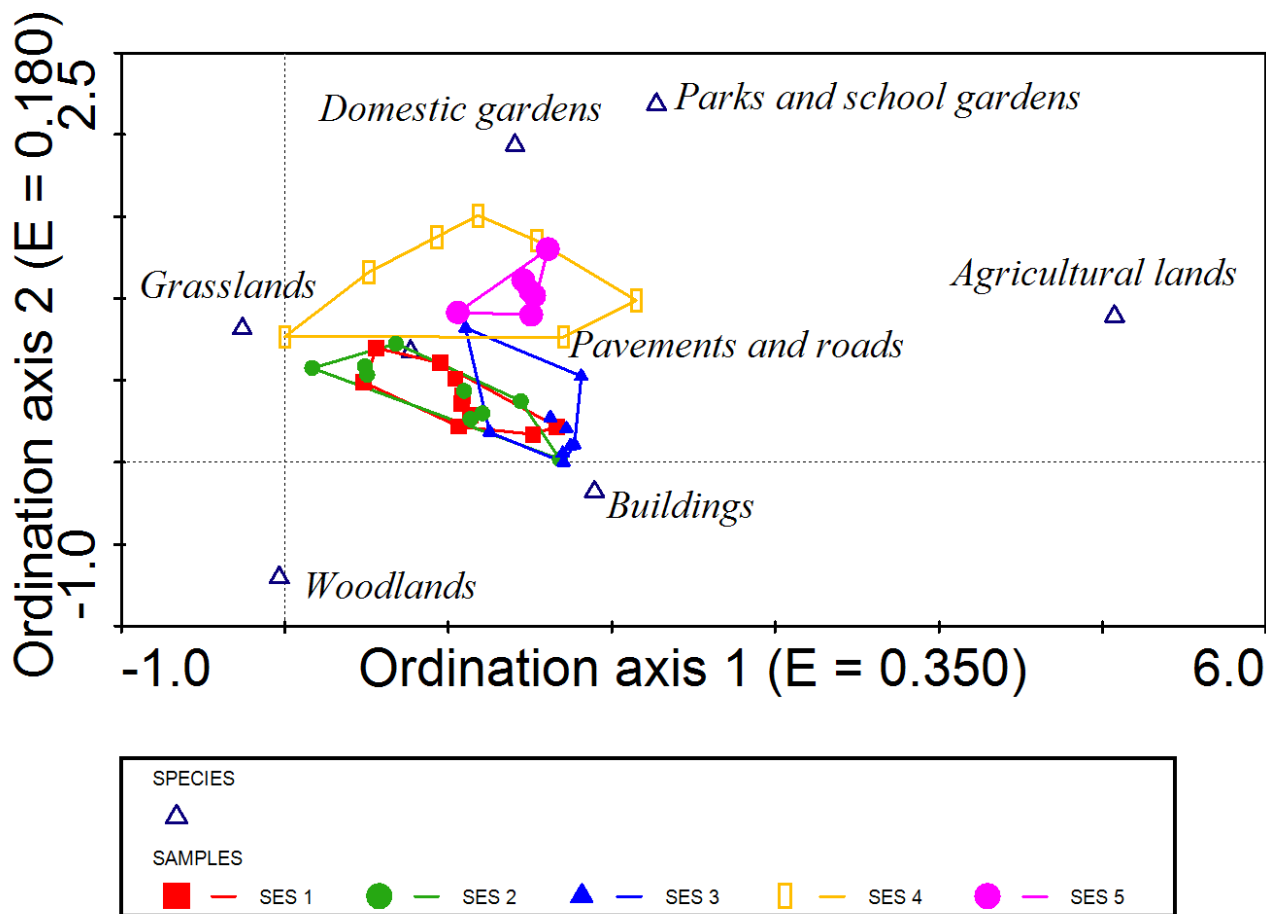


Figure 7.7: DCA-biplot illustrating the surrounding land-uses and the differences between the socio-economic status classes.

From Fig. 7.7 two groups could be identified. The land-uses surrounding the lower income households were similar and those of the two higher income classes were more analogous. The greatest variability should be ascribed to the percentages of the residents and the neighbors' domestic garden areas and surrounding buildings (Fig. 7.7). From Fig. 7.8, it is evident that SES classes 1, 2 and 3 had a higher percentage of buildings surrounding their gardens, with SES class 3 obtaining the highest values. Also, SES classes 4 and 5 had a high percentage of domestic gardens surrounding their households (Fig. 7.8). However, the percentage cover of pavements and roads as well as parks and school gardens were more or less similar between

households from all the socio-economic status classes (Figures 7.7 and 7.8). SES classes 1, 2 and 4 also had the highest cover of grasslands in the surrounding areas (Fig. 7.8). The percentage of woodlands (only SES classes 1 and 2) and agricultural lands (only SES class 4) within the 200 m radius was very low (Fig. 7.8).

The average percentages of the surrounding land-uses are provided in Figure 7.8. An interesting factor was that SES classes 1, 2 and 4 were the classes with the highest coverage of natural grasslands surrounding the participants' gardens, whilst the coverage in SES classes 3 and 5 was much lower (Fig. 7.8). This can be explained because SES classes 1 and 2 forms part of the formal and informal settlements where the people have constructed their houses in recent times within natural grasslands (Lubbe *et al.*, 2010), while SES class 4 are those households that are considered to be small holdings on the edges of the city (Lubbe *et al.*, 2011). SES classes 3 and 5 however are situated in typical residential areas and therefore may not possibly have as many natural grassland areas as the other classes

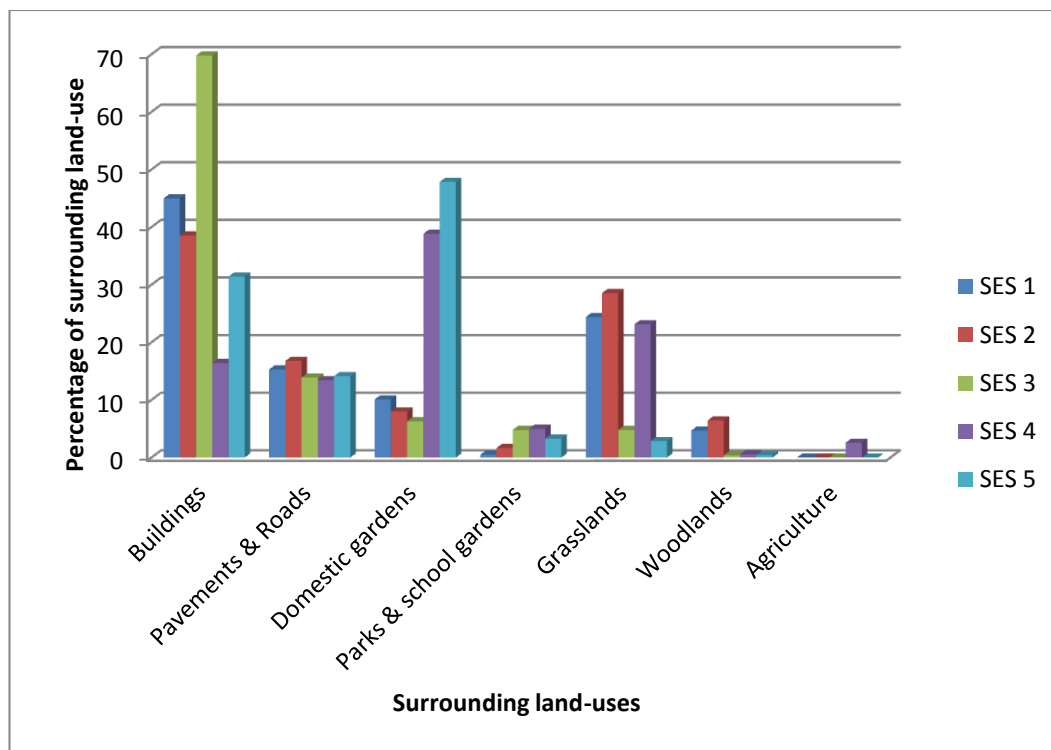


Figure 7.8: An indication of the average percentage of the different surrounding land-uses for all the socio-economic status classes.

The surrounding garden areas may have an influence on the arthropod diversity within the gardens (as discussed in Chapter 5). This assumption will only be verified later on in this chapter.

Band *et al.* (2005) stated that similar neighborhoods tend to have more or less the same land cover patterns that were an expression of the social and economic norms of that neighborhood. Our results also support these findings because there was a distinction between the land cover of the poorer and the more affluent households with regards to the surrounding land-uses of domestic gardens. The percentage cover of surrounding garden areas within the same SES classes was similar. In our study wealthier households had a larger proportion of surrounding garden areas. One of the studies of domestic gardens in Sheffield, UK indicated that the garden area has an influence on the particular land cover present, which in turn may evidently determine the habitat quality for potential wildlife (Smith *et al.*, 2005). However, the extent to which these surrounding domestic garden areas may influence biodiversity will only be discussed later on in this chapter. Results from a previous study in Tasmania, Australia also indicated that a higher percentage of tree cover was associated with higher socio-economic status classes (Kirkpatrick *et al.*, 2007). Therefore, it is evident that certain land cover patterns can be found within residential areas based on socio-economic influences.

7.3.3. Evaluation of the plant- and arthropod diversity

As mentioned previously (see Chapter 4), a two-way ANOVA was conducted for the plant and arthropod data and were compared between each other. The results showed that for the combined data there were significant differences between the socio-economic status classes ($p < 0.05$) as well as whether the species were located within the vegetable gardens and lawns ($p = 0.02$). There was however no interaction between the vegetable gardens and lawns (Place) for different SES classes ($p = 0.16$). The Spearman's rank order correlations did also not show any significant correlations between the plants and arthropods.

A two-way ANOVA was also conducted separately for both the plant and arthropod data and these results are provided in Figures 7.9 and 7.10. From the total number of arthropods it was evident that there were no statistically significant differences ($p = 0.94$) for Place, therefore indicating that no distinctions were made for the number of arthropods within the vegetable gardens and lawns (Fig. 7.9).

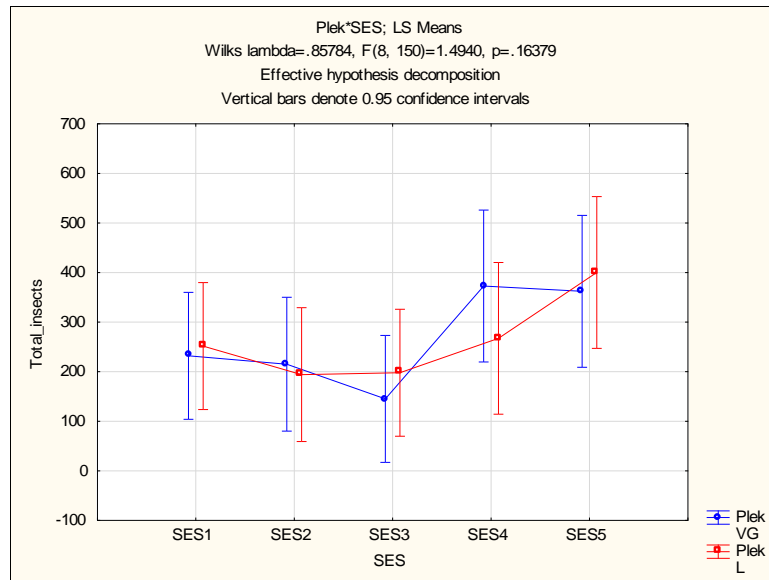


Figure 7.9: Results of the two-way ANOVA for the total number of arthropods between the five socio-economic status (SES) classes.

Blue line (VG) indicate Vegetable garden, Red line (L) indicate Lawn

A statistically significant difference was found for SES ($p = 0.03$), but it could only be ascribed to SES classes 3 and 5. No interaction was also evident between vegetable gardens and lawns with regards to SES classes.

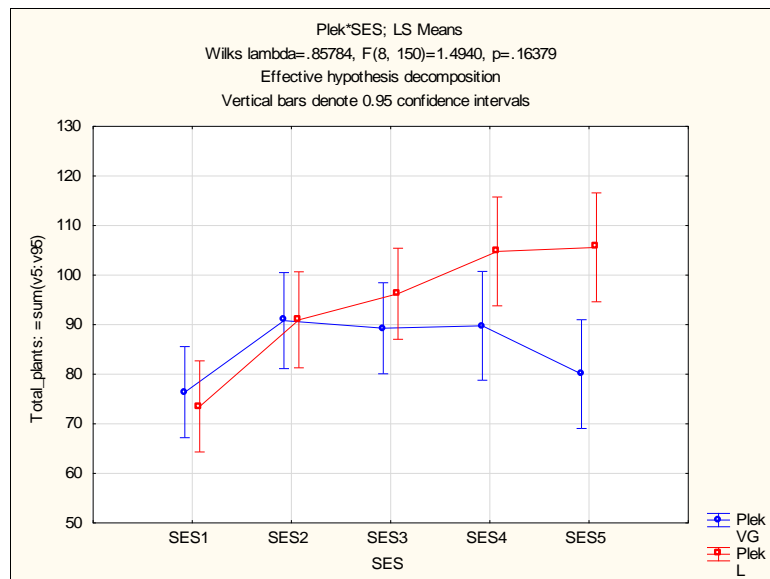


Figure 7.10: Results of the two-way ANOVA for the total number of plants between the five socio-economic status (SES) classes.

Blue line (VG) indicate Vegetable garden, Red line (L) indicate Lawn

The results from the total number of plants (as given in Fig. 7.10) indicate that there were statistically significant differences between vegetable gardens and lawns ($p = 0.006$) as well as between the socio-economic status classes ($p < 0.05$). Additionally, there was an interaction between SES and Place, which indicates that the differences within the total number of plants in the vegetable gardens and lawns could possibly be ascribed to differences within the SES classes ($p = 0.05$).

From the combined data it is clear that there are significant differences between the SES classes and vegetable gardens and lawns for the total number of arthropods and plants. Since the plant and arthropod data do not correlate, this deviates from many previous studies which indicated that higher plant diversity has led to an increased number of arthropods (Cai *et al.*, 2010). For example, two studies that were conducted along hedgerows and field edges as well as agricultural landscapes showed that there was a distinct positive correlation between the plant and arthropod diversity (Thomas & Marshall, 1999; Biaggini *et al.*, 2007). Similarly, Procheş & Cowling (2006) found that in the fynbos biome of South Africa there was a linear relationship between the floral and faunal diversity. A possible explanation why these results may differ from our results is that for the purposes of our study only the plants within vegetable gardens and lawns were noted and not the total species composition of domestic gardens. This should be verified in future studies along the socio-economic gradient in which total species composition of the entire domestic gardens are taken into consideration.

From the total number of arthropods in Fig. 7.9 there was a difference between the SES classes in vegetable gardens and lawns. It was also evident that there was no interaction between SES and Place that indicates that SES is not a driver of arthropod diversity. Plant diversity and SES was correlated as there was an interaction between SES and Place for the plant data. This indicates that socio-economic status is a possible driver of plant diversity in domestic gardens. This has been indicated in numerous other studies. In Phoenix, Arizona in the USA, it was found that the vegetation richness increased from neighborhood areas with low SES to the wealthier neighborhoods that had the highest SES (Martin *et al.*, 2004). In this study in Phoenix, median household income was the factor which showed the most variability (89%) in the vegetation richness (Martin *et al.*, 2004). Lubbe *et al.* (2010) also found in Potchefstroom that in the domestic gardens the gamma diversity of plants of the most affluent households (SES classes 4 and 5) was more than double than those found in the three lower income classes.

7.3.4. Plant- and arthropod data with the surrounding land-uses

A PCA-ordination was conducted within the STATISTICA 10 software program to determine how plant and arthropod diversity are associated with the surrounding land-uses. From this PCA four factors were identified that explained 72.3% of the variation in the data. A PCA ordination was conducted to compare all four these factors with one another. Similarly, one-way ANOVA's were used for all four these factors to determine how the SES classes compare with one another. However, only the results of the two factors that contributed to the most variation in the data and that proved to have significant differences in the ANOVA's will be given in this chapter. The other factors and how they compare with these two factors are given in Appendix H. Spearman's rank order correlations were also determined. The PCA-ordination of the two factors that explained the most variation is provided in Fig. 7.11.

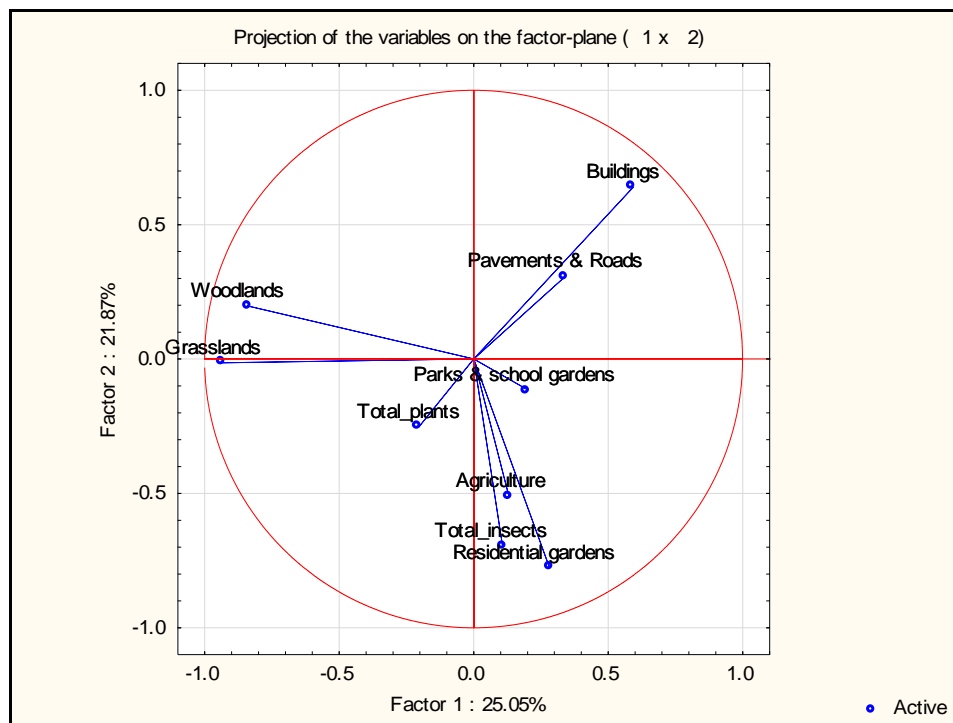
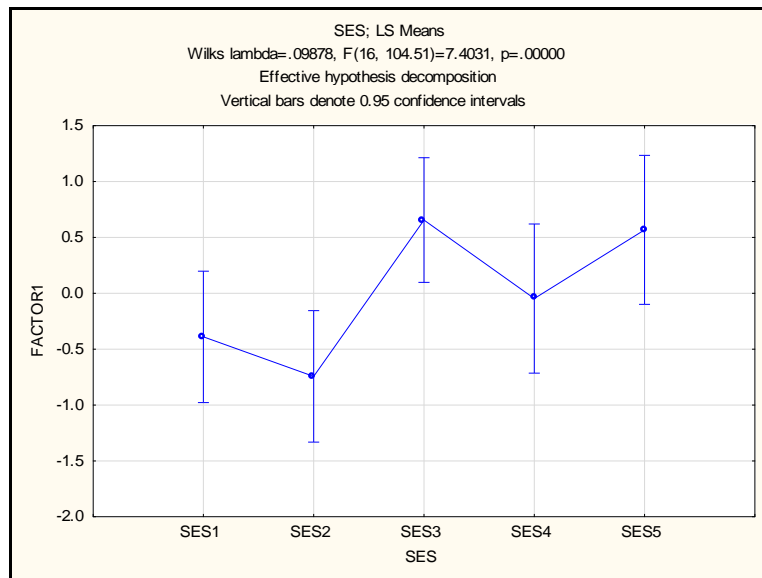


Figure 7.11: PCA-ordination of the total plant and arthropod numbers and their variability between the different surrounding land-uses.

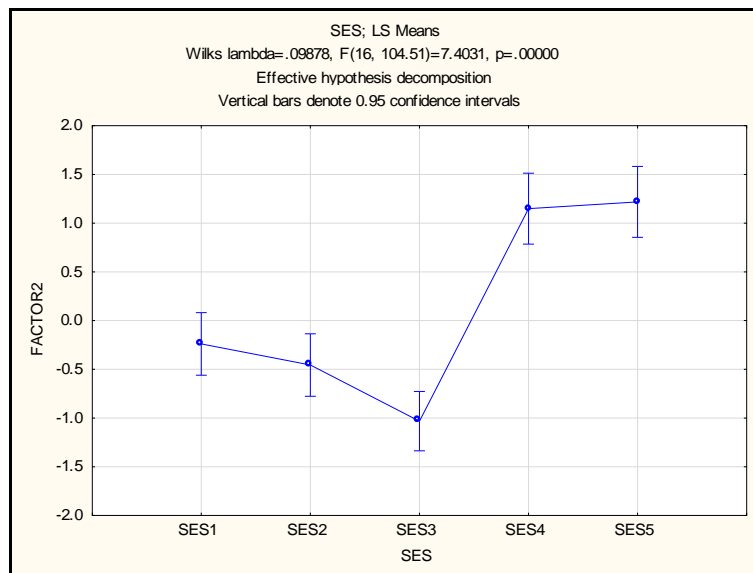
In Fig. 7.11, the first axis explained 25.05% of the variability, whilst the second axis explained 21.87%. From Fig. 7.11 it is evident that the percentage buildings is associated with the pavements and roads, whilst woodlands and grasslands within the surrounding areas were closely linked. This can be considered to be factor 1 in the analysis. Factor 2 gives an indication of how the arthropod data were associated with the surrounding domestic gardens. Factor 2

also has a negative association with the percentage buildings, roads and pavements in the surrounding area. Therefore in areas with high cover of buildings there is a low number of domestic gardens and arthropods.

One-way ANOVA's were conducted for both of these factors to determine how they differed between the socio-economic status classes (Fig. 7.12).



A)



B)

Figure 7.12: One way ANOVA's explaining how factors 1 (A) and 2 (B) differ between the socio-economic status classes.

It is evident that there were differences between the socio-economic status classes with regards to the two factors previously mentioned. For factor 1 (Fig. 7.12A), which refers to the woodlands and grasslands opposite to the buildings with the pavements and roads, it showed there were significant differences between SES class 2 with SES classes 3 and 5 ($p < 0.05$). This means that SES class 2 had a higher percentage of woodlands and grasslands that differs statistically significantly from SES classes 3 and 5, which had more densely built structures and much less natural areas (see also Fig. 7.8).

There were also significant differences between the SES classes with regards to factor 2 (Fig. 7.12B). This factor gives an indication of how the arthropod data were associated with the surrounding domestic gardens opposite to the percentage buildings, pavements and roads. For this factor there were statistically significant differences between the two higher income and the three lower income classes, which implies that the surrounding domestic gardens had a great influence on arthropods within the participants' gardens (Fig. 7.12B). In fact, the Spearman's rank order correlations showed that there is a statistically significant positive correlation between the total numbers of arthropods in the gardens with the percentage of domestic garden cover surrounding the gardens (correlation coefficient = 0.41).

It was evident that the arthropod richness within the gardens were significantly influenced by the adjacent domestic gardens within the vicinity and this differed between the socio-economic status classes. This is because from the satellite images, the highest percentage cover of domestic gardens was from affluent households (Fig. 7.9). This corresponds with many previous studies both in agroecosystems and urban environments. From the studies in Sheffield, UK, Smith *et al.* (2006b) found that the abundance of beetles and social wasps was positively related to other areas of green space surrounding a domestic garden. This is further supported by the fact that domestic gardens are interconnected and contribute to a large proportion of land within the urban matrix (Smith *et al.*, 2005), therefore, arthropods of a specific garden should be influenced by these surrounding areas outside of the boundaries of a single garden (Smith *et al.*, 2006a). Therefore, arthropod diversity is influenced on a landscape level. Likewise, it has been stated by McIntyre *et al.* (2001) that arthropods in different urban land-use types should be studied on a landscape level.

7.4. Summary

In this chapter we determined the specific management practices and socio-economic characteristics of the surveyed households. Distinct differences between the SES classes were

apparent, especially between the poorer (SES classes 1, 2 & 3) and wealthier (SES classes 4 & 5) households. It was found that certain management practices, such as the sweeping of the garden, are associated with households that have the same ethnicity and culture. Therefore, specific trends were found between the residents of the same social classes.

Another aspect from this chapter was that the percentage cover of different land-uses surrounding the households also differed between the poorer and wealthier residents. It was the two affluent SES classes that obtained the highest cover of other domestic gardens in the vicinity of the garden, which in turn had a significant correlation and effect on arthropod diversity in the gardens. However, there was no correlation between the total number of arthropods and plants from our study. Nevertheless, socio-economic status proved to have a significant effect on the plants within the gardens which indicate that SES is a possible driver of plant diversity in vegetable gardens. This correlates with numerous previous studies (Martin *et al.*, 2004; Kirkpatrick *et al.*, 2007; Lubbe *et al.*, 2010). Our study also showed that the arthropods were significantly associated with the percentage coverage of domestic gardens. This implies that the surrounding land-uses is a driver of arthropod diversity and that the higher income classes, which had the highest coverage of domestic gardens in the area, also had the highest arthropod diversity (see Chapter 5).

Chapter 8: Conclusions & Recommendations

8.1 Aims of the study

The aim of this study was to determine the plant- and arthropod diversity of urban vegetable gardens and compare it with lawns adjacent to those gardens. Another vital component was to determine how plants and arthropods differed between the previously described socio-economic status classes. It was also imperative for this study to establish how plants and arthropods are associated and/or influenced by other factors such as soil characteristics, the management tendencies of the residents as well as the impact of the surrounding land-uses. This could aid in the basic knowledge of urban domestic gardens that will support and benefit the ecological theory of urban ecosystems and how they interact with the social component of cities.

These aims were addressed within the three results chapters. The arthropod diversity and functional groups were determined in Chapter 5 and the plant diversity and edible species composition together with the soil analysis results were given in Chapter 6. Finally the correlation of the plant and arthropod diversity, and how they correlate with the surrounding land-uses, as well as the management regimes was verified in Chapter 7.

The hypotheses of this study were that:

- Socio-economic status is a driver of plant- and arthropod diversity. Socio-economic status will influence the plant diversity preferences in gardens. The composition of plants will in turn determine arthropod diversity. The generalist arthropod species will be less affected than those arthropods that are considered to be specialist species.
- Vegetable gardens will have higher plant- and arthropod diversity than their associated lawns. Lawns will have mainly one dominant species with few other species.
- The surrounding land-uses and socio-economic status of residents determine the plant- and arthropod diversity of the different SES classes. The surrounding land-uses will have an influence on many of the plant species in domestic gardens. This will be especially true for many of the weeds that proliferate. Also, many arthropods do not have an extensive distribution range and species found in domestic gardens would have derived from those gardens or the adjacent areas.

A short summary of these results will be given within sections 8.2 to 8.4 of this chapter. The concluding remarks, discussion of the hypotheses and recommendations for future studies are given in section 8.5

8.2 Arthropod diversity of vegetable gardens and lawns along a socio-economic gradient

Morphospecies and functional group diversity of the arthropods were determined in both the vegetable gardens and the lawns of the five socio-economic status (SES) classes. The following functional groups were included: herbivores, predators, parasitoids, decomposers/detritivores and pollinators. SES classes were used to determine whether socio-economic status can be a driver of arthropod diversity in domestic gardens and to determine whether these domestic gardens form adequate green space for arthropod conservation in cities. Four diversity indices were used namely, Margalef's species richness index, Pielou's evenness index, Shannon-Wiener and Simpson's diversity indices.

Our results showed that Pielou's evenness index was similar throughout all the SES classes but, that the more affluent SES classes obtained the highest values for the Shannon and Simpson's diversity indices and Margalef's species richness index. However, I found that socio-economic status and Place were independent from each other and therefore had their own influence on arthropod diversity in these gardens. The vegetable gardens also obtained higher diversity index values than any of their associated lawns, which are the most abundant green areas in cities.

From the functional groups, predators had the highest number of individuals in vegetable gardens and lawns. More herbivores were found in vegetable gardens than lawns since they are attracted to a higher plant species richness. Our results also showed that vegetable gardens had a higher turn-over of species (beta-diversity) than lawns which implies that vegetable gardens in urban domestic gardens can be used for the conservation of arthropods in cities. Also, not only do these domestic gardens cover a large area of urban land (Thompson *et al.*, 2003; Mathieu *et al.*, 2007) but, residents can also be educated on the importance of arthropod diversity in gardens and be motivated to enhance diversity in their gardens.

8.3 Plant diversity of vegetable gardens and lawns along a socio-economic gradient

The vegetation survey showed that the largest proportion of the species found within the study was from vegetable gardens and that lawns were species poor. In fact, lawns from all the SES

classes were quite similar in species composition and were dominated by the invasive grass species *Pennisetum clandestinum*. This is similar to a previous study conducted in Potchefstroom that found that this invasive grass species was the dominant plant in most of the gardens surveyed along the socio-economic gradient (Lubbe *et al.*, 2011). SES classes 1 and 2 (lowest income classes) had the highest total number of plant species in vegetable gardens. This is because of the high number of weeds from these gardens that were not removed or because of more vegetables that were planted for harvesting. In addition, these two classes had obtained the highest species richness of native perennial species. A possible explanation for this is that these households (informal settlements) are newly constructed and located within less urban and more natural areas. As a result, these native perennial species could be more easily established within these areas. Vegetable gardens also had a higher beta-diversity than lawns. Lawns are mainly monocultural (Robbins & Birkenholtz, 2003; Lubbe *et al.*, 2011) and the intensive management associated with lawns (such as regular mowing) most likely prevents certain species from becoming established.

Edible crop species contributed 22.7% of the total number of species recorded. Tomato (*Lycopersicon esculentum*) was the most common edible species in all the SES classes. Some of the SES classes had preferences for specific vegetables. For example, households from SES class 2 had preferences for maize, red peppers and chilli peppers. Similarly, members from SES class 4 had a preference for pumpkins and sweet potatoes, which were uncommon in the other SES classes. Overall, plant diversity was driven by socio-economic status (see also Chapter 7) as was predicted in the hypothesis.

No differences were found between the SES classes with regards to the soil analysis (as discussed in Chapter 4). This indicates that socio-economic status of the residents does not directly influence urban soils. Generally the soil from the different domestic gardens had a neutral to alkaline pH and had a large proportion of sand, which is common in urban areas (Basioli *et al.*, 2006).

8.4 Integration of plant- and arthropod diversity and various other variables

The final results chapter of this study focused on various other aspects that can possibly influence plant or arthropod diversity. These aspects include the management regimes and certain socio-economic characteristics of residents from the different SES classes. This information was collected through questionnaires. Other factors that were determined included the percentage cover of the surrounding land-uses such as other green spaces (domestic

gardens, parks and school gardens and natural woodlands and grasslands). It also included the percentage cover of infrastructure such as the buildings, pavements and roads. It was also determined whether any correlation exist between plant and arthropod diversity and how these two variables are influenced by the surrounding land-uses.

There were many differences between the poorer (SES classes 1,2 & 3) and wealthier (SES classes 4 & 5) households. The management practices differed in aspects such as the use of chemicals and the management of weeding. For example, many households from the lower SES classes use the sweeping method, referred to as the 'lebala' concept (Cilliers, 2010). The areas surrounding the houses are kept open from vegetation and are swept which signifies the tidiness of the households (Cilliers, 2010). In our study the lower income residents had a large area of bare ground in their gardens as a result of the sweeping method, together with a patch of lawn and a vegetable garden. The more affluent residents (SES classes 4 & 5) had obtained higher educational levels, higher level of employment and even entrepreneurship, better housing and access to basic services and substantially higher levels of income than those of the poorer households. Only a small proportion of SES class 2 sell their vegetable produce and therefore attains an additional income that also ensures self-employment opportunities. The gap between poorer and wealthier SES classes with regards to management practices was great and therefore future studies should include social aspects because they have an influence on the management practices.

The estimations of the surrounding land-uses also differed between the higher and lower income classes. The more affluent residents had the largest cover of other domestic gardens in the vicinity. Domestic gardens as opposed to the percentage of buildings, pavements and roads seemed to be the most significant factor that explained and correlated with the arthropod diversity and is therefore considered to be the most important driver of arthropod diversity in homegardens.

Plant diversity in vegetable gardens and to a lesser extent lawns was driven by socio-economic status, which has been found in various other studies (Martin *et al.*, 2004; Kirkpatrick *et al.*, 2007; Lubbe *et al.*, 2010). There were however, no positive correlation found between the total number of arthropods and plants within the domestic gardens, maybe because our study focused on vegetable gardens and lawns and not the total plant species diversity in domestic gardens.

8.5 Concluding remarks and recommendations for future studies

This study showed that for most of the factors that were examined there was a distinction between the three lower (SES classes 1, 2 & 3) and the two higher (SES classes 4 & 5) income classes. Therefore, socio-economic status did have an influence on biodiversity of vegetable gardens and lawns in domestic gardens. However, SES was only a driver of plant diversity (as was hypothesized), while the adjacent land-uses were driving arthropod diversity. Higher arthropod diversity was found in households that had a higher percentage cover of domestic gardens in the surrounding area and in the absence of dense buildings and/or pavements and roads. However, the hypothesis that the surrounding land-uses had an influence on the plant diversity as well was not supported. No correlation was found between the plants and arthropods. This is different from our hypothesis where it was expected that SES would also be a driver of arthropod diversity considering that many studies found strong correlations between plants and arthropods (Thomas & Marshall, 1999; Procheş & Cowling, 2006; Biaggini et al., 2007). This may be because our study did not include the total plant species diversity in domestic gardens. It is recommended that the correlation of total plant- and arthropod diversity of domestic gardens be determined in future studies. The hypothesis that the vegetable gardens had higher plant- and arthropod diversity than the lawns was supported.

Previous studies stated that urban green spaces are becoming very important for the conservation of arthropods (Connor *et al.*, 2002; McGeoch, 2002). Urban domestic gardens is valuable in this regard because it provides habitat for arthropods that is preserved in the residents' gardens (Smith *et al.*, 2006a; Smith *et al.*, 2006b). From this study it has been found that domestic gardens may contribute to the conservation of biodiversity in cities. However, for conservation of arthropods in domestic gardens to be successful, it will require the cooperation of the residents and for that they need to understand the importance of biodiversity, especially in urban environments. This will require that people from all generations are educated on the importance and ecological benefit of biodiversity.

The results from the social survey also showed that there were major differences between poorer and wealthier households. The wealthier households had much higher income, educational status, employment and access to basic services. There were also differences in their garden management practices (see section 8.4). These social aspects seemed to have an influence on the diversity of plants and arthropods as was stated in the hypothesis. The soil characteristics did not differ much between the domestic gardens from the different SES classes

but overall the gardens seem to have neutral to alkaline pH and sandy soils. For future studies it is recommended to conduct soil analyses where the soil from urban domestic gardens are compared with soil from natural and semi-natural areas in and around cities. This will give a better indication of the condition of the soil in the domestic gardens.

Another possibility for future studies is to compare the total diversity of arthropods and plants in domestic gardens of Potchefstroom with the natural areas surrounding the city or to determine the plant- and arthropod diversity along an urban-rural gradient. This will give a better understanding of how valuable conservation of biodiversity in urban domestic gardens really are when compared to the natural areas.

For future studies in domestic gardens of Potchefstroom, it is recommended to rather have two large socio-economic classes than the five we used in this study. The reason for this is because two previous studies along the same socio-economic gradient in Potchefstroom, one on birds and one on vegetation composition also found the same disparity in SES than we did from our study (Smith, 2004; Lubbe *et al.*, 2010). Therefore, these two larger groups would give an adequate representation of biodiversity along the socio-economic gradient. In addition it is also recommended that all types of studies in urban domestic gardens include socio-economic classes and/or factors mainly because they have such a huge influence on the biodiversity. This would ensure that these biodiversity studies have a more complete integration of the human component and it will help determine how biodiversity is affected from various angles.

Lastly, I would like to conclude on a personal note. Even though I am still a young scientist, I have come to understand the importance of conducting interdisciplinary science on biodiversity studies in urban environments. Even though this study that I have conducted is on a small scale, I was able to find a more comprehensive understanding of gardens and of urban environments through trying to integrate different scientific disciplines to some extent. Unfortunately, my knowledge of a variety of disciplines is limited and therefore I believe that future studies in urban environments should include scientists from different disciplines that have a thorough understanding of their scientific fields. These types of collaborations would improve conservation strategies and give a better understanding of the ecology of cities and would ensure that urban planning and development are conducted in a more sustainable manner.

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Appendices

Appendix B: Social survey questionnaire

Garden Number:

Date:

GPS:



NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

SECTION 1: Management and Maintenance

1. Do you use any of the following in your garden?

	YES	NO
Fertilizer		
Insecticides		
Compost (own)		
Commercial compost		
None		

2. Which of the following activities take place in your garden?

	YES	NO
Water the garden		
Fertilize the garden		
Weed the garden – chemically		
Weed the garden – mechanically		
Sweep the garden		

3. How many times per week do you water the plants?

Only once	
2 Times	
3 Times	
4 Times	
More than 4 times	

4. How old is the vegetable garden?

1 Year or less	
2 Years	
3 Years	
4 Years	
More than 4 years	

SECTION 2: Socio-economic aspects

1. The vegetables that are produced are used for:

	YES	NO
Own consumption		
Selling as a source of income		
Medicinal use		

2. The nearest water tap is situated:

	YES	NO
In the garden		
100 m from the garden		
200 m from the garden		
More than 200 m		

3. How many people live in the household?

Only one	
Two people	
Three people	
Four people	
More than four people	

4. How many rooms are available in the house?

Only one	
Two rooms	
Three rooms	
Four rooms	
More than 4 rooms	

5. The highest level of education is:

No education	
Primary	
Secondary (Grade 12 excluded)	
Secondary (Grade 12)	
Tertiary (Undergraduate)	
Tertiary (Postgraduate)	

6. In which of the following class ranges is your monthly income?

R 0 – R 1 000	
R 1 000 – R 5 000	
R 5 000 – R 20 000	
R 20 000 – R 30 000	
More than R 30 000	

7. How do you attain your income?

Permanent job	
Odd jobs	
Self-employed	
Government grants	

Appendix C: Arthropod taxa

Family names and number of morphospecies of arthropods per family collected by means of suction and pitfall traps in vegetable gardens and lawns. The juveniles are also included even though they were excluded from the functional group analysis.

Order	Family	Number of morphospecies
Hymenoptera	Formicidae	11
	Ichneumonidae	3
	Vespidae	3
	Apidae	11
	Other Families	82
Diptera	Agromyzidae	1
	Calliphoridae	2
	Culicidae	3
	Dolichopodidae	1
	Drosophilidae	2
	Muscidae	10
	Mycetophilidae	3
	Sciaridae	1
	Tachinidae	6
	Tephritidae	1
	Tipulidae	3
	Other Families	35
	Larvae of Diptera	1

Order	Family	Number of morphospecies
Diptera	Growth stage: Chrysalis	1
Coleoptera	Anthicidae (<i>Formicomus</i>)	1
	Bostrichidae	1
	Bruchidae	1
	Carabidae	5
	Chrysomelidae	15
	Chrysomeloidea (Super Family)	15
	Coccinellidae	10
	Curculionidae	9
	Elateridae	4
	Histeridae	1
	Lycidae	1
	Meloidae	1
	Melyridae (<i>Astylus</i>)	1
	Mordellidae	1
	Nitidulidae	1
	Scarabaeidae	9
	Scydmaenidae	1
	Staphylinidae	8
	Tenebrionidae	6
	Other Families	28

Order	Family	Number of morphospecies
Coleoptera	Scarabaeidae (larvae)	1
	Larvae of Coleoptera	10
	Coccinellidae (larvae)	2
	Tenebrionidae (larvae)	1
Hemiptera	Alydidae	1
	Aphididae	2
	Berytidae	1
	Cercopidae	6
	Cicadellidae	3
	Coreidae	2
	Cynidae	1
	Lygaeidae	4
	Miridae	10
	Miridae (<i>Orius</i>)	1
	Reduviidae	2
	Scutelleridae	1
	Tettigometridae (<i>Hilda patruelis</i>)	1
	Tingidae	4
	Nymph Hemiptera	1
	Cercopidae (nymph)	1
	Reduviidae (nymph)	3

Order	Family	Number of morphospecies
Lepidoptera	Geometridae	1
	Noctuidae	3
	Pyralidae	1
	Other Families	4
	Larvae of Lepidoptera	10
	Geometridae (larvae)	1
	Noctuidae (larvae)	7
Collembola	Entomobryoidea	1
	Poduroidea	1
	Sminthuridae	1
Orthoptera	Acrididae	5
	Gryllidae	7
	Gryllotalpidae	1
	Tetrigidae	1
	Tettigoniidae	1
	Tridactylidae	1
	Other Orthoptera	1
Phthiraptera	Menoponidae	1

Other taxa that were also collected during the study of which no Family classification was done, are provided below.

Phylum	Class	Order	Number of morphospecies
Arthropoda	Insecta	Thysanoptera	3
	Insecta	Isoptera	1
	Insecta	Dermaptera	2
	Insecta	Mantodea	2
	Insecta	Neuroptera	1
	Insecta	Blattodea	2
	Myriapoda (Superclass)	Unknown	4
	Arachnida	Araneae	68
	Arachnida	Acari	6
Crustacea*	Malacostraca	Isopoda	1
Chordata*	Amphibia	Anura	1
	Reptilia	Squamata	1
Annelida*	Unknown	Unknown	1
Mollusca*	Gastropoda	Stylommatophora	1
Unknown species*	Unknown	Unknown	14

**Taxa not included in analysis*

Appendix D: Total plant species list

The plant species list as identified in both the vegetable gardens and lawns.

Species name	Family	Annual/Perennial	Growth form
<i>Acacia karroo</i> Hayne	Fabaceae	Perennial	Tree/shrub
<i>Acanthospermum glabratum</i> (DC.) Wild*	Asteraceae	Annual	Herb
<i>Agapanthus</i> L'Her spp.	Agapanthaceae	Perennial	Herb
<i>Allium cepa</i> L.*	Liliaceae	Annual	Herb
<i>Allium sativum</i> L.*	Liliaceae	Perennial	Herb
<i>Alternanthera pungens</i> Kunth.*	Amaranthaceae	Perennial	Herb
<i>Amaranthus hybridus</i> L.*	Amaranthaceae	Annual	Herb
<i>Ananas comosus</i> (L.) Merr. var. <i>comosus</i>	Bromeliaceae	Perennial	Herb
<i>Anoda cristata</i> (L.) Schltld.*	Malvaceae	Annual	Shrub/herb
<i>Apium graveolens</i> L.*	Apiaceae	Biennial/perennial	Herb
<i>Arachis hypogaea</i> L.*	Fabaceae	Annual	Herb
<i>Atriplex</i> L. (species 1)	Chenopodiaceae	Perennial	Shrub
<i>Atriplex</i> L. (species 2)	Chenopodiaceae	Perennial	Shrub
<i>Beta vulgaris</i> L. subsp. <i>vulgaris</i> *	Chenopodiaceae	Annual	Herb
<i>Bidens bipinnata</i> L.*	Asteraceae	Annual	Herb
<i>Bidens pilosa</i> L.*	Asteraceae	Annual	Herb
<i>Boerhavia erecta</i> L.*	Nyctaginaceae	Annual	Herb
<i>Brassica oleracea</i> L.*	Brassicaceae	Perennial	Herb
<i>Capsella bursa-pastoris</i> (L.) Medik*	Brassicaceae	Annual	Herb
<i>Capsicum annuum</i> L. var. <i>glabriusculum</i> (Dunal) Heiser & Pickersgill*	Solanaceae	Perennial	Shrub/herb
<i>Capsicum frutescens</i> L.*	Solanaceae	Perennial	Shrub/herb
<i>Cestrum aurantiacum</i> Lindl.*	Solanaceae	Perennial	Shrub
<i>Chenopodium carinatum</i> R.Br.*	Chenopodiaceae	Annual	Herb
<i>Chloris virgata</i> Sw.	Poaceae	Annual/Perennial	Graminoid

Species name	Family	Annual/Perennial	Type
<i>Ciclospermum leptophyllum</i> (Pers.) Sprague*	Apiaceae	Annual	Herb
<i>Commelina benghalensis</i> L.	Commelinaceae	Annual	Herb
<i>Conyza bonariensis</i> (L.) Cronquist*	Asteraceae	Annual	Herb
<i>Conyza podocephala</i> DC.	Asteraceae	Perennial	Herb
<i>Cucumis melo</i> L. subsp. <i>agrestis</i> (Naudin) Pangalo	Cucurbitaceae	Annual	Herb
<i>Cucurbita pepo</i> L.*	Cucurbitaceae	Annual	Herb
<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	Perennial	Graminoid
<i>Dactyloctenium aegyptium</i> (L.) Willd.	Poaceae	Annual	Graminoid
<i>Daucus carota</i> L.*	Apiaceae	Biennial	Herb
<i>Dichondra micrantha</i> Urb.*	Convolvulaceae	Perennial	Herb
<i>Digitaria ternata</i> (A.Rich.) Stapf	Poaceae	Annual	Graminoid
<i>Eleusine coracana</i> (L.) Gaertn.	Poaceae	Annual	Graminoid
<i>Eragrostis lehmanniana</i> Nees.	Poaceae	Perennial	Graminoid
<i>Eragrostis tef</i> (Zucc.) Trotter*	Poaceae	Annual	Graminoid
<i>Euphorbia hirta</i> L.*	Euphorbiaceae	Annual	Herb
<i>Euphorbia prostrata</i> Aiton*	Euphorbiaceae	Annual	Herb
<i>Fragaria vesca</i> L.*	Rosaceae	Perennial	Herb
<i>Galinsoga parviflora</i> Cav.*	Asteraceae	Annual	Herb
<i>Gomphrena celosioides</i> Mart.*	Amaranthaceae	Perennial	Herb
<i>Guilleminea densa</i> (Willd. ex Roem. & Schult.) Moq*	Amaranthaceae	Perennial	Herb
<i>Indigofera</i> L. spp.	Fabaceae	Perennial	Shrub/herb
<i>Ipomoea batatas</i> (L.) Lam.*	Convolvulaceae	Annual/Perennial	Herb/Geophyte
<i>Ipomoea purpurea</i> (L.) Roth.*	Convolvulaceae	Annual	Herb
<i>Lactuca capensis</i> Thunb.	Asteraceae	Perennial	Herb
<i>Lepidium bonariense</i> L.*	Brassicaceae	Annual	Herb
<i>Lycopersicon esculentum</i> Mill. var. <i>esculentum</i> *	Solanaceae	Annual	Herb
<i>Malva neglecta</i> Wallr.*	Malvaceae	Perennial	Herb
<i>Malva parviflora</i> L.*	Malvaceae	Annual	Herb
<i>Malvastrum coromandelianum</i> (L.) Garcke*	Malvaceae	Biennial	Dwarf shrub

Species name	Family	Annual/Perennial	Type
<i>Mentha</i> L. spp.	Lamiaceae	Perennial	Herb
<i>Modiola caroliniana</i> (L.) G.Don*	Malvaceae	Annual	Herb
<i>Oxalis corniculata</i> L.*	Oxalidaceae	Annual	Herb
<i>Panicum coloratum</i> L.	Poaceae	Perennial	Graminoid
<i>Paspalum dilatatum</i> Poir*	Poaceae	Perennial	Graminoid
<i>Pennisetum clandestinum</i> Hochst. ex. Chiov.*	Poaceae	Perennial	Graminoid
<i>Petroselinum crispum</i> (Mill.) A.W.Hill*	Apiaceae	Biennial	Herb
<i>Phaseolus vulgaris</i> L.*	Fabaceae	Annual	Herb
<i>Polygonum maritimum</i> L.*	Polygonaceae	Perennial	Dwarf shrub/herb
<i>Portulaca oleracea</i> L.*	Portulacaceae	Annual	Herb
<i>Prunus persica</i> (L.) Batsch. var. <i>persica</i> *	Rosaceae	Perennial	Tree/shrub
<i>Pyrus communis</i> L.*	Rosaceae	Perennial	Tree/shrub
<i>Raphanus sativus</i> L.*	Brassicaceae	Annual	Herb
<i>Richardia brasiliensis</i> Gomes*	Rubiaceae	Perennial	Herb
<i>Setaria sphacelata</i> (Schumach.) Moss var. <i>torta</i> (Stapf) Clayton	Poaceae	Perennial	Graminoid
<i>Setaria verticillata</i> (L.) P.Beauv.	Poaceae	Annual	Graminoid
<i>Sida rhombifolia</i> L.	Malvaceae	Annual/Biennial	Shrub/herb
<i>Sida spinosa</i> L.	Malvaceae	Annual	Dwarf shrub/herb
<i>Solanum melongea</i> L.*	Solanaceae	Annual	Shrub
<i>Solanum tuberosum</i> L.*	Solanaceae	Perennial	Herb
<i>Sonchus oleraceus</i> L.*	Asteraceae	Annual	Herb
<i>Spinacia oleracea</i> L.*	Chenopodiaceae	Perennial	Herb
<i>Tagetes minuta</i> L.*	Asteraceae	Annual	Herb
<i>Taraxacum officinale</i> Weber*	Asteraceae	Perennial	Herb
<i>Tragus berteronianus</i> Schult.	Poaceae	Annual	Graminoid
<i>Tribulus terrestris</i> L.	Zygophyllaceae	Annual	Herb
<i>Tropaeolum majus</i> L.*	Tropaeolaceae	Annual	Herb
<i>Tulbaghia simmleri</i> P.Beauv.	Alliaceae	Perennial	Herb
<i>Urochloa mosambicensis</i> (Hack.) Dandy	Poaceae	Perennial	Graminoid
<i>Urochloa panicoides</i> P.Beauv.	Poaceae	Annual	Graminoid

Species name	Family	Annual/Perennial	Type
<i>Verbena bonariensis</i> L.*	Verbenaceae	Annual	Herb
<i>Verbena tenuisecta</i> Briq.*	Verbenaceae	Perennial	Herb
<i>Vigna</i> Savi spp.	Fabaceae	Annual/Perennial	Herb
<i>Zea mays</i> L.*	Poaceae	Annual	Graminoid

**indicates exotic species*

Appendix E: Complete list of soil values

The complete results from the soil analyses.

VCS = Very coarse sand, CS = Coarse sand, MS = Medium sand, FS = Fine sand, VFS = Very fine sand

SES (class)	us/cm	tdsppm	ORP	pH	> 2 %	VCS	CS	MS	FS	VFS	Silt	Clay
SES 1	455	227	-104.1	7.57	17.2	3	3.4	7.2	15.1	19.6	24.6	27.3
	129	64	-111.7	6.76	21.6	8.4	9.2	8.4	16.6	19.7	14.4	23.3
	151	76	-119.5	7.61	3.6	2.2	2.9	9.4	24.8	19.2	26.7	14.8
	446	223	-112.3	7.58	14.7	7.2	6.3	10.9	24.8	15.9	19.2	15.7
	678	339	-100.3	7.46	36.3	9.4	6.2	9.5	21.7	22	18	13.2
	324	161	-113.3	7.01	9.6	3.2	4.1	12.4	26.7	14.3	24.3	15.1
	272	136	-110.2	7.03	24	8.7	5.5	8.3	18	20.5	17.7	21.3
	554	277	-103.2	6.85	2.6	2.1	3.7	8.8	20.7	24.4	22.8	17.5
	296	148	-108	7.41	2.9	2.9	4.4	9.1	23	25.2	18.9	16.5
	149	74	-121.4	7.7	3.2	2.6	3.1	5.6	14	19.1	33.6	22
SES 2	124	62	-111	7.33	46.4	14.2	6.8	6.2	11.3	11.9	25.1	24.4
	153	76	-118.3	7.67	2.9	1.3	2.9	32.7	37.9	14.7	3	7.6
	276	138	-110.2	7.66	2.2	2.8	4.7	7.6	15.4	22.7	28.9	17.9
	523	262	-96.9	7.56	30.2	5.6	10	15.5	27.6	21.9	5.1	14.4
	139	69	-120.5	7.21	5.9	3.5	3.3	7	17.3	19.9	27.6	21.3
	109	54	-116.4	8.13	10.2	6	8.3	14.8	24.9	23.1	9.1	13.8
	160	80	-109.1	7.02	7.8	2.8	4.7	14.3	32.7	22.4	9.1	13.9
	202	101	-115.8	7.12	10.9	9.4	9.8	16.2	22.3	18.2	12.3	11.9
	335	168	-107	7.91	3.2	1.7	5.5	18	29.7	16.4	12	16.8
	197	99	-118.3	7.6	12.5	6.1	10.2	13.6	16.6	12.9	24.9	15.7
SES 3	186	93	-118.4	7.17	19.1	6.7	6.7	11.9	24.7	25.1	12.4	12.5
	239	119	-109.5	8.1	8.1	4.1	5.8	11.8	23.9	23.1	16.8	14.4
	380	190	-105.4	7.71	14.7	7.5	9	14.8	23.9	19.7	15.8	9.4
	81	40	-127.2	7.76	2.7	3.5	7.3	12.5	19.7	22.5	21.1	13.3
	435	218	-107.4	7.36	4.7	4.1	7.3	16.5	28.4	23.5	8.9	11.2

SES (class)	us/cm	tdsppm	ORP	pH	> 2 %	VCS	CS	MS	FS	VFS	Silt	Clay
SES 3	345	172	-107.6	6.48	20.4	4.7	5.7	10.8	20.6	29.6	16	12.6
	311	156	-116.4	7.89	15.3	5.9	8.9	16.5	26.1	20.6	12.7	9.3
	323	112	-111.4	6.8	3.2	3.8	5.6	12.2	22.9	23.2	16	16.2
	86	43	-117.9	6.9	16.9	8	9.5	14.5	21.3	21.2	16	9.5
	91	46	-122.2	7.17	30.5	11	10.1	12.8	16.9	15.7	11.7	21.8
SES 4	541	270	-94.2	7.66	24.4	16.9	13.7	12.3	15.1	12.4	15	14.5
	180	90	-119.7	7.51	4.6	2.6	6.1	17.1	18.9	14.9	20.4	20
	339	170	-108.7	7.97	22.7	7.8	7	14.1	17.7	12.5	24	16.9
	241	120	-107.3	7.64	25.6	8.8	7.1	12.4	21.7	19.8	16.9	13.3
	257	129	-110.3	7.43	15.4	10.6	7.9	11.4	18.4	16.5	16.3	18.9
	545	272	-100.7	6.89	2.2	1.9	5.1	20.7	30.3	20.7	8.3	13
	286	143	-111.8	7.18	3.8	2.1	6.5	16.2	19.3	13.7	27.2	15.1
SES 5	182	91	-113.6	7.82	15.1	8.8	8.2	16.1	26.4	18.3	9.8	12.3
	445	222	-103.5	7.68	18.1	8.8	7	12.4	22.1	21.7	10.9	17
	372	185	-96.7	6.27	1.7	5.3	9.2	17.2	24.1	19.8	11.1	13.3
	287	143	-104.9	7.72	27.8	8.1	9.2	15.8	21.5	14.1	17.5	13.8
	334	167	-102.1	7.68	12	6.4	7.8	16.3	25.9	17.2	12	14.4
	99	50	-116.7	7.85	16.4	8	6.2	10.6	19.9	19.6	16.6	19.2
	354	162	-108.8	7.54	9.2	5.7	8.5	16.7	26	17.8	11.5	13.8

Definitions for soil measurements

EC	<i>Electrical conductivity (EC) refers to the ability of soil to conduct electrical current, through measuring salinity. It is expressed in microsiemens per centimeter (us/cm).</i>
us/cm	<i>Microsiemens per centimeter (us/cm) is a unit expressing the amount of electrical conductivity (EC) of a solution as measured between opposite faces of a centimeter cube of a solution at a specific temperature.</i>
TDS	<i>Total Dissolved Solids (TDS) are the total amount of mobile charged ions, including minerals, salts or metals dissolved in a given volume of water, expressed in units of mg per unit volume of water (mg/L) also referred to as parts per million (ppm).</i>
tdsppm	<i>The unit is used to express the Total Dissolved Solids (TDS) in a volume of water and is referred to as parts per million (ppm) or mg per unit volume of water (mg/L).</i>

ORP	<i>Oxidation Reduction Potential (ORP) is a measure of the sanitizing ability of water. ORP readings are expressed in millivolts (mV) and are generated voltages in the presence of the oxidizing agent. The more oxidizer available, the greater the voltage.</i>
Redox potential	<i>Redox potential measures electron activity in soil. It refers to the tendency to transfer electrons, with one group accepting electrons (redox) and the other group donating electrons (oxidation). It is measure in Eh.</i>
Eh	<i>Eh is the unit that is used to measure the redox potential of soil.</i>

Appendix F: Data from socio-economic questionnaire

Results from the socio-economic questionnaire for households from the SES classes in our study (see also five parameters of Tlokwe City Municipality in Table 3.1). Each quantity is the number of households per SES class. *SES classes 1 to 3 = ten households each, SES classes 4 and 5 = seven households each.*

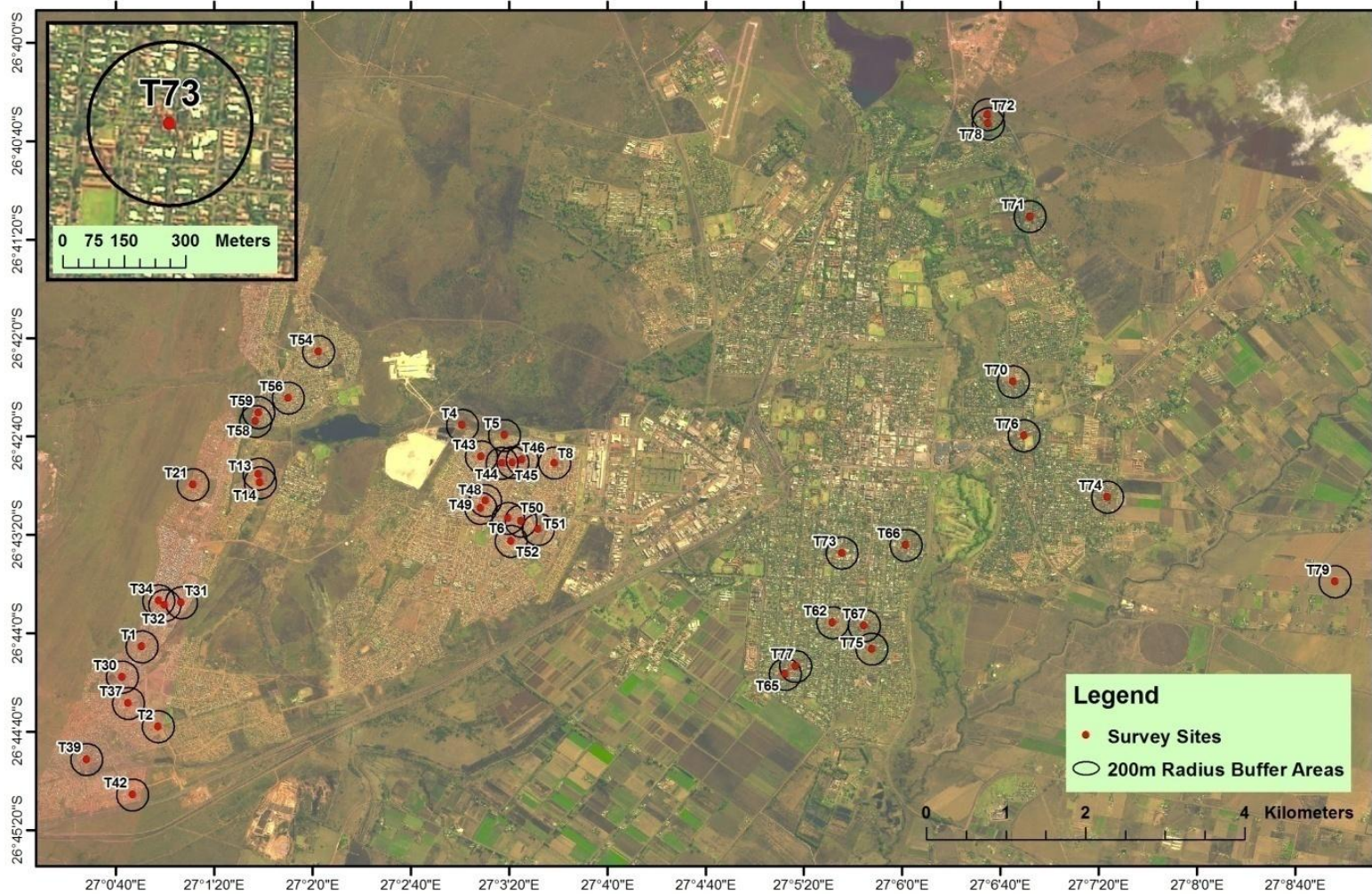
SES Class	Access to basic services ¹	Household Size ²	Number of rooms ³	Education ⁴	Employment ⁵					
1	In the garden	0	Two or less people	0	Two or less	3	No/Primary	5	Permanent	0
	100m from garden	10	Three people	0	Three rooms	4	Secondary (Gr.12 Excl)	5	Temporary	0
	200m from garden	0	Four people	2	Four rooms	1	Secondary (Gr. 12 Incl)	0	Self-employed	0
	More than 200m	0	More than four	8	More than four	2	Tertiary	0	Unemployed	10
2	In the garden	0	Two or less people	4	Two or less	4	No/Primary	5	Permanent	1
	100m from garden	10	Three people	1	Three rooms	0	Secondary (Gr.12 Excl)	3	Temporary	0
	200m from garden	0	Four people	2	Four rooms	4	Secondary (Gr. 12 Incl)	2	Self-employed	2
	More than 200m	0	More than four	3	More than four	2	Tertiary	0	Unemployed	7
3	In the garden	0	Two or less people	1	Two or less	0	No/Primary	2	Permanent	2
	100m from garden	10	Three people	0	Three rooms	0	Secondary (Gr.12 Excl)	4	Temporary	0
	200m from garden	0	Four people	3	Four rooms	9	Secondary (Gr. 12 Incl)	4	Self-employed	0
	More than 200m	0	More than four	6	More than four	1	Tertiary	0	Unemployed	8
4	In the garden	7	Two or less people	2	Two or less	0	No/Primary	0	Permanent	6
	100m from garden	0	Three people	1	Three rooms	3	Secondary (Gr.12 Excl)	0	Temporary	0
	200m from garden	0	Four people	2	Four rooms	2	Secondary (Gr. 12 Incl)	2	Self-employed	0
	More than 200m	0	More than four	2	More than four	2	Tertiary	5	Unemployed*	1
5	In the garden	7	Two or less people	3	Two or less	0	No/Primary	0	Permanent	3
	100m from garden	0	Three people	0	Three rooms	4	Secondary (Gr.12 Excl)	0	Temporary	0
	200m from garden	0	Four people	1	Four rooms	2	Secondary (Gr. 12 Incl)	2	Self-employed	2
	More than 200m	0	More than four	3	More than four	1	Tertiary	5	Unemployed*	2

¹households with pipe water in garden, ² number of people per household, ³ number of rooms per household, ⁴ highest level of education, ⁵ type of employment

* *Individuals that are retired and have pension*

Appendix G: Satellite images and surrounding land-uses

An illustration of the 200 m radius used to determine the surrounding land-uses in the proximity of the domestic gardens. Red dots indicate the domestic gardens and the circles indicate the 200 m radius buffer areas. An enlarged example is included.



Surrounding land-uses

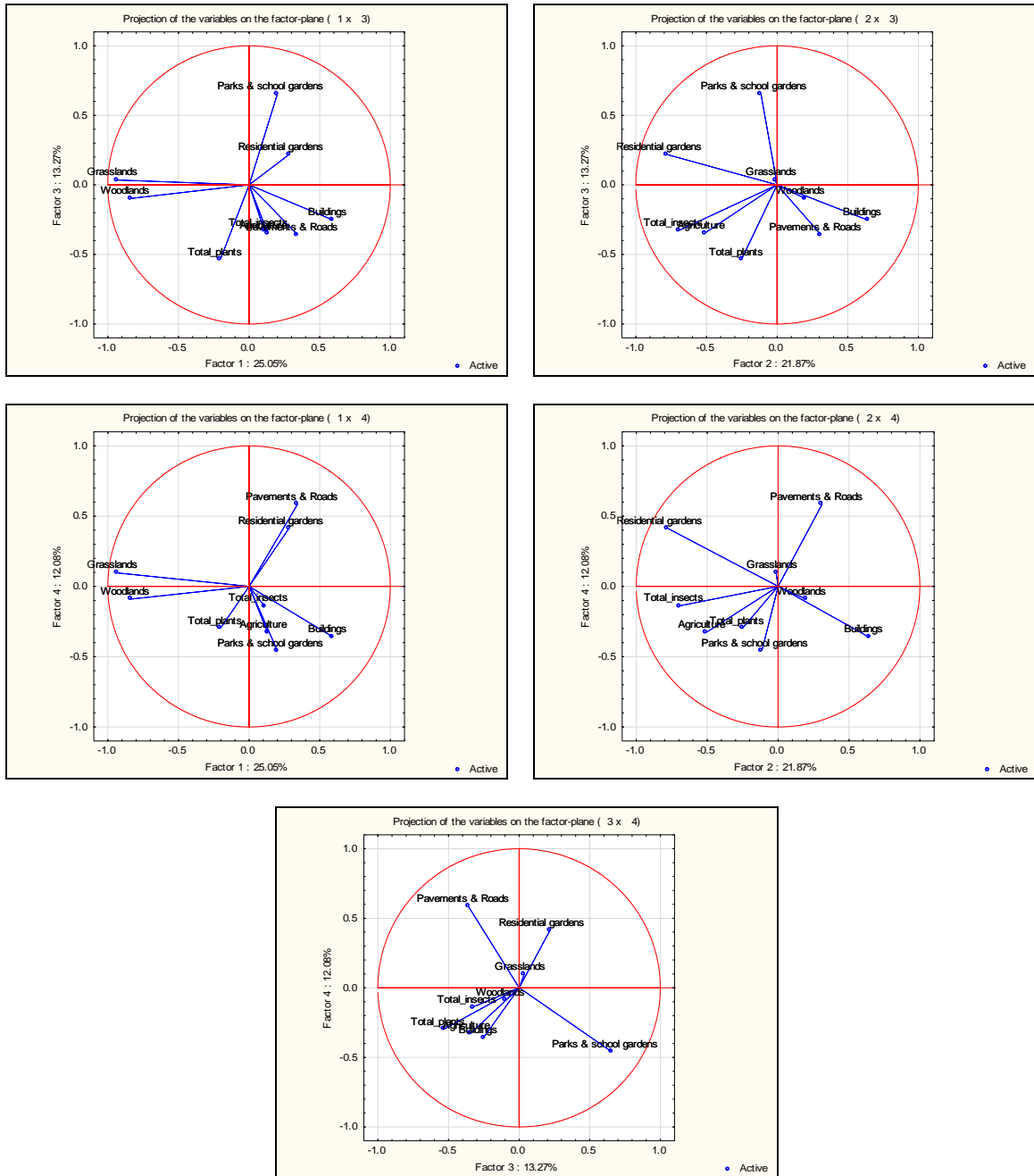
The complete results of the surrounding land-use cover estimations (% cover). See pages 96 to 97.

SES (class)	Buildings	Pavements & roads	Domestic gardens	Parks & school gardens	Grasslands	Woodlands	Agriculture
SES 1	52	18	5	0	22	3	0
	20	18	12	0	48	2	0
	65	10	15	0	0	10	0
	25	10	5	0	52	8	0
	70	20	5	5	0	0	0
	47	12	12	0	25	4	0
	35	20	15	0	30	0	0
	45	15	12	0	20	8	0
	43	12	15	0	28	2	0
SES 2	48	18	5	0	19	10	0
	22	15	7	0	48	8	0
	50	16	8	0	18	8	0
	52	20	8	0	16	4	0
	10	10	5	0	63	12	0
	44	14	15	0	21	6	0
	18	8	4	15	45	10	0
	18	15	11	0	46	10	0
	80	18	2	0	0	0	0
SES 3	53	35	12	0	0	0	0
	63	10	8	19	0	0	0
	80	15	5	0	0	0	0
	80	15	5	0	0	0	0
	80	12	5	3	0	0	0
	75	12	10	3	0	0	0
30	15	8	17	30	0	0	

SES (class)	Buildings	Pavements & roads	Domestic gardens	Parks & school gardens	Grasslands	Woodlands	Agriculture
SES 3	60	14	4	0	18	4	0
	68	18	14	0	0	0	0
	80	12	2	6	0	0	0
	82	16	2	0	0	0	0
SES 4	3	20	55	0	22	0	0
	50	12	23	15	0	0	0
	3	12	35	0	50	0	0
	8	10	70	0	12	0	0
	30	10	42	0	0	0	18
	18	20	42	20	0	0	0
	3	10	5	0	78	4	0
SES 5	25	12	45	18	0	0	0
	30	15	55	0	0	0	0
	40	15	45	0	0	0	0
	35	15	45	5	0	0	0
	35	12	53	0	0	0	0
	30	15	55	0	0	0	0
	25	15	37	0	20	3	0

Appendix H: Statistical analyses factors

The PCA-ordination results of the total number of arthropods, plants and surrounding land-uses that were excluded from Chapter 7 are given below. These include factors 3 and 4 that did not have significant results. Factor 3 associated the total number of plants and arthropods with the percentage cover of agricultural lands. Factor 4 made a division between the percentage parks and school gardens with the percentage of pavements and roads.



The one-way ANOVA results for the two factors (3 & 4) are given below. No statistical significant results were obtained.

