Vegetation dynamics of urban open spaces subjected to different anthropogenic influences.

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ABSTRACT

Urbanisation contributes to the degradation of urban biospheres, and the degeneration of the quality of life for future generations. In the North West Province the urbanisation rate is expected to rise dramatically due to continued drought in rural areas that causes a high poverty rate and low levels of job opportunities. The increasing urbanisation and the need to provide homes for the homeless, place the natural, spontaneous and other vegetation types under extreme pressure.

Conservation of open spaces, especially those with natural and semi-natural vegetation, is constantly in competition with urban development. Little research has been done on vegetation in man-made habitats and therefore, planners and national, provincial and local governments in South Africa are unaware of the true biological and ecological value of urban open spaces.

Biotope mapping for urban areas based on land-use is one method to determine and map those areas worthy to protect. The map of the urban biotopes forms an important background for planning, management and conservation of urban open spaces. The first urban biotope mapping project in South Africa was completed in 2001 in the city of Potchefstroom. A key for urban biotope mapping was developed, based on German experiences, but adapted to South African conditions. Maps were also drawn up to assist in proposed measures for development and conservation and additional general ideas and proposals to create a better environmental situation for Potchefstroom. Decisions on which plant communities and species must be controlled and which must be conserved could, however, only be based on long-term vegetation dynamics studies.

In this thesis, quantitative methods were used to study the vegetation dynamics of certain urban biotopes subjected to different anthropogenic influences. These biotopes include management grasslands, secondary grasslands and a variety of pavements occurring in different land-use areas. Changes in management practices such as the termination of mowing and weeding as well as human impacts such as trampling in areas that haven't

been disturbed for a while, brought about changes in species composition and/or abundance within one year. Changes in species importance values over time can be attributed to changes in management practices, especially in managed and ruderal grasslands. Experimental studies are, however, needed to verify the results. The time span over which this study took place was probably not long enough, although changes did occur within the first year. Seed-bank analyses were also performed on the different biotopes to investigate the real plant diversity, including plants only present as seeds at the time of the survey. The data collected were analysed using multivariate statistics.

UITTREKSEL

'n Toename in verstedeliking, wat kenmerkend is van 'n groeiende menslike bevolking, dra by tot die degradasie van die stedelike biosfeer wat weer 'n verlaging van die lewenskwaliteit van toekomstige generasies tot gevolg kan hê. Daar word verwag dat verstedeliking in die Noordwes-Provinsie drasties gaan toeneem, veral as gevolg van droogte in landelike omgewings wat lei tot armoede en verminderde werksgeleenthede. 'n Tekort aan basiese benodigdhede en dienste is ook 'n rede vir die toename in verstedeliking. 'n Toename in verstedeliking en die behoefte om huise te voorsien plaas egter die natuurlike, spontane en ander plantegroei tipes onder geweldige druk.

Die bewaring van plantegroei in stedelike oop ruimtes is dus in stryd met stedelike ontwikkeling, en daarom is meer inligting nodig oor plantegroei in en om stede. Min navorsing is al gedoen op plantegroei in mensgemaakte habitatte en dus is beplanners en nasionale, provinsiale en plaaslike owerhede onbewus van die werklike biologiese en ekologiese waarde van stedelike oop ruimtes.

Biotoopkartering van stedelike gebiede, gebaseer op grondgebruike, is een metode wat gebruik word om gebiede wat beskerm moet word te identifiseer en te karteer. Die kaart van stedelike biotope vorm die basis van enige beplanning, bestuur en bewaring van stedelike oop ruimtes. Die eerste biotoopkartering wat gedoen is in Suid-Afrika was in 2001 in Potchefstroom. 'n Sleutel vir stedelike biotoopkartering is gebaseer op ondervinding wat in Duitsland opgedoen is maar is aangepas vir Suid-Afrikaanse toestande. Kaarte is ook saamgestel wat kan bydra in die maak van voorstelle vir die ontwikkeling en bewaring van bepaalde gebiede om sodoende beter omgewingstoestande in Potchefstroom te skep. Die keuse om sekere plantgemeenskappe of spesies te beheer en ander te beskerm, kan egter net bepaal word deur langtermyn plantegroeidinamika studies.

In hierdie verhandeling is kwantitatiewe metodes gebruik om die plantegroei dinamika van sekere stedelike biotope wat onderwerp is aan verskillende antropogeniese invloede,

te bestudeer. Hierdie biotope sluit in bestuurde grasvelde, sekondêre grasvelde en 'n verskeidenheid van sypaadjies wat in verskillende grondgebruiksgebiede voorkom. Veranderings in bestuurspraktyke soos die staking van die sny van gras en verwydering van onkruid en menslike impak soos vertrapping het al reeds in die eerste jaar na verandering 'n verandering in spesie samestelling en vollopheid te weeg gebring. Eksperimentele studies sal egter gebruik moet word om hierdie resultate te bevestig. Die tydsduur van hierdie studie was egter nie lank genoeg nie, alhoewel daar al reeds verandering plaasgevind het in die eerste jaar van die studie. Saadbankanalises is ook gedoen van die verskillende biotope om die werklike plantdiversiteit te bepaal, deur plante in te sluit wat as saad in hierdie stadium van die studie teenwoordig was. Die data in hierdie studie is ingesamel en deur middel van meervoudige analitiese tegnieke verwerk.

TABLE OF CONTENTS

CHAPTER 3: Urban biotope mapping based on vegetation studies

CHAPTER 4: Vegetation dynamics in intensively-managed urban areas

CHAPTER 5: Seed-bank Analysis

CHAPTER 6: Final Conclusions

List of References

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

CHAPTER 1

INTRODUCTION

1.1 Background

Increasing urbanisation, which is characteristic of growing human populations contributes to the degradation of urban biospheres, but may also lead to the degeneration of the quality of life for future generations living in these areas (Cilliers, 1998). The proportion of the world's human population living in cities is expected to surpass 60% by the year 2005 (Douglas, 1992). The world's urban population is growing by 2.5 % annually and this means that urban areas are absorbing 61 million more people each year. Cities have long been recognised as the primary human habitat in the presently-"industrialized" countries, the remaining human population is now also rapidly urbanising (Rees, 1997). Next to the sheer growth in human numbers, this mass migration of people to the cities is arguably the most significant human ecological event of the past 100 years, according to McDonnell & Pickett (1990). The increase in urban populations has resulted in the conversion of cropland, pastures, and forests into urban and suburban environments. Urbanisation can be characterised as an increase in human habitation, coupled with increased per capita energy consumption and extensive modification of the landscape, creating a system that does not depend principally on local natural resources to persist (McDonnell & Pickett, 1990).

The mentioned increase in urbanisation rates and its negative impacts are also a reality in South African urban areas. The urbanisation rate in South Africa is regarded as 53.7 %, but according to more recent statistics (Statistics South Africa 2000), the population of South Africa is estimated at 43 million, with a growth rate of 2% per annum. It is further estimated that unemployment is currently at 23.3% and the disparities in distribution of wealth and associated environmental problems are acknowledged (Statistics South Africa 2000). Although the urbanisation rate of some of the provinces, such as the North West

Province is much lower (34,9 % in 1996), rapid urbanisation is expected in this province in future, mainly because continued droughts in rural areas cause a high poverty rate and low level of job opportunities (Coetzee, 1994). Poor access to basic needs and services also drive people to urban areas (Coetzee, 1994) and lead to the degradation of natural ecosystems, which in turn make them less able to support human needs.

Cities are constantly changing, and as a result, land is continuously being recycled. Due to economic stringencies, the recycling is often imperfect and modern cities have, therefore, considerable areas of derelict land. These areas are extremely unattractive and encourage vandalism and illegal rubbish dumping. They also represent a complete waste of land area in situations where open spaces are very deficient. As long ago as 1982, Bradshaw stressed his concern regarding the lack of sufficient treatments of these areas at low cost to provide temporary or permanent open spaces for public use. Inevitably, these open areas do not attract much financial support and therefore any solution should be as inexpensive as possible (Bradshaw, 1982)

Several researchers stressed the importance of urban vegetation and studies thereof to establish a greater acceptance of urban open spaces (Henke & Sukopp, 1986; Vincent & Bergeron, 1985; Woodell, 1997). Woodell (1997) dealt with this issue as follows: "Modern cities are often deserts of brick, stones and concrete; plants can break this monotony...... the more we know about the plants, the better we can help them to do so"
In European urban areas vegetation in man-made habitats has received an increasing amount of attention from researchers over the last twenty years. This is partially because of the growing importance of man-made habitats which are linked to ever-increasing synanthropisation (the totality of changes in plant cover caused directly or indirectly by human activities) of vegetation. Results of research on urban vegetation are useful for urban land management and nature conservation (Henke & Sukopp, 1986). An extreme focus was also placed on investigations of plant species which are able to grow in severely disturbed habitats, the so-called ruderal plant species. Vegetation that establish in a spontaneous manner, reflect the interaction between human impact and natural development and can be used as general indicators of environmental conditions and

ecological processes in the urban environment. According to Vincent & Bergeron (1985) a better understanding of the synecology and the dynamics of the so-called weedy plant communities will enhance better control of the particulary noxious species in urban areas.

1.2 The extent of urban ecology

Urban ecology represents investigations on the biosphere in towns and cities using ecological methods in the same way as other branches of ecology, such as investigations on farm-land, forests or macro-organisms in the sea (Sukopp, 1990). The concept of "urban ecology" is often used in two different ways. According to Sukopp (1990) it may be used in a public political sense for "urban environmental planning", but in this dissertation the focus will be placed on urban ecology as a natural science. Sukopp (1990) also mentioned the importance of indicating the relationship between urban ecology as a science and other aspects such as politics, environmental policy-making and urban development.

In an attempt to prove that urban ecology can be regarded as a science, Trepl (1995) provided a framework or theory for urban ecosytems in setting a number of research questions and hypotheses regarding aspects such as integration, succession and invasion. Some of these hypotheses included the following: urban ecosystems have a low degree of integration, the degree of disintegration correlates with increasing anthropogenic influence, successions in urban biocoenoses are not deterministically directed, they are unpredictable and not repeatable, mainly because of the high degree of invasions and immigrations of plant and animals (Trepl, 1995).

As in the case of the term urban ecology, there are also different views of what the term "urban" implies. Social scientists refer to areas with high human population as "urban", while ecologists use the term more broadly in describing areas under human influence (McIntyre *et al.*, 2000). Forman & Godron (1986) also followed the ecological approach by characterising landscapes along a continuum from pristine, managed, cultivated and suburban to urban - the landscape with the most intense human influence. Trepl (1995) has followed a more detailed analysis by distinguishing between the following five different kinds of urban ecosystems:

1. Typical urban ecosytems such as those that exist in vacant industrial land, and exclude those with a more natural or rural character, for example remnants of grasslands or forests inside cities.
2. All ecosystems within the limits of the city, regardless of whether they are specifically urban or not.
3. Ecosystems with special characteristics due to their location in a city, for example the existence of ruderals in more natural areas.
4. Ecosystems that owe their existence to a complex of factors which are specific to urban environments.
5. Ecosystems that owe their existence to a complex of factors which are specific to industrial environments, even if they are located in the countryside.

McIntyre *et al.* (2000) argued that although there is a need for an unambiguous, quantitative definition of the term "urban", as research in urban ecosystems expands, it is probably not feasible. Firstly, the description of "urban" depends on the research question and secondly, there is often not a clear distinction between the urban environment and the surrounding landscape, but there is often a gradient from rural to suburban to urban areas.

Although the general tendancy in urban ecological studies in South Africa is to regard all biocoenoses within the limits of the city as urban (Cilliers, 1998), the emphasis in this dissertation will be placed on disturbed areas such as parks, pavements and areas of derelict land. To describe and characterise these disturbed areas better within the entire urban fabric, an attempt will be made to initially give an overview of the entire urban area following the biotope approach (chapter 3). The best place to study anthropogenic (synanthropic) communities in urban environments are in those habitats which are not only man-made, but which are subjected to intensive management practises, such as the frequent removal of the plant cover by mowing, weeding or the use of herbicides. Paved areas, pavements in general and the lawns of parks can be regarded as intensively managed sites. Sudnik-Wojcikowska (1986) classified these intensively managed areas under anthropopressure zone V, which can be regarded as the most intensive type of pressure on vegetation. Anthropopressure is defined as the complex of direct and indirect human impact, which causes changes in the vegetation cover, multistage modification system of the factors existing in nature, as well as the introduction of new factors (Sudnik-Wojcikowska, 1986).

1.3. Previous studies on urban vegetation

In European urban areas vegetation has received an increasing amount of attention from researchers (Henke & Sukopp, 1986; Pyšek, 1995). Examples of relevant studies include that of Mandak *et al.* (1993), on the distribution of ruderal vegetation in different urban zones in a small industrial town. Mandak *et al.* (1993) classified twenty plant communities, which are mainly encouraged by various types of disturbances such as building activities and trampling. Most of the studies on urban vegetation in Europe are based on syntaxonomical studies, which include publications of lists of phytosociological units without an assessment of their ecology or dynamics, as well as studies with a more ecological approach (Pyšek, 1995).

In Europe a number of studies were done on intensively managed sites, while very few such studies were done in South Africa before 1998. Müller (1990) made a phytosociological comparison between lawns which are regularly cut short (10-20 times a year) in a number of German Cities, but did not only concentrate on spontaneously-growing plants. Trampled communities, where the effect of human impact is astonishing, are widely studied in Europe, for example the studies of Kopecky (1982) and Mucina & Kolbek (1989). Some of the most important responses to human trampling are soil compaction, reduction in soil organic matter, decrease of vegetation cover, erosion and loss of biodiversity, but low levels of trampling may enhance species diversity, by keeping communities in a dynamic stage (Andersen 1995). Human impact has been recognised as the most important influence on the composition of flora and vegetation in urban environments in Europe (Kowarik 1990).

Studies on urban vegetation often have direct implications on urban nature conservation. The key to nature conservation in urban areas lies in effective and informed planning, and partnerships between local government and people living in the region (Given, 1994). According to Henke & Sukopp (1986), nature conservation in the urban environment must also be elevated to a strategic planning level and it must form part of political thinking. To a certain extent this is already a reality in Europe as was shown by the publication of the "Green Paper on Urban Environment" by the European Community in 1990, which stressed the importance of the conservation of urban nature in general (Sukopp, 1990). In Germany, the Federal Conservation Law (Bundesnaturschutsgesetz) demands that nature is conserved, maintained and developed in populated and unpopulated areas (Starfinger & Sukopp, 1990).

In the evaluation of natural areas for conservation purposes, criteria such as rarity, high biodiversity, large size, naturalness, high productivity, non-recreatibility, historical continuity and representativeness are highlighted as the most important factors (Smith & Theberge, 1986). If only these traditional criteria are used to evaluate areas in the urban environment, conservation will occur exclusively at the urban fringe areas, and the true meaning of nature in cities will not come to its own. Gilbert (1989), therefore stressed the importance of including social factors such as ease of public access, aesthetic appeal, proximity to town center, ability to withstand disturbance and occurrence in areas of local deficiency, in the evaluation of areas for conservation in the built-up environment.

Wittig & Schreiber (1983) proposed a quick method for assessing the importance of open spaces in the city of Düsseldorf for urban nature conservation. This method is based only on vegetation structure and more specific on the simultaneous consideration of scores for four parameters, namely period of development, area, rarity and habitat. This method was tested in the town of Worthing in Sussex and it was found that rarity was not particularly suitable, but other parameters such as typicalness and value as a connecting biotope were added (Spellerberg, 1992). Although this quick method has its advantages as a useful, cost- and time- effective, preliminary method, protection and management of urban habitats need to be based on detailed surveys (Spellerberg, 1992).

The first studies in cities to especially estimate the areas that are important for nature conservation started in Germany in the 1980s and became famous as "biotope mapping" (Müller, 1997). This systematic investigation of biotopes was at first limited to the open landscape and focused on habitats for rare and endangered species (Kaule, 1975). In contrast "biotope mappings of urban areas" are oriented towards special tasks of urban nature conservation as which are to protect or develop nature in cities as a basis for a direct contact between urban dwellers and the natural elements of their surroundings (Sukopp et al. 1980). Biotopes in urban areas are important: as refuges for rare species, dispersal centers and corridors for species; for environmental protection and ecological balance (hydrological cycle, water resources and hygiene, climate, air hygiene, noise protection); for the aesthetic quality of the urban landscape, especially for structuring and enlivening the townscape; for providing low-key recreation opportunities; as informal playgrounds for children; as demonstration and experimental areas for educational purposes; as bioindicators for environmental changes and pollution; for fundamental research into urban ecology (Starfinger & Sukopp, 1990; Müller, 1997). More information on urban biotope mapping will be presented in Chapter 3 of this thesis.

1.4 Studies on urban vegetation in South Africa

Little research has been done on vegetation in man-made habitats such as urban environments, and therefore, planners and national and local goverments are unaware of the true biological and ecological value of urban open spaces (Poynton & Roberts, 1985; Cohen & Hugo, 1986). No information exists on vegetation dynamics under different anthropogenic influences in urban open spaces in South Africa. Roberts & Poynton stated the need for a new approach in planning and management of urban open spaces in South Africa as long ago as 1985. Urban open spaces should not be seen as "left-overs" or 'waste land", but rather as vegetated areas, so that the true biological and ecological importance of these areas can be emphasised (Poyton & Roberts, 1985).

According to Poynton & Roberts (1985) biogeographical guidelines require greater emphasis if urban open space system are to be made ecologically resilient and diverse, and combine a relatively low cost of maintenance with high scientific, educational, aesthetic and recreational value. Taking all urban open spaces into consideration will ensure that an urban open spaces system functions optimally as an ecological unit (Roberts & Poynton, 1985).

The need for the conservation of urban wetlands resulted in the development of programmes such as the Metropolitan Open Space System (MOSS) programme of which the Durban MOSS (D'MOSS) is a prime example. This programme proposed a new holistic approach to city planning, one whereby indigenous plants form an integral part of the urban landscape (Roberts, 1993). Because rivers, streams, pans, marshes, estuaries, and lagoons are critically important to both man and wildlife (Cooper & Duthie, 1992), wetlands within urban areas should form the essential core areas of any MOSS network. The MOSS approach is presently also being implemented in Durban, Pietermaritzburg, East-London, Port Elizabeth, Bloemfontein, the East-Rand, Port Alfred and Empageni. One of the first priorities, before a system such as MOSS can be implemented, is an extensive phytosociological survey of the plant communities within the municipal borders of a city (Roberts, 1993).

Roberts (1993) in a vegetation ecology study of municipal Durban have analysed spontaneous vegetation, but only in the so-called remaining vegetated areas, while landscaped and formally managed areas were excluded from the study. Two of the three landscape types mentioned by Gilbert (1989), namely technological and gardenesque, where quite a number of plant species grow spontaneously, were, therefore, not included in the study of Roberts (1993b). Spontaneous vegetation was, up to now, excluded from urban vegetation studies, which lead to effective planning and management regimes in most urban open spaces in South Africa. The main reason for that is probably because many of these species are regarded as invaders, weeds or problem plants, as described by Wells *et al.* (1986) and Bromilow (1995).

Another reason for the exclusion of spontaneous vegetation in urban vegetation studies, could be the so-called aesthetic conflict (Gilbert, 1989). Spontaneous vegetation has an untidiness about it, which does not fit into the general view of urban open spaces as well as manicured parks (Cohen & Hugo, 1986), by city residents. Low-level management is often mistaken for neglect and these sites are regarded as a disgrace rather than an amenity (Gilbert, 1989). The possibility that a reduction in management costs of urban open spaces may lead to a reduction in municipal rates is not realised by city residents in general.

The realisation of the overall importance of urban vegetation studies has led to the development of a comprehensive research programme on urban open spaces in a number of cities in the North West Province of South Africa. These studies included the hills and ridges and wetlands in Klerksdorp (Van Wyk *et al.*, 1997, 2000) and railway reserve areas, vacant lots, intensively managed sites, wetlands, roadside verges and other natural and semi-natural areas in the Potchefstroom Municipal area (Cilliers & Bredenkamp, 1998, 1999a,b, 2000a,b, Cilliers *et al.* 1998, 1999). Results from studies on railway reserve areas show that ruderal communities bordering railroads all over the world, frequently contain a distinctive flora, because of the permeable and calcareous nature of the substrate which favors a number of species (Whitney, 1985). Whether the communities described in the current study are unique to railways, reserves can only be established once all the other land-use types in the urban environment have been studied (Cilliers & Bredenkamp, 1998). Results on studies done on road verges also showed that much more research is needed on this topic, focussing on the vegetation dynamics of road verges in the Grassland Biome and the careful monitoring of the type and intensity of human impact (Cilliers & Bredenkamp, 1999a). Cilliers and Bredenkamp (1998) also stated that the conservation of spontaneous communities in urban areas, especially in intensively managed areas, is not a priority in South Africa. Long-term monitoring of changes to plant communities in reaction to different types and intensities of specific management practices could form the basis of future management and maintenance programmes of lawns and other intensively managed sites (Cilliers and Bredenkamp, 1998). Decisions on which plant communities must be controlled and which could be conserved can only be based on long-term vegetation dynamics studies (Cilliers and Bredenkamp, 1998).

Information gathered on the different successional stages in the study of vegetation dynamics, will enable city planners, landscape architects and urban ecologists to develop an ecologically-sound planning, management and rehabilitation programme for fragmented and other natural and semi-natural areas in the urban environment (Cilliers and Bredenkamp, 1998). It must be emphasised, that these programmes cannot be based on ecological research alone, but also on the incorporation of sociological aspects, as was clearly indicated by Gilbert (1989). Incorporating human sociology in urban ecological studies is not easy and ecologists have always struggled with the problem of how to deal with humans (McDonnell, 1997). According to Pickett *et al.* (1997a), humans should be seen as important ecological agents whose impacts are included and studied within the conceptual framework of ecology, and their powerful capacities for social and spatial organization and for individual and group learning should also be recognised. To motivate and support research into the patterns and processes of any human-occupied ecosystem, an integrated research approach satisfying both natural and social scientists is needed. Pickett *et al.* (1997a,b) proposed the so-called human ecosystem approach. The human ecosystem model includes many social components and processes in which connections to ecological fluxes, processes and structures exist. The intensity of different direct and indirect human influences in the context that the inhabitants of different cities, towns and suburbs have different needs should be quantified. It is also necessary to encourage public awareness of the importance of natural and semi-natural urban open spaces, in order to promote an integrated and participatory approach in the conservation of these areas (Cilliers *et al.*, 1999).

Ecosystems that have developed in urban conditions may be the prevailing ecosystems of the future (Sukopp *et al.*, 1980). Unfortunately, much of the efforts devoted to studying these ecosystems so far have been concerned with pure phytosociology, repeatedly describing common vegetation types, without any ambition to get deeper under the cover of the issue using, for example, quantitative methods (Sukopp *et al.*, 1980).

1.5 Aims of this study

The studies mentioned so far were done on a phytosociological level. One must remember though that phytosociological studies form an important starting point to any vegetation study, also in urban areas, but the next step is to investigate on a deeper level. To study these ecosystems in depth, it is important to look at it on a vegetation dynamic level. There is no information about vegetation dynamics under different anthropogenic influences in urban open spaces in South Africa. Both phytosociological and dynamics studies done on the vegetation in Potchefstroom will help in the developing of the biotope mapping system for South Africa. Presently there is no biotope mapping done in South Africa. The first biotope-mapping project in South Africa, based on German biotope mapping, started in 2001 and will be finished in 2002. The study area for this mapping is the Potchefstroom municipality area that also includes the areas of this study. Biotope mapping will play a big role in helping with nature conservation and infrastructure planning of cities.

The aims of this study are to answer the following questions:

- **Is it possible to adapt the process of urban biotope mapping for use in South African cities?**
- **Are vegetation dynamics in urban open spaces correlated with specific anthropogenic influences such as mowing and trampling?**
- **Are soil seed banks comparable with above-ground vegetation in areas subjected to different anthropogenic influence?**

1.6 Layout of dissertation

Chapter 2 consists of the description of the study area and materials and methods, where the study area and materials and methods used in the study is discussed in more detail. Chapter 3 is about urban biotope mapping based on vegetation studies. In this chapter, biotope mapping for South African conditions is discussed. Chapter 4 is about vegetation dynamics in intensively managed urban areas. In this chapter we look at the different vegetation dynamics of the different biotopes. In Chapter 5 we look at seed-bank analysis of the different areas in the biotopes descussed in Chapter 4. Chapter 6 is the final conclusions where a short discussion of the results found in Chapters 3, 4 and 5 will be given.

CHAPTER 2

Study area

2.1 Study area

2.1.1 Introduction

The study area is the municipal area of the city of Potchefstroom which is situated between 27°00' and 27°07' longitude and 26°40' and 26°44' latitude (Figure 2.1).

Potchefstroom is regarded as the first settlement north of the Vaal River, which was established as a town. It was founded in 1838 by the Voortrekker leader Andries Hendrik Potgieter on the banks of the Mooi River at a locality 11 km north of the present town. In 1841 a full-scale downstream shifting of the town to its present location took place, for some unknown reason. Potchefstroom largely owes its establishment and situation to the Mooi River, which was once regarded as a "mighty stream", but was reduced to a "tame little stream" by the building of two dams (Potchefstroom Dam and Boskop Dam) at the beginning and the middle of the previous century. Fortunately, it was decided not to turn the Mooi River into a canal, and the river and the riverbanks became increasingly important as a green belt area (Bawcombe & Kuijers, 1988).

Since its inception, Potchefstroom has been an important centre, initially as a church centre and government seat, capital, battlefield and military base and as an economic growth point, during previous centuries. Since 1903 it became an ever-growing educational centre, a well-known and popular sports and recreation centre and an industrial centre since 1930 (Bawcombe & Kuijers, 1988).

With a total population of about 180 000, Potchefstroom consists of the Potchefstroom City (formerly White area), Ikageng (formerly Black area which was established in 1954 as an extension of an area which was established in 1888), a number of informal black housing settlements, Promosa (formerly Coloured area which was established in 1959) and Mohadin (formerly Indian area which was established in 1971) (Prinsloo, 1988).

Potchefsroom City Council joined the Cities for Climate Protection (CCP) Programme of the International Council for Local Environmental Initiatives (ICLEI) in 2001. The CCP Programme is a performance-orientated campaign that offers local governments a framework for developing a strategic agenda and project to reduce its contribution to the greenhouse gas emissions (GHG) that results in global warming. Greenhouse gasses (GHG), such as carbon dioxide, methanenitrous oxide, and ozone are transparent to incoming short wave radiation from the sun, but retain outgoing long wave radiation. This is known as the natural greenhouse effect, which is the phenomenon that keeps the earth's surface warmer than the free space temperature. Researchers predict that the increasing concentration of GHGs will produce changes to the global climate, including changes in surface temperatures as well as changes in precipitation patterns. These changes will lead to delayed effects such as sea level rises and changes in the hydrological and vegetation patterns, as well as in agricultural production patterns. The CCP Programme empowers local governments to reduce greenhouse gas (GHG) emissions (Roopa, 2004).

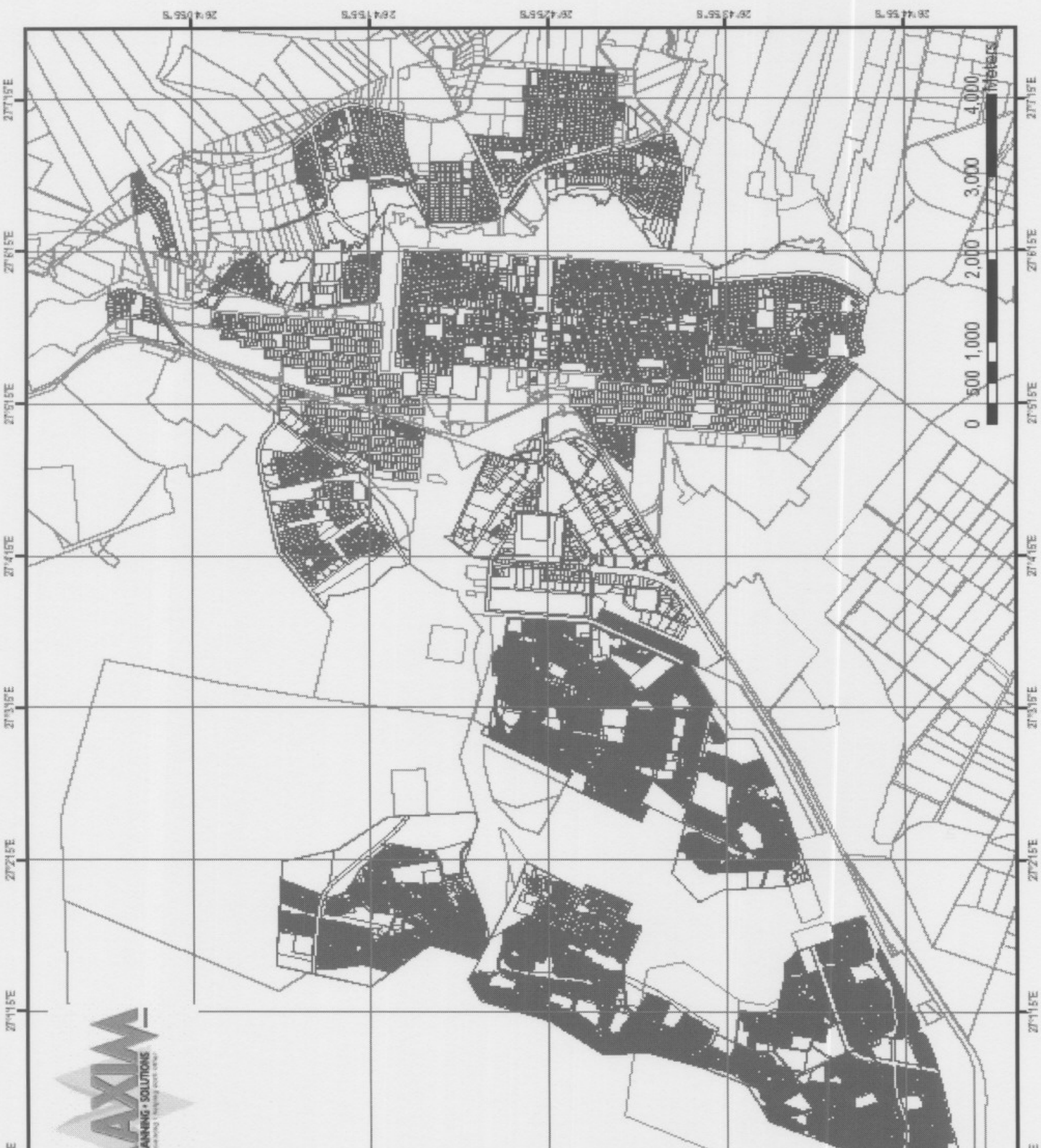

Figure 2.1: The study area is the municipal area of the city of Potchefstroom which is situated between 27°00' and 27°07' longitude and 26°40' and 26°44' latitude.

A number of projects were initiated in Potchefstroom to reduce the city's GHG footprint (Roopa, 2004). The different projects were:

- Recovering methane from the sewage treatment plant.
- Reduction of energy consumption by upgrading of streetlights.
- Retrofitting of the airport runway and taxiway with energy saving light emitters.
- Incorporating energy efficiency guidelines into building plans of new municipal buildings.
- Reducing electricity consumption of all large energy users owned by the City Council.
- A tree-planting project aimed at sequestrating carbon dioxide from the atmosphere.

The city succeeded in achieving its objective to reduce GHG emissions with reduction in excess of 25% when compared to the 2001 base case (Roopa, 2004). Other sustainable projects include:

- Improvements in waste water treatement.
- Sanitary landfilling and closure of insanitary landfill practices.
- Campaigns to keep the city clean.
- Entrepreneurial development in waste buy-back schemes.
- Eco-circles – feeding the poor.
- Caring for the elderly and HIV/Aids support programme.

2.1.2 Geology

The major rock types in the area surrounding Potchefstroom are from the Pretoria Group of the Transvaal Sequence. The Transvaal Sequence fills an east-west elongated basin in the south-central part of Transvaal and includes the corresponding succession in the Potchefstroom synclinorium. The rocks are divided in three groups, namely the Wolkberg, Chuniespoort and Pretoria Groups, based upon lithological differences (SACS, 1980). The Pretoria Group consists mainly of quartzite, shale and prominent volcanic elements in the Hekpoort Andesite Formation, as well as diabase sills which intrude into the Strubenkop shale (Nel *et al.*, 1939; SACS, 1980).

2.1.3 Land type

Potchefstroom is mainly situated in the Bc land type (Bezuidenhout & Bredenkamp, 1991), but the western parts of the city occurred in Fb land type (Bezuidenhout, 1993). In the Bc land type, red, eutrophic soils are wide spread, while the geology is representative of the Pretoria Group with shale, quartzite and the intrusive diabase the most prominent rock type. In the Fb land type, the quartzites and shales of the Pretoria Group give the landscape a mountainous appearance. According to the Köppen classification, it has a Bs-climate that is cool dry steppe with a summer rainfall. Average rainfall is more than 600 mm per annum.

2.1.4 Topography

The study area forms part of the Central Interior Plain and the landscape varies from a flat to an undulating plain (Kruger, 1983). Quartzite ridges sporadically interrupt these undulating plains, because the quartzite is more resistant to erosion than the shales from the plains. Hills also occur occasionally and are usually formed by diabase plates (Barker, 1985).

The undulating plains and ridges are only visible in the more natural areas on the city margin. The original landscape of urban areas has to a great extent been reshaped, filled or cut as a result of urbanisation, and this modification of the topography creates the so-called man-made land as described by Craul (1985). In the residential, business and industrial areas of the city of Potchefstroom, buildings and other structures, which have an important effect on the climate of cities, replaced the original topography.

2.1.5 Climate

South Africa can be divided into 15 climatic zones (Weather Bureau, 1988). Potchefstroom is situated in the Highveld area (H-area) with a precarious, warm, temperate to semi-dry climate in a summer rainfall region. Marked climatic contrasts between summer and winter are common in the area with extremes like droughts, flooding, hail, regular frost and rare snow occuring (Weather Bureau, 1988).

2.1.6 Habitat

According to Daubenmire (1968) and Gauch (1982) the distribution of the plant communities are closely related to environmental conditions. Therefore it is inevitable that certain environmental information, such as rock type (geology), terrain type (topographical position) and soil type as well as soil depth and an estimation of rockiness of soil surface must be kept in mind.

2.1.7 Vegetation

Potchefstroom is situated in the Dry Sandy Highveld Grassland (Bredenkamp & Van Rooyen, 1996) of the Grassland Biome (Rutherford & Westfall, 1994). The Dry Sandy Highveld Grasslands have a very poor conservation status and natural vegetation is only represented by small remnants, which are often degraded as a result of overgrazing (Bredenkamp & Van Rooyen, 1996). In a study of the natural area around Potchefstroom, Louw (1951) described the vegetation of vleis and streams, hills and ridges, grassveld and thornveld. The realisation of the overall importance of urban vegetation studies has lead to the development of a comprehensive research programme on urban open spaces in cities in the North West Province of South Africa (Cilliers, 1998), as described earlier.

2.1.8 Urban biotope mapping

The detailed phytosociological and floristic studies in the city of Potchefstroom (Cilliers, 1998, 1999; Cilliers and Bredenkamp, 1998, 1999a, b, 2000a; Cilliers *et al.*, 1998, 1999) formed a comprehensive basis for testing urban biotope mapping under South African conditions. A representative, comprehensive method of urban biotope mapping, based on the flora and the phytosociological studies mentioned earlier, was followed by Rost (2002) and Röthig (2002) for the city of Potchefstroom. See further information about urban biotope mapping in Chapter 3 of this study.

2.1.9 Urban soils

The soils of the greatest part of the study area (urban soils) are disturbed and transformed in such a way by various human activities that they differ in appearance and properties from the soils which generally occurred in the Bc and Fb land types. Urban soils are usually defined as having a non-agricultural, man-made surface layer of more than 50 cm thick, that has been produced by mixing, filling, or contamination of land surface in urban and suburban areas (Craul, 1985). Other important characteristics of urban soils, according to Steiner (1980), Craul (1985), Gilbert (1989) and Jim (1991) include great vertical and spatial variability, modification of the soil structure (which leads to compaction). Presence of a surface crust on bare soil that tends to be water-repellent, restricted aeration and water drainage, interrupted nutrient cycling and modified soil organism activity, presence of anthropogenic materials which may alter the alkalinity levels of soils as well as other soil contaminants, and modified soil temperature regimes. All of the anthropogenic soils in the study area with some or all of the characteristics mentioned, are classified as the Witbank soil form (Soil Classification Work Group, 1991).

2.1.10 Anthropogenic disturbance

Human impact is sometimes difficult to assess, because the effect of many anthropogenic disturbances closely mimic natural disturbances (Kowarik, 1990). At this stage the type and intensity of human disturbance in synanthropic vegetation in South Africa are not adequately known. For this study, a qualitative description for human disturbances such as mowing, weeding, watering and trampling is used.

2.2 General Materials and Methods

Specific descriptions of the biotopes studied, vegetation sampling, techniques and analyses, including soil sampling and description of anthropogenic disturbances and management practices will be given in Chapter 4. The methods used for the seed-bank analysis will be discussed in Chapter 5.

CHAPTER 3

Urban biotope mapping based on vegetation studies

3.1. Introduction

There is a decrease in natural habitats, due to the fact that the world's cities get bigger in size and the numbers of cities' inhabitants grow rapidly. Another reason for this decrease is the destruction and pollution of the environment, because of increasing industrialisation, mining for resources or sealing of ground for building and other development. All these facts cause a decrease in nature's diversity and will have negative consequences for human needs in future. To achieve an important status of nature in cities, that already exists in some European countries, there must be an essential background, which provides the introduction of specific laws for nature conservation (Cilliers, 1998).

Legislation, which includes conservation of urban areas, is a reality all over the world today. The UN (United Nations) conferences for nature conservation in 1992 in Rio and in 1996 in Istanbul (Habitat II) enforced the efforts on nature conservation in cities (Müller, 1997). At the Rio conference (1992) the advancement of sustainable development of human settlements, focusing on the improvement of the ecological, economical, cultural and social conditions, was confirmed. Bearing in mind the change that took place and will take place in South Africa in future, local management strategies of urban areas could differ markedly from those of European and North American cities (Cilliers, 1998). Hindson (1994) reported that from the decisions at the Global Forum '94, it was clear that the major concerns of countries in the northern hemisphere were over issues such as conservation, biodiversity, energy efficiency and rehabilitation of damaged landscapes. Countries in the southern hemisphere regarded issues such as poverty, equity, redistribution of wealth and wealth creation, as more important (Hindson, 1994).

In Europe, the first projects that focussed on nature conservation in cities became famous as urban biotope mapping (Sukopp *et al.,* 1980; Starfinger & Sukopp, 1990; Müller, 1997). Biotope mapping was initially limited to natural landscapes and focussed only on habitats for rare and endangered species (Kaule, 1975), but it gradually developed towards the protection and establishment of nature in cities as a basis for the direct contact between urban dwellers and natural elements (Sukopp *et al.,* 1980; Starfinger & Sukopp, 1990). The first biotope mappings in urban areas were conducted in Berlin (Sukopp *et al.*, 1980), Augsburg (Bichlmeier *et al.*, 1980, Müller & Waldert, 1981) and Munich (Brunner *et al.*, 1979). As of today biotope mappings are being done in 175 German cities (Sukopp, 1990).

The results of these studies were quickly recognised as basic information for nature conservation and infrastructure planning in cities. In 1978 a working group for biotope mapping in urban areas was established in Germany with the main aim to exchange experiences about the methods and results of biotope mapping as well as its application in ecological city planning. The group published recommendations for a basic programme for biotope mapping in urban areas (Arbeitsgruppe "Methodik der Biotopkartierung im Besiedelten Bereich", 1993) and a bibliography of research on nature conservation in urban areas (Sukopp, 1990). They found their application in programmes like "Program of protecting the species and biotopes of Berlin (Arbeitsgruppe Artenschutzprogramm" Berlin, 1984), and plans e.g. "Landuse and Landscape Plan Augsburg" (Müller, 1990) as well as in the daily practice of management of green spaces. The results also formed the basis for "ecological city planning" in many European cities, especially in Germany (Müller, 1997).

Although urban biotope mapping was first done in Germany, several similar projects have been completed in other countries such as Japan (Müller, 1997), Brazil (Weber & Bede, 1998) and Sweden (Lövfenhaft *et al.,* 2002). Urban biotopes are important as refuges, dispersal centres and corridors for species; for environmental protection and ecological balance (hydrological cycle, water resources and hygiene, climate, air hygiene, noise protection); for the aesthetic quality of the urban landscape; as areas for low-key recreation opportunities; as informal playgrounds for children; as demonstrational and experimental areas for educational purposes; as bio-indicators of environmental changes and pollution; and for fundamental research into urban ecology (Starfinger & Sukopp, 1990; Müller, 1997). In general, biotope mapping is focused on floristic and phytosociological features, as plant studies are relatively easy compared to animal studies (Sukopp & Weiler, 1988).

Efforts were also made in South Africa to incorporate environmental issues in the form of legislation aimed upon urban areas. The Reconstruction and Development Programme (RDP) of the Government of South Africa (African National Congress, 1994) stressed that sustainable urbanisation must be part of the process of post apartheid-reconstruction. The Development Facilitation Act (Act 67 of 1995) introduced extraordinary measures to facilitate and speed up the implementation of reconstruction and development programmes in relation to land; and in so doing to lay down general principles governing land development thoughout the country (South Africa, 1995). From a planning point of view, legislation was passed in the Environmental Conservation Act (Act 73 of 1989), whereby the environmental impact had to be determined before new urban development could take place, especially with regard to public and private parks (South Africa, 1989). Recently, land use management has become an essential part of Integrated Development Planning (IDP), a strategic management process that is formulated on the local and district government levels in the form of the Municipal System Act (Act 32 of 2000) (South Africa, 2000). The main departure point in these legislative issues is to curb urban sprawl and encourage sustainable development within the urban sphere (South Africa, 2000). What is, however, distressing about all these issues is the lack of detail with respect to specific urban nature conservation principles in the planning and management process of urban areas, mainly because of a lack of ecological information and environmental awareness, especially on aspects such as biodiversity and ecological interactions and fluxes (Cilliers *et al.*, 2004).

In South Africa the important role of nature in urban settlements and its establishment through special laws for conservation is not realised by the government, to the same extent as for example in Germany. There has, however, recently been a growing awareness among planners and the public to conserve and develop natural areas in the cities. But there still is a great lack in policy, which does not see a need in protecting natural areas inside built-up areas (Low, 1995). Although the urban environment is mentioned in the General Environmental Policy (1994) compiled by the Department of Environmental Affairs, urban open spaces are not included in those areas that must be conserved. According to Cilliers *et al.* (2004) another problem regarding conservation-orientated planning and management is that provincial governments and municipal authorities in South Africa lack the ecological expertise to apply the legislation, mainly due to the fact that ecological information is not in an understandable format. Urban biotope mapping could be the answer to this in that it can be used to identify areas worthy of protection.

The aim of this chapter is to give a more detailed summary of some of the vegetation studies (Cilliers, 1998) and applications of these studies in the form of urban biotope mapping (Rost, 2002; Röthig, 2002) of the Potchefstroom Municipal Area. This information will give a good background of the biotopes, plant communities and specific species that can be found in intensively-managed areas of Potchefstroom.

3.2. Biotope Mapping in South Africa

The first urban biotope mapping done in South Africa was in 2000 – 2001 by Röthig and Rost, German exchange-students who mapped the city of Potchefstroom. I've contributed in this project through the development of a biotope mapping key and the collection of data. The mapping method is described as a comprehensive-representative method. With the aid of aerial photographs and an already existing "Land-use Control Map", potential naturally rich areas were determined and verified in the field by using the selective method. With the aid of these aerial photos a comprehensive view of the land-use and biotope types could be obtained. The method is also representative because examples of each biotope type is selected and studied in the field. Several maps were drawn up showing the different biotopes in and around the city of Potchefstroom (Rost, 2002; Röthig, 2002). This project forms part of an "Urban and settlement ecology programme" of the University of Potchefstroom, which is about the "Natural and social processes in sustainable urban environments". The whole programme lasted six years and the biotope mapping of Potchefstroom is a prerequisite work for the first part of the programme, the initial and descriptive phase.

The decisive difference in general between the methods of South Africa and Germany, is that in Germany, there is an official law for protecting nature in urban areas as well as in the open landscape. In Germany the role of nature in laws and structures of cities has a long history, which started in the 19th century. In South Africa this progress will need time and understanding from the public society.

3.2.1 Adaptation to South African conditions

The South African mapping key for urban biotope mapping is a simplified version oriented on the structure of German mapping key examples but based on experience of South African Cities. As mentioned earlier, this key was developed by myself in cooperation with Prof. Sarel Cilliers, Prof. Norbert Müller and Britta Hackenberg in January 2001. It was only developed for the city of Potchefstroom and contains all the existing biotope types (Table 3.1). It was especially established for urban biotope mapping structures with at least 3 numbers indicating the main, specific and detailed biotope types, for example:

-2. Biotopes of residential areas

-2.1. Block of flats

-2.1.1. Closed (...)

The key contains the 13 main biotope types with subdivisions (specific and detailed biotope types) and the main biotope types were also indicated on the map of the Potchefstroom Municipal Area (Figure 3.1). The main difference between this mapping key and those in Germany is the variety of biotope types. More detail is included in the key used in Germany, for example different types of cemeteries, hedges or city walls. This mapping key for Potchefstroom (Table 3.1) is just the start of general urban biotope mapping for South Africa's cities and must be developed in more detail in future, to include even smaller biotopes structures.

Table 3.1: Mapping key for biotope types based on land-use and vegetation types developed for the Potchefstroom Municipal Area.

Major biotope types	Specific biotope types	Further detail
1. Central city (commercial/ residential)		
2. Residential areas	2.1 Blocks of flats	2.1.1 Closed (no/small gardens, 70 –100 % sealed) 2.1.2 Open (larger gardens, < 60 % sealed)
	2.2 Townhouses (> one unit per plot, one small garden per unit)	
	2.3 Large single houses, park-like gardens (trees, shrubs, lawns, flowerbeds)	2.3.1 Large gardens, < 30 % sealed 2.3.2 Small gardens, 30-50 % sealed
	2.4 Small single houses, basic services, small gardens (few trees, shrubs, small lawns)	2.4.1 Sealed areas < 50 % 2.4.2 Sealed areas > 50 %
	2.5 Small single houses, reduced basic services (water, sewage), gardens small/absent	2.5.1 Permanent houses with electricity 2.5.2 Temporary houses without electricity
3. Commercial areas	3.1 Predominantly-sealed surfaces (> 70 %)	

	3.2 Lesser-sealed surfaces (< 70 %), with intensively managed green spaces	
	3.3 Lesser-sealed surfaces (< 70 %), with extensively managed green spaces, including small wastegrounds	
4. Industrial areas	4.1 Predominantly-sealed surfaces (> 70 %)	
	4.2 Lesser-sealed surfaces (< 70 %), with intensively managed green spaces	
	4.3 Lesser-sealed surfaces (< 70 %), with extensively managed or unmanaged green spaces, including small wastegrounds	
5. Managed green spaces	5.1 Intensively-managed public parks (mowing > 10x per year)	5.1.1 For passive recreation 5.1.2 For active recreation (with playing apparatus, trim park)
	5.2 Extensively-managed public parks (mowing usually 3-4 x per year)	5.2.1 For passive recreation 5.2.2 For active recreation (with playing apparatus, trim park)
	5.3 Private park-like open spaces (gardens of University, College, Agricultural College)	
	5.4 Sports fields and grounds	5.4.1 Predominantly-sealed surfaces (> ca. 70 %) (tennis courts, athletic and hockey field with synthetic surfaces) 5.4.2 Lesser sealed surfaces

		(< ca. 70 %) (cricket, rugby, soccer fields) 5.4.3 Informal sports fields (mainly soccer, basketball, netball) on bare ground
	5.5 Cemeteries	
	5.6 Camping sites	
	5.7 Botanical garden	
6. Man-made waterbodies	6.1 Lake (dam)	
	6.2 Ponds	
	6.3 Channels	
7. Traffic areas	7.1 Railway areas	7.1.1 Outside stations 7.1.2 Stations
	7.2 Roads	7.2.1 Main roads/highways with green verges (including traffic circles and islands) 7.2.2 Local roads with street trees 7.2.3 Local roads without green verges 7.2.4 Unsealed local roads (dirt roads) 7.2.5 Parking areas 7.2.6 Trails (foot paths)
	7.3 Airstrip and hangars	
8. Agricultural areas	8.1 Crop fields	
	8.2 Sown pastures	
	8.3 Vegetable gardens	

9. Plantations	9.1 *Eucalyptus* dominated plantations	
	9.2 Others	
10. Natural and semi-natural areas (usually not mown)	10.1 Wetlands	10.1.1 Rivers 10.1.2 Streams 10.1.3 Marshes and vleis 10.1.4 Channelised rivers and streams
	10.2 Grasslands (less than 10 % woody species)	10.2.1 Sandy grasslands 10.2.2 Rocky grasslands 10.2.3 Clayey grasslands
	10.3 Woodlands	10.2.1 Dominated by trees 10.2.2 Dominated by shrubs
11. Disposal sites and ditches	11.1 Household disposal and building rubble sites	
	11.2 Industrial disposal sites	
	11.3 Gravel ditches	
12. Waste-grounds	12.1 Annual and biennial communities	
	12.2 Perennial communities	
13. Special land-use types	13.1 Military areas	
	13.2 Schools (ornamental gardens and sports fields)	

Figure 3.1: Biotope map of the Potchefstroom Municipal Area indicating the 13 main biotope types (numbers refer to the different biotope types as indicated in Table 3.1)

3.2.2 Results of biotope mapping

From the different biotope types that were identified in Potchefstroom, the following biotopes need to be looked at in this study, as they are associated with extensive anthropogenic influences:

5. Biotopes of managed green spaces
   - 5.1. Intensively-managed public parks (mowing >10x per year)
     - 5.1.1. For passive recreation (sitting)
   - 5.2. Extensively-managed public parks (mowing < 10x per year, usually 3-4x)
     - 5.2.1. For passive recreation (sitting)
   - 5.3. Private park-like open spaces (gardens of University, Colleges).
   - 5.7. Botanical garden
7. Traffic areas
   - 7.2 Roads
     - 7.2.1 Main roads/ highways with green verges
     - 7.2.2 Local roads with street trees
     - 7.2.3 Local roads without green verges
     - 7.2.4 Unsealed local roads
     - 7.2.6 Trails (foot paths)

These two major biotope types with their subdivisions contain the study areas for this study and it is useful to compare the results of the biotopes described by Rost (2002) and Röthig (2002) to the species found in the study done by Cilliers (1998). This will give a good background about the species composition and community structure of the urban open spaces subjected to heavy anthropogenic disturbances that can be used in vegetation dynamics studies.

Here follows the description by Rost (2002) and Röthig (2002) of the biotopes- and land use types for the two biotopes mentioned:

Biotopes of managed green spaces (5.):

- **Intensively-managed public parks (5.1)**: Often include intensively managed public lawns, which are mown more than ten times a year. Several planted trees and bushes, sometimes-ornamental flowerbeds, can be found on these areas. It has to be distinguished between intensively managed public parks for **passive recreation** (5.1.1.) (like sitting) and **active recreation** (5.1.2.) (like playing apparatus, trim park, golf course). Dominating species are the exotic herbaceous plants: *Plantago lanceolata, Conyza bonariensis, Oxalis corniculata, Solanum elaegnifolium* (declared weed), *Dichondra repens, Medicago polymorpha, Verbena tenuisecta, Pennisetum clandestinum* and the indigenous plants *Falckia oblonga* and *Cynodon dactylon.*
- **Extensively-managed public parks (5.2.)**: Areas that are mown in general three to four times a year. Typical for these biotopes is a higher diversity in species, compared with the intensively managed areas. The grass can grow quite high before it will be mown, so a relatively natural character is achieved. Many species find shelter here from the harsh city environment. These biotopes are further divided into **passive recreation (5.2.1.)** (like sitting) and **active recreation areas (5.2.2.)** (with playing apparatus for children). Dominated species are the indigenous species *Cynodon dactylon, Ledèbouria revoluta, Themeda triandra, Falckia oblonga, Sporobulus africana, Gazania krebsiana* and the exotic forb *Conyza bonariensis.*
- **Private park-like open spaces (5.3)**: These open spaces are private properties with a more or less managed character, are often fenced and entrance for the general public is difficult (like gardens of the University, Colleges). Dominant species are mainly exotics such as *Dichondra repens, Solanum elaeagnifolium* (declared weed), *Pennisetum clandestinum* and *Medicago polymorpha*
- **Botanical gardens (5.7.):** The botanical garden belongs to the University of Potchefstroom and is located to the north of the Campus. Typical for this area is a high number of species, green houses for peri phyton of species and a mixture of managed and natural plots. The botanical garden has extensively managed areas and a high number of indigenous plant species typical of the

North West Province. Although detailed vegetation studies were not done for these managed grasslands, they were included in the vegetation dynamics, mostly due to the ease of which management could be manipulated without direct public interference.

Biotopes of traffic areas (7.): Includes all areas characterised by different kinds of traffic use and traffic rates.

- **Railway areas (7.1):** This includes the area of the **railway station (7.1.1)** with its gardening structure and ruderal vegetation and the natural-/semi natural biotopes along **the railways (7.1.2.)**. The railways with their quite natural vegetation slopes have an important role as a network of ruderal vegetation biotopes through the city and should be extensively managed. Dominant species along the railway lines are the exotic herbaceous species *Tagetes minuta, Conyza bonariensis, Argemone ochroleuca* (declared weed), *Plantago lanceolata, Physalis viscosa, Verbena bonariensis, Modiola caroliniana,* and the indigenous herbaceous species *Conyza podocephala* and *Lactuca capensis.*
- **Roads** (7.2): This describes all different kinds of **roads** (7.2.1.- 7.2.3.) even **unsealed roads** (7.2.4.) including **parking areas** (7.2.5.) and **trails** (7.2.6.). Due to the fact that roads can form small networks of biotopes through the city, it must be clearly distinguished between roads with vegetation structures (main roads with green verges and local roads with street trees) and mainly sealed roads (local roads without green verges). Main roads have old trees on the verges, for example, Tom Street, which is characterised by old *Quercus robur* trees along the sides and main roads with wide green verges. Unsealed local roads are also very important, because they are situated mainly at the city's margin and often have a high number of species along their verges. Parking areas can be very different and the species richness depends on the level of the sealed surface. The highest number of species will occur in the biotope of the trails, because of the low human influence. Trails are not very wide in size and are mostly unsealed. The number in species depends on the

number of people walking every day through this biotope type. Dominant species of local roads / main roads with green verges and dirt roads are the indigenous species *Cynodon dactylon, Lactuca capensis* and *Celtis Africana. Ulmus parvifolia, Populus canescens, Plantago lanceolata, Verbena officinalis* and *Verbena tenuisecta* are exotic plants. Dominant species of unsealed parking areas are indigenous species such as *Conyza bonariensis, Alternanthera pungens, Malvastrum coromandelianum, Dichondra repens* and different *Pinus* species. Dominant species of trails are indigenous plants such as *Lactuca capensis* and *Hibiscus pusillus* and exotic forbs such as *Conyza bonariensis*. Dominant species of the mainly sealed biotope types like sealed parking areas and local roads without green verges were not found.

All the information gathered in the biotope studies were used by Rost (2002) and Röthig (2002) to determine the worthiness of the specific biotope type for conservation purposes (Table 3.2). Although this was based on studies in Germany, most of the specific evaluation criteria and their different levels (Table 3.2) were chosen for South African conditions based on previous studies, according to Cilliers *et al.* (2004). Each representative area received a score based on the evaluation criteria (Table 3.2) and was classified as an area with very high, high, moderate or low ecological values (Rost, 2002; Röthig, 2002) and was indicated on a map (Figure 3.2). All the stydy areas included in this thesis were, however, regarded as areas with moderate to low ecological value.

Table 3.2: Key for evaluation of specific biotope types regarded as worthy of protection in selected cities in the North West Province, South Africa (Rost 2002; Röthig 2002).

EVALUATION CRITERIA		1	2	3	4
Species richness (plant species)	(x1)	< 60	61-80	81-100	>100
Area (m^2)	(x1)	100-200	200-500	500-1000	>1000
Sealed area (%)	(x1)	100-75	75-50	50-25	<25
Networking of biotopes	(x1)	None/ isolated	Few	Moderate	High
***Protected Plant Species "Red List"* (Hilton-Taylor, 1996)**	(x1)	None	Insufficiently known + no longer threatened	Rare + Indeter-minate	Endangered + vulnerable
Plant structural diversity	(x1)	1 Level	2 Levels	3 levels	Mosaic
Age	(x1)	0-2	2-10	10-50	>50

Estimated expenses to restore this biotope type	(x2)	Low	Average	High	Not restorable
Indigenous Plants **(Arnold & de Wet, 1993)**	(x3)	0-10	10-30	30-50	>50
Declared Weeds and Invaders **(Henderson, 2001)**	(x1)	>10	2-10	0-2	0

Sum of worthiness

13 - 22	Points	Low ecological value
23 - 32	Points	Moderate ecological value
33 - 42	Points	High ecological value
43 - 52	Points	Very high ecological value

Figure 3.2: Map indicating the ecological value of the different biotopes in the Potchefstroom Municipal Area based on the criteria mentioned in Table 3.2.

3.3. Phytosociological studies of Potchefstroom

It is also important to compare the results of the study done by Rost (2002) and Röthig (2002), on species level, to the phytosociological results of Cilliers done earlier in 1998, on community level. The study by Cilliers (1998) included analyses of the spontaneous vegetation of intensively managed urban open spaces in the Potchefstroom municipal area (Cilliers & Bredenkamp, 1999). The investigation was performed on pavements and paved areas, as well as on lawns of twelve intensively managed parks and a number of other lawns in urban Potchefstroom. The TURBOVEG programme (Hennekens, 1996a) and the TWINSPAN classification algorithm (Hill, 1979a) were used for the input, processing, and presentation of phytosociological data, and subsequently Braun-Blanquet procedures were implemented to refine the results. An ordination algorithm, DECORANA (Hill, 1979b) was also applied to the floristic data to determine possible gradients in vegetation.

From the classification, in the study of intensively managed urban open spaces (Cilliers & Bredenkamp, 1999a) the following communities could be recognised:

1 *Chamaesyce prostrata* Community
2 *Guilleminea densa – Cynodon dactylon* Community
  2.1 *Alternanthera pungens – Guilleminea densa* -Sub-community
    2.1.1 *Eragrostis lehmanniana* Variant
    2.1.2 *Tribulus terrestris* Variant
  2.2 *Paspalum dilatatum* Sub-community
3 *Amaranthus hybridus – Cynodon dactylon* Community
4 *Chamaesyce hirta – Cynodon dactylon* Community
5 *Plantago lanceolata – Cynodon dactylon* Community
6 *Chloris virgata* Community
7 *Hermania depressa – Ledebouria revoluta* Community
8 *Taraxacum officinale – Medicago lupulina* Community
  8.1 *Trifolium repens* Sub-community

8.2 *Ciclospermum leptophyllum* Sub-community

9 *Capsella bursa-pastoris* Community

10 *Sisymbrium orientale* Community

A brief summary of each of the plant communities will be given:

1. *Chamaesyce prostrata* Community

The *Chamaesyce prostrata* Community is situated between paving stones on pavements and in parking areas in full sun or semi-shade, and also in cracks in paving on the northern sides of buildings. This community only consists of an herbaceous stratum of mainly sprawling, annual forbs such as the dominant species, *Chamaesyce prostrata.*

2. *Guilleminea densa – Cynodon dactylon* Community

This community is typically found on pavements, which are not covered by any paving stones or slabs, but with moderately to very heavily-compacted soil due to trampling. The soil of this community is skeletal and belongs to the anthropogenous soil type, Witbank (Soil Classification Work Group, 1991), like most of the soil in the intensively managed areas. The amount of surface gravel varies between the different relevés. The plant cover on the pavements where these communities can be found, is mown quite frequently and sometimes weeding takes place. The specific use as well as the type and frequency of maintenance also lead to the establishment of mainly sprawling, annual forbs, like in the *Chamaesyce prostrata* Community (1.) on paved areas, but different species are dominant. The dominant species, *Guilleminea densa* and other species such as *Cynodon dactylon, Alternanthera pungens, Gomphrena celosiodes* and *Medicago laciniata* are all sprawling forbs. Although this is already a highly-invasive community of trampled lawns, it also invades adjacent spontaneous communities such as the *Chamaesyce prostrata* Community on paved areas and the *Chamaesyce hirta – Cynodon dactylon* Community in parks.

2.1. *Alternanthera pungens – Guilleminea densa* Sub-community

This sub-community of the *Guilleminea densa – Cynodon dactylon* Community is situated on pavements where no walking area of paved slabs exists, and sometimes occurs in drive-ways in residential areas. Heavy trampling of the vegetation cover takes place, which may result in the development of bare patches that are not suitable for the establishment of any vegetation, because of the high degree of compaction. The dominant species are *Guilleminea densa, Cynodon dactylon* and *Alternanthera pungens.*

Two variants can be distinguished in the *Alternanthera pungens – Guilleminea densa* Sub-community on the basis of species composition.

2.1.1. *Eragrostis lehmaniana* Variant

Although no diagnostic species occur for this variant, it is characterised by the relatively high cover of the indigenous grass *Eragrostis lehmanniana* that are typical of disturbed areas in South Africa (Van Oudtshoorn, 1991).

2.1.2. *Tribulus terrestris* Variant

This variant can be distinguished from the *Eragrostis lehmanniana* Variant with respect to the absence of the species and the presence of the diagnostic species, *Tribulus terrestris,* which is an indigenous sprawling forb.

2.2.*Paspalum dilatatum* Sub-community

The *Paspalum dilatatum* Sub-community is also situated on pavements, but usually next to a walking area of paved slabs in wetter areas. In some cases the sub-community invades *Pennisetum clandestinum* lawns, which are planted by some home owners on pavements. The opposite scenario, where *Pennisetum clandestinum* from these lawns invade into the *Paspalum dilatatum* Sub-community, is also evident. Although moderate trampling of vegetation does exist, it is never as heavy as in the *Alternanthera pungens – Guilleminea densa* Community. Moderate trampling intensities and the availability of water in some cases (irrigation points are present) resulted in the development of a distinct community with an herbaceous cover of close to 100% in some areas.

3. *Amaranthus hybridus – Cynodon dactylon* Community

This is a rare community, which develops only occasionally on gravel areas in parking areas and on entrance roads to businesses in the industrial area. Heavy trampling occurs, but total removal of the plant (weeding) does not really take place, probably because amenity (aesthetics) does not have very high priority in these areas. Spontaneously-growing vegetation is usually removed in urban areas as they are not aesthetically acceptable, as Gillbert (1989) pointed out in this discussion on the aesthetic conflict in urban areas.

4. *Chamaesyce hirta – Cynodon dactylon* Community

The *Chamaesyce hirta – Cynodon dactylon* Community is mainly visible in summer in full sun or semi-shade on *Pennisetum clandestinum* lawns in intensively managed parks and gardens troughout Potchefstroom. Although no to light trampling occurs in this community it shows an affinity with two of the trampled communities, because of the co-existence of species like *Cynodon dactylon*, *Alternanthera pungens* and *Gomphrena celosioides*.

5. *Plantago lanceolata – Cynodon dactylon* Community

Although the introduced forb *Plantago lanceolata* is present in most of the other communities described here, it forms very small but distinct communities in wet places, together with *Cynodon dactylon* on pavements and in parks.

6. *Chloris virgata* Community

The *Chloris virgata* community is developing on a part of fragmented natural grassland, which was converted into a children's playground. A lawn of *Pennisetum clandestinum* was planted, but the grass *Chloris virgata* and quite a number of other forbs, because of heavy trampling, invaded it.

7. *Hermannia depressa – Ledebouria revoluta* Community

This community occurs on small pieces of fragmented natural grasslands, which are managed in exactly the same way as any formal park in Potchefstroom, for example frequent mowing. These parks are situated in densely-populated residential areas and are characterised by networks of foot-paths, traversing the whole area. The soils of these paths are so compacted that no distinct ruderal community can be established there. On the edge of these parks, invasion of the adjacent *Guilleminea densa – Cynodon dactylon* Community from the pavement takes place.

8. *Taraxacum officinale – Medicago lupulina* Community

The leguminous annual, *Medicago lupulina* totally dominates this community in most cases. Other species that occur are those of species which include the indigenous annual grass *Digitaria ternata* and the introduced perennial forb *Taraxacum officinale.*

Although occurring throughout the year, the *Taraxacum officinale – Medicago lupulina* Community is much better developed during the winter months on *Pennisetum clandestinum* lawns in parks, in either full sun or semi-shade. It is very conspicuous during these months forming large lush-green on the dull-looking frost-bitten lawns.

This community can be divided into two sub-communities on the basis of species composition and persistence during the summer months:

8.1 *Trifolium repens* Sub-community

In this sub-community of the *Taraxacum officinale – Medicago lupulina* Community, another leguminous annual, *Trifolium repens* colonises bare patches on the *Pennisetum clandestinum* lawns. The cover of *Medicago lupulina* is, therefore, much lower. The *Trifolium repens* Sub-community tends to form smaller patches than the *Ciclospermum leptophyllum* Sub-community, but is also conspicuous during the summer as well and is only overgrown by *Pennisetum clandestinum* when frequent mowing takes place.

8.2 Ciclospermum leptophyllum Sub-community

The *Ciclospermum leptophyllum* Sub-community is the most conspicuous during the winter months and tends to disappear during summer when it is overgrown by the *Pennisetum clandestinum* lawn.

9. *Capsella bursa-pastoris* Community

The *Capsella bursa-pastoris* Community developed mainly during winter in shady areas under trees and near buildings in parks, and in cracks on pavements where no heavy trampling occurs. This is a good example of a community that established due to a lack of maintenance during the winter months.

10. *Sisymbrium orientale* Community

This is a short-lived community, occupying cracks in pavements in winter. The dominant and only diagnostic species is *Sisymbrium orientale.*

3.4 Conclusions

To be able to evaluate the species it is important to know more about the dynamics of the species and what kinds of species are situated in the city areas of Potchefstroom. The phytosociological studie done by Cilliers and Bredenkamp (1999) help to give us an idea of the species found under certain anthropogenic conditions. Due to the high frequency of specific maintenance practices in the studied areas, species numbers are lower than in other disturbed areas in Potchefstroom. A total of 100 species of which 46% were introduced were recorded in intensively managed sites in comparison to 253 species (26% introduced) on roadside verges (Cilliers & Bredenkamp, 2000a), 171 species (38% introduced) on vacant lots (Cilliers & Bredenkamp, 1999) and 168 species (35% introduced) in railway reserves (Cilliers & Bredenkamp, 1998). Many communities such as the *Guilleminea densa-Cynodon dactylon* Community, the *Chamaesyce hirta-Cynodon dactylon* Community and the *Taraxacum officinale-Medicago lupulina* Community are, however, regarded as invasive as they establish on lawns in parks and private gardens. Lawns in South Africa are traditionally managed as monocultures. Gilbert (1989) distinguished between technological, gardenesque and ecological landscapes, each of which should have a place in the urban environment. The presence of all the different landscape types will provide various habitats for the establishment of different plant communities, which will lead to higher species diversity resulting in a more stable urban ecosystem (Gilbert 1989). Gibert (1989) acknowledges, however, that spontaneous communities in cities and towns are regarded as unacceptable, because city residents often mistake low-level management for neglect. This is called the aesthetic conflict by Gilbert (1989). Conservation of the spontaneous communities does not necessarily mean any changes to current maintenance practices, because these practices have resulted in the development of certain unique communities. Although it is not a priority in South Africa, conservation of spontaneous communities, especially in intensively managed areas need to be looked at. Therefore the study done by Cilliers & Bredenkamp (1999a) formed the basis for vegetation dynamics studies. To form a basis for future management and maintenance programmes of lawns and other intensively managed sites, one must look at the long-term monitoring of changes to plant communities in reaction to different types and intensities of specific management practices. Decisions on which plant communities must be controlled and which must be conserved can only be based on long-term vegetation dynamics studies (Cilliers & Bredenkamp, 1999a).

CHAPTER 4

Vegetation dynamics in intensively managed urban areas

4.1 Introduction

In recent years, urban vegetation (including ruderals) has been the subject of many studies (Sukopp, 1990; Miller, 1988; Trepl, 1995; Pickett, 1997; Lyons, 1997; Müller, 1997). Interest in urban vegetation is partially due to the growing importance of man-made habitats, which are linked to the ever-increasing synanthropisation of vegetation. The best place to study anthropogenic communities in urban environments are in those habitats which are not only man made, but which are subjected to intensive management practices, such as the frequent removal of plant cover by mowing, weeding or the use of herbicides. In Potchefstroom, the paved areas in general and the lawns of parks, can be regarded as intensively managed sites (Cilliers & Bredenkamp, 1999a).

Urban areas are characterised by a high level of disturbance and environmental modification, thus knowledge of vegetation dynamics is important for an understanding of the ecology of urban areas (Gilbert, 1989). Results of research in this field are useful for urban land management and conservation. Conservation and reintegration of nature into the city is very important, not only for the improvement of environmental quality, but also for that vital change in man's view of himself in relation to nature (Henke & Sukopp, 1986; Pyšek, 1995). It is well known that developing countries regard socio-economic issues such as poverty alleviation, equity, redistribution of wealth and safe living conditions, as more important than bio-physical issues, such as conservation, biodiversity, energy efficiency, and rehabilitation of damaged landscapes (Hindson, 1994). It is, therefore, important to embark upon urban vegetation studies to illustrate the importance of conservation, biodiversity, and energy efficiency that can be used by government or policy makers of tomorrow. Long-term monitoring of changes to plant communities in reaction to different types and intensities of specific management practices could form the basis of future management and maintenance programmes of these intensively-managed areas. Decisions on which plant communities and species should be managed or conserved can only be based on long-term vegetation dynamics studies (Cilliers & Bredenkamp, 1999a). People need to be made aware about vegetation dynamics and the advantages thereof in the long term. Urban vegetation studies have several advantages, such as bio-indicators of environmental conditions and ecological processes (Sukopp & Werner, 1983) and a better understanding of the synecology and dynamics of communities will enhance better management of these systems (Vincent & Bergeron, 1985). Urban vegetation also includes invading or allergen species or vectors of disease and insect host species that cause damage to cultivated plants in the household environment (Franceschi, 1996).

Several descriptive studies on the urban vegetation in different land-use areas of Potchefstroom have been completed over the last couple of years (Cilliers & Bredenkamp 1998, 1999a,b, 2000; Cilliers *et al.* 1998, 1999). These phytosociological studies formed the basis for several other studies, such as urban biotope mapping (Rost, 2002; Röthig, 2002), which was used for conservation-orientated planning and management (see Chapter 3). Rost (2002) and Röthing (2002) proposed specific management practices for the urban open spaces of Potchefstroom. In the inner city and traditionally well-managed areas, the regime of over-management continues, mainly because low-level management is mistakenly regarded as neglect, the so-called aesthetic conflict (Gilbert, 1989). Vegetation classification of intensively managed parks, pavements and parking areas indicated that a variety of plant communities, characterised by just over 100 plant species (54% native species), occurred. This is probably due to a variety of management practices such as mowing, weeding and human impact through trampling (Cilliers & Bredenkamp, 1999a).

Experimental studies to identify factors, which determine the composition and structure of multi-species communities, have been recognised to be very important in plant ecology (Knapp, 1954; Mueller-Dombois and Ellenberg, 1974; Austin and Austin, 1980; Austin *et al.*, 1985), in interspecific competition (Connell, 1983; Schoener, 1983; Fowler, 1986) and disturbances which influence the pattern of plant communities (Grubb, 1977; Connell, 1978; Huston, 1979; Sousa, 1984). According to White & Pickett (1985), a disturbance is a relatively discrete event, which suddenly disrupts the structure of an ecosystem, community or population, changing either the availability of resources or the physical environment. Disturbances may have physical and biological causes and generally lead to the death or decrease in abundance of a species, which can in turn favour other species. Sousa (1984) mentioned discrete, punctuated killing, displacement, or damaging of one or more individuals (or populations) that directly or indirectly create an opportunity for new individuals (or populations) to become established. Disturbances in ecosystems do not, however necessarily lead to the death of organisms. Soil disturbances, for example, can improve the conditions for germination, or increase the availability of nutrients. Natural disturbances include storms, fires and land slides, but also the impact of grazing animals. Anthropogenic disturbances are usually of much greater importance in urban habitats than natural environments and in towns and cities there are a number of additional disturbances, particularly those linked to construction activities including gardening and recreation (Rebele, 1994). The extent and the intensity of disturbances have an important influence on its biological effectiveness. Localised disturbances can increase the heterogeneity of the environment, creating a larger number of safe sites for plant species (Harper, 1977; Grubb, 1977).

In urban ecology, some other topics of general importance in vegetation dynamics that need to be mentioned are succession, biological interaction and the establishment of a greater variety of species. Succession is a directed change of the species composition over time (Kent & Coker, 2000). The Clementsian model of succession proposed a process of convergence to one stable state (the climax) and would therefore result in a decrease of the compositional gradient (Barbour *et al.*, 1987). Succession is also believed to be unidirectional and a change in community composition follows a unidirectional pattern in old fields studies (Lepš, 1987). Tansley (1935) and Whalley (1994) proposed, however, that succession can follow a multidirectional pattern that may result in the divergence of different pioneer plant communities. The phenomenon of multiple persistent states in the dynamics of plant communities has also lead to the establishment of a more contemporary paradigm of ecosystems from an equilibrium to a non-equilibrium approach (Pickett *et al.*, 1997). According to Pickett (1997) this approach violates the dominant role of the climax state in guiding system changes.

Vegetation succession is generally also linked to a clear change of the vegetation structure. A distinction is usually made between primary and secondary succession. Primary succession occurs naturally on sand dunes, glacial debris or volcanic ash where no or very little vegetation occurred previously. Due to man's industrial activities, primary succession can also occur in cities, wherever natural soil is excavated so that the soil that is exposed did not bear any plant growth previously and thus is devoid of any seed bank. The content of organic substances and nitrogen in the growth substrate is initially very low in primary succession (Tilman, 1986). There is usually an increase in species richness in the first year of primary vegetation succession, which then levels off in the course of secondary succession (Crawley, 1986). In cities, the establishment of primary habitats by plants is often more rapid than in isolated natural primary succession, since there are usually large numbers of seeds present in the seed bank of colonising species in the near vicinity. Birds perching in adjacent gardens, parks, roadsides or wasteland, can also accelerate the colonisation process (McDonnell & Stiles, 1983). In Chapter 5 the seed banks of the different areas under anthropogenic influence will be discussed.

Secondary succession occurs when sites, which already have some vegetation cover, are disturbed, or when cultivated land is left to lie fallow. In cities, secondary succession is particularly frequent, since both disturbances and also sites, which are in a temporary fallow phase, are very common (Rebele, 1994). Features of secondary succession are that organic matter is present at the start and that an increased release of nutrients occurs after a disturbance of the vegetation cover (Rebele, 1994). The vegetation establishment on deposited top-soils and landfill-soils in cities is usually characterised by secondary succession, or a mixed-form of primary and secondary succession. A further important feature of secondary succession is the initial floristic composition factor (Egler, 1954), since most species, which play a part in the course of succession, are already present at the start of succession, or established from adjacent areas, soon after the disturbance or the deposition of the substrate. In urban and industrial areas, the frequency of disturbances means that early- and mid- successional stages are common. Late successional stages, on the other hand, are very rare (Rebele, 1994), because of continuous disturbances also through management. Grassland fragments in South African cities are believed to be in a sub-climax state due to these continuous management practices (Nel, 1991).

The rate of succession is greatly influenced by several different kinds of competition. Resources or exploitative competition, which is particularly important for plants, require niche differentiation if not lead to competitive exclusion. Interference competition and competition for space on the other hand, do not require niche differentiation (Yodzis, 1986). Some urban habitats demonstrate considerable heterogeneity over time and space. For autotrophic plants, light and nitrogen, for example, are two important factors, for which plants compete, especially if they are at minimum levels. Even when there is exploitative competition, the spatial and temporal environmental heterogeneity can ensure the coexistence of competing species. Under urban conditions, unforeseeable disturbances like excavations, trampling and changing management practices, could make the environment extremely unstable. Since gaps are repeatedly being created in urban communities by physical disturbances, there are always competition-free situations, which allow weaker species to co-exist with superior competitors (Rebele, 1994). In Chapter 5 the influences of the seed bank will be examined by comparing the above-ground (extant) species with those found in the seed bank.

The destruction of existing natural and semi-natural vegetation in urban areas, and thus the pressure and decline of native species, is still increasing. It is also true that the typical urban vegetation and fauna is declining and must be considered to be endangered. The cause of the decline in species richness, are changes in land-use due to urban development and, in the case of plants found for example in newly built residential neighbourhoods, more intensive use and changes in the methods of the management of existing vegetation. In heavily built-up neighbourhoods, which offer urban planners an opportunity to introduce more nature into the city, the existing species-rich, spontaneous vegetation is often destroyed and replaced by monotonous ornamental lawns, which require intensive maintenance. The surfaces surrounding newly-constructed residential and industrial buildings are generally sealed, or are planted with ornamental species that are unsuited to the particular site and offer no source of food for the native fauna. This problem must be faced and the selecting of appropriate strategies aimed at curbing, or even reversing, this trend must be taken. According to Sukkop (1985) the conservation of the variety of typical urban landscape elements (species and wildlife communities) can only be maintained by means of a wide spectrum of land-use forms in city neighbourhoods.

The objective of this section of the study was to indicate how management practices and other anthropogenic impacts, such as trampling, could influence species composition and abundances over time using multivariate data analysis techniques.

4.2 Materials and Methods

4.2.1 Study area

Specific biotopes in which certain management practices were followed over a long time as well as areas with certain human impacts, were selected in the Potchefstroom Municipal Area (Figure 1.1). These biotopes were mentioned under 3.2.2 of this dissertation and include managed grasslands in a Botanical garden (Figure. 4.1), 3 different pavements areas (Figure 4.2 – 4.4) and neglected secondary grasslands with ruderal vegetation in which urban agricultural practices (eco-circles) (Figure 4.5 – 4.6) were started at the beginning of the study. In Table 4.1 a summary of the biotopes and

their locations are given, as well as management practices, human impacts and deliberate changes to management practices including human impacts. More discussions on the table will follow later.
Eco-circles were included in the study because of the unique human impact on vegetation in urban areas as an agricultural practice. The use of eco-circles is a new method of urban agriculture in which vegetables are cultivated in circles with a diameter of 1m (Trowbridge, 1998), forming clusters of 7 circles, and where the natural, semi-natural or ruderal vegetation inbetween the circles are left intact. Eco-circles were chosen as a community-upliftment urban agriculture project for the city of Potchefstroom, North West Province. The main objectives of this project was to create jobs, counter malnutrition with minimum environmental impact, minimum water consumption and maximum community involvement by the use of a method that is more in balance with nature and its processes.

Urban agriculture can be defined in different ways in literature, but in general it refers to the activities linked to food production in cities (Smith & Nasr, 1992). From an ecological point of view, urban agriculture can improve the environmental quality of cities through the reduction and transformation of waste, the reduction of food-related transport, natural resource saving, prevention of soil erosion, reduction in pollution and city beautification by converting vacant lots and degraded land into healthy green areas (Madaleno, 2000; Olivier, 1999). The main advantages of the eco-circle approach of urban agriculture, according to Trowbridge (1998), include conservation of water, reduction in rain run-off, less degradation and erosion, conservation of existing vegetation, cost-effectiveness, planned and maintained production and reduction in labour. Other factors that are positive for maintaining a sound environment are minimum tillage because once the area is established, no machinery is required and no use of pesticides is needed. Many of these ecological advantages of eco-circles rely on the state of the vegetation inbetween the circles and vegetation dynamics of these areas are therefore the focus of our interest.

Figure 4.1: Managed Grassland (Botanical Garden) in the Potchefstroom Municipal Area with mown area on the right and unmown area on the left

Figure 4.2: Pavement area (Commercial area) in the Potchefstroom Municipal Area with heavy trampling to the right and moderate to no trampling to the left, because of obstacle (pole fence).

Figure 4.3: Pavement area (next to sports field) in the Potchefstroom Municipal Area with no trampling to the left, heavy trampling in the middle and moderate trampling to the right.

Figure 4.4: Pavement area (residential area) in the Potchefstroom Municipal Area with heavy trampling on the left and moderate trampling on the right.

Figure 4.5: Secondary grassland (Eco-circles), in the Potchefstroom Municipal Area clusters of 7 circles, where the natural, semi-natural or ruderal vegetation inbetween the circles are left intact.

Figure 4.6: Secondary grassland (Eco-circles), in the Potchefstroom Municipal Area area before circles were established

Table 4.1: Biotopes identified in the Potchefstroom Municipal Area in which vegetation dynamics were studied, indicating their location, number of sample plots, management practices, possible human impact and deliberate changes to the management practices.

Biotopes	**Location in main biotope type and number of plots**	**Management practices**	**Human impact**	**Deliberate changes during study**
A. Managed gasslands	Botanical Garden – 4 areas [2 in shade (7 replicate plots) 2 in full sun (7 replicate plots)]	Mowing to height of 10cm. Irrigation.	Moderate trampling	Mowing stopped in only 2 areas (1 sun and 1 shade)
B. Pavement	Residential area – 3 areas [1 trampled (4 replicate plots), 1 next to trampled area (4 replicate plots), 1 outside of trampled area (5 replicate plots)	Occasional weeding and chemical control (not on a regular basis)	Heavy, moderate and lightly-trampled depending on position	Weeding and herbicide application stopped.
C. Pavement	Next to sport field – 4 areas [2 trampled (8 replicate plots), 1 next to trampled area (4 replicate plots), 1 protected from any trampling (7 replicate plots)]	Occasional weeding and chemical control (not on a regular basis)	Heavy, moderate and no trampling depending on position	Weeding and herbicide application stopped.
D. Pavement	Commercial area – 2 areas [1 trampled (4 replicate plots), 1 protected from any trampling (4 replicate plots)]	Weeding and chemical control on a regular basis	Heavy and no trampling depending on position	Weeding and herbicide application stopped.
E. Secondary grasslands (Eco-circles) Agriculture	Disturbed secondary grassland – 4 areas in between circles [12 replicate plots].	None for 2 years (areas inbetween circles)	None for 2 years (area inbetween circles) before establishment of eco-circles	12 eco-circles established for vegetable cultivation.

4.2.1.1 Soil

A soil sample was taken from every sample plot (75 samples in total) using a soil auger to a depth where the soil is limited for the herbaceous vegetation. The limiting factor in all the samples were mostly rock. The depth of this limiting factor (rock) was not constant, but varied in the different study areas (depth varied but on average 30cm deep). Physical and chemical soil properties, such as percentage gravel, silt, and clay; exchangeable potassium (K^+), sodium (Na^{2+}), magnesium (Mg^+) and calcium (Ca^+) (mg/100g soil), soil conductivity (mS/cm) and soil pH of the topsoil were determined. The compaction of the soil was tested with a hand soil test penetrometer (readings were taken directly from measurements on the penetrometer). The higher the reading the more compacted the soil was. A reading of 100 will be a solid surface and 0 will be very soft. Compaction is directly correlated with trampling or on the weight of a certain amount of mass moving over the soil at a given area.

Pavements in residential areas form 3 groups based on trampling levels (Table 4.1)

- Heavy trampling = associated with most pavements in commercial areas (Figure 4.2) and some areas along sports fields (Figure 4.3) (high readings on penetrometer, average of 40-80 on penetrometer)
- Moderate trampling = associated with pavements in residential areas (Figure 4.4) and along sport fields (Figure 4.3) and especially areas next to pavement curbs and in the managed grasslands (Figure 4.1) (average readings on penetrometer of 35)
- Light trampling = associated with pavement, areas situated next to obstacles that prevent trampling (Figure 4.2) and managed grasslands (Figure 4.1) (low readings on penetrometer, average of 10-25 on penetrometer).

The dominant soil type was Witbank soils, as described in the South African soil classification (Soil Classification Work Group, 1991).

4.2.1.2 Anthropogenic disturbance and management practises

Human impacts are sometimes difficult to assess, because the effect of many anthropogenic disturbances closely mimic natural disturbances such as burning, flooding and wind effect (Kowarik, 1990). At this stage, the type and intensity of human disturbance in synanthropic vegetation in South Africa is not adequately known. For this study, qualitative descriptions for human disturbances such as mowing, weeding, irrigation and trampling (discussed above) is used. For mowing, weeding and irrigation it was merely indicated whether the specific management practice was present or absent. For trampling a more elaborate description was used, as discussed under 4.2.1.1.

4.2.2 Vegetation sampling

In this study, a conventional quadrat of 1x1m made from a metal frame was used in measuring the basal cover, density and frequency of all species present. The metal frame was subdivided into smaller quadrats of $25cm^2$. In each corner of the $25cm^2$ quadrats a metal pin, of ± 18cm was attached to the frame (Figure 4.7). When the metal frame with pins was placed on the sample plot, the method could then be called a descending point method according to Kent & Coker (2000).

Frequency is defined as the probability or chance of finding a species in a given sample area or quadrat. Density is a count of the numbers of individuals of a species within the quadrat. Basal cover can be determined when the pins are lowered vertically onto the ground and the basal part of species, which is touched, is recorded (Kent & Coker, 2000). In this study the sample plots were observed over a period of three years (1999-2001). Data were collected every third month in all the sample plots in the different areas (see Table 4.1), but only results of May were used in this chapter to ensure more repetitions because the study was started in May.

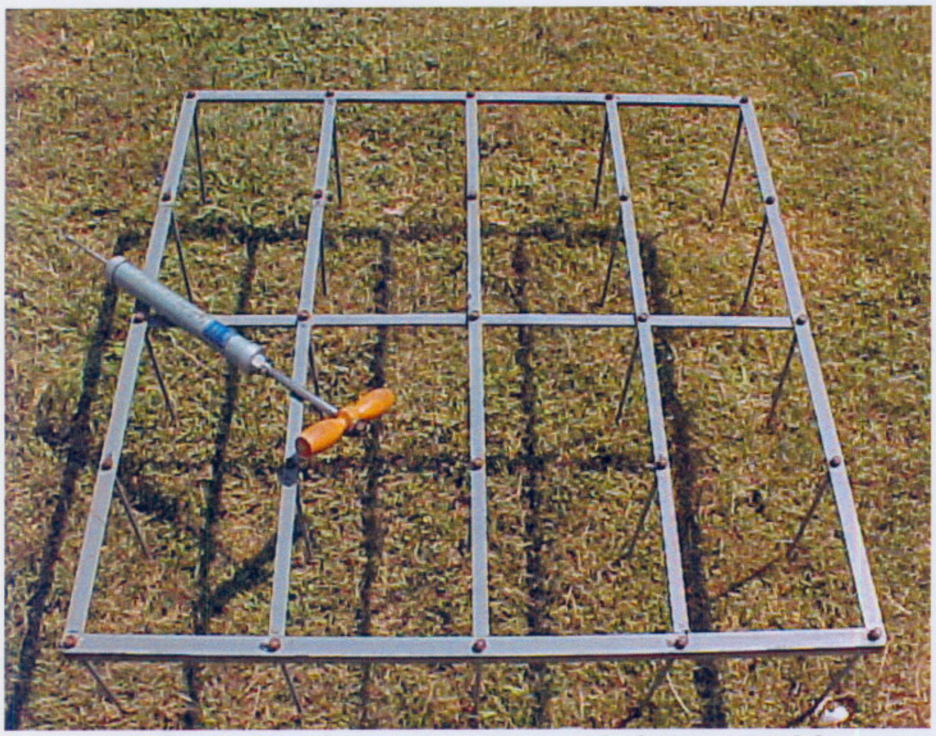

Figure 4.7: Conventional square quadrat made from a metal frame ($1m^2$), used in vegetation sampling in the Potchefstroom Municipal Area.

In 1999, 65 permanent sample plots were subjectively chosen in the different areas found in the five biotopes (Table 4.1) and their positions clearly marked with metal pins to enable follow-up surveys in 2000 and 2001.

The importance values of species were calculated by the summation of relative frequency, relative density and relative basal cover of each species (Mueller- Dombois & Ellenberg, 1974; Kent & Coker, 2000). Goff & Cotham (1967) argued that although importance values obscure some ecological information of species, it allows a more direct way of comparison of species proportions in a sample. Importance values therefore give a good summary of the biological influence of each species in a sample and were also successfully used by Skousen *et al.* (1994) to evaluate the natural revegetation of woodland communities on abandoned open coal mine sites. The same method was used by Morgenthal (2002) in vegetation dynamics studies on rehabilitated coal-ash disposal sites in Mpumalanga, South Africa. To determine, however, which specific measure of abundance (density, frequency or basal cover) has changed over the three-year period, average number of density, frequency and basal cover were indicated in the results (Tables 4.5 to 4.20). This also gave an idea of the growth form of certain species, like in big, tufted grass species (*Paspalum dilatatum* and *Sporobolus africanus*) basal cover is high, but frequency is low and stoloniferous species (*Cynodon dactylon*) could have a low basal cover but high density.

4.3.3 Data analysis

Repeated observations on permanent plots are among the most useful tools for the study of succession and the investigation of competitive relationships (Herben, 1996; Lepš *et al.*, 2000). To demonstrate succession mechanisms, experiments are the only reliable tools, but repeated observation of permanent plots provides insights into the dynamics of population processes and demonstrates convergence or divergence during succession (Lepš, 1995; Lepš *et al.*, 1999; Lepš *et al.*, 2000). Recent development in multivariate methods, particularly in constrained ordinations (Ter Braak & Prentice, 1988) as in the CANOCO-programme (ter Braak & Smilauer, 1998) provides ecologists with a powerful tool to test various hypotheses in which the test can be adjusted to the design of the observation.

The data were analysed statistically with the CANOCO-programme (Canonical Correspondence analysis) using several ordination techniques (Ter Braak, 1992). Ordination is the arrangement of vegetation samples in relation to each other in terms of their similarity of species composition and/or their associated environmental controls (Kent & Coke, 2000). Ordination methods are also part of gradient analysis. In gradient analysis, variation in species composition is related to variation in associated environmental factors, which can usually be represented by environmental gradients. Ordination techniques that were used, included Detrended Correspondence Analysis (DCA), Canonical Correspondence Analysis (CCA) and Redundance Analysis (RDA). From now on abbreviations will be used when referring to the different ordination techniques. The CANOCO-programme allows a quick appraisal of how community composition varies with the environment, and uses correlation coefficients to analyse the data (Ter Braak & Smilauer, 1998).

The first ordination used in this study was a DCA-ordination of all the sample plots of 1999 in all the biotopes, to identify any arrangement of vegetation samples in relation to each other in terms of their similarity of species composition. After the DCA-ordination, CCA-ordinations were applied to determine any correlation between species composition and environmental factors of all the biotopes. CCA is different from all the ordination methods as it incorporates the correlation and regression between floristic data and environmental factors within the ordination analysis itself. The resulting ordination diagram thus expresses not only patterns of variation in floristic composition but also demonstrates the principal relationships between the species and each of the environmental variables (Kent & Coker, 2000). RDA was also used in this study to give more information on the vegetation dynamics of each biotope. RDA is a direct ordination technique, based on the principles of the PCA-ordination technique, where the species are constrained by a number of environmental factors. Because it is based on the PCA-ordination technique, it is a linear model (Ter Braak, 1994; Verdonschot & Ter Braak, 1994).

4.3 Results

4.3.1 Management practices in the different biotopes

In a DCA-ordination result where all the biotopes studied are correlated, most of the sample plots representing the different biotopes, grouped together (Figure 4.8). Along ordination axis 2, the samples monitored in the secondary grasslands in between eco-circles (E) are clearly distinguished from all the pavement areas (B,C and D) and the managed grasslands (A) according to species composition and abundance. Managed grasslands (A) and pavement areas next to sports fields (C) are clearly distinguished by 2 separate groups from left to right along ordination axis 1. The sample plots of the different pavements areas (B,C and D) do not form clearly defined separate groups. Areas of pavements in residential areas (B) that are not directly subjected to trampling associated well with areas of managed grasslands (A), which are situated in full sun.

Areas of pavements (B) that are subjected to heavy and moderate trampling associated better with similar areas of pavements next to sports fields (C) (Figure 4.8).

In this DCA there is a good gradient visible along ordination axis 1, which can probably be ascribed to the influence of soil compaction, i.e. from the left (of the ordination) plots are less trampled/compacted to the right (of the ordination) where plots are more-heavily trampled/compacted. The gradient along ordination axis 2 can be ascribed to anthropogenic influences in general, if we look at group E representing secondary grasslands inbetween eco-circles (low level of anthropogenic influence) and D representing pavement in commercial area (high level of anthropogenic influence). To verify these assumed gradients, CCA-ordinations were carried out.

4.3.2 Influence of environmental factors on management in biotopes

In the CCA-ordination (Figure 4.9) different gradients and correlations between sample plots, species and environmental factors can be identified. Quantitative environmental variables are indicated by arrows, which reflect certain gradients, while qualitative environmental variables are indicated by black crosses and could not reflect any gradient. Please take note that environmental variables were not collected for each individual sample plot, but only for groups of plots representing a specific situation of a biotope (e.g. mown, sunny, managed grassland). There are, therefore, fewer symbols for each biotope in Figure 4.9 than in Figure 4.8. To investigate the possible correlations, mentioned earlier, one must look at the different correlation coefficients between the environmental factors and the two ordinations axes (Table 4.2).

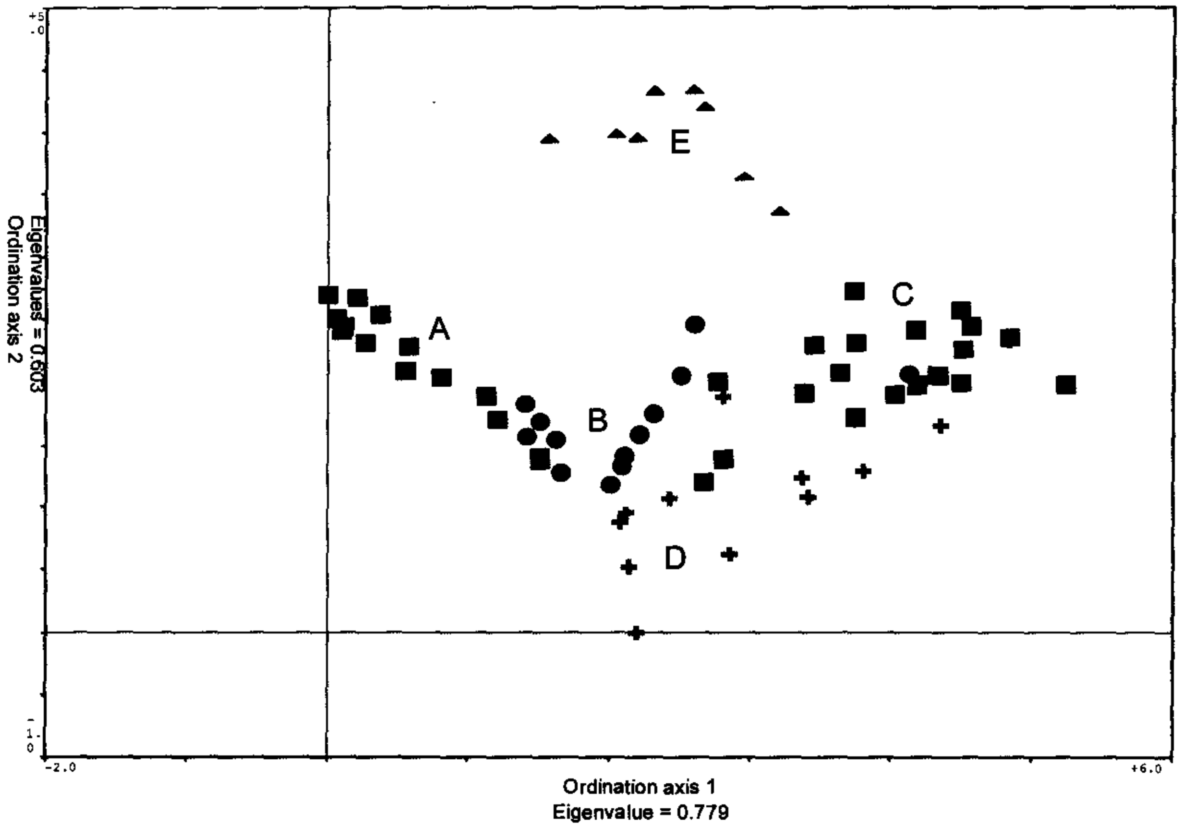

Figure 4.8: DCA-ordination of sample plots in managed grasslands, pavements and agricultural areas studied in the Potchefstroom Municipal Area at the start of the study (May 1999 – no change to management practice or human impact). [A (blue squares) = managed grasslands, B (green circles) pavements in residential area, C (red squares) pavements next to sport fields, D (orange crosses) pavements in commercial areas and E (purple triangles) = secondary grasslands inbetween eco-circles]

Table 4.2: Correlation coefficients of selected environmental factors studied in all the biotopes of the Potchefstroom Municipal Area at the start of the study (May 1999).

Environmental Factors	Ordination Axis 1	Ordination Axis 2
Compaction	-0.6423	-0.1051
Calcium (Ca)	0.4378	0.5243
Magnesium (Mg)	0.7086	0.2914
Potassium (K)	-0.1964	0.4246
Cation Exchange Capacity (CEC)	0.2045	0.6644
pH	-0.0078	0.6391
Sand	-0.5684	0.0394
Clay	0.4926	-0.1520

From Figure 4.9 it is evident, that a clear gradient of compaction exists from left (high compaction) to right (low compaction) along ordination axis 1. Compaction is also one of the factors that shows the highest negative correlation with ordination axis 1 (Table 4.2). Another positive correlation is found between Mg (magnesium) and ordination axis 1 (right of axis 1). Along ordination axis 2 there are positive correlations with pH and CEC and to a lesser extant, Ca (calcium).

According to the CCA-ordination (Figure 4.9) the managed grasslands (blue squares) are associated with low soil compaction levels and with high soil clay content. Lawn and irrigation are two nominal environmental factors that are also associated with managed grasslands. The species best associated with managed grasslands and the environmental factors are *Taraxacum officinale* (Tar off), *Paspalum dilatatum* (Pas dil), *Chamaesyce hirta* (Cha hir), *Sporobolus africanus* (Spo afr), *Conyza podocephala* (Con pod), *Hermannia depressa* (Her dep), *Falkia oblonga* (Fal obl) and representatives of the family Cyperaceae (Cyp spp). There is also a correlation between high soil compaction levels and the pavements next to sports fields (red squares) (see Table 4.1 and Figure 4.3) along ordination axis 1. Sample plots of pavements (red squares) on the left of ordination axis 1 had high compaction levels, while those more towards the centre of the ordination had light to moderate compaction levels. Trampling is a nominal environmental factor that is also positively associated with the sample plots in pavements next to sports fields. The species associated with these factors are *Tribulus terrestris* (Tri ter), *Cynodon hirsutus* (Cyn her), *Tragus berteronianus* (Tra ber), *Panicum maximum* (Pan max), *Eragrostis lehmanniana* (Era lem) and *Malvastrum coromandelianum* (Mal cor). Along ordination axis 2 an association is found between the sample plots associated with pavements at commercial areas (orange crosses) (see Table 4.1 and Figure 4.2) and pH as well as CEC. The species mostly associated with these factors is *Pennisetum clandestinum* (Pen cla). Along ordination axis 2, the sample plots representing secondary grasslands inbetween eco-circles (purple triangles) are associated with low levels of pH and CEC as well as with the nominal environmental factor, Agriculture, which indicates eco-circles and the associated species are *Conyza bonariensis* (Con bon), *Urochloa panicoides* (Uro pan), *Chloris virgata* (Chl vir), *Enneapogon cenchroides* (Ehn cen), *Cynodon dactylon* (Cyn dac), *Lepidium bonariense* (Lep bon) and *Chamaesyce inaequilatera* (Cha inq).

To summarise, there are different gradients present in the CCA-ordination. Along the first ordination axis from left to right we see a gradient from high compaction to lower compaction. Along ordination axis two a gradient from higher influence of pH and CEC at the top to a lower influence of pH and CEC, at the bottom.

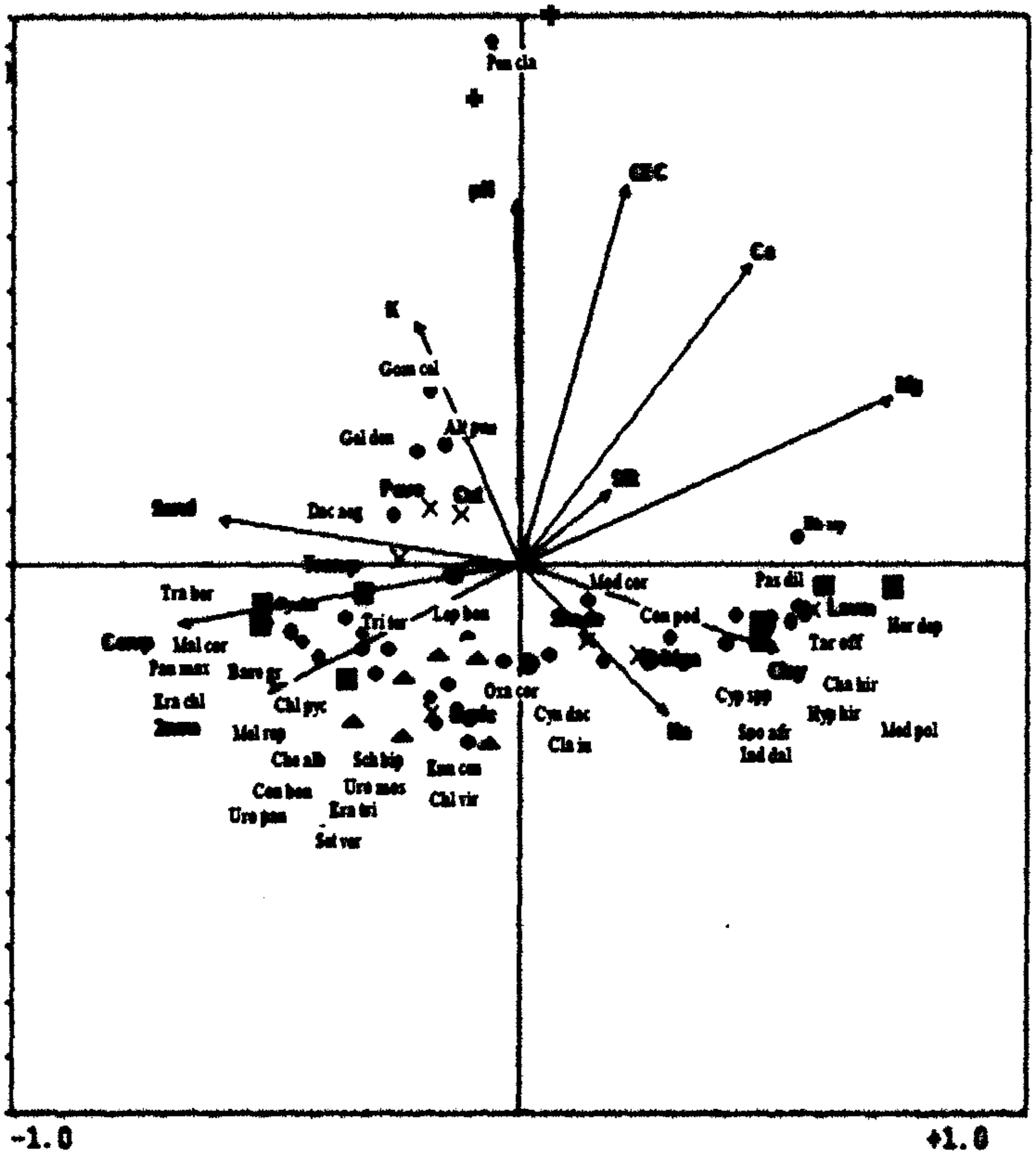

Figure 4.9: CCA ordination tri-plot of selected species (black circles), quantitative soil properties (arrows) and qualitative (nominal) environmental factors (black crosses) of pavements (green circles, red squares and orange crosses), managed grasslands (blue squares) and secondary grasslands (purple triangles) in the Potchefstroom Municipal Area at the start of the study (May 1999). Explanations of abbreviations: CEC = Cation Exchange Capacity, Iriga = irrigation, Agric= agricultural, 2mm = soil particle size, Comp = compaction, Pave = pavements, Tramp = trampling. Abbreviations of relevent species names will be explained in text.

4.3.3 Transitions in species composition in the biotopes over time

In Figure 4.10, the distribution of sample plots of the different biotopes (A-E) for the May 2000 survey is given. If the results of the 2000 survey were compared to the distribution of samples of the 1999 survey (Figure. 4.8), it could be observed that three major transitions occurred from 1999 to 2000. This can mainly be attributed to specific changes in management practices from 1999 to 2000.

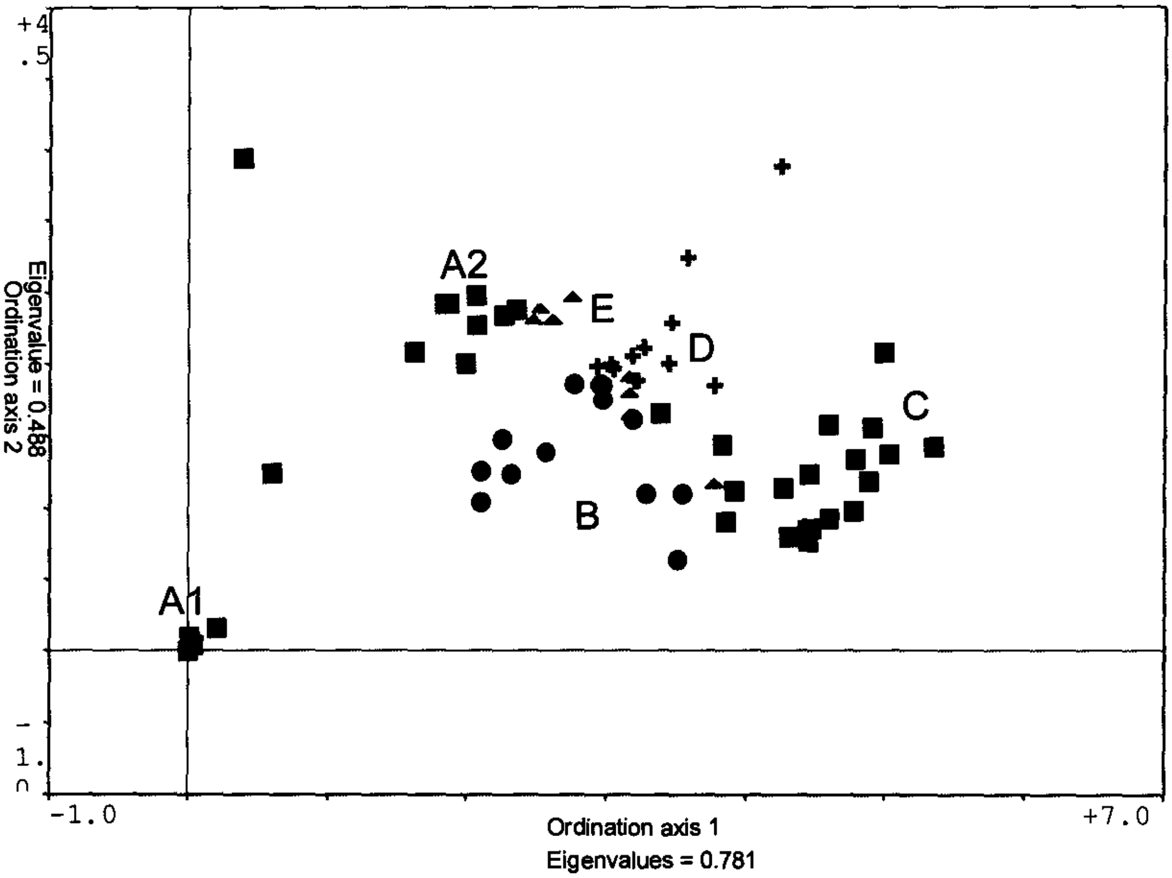

Figure 4.10: DCA-ordination of sample plots in managed grasslands, pavements and agricultural areas studied in the Potchefstroom Municipality Area during May 2000. [A (blue squares) = managed grasslands, B (green circles) pavements in residential areas, C (red squares) pavements next to sports fields, D (orange crosses) pavements in commercial areas and E (purple triangles) = secondary grasslands inbetween eco-circles)].

The following important changes occurred from 1999 (Figure 4.8) to 2000 (Figure 4.10).

- The managed grasslands (A) are now separated into two groups, i.e. unmown areas (A1) and mown areas (A2)

- The pavements in the commercial areas (D) are now more associated with other pavement areas (B and C), which have undergone heavy trampling and similar management practices. Although the difference in pH and CEC of the soil of pavements in commercial areas (D-orange crosses) seemed to cause the differences in species composition and abundance between pavements in commercial areas and other biotopes (Figure 4.9), the soil characteristics are of less significance if changes in management take place. Areas with low trampling levels (E) associated more with the managed grasslands, which were mown (A2). The main reason for this considerable change in species composition from 1999 to 2000 could probably be related to the termination of weeding and chemical control.

- In the secondary grasslands (E) where trampling and soil compaction increased due to the implementation of a new agricultural approach, i.e. the formation of eco-circles, most of the sample plots are now more closely associated with pavement areas (B, C, D), where moderate to heavy trampling occurs.

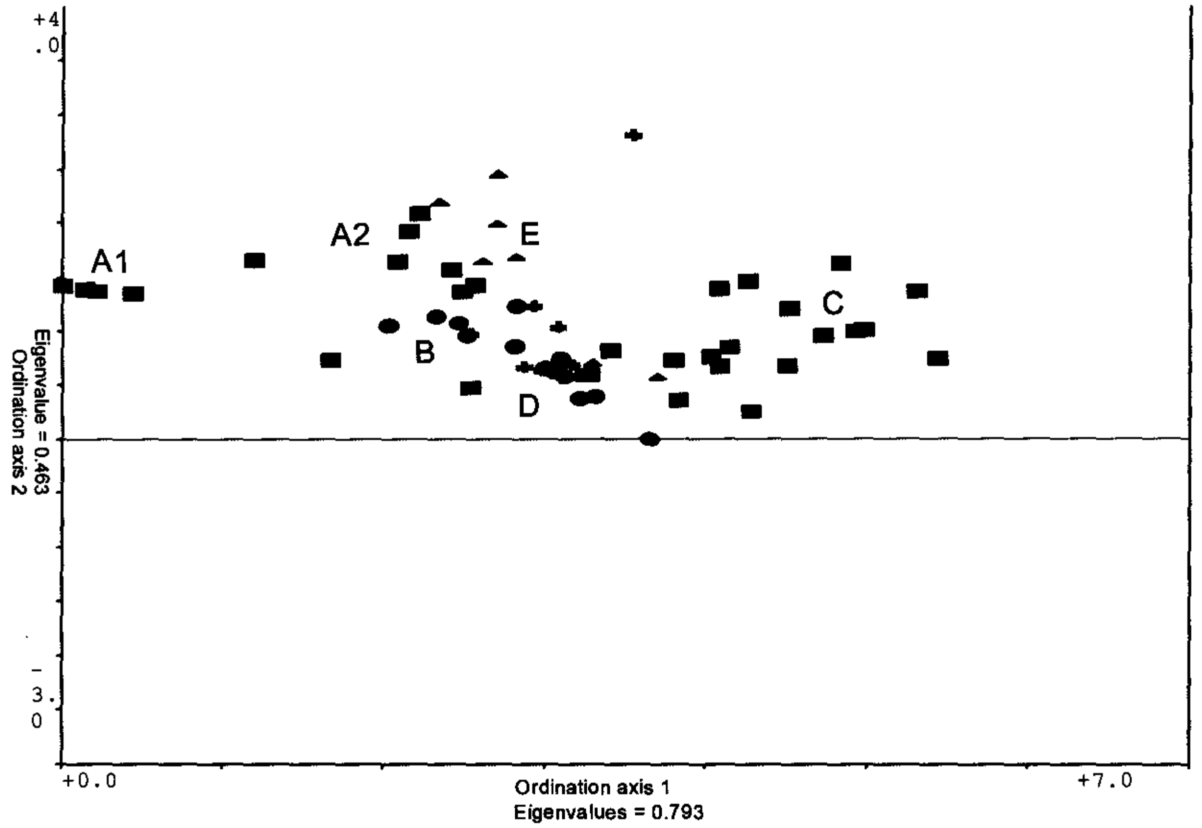

Figure 4.11: DCA-ordination of sample plots in managed grassland, pavements and agricultural areas studied in the Potchefstroom Municipal Area during May 2001. [A (blue squares) = managed grasslands, B (green circles) pavements in residential area, C (red squares) pavements next to sports field, D (orange crosses) pavements in commercial area and E (purple triangles) = secondary grasslands inbetween eco-circles)].

When the results of the May 2001 surveys were analysed, (Figure 4.11) it is clear that they were quite similar to the ordination results of the May 2000 surveys (Figure 4.10), indicating a similarity in species composition between these two surveys. The same management practice was also applied at each study site between May 2000 and 2001. The managed grasslands (group A) were still divided into two groups (A1 and A2) as a result of the change in management. The groups found on the pavements, shown as B, C and E, showed very little change. The secondary grassland (Ecocircle) group E, was more associated with groups B, C and D (pavements). This indicates that the effects of the type of management practice on the vegetation of the agricultural area (Ecocircles), can be closely related to the effects of management practices on the vegetation of pavements. This could also be because of the increase in trampling over time between ecocircles.

In conclusion, it is eminent that the position of the sample plots along ordination axis 1 stayed more or less the same from May 1999 to May 2001 (Figures 4.8, 4.10 and 4.11). Managed grasslands (A) are situated to the left and pavement areas next to sport fields (C) to the right with the other biotopes inbetween indicating a gradient which could be related to soil particle distribution (high clay content to the right and high sand and 2mm particles to the left) and soil compaction as well as trampling which were higher on the left. Major changes in position of sample plots occur along ordination axis 2, that could be ascribed to changes in management practices (weeding, mowing) and human impact (trampling).

4.3.4 Vegetation dynamics of managed grasslands (Botanical garden)

In Figure 4.12 the effect of time (years 1999 – 2001), shade and mowing as possible environmental and athropogenic effects on species compositional changes is shown by an RDA tri-plot ordination graph. The eigenvalues of the first two axes were 0.36 and 0.09 respectively and therefore explained 45% of the species data and 99.2% of the species environmental relationship. Most of the variation in the RDA tri-plot is explained by the first ordination axis, which has a species environmental correlation of 0.97. The first ordination axis of the RDA tri-plot can be best explained by mowing ($r = 0.68$). The second ordination axis was correlated with the effect of shade ($r = -0.597$). The time gradient (year) was only weakly associated with the first ordination axis ($r = -0.39$), indicating that there were no major changes in species composition over the three-year study period.

The following results can be derived from the RDA tri-plot (Figure 4.12). The effect of mowing was situated to the right of ordination axis 1. Sites frequently mown and species which occurrences and abundances associated with this effect will occur to the right of the ordination axis. Unmown sites and associated species affected by mowing will mostly be situated to the left of ordination axis 1. Ordination axis 2 indicated a shade: sun gradient with sites in shade and associated species situated to the bottom of ordination axis 2 and sites in sun and associated species will be situated at the top of ordination axis 2.

The sample plots in the top right corner of the ordination were mown and subjected to sunny conditions (Figure 4.12). *Cynodon dactylon* (Cyn dac), *Conyza podocephala* (Con pod), *Ciclospemum leptophyllum* (Cic lep), *Chloris pycnothrix* (Chl pyc), *Gomphrena celosiodes* (Gom cel) and *Hermannia depressa* (Her dep) associated better with these frequently mown sites occurring in full sun from 1999 to 2001 than with any of the other sites (Figure 4.12). Although years do not associate strongly with ordination axis 1, there are some changes in abundances and species composition within the mown, sunny plots over the three-year period, as indicated in Table 4.5. In the first year (1999) *Dichondra repens* (Dic rep) and *Cynodon dactylon* (Cyn dac) had the highest importance value. *Dichondra repens* (Dic rep) had a high density, frequency and basal cover in the first year (1999). The density of *Dichondra repens* (Dic rep) increased in the second year (2000), it also had a higher frequency but a lower basal cover. In the third year (2001), *Dichondra repens* (Dic rep) had a low importance value if compared to the year 2000, due to a decrease in frequency and basal cover (Table 4.5). A possible reason could be that in the third year (2001), species such as *Medicago polymorpha* (Med pol), *Oxalus corniculata* (Oxa cor), *Sporobolus africanus* (Spo afr) and *Pennisetum clandestinum* (Pen cla) increased in importance value causing more competition with other species (Table 4.5). *Cynodon dactylon's* (Cyn dac) importance value also decreased in the second year (2000), but increased in the third year (2001) and could also be a reason for the decline in *Dichondra repens's* (Dic rep) importance value in the third year (Table 4.5). This increase in importance value for *Cynodon dactylon* (Cyn dac) in the third year was due to an overall increase in density and frequency (Table 4.5). *Paspalum dilatatum* (Pas dil) increased in importance value over the three years when looking at Table 4.5, mainly because of an increase in density over the three years, although *Paspalum dilatatum* (Pas dil) was not clearly associated with the sample plots in this area (Figure 4.12). *Conyza podocephala* (Con pod) had relatively high importance values over the three-year period and was the highest in the second year (2000) (Table 4.5.). *Chloris pycnothrix* (Chl pyc), *Ciclospermum leptophyllum* (Cic lep) and *Gomphrena celosioides* (Gom cel) had relatively low importance values over the three-year period, and were only present in the second year (2000), except *Ciclospermum leptophyllum* (Cic lep) that was present in the third year (2001) as well (Table 4.5).

The sample plots in the bottom right corner of the ordination were mown but occurred in the shade (Figure 4.12). The species *Dichondra repens* (Dic rep), *Chamaesyce hirta* (Cha hir), *Medicago polymorpha* (Med pol) and *Hypochoerus glabra* (Hyp gla) are better associated with these conditions, than with those of any of the other sites (Figure 4.12). From Table 4.6 it is clear that *Dichondra repens* (Dic rep) has the highest importance value over the three-year period. *Cynodon dactylon* (Cyn dac) also has a high importance value, but it decreased in the second year (2000), mainly due to a decrease in frequency and basal cover (Table 4.6). In the third year (2001) *Cynodon dactylon* (Cyn dac) increased in importance value, to its highest for the three-year period. *Cynodon dactylon* (Cyn dac) occurred in most of the sample plots as is indicated in the other Tables (Table 4.5-4.8). The importance value of *Dichondra repens* (Dic rep) increased from 1999 to 2000 mainly due to an increase in density and frequency, but it decreased again in 2001. The increase in importance value of *Dichondra repens* (Dic rep) is probably due to the constant removal of the leaves of higher growing species which used to prevent light penetration to lower growing species. In 2001 the importance value of *Dichondra repens* (Dic rep) decreased again as other species such as *Paspalum dilatatum* (Pas dil), *Medicago polymorpha* (Med pol) and *Oxalis corniculata* (Oxa cor) (Table 4.6) established. The effect of mowing was also positive for other lower-growing species such as *Chamaesyce hirta* (Cha hir) and *Medicago polymorpha* (Med pol) as their importance values also increased over the three-year period (Table 4.6).

The sample plots in the bottom left corner of the ordination also occurred in the shade but were unmown (Figure 4.12). The grasses *Paspalum dilatatum* (Pas dil), *Sporobolus africanus* (Spo afr), the forbs *Veronica persica* (Ver per) and *Lobelia nuda* (Lob nud) and the shrub *Acacia karroo* (Aca kar) associated better with these conditions than with those of any of the other sites (Figure 4.12). The species with the highest importance values, according to Table 4.7, were *Dichondra repens* (Dic rep), *Paspalum dilatatum* (Pas dil) and *Sporobolus africanus* (Spo afr). *Dichondra repens* (Dic rep) had high importance values in the first year of study (1999) (Table 4.7). The importance value of *Dichondra repens* (Dic rep) increased in the second year (2000), but declined dramatically in the third year (2001). The reason for this is that *Dichondra repens* (Dic rep) is a low-growing species, making it difficult to compete for sunlight against high-growing species such as *Paspalum dilatatum* (Pas dil) and *Sporobolus africanus* (Spo afr) whose importance values were higher than *Dichondra repens* (Dic rep) in the third year (2001). The decline in importance value of *Paspalum dilatatum* (Pas dil) in the third year could be of a higher presence or importance value than *Sporobolus africanus* (Spo afr), *Taraxicum officinale* (Tar off) and *Veronica persica* (Ver per) in the third year (Table 4.7). It is also important to note that the importance value of *Cynodon dactylon* (Cyn dac) (low growing species) decreased over the three-year period, also mainly due to the inability to compete for sunlight against the higher growing species or could be ascribed due to no stimilation to grow as no mowing occurred (Table 4.7). *Veronica persica* (Ver per) became evident in the second year (2000) and was also noted in the third year (2001) of the study (Table 4.7). *Veronica persica* (Ver per) is according to Wells *et.al.* (1986) a competitive species with an erect or sprawling life form, and because of those characteristics it became evident in the area when mowing was stopped. *Acacia karroo* (Aca kar) was also present, although with very low importance value (Table 4.7), it is the only place where *Acacia karroo* (Aca kar) seedlings could be established. *Acacia karroo* (Aca kar) is regarded as a grassland encroacher (Bezuidenhout *et al.*, 1994)

The sample plots in the top left corner of the ordination occurred in the sun and were unmown (Figure 4.12). *Hyparrhenia hirta* (Hyp hir), *Themeda triandra* (The tri) and *Taraxicum officinale* (Tar off) associated better with these conditions than with those of any of the other sites (Figure 4.12). These species were also the only species positively related to the time (year) gradient (Figure 4.12). When looking at Table 4.8 it is clear that the species with the highest importance values in the first year (1999) in areas unmown and in full sunlight, were *Cynodon dactylon* (Cyn dac), *Dichondra repens* (Dic rep) and *Paspalum dilatatum* (Pas dil). *Hyparrhenia hirta* (Hyp hir) was more prominent in the first year (1999) and third year (2001), while *Themeda triandra* (The tri) was only noted in the second year (2000). Both these two species were high-growing species, but their abundance was not as important as that of *Paspalum dilatatum* (Pas dil). This is evident in the importance values of *Paspalum dilatatum* (Pas dil) over the three-year period (Table 4.8). The importance value of *Paspalum dilatatum* (Pas dil) increased from the first year (1999) to the second year (2000), mainly because of higher density and frequency (Table 4.8). In the third year (2001) the importance value increased even more because of higher values in density and frequency for *Paspalum dilatatum* (Pas dil). Both *Cynodon dactylon* (Cyn dac) and *Dichondra repens'* (Dic rep) importance values declined over the three-year period (Table 4.8). *Cynodon dactylon* (Cyn dac) had a lower importance value in the year 2000 because of lower density, frequency and basal cover. In the third year the main reason for *Cynodon dactylon's* (Cyn dac) low importance value was because of a lower density and frequency. This could be explained in that *Cynodon dactylon* (Cyn dac) is a low-growing species and couldn't compete any more with the higher-growing species for sunlight and it is known that mowing stimulates the growth of *Cynodon dactylon*.

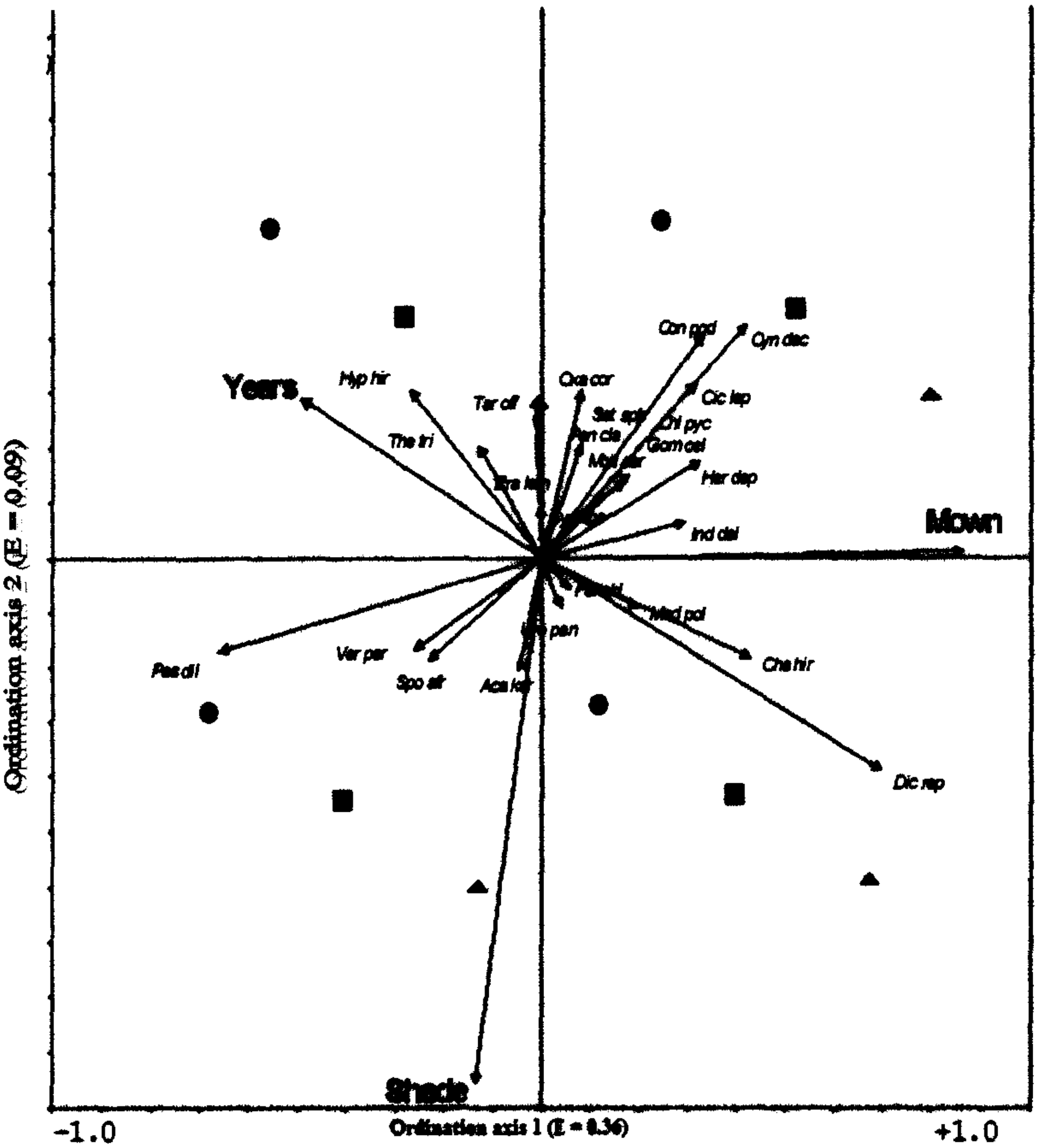

Figure 4.12: RDA-ordination tri-plot of managed grassland to show the effect of shade, mowing and years on the species composition in the Botanical Garden situated in Potchefstroom. The symbols in the ordination represent the sample plots studied over the different years of the survey; red triangles = 1999, green squares = 2000 and blue circles = 2001. Abbreviations of relevant species names will be explained in text.

Table 4.5: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on managed grasslands (Botanical Garden), situated in full sun and mown, over three-year period (1999-2001).

Managed grasseland (Botanical garden) Mown and full sun												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	9.6	12	5	98	22.6	7.3	1.3	51.2	26.6	14.3	3	66.2
Dichondra repens	16	9	3	79.4	26.6	12.6	1.3	98.7	66.6	7.6	1.3	78.4
Conyza podocephala	11.6	0.6	0	23.2	27	2.6	0.3	33.6	24.3	2.3	0	24.8
Indigofera daleoides	4.6	1	0.3	12.9	0	0	0	0	0.6	0.3	0	1.7
Oxalis corniculata	2,3	0	0	10.9	28.3	1.3	0	11.2	18	1.6	0	18.1
Sporobolus africanus	0	0.6	0	3.2	2.6	0.6	0.6	7.5	1.3	0.3	0.3	2.1
Hermannia depressa	2.3	0.3	0.3	2.7	1.3	0	0	1.1	1	0	0	0.6
Paspalum dilatatum	0.3	0.3	0	2	1.6	0.3	0.3	3	2	0.3	0	4
Taraxacum officinale	0.6	0	0	1.8	4.3	0.3	0	4.8	2	0	0	1.3
Cyperus esculentus	0.3	0.3	0	1.3	0	0	0	0	0	0	0	0
Falckia oblonga	0.3	0.3	0.3	1.1	0.3	0	0	0.3	0	0	0	0
Chamaesyce hirta	1.3	0	0	0.9	0	0	0	0	7	1.3	0.3	11
Medicago polymorpha	0.6	0	0	0.9	0.6	0	0	0.5	0.6	0.6	0	3
Chloris pycnothrix	0	0	0	0	0.3	0	0	0.3	0	0	0	0
Modiola caroliniana	0	0	0	0	2.3	0	0	1.9	5	0.3	0.3	5.8
Ciclospermum leptophyllum	0	0	0	0	1.6	0	0	1.3	0.6	0	0	0.4
Gomphrena celosioides	0	0	0	0	0.3	0	0	0.3	0	0	0	0
Setaria sphacelata	0	0	0	0	0	0	0	0	0	0.3	0	1.3
Pennisetum clandestinum	0	0	0	0	0	0	0	0	1.3	0.3	0	2.1

Table 4.6: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on managed grasslands (Botanical Garden), situated in shade and mown area, over three-year period (1999-2001).

Managed grassland (Botanical Garden) Mown and shade												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Dichondra repens	53.3	15	6	151	90	16.3	4	157.1	266	10	1.6	97.2
Cynodon dactylon	6.6	4.6	2.3	37.9	20.6	1.3	0.3	15.9	50.6	7.3	0.6	53.3
Modiola caroliniana	5	0.6	0	10.5	4	0	0	1.8	3.6	0	0	2.4
Sporobolus africanus	0.6	1.3	0	9.3	2.6	1.3	1.3	11.8	0.6	2	0.6	11.1
Indigofera sp	2.3	0.3	0	6.7	0	0	0	0	0	0	0	0
Paspalum dilatatum	20.6	1	0.6	5.8	1.6	1.3	0.3	7.3	2.3	2.6	0.6	14.9
Cyperus esculentus	1.3	0.3	0	5.2	0	0.3	0	1.3	0.6	0.6	0	3.1
Medicago polymorpha	1.6	0.3	0	4.1	5	0	0	2.2	5.3	0.6	0	6.2
Conyza podocephala	0.3	0.3	0	3.3	5.3	1	0	6.4	3.3	0.3	0	3.5
Chamaesyce hirta	0.3	0.6	0	2.9	3	1.3	0	6.6	7.6	0	0	5.1
Oxalis corniculata	0	0.3	0	2.7	5	0	0	7.5	15	0.3	0	10.7
Taraxacum officinale	1	0	0	2	6	0.6	0.3	6.7	4	0.6	0	5.3
Hermannia depressa	0.3	0	0	1.8	0	0	0	0	0	0.3	0.3	2.6
Falckia oblonga	0.3	0	0	0.7	0.6	0	0	0.3	0	0	0	0
Urochloa panicoides	0	0	0	0	0	0	0	0	0	0.2	0.2	2.6

Table 4.7: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on managed grasslands (Botanical Garden), situated in shade and unmown area, over three-year period (1999-2001).

Managed grassland (Botanical Garden) Unmown and shade												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Dichondra repens	67.5	15.7	6.5	137.5	1	0.5	0	154.9	1.2	0	0	4.9
Paspalum dilatatum	35.7	6	3	53.7	32.7	17.2	3	149	17.2	18	2.2	147
Sporobolus africanus	3.2	3	1.5	16.5	2.5	3	0.2	18.5	4	3	0.2	28.3
Cynodon dactylon	0.7	0.5	0	4.4	0	0.5	0	2	0	0	0	0
Falckia oblonga	2.7	0	0	3.8	0.2	0.2	0	1.6	0	0	0	0
Oxalus corniculata	0.5	0	0	3.1	0.2	0.5	0	2.6	0	0	0	0
Taraxacum officinale	2	0	0	1.8	0.5	0.2	0	2.1	0.5	0.75	0	4.9
Medicago polymorpha	0.5	0	0	1.5	0	0.2	0	1	0	0	0	0
Modiola caroliniana	0.2	0	0	0.2	0	0	0	0	0	0	0	0
Cyperus esculentus	0.2	0	0	0.1	0	0.2	0	1	0	0.25	0	1
Acacia karroo	0.2	0	0	0.1	0	0	0	0	0	0	0	0
Veronica persica	0	0	0	0	7.5	2.2	0.5	27.6	2.5	1.75	0.5	18.7
Conyza podocephala	0	0	0	0	0.5	0	0	1.1	0	0	0	0
Indigofera sp.	0	0	0	0	0	0	0	0	0.2	0	0	1

Table 4.8: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on managed grasslands (Botanical Garden), situated in full sun and unmown area, over three-year period (1999-2001).

Managed grassland (Botanical Garden) Unmown and full sun												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	39	9.7	2	72.5	6	6.5	0.5	49.4	13	9.7	1.5	32.6
Dichondra repens	6.6	1.2	0	55.9	75	0	0	2.7	0	0.2	0	1
Paspalum dilatatum	2	4.5	1.5	29.6	9.7	9	1.5	76.8	11.7	10.7	1.2	107
Taraxacum officinale	3.2	2.5	0.5	13.3	2.2	1.2	0	13	3	3.2	0	27.8
Modiola caroliniana	0.5	0.5	0.5	6.8	0.5	0.5	0	2	0	0.5	0	5.6
Sporobolus africanus	1.2	0	0	6.6	2.2	2.7	0.2	18.3	0	0.5	0	2
Cyperus esculentus	0	1.7	0	6.1	0	0.2	0	1	0	0.2	0.5	1
Hyparrhenia hirta	0.7	0	0	3	0	0	0	0	2	3.5	0.7	18.1
Conyza podocephala	1.5	0	0	2	2.7	3	0	19.8	0	0	0	0
Oxalus corniculata	0.5	1	0	1.8	2.2	1.5	0	15	2.5	1	0	6.5
Falckia oblonga	1	0	0	1.7	0.5	0	0	1.8	0	0	0	0
Medicago polymorpha	0.5	0	0	0.8	0	0	0	0	0	0	0	0
Chamaesyce hirta	0.2	0	0	0.3	0	0	0	0	0	0	0	0
Themeda triandra	0	0	0	0	0.7	0	0	2.7	0	0	0	0
Eragrostis lehmanniana	0	0	0	0	0	0.2	0	2	0	0	0	0
Veronica persica	0	0	0	0	0	0	0	0	0	0.7	0	3

To summarise the results, a clear distinction exists between species composition and abundances of sites situated in the shade (to the bottom of the RDA tri-plot) and sites occurring in full sunlight (top of tri-plot). The successional change that occurred in the experimental plots can also be inferred from the diagram. All 12 sites were managed by mowing before the experiment was initiated. Six plots were continuously mown and six plots were not mown. Three sites of the mown and unmown plots were under the shade of trees and three plots were in full sunlight. The abundance of the species in the plots in the full sunlight that were left unmown, changed from being characterised by *Cynodon dactylon* (Cyn dac), *Conyza podocephala* (Con pod), *Ciclospemum leptophyllum* (Cic lep), *Chloris pycnothrix* (Chl pyc) to being characterised by *Hyparrhenia hirta* (Hyp hir), *Themeda triandra* (The tri) and *Stellaria media* (Ste med). If the descriptions of the plant communities of intensively managed sites of the Potchefstroom Municipal Area (Cilliers & Bredenkamp, 1999a) as discussed under 3.3 in Chapter 3 of this thesis, are taken into consideration, it seems as if the managed grasslands changed from a *Hermannia depressa – Ledebouria revoluta* Community to a community not even described before in intensively managed sites. The "new" community that developed in the unmown sunny sites resembles to a certain degree the *Hyparrhenia hirta* Community described as a secondary, climax grassland along roadside verges in Potchefstroom (Cilliers & Bredenkamp, 2000). Plots occurring in the shade were also affected by the change in management practices. After mowing was stopped in six of the plots the vegetation changed from a dominant *Dichondra repens* (Dic rep), *Chamaesyce hirta* (Cha hir) vegetation to *Paspalum dilatatum* (Pas dil), *Veronica persica* (Ver per) and *Sporobolus africanus* (Spo afr). In shady areas there was a change from probably a *Chamaesyce hirta – Cynodon dactylon* Community to a community in which the tall-growing grass, *Paspalum dilatatum* dominated. Similar communities were described on pavements subjected to irrigation (Cilliers & Bredenkamp, 1999a) and along heavily disturbed wetland areas (Cilliers *et al.*, 1998) in the Potchefstroom Municipal Area. Another interesting aspect to note is that species with a creeping and stoloniferous growth form were now less abundant in the unmown areas than the species with a more upright growing, tufted growth form (Tables 4.7 and 4.8).

4.3.5 Vegetation dynamics of pavements

In Figure 4.13 the effect of compaction and time (years 1999-2001) on species compositional changes is shown by an RDA tri-plot ordination graph. The eigenvalues of the first two axes were very low at 0.083 and 0.036 respectively and therefore explained only 12% of the species data and 100% of the species-environment relationships. Most of the variation found in this ordination is explained by the first ordination axis, which has a species-environment relationship of 0.58. The first ordination axis of the RDA tri-plot can be best explained by compaction (r = -4.43). The second ordination axis was weakly associated with year (r = -0.37), this could be expected because no change in management practices exists over the study period.

The following results can be derived from the RDA tri-plot. Species situated to the left of ordination axis 1 are those that have higher abundance in areas with higher compaction levels (Figure 4.13). These species include *Cynodon hirsutus* (Cyn hir), *Guilleminea densa* (Gui den) and to a lesser degree *Dactyloctenium aegyptium* (Dac aeg), *Conyza bonariensis* (Con bon) and *Tribulus terrestris* (Tri ter) (Figure 4.13). Compaction can be correlated with trampling or amount of load moving over the soil of a given area and, it would be important to compare this information to the actual data of sample plots studied on pavements which had undergone heavy trampling (Tables 4.10, 4.14 and 4.16). In residential areas and next to sports fields *Cynodon dactylon* (Cyn dac) and *Guilleminea densa* (Gui den) have the highest importance values (Table 4.10 and 4.14) while *Pennisetum clandestinum* (Pen cla) and *Guilleminea densa* (Gui den) dominated the commercial areas. In residential areas *Cynodon hirsutus* (Cyn hir) was abundant in 1999 but was not encountered in 2000 and 2001 – the only explanation for this is incorrect identification and the data with respect to *Cynodon hirsutus* (Cyn hir) are not "valid" (Table 4.10). Although ordination axis 1 is poorly associated with time, there was quite an increase in species richness noted from 1999 to 2000 on all the heavily trampled pavements (higher compaction) (Table 4.10, 4.14 and 4.16) and to a lesser extent on moderately trampled pavements (Table 4.9, 4.12 and 4.15). This phenomenon is a clear indication of the dynamic nature of intensively managed areas.

Species situated to the right of ordination axis 1 are those that have higher abundance in areas with lower compaction levels (Figure 4.13). These species include *Paspalum dilatatum* (Pas dil), *Chamaesyce hirta* (Cha hir), *Dichondra repens* (Dic rep), *Modiola caroliniana* (Mod car) and *Cynodon dactylon* (Cyn dac) (Figure 4.13). All these species mentioned have shown high importance values in lightly-trampled pavements in residential areas (Table 4.11) and to a lesser degree in moderately trampled pavements in residential areas, commercial areas and along sports fields (Table 4.9, 4.12 and 4.15). On lightly-trampled pavements next to sports fields the species composition was quite different from most of the other pavement areas with *Eragrostis lehmanniana* (Era leh), *Cynodon dactylon* (Cyn dac) and *Chloris pycnothrix* (Chl pyc) the species with the highest importance values.

When looking at pavements with moderate trampling, the following was evident. The species with the highest importance values in all three areas (residential, commercial and next to sport fields) of the first year of the study were mainly *Cynodon dactylon* (Cyn dac), *Guilleminea densa* (Gui den), *Chamaesyce hirta* (Cha hir), *Chamaesyce inaequilatera* (Cha ina) and *Alternanthera pungens* (Alt pun). *Cynodon dactylon* (Cyn dac) decreased in importance value from the first (1999) to the second year (2000) in both areas with moderate trampling (residential and next to sports fields) (Tables 4.9 and 4.12). In the third year (2001) in both areas mentioned, *Cynodon dactylon* (Cyn dac) slightly increased again in importance value but in the second year (2000) the importance value decreased because of a lower density, frequency and basal cover.

On pavements with moderate trampling in commercial areas, *Cynodon dactylon* (Cyn dac) was only noted from the second year (2000) to the third year (2001) (Table 4.15). *Guilleminea densa* (Gui den) decreased in importance value over the three-year period on pavements with moderate trampling (Table 4.12 and 4.15), except on pavements with moderate trampling in residential areas (Table 4.9). In the residential area (Table 4.9) *Guilleminea densa* (Gui den) had a lower importance value in the second year (2000), but increased dramatically in the third year (2001). *Chamaesyce hirta* (Cha hir) and *Chamaesyce inaequilatera* (Cha ina) did not change significantly in abundance on pavements with moderate trampling. *Alternanthera pungens* (Alt pun) had varied importance values over the three years (1999-2001) on the different pavements. On pavements in residential areas (Table 4.9) *Alternanthera pungens* (Alt pun) was only noted in the third year (2001).

On pavements with moderate trampling next to sports fields *Alternanthera pungens* (Alt pun) increased in importance in the second year (2000), but decreased in the third year (2001), mainly because of changes in density and frequency (Table 4.12). On pavements in commercial areas with moderate trampling, *Alternanthera pungens'* (Alt pun) importance value decreased over the three-year period (1999-2001), due to changes in density, frequency and basal cover (Table 4.15).

Species with high importance values on lightly-trampled pavements (Table 4.11 and 4.13) were *Cynodon dactylon* (Cyn dac), *Paspalum dilatatum* (Pas dil), *Guilleminea densa* (Gui den), *Chamaesyce hirta* (Cha hir) and *Chloris pycnothrix* (Chl pyc). *Cynodon dactylon* (Cyn dac) decreased in importance value in the second year (2000) and increased again in the third year (2001), on both pavements (Table 4.11 and 4.13). *Paspalum dilatatum* (Pas dil) was only present on pavements that were lightly trampled in the residential area. The importance value of *Paspalum dilatatum* (Pas dil) decreased over the three-year period due to a decrease in species density, frequency and basal cover (Table 4.11). *Guilleminea densa* (Gui den) generally decreased in importance value over the three-year period on pavements with light trampling, because of a decrease in species density. *Chamaesyce hirta* (Cha hir) increased in importance value, on pavements in residential areas with light trampling (Table 4.11), over the three-year period (1999-2001). *Chloris pycnothrix* (Chl pyc) increased in importance value, on pavements next to sports fields with light trampling (Table 4.13), over the three-year period (1999-2001). One must also take into consideration the changes of environmental factors such as rainfall, can also influence species importance values. The effect of rainfall was not measured in the study, but must be investigated in further studies.

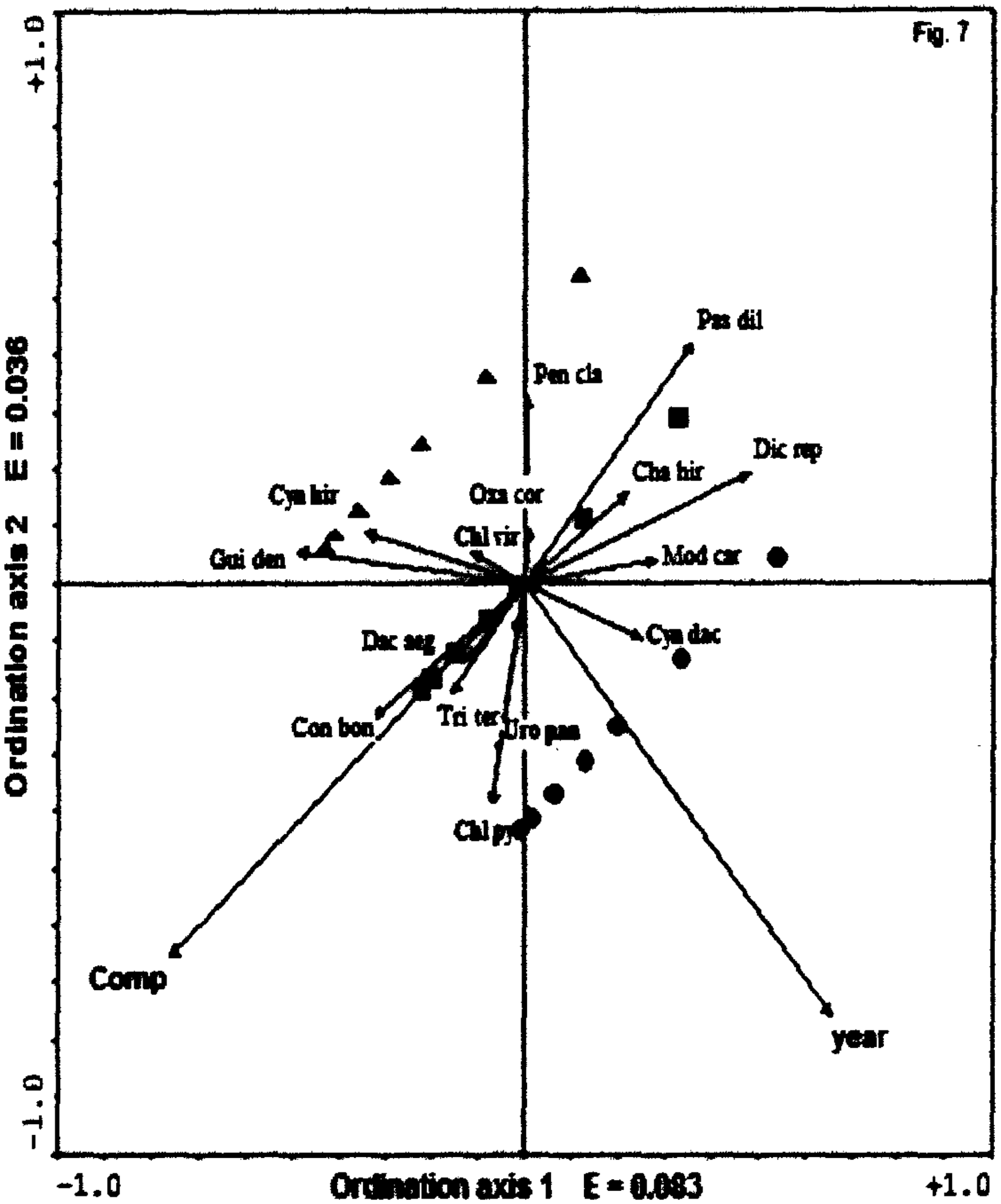

Figure 4.13: RDA-ordination tri-plot of pavements situated in Potchefstroom, to show the effect of compaction and years (time) on pavements areas on the species composition. The symbols in the ordination represent the sample plots studied over the different years of the survey; red triangles = 1999, green squares = 2000 and blue circles = 2001. Abbreviations of relevant species names will be explained in text.

Table 4.9: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on pavements in residential areas with moderate trampling, over the three-year period (1999-2001).

Pavement (Residential area) moderate trampling												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	34.7	26.5	10.7	202.3	33.2	20	5.5	153.1	40.7	17	5.2	160.1
Guilleminea densa	11	2.2	1	41.2	8	2	0	20.2	4.7	1.5	0	12.6
Chamaesyce inaequilatera	0	0.5	0.2	3	1.2	1	0	5.8	2	0.2	0	3.8
Chamaesyce hirta	0.2	0	0	0.5	2	0.2	0	4	1	0	0	1.4
Conyza bonariensis	0	0	0	0	0.2	0	0	0.4	0	0	0	0
Dichondra repens	0	0	0	0	21	0.2	0	32	16.2	1	0.2	27.5
Eragrostis lehmanniana	0	0	0	0	0	0.2	0	1	1	0	0	1.4
Modiola caroliniana	0	0	0	0	1	0.2	0	2.5	1.2	1	0	5.7

Table 4.10: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on pavements in residential areas with heavy trampling, over the three-year period (1999-2001).

Pavement (Residential area) heavy trampling												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	13.7	10	2.5	101.4	21.7	12.2	1.5	117.1	24.7	17.2	2.5	155.2
Cynodon hirsutus	4.2	5	1.2	41.5	0	0	0	0	0	0	0	0
Guilleminea densa	7.2	8.7	0.5	16.4	5.5	1.2	0	16.4	4.7	3	0	26.6
Dichondra repens	0	0	0	0	0.7	0.2	0	3.1	0	0	0	0
Lepidium bonariense	0	0	0	0	0.7	0.5	0	4.1	0	0	0	0
Eragrostis lehmanniana	0	0	0	0	1	1.5	0	8.9	0.5	0	0	1.5
Chamaesyce inaequilatera	0	0	0	0	4	7	1	42.4	0	0.2	0	1
Modiola caroliniana	0	0	0	0	0.7	0.2	0	4.1	1.3	0.2	0	3.3
Medicago polymorpha	0	0	0	0	0	0.2	0.2	2	0	0	0	0
Urochloa panicoides	0	0	0	0	0.2	0	0	0.7	0	0	0	0
Chamaesyce hirta	0	0	0	0	0.5	0.2	0	2.4	0	0	0	0
Tragus berteronianus	0	0	0	0	0.5	0	0	1.4	0	0	0	0
Tribulus terrestris	0	0	0	0	0.5	0	0	1.4	1	0.5	0	5.1
Dactyloctaenium aegyptium	0	0	0	0	0	0	0	0	0.5	0.2	0	2.5

Table 4.11: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on pavements in residential areas with light trampling, over the three-year period (1999-2001).

Pavement (Residential area) light trampling												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	14.4	6.3	3.2	131.8	13.8	5.9	1	108.3	26.6	6.2	0.3	121.1
Paspalum dilatatum	10.4	2.6	1.2	64.6	5.8	1.4	0.7	37.5	6.6	1.9	0.3	35.9
Guilleminea densa	4.7	0.7	0.1	20	0.7	0.1	0	3	0.9	0.3	0	4.9
Chamaesyce hirta	2.5	0	0	6.4	3.7	0.6	0	15.1	2	0.3	0	7.2
Chamaesyce inaequilatera	0.9	0.2	0.1	5.6	0.7	0.2	0	4	0.3	0.2	0	2.6
Dichondra repens	1.4	0.1	0	4.6	1.4	0.1	0	5	4.8	0.6	0.1	17.1
Alternanthera pungens	0.9	0.1	0.1	4.3	0.7	0.3	0	5	0.3	0	0	0.6
Cyperus esculentus	1.6	0	0	4.1	0.3	0.1	0	1.9	1.3	0	0	2.7
Modiola caroliniana	1.2	0	0	3.1	5.3	1.3	0.1	30.5	2.8	0.5	0	10.9
Oxalis corniculata	0.4	0	0	1	1	0	0	2.8	1.3	0	0	2.7
Lepidium bonariense	0.1	0	0	0.8	0.9	0	0	2.6	0	0	0	0
Malvastrum coromandelianum	0.1	0	0	0.3	0	0	0	0	0	0	0	0
Chloris pycnothrix	0.1	0	0	0.3	0	0	0	0	0.1	0	0	0.2
Conyza bonariensis	0	0	0	0	0.3	0	0	0.9	0.3	0	0	0.6

Table 4.12: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on pavements next to sports fields with moderate trampling, over the three-year period (1999-2001).

Pavement (next to sport field) moderate trampling												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	2.7	5.2	1.2	115.2	9.2	5.5	0.2	46.9	10.7	6.2	1	61.1
Guilleminea densa	2.7	5	2	48.7	9.7	4	0.2	42.2	2.5	2.5	0	22.7
Chloris pycnothrix	2.2	0.5	0.2	14	7.5	6	1.2	49.4	7	5.2	0.2	45.9
Alternanthera pungens	1	2	0.2	13.9	4.2	1.7	0	18	1	2.7	0	14
Urochloa panicoides	1	1.2	0.2	10.9	1	0.2	0	3.6	9.7	5	0.7	48.4
Chloris virgata	0.5	0.5	0	4.2	0	0	0	0	0	0	0	0
Tragus berteronianus	0.2	0.5	0	3.2	0.2	0	0	0.6	0	0	0	0
Gomphrena celosioides	0.2	0.2	0	2.2	0	0	0	0	0	0	0	0
Chamaesyce hirta	0.2	0	0	1.2	2	1	0	8.2	0.2	0.2	0	1.7
Dactyloctenium aegyptium	0	0	0	0	1.7	2	0.5	14.5	0	0	0	0
Eragrostis lehmanniana	0	0	0	0	1.7	3.7	0	21.8	0.2	1	0.2	5.7
Tribulus terrestris	0	0	0	0	0.2	0	0	0.6	0	0	0	0
Portulaca oleracea	0	0	0	0	0	0	0	0	0.2	0	0	0.7
Modiola caroliniana	0	0	0	0	0	0	0	0	0.2	0.2	0	1.7

Table 4.13: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on pavements next to sports fields with light trampling, over the three-year period (1999-2001).

Pavement (next to sport field) light trampling												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Eragrostis lehmanniana	5.3	4.1	0.7	59.5	2.7	1.4	0.3	22.3	0.4	0.6	0	5.1
Cynodon dactylon	4.6	2.6	0.3	45.4	1.4	1.6	0	16.5	4.6	1.9	0.1	27.5
Chloris pycnothrix	1.4	1	0	14.2	7.5	4.3	0.8	66	16.1	5.3	0	86
Guilleminea densa	0.9	0.9	0.1	12.3	0.3	0.4	0	4.1	0.2	0.9	0.1	7.6
Dactyloctenium aegyptium	0.4	0.6	0	10.8	1.4	1	0	12.7	2.1	0.6	0	10.4
Malvastrum coromandelianum	1.1	0.6	0	9.8	0.2	0.1	0	2.2	0.2	0.7	0	6.1
Panicum maximum	0.9	0.6	0.1	9.3	0.1	0.5	0	4.4	0.1	0	0	0.4
Urochloa panicoides	0.3	0.3	0	6.3	1	0.6	0	8	1.4	0.9	0.1	11.1
Melinis repens	0	0.7	0	5	0.4	0.5	0	5.6	1.4	1	0	11.1
Conyza podocephala	0.7	0.3	0	4.9	0	0	0	0	0	0	0	0
Oxalis corniculata	0.7	0.1	0	4.6	1	0	0	4.2	0	0	0	0
Conyza bonariensis	0.3	0.3	0	3.4	1.3	0.3	0	7.9	1	0.2	0	5
Modiola caroliniana	0.1	0.3	0	3.4	0.7	0	0	3	2.7	1.3	0	9
Alternanthera pungens	0.3	0	0	1.4	0	0	0	0	0.7	0	0	2.2
Taraxacum officinale	0.1	0	0	0.7	0	0.1	0	1	0	0	0	0
Bromus catharticus	0	0	0	0	0.2	0.2	0	3.1	0	0	0	0
Chenopodium album	0	0	0	0	0.7	0.1	0	4	0.7	0.6	0	6
Pseudognaphalium luteo-album	0	0	0	0	2.5	0.5	0	15.8	0.2	0.1	0	1.8
Pennisetum clandestinum	0	0	0	0	0.4	0.2	0.1	4.7	0	0	0	0
Capsella bursa-pastoris	0	0	0	0	0.1	0.1	0	1.6	0	0	0	0

Table 4.14: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on pavements next to sports fields, with heavy trampling, over the three-year period (1999-2001).

Pavement (next to sport field) heavy trampling												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	13.7	12.2	2.2	120.7	10.2	6.7	0.7	63.1	15.5	14.2	1.5	113.4
Guilleminea densa	2.2	4.7	0.5	31.6	5.7	5.7	0	41.5	5.5	4.2	0.2	35.9
Eragrostis lehmanniana	3.7	2.7	0	28.6	7.2	3.7	0.2	39.4	1.2	1.5	0	10.1
Alternanthera pungens	1	0.7	0	7.7	1	1	0	7.2	3.5	0.5	0	13.4
Tribulus terrestris	0.5	0.5	0	4.4	0	0	0	0	0	0	0	0
Chloris pycnothrix	0.2	0	0	1	2.5	2.2	0.5	19.1	2.2	0.2	0	8.3
Urochloa panicoides	0	0.2	0	1	0.5	0.5	0	3.6	0.7	0.5	0	4.4
Chamaesyce hirta	0	0	0	0	0.7	1	0.2	7.4	0	0	0	0
Dactyloctaenium aegyptium	0	0	0	0	0.2	1.5	0.2	7.8	0	0.7	0	3
Malvastrum coromandelianum	0	0	0	0	0.7	0.2	0	3.4	0.2	0	0	0.8
Conyza bonariensis	0	0	0	0	0.2	0	0	0.8	0	0	0	0
Tragus berteronianus	0	0	0	0	0.2	0.2	0	1.8	0	0	0	0
Lepidium bonariense	0	0	0	0	0.5	0	0	1.6	0	0	0	0
Chamaesyce inaequilatera	0	0	0	0	0.5	0.2	0	2.6	0.7	0	0	2.4
Amaranthus hybridus	0	0	0	0	0.2	0.2	0	0.8	0	0	0	0
Modiola caroliniana	0	0	0	0	0.2	0.5	0	2.8	0	0	0	0

Table 4.15: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on pavements in commercial areas with moderate trampling, over the three-year period (1999-2001).

Pavement (Commercial area) moderate trampling												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Pennisetum clandestinum	20.2	14.7	3.7	125.6	4.2	2.5	0.7	19	10.5	3.5	1	27
Dichondra repens	9.2	4.5	1	45.6	38.5	10.7	1.7	104.8	78	13.5	2	128.8
Guillemenea densa	5.2	2.2	0.7	25.4	2.7	0.7	0	6.9	0.7	1.2	0	5.6
Alternanthera pungens	4	3	0.5	24.2	4.7	3.5	0.2	21.8	1.2	1	0	5.1
Modiola caroliniana	0.5	0.2	0	2.3	1.5	0.2	0	3.1	0	0	0	0
Gomphrena celosioides	0	0.2	0	1	0	0	0	0	0	0	0	0
Cynodon dactylon	0	0	0	0	14.7	4	0.5	41	21.5	4.7	0.5	39.4
Chamaesyce hirta	0	0	0	0	1.2	0.2	0	2.8	1	0	0	0.9
Oxalis corniculata	0	0	0	0	0.7	0	0	1.1	0.2	0	0	0.2
Urochloa panicoides	0	0	0	0	1.7	0	0	2.5	3	0.7	0	5.6

Table 4.16: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species on pavements in commercial areas, with heavy trampling, over the three-year period (1999-2001).

Pavement (Commercial area) heavy trampling												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Pennisetum clandestinum	8.7	12	4.5	120.7	0	0.5	0	2	0	0.5	0.2	3
Guillemenea densa	5.5	7.5	2.7	75.4	5	2.2	0.2	28.4	2	1.5	0	9.3
Dactyloctaenium aegyptium	1.7	0.7	0	13.9	0.5	0.2	0	3.2	2.2	1.5	0.2	10.8
Alternanthera pungens	0	2.5	0.7	13	1	2.5	0	14.3	0.7	0.5	0	3.3
Cynodon dactylon	0	0	0	0	17.2	15.5	4	152	23.5	16.5	3.5	119.2
Urochloa panicoides	0	0	0	0	0.2	0	0	1.1	0.7	0	0	1.3
Dichondra repens	0	0	0	0	0	1.2	0	5	30	2.2	0.7	62
Chamaesyce hirta	0	0	0	0	0	0.2	0.2	2	0	0	0	0
Chloris pycnothrix	0	0	0	0	0	0	0	0	0.7	0	0	1.3

To summarise, the following could be seen in Tables 4.9 - 4.16. Moderate compaction/trampling on pavements is associated with high importance values of *Cynodon dactylon, Guillemenia densa, Dichondra repens* and *Pennisetum clandestinum*

(Table 4.9, 4.12 and 4.15). Pavements with heavy trampling (Tables 4.10, 4.14 and 4.16) are mostly associated with high importance values of *Cynodon dactylon* and *Guillemenia densa* that had a high species density and freqeuncy. This was not reflected in Figure 4.13 and could be explained by the fact that compaction is not strongly associated with ordination axis 2. On pavements that were lightly trampled (Table 4.11 and 4.13) species with high importance values were *Cynodon dactylon*, *Paspalum dilatatum* and *Eragrostis lehmanniana*. The density and frequency of these species were high on lightly trampled pavements. When looking at the results of pavements, *Cynodon dactylon* is very successful in these types of management practices independent of the different compaction levels. The reason for this is the lower growth form of this species as well as the method of reproduction through seeds, rhizomes and stolons. The typical plant community existing on pavements in the Potchefstroom Municipal Area (Cilliers & Bredenkamp, 1999a) as discussed under 3.3 in Chapter 3 is the *Guilleminea densa* - *Cynodon dactylon* Community. The trampling intensity determines which of the sub-communities and variants of this community dominates on the pavements. The *Paspalum dilatatum* Sub-community is more prominent on lightly-trampled areas while the *Alternanthera pungens – Guilleminea densa* Sub-community occurred more frequently on moderately and highly-trampled pavements. In most of the moderately and highly-trampled pavements, there is an increase in importance values of species which were not regarded as diagnostic for the described communities of pavements by Cilliers & Bredenkamp (1999a). This dynamic nature could lead to the development of other plant communities in which species such as *Chamaesyce inaequilatera* (Table 4.10), *Urochloa panicoides* (Table 4.12), *Chloris pycnothrix* (Table 4.14), *Dichondra repens* and *Pennisetum clandestinum* (Table 4.15) are the characteristic species.

4.3.6 Vegetation dynamics of the secondary grasslands inbetween eco-circles.

Figure 4.14 illustrates the RDA tri-plot of secondary grasslands between eco-circles and the effects of shade, sand, pH, potassium, compaction and silt on species composition. The eigenvalues of the first two axes were also very low at 0.075 (ordination axis 1) and 0.025 (ordination axis 2) respectively. As explained previously, several gradients can be found between the factors in this ordination. They include species that are positively associated with shade, namely *Schkuhria pinnata* (Sch bip), *Eragrostis lehmanniana* (Era lem) and *Taraxacum officinale* (Tar off). Species that are positively associated with pH and sandy soil are *Urochloa panicoides* (Uro pan), *Dichondra repens* (Dic rep) and *Malvastrum coromandelianum* (Mal cor). Species positively correlated with potassium are *Guilleminea densa* (Gui den) and *Eragrostis trichophora* (Era tri). Species positively associated with compaction are *Cynodon dactylon* (Cyn dac) and *Alternanthera pungens* (Alt pun). Species positively associated with silt are *Urochloa mosambicensis* (Uro mos) and *Tribulus terrestris* (Tu ter).

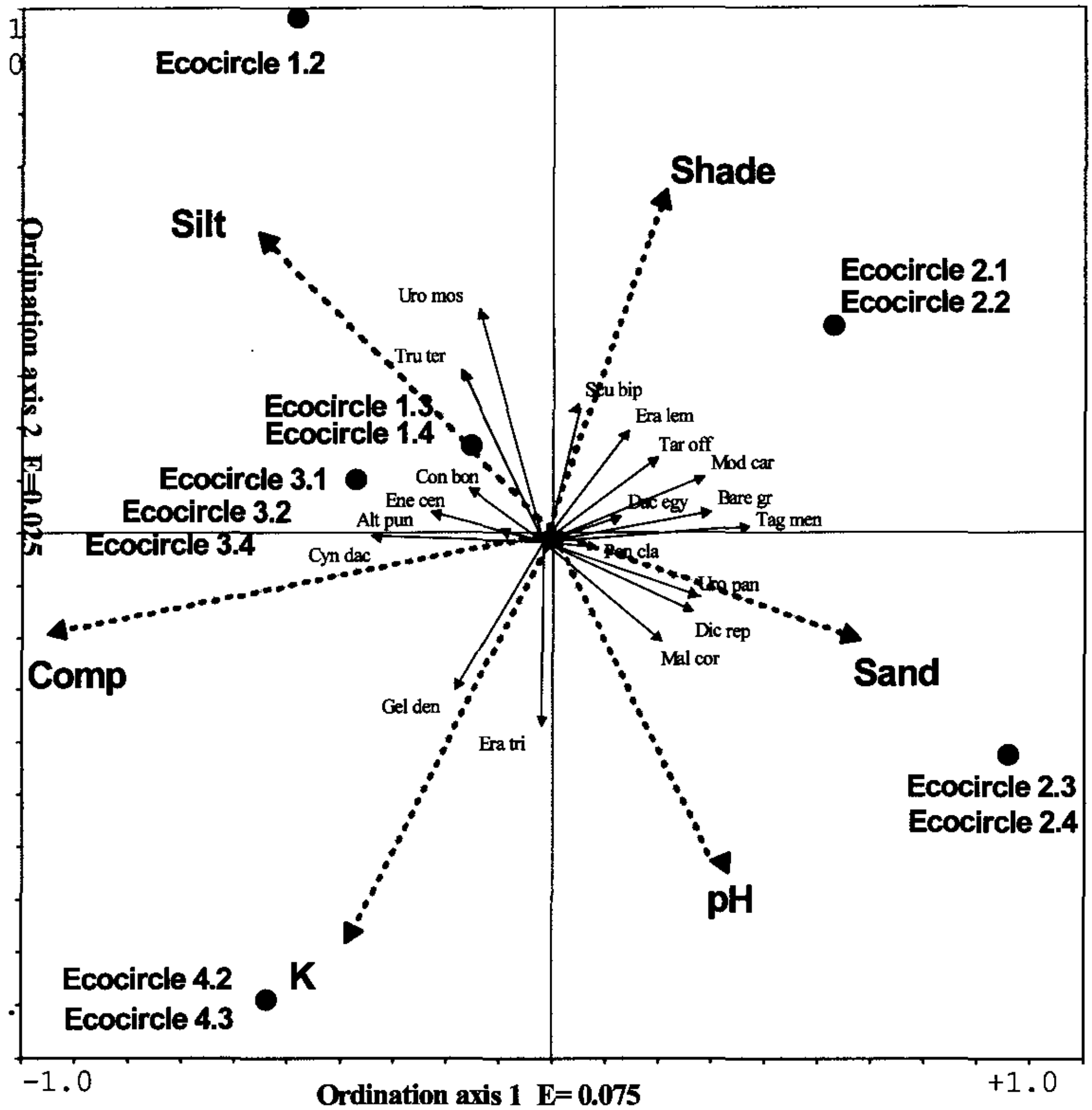

Figure 4.14: RDA ordination tri-plot of secondary grasslands inbetween eco-circles in Potchefstroom to show the effect of shade, sand, pH, potassium, compaction and silt on species composition. Abbreviations of relevant species names will be explained in text.

Table 4.17: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species in secondary grasslands area 1 (eco-circles 1.2-1.4), over the three-year period (1999-2001).

Secondary grassland (eco-circles) Area 1												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	3.3	11.6	1.3	69.4	15.6	19	0.7	135.5	45.6	16.25	3	189.4
Alternanthera pungens	2.3	2.7	0.7	33.4	2.5	2	0.3	22	0	0	0.3	1.3
Tribulus terrestris	0.7	2.3	0	15.2	0	0	0	0	0	0	0	0
Urochloa mosambicensis	1	1.3	0.3	14.1	3.7	2	0	24.6	0.7	0.7	0.3	5.3
Eragrostis trichophora	1	1.3	0	14.1	0.3	0	0	1.3	0	0	0	0
Schkuhria pinnata	1	0.3	0	10.1	0.7	0.3	0	3.8	0	0	0	0
Chloris pycnothrix	0.3	1	0	6.9	0	0	0	0	0	0	0	0
Enneapogon cenchroides	0.3	0.3	0	4.2	0	0	0	0	0	0	0	0
Eragrostis lehmanniana	0.3	0	0	2.9	0	0.7	0	2.7	0	0	0	0
Dactyloctaenium aegyptium	0.3	1	0	2.9	0.3	0.3	0	2.6	0	0	0	0
Urochloa panicoides	0	0.3	0	2.6	0	0	0	0	0	0	0	0
Verbena bonariensis	0	0	0	0	0.3	0	0	1.3	0	0	0	0
Conyza bonariensis	0	0	0	0	0.3	0	0	2.6	0	0	0	0
Malvastrum coromandelianum	0	0	0	0	0.7	0	0	2.5	0.3	0	0	0.7
Malva parviflora	0	0	0	0	1	0	0	3.8	0	0	0	0
Chenopodium album	0	0	0	0	0	0	0	0	1.3	0	0	2.6
Sida spinosa	0	0	0	0	0	0	0	0	0	0.3	0	1.3
Pennisetum clandestinum	0	0	0	0	0	0	0	0	2.3	2	0	12.6

Table 4.18: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species in secondary grasslands area 2 (eco-circles 2.1-2.4), over the three-year period (1999-2001).

Secondary grassland (eco-circles) Area 2												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Urochloa mosambicensis	1	2	0.5	50	0.5	1.2	0	7.5	1.5	0.5	0	5.5
Eragrostis trichophora	0.5	3.2	0	33	1	0.7	0	5.9	1.7	0.2	0	9
Cynodon dactylon	0	6.2	1	29	19.2	13.7	1	115.2	30	16.7	1.2	141.4
Setaria verticillata	0.5	0	0	20	0	0	0	0	0	0	0	0
Schkuhria pinnata	2	0.7	0	13	1.5	0.7	0	7.4	0.2	0	0	0.6
Malvastrum coromandelianum	0.2	0.2	0	11	0.5	0	0	1.5	0.7	0	0	1.7
Dactyloctaenium aegyptium	0	0.5	0	2	0.5	0.7	0	3.7	0	0	0	0
Pennisetum clandestinum	0	0.2	0	1	0	0.2	0	1	0	0.7	0	3
Eragrostis lehmanniana	0	0	0	0	2	1.2	0	7.8	0	0	0	0
Chloris pycnothrix	0	0	0	0	0.7	0.2	0	3.2	0	0	0	0
Tagetes minuta	0	0	0	0	0.2	0.7	0	3.7	0	0	0	0
Bidens formosa	0	0	0	0	7	2.5	0	30.4	0	0	0	0
Alternanthera pungens	0	0	0	0	1.2	1	0	7.6	0.2	0	0	0.6
Lepidium bonariense	0	0	0	0	0	0.7	0	3	0	0	0	0
Modiola caroliniana	0	0	0	0	0	0.2	0	1	0	1	0	4
Taraxacum officinale	0	0	0	0	0	0	0	0	5.2	1.7	0	19.1
Urochloa panicoides	0	0	0	0	0	0	0	0	0	0.5	0	2
Ciclospermum leptophyllum	0	0	0	0	0	0	0	0	0	0.2	0	1
Bidens bipinnata	0	0	0	0	0	0	0	0	3.2	1.5	0	13.5
Dichondra repens	0	0	0	0	0	0	0	0	0	0.7	0	3

Table 4.19: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species in secondary grasslands area 3 (eco-circles 3.1; 3.2 and 3.4), over the three year-period (1999-2001).

Secondary grassland (eco-circles) Area 3												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon dactylon	4	8.7	1.3	68.5	20.5	20	1.7	158.6	40	23.5	1.5	193
Eragrostis trichophora	2	1.3	0	33.1	1.7	0.7	0.3	8.4	0	0	0	0
Physalis viscosa	2.7	0.7	0	26.2	0	0.3	0	0.9	0	0	0	0
Urochloa mosambicensis	0.3	3.7	1.7	24.3	0	0.3	0	1.3	0.5	0	0	1.2
Chloris virgata	1	1	0.3	14.1	0	0	0	0	0	0	0	0
Alternanthera pungens	0.3	1.2	0	9.6	1	1.3	0	7.9	0	0	0	0
Schkuhria pinnata	0.3	0.3	0	4.2	1	0.7	0	5.3	0	0	0	0
Eragrostis lehmanniana	0	0.3	0.3	2.6	0	0	0	0	0	0	0	0
Dactyloctenium aegyptium	0	0.3	0	1.3	0	0	0	0	0	0	0	0
Enneapogon cenchroides	0	1.3	0	1.3	0	0	0	0	0	0	0	0
Malvastrum coromandelianum	0	0	0	0	1	1	0	5.8	0	0	0	0
Bidens formosa	0	0	0	0	6	0.3	0	17.1	0	0	0	0
Conyza bonariensis	0	0	0	0	0	0.3	0	1.3	0	0	0	0
Bidens bipinnata	0	0	0	0	0	0	0	0	2.5	1.5	0	11.8

Table 4.20: Changes in average density (number of individuals/m^2), average frequency (%), average basal cover (%) and importance values of selected species in secondary grasslands area 4 (eco-circles 4.2 and 4.3), over the three-yearperiod (1999-2001).

Secondary grassland (eco-circles) Area 4												
	1999				2000				2001			
Species	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value	Dens	Freq	Basal cov	Imp Value
Cynodon hirsutus	9.7	8.3	1	82.6	0	0	0	0	0	0	0	0
Cynodon dactylon	7.7	9.3	1	76.1	20	13.3	0.7	111	50	25	5.5	211
Eragrostis trichophora	2	1	0.3	14.4	5.7	4.7	0.7	37	0	0	0	0
Dactyloctenium aegyptium	0.3	2.3	0.7	13.5	1	1	0	6.8	0	0	0	0
Alternanthera pungens	1.7	1	0	11.6	1.7	3.3	0	17.9	0	0	0	0
Panicum coloratum	0.3	0.3	0	2.8	0	0	0	0	0	0	0	0
Chloris virgata	0.3	0	0	1.5	0	0	0	0	0	0	0	0
Malva parviflora	0.3	0	0	1.3	0	0	0	0	0	0	0	0
Chloris pycnothrix	0	0.3	0	1.3	1	1	0	6.8	0	0	0	0
Tribulus terrestris	0	0.3	0	1.3	0	0	0	0	0	0	0	0
Conyza bonariensis	0	0	0	0	5	0.7	0	16.5	0	0	0	0

In secondary grassland (Eco-circles) area 1 *Cynodon dactylon* (Cyn dac) and *Alternanthera pungens* (Alt pun) were most abundant in the first year (Table 4.17). In the second year (2000) *Cynodon dactylon* (Cyn dac) increased in density and frequency, but basal cover was less than the first year. *Alternanthera pungens* (Alt pun) density also increased in the second year (2000) but the frequency and basal cover decreased, giving the species a lower importance value. In the second year, *Urochloa mosambicensis* (Uro mos) became more prominent because of higher density and frequency. The basal cover, however, was less than the first year. In the third year (2001), *Cynodon dactylon* (Cyn dac) became very dominant because of a very high density, frequency and basal cover. *Alternanthera pungens'* (Alt pun) density and frequency decreased in the third year. *Urochloa mosambicensis'* (Uro mos) density and frequency decreased, while the basal cover increased in the third year.

In secondary grassland (Eco-circle) area 2 *Urochloa mosambicensis* (Uro mos), *Eragrostis trichophora* (Era tri) and *Cynodon dactylon* (Cyn dac) had the highest importance values in 1999 (Table 4.18). *Urochloa mosambicensis'* (Uro mos) importance value decreased over the three-year period mainly because of a lower density and basal cover in the second year (2000) and a lower frequency and basal cover in the third year (2001). *Eragrostis trichophora* (Era tri) in general decreased in importance value over the three-year period, but it was higher in the third year (2001) than the second year (2000). The reasons for the lower importance values were mainly because of a lower frequency in the second and in the third year. *Cynodon dactylon* (Cyn dac) increased in importance value over the three-year period. The reason for the increase in importance value over the three-year period was because of increasing density and frequency in the second (2000) and third year (2001), basal cover only increased in 2001. Species whose importance values also decreased over the three-year period were *Schkuhria pinnata* (Sch pin) and *Malvastrum coromandelianum* (Mal cor). Species that had a high importance value only in 2000 were *Eragrostis lehmanniana* (Era leh), *Chloris pycnothrix* (Chl pyc), *Tagetes minuta* (Tag min) and *Bidens Formosa* (Bid for).

Taraxacum officinale (Tar off) and *Bidens bipinnata* (Bid bip) had the highest importance value only in 2001.

In secondary grassland (Eco-circle) area 3, *Cynodon dactylon* (Cyn dac) and *Eragrostis trichophora* (Era tri) had the highest importance value in the first year of the study (Table 4.19). *Cynodon dactylon* (Cyn dac) increased over the three-year period in importance value mainly because of a higher density and frequency. The importance value of *Eragrostis trichophora* (Era tri) decreased over the three years and was not noted in the third mainly due to lower density and frequency. *Alternanthera pungens* (Alt pun) and *Schkuhria pinnata* (Sch pin) were also two species with high importance values in only the first two years (1999-2000). *Malvastrum coromandelianum* (Mal cor) and *Bidens Formosa* (Bid for) were only recorded in 2000. *Bidens bipinnata* (Bid bip) was only present in 2001.

In secondary grassland (Eco-circle) area 4, *Cynodon hirsutus* (Cyn hir), *Cynodon dactylon* (Cyn dac) and *Eragrostis trichophora* (Era tri) had the highest importance value in the first year of the study (Table 4.20). *Cynodon hirsutus* (Cyn hir) was only recorded in the first year but could be mistaken for *Cynodon dactylon* (Cyn dac) for the remaining two years, because of similar visual characteristics. The importance value of *Cynodon dactylon* (Cyn dac) increased over the three-year period, mainly due to a higher density and frequency in 2000 and 2001. *Eragrostis trichophora's* (Era tri) importance value also increased in the second year (2000), but this species was not noted in the third year. Species that were also noted over the first two years but not in the third year were *Dactyloctenium aegyptium* (Dac aeg), *Alternanthera pungens* (Alt pun) and *Conyza bonariensis* (Con bon).

When looking at secondary grassland (eco-circles), it is evident that the tendency over the three-year period in all the study sites (Tables 4.17 – 4.20), was that *Cynodon dactylon* became much more abundant over the three-year period while most other species became less abundant. With the exception of area 2 (Table 4.18), the general decrease in species richness from 1999 to 2000 and 2001 is clearly visible (Tables 4.17, 4.19 and 4.20). This shows the competitiveness of *Cynodon dactylon* in areas that undergone human disturbance. From Figure 4.14 it is clear that high compaction levels associated positively with an increase in abundance of *Cynodon dactylon*. There are, off course, other factors that also could contribute to the decrease in species richness, such as rainfall, temperature and availability of seed in the seed bank. Few other species have increased in abundance over time. Only *Pennisetum clandestinum* (Table 4.17), *Taraxacum officinale* (Table4.18) and *Bidens bipinnata* (Table 4.18 and 4.19) were also positively associated with human disturbances such as trampling inbetween eco-circles, in other words they show a similar reaction to *Cynodon dactylon*. None of the communities described in intensively-managed sites in Potchefstroom (Cilliers & Bredenkamp, 1999a) resemble the community encountered inbetween eco-circles.

4.4 Conclusions

The Biotopes of differently-managed areas differ with respect to importance values of species if Figures 4.8 and 4.10 - 4.11 are studied. These differences in species composition and abundance of the biotopes seemed to be the result, first of all of soil physical and chemical properties and secondly of anthropogenic influences such as mowing and trampling (Figure 4.9 together with Table 4.2). Changes in management practices and human impact such as the termination of mowing and weeding and increasing in trampling in areas, which haven't been disturbed for a while brought about changes in species importance values within one year (Figure 4.8 and 4.10). Changes in species importance values over time can be attributed to changes in management practices, especially in managed and ruderal grasslands.

In managed grasslands when management changed from being mown to not mown in certain areas (Table 4.7 and 4.8) the community changed from the community described by Cilliers & Bredenkamp (1999a), the *Chamaesyce hirta – Cynodon dactylon* Community, to a community not even described in intensively managed sites.

On pavements the trampling intensity determines which of the sub-comunities and variants of the community, described by Cilliers & Bredenkamp (1999a), dominate. The typical plant community existing on pavements in the Potchefstroom Municipal Area (Cilliers & Bredenkamp, 1999a) as discussed under 3.3 in Chapter 3 is the *Guilleminea densa - Cynodon dactylon* Community. The trampling intensity determines which of the sub-communities and variants of this community dominates on the pavements. The *Paspalum dilatatum* Sub-community is more prominent on lightly trampled areas while the *Alternanthera pungens – Guilleminea densa* Sub-community occurred more frequently on moderately and highly-trampled pavements. In most of the moderately and highly-trampled pavements, there is an increase in importance values of species which were not regarded as diagnostic for the described communities of pavements by Cilliers & Bredenkamp (1999a). In this study moderate compaction/trampling on pavements is associated with high importance values of *Cynodon dactylon, Guillemenia densa, Dichondra repens* and *Pennisetum clandestinum.* Pavements with heavy trampling are mostly associated with high importance values of *Cynodon dactylon* and *Guillemenia densa* that had a high species density and freqeuncy. This dynamic nature could lead to the development of other plant communities.

In secondary grasslands inbetween eco-circles, there were general decreases in species richness since human disturbance through trampling took place. There are of course other factors that also could contribute to the decrease in species richness, such as rainfall, temperature and availability of seed in seed bank. Therefore a more in-depth study over a longer time shoul be done to confirm these results.

In general our results have implied that the species composition of a specific managed area could be manipulated by changing the type and intensity of the management practice or anthropogenic influence. This could lead to an increase of richness and abundance of indigenous species in the intensively managed areas of our towns and cities. Before this could be proposed as management practice to municipal authorities, experimental studies are, however, needed to verify these results.

The time span over which this study took place was probably not long enough, although changes did occur within the first year, indicating the dynamic nature of disturbed areas. It is difficult to keep up with changes in management practices, especially if there is a long history of intensive management. It would, therefore, be better to study vegetation dynamics in space, which imply studies along gradients. Urbanisation gradient studies imply that areas which were relatively similar due to environmental characteristics and species composition, but which differ now regarding certain human impacts and management practices, are compared. The "gradient paradigm" is summarised as the view that environmental variation is ordered in space and that spatial environmental patterns govern the corresponding structure and function of ecological systems (McDonnell & Pickett, 1990). The degree of the environmental change in space determines, in part, the steepness of the gradient in system structure and function (McDonnell & Pickett, 1990). Interaction within the ecological systems and between the environmental gradient and ecological systems will affect the distribution and behaviour of systems along the gradient. Because urban areas appear so often as a dense, highly-developed core, surrounded by irregular rings of diminishing development, the gradient paradigm is a powerful organising tool for ecological research on urban influences on ecosystems. Urban-rural gradients, moreover, provide an opportunity to explicitly examine the influence of humans on the environment (McDonnell & Pickett, 1990).

Chapter 5
Seed bank Analysis

5.1 Introduction

A seed bank analysis is common practice for vegetation dynamic studies, but mostly focused on natural systems such as forests (Hanlon & Williams, 1998) and grasslands (Akinola *et al.*, 1998; Thompson *et al.*, 1990). Other studies include disturbed areas such as cultivated agricultural lands (Levassor *et al.*, 1990) and construction areas (Collins & Wein, 1995), but no interactions were found on seed banks of intensively managed urban sites. Seed bank analysis could, however, play a critical role in population dynamics and the survival of species in urban areas (Cilliers & Bredenkamp, 1998). Seed bank studies form the basis of regeneration of species after a disturbance has taken place. Studies show that after a disturbance has taken place, changes occurred in the composition and abundance of below and above-ground species. According to Odgers (1994) these changes in composition and abundance give certain species an advantage above species found in more natural areas. Human impact is the most important influence in urban vegetation dynamics. The effect of trampling is a good example. Trampled areas are highly compacted with a loss in organic material, the loss of plant cover and biodiversity and erosion of topsoil. In Potchefstroom, paved areas, as well as parks can be seen as intensively-managed areas. These areas under-go regular mowing, weeding and the use of pesticides are frequent (Cilliers & Bredenkamp, 1999a).

A number of studies have detailed above-ground plant species diversity of linear habitats in several countries. In intensively-managed areas the linear landscape elements (e.g. road verges) are among the few habitats left where natural or semi-natural vegetation subsists (Hansen & Jensen, 1972; Pollard *et al.*, 1974; Zanaboni & Lorenzini, 1989; Bunce & Hallam, 1993). The plant species diversity of these habitats constitutes a significant subset of the total biodiversity of such landscapes, and for this reason their management ought to be given careful consideration In contrast, the soil seed banks of these habitats have received much less attention (Milberg & Persson, 1994). The soil seed bank is, however, an important repository for the total plant species richness of a habitat. Often soil seed banks contain species or genotypes not found in the above-ground vegetation (e.g. Champness & Morris, 1948; Levin, 1990; Bennington *et al.*, 1991; Del Castillo, 1994). For the population dynamics and persistence of species, the soil seed bank plays a crucial role (Harper, 1977) and for the rational management of diversity and abundance, knowledge of the seed bank is literally vital (Keddy et al., 1989). According to Leck (1989), the seed bank of a site harbours a potential plant community. The contribution of this plant community to extant vegetation may differ with the local physical or biotic environment (Collins & Wein, 1995). The objective of this part of the study was to compare the seed bank composition with above-ground (extant) vegetation, in different biotope types and to compare the seed banks of different study sites in some of the biotope types.

5.2 Materials and Methods

5.2.1 Study area

The local municipality does the management of the study areas and their main practice is to mow the lawns to a height of about 50mm every 6 weeks between October and April (Cilliers & Bredenkamp, 1999a). Pavements (Figure 4.2-4.4) and the managed grasslands (Figure 4.1) in the Botanical garden were also included in the seed bank study. The samples taken in the botanical garden consisted of mown and unmown areas. Eco-circles were not included in the study, because the gravelly nature of the soil made it difficult to take samples inbetween all the eco-circles. The following biotopes and sample plots were used:

Paved areas

- Sample plots: 1,3,5,7: residential area = moderate trampling
- Sample plots: 2,4,6,8: residential area = heavy trampling
- Sample plots: 9-18: residential area = low trampling
- Sample plots: 19-22: next to sport field = heavy trampling

- ➢ Sample plots: 23-29: next to sport field = moderate trampling
- ➢ Sample plots: 30-33: next to sport field = moderate trampling
- ➢ Sample plots: 34-37: next to sport field = heavy trampling
- ➢ Sample plots: 38-41: commercial area = low trampling
- ➢ Sample plots: 42-45: commercial area = heavy trampling

(See Chapter 4 under point 4.2.1.1 (soil) for description of trampling/compaction scale)

Managed grassland areas

- ➢ Sample plot: 1-4 and 13-16: Botanical garden = low trampling and not mown
- ➢ Sample plot: 6-8 and 9-12: Botanical garden = moderate trampling and mown

5.2.2 Sampling methods

Soil was taken around the sample plots, containing the soil seed bank of each specific sample plot in March 2000. It was taken around and not in the plots, so that the vegetation was not disturbed over the three-year study period. Three core samples were taken in each sample plot about 30cm deep. Cores were returned to the laboratory where they were sieved, mixed into equal volumes and spread onto potting soil. Seedling trays were arrayed in a randomised block design on green house benches (Figure 5.1). The green house temperatures were set for 20°C at night and 25°C at day time (Figure 5.2). The seedling trays were irrigated every day and the emerging seedlings were counted and identified every second day. Seedlings were counted and removed as soon as they could be identified or they were transplanted for later identification. The density of the seedlings was therefore determined by the number of seedling counted per unit area, in the seedling trays (400 x 600mm). The number of above-ground species also reflects the density of the species in the 250 x 250mm sample area (see 4.2.2 of chapter 4). This is known as the "emergent" method (Ter Heerdt *et al.,* 1999). The number of seedlings per area will be discussed in the results.

Figure 5.1: Seedling trays were arrayed in a randomised block design on green house benches.

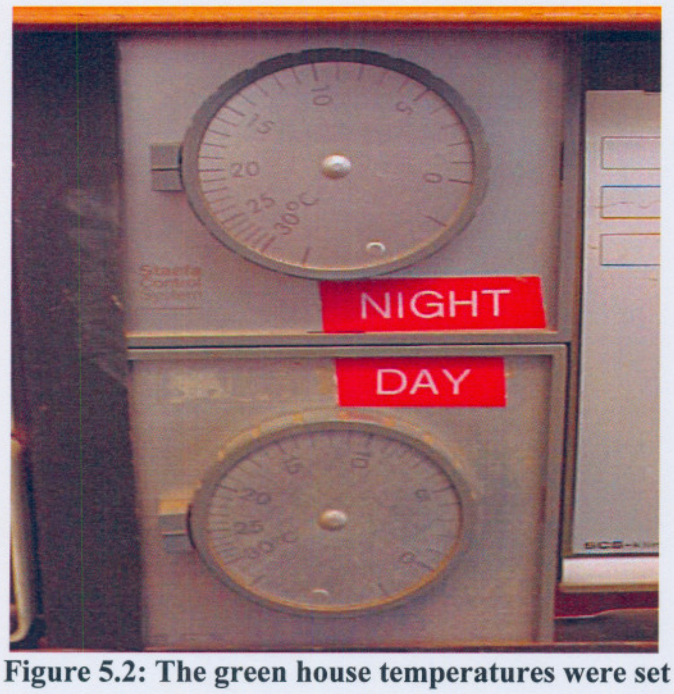

Figure 5.2: The green house temperatures were set for 20°C at night and 25°C through the day.

5.4 Results and Discussion

The results of the different study areas (see 5.2.1) will be discussed, using Windows Excel graphs (Figures 5.3 – 5-17), to show the number of individuals of selected species present above ground and in the seed bank in different human disturbances.

5.4.1 Paved areas

(a) Moderately trampled sites (sample plots 1, 3, 5, 7) in the residential area.

The above-ground vegetation is dominated by *Cynodon dactylon* and *Guilleminea densa* (Figure 5.3 and Table 4.9). Both of these species can reproduce also vegetatively and is probably the reason why no seeds could be recorded in the soil seed bank. Species that were recorded in the seed bank included *Alternanthera pungens*, *Chamaesyce hirta*, *Eragrostis lehmanniana* and *Medicago polymorpha* (Figure 5.3). Of these four species, *Alternanthera pungens* and *Medicago polymorpha* were not encountered in the above-ground vegetation (Figure 5.3 and Table 4.9). The reason for this could be that *Cynodon dactylon* and *Guilleminia densa* suppressed their development, and that the above-ground species are better adapted to the higher trampling conditions, or the environmental conditions such as rainfall and temperature were not favourable for the germination of the seeds at the time of sampling.

Cynodon dactylon is a creeping perennial native grass and spreads by means of an extensive system of stolons and underground rhizomes. It does not grow very tall, with the flowering stem rarely reaching 40cm. The flowers do produce viable seed (Bromilow, 1995). *Cynodon dactylon* is a vigorous grower and is capable of breaking up tarred or concrete surfaces. Its tough growth habit, however, also makes it a valuable grass for combatting erosion. This weed has an extensive underground system, and is extremely difficult to eradicate. *Cynodon dactylon* is not susceptible to most pre-emergence herbicides but can be controlled pre-emergently on roadsides and in industrial situations with some industrial herbicides (Bromilow, 1995).

Guilleminia densa is an annual exotic plant, reproducing also from seed. No explanation can be given for its absence in the soil seed bank. According to Bromilow (1995) the large, fleshy underground parts, can survive from year to year and for this reason it is a difficult weed to control. Removal by hand is difficult, because the plant can regrow from roots left behind. When using herbicides, it is always better to fertilise and avoid mowing for as long as possible prior to application. This allows the weed to become large, lush, vigorous and more capable of absorbing and translocating the herbicide (Bromilow, 1995).

Alternanthera pungens was supposedly introduced as an impurity of fodder brought in for the British troops during the Anglo-Boer War (Bromilow, 1995). The species followed the railway system and was usually first seen in areas near the station, being easily spread on grain sacks as they were loaded and unloaded. It is a very unpleasant weed as the fruits can penetrate bare feet and even stick to rubber soled shoes. It has a large tap root and roots at the nodes, thereby forming large mats which are difficult to remove (Bromilow, 1995).

Chamaesyce hirta occurs in bare exposed areas such as pathways, lawns and crops. This species is recorded as an alternate host to some important nematode species. The weeds are easy to remove by cultivation and are susceptible to conventional herbicides (Bromilow, 1995).

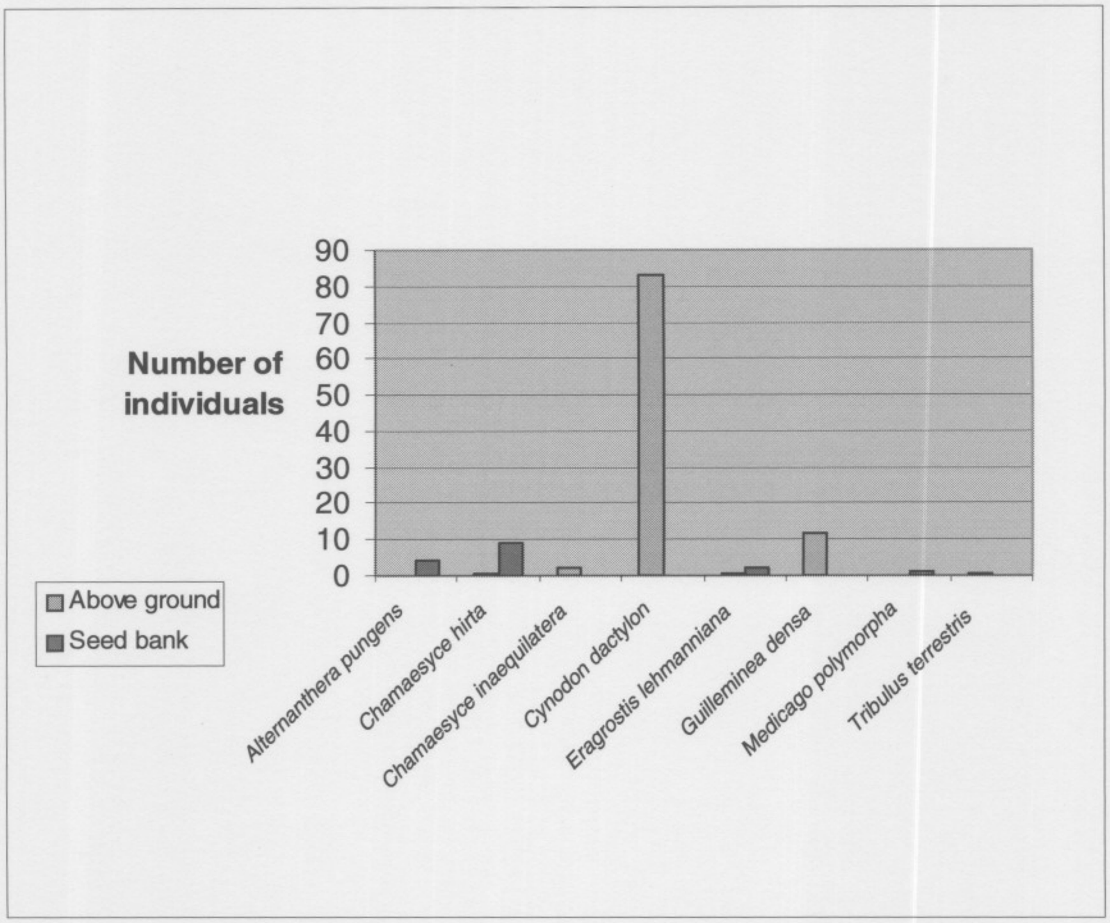

Figure 5.3: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (1,3,5,7) in moderately-trampled pavement areas in residential sites in the Potchefstroom Municipal Area.

(b) Heavy trampled sites (sample plots 2,4,6,8) in the residential area.

As in the moderately-trampled areas (Figure 5.3) the above ground is dominated by *Cynodon dactylon* and *Guilleminea densa* (Figure 5.4 and Table 4.10). The characteristics of these two species were already discussed under 5.4.1 (a). *Chamaesyce inaequilatera* also had a high presence above ground (Figure 5.4 and Table 4.10) and could be ascribed to the higher trampling zone. No explanation can, however, be given for the absence of any seeds of *Chamaesyce inaequilatera* as it has the same characteristics as *Chamaesyce hirta* (discussed earlier under 5.4.1(a). *Alternanthera pungens* had the highest presence in the seed bank, but was also not encountered above ground (Figure 5.4 and Table 4.10), in the case of moderately-trampled areas.

Other species that occurred in the seed bank (Figure 5.4) and also have relatively high importance values above ground (Table 4.10) were *Eragrostis lehmanniana*, *Tribulus terrestris* and *Urochloa panicoides*.

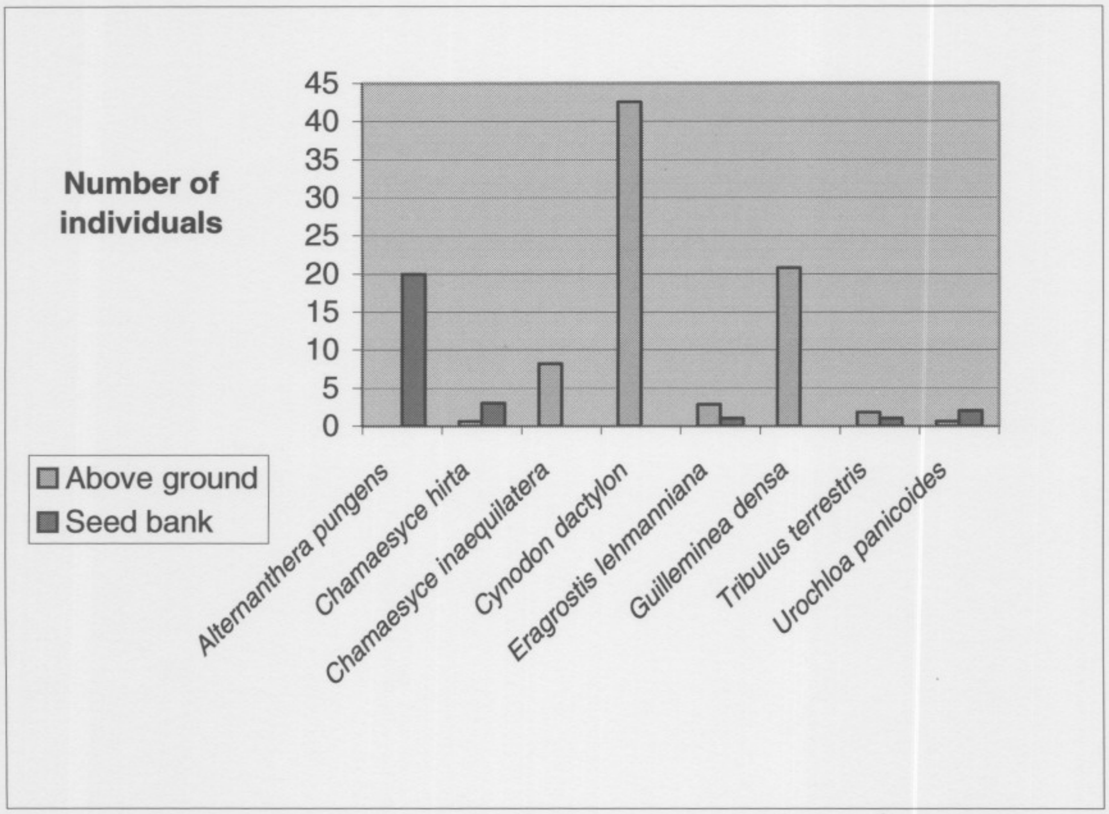

Figure 5.4: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (2,4,6,8) in heavily-trampled pavement areas in residential sites in the Potchefstroom Municipal Area.

(c) Lightly-trampled sites (sample plots 9-18) in the residential areas.

As for the 2 previous areas, *Cynodon dactylon* and *Gelleminia densa* are the dominant species in the above-ground vegetation (see discussion under 5.4.1(a) for characteristics of these two species) (Figure 5.5 and Table 4.11). *Paspalum dilatatum* is also dominant above ground and can be ascribed to the low trampling and higher moisture regime. *Paspalum dilatatum* is a perennial, being spread by seed or rhizomes, and is especially difficult to control once established. It is an important weed of fruit orchards, often interfering with micro-irrigation systems (Bromilow, 1995)

There is a difference in species composition of the seed bank, between lightly-trampled and moderately and heavily-trampled residential areas. *Malvastrum coromandellianum*, *Chenopodium carinatum* and *Eragrostis lehmanniana* is present in this seed bank of moderately-trampled areas (Figure 5.5) together with *Alternanthera pungens* and *Chamaesyce hirta*. *Malvastrum coromandelianum* is a common and sometimes serious weed of roadside, orchards, waste places and perennial crops in the summer rainfall region, with the exception of the Free State. It is very drought resistant and is found growing on dry road shoulders where other weeds may perish. The species reproduces with seed only (Botha, 2001). *Chenopodium carinatum* is a moderate competitor, except in dense stands where it strongly competes (Botha, 2001). *Eragrostis lehmanniana* is a very competitive grass, replacing preferred vegetation, and reproduces through seeds and stolons (Wells *et al.*, 1986).

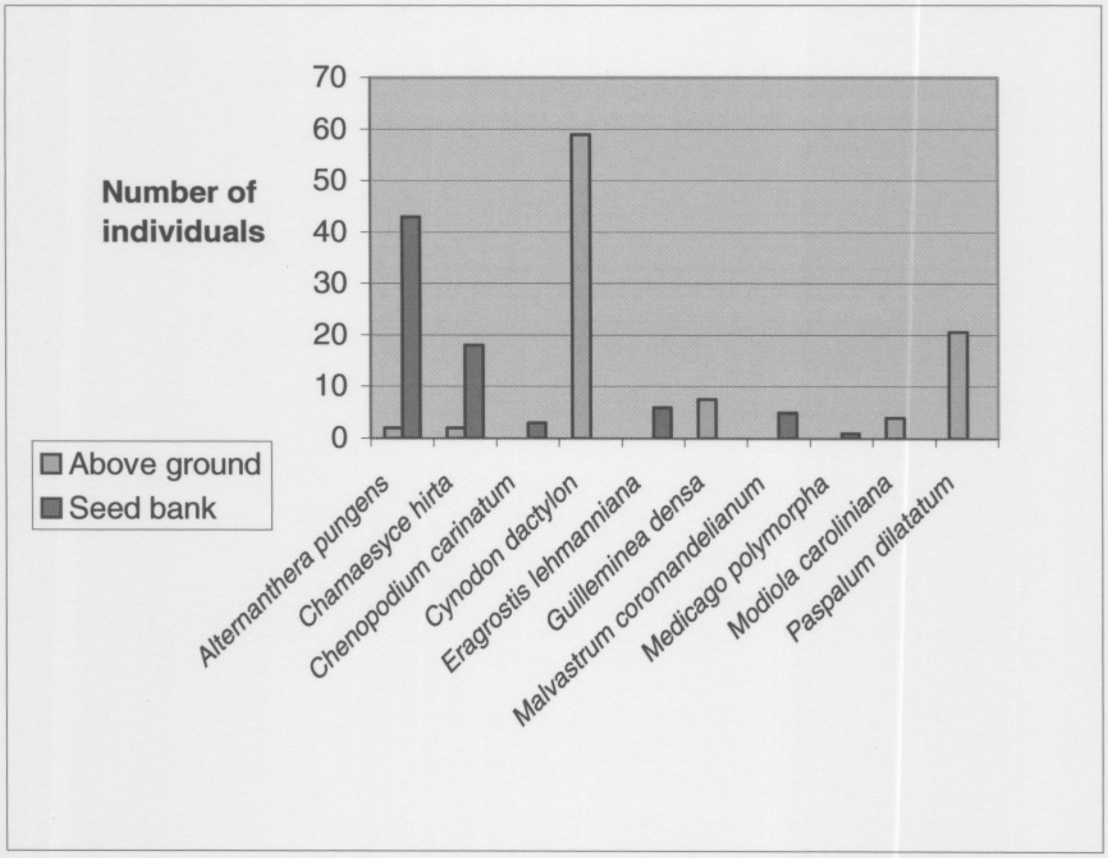

Figure 5.5: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (9-18) in lightly-trampled pavement areas in residential sites in the Potchefstroom Municipal Area.

(d) Heavily-trampled sites (19-22) next to sports fields

Pavements next to sports fields (sample plots 19-22) are characteri-sed by high trampling and a low moisture regime. *Cynodon dactylon* and *Guilleminia densa* dominate above ground (see description of species under 5.4.1 (a)), together with *Chloris pycnothrix* (Figure 5.6 and Table 4.14). The presence of *Chloris pycnothrix* in this area only shows that it could be restricted to certain areas in Potchefstroom. *Chloris pycnothrix* mainly occurs in cultivated fields, in gardens and along roadsides. It is a weak competitor, because it seldom occurs in dense stands. Reproduction take place through seed only and it is a shallow germinator (Botha, 2001). Other species that are also present include *Dactyloctenium aegyptium*, *Tragus berteronianus* and *Poa annua*. *Dactyloctenium aegyptium* spreads by means of stem-suckers formed where nodes on the stem touch the ground and take root. The plant produces an abundance of seed. It is found along roadsides and in waste places and is frequently a pest in sub-tropical fruit orchards (Bromilow, 1995). In the seed bank *Chamaesyce hirta* is dominant. Species that are present in both seed bank and above ground include *Alternanthera pungens* and *Eragrostis lehmanniana*.

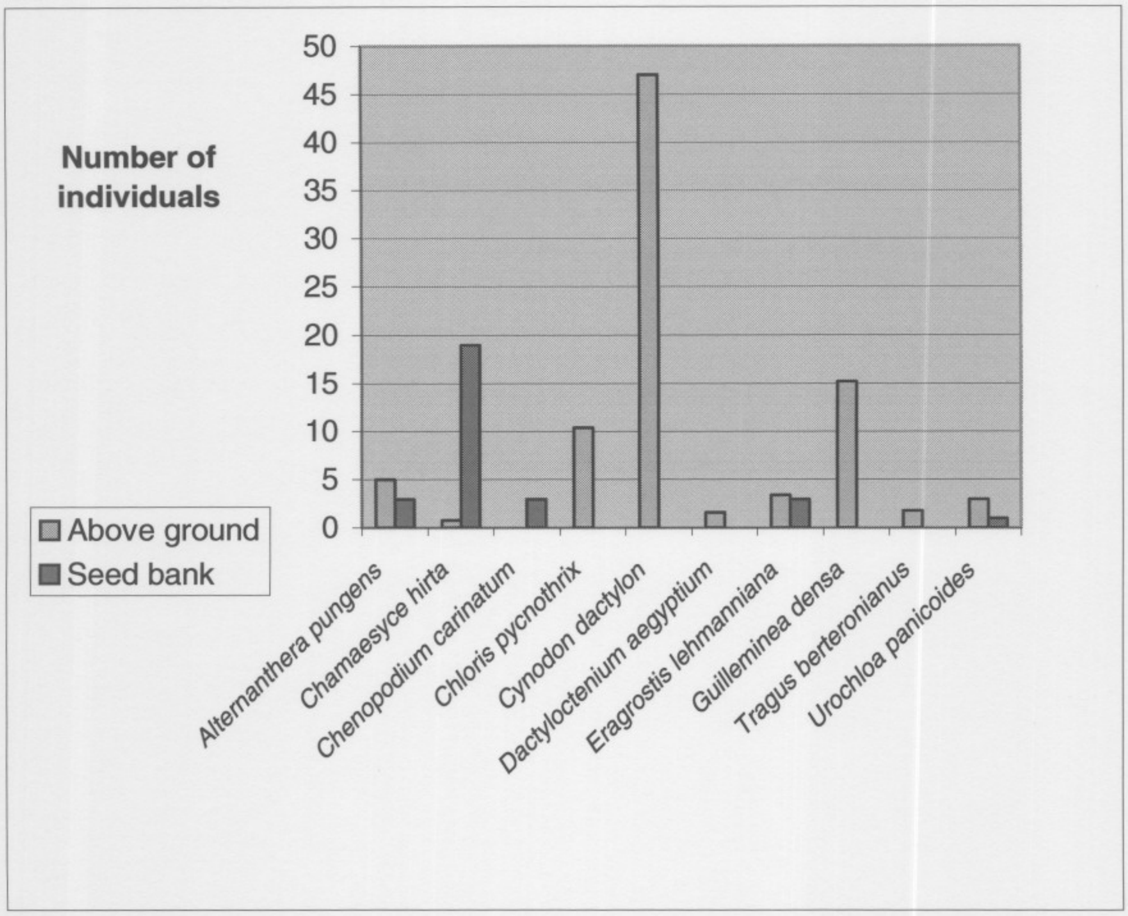

Figure 5.6: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (19-22) in heavily-trampled pavement areas next to sports fields in the Potchefstroom Municipal Area.

(e) Moderately-trampled sites (23-29) next to sport fields

This area has the highest species diversity. Species that are dominant above ground, include *Cynodon dactylon*, *Eragrostis lehmanniana* and *Chloris pycnothrix* (Figure 5.7 and Table 4.12). The number of individuals of *Cynodon dactylon* is low according to the other study sites. This shows that the other species are in competition with *Cynodon dactylon*. Species that compete with *Cynodon dactylon* include *Conyza bonariensis*, *Melinis repens*, *Panicum maximum* and *Urochloa panicoides*. The seed bank is dominated by *Chamaesyce hirta*, *Alternanthera pungens*, *Eragrostis lehmanniana*, *Chenopodium carinatum* and *Chenopodium album* (Figure 5.7).

Panicum maximum is a vigorous grower and a palatable plant. Some varieties have been selected and bred for commercial use as pasture grasses. The seedlings are very weak and slow growing and high mortality rates are experienced during drought periods. It is important to control this grass early, as plants that are not controlled at an early stage, develop large perennial clumps or "stools". These clumps are tolerant of even the strongest herbicides and must usually be removed by hand (Bromilow, 1995). *Melinis repens* is a common annual or short-lived perennial weed of places such as roadsides and waste places. It reproduces only by means of seed, but frequently takes root at the lower nodes (Bromilow, 1995). *Conyza bonariensis* are common annual weeds of gardens, roadsides, fallow land and forestry and to a lesser extent, annual crops (Bromilow, 1995). This species is a severe competitor, especially late in the season and reproduces through seeds only (Botha, 2001). *Urochloa panicoides* is a common weed in cultivated fields, in gardens and in disturbed areas. The seed especially germinates during the early season. This species reproduces through seeds only (Botha, 2001). *Chenopodium carinatum* is a moderate competitor and reproduces through seeds only. *Chenopodium album* is a severe competitor and reproduces only with seed.

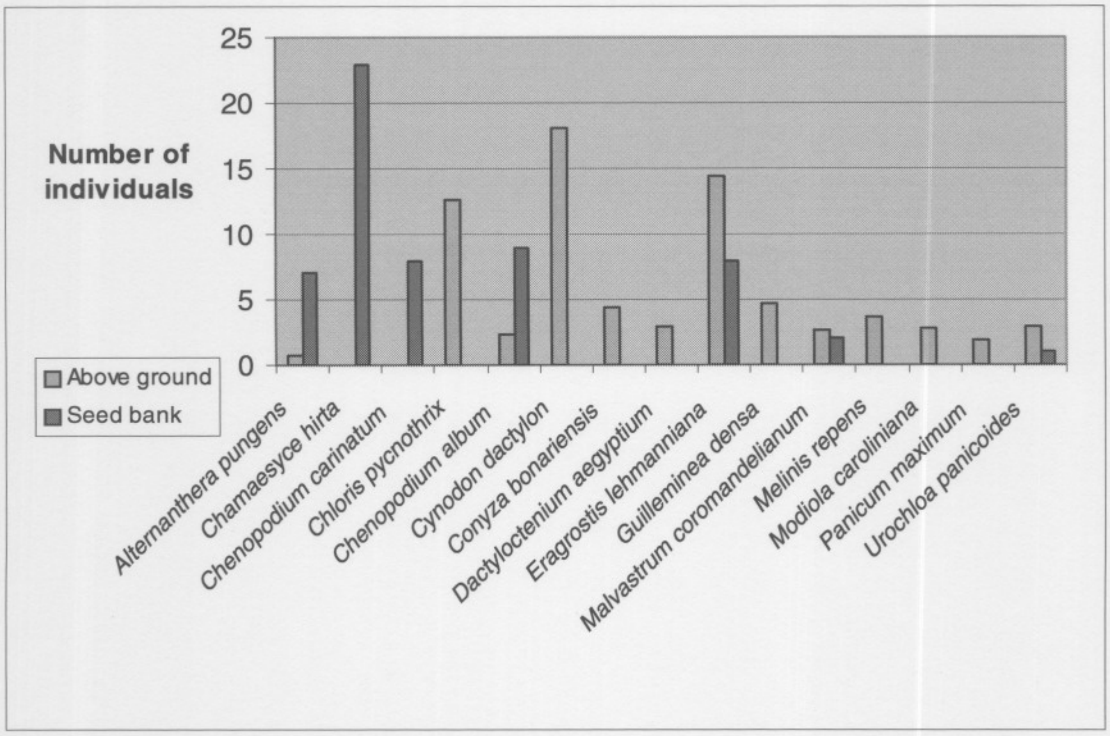

Figure 5.7: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (23-29) in moderately-trampled pavement areas next to sports fields in the Potchefstroom Municipal Area.

(f) Moderately-trampled sites (30-33) next to sports fields

The pavements next to sports fields (sample plots 30-33) are characterised by moderate trampling and a low moisture regime. The above-ground species composition is similar to the composition of species in the residential area with moderate trampling (Figure 5.8 and Table 4.12). The number of individuals of *Cynodon dactylon* is low according to the other study sites. The seed bank composition is similar to the residential area with moderate compaction. *Alternanthera pungens* is dominant in the seed bank. *Alternanthera pungens* is described under 5.4.1(a).

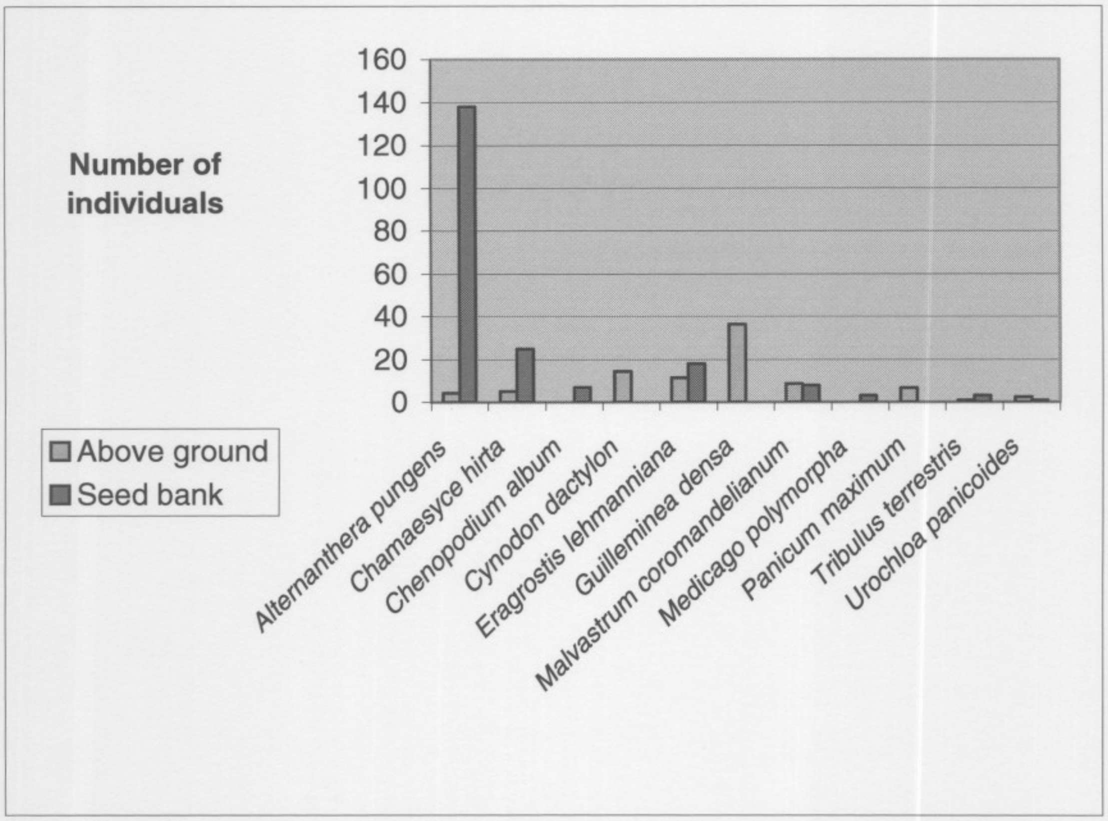

Figure 5.8: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (30-33) in moderately-trampled pavement areas next to sports fields in the Potchefstroom Municipal Area.

(g) Heavily-trampled sites (34-37) next to sports fields

Species that dominate above ground include *Cynodon dactylon*, *Guilleminia densa* and *Eragrostis lehmanniana*. *Alternanthera pungens* is present above ground and is dominant in the seed bank (Figure 5.9 and Table 4.14). The characteristics of these species are already explained under 5.4.1(a) and (c). *Eragrostis lehmanniana* had the highest presence in the seed bank.

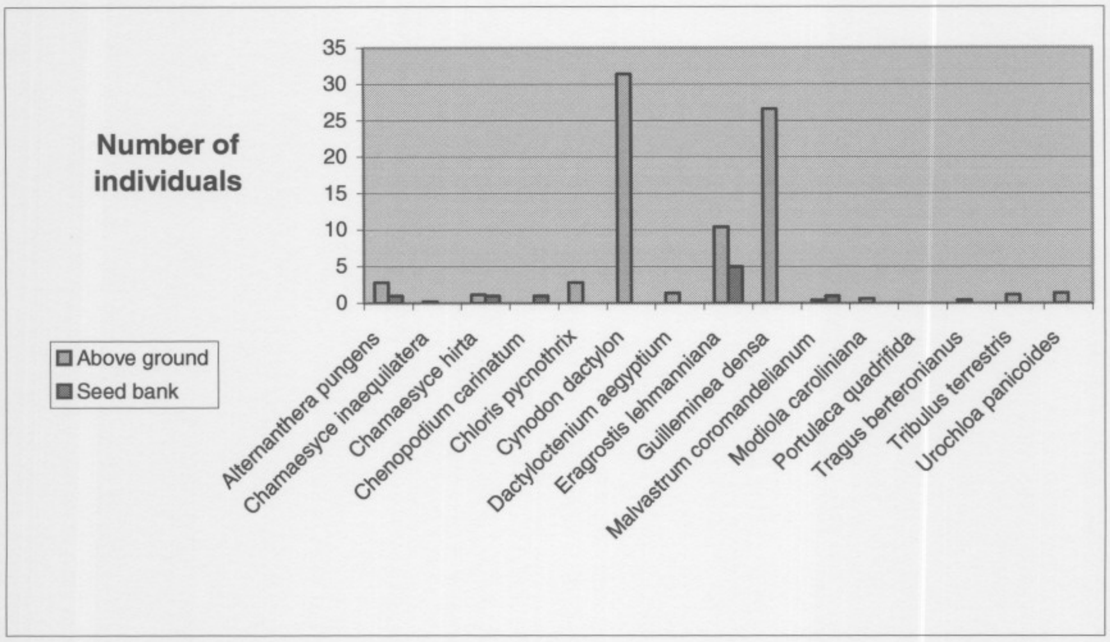

Figure 5.9: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (34-37) in heavily-trampled pavement areas next to sports fields in the Potchefstroom Municipal Area.

(h) Moderately-trampled sites (38-41) in the commercial areas.

Above ground, *Pennisetum clandestinum* is dominant and also develops like *Cynodon dactylon* through rhizomes. Species found above ground and the seed bank is *Alternanthera pungens* and *Urochloa panicoides* (Figure 5.10 and Table 4.15). *Dichondra repens* was also dominant above ground. The two dominant species in the seedbank was *Chamaesyce hirta* and *Alternanthera pungens*.

Pennisetum clandestinum is a robust, perennial, creeping plant that is a common site, but the local strains have always produced little or no seed (Bromilow, 1995). This explains the absence of *Pennisetum clandestinum* in the seed bank. This species reproduces mainly through rhizomes. *Dichondra repens* is a perennial, creeping, mat-forming plant that is a severe competitor, especially on lawns. It reproduces through seeds, rhizomes and stolons.

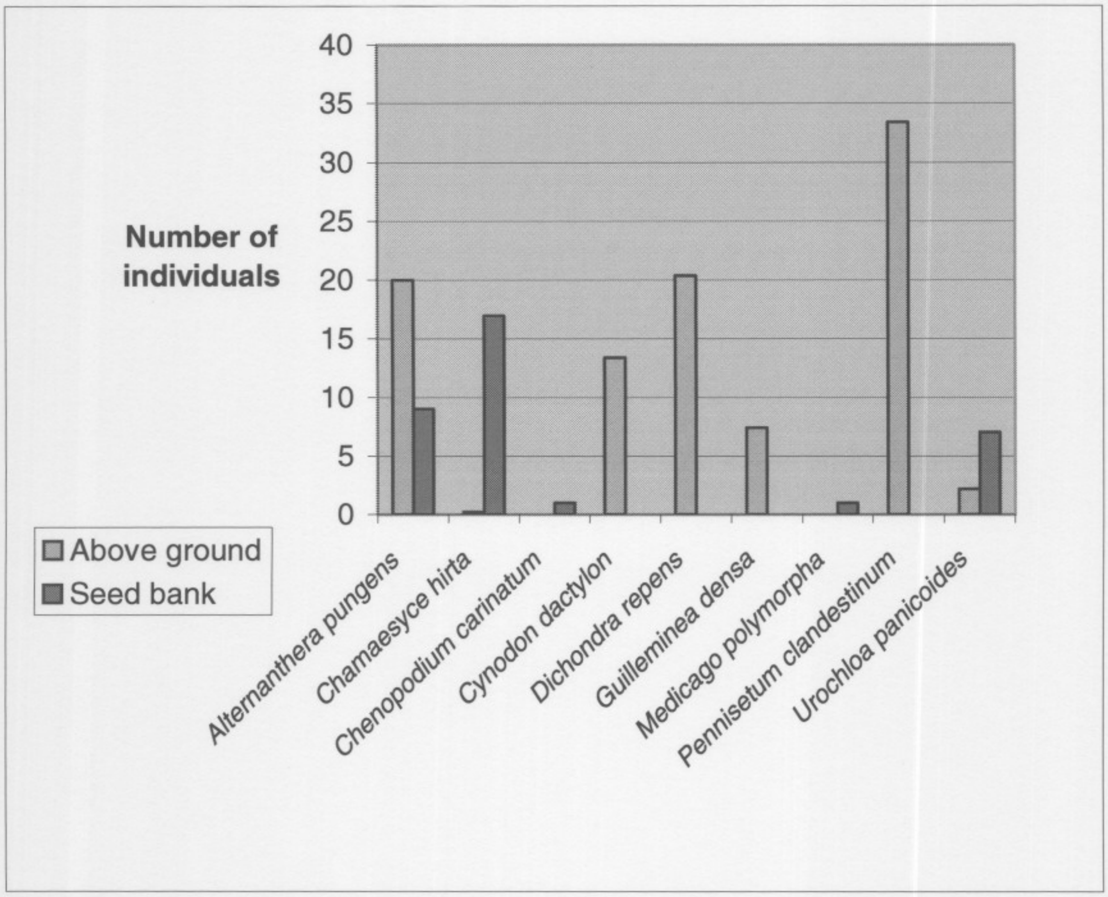

Figure 5.10: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (38-41) in moderately-trampled pavement areas in commercial sites in the Potchefstroom Municipal Area.

(i) Heavily-trampled sites (42-45) in the commercial area.

The composition of species in both the seed bank and above ground is similar to other areas with high trampling, except for *Panicum coloratum* that is only present in this area (Figure 5.11 and Table 4.16). *Eragrostis lehmanniana* is highly dominant in the seed bank together with *Alternanthera pungens*. In these sites *Alternanthera pungens* had a higher precence in the seed bank than above ground.

Panicum coloratum is a very competitive perennial species and reproduces through seeds, rhizomes and stolons (Wells *et al.*, 1986).

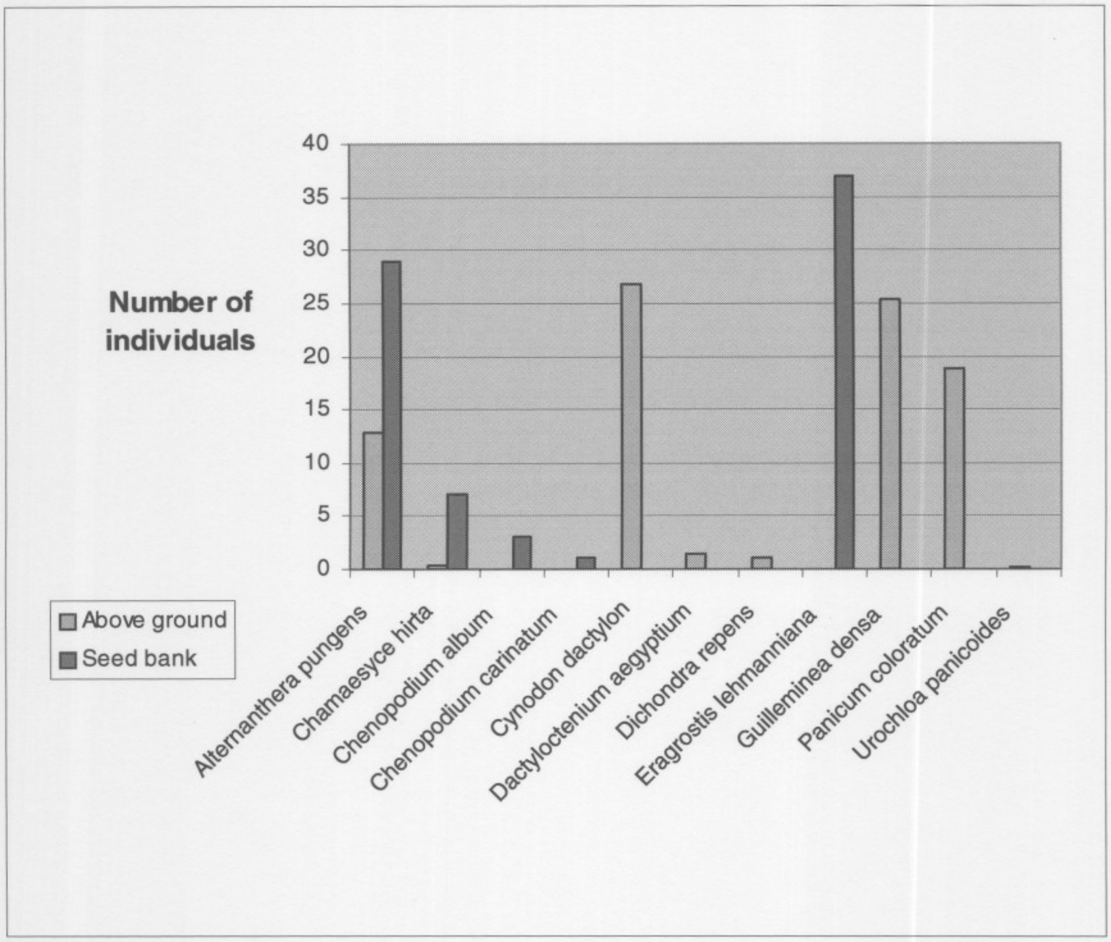

Figure 5.11: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots (42-45) in heavily-trampled pavement areas in commercial sites in the Potchefstroom Municipal Area.

(j) Summary of seed bank results, found in the different trampling levels on all the pavements

From Figure 5.12 it is clear that *Alternanthera pungens* had the highest average number of individuals found in the seed banks of all the pavements areas (heavily, moderately and lightly trampled). *Alternanthera pungens* had the highest number of individuals in moderately trampled sites on pavements (Figure 5.12). *Chamaesyce hirta* showed the same pattern as *Alternanthera pungens*. The number of individuals of *Eragrostis lehmanniana* found in seed banks decreased as the trampling levels decreased (heavily-trampled sites had more individuals and lightly-trampled sites had less individuals).

Other species that were found in the seed banks of pavements with different trampling levels include *Medicago polymorpha*, *Tribulus terrestris*, *Chenopodium carinatum*, *Chenopodium album* and *Malvastrum coromandelianum*, all with a higher number of individuals in moderately-trampled sites (Figure 5.12). In lightly-trampled sites *Urochloa panicoides* showed the higest number of individuals in the seed banks (Figure 5.12)

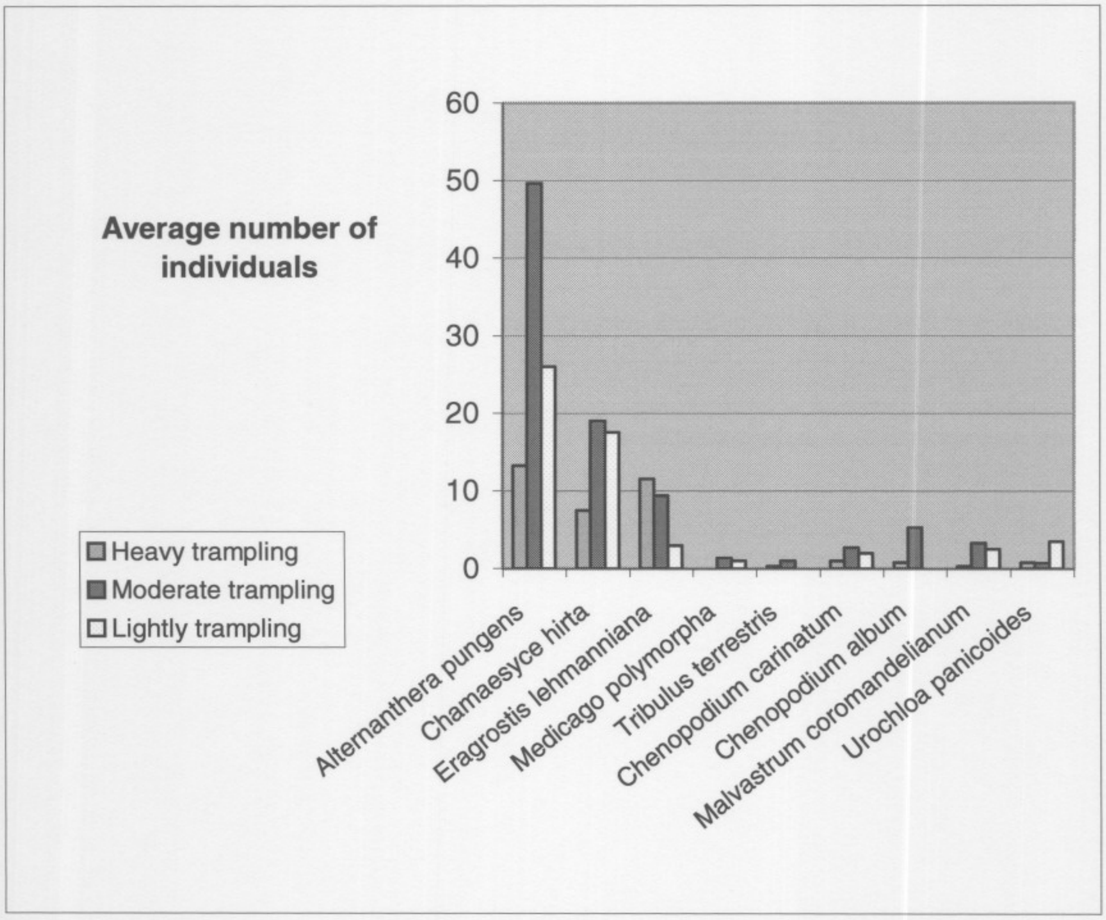

Figure 5.12: Graph showing the average number of individuals present in the seed banks of sample plots with heavily, moderately and lightly trampled pavements, in the Potchefstroom Municipal Area.

5.4.2 Managed grassland areas

(a) Low trampling and unmown area in Botanical garden (managed grassland). These areas in the Botanical garden were not mown since the beginning of the study and were protected from trampling. From the number of individuals in Figure 5.13, it is clear that in the time the samples were taken *Paspalum dilatatum* was the dominant species above the ground (Tables 4.7). Other species that were dominant above ground included *Sporobolus africanus* and *Veronica persica*. Only two species were very prominent in the seed bank, i.e. *Dichondra repens* and *Oxalis repens* (Figure 5.13).

Paspalum dilatatum is a perennial, being spread by seed or rhizomes, and is especially difficult to control once established. It is an important weed of fruit orchards, often interfering with micro-irrigation systems. Although it should be controlled before it becomes established, it is susceptible to the systemic grass herbicide (Bromilow, 1995). *Sporobolus africanus* is a perennial grass that is commonly found in disturbed ground and compacted areas (Bromilow, 1995). The reason for the occurrence of *Sporobolus africanus* could possibly be ascribed to the previous (before the study) management practices (mowing and higher trampling). *Veronica persica* is a semi-erect, multi-branched, herbaceous and annual plant. This species is also a weak competitor and reproduces only through seed. *Dichondra repens* is a perennial, creeping, mat-forming plant with rhizomes and stolons, forming roots at the nodes (Botha, 2001). This species is a severe competitor, especially on lawns and reproduces through seeds, rhizomes and stolons (Botha, 2001). *Oxalis repens* is a creeping, stoloniferous plant that is a moderate competitor. It only reproduces through seeds and stolons (Botha, 2001).

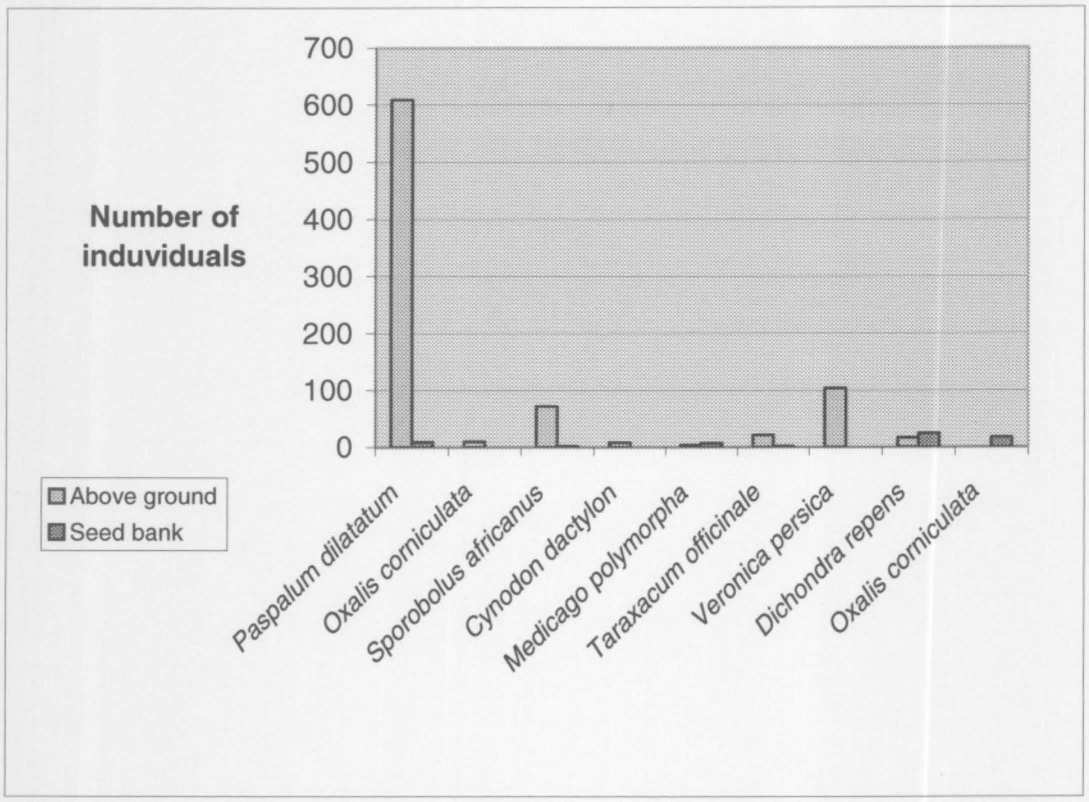

Figure 5.13: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots: 1-4 in Managed grassland areas (Botanical garden = low trampling and not mown) in the Potchefstroom Municipal Area.

(b) Trampled and mown area in Botanical garden (managed grassland).

The sample plots were managed without any changes in management, which included mowing and trampling. When looking at Figure 5.14 it is clear that the seed bank had a poor representation of seeds. The dominant species above ground were *Dichondra repens* and *Cynodon dactylon* (Table 4.5). In the seed bank there were only three species present, *Dichondra repens*, *Medicago polymorpha* and *Sporobolus africanus*.

Dichondra repens is a perennial, creeping, mat-forming plant with rhizomes and stolons, forming roots at the nodes (Botha, 2001). This species is a severe competitor, especially on lawns and reproduces through seeds, rhizomes and stolons (Botha, 2001). This is a possible reason for the high presence in the above ground area. *Cynodon dactylon* is a creeping perennial that spreads by means of an extensive system of stolons and underground rhizomes (see further discussion under 5.4.1(a)). *Oxalis corniculata* is a creeping, stoloniferous plant that is a moderate competitor. It only reproduces through seeds and stolons (Botha, 2001).

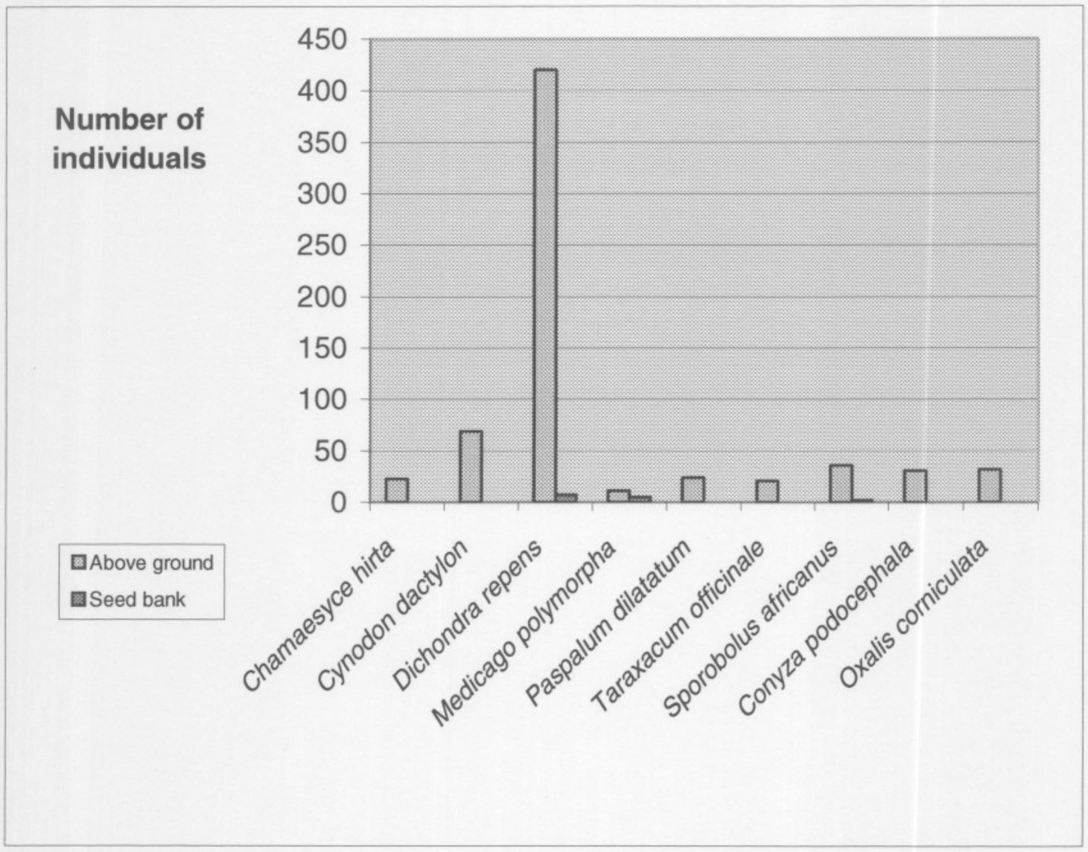

Figure 5.14: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots: 6-8 in Managed grassland areas (Botanical garden = Trampling and mown) in the Potchefstroom Municipal Area.

(c) Trampled and mown area in Botanical garden (managed grassland).

As described previously for the same management (Figure 5.14), there is almost no seed in the seed bank in this area (Figure 5.15). In the above vegetation *Dichondra repens*, *Cynodon dactylon*, *Conyza podocephala* and *Taraxacum officinale* is dominant (Table

4.6). There were only three species present in the seed bank with a very low number of individuals. These included *Paspalum dilatatum*, *Dichondra repens* and *Medicargo polymorpha*. It is clear that *Cynodon dactylon* and *Dichondra repens* are best adapted for the conditions of mowing and trampling in the managed grassland.

Conyza podocephala and *Taraxacum officinale* are the other two species that were dominant above ground. *Conyza podocephala* is an indigenous species with a strong tap root, which sometimes produces runners. It is a common annual weed of gardens, roadsides, fallow land and forestry and to a lesser extent, annual crops (Bromilow, 1995). *Taraxacum officinale* is a perennial herb with an underground stem and long sturdy tap root. It reproduces through seed only and it can become a problem weed in lawns (Botha, 2001). *Paspalum dilatatum* is a perennial, being spread by seed or rhizomes, and is especially difficult to control once established. It reproduces through seeds and rhizomes (Wells *et al.*, 1986). *Dichondra repens* is a perennial, creeping, mat-forming plant with rhizomes and stolons, forming roots at the nodes (Botha, 2001). This species is a severe competitor, especially on lawns and reproduces through seeds, rhizomes and stolons (Botha, 2001). *Medicargo polymorpha* is an annual, decumbent to creeping herbs with numerous, spreading stems, with long taproots. It reproduces through seed only.

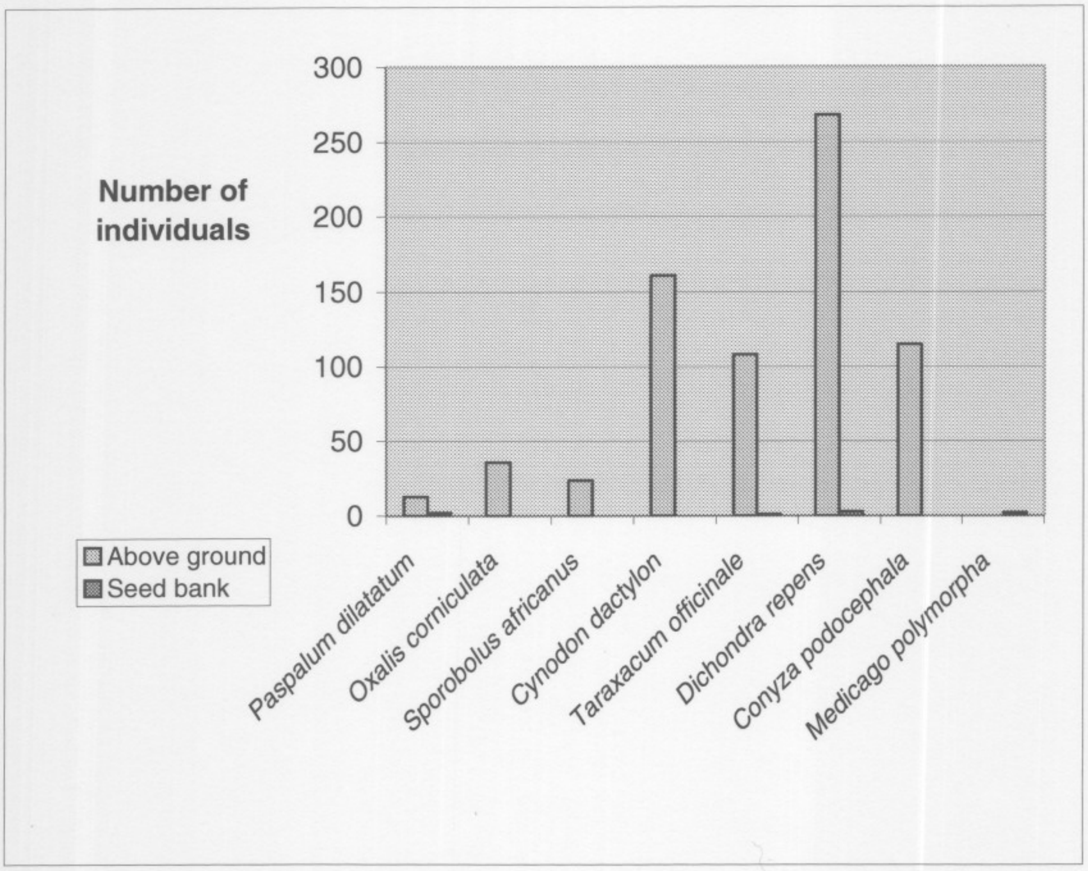

Figure 5.15: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots: 9-12 in Managed grassland areas (Botanical garden = Trampling and mown) in the Potchefstroom Municipal Area.

(d) Low trampling and unmown area in Botanical garden (managed grassland).

As for the low trampling and unmown area under 5.4.2(a) and Figure 5.13, *Paspalum dilatatum* is dominant in this area (Figure 5.16). The second highest number of individuals is characterised by *Cynodon dactylon*. The seed bank also had a low count of species and was only represented by *Dichondra repens*, *Taraxacum officinale* and *Sporobolus africanus*.

The characteristics from species found in this area were already mentioned in the above results 5.4.1(a) and 5.4.2(a), (b) and (c) (Table 4.8).

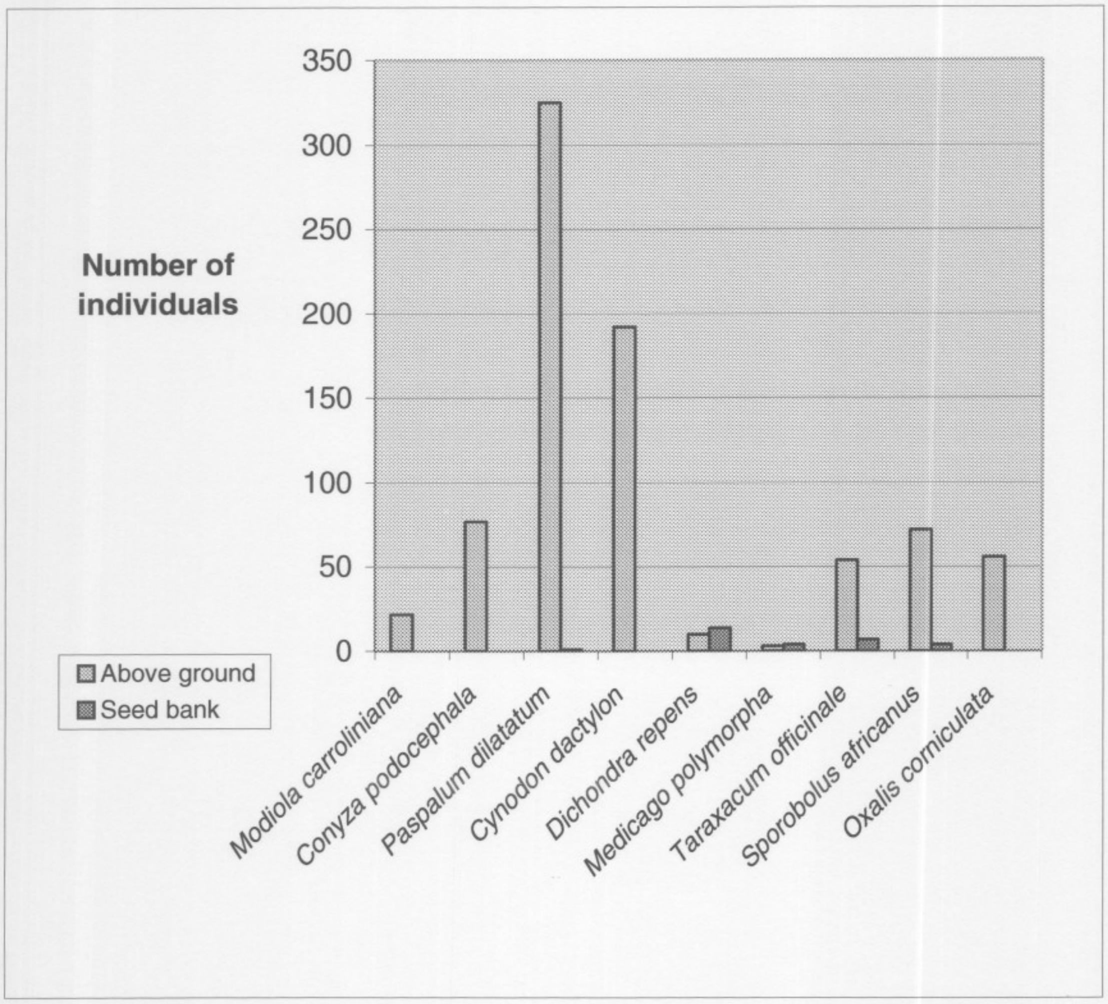

Figure 5.16: Graph showing the number of individuals of selected species present above ground and in the seed banks of sample plots: 13-16 in Managed grassland areas (Botanical garden = Trampling and mown) in the Potchefstroom Municipal Area.

(e) Summary of seed bank results found in the different management practices (mown and unmown) in managed grasslands (Botanical garden)

The species with the highest number of individuals found in the seed banks of managed grasslands (Botanical garden), in both mown and unmown areas was *Dichondra repens*, but of these two areas it had the highest number of individuals in unmown areas. All the species found in the seed banks of managed grasslands had the highest average number of individuals in unmown areas. *Oxalis corniculata* was found in only the unmown areas of managed grasslands. All the other species found in seed bank were present in both mown and unmown areas. These included *Paspalum dilatatum*, *Sporobolus africanus*, *Medicago polymorpha, Taraxacum officinale* and *Dichondra repens*.

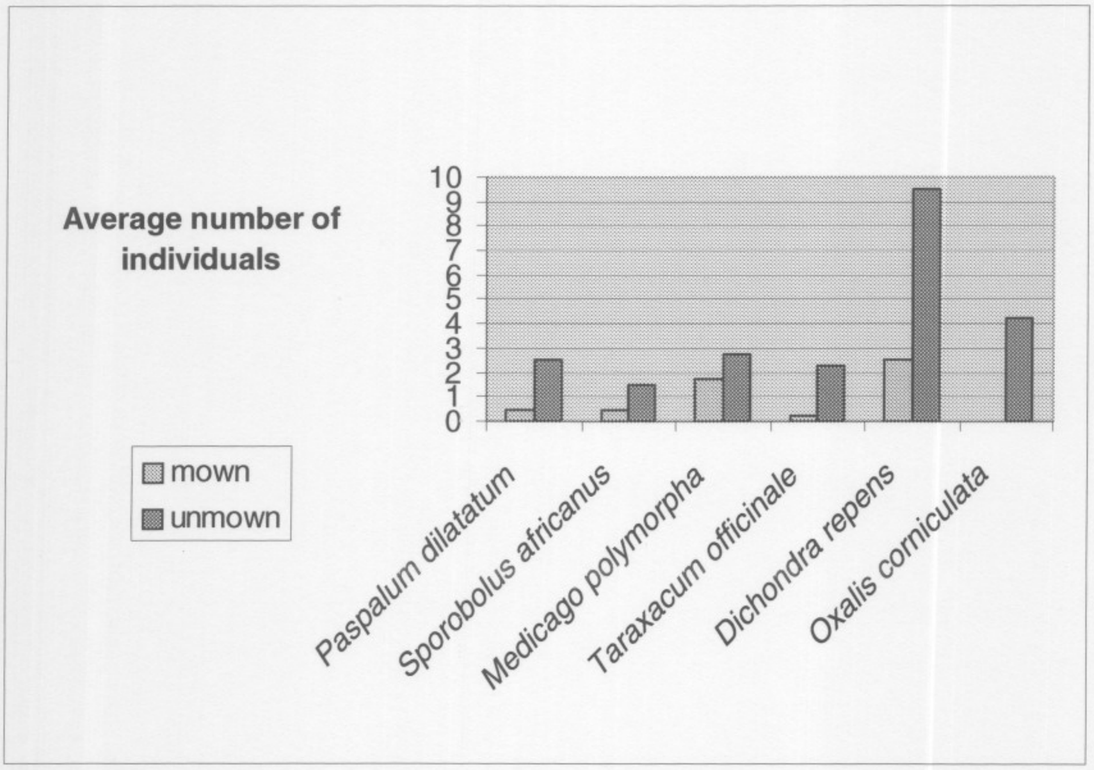

Figure 5.17: Graph showing the average number of individuals present in the seed banks of sample plots with mown and unmown areas in managed grasslands (Botanical garden), in the Potchefstroom Municipal Area.

5.5 Conclusions

In paved areas the following could be summarised for the seed banks under different trampling levels. *Alternanthera pungens, Eragrostis lehmanniana* and *Chamaesyce hirta* had the highest average number of individuals found in the seed banks at all the different trampling levels, except for *Urochloa panicoides* which had a higher average number of individuals in lightly-trampled areas (Figure 5.12). Pavements with heavy trampling were characterised by *Alternanthera pungens, Eragrostis lehmanniana* and *Chamaesyce* *hirta* in the seed bank (Figure 5.12). It is important to note that seed banks of heavily-trampled sites, found on paved areas, had the lowest number of individuals according to other trampling levels, except for *Eragrostis lehmanniana* and *Urochloa panicoides*. *Eragrostis lehmanniana* was the only species that had a higer average number of individuals on heavily-trampled sites on paved areas (Figure 5.12). *Urochloa panicoides* was the only species that had a higer average number of individuals on lightly-trampled sites on paved areas (Figure 5.12). Moderately-trampled paved areas were characterised with *Alternanthera pungens* and *Chamaesyce hirta.* The moderately-trampled sites found on paved areas had the higest average number of individuals, if compared to other sites with different trampling levels. In lightly-trampled paved areas had mostly the second higest average number of individuals according to Figure 5.12, except for *Urochloa panicoides* and *Eragrostis lehmanniana.*

When looking at the above ground species of paved areas, the following could be summarised. Areas with heavy trampling levels were characterised by *Cynodon dactylon, Guilleminia densa, Paspalum dilatatum, Pennisetum clandestinum, Alternanthera pungens* and *Dichondra repens* above ground (Figures 5.4, 5.6, 5.9 and 5.11) All these species have low-growing and mat-forming characteristics that made these conditions of high trampling favourable for this type of species. In the moderately-trampled areas *Cynodon dactylon, Eragrostis lehmanniana, Chloris pycnothrix* and *Guilleminea densa* had the higest number of individuals above ground (Figures 5.3, 5.7, 5.8 and 5.10). When looking at the growth form in this area of the species found above ground, there is a combination between low-growing (*Cynodon dactylon* and *Guilleminea densa*) and higher-growing species (*Eragrostis lehmanniana* and *Chloris pycnothrix).* This just shows that both types of species were able to adapt in moderate-trampling conditions. Therefore one can expect a greater variety of species in moderately-trampled areas. The same was reflected in the seed banks. Lightly-trampled areas are characterised above ground by *Pennisetum clandestinum, Cynodon dactylon, Gelleminia densa* and *Paspalum dilatatum.* One would expect to see higher-growing species, but this area is dominated by highly competitive species such as *Pennisetum clandestinum, Cynodon dactylon* and *Guilleminia densa.*

In Managed grassland areas (Botanical garden), the following could be summarised for the seed banks under different management practices (mown and unmown areas). The species with the higest number of average individuals found in the seed banks of managed grasslands (Botanical garden), in both mown and unmown areas was *Dichondra repens*, but of these two areas it had the highest average number of individuals in unmown areas. All the species found in the seed banks of managed grasslands had the highest average number of individuals in unmown areas. *Oxalis corniculata* was found in only the unmown areas of managed grasslands. All the other species found in seed banks were present in both mown and unmown areas. These species included *Paspalum dilatatum, Sporobolus africanus, Medicago polymorpha, Taraxacum officinale* and *Dichondra repens.*

When looking at the above ground vegetation of managed grasslands (Botanical garden), it was also evident that the type of management determines the type of vegetation. The regular mowing gives the low-growing species an advantage over the higher-growing species. As for the mown areas, the low-growing and mat-forming characteristics of species *Dichondra repens* and *Cynodon dactylon* made it possible for them to establish. In the unmown areas, high-growing species that were high in numbers were *Paspalum dilatatum* and *Sporobolus africanus.*

Chapter 6

Final Conclusions

6.1 It is possible to adapt the process of urban biotope mapping for use in South African cities.

From the work done by Rost (2002) and Röthig (2002) maps were drawn up to assist in the proposal of measures for development and conservation and additional general ideas and proposals to create a better environmental situation for Potchefstroom. Some of the proposals will be discussed. Factory/ industry should be scrutinised for polluting factors regarding air pollution, water pollution and soil pollution. Laws and regulations do not protect the environment enough when one look at the pollution that is still taking place. The punishment is also not high enough for those factories, which do not follow these environmental rules. Other points, mentioned under pollution factors, are the following: scrutinising and removal of dischargers, especially in water channels; developing of industrial disposal sites; remove/ develop household disposal sites. Measures should also be taken to connect biotopes to form a network of biotopes. The need to plant more trees is also emphasised. Trees have several advantages like the reduction of the effect of "heat islands" in the city because of their shading, filtering polluted air and provision of oxygen. Small habitats for animals such as birds and insects can also be created along the street. High-sealed areas in the city central should also be changed through the establishment of green structures like flower beds or planted trees and shrubs. Another advantage of vegetation in the central city is the improvement of the city's climate and air quality, where traffic density is a big problem. Several public park-like open spaces in the city are too intensively managed. They are low in species diversity and indigenous plants. To increase the diversity of these areas the intensive management practices should be changed extensively. To increase the indigenous vegetation, the declared invaders should be removed. Not only will these measures advance the ecology of these areas, but a lot of money would also be saved on maintenance. To increase the aesthetic aspect and reduce the natural character of these areas one can create a combination of intensively-managed and extensively-managed plots and perhaps some flower beds and ornamental trees and shrubs. Areas of natural biotopes should be declared as non-build-up areas, because they are very rich in species diversity and must be conserved in future. Green belts must be created for extensively-managed natural biotopes throughout the city. These belts or networks are very important for the species in the city as a shelter, because natural areas are very rare in the central city. For the climate of the city, such a belt of green spaces would mean a decrease in the heat island effect, because of the cooling factor of plants, as well as the refreshment of dusted and polluted air. By identifying areas for housing development it is always necessary to compare different areas in the city with each other with respect to species diversity and meaning for natural household and recreation. One has to set priorities in favour of the more worthy biotopes of protection. Therefore a method must be used where-by these biotopes can be prioritised.

Looking at the results of urban biotope mapping of Potchefstroom, I would certainly say that it could be adapted for Sout African conditions. It is, however, necessary to refine the key for detailed biotope types. Our study on intensively-managed sites (managed grasslands, pavements and secondary grasslands) indicated clearly the heterogeneity of habitats and species found within one biotope type, for example pavements, depending on type and intensity of human impact. We would like to propose that within each of the existing biotope types of roads, specific emphasis be placed on pavements with different trampling levels. This will contribute as important biotopes whose dynamics should be protected.

6.2 Vegetation dynamics in urban open spaces are correlated with specific anthropogenic influences such as mowing and trampling.

As mentioned earlier spontaneous vegetation can be used as indicators of changes in environmental conditions and ecological processes in the urban environments (Sukopp & Werner 1983). Urban areas are characterised by high level of disturbance and environmental modification, thus knowledge of vegetation dynamics is important to an understanding of their ecology (Gilbert 1989).

The biotopes of differently-managed areas differ with respect to importance values of species (Figures 4.8 and 4.10 - 4.11). The differences in species composition and abundance of the biotopes seemed to be the result, first of all of soil physical and chemical properties and secondly of anthropogenic influences such as mowing and trampling (Figure 4.9 and together with Table 4.2). Changes in management practices and human impact such as the termination of mowing and weeding and increasing in trampling in areas that haven't been disturbed for a while brought about changes in species importance values within one year (Figure 4.8 and 4.10). Changes in species importance values over time can be attributed to changes in management practices, especially in managed and ruderal grasslands.

In general, our results have implied that the species composition of a specific managed area could be manipulated by changing the type and intensity of the management practice or anthropogenic influence. This could lead to an increase of richness and abundance of indigenous species in the intensively-managed areas of our towns and cities. Before this could be proposed as management practices to municipal authorities, experimental studies are, however, needed to verify these results. The time span over which this study took place was probably not long enough, although changes did occur within the first year, indicating the dynamic nature of disturbed areas. It is difficult to keep up with changes in management practices, especially if there is a long history of intensive management. It would, therefore, be better to study vegetation dynamics in space, which imply studies along gradients

Results of research in this field are useful for urban land management and conservation. Conservation and reintegration of nature into the city is very important, not only for the improvement of environmental quality, but also for that vital change in man's view of himself in relation to nature (Henke & Sukopp 1986; Pyšek 1995).

The effects of urbanisation and the search for means and ways to develop sustainable cities seem to be a formidable task. By undertaking studies into the dynamics of the interactions of humans and their surrounding environments we could provide them with the necessary ecological information to assist us in the development of these sustainable cities. At no time in the history of the development of South Africa has it been more necessary to understand the effect of urbanisation not only helping to improve human life, but the environment too.

6.3 Soil seed banks are comparable with above ground vegetation in areas subjected to different anthropogenic influences.

In paved areas the following could be summarised for the seed banks under different trampling levels. *Alternanthera pungens, Eragrostis lehmanniana* and *Chamaesyce hirta* had the highest average number of individuals found in the seed banks in all the different trampling levels, except for *Urochloa panicoides* that had a higher average number of individuals in lightly trampled areas (Figure 5.12). The above ground vegetation is dominated by *Cynodon dactylon* and *Guilleminea densa* in all the paved areas under different trampling levels. Pavements with heavy trampling were characterised by

Alternanthera pungens, Eragrostis lehmanniana and *Chamaesyce hirta* in the seed bank (Figure 5.12). It is important to note that seed banks of heavily-trampled sites, found on paved areas, had the lowest number of individuals according to other trampling levels, except for *Eragrostis lehmanniana* and *Urochloa panicoides*. *Eragrostis lehmanniana* was the only species that had a higher average number of individuals on heavily-trampled sites on paved areas (Figure 5.12). When looking at the above ground species of paved areas with heavy trampling levels, they were characterised by *Cynodon dactylon, Guilleminia densa, Paspalum dilatatum, Pennisetum clandestinum, Alternanthera pungens* and *Dichondra repens* above ground (Figures 5.4, 5.6, 5.9 and 5.11). All these species have low-growing and mat-forming characteristics that made these conditions of high trampling favourable for this type of species. Moderately-trampled paved areas were characterised by *Alternanthera pungens* and *Chamaesyce hirta* in the seed bank analysis.

The moderately-trampled sites found on paved areas had the higest average number of individuals, if compared to other sites with different trampling levels in seed banks. The moderate-trampling areas above ground had *Cynodon dactylon, Eragrostis lehmanniana, Chloris pycnothrix* and *Guilleminea densa* with the higest number of individuals (Figures 5.3, 5.7, 5.8 and 5.10). When looking at the growth form in this area of the species found above ground, there is a combination between low-growing (*Cynodon dactylon* and *Guilleminea densa*) and higher-growing species (*Eragrostis lehmanniana* and *Chloris pycnothrix).* This just shows that both types of species were able to adapt in moderate-trampling conditions. Therefore one can expect a greater variety of species in moderately-trampled areas and it was reflected in the seed banks.

The seed banks of lightly-trampled paved areas had mostly the second-highest average number of individuals according to Figure 5.12, except for *Urochloa panicoides* and *Eragrostis lehmanniana*. *Urochloa panicoides* was the only species that had a higher average number of individuals in the seed banks on lightly-trampled sites on paved areas (Figure 5.12). Lightly-trampled areas are characterised above ground with *Pennisetum clandestinum, Cynodon dactylon, Gelleminia densa* and *Paspalum dilatatum*. One would expect to see higher-growing species, but this area is dominated by highly-competitive species such as *Pennisetum clandestinum, Cynodon dactylon* and *Guilleminia densa.*

In Managed grassland areas (Botanical garden), the following could be summarised for the seed banks under different management practices (mown and unmown areas). The species with the higest number of average individuals found in the seed banks of managed grasslands (Botanical garden), in both mown and unmown areas, was *Dichondra repens*, but of these two areas it had the highest average number of individuals in unmown areas. All the species found in the seed banks of managed grasslands had the highest average number of individuals in unmown areas. *Oxalis corniculata* was found in only the unmown areas of managed grasslands. All the other species found in seed banks were present in both mown and unmown areas. These species were *Paspalum dilatatum*, *Sporobolus africanus*, *Medicago polymorpha, Taraxacum officinale* and *Dichondra repens.* When looking at the above ground vegetation of managed grasslands (Botanical garden), it was also evident that the types of management practices determined the type of vegetation. The regular mowing gives the low-growing species an advantage over the higher-growing species. Like in the mown areas, the low-growing and mat-forming characteristics of species *Dichondra repens* and *Cynodon dactylon* made it possible for them to establish. In the unmown areas species that were high in number of individuals were high growing *Paspalum dilatatum* and *Sporobolus africanus.*

6.4 Recommendations

From this study it is clear that there is a correlation between species, sample plots and environmental variables in areas subjected to different antropogenic influences. Low-cost maintenance guidelines can be determined out of similar studies with the emphasis on urban open-space systems that are ecologically resilient and diverse and that are scientifically, educationally, aesthetically and recreationally acceptable. The need for the conservation of urban vegetation or biotopes will lead to these types of guidelines for management or development of urbanised areas. These programmes will propose a new holistic approach to city planning, one whereby indigenous plants form an integral part of the urban landscape. Information gathered on the different successional stages in the study of vegetation dynamics, will enable city planners, landscape architects and urban ecologists to develop an ecologically sound planning, management and rehabilitation programme for fragmented and other natural and semi-natural areas in the urban environment. It must be emphasised, that these programmes cannot be based on ecological research alone, but also on the incorporation of sociological aspects

From the results of this study it can be seen that species composition could be manipulated by changing the type and intensity of the management practice. Biotopes should, therefore, be managed in such a way that higher species diversity is maintained. This could result in less mowing in managed green spaces or the encouragement of more or less trampling along verges.

When looking at the specific biotopes mentioned in the study, pavements must be less or more trampled to a stage of moderate trampling to encourage higher species diversity. Less mowing could also encourage the process. Methods must be found to establish this stage of trampling, for example the use of barriers where trampling is too high. In managed grasslands it was found that mowing enhanced high species diversity. A certain amount of mowing is therefore important, but too much mowing can result in a decline in species richness. The right frequency of mowing should be established for certain areas. Ecocircles already play a big role in conserving plant species in that the vegetation is preserved inbetween the circles rather than removed like in common practice. It is found that when disturbances are too high in-between circles, that species diversity will decline.

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