Plant and arthropod diversity of maize agro-ecosystems in the Highveld and Lowveld regions of South Africa

Bheki George Maliba
22151869

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Supervisor: Prof. S.J. Siebert
Co-Supervisor: Prof. J. van den Berg

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Dedication

This dissertation is dedicated to my grandparents

Declaration

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

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

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

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

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Abstract

Surveys of plant and selected insect species was conducted in Highveld and Lowveld agro-ecosystems of four provinces of South Africa, namely North-West, Mpumalanga, KwaZulu-Natal and Limpopo. The objectives of the study were to compare insect and plant diversity between localities (grassland and savanna) and treatments (maize field, semi-transformed and untransformed) to test for a general relationship between plant and insect diversity along a maize field-field margin gradient. Plant and insect diversity patterns were studied along the gradient and quantified in terms of richness and diversity indices. Plant and insect species compositional turnover was also measured along the maize field-field margin gradient. Plant diversity increased with increasing distance from maize fields into the margin. The flora in maize fields and of margins differed, but in contrast, insect species assemblages were similar in maize fields and margins. There was no statistical difference in insect diversity between treatments (maize field, semi-transformed and transformed). A relationship was revealed between plant and insect diversity, as plant diversity enhanced insect diversity.

Keywords: agro-ecosystem; diversity indices; grassland; insect diversity; maize field; plant diversity; savanna.

Opsomming

Opnames van plant- en geselekteerde insekspesies was in vier provinsies van Suid-Afrika in Hoëveld en Laeveld landbou-eksosisteme uitgevoer. Die doelstellings van hierdie studie in Noordwes, Mpumalanga, KwaZulu-Natal en Limpopo was om insek- en plantdiversiteit tussen lokaliteite (grasveld en savanna) en behandelings (mielieland, gedeeltelik getransformeer en ongetransformeer) te vergelyk en te toets vir ŉ algemene verwantskap tussen plant- en insekdiversiteit langs ŉ mielieland-bufferstrook gradiënt. Plant- en insekdiversiteitspatrone wat langs die gradiënt bestudeer is, is in terme van rykheid en diversiteitsindekse gekwantifiseer. Veranderinge in plant- en insekspesie samestelling was ook langs die mielieland-bufferstrook gradiënt gemeet. Resultate wys dat plantdiversiteit toeneem met toenemende afstand vanaf die mielieland in die bufferstrook in. Die flora in mielielande en van bufferstroke het nie noemenswaardig verskil nie, maar in teenstelling het die inseksamestelling in mielielande en bufferstroke tot ŉ mate ooreengestem. Insekdiversiteit het geen statisties betekenisvolle verskille tussen behandelings (mielieland, gedeeltelik getransformeer en ongetransformeer) getoon nie. ŉ Verwantskap tussen plant en insekdiversiteit was opvallend, spesifiek die mate waartoe plantdiversiteit insekdiversiteit laat toeneem.

Sleutelwoorde: diversiteitsindekse; grasveld; insekdiversiteit; landbou-ekosisteem; mielieland; plantdiversiteit; savanna.

Chapter 1: Introduction

1.1 Introduction

A substantial part of South Africa’s biodiversity occurs on farms or agricultural land (agro-ecosystems), more so than is currently found in conservation areas (Wessels *et al*., 2003). Agro-ecosystems are ecological systems modified by humankind to produce food or other agricultural products (Walker and Schulze, 2008). However, transformation of natural areas for crop cultivation and urban development presents the single most significant threat to global biodiversity (Wessels *et al*., 2003). According to New (2005), disturbance in a broad sense may alter the biodiversity within an ecosystem directly (by killing individuals) or indirectly (by transforming its habitat). In the last decade biodiversity has decreased in agro-ecosystems, including large declines and changes in species richness due to an increasing intensification in agricultural practices (Gabriel and Tscharntke, 2007). In stark contrast to the unopposed biodiversity loss worldwide, current evidence suggests that the conservation of biological diversity is important for the stability and functioning of ecosystems (Toft *et al*., 2001), and hence the productivity of agro-ecosystems.

Biodiversity is needed for ecosystems to function effectively, and thus to deliver services (van Wilgen *et al*., 2008). Biodiversity includes genetic diversity, species richness and ecosystem diversity (Jury *et al*., 2007). Ecosystem services can be grouped into categories meeting basic human needs, by supporting (e.g. soil retention and formation), regulating (e.g. water purification), providing services (medicinal plants and firewood) and enhancing human well-being *i.e.* cultural services (van Wilgen *et al*., 2008; Egoh *et al*., 2009). Most farming systems rely heavily on ecosystem services for soil fertility, pollination, pest regulation, water filtration, and erosion control (Cumming and Spiesman, 2006). In the long term, it makes good economic sense to maintain ecosystem goods and services in both untransformed areas and agro-ecosystems (Cumming and Spiesman, 2006).

Agricultural crops often depend, at least in part, on unmanaged or wild pollinator populations from adjacent semi-natural habitats for their productivity (Potts *et al*., 2006).

Pollination by insects is vital for maintaining plant diversity. Approximately 67% of all flowering plants depend on insects for pollination needs (Campbell *et al*., 2007). Therefore knowledge of the diversity of plants and insect-visitors in agro-ecosystems is important to identify sensitive areas in need of protection to maintain its service. There is an overwhelming abundance of scientific literature highlighting the important ecological service that pollinators provide to the survival of wild plant species, the productivity of many food crops and maintenance of whole ecological communities (Arpaia, 2006). According to Gemmill-Herren and Ochieng (2008), recent ecosystem-level approaches in macadamia, watermelon, tomato and coffee cropping systems have documented the role of wild bees and landscape configuration in the provisioning of pollination services in farming systems. Worldwide some 25,000 bee species exist, comprising the most important pollinators of the 240,000 species of flowering plants and of more than half of the 3,000 crop species (Kuhlmann, 2009).

During the past 50 years, agricultural intensification resulted in increased crop yields, but has been associated with a decrease in biological diversity at the landscape level (Asteraki *et al*., 2004). Habitat fragmentation, land-use changes, agricultural practices, use of pesticides and herbicides, and exotic species invasions are some of the threats that pollinators face (Campbell *et al*., 2007). The greatest negative effect of agriculture on wildlife is the conversion of natural vegetation to agro-ecosystems consisting of monocultures (Lacher *et al*., 1999). Where native vegetation is largely replaced by alien species, the structure of the invertebrate community is altered and species richness can decline (Toft *et al*., 2001).

Field margins include a variety of landscape features like hedges, walls, grassy strips, lines of trees or shrubs, and combinations thereof (Petersen *et al*., 2006). Field margins are an important resource for farmland wildlife, e.g. birds, mammals, invertebrates and plants (Asteraki *et al*., 2004) and important refugia for some lepidopteran species (Gathmann *et al*., 2006). Field margins have become increasingly important habitats for conservation of biodiversity (Gathmann *et al*., 2006) in agricultural systems. The biodiversity of the margin may be of particular importance for the maintenance of species at higher trophic levels and at the landscape level (Marshall and Moonen, 2002;

Petersen *et al*., 2006). Agricultural operations, such as fertilizer and pesticide application have effects on the margin's flora (Marshall and Moonen, 2002). Substantial research has been conducted on arthropod pests of maize, but there is a shortage of information on general plants and arthropods biodiversity within field and along margins of maize fields.

The advent of genetically modified (GM) maize has, however, highlighted the importance of biodiversity within field and along field margins. It has now become necessary to study the potential effects of transgenic plants on nearby organisms and to quantify species diversity in maize fields and surrounding margins to gather baseline data for future research on the possible environmental impacts of GM maize. Consumption of transgenic insecticidal pollen by non-targeted organisms that have moved onto non-crop plants outside crop fields is one probable environmental risk to arthropods that use non-crop plants as hosts (Jesse and Obrycki, 2000). Non-cultivated habitats embedded in agro-ecosystems are important sources of pollinator biodiversity for agricultural fields (Carriére *et al*., 2009), and are therefore at risk of being affected by GM plant material that end up in these habitats.

The type and abundance of biodiversity differ across agro-ecosystems which differ in age, diversity, structure, and management (Altieri, 1999). In general, biodiversity in agro-ecosystems depends on four broad characteristics of these systems (New, 2005), namely:

- diversity of vegetation within and around the agro-ecosystem;
- permanence or longevity of the various crops within the agro-ecosystem;
- intensity (extent, frequency, variety) of management; and
- degree of isolation of the agro-ecosystem from natural vegetation.

Information on plant diversity and associated arthropods around maize fields is non-existent in South Africa. Van Wyk *et al.* (2008) reported fifteen Lepidopteran species occurring inside maize fields. After 12 years of GM plant commercialization, only a few recent studies have assessed the impact of transgenic cotton on insect populations and subpopulations (groups) despite the wide range of GM plant species now being cultivated (Hofs *et al*., 2008). As many insects that exploit transgenic crops must disperse to other agricultural fields or non-cultivated habitats to persist within and between cropping seasons, fields of transgenic crops may affect insect populations locally as well as across agricultural landscapes (Carriére *et al*., 2009). Yet, most studies assessing impacts of transgenic crops on insect biodiversity have focused on in-field effects (Carriére *et al*., 2009).

To investigate the state of biodiversity in areas bordering on agro-ecosystems (field margins), this study will focus on maize farming systems. Maize or corn (*Zea mays)* is a monoecious, allogamous species increasingly improved by the expression of technological traits, such as resistance to pests and production of vaccines, industrial enzymes and plant-made pharmaceuticals (Porta *et al*., 2008). Maize farming systems are here defined as the whole of the maize crop, any in-field crops and the natural or disturbed field margin habitat associated with the agro-ecosystem. Maize fields are generally surrounded by natural habitats that serve as reservoirs and refuges (Kanya *et al*., 2004) for biodiversity.

1.2 Aims and objectives

In the past, a lot of research has focused on the insect diversity of tropical forest canopies (Krüger and McGavin, 1998). Recently, a study by Procheş and Cowling (2006) compared insect diversity in fynbos and three neighbouring biomes of South Africa. Therefore, this study was structured to provide a new angle by studying the insect diversity of the canopies of crops and vegetation of the Grassland and Savanna Biomes in South Africa. The main theme of this study was to investigate the biodiversity of arthropods and plants inside maize fields, as well as surrounding vegetation of the field margin. This will provide baseline data on arthropods and plants which may potentially be affected by agricultural practices or be exposed to genetically modified (GM) crop traits, such as insectidal or weed control proteins, which may have adverse effects on biodiversity. Therefore this research attempts to address the current lack of knowledge surrounding the diversity of arthropods and plants in both inside maize field and the maize field margin.

The aim and objectives of the study were to:

- quantify the richness and abundance of plants within maize fields and field margins;
- quantify the richness and abundance of arthropods within maize fields and field margins;
- determine the relationship of the diversity of plants and insects along maize field-field margin gradients in the Highveld (Grassland Biome) and Lowveld (Savanna Biome) agro-ecosystems.

1.3 Hypotheses

This study tested whether plant and arthropod diversity patterns in agro-ecosystems can be explained by one of the following;

- diversity of plants and insects are higher in maize field margins than inside maize fields;
- diversity patterns and abundance of plants and insects in maize fields and field margins differ in grassland and savanna;
- biodiversity of Lowveld agro-ecosystems is higher than the Highveld agro-ecosystems;
- insect species habitat includes both the maize fields and the maize field margins.

1.4 Layout of dissertation

Chapter 1. Introduction: Research problem, background, hypotheses and the aims and objectives of the study.

Chapter 2. Literature review: Extensive literature survey related to the research statement.

Chapter 3. Study area: Detailed overview of the study sites (*i.e.* climate, altitude, vegetation type, geology, soil and land types).

Chapter 4. Plant species diversity and composition along maize field-field margin gradients in grassland and savanna in South Africa: Patterns of plant diversity and plant species assemblage along a maize field-field margin gradient.

Chapter 5. Insect species diversity and composition along maize field-field margin gradients in grassland and savanna in South Africa: Patterns of insect diversity and insect species composition along a maize field-field margin gradient.

Chapter 6. Insect-plant diversity relationships of a maize field-field margin gradient: General relationships between plant and insect diversity along a maize field-field margin gradient.

Chapter 7. Conclusion and Recommendations: Current state of biodiversity as observed along maize field-field margin gradients. Summary and recommendations for each chapter are presented.

Bibliography: All the sources used or quoted in the form of complete reference list.
Appendices: Complete tables of statistical analysis.

Chapter 2: Literature review

2.1 Introduction

South Africa is one of the 25 biologically richest countries in the world (Wessels *et al*., 2003). It comprises a variety of biomes including Mediterranean type, arid, alpine and tropical environments, and within these biomes there is enormous species diversity and endemism (Crane, 2006). It was stated in Chapter 1 that a substantial part of South Africa's biodiversity occurs in agricultural areas, more than is currently found in conservation areas (Wessels *et al*., 2003). According to Asteraki *et al*. (2004), agricultural expansion is generally associated with a decrease in biological diversity. If species and genetic variation are diminished by human activities, options for improving agriculture and other activities essential to human health and economic growth are diminished (Wessels *et al*., 2003). Conservation of plant species diversity and structural diversity in both crop and non-crop production areas is essential for the maintenance of habitats for terrestrial wildlife species in agricultural landscapes (Sullivan and Sullivan, 2006). According to Darkoh (2003), there are four proximate causes of biodiversity loss in Sub-Saharan Africa:

- habitat loss or change through expansion of mining, forestry and agriculture;
- degradation, especially desertification of arable and grazing lands;
- controlled and uncontrolled introduction of alien species; and
- unsustainable harvesting and hunting of wild species.

2.2 Biodiversity in agro-ecosystems

In agro-ecosystems, biodiversity performs a variety of ecological services beyond production of food, including recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms, detoxification of noxious chemicals, pollination of crops and other vegetation, control of agricultural pests and dispersal of seeds (Altieri and Nicholls, 1999; Darkoh, 2003). Agro-ecosystems differ from natural systems in some ways with the extent of differences reflecting the intensity of agricultural practices (New, 2005). The major features of agro-ecosystems are that they:

- often have very limited duration, because the lifecycles of crops can be short and each crop may be removed completely at harvest, so any equivalent to long-term successional change is prevented;
- commonly undergo massive changes through external management, such as tilling, ploughing, chemical applications and changes in microclimate and soil quality;
- are commonly dominated by alien species and when indigenous species are used these may have been modified substantially from their ancestral forms through long histories of artificial selection or imposed genetic uniformity;
- are assumed to have very low species diversity - many are monocultures, fields dominated by a single plant species or variety with little intraspecific variability and with measures taken to prevent increase of diversity during crop life;
- consist of plants of imposed uniform age and size, so development from germination to harvest is uniform, with phases such as flowering or seeding occurring simultaneously in all individuals (density of the plants may be much higher than in natural communities); and
- are commonly enriched by addition of fertilisers, rendering the plants nutritious and attractive to many herbivores.

The biodiversity components of agro-ecosystems can be classified in relation to the role they play in the functioning of cropping systems (Altieri, 1999). Agricultural biodiversity can be grouped as follows:

- productive biota: crops, trees and animals chosen by farmers which play a determining role in the diversity and complexity of the agro-ecosystems;
- resource biota: organisms that contribute to productivity through pollination, biological control, decomposition; and

- destructive biota: weeds, insect pests, microbial pathogens, etc. which farmers aim at reducing through management practices.

2.3 Sampling biodiversity: arthropods and plants

This section provides a short description of different methods of arthropods and plants sampling in agro-ecosystems.

2.3.1 Invertebrate sampling

2.3.1.1 Suction sampling

The Dietrick vacuum (D-vac) was the first commercially available suction machine for sampling terrestrial arthropods and has been used extensively to sample arthropods in numerous terrestrial habitats including agricultural crops (Elliot, *et al*., 2006). The efficiency of D-vac is also likely to be influenced by vegetation structure and density, but because it is not dependent on the activity of the sampled organisms, it is in general less prone to error (Thomas and Marshall, 1999). It is very effective at sampling a wide range of arthropod taxa that are diurnally active in the vegetation layer and on the soil surface (Thomas and Marshall, 1999).

The D-vac has certain disadvantages compared to other suction samplers, notably its weight and bulkiness, and relatively low air velocity at the collection nozzle (Elliot, *et al*., 2006). The D-vac does not sample nocturnally active ground beetles effectively because they are normally hidden in inaccessible refugia during the day (Thomas and Marshall, 1999). Plant growth stage also influence the efficiency of suction sampling for larvae, with efficiency decreasing as plant development increases and plants become larger (Elliot *et al*., 2006). Vegetation structure apparently affects the sampling efficiency by altering airflow through the foliage and also by forming a filter through which predators are differentially extracted (Elliot *et al*., 2006).

2.3.1.2 Sweepnet sampling

Sweepnet sampling is a technique that provides relative population estimates while providing a relatively large amount of information with minimal effort (Pedigo and Buntin, 1993). According to Nummelin and Zilihona (2004), sweep netting of arthropods is useful as a tool for environmental impact assessments. Sweep netting is known to favour larger insects, but small and soft bodied arthropod groups are often damaged by this method (Nummelin and Zilihona, 2004).

2.3.1.3 Trap sampling

Pitfall traps are the best known and most often used inventory method in agro-ecosystems (Duelli *et al*., 1999). Pitfall traps continue to be widely used for assessing diversity and abundance, because they are cheap, easy to set and collect, can be left unattended and specimens are collectable at specific time intervals (Pedigo and Buntin, 1993; Thomas and Marshall, 1999). However, catches are dominated by ground active carabids (Thomas and Marshall, 1999) and provide no data on organism that occur on plants. Traps are used to provide direct evidence of the presence of pest species in a specific area (Pedigo and Buntin, 1993) and are widely used to arrive at an indication of habitat quality and for measuring nature conservation values (Duelli *et al*., 1999). There are three reasons why pitfall traps are not always used in biodiversity evaluation (Duelli, 1999). These are:

i) while epigeal predators are excellent indicators for habitat quality in terms of biological control of pest organisms, they make poor correlates for overall organismal biodiversity.

ii) biodiversity evaluation in most cases is primarily motivated by nature conservation, therefore, it tends to be focused on rare, attractive and threatened species rather than on common and inconspicuous beneficial organisms.

iii) the efforts and costs for collecting, sorting and identifying epigeal arthropods are often too high compared to higher plants or birds.

2.3.2 Plant sampling

Sampling methods for plants must be chosen in accordance with the particular type of vegetation being studied, *i.e*., plant density, size, and height are important considerations (Leis *et al*., 2003). Other important considerations include number of samples necessary to represent the community and time needed to collect data (Leis *et* *al*., 2003). Sampling and data analysis are not independent of each other, and some methods of analysis require specific methods of sampling (Barbour *et al*., 1987).

2.3.2.1 Transects

A transect is a line along which samples of vegetation are taken (Kent and Coker, 1992). Transects are usually deliberately placed across areas where there are rapid changes in vegetation and marked environmental gradients (Kent and Coker, 1992). Length of transect is also important since several short transects can be read more quickly than a single long transect, but with the same accuracy (Leis *et al*., 2003).

2.3.2.2 Quadrants

The usual means of sampling vegetation for floristic description is the quadrant (Kent and Coker, 1996). Traditionally quadrants are squares, although rectangular and even circular quadrants have been used (Barbour *et al*., 1999). Quadrant size is very important and will vary from one type of vegetation to another (Kent and Coker, 1992). Precision is best when quadrants are long, narrow rectangles (Barbour *et al*., 1999). Square and round quadrants are often less precise because each one encompasses less heterogeneity within it, than a long, narrow plot placed parallel to the major environmental gradient (Barbour *et al*., 1999).

2.3.2.3 Fixed point method

If a quadrant is reduced to no dimension, it becomes an infinitely small point (Barbour *et al*., 1999). In practice, metal pins with sharp tips serve as the points (Barbour *et al*., 1999). As the pin is lowered, the first plant it touches is recorded. If no plant is hit, then the point is recorded as bare ground. Disadvantages of the point method are that density cannot be measured and the method is limited to low vegetation (*i.e.* grassland) (Barbour *et al*., 1999).

2.4 Plant and insect relationships

2.4.1 Role of insects as pollination vectors

In natural and semi-natural habitats up to 90% of all flowering plants rely on pollination by animals, mainly insects (Gabriel and Tscharntke, 2007). Pollination is simply the transfer of pollen from the anther of one flower to the stigma of another or the same flower (Kevan, 1999). Pollination is important for the maintenance of diversity in wild flowers, and is indirectly responsible for the persistence of other guilds that depend upon floral resources, such as herbivores and seed eaters (Potts *et al*., 2006). Pollinating insects constitute an important factor in increasing the yield of many crops such as fruit trees. This function is successfully fulfilled by honey bees (Banaszak, 2000). However, to pollinate some certain other crops, particularly fodder plants, participation of a variety of insects is necessary (Banaszak, 2000).

In most *Acacia* species examined to date, insects are the main pollinators (Fleming *et al*., 2007). Flowers of the critically endangered orchid *Disa scullyi* is pollinated by the large nemestrinid fly species *Prosoeca ganglbaueri* (Johnson, 2006). *Aloe inconspicua* is effectively and exclusively insect-pollinated, with *Apis fallax* (a bee) being the primary pollinator (Hargreaves *et al*., 2008). Beetles (Coleoptera) have been identified as the most common pollinators of cycads (Suinyuy *et al*., 2009). According to Suinyuy *et al*. (2009), surveys of the pollination ecology of the male and female cones of South African cycads indicated that three beetle species were present in sufficient numbers during pollination to be potential pollinators, *i.e.* Erotylidae sp. (Cucujoidea), *Metacucujus encephalarti* (Cucujoidea), and *Porthetes hispidus* (Curculionidae). In fynbos, pollinators (especially beetles belonging to the Melyridae, Scarabaeidae and Nitidulidae) are more diverse and abundant (Procheş and Cowling, 2006). Therefore, flower visitors play a significant role in pollination of plants.

2.4.2 The insect fauna in vegetation

The Cape Floral Kingdom (CFK) of South Africa is recognised globally as distinctive and biologically rich in endemic species (Pressey *et al*., 2003). The Cape Floral Region’s (CFR) extremely high levels of plant endemism and diversity has led it to being recognized as one of the six floral kingdoms of the world and one of the 34 global hotspots (Pryke and Samways, 2009).

Plant genera are good predictors of insect species diversity across spatial scales (Procheş *et al*., 2006). Thirty-eight percent of southern Africa’s Red Listed butterflies occur in the CFR (Pryke and Samways, 2009). In southern Africa a general coincidence can be observed for patterns in diversity and endemism of bees and plants and both have their centre of highest species diversity in the winter rainfall area in the Western Cape (Kuhlmann, 2009). The CFR is the only place on earth where a centre of bee diversity coincides with a plant diversity hotspot. In New Zealand, the richness of beetle and fungus gnats is correlated with vascular plant richness (Toft *et al*., 2001). However, this relationship may be obscured or complicated by other characteristics of plant communities that influence insect distribution (e.g. structural complexity and productivity of plants) (Wenninger *et al*., 2008). The good relationship between plant and insect species richness is likely to be due to both direct interactions (the plant providing primarily microhabitats and secondarily food for the insects) and parallelism (both groups responding to similar environmental factors (Procheş and Cowling, 2006)).

2.5 Invertebrates and the ecosystem

Invertebrates make up at least 95% of all species and they occupy almost every terrestrial and freshwater habitat (Lovell *et al*., 2007). They are the most abundant consumers in African savannas and, in some instances, have a greater biomass than vertebrates (Fabricius *et al*., 2003). Invertebrate species diversity and population density are related to type of farmland or other surrounding vegetation (Asteraki *et al*., 1995). The surrounding vegetation may, for example, be entirely grassland or woodland (Asteraki *et al*., 1995).

Invertebrates play important roles in altering the structure and fertility of soils, pollinating flowering plants and cycling nutrients (Fabricius *et al*., 2003). Arthropods are potential indicators of subtle habitat change because they respond to the environment at a finer scale than larger organisms and require smaller habitat patches than larger animals for survival (Fabricius *et al*., 2003). The realization that invertebrates are indispensable components of biodiversity has led to a rapid increase in surveys incorporating a wide range of invertebrate taxa and greater pressure to provide information and guidelines for invertebrate conservation and monitoring (Lovell *et al.*, 2007).

The realization that man-made monocultures are more vulnerable to pest outbreaks than natural species-rich plant communities has been used as one of the most important sources of evidence supporting the diversity-stability hypothesis, which states that the greater the diversity of a community the greater its stability (Vehviläinena *et al*., 2006). It is suggested that a greater diversity of primary producers should support a greater diversity and abundance of consumers (Vehviläinena *et al*., 2006).

2.6 Structural changes of agro-ecosystems

Human development is considered the primary force of landscape change (Fairbanks *et al.*, 2001). Landscape modifications by humans are the most important modern cause of habitat loss and habitat fragmentation, reducing levels of biodiversity worldwide (Lindenmayer and Fischer, 2006). Agro-ecosystems generally contain fewer plant species than the native flora, and they contain less diversity in foliage structure than native ecosystems, and they also contain far fewer species of invertebrates and vertebrates than natural ecosystems (Boutin *et al*., 2008). When agro-ecosystems are extensive and remaining habitat is fragmented, local extinctions that results from fragmentation will also reduce the species and functional diversity of the region as a whole (Lacher Jr *et al*., 1999). Considering all the impacts of human development on biodiversity, conservation and management of biodiversity in modern society is critical.

2.6.1 Effects of habitat fragmentation

Habitat fragmentation implies the loss of continuity of previously widespread habitat as it is alienated progressively by human changes and the remaining patches are spread more widely over the landscape (New, 2005). Habitat fragmentation usually occurs in densely human populated regions. For example, mountain habitats are mostly pristine and well conserved with lowland regions have been severely impacted by alien plants and agriculture and urbanisation resulting in the fragmentation of natural habitat over large areas (Kemper *et al*., 1999). Although habitat fragmentation occurs naturally, it is mostly caused by the expansion and intensification of anthropogenic land use (Kruess and Tscharntke, 2000).

In modern agriculture, habitat loss on a landscape scale has often reached 80% or more (Kruess and Tscharntke, 2000). At such a high level, isolation appears to be a major threat to biological diversity (Kruess and Tscharntke, 2000). Fragmentation affects both biodiversity and plant reproductive success when small, isolated fragments sustain a reduced diversity or abundance of pollinators (Aguirre and Dirzo, 2008) which may lead to local extinction.

Steffan-Dewenter and Tscharntke (2002) studied the effects of habitat fragmentation on the diversity and biotic interactions of insect communities with special emphasis on calcareous grasslands. They found that as a result of decreased pollinator diversity or abundance in small fragments, plants may increasingly compete for pollinators. Small or less dense plant patches may receive fewer pollinator visits, thereby reducing pollination efficiency and gene flow by pollen dispersal (Steffan-Dewenter and Tscharntke, 2002). Fragmentation of habitats is characterized by at least three important processes each affecting the diversity and the spatial distribution of species (Kruess and Tscharntke, 2000). These processes are:

i) area reduction of the original habitat in the landscape due to habitat loss.

ii) area reduction of the emerging habitat fragments.

iii) increasing distance between fragments (fragment isolation).

Kemper *et al*. (1999) studied fragmentation effect in renosterveld shrublands. They found a weak fragmentation effect. Kemper *et al*. (1990) proposed three reasons for this:

i) most renosterveld species resprout after fire or have wind-dispersed seeds. Sprouters are able to persist for long periods, so the relatively recent fragmentation of this vegetation type may obscure the expression of recruitment failure. Wind-dispersal may enable the propagules of many of the dominant asteraceous shrubs to disperse among fragments, thus avoiding local extinction.

ii) livestock grazing has caused the conversion of much of the renosterveld habitat from shrubby grassland to grassy shrubland, dominated by unpalatable species. Thus, the long history of disturbance may have predisposed renosterveld species to withstand the deterministic impacts of fragmentation.

iii) renosterveld does have a number of locally rare plant species. These small and isolated, but entirely natural, populations may well have been resistant to inbreeding depression and loss of heterozygosity prior to fragmentation.

2.6.2 Impact of land-use change on biodiversity of the Grassland Biome

The Grassland Biome of South Africa harbours a rich species, community and ecosystem diversity (O`Connor and Kuyler, 2009). Its unique biodiversity features include globally significant centres of plant endemism, half of the South Africa’s endemic mammal species, a third of its endangered butterfly species and 10 of 14 of its globally threatened bird species (O`Connor and Kuyler, 2009). The Grassland Biome also supports a large human population through the goods and services it provides, which renders grasslands vulnerable to transformation (Short et *al.*, 2003). Many grassland plant species are threatened by modern agricultural practices (Johansson *et al.*, 2008) and other land use activities. The Grassland Biome is poorly maintained in southern Africa because 23% is under cultivation, 60% is irreversibly transformed, only 2% is protected and most of the remaining area is used as rangeland for livestock (O`Connor and Kuyler, 2009). Alien trees are cultivated commercially and the alteration of grasslands to tree-dominated landscapes has had negative impacts on the functioning of grassland ecosystems (Malan *et al.*, 2007). Future threats to the vegetation of the Grassland Biome include continuous transformation by existing land uses due to the suitability of many areas of the biome for economic activities as destructive as coal mining (Mucina and Rutherfold, 2006).

2.6.3 Impact of land-use change on biodiversity of the Savanna Biome

Savanna is a mixture of trees, shrubs and grasses, also referred to as the bushveld (Ferrar and Lötter, 2007). Savanna is characterized by having a continuous, well-developed grass layer and an open, discontinuous layer of shrubs or trees (Knoop and Walker, 1985). There has been a substantial loss of savanna area due to cultivation, rather than other transformational land use practices (Mucina and Rutherford, 2006) (e.g. trees and shrubs are cleared and burnt before cultivation).

Different and complex impact gradients can occur around rural human settlements both as combination of the effects of domestic livestock and use of other resources by people (Mucina and Rutherford, 2006). In rural settlements in the Lowveld (Mpumalanga Province) woody vegetation decreases, but herbaceous cover increases (Mucina and Rutherford, 2006). This strongly suggests that wood is the primary source of domestically used energy in rural settlements (Shackleton *et al.*, 1994).

Livestock grazing is the primary land use in communal rangelands, with additional natural resource harvesting (Smart *et al*., 2005). Grazing by domestic livestock can have a dramatic impact on savanna ecosystems and is often responsible for extensive bush encroachment (Tobler *et al*., 2003). Bush encroachment reduces carrying capacity and is difficult to reverse, reducing the value of the land for livestock (Ferrar and Lötter, 2007). Clearly, intensive domestic livestock grazing and wood collection results in a decrease of savanna biodiversity.

2.6.4 Impacts of alien invasive plants and insects

Invasive plants are alien species introduced in new areas where they are able to successfully reproduce and disperse efficiently to such an extent that they spread rapidly (Vanparys *et al*., 2008). Worldwide, over 120,000 alien species of plants, animals and microbes have invaded countries and many have caused major economic losses in agriculture and forestry, as well as impacting negatively on ecological integrity (Pimentel, 2001). According to Pimentel (2001), insect and mite pests in South Africa cause extensive losses of potential crop production each year, with approximately 45% of these insect and mite pests being alien species.

The invasion of ecosystems by alien species is identified as a large and growing threat to the delivery of ecosystem services (Bjerknes *et al*., 2007; van Wilgen *et al*., 2008). Invasive alien plants affect the structure and function of ecosystems (Beater *et al*., 2008, Samways *et al*., 1996) and can lead to an increase in rarity and vulnerability of indigenous invertebrates, as well as plant species and physiognomy (Samways *et al*., 1996). Some alien plants became invasive due to a high attractiveness to pollinators, and therefore they have negative consequences on the reproductive success of native species (Vanparys *et al*., 2008; Bjerknes *et al*., 2007).

2.7 Field margin habitats

Semi-natural habitats in the agricultural landscape, e.g. hedgerows and other types of field boundaries, provide a diverse flora and habitat structure that can support a diverse arthropod fauna (Marshall and Arnold, 1999). As stated in Chapter 1, boundaries serve as refugia for plants, insects (i.e. some lepidopteran species (Gathmann *et al*., 2006)) or other animals (Marshall and Arnold, 1995; Asteraki *et al*., 2004) that are either neutral or beneficial to agriculture (Thomas and Marshall, 1999; Clark *et al*., 2005). However, increasing intensive agricultural production methods, involving wide spread use of herbicides and insecticides, have raised concern over the potential for agricultural practices to reduce the diversity and abundance of arthropods and these effects may possibly propagate upwards through the food chain to affect higher trophic levels in the agro-ecosystem (Marshall and Arnold, 1999). The repeated low-dose (i.e. herbicides and insecticides) events associated with drift when insecticide applications are done may also have more subtle effects on community structure of plants and arthropods in agro-ecosystems (Marshall and Arnold, 1995).

Field margins are a key feature of agricultural landscapes, present at the edges of all agricultural fields (Marshall and Moonen, 2002). These habitats increase the diversity and abundance of insects, especially if the margins are botanically and structurally diverse (Thomas and Marshall, 1999). Indigenous plants often are more common farther from field edges (margins), whereas weeds are more abundant in boundaries directly adjacent to intensively managed agriculture fields, possibly as a result of competitive advantages or outright loss of native species created by disturbance and agrochemical use (Clark *et al*., 2005).

2.8 Genetically modified crops

South Africa approved the first field trials with genetically modified (GM) crops in 1992 and the first conditional commercial releases started in 1997 (Aerni, 2005). South Africa is the first country in Africa to have introduced genetically modified crops for commercial production (Hofs *et al*., 2006). The GMO Act of 1997 approved the importation and the use of GM seeds and the establishment of the institutions required for evaluation (Thirtle *et al*., 2003). GM plants have been deliberately developed for a variety of reasons: e.g. longer shelf life, disease resistance, pest resistance, herbicide tolerance, nutritional improvement and resistance to stresses such as drought or nitrogen starvation (Icoz and Stotzky, 2008). The targeted pests of *Bacillus thuringiensis* (Bt) maize in South Africa are stem borers, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), and *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) which can cause between 10 and 100% yield loss (van Wyk *et al*., 2008). Bt is, however, also likely to have impacts on non-target Lepidoptera feeding on these crops and species that interact with Lepidoptera (Walker *et al.,* 2007).

It was proposed that transgenic Bt crops could be valuable tools for increasing agricultural productivity while minimizing the environmental impacts of agriculture (Cattaneo *et al*., 2006). It is clear that in agriculture genetically modified maize crops were marketed largely on the basis of its contribution to increased effectiveness of pest management (Douville *et al.*, 2007). The potential effects of transgenic crops on non-target arthropods have caused concern (Cattaneo *et al*., 2006), since insecticidal Bt crops could directly or indirectly affect non-target organisms that currently exist in agroecosystem and prevent significant services to ecosystem functioning (Hilbeck *et al*., 2004).

Biological control agents can be affected by GM crops when the quantity or quality (either reduced nutritional suitability or increased toxicity) of their food is affected by the GM crop, or when the GM crop alters the environment in which biological control agents live (Lundgren *et al*., 2009). The Bt protein (toxin) produced by Bt crops can enter streams where it might be toxic to aquatic (insect) life, possibly having an effect at ecosystem level. If Bt maize is detrimental to aquatic microbial organism through organic-matter decomposition, the overall carbon cycling may also be affected in streams that drain fields planted with genetically modified maize (Griffiths *et al*., 2009).

Every plant protection measure has an impact on agro-ecosystems (Gathmann *et al*., 2006). Since this study focuses on arthropod and plant diversity both inside and outside maize fields, the discussion below will consider some of the environmental effects that Bt maize could have.

2.8.1 Possible environmental effects of Bt maize

2.8.1.1 Effects of insect-resistant Bt crops on soil ecosystems

Soil meso- and macrofauna, such as earthworms, nematodes and arthropods, feed on living and dead plant tissues and play a vital part in soil nutrient cycling (Hagler *et al*., 2009). Earthworms are the most important components of soil that physically transform above-ground plant litter into soil (Icoz and Stotzky, 2008). The close relationship between plants and soil ecosystem function causes concern that GM-associated changes in crops and agronomic practices will affect soil systems (Lilley *et al.*, 2006). Bt plant material and Bt proteins can enter the soil through various potential routes, depending on the crop and environments (Hagler *et al*., 2009). These pathways include:

- direct input of Bt proteins via root exudates;
- input of Bt-expressing plant parts falling to the ground under plants; and
- input of plant residues (dead or alive, e.g. seeds) remaining in the field after harvest.

2.8.1.2 Toxic effects on non-target organisms

Larvae of non-target arthropods may inadvertently ingest the Bt toxin whilst feeding on plants growing near Bt maize fields (Obrist *at al*., 2006). In the vicinity of the Bt maize fields, such as field margins, larvae may be exposed to the toxin when Bt maize pollen is deposited on plants on which they are feeding (Gathman *et al*., 2006). Jesse and Obrycki (2000) found the first evidence that transgenic Bt maize pollen, which is naturally deposited on *Asclepias syriaca* (common milkweed) inside maize fields could cause significant mortality of *Danaus plexippus* L. (monarch butterfly) (Lepidoptera: Danaidae) larvae. Milkweed is commonly found in maize fields and adjacent non-cultivated habitats where it is a food plant for monarch butterfly larvae (Jesse and Obrycki, 2000).

2.8.1.3 Toxic effects on beneficial insects

One of the ecological risks of releasing transgenic Bt-plants would be the unanticipated effects of the toxin on organisms that are not pests of the crop itself – especially if those organisms are predators and parasites of pests and therefore of immense benefit to agriculture (De Maagd *et al*., 1999). Bt maize could adversely affect beneficial insects that are important in the natural control of maize pests, for example those that prey on maize pests, as has been shown for the predatory green lacewings, *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) (Wei *et al*., 2008). According to Ammann (2005), results from laboratory experiments on forced-fed predators, such as lacewing larvae, show significant negative impact of the Bt toxin on the well-being of the predator. Bt maize can, therefore, affect the abundance and diversity of beneficial species.

Chapter 3: Study area

3.1 Introduction

Study areas were identified in four of the maize producing provinces of South Africa, namely North-West, Mpumalanga, KwaZulu-Natal and Limpopo (Figure 3.1; 3.2 and 3.3). The study was conducted on commercial farms (with fields up to 500 000 m^2) and land of small farmers (with fields up to 5 000 m^2). Commercial farmers are mainly active in the Grassland Biome on the Highveld and small farmers in the Savanna Biome in the Lowveld (Mucina and Rutherford, 2006). Hence, our study areas were chosen accordingly. Two of the study areas were selected from the commercial maize belt on the temperate Highveld of South Africa and two in the rural, small farmer communities of the sub-tropical Lowveld. The study areas were not specifically selected to represent commercial farms and small holdings, but rather to include the different bioregions of the Highveld and Lowveld of South Africa. At each study area, two study sites were chosen, and at each study site two transects were sampled (Figure 3.1; see Table 3.2. for climate and altitude).

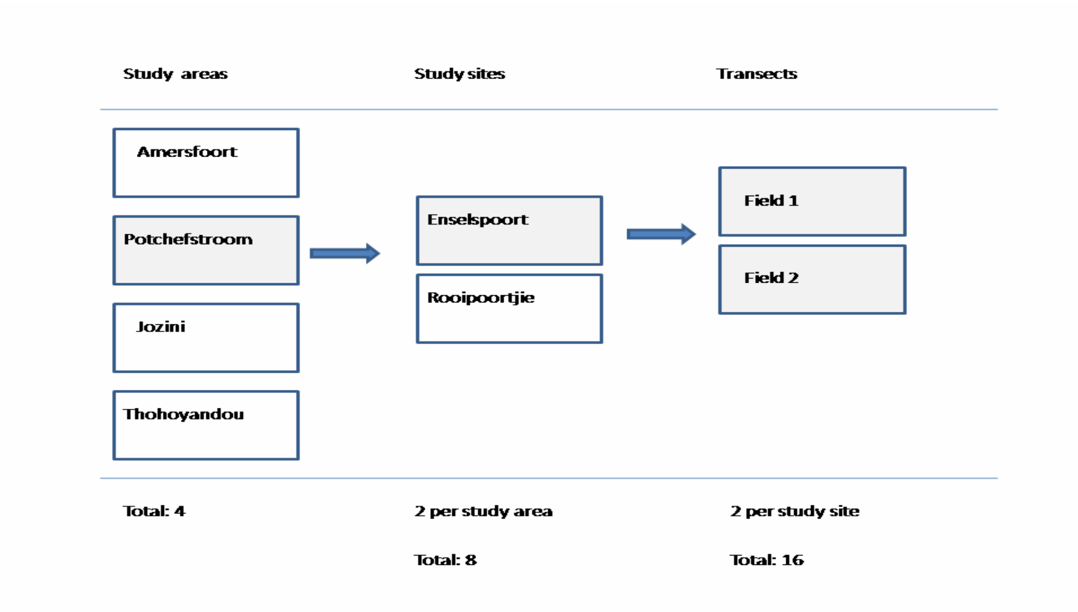

Figure 3.1: Approach to select study areas, sites and transects (e.g. Potchefstroom study area).

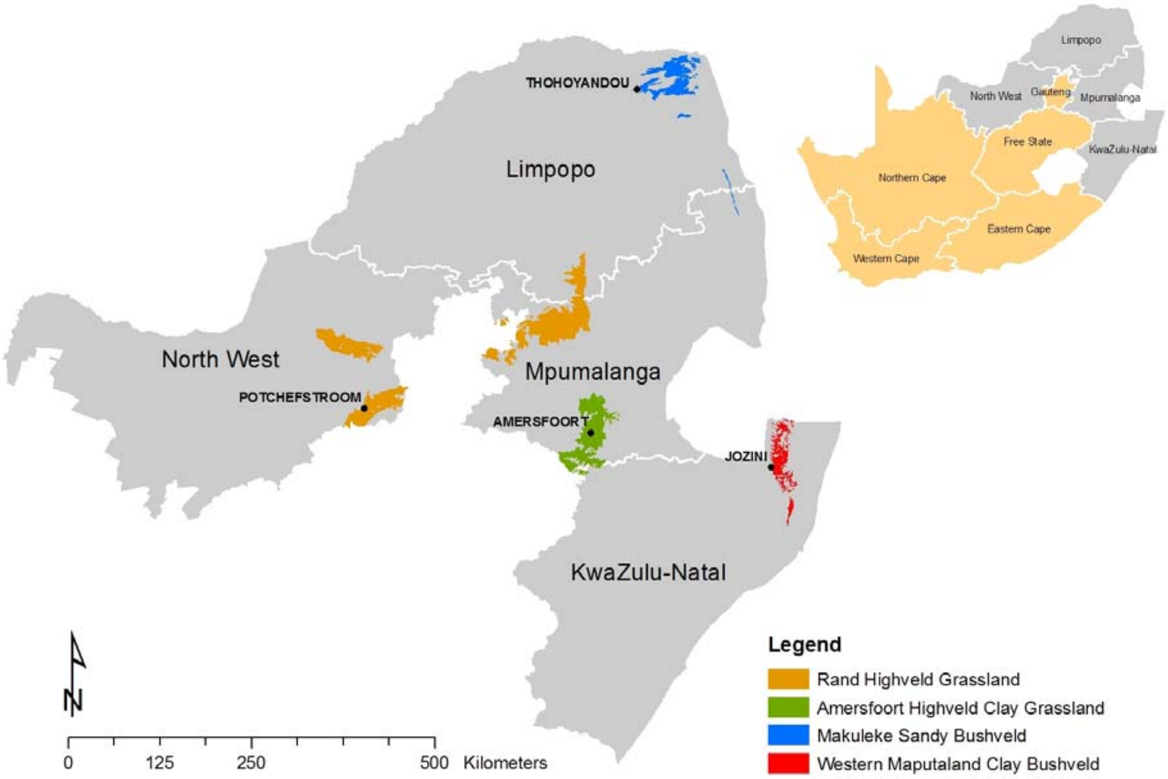

Figure 3.2: Nearest town and associated vegetation unit for each of the study areas.

3.2 Study sites

3.2.1 Potchefstroom

The fieldwork was carried out at two sites, Enselspoort and Rooipoortjie near Potchefstroom, North-West Province, South Africa (26° 43’S, 27° 15’E, altitude 1407-1490 m). Potchefstroom is part of the Tlokwe Municipality (Dr. Kenneth Kaunda District Municipality), which also includes the following towns: Promosa, Ikageng and Mohadin (TCC, 2009).

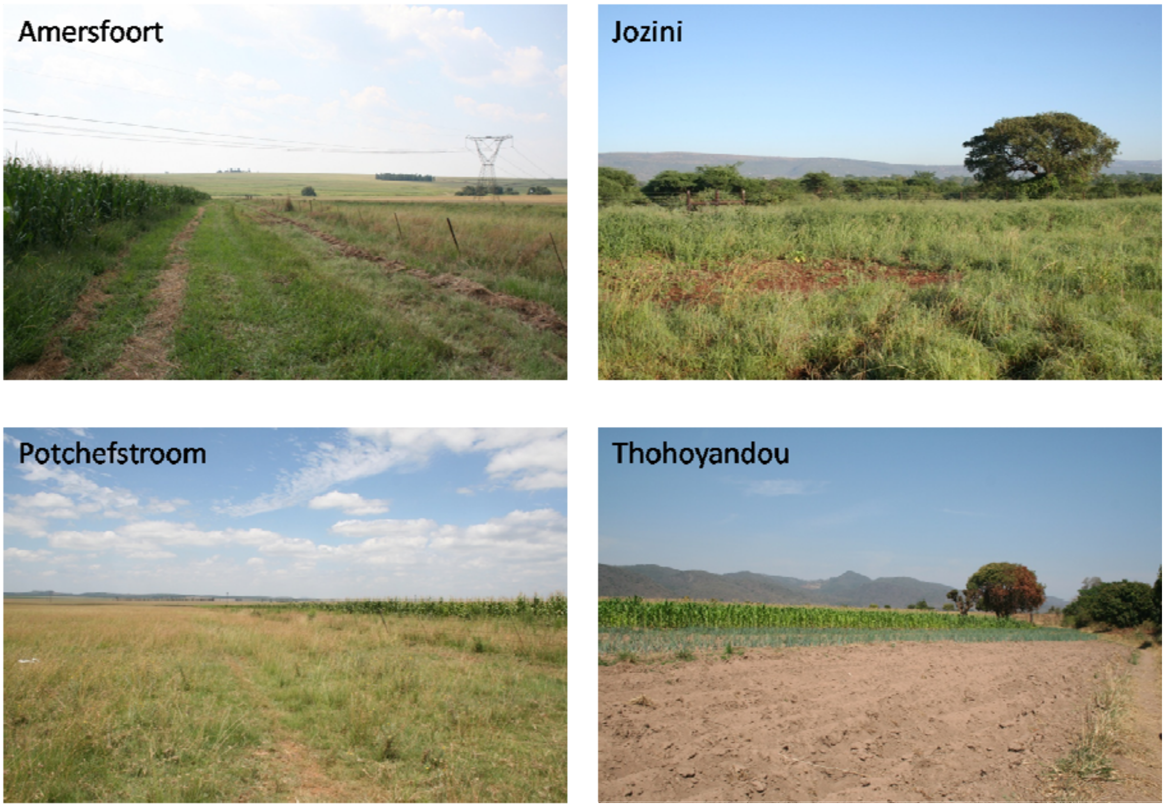

Figure 3.3: Visual representations of the vegetation and fields of each of the four study areas in the Highveld (Amersfoort and Potchefstroom) (left-hand side) and Lowveld (Jozini and Thohoyandou) (right-hand side) regions of South Africa.

3.2.1.1 Maize cultivation

Maize is the major summer crop in the region and is produced in commercial, high-input production systems. The North-West Province produced about 2 829 t of commercial maize in 2007/08 season (Table 3.1). The distance between rows of maize was 2 m, which is much wider than other localities to compensate for the lower rainfall. Dirt roads and fences act as boundary between maize fields and surrounding vegetation. The surrounding vegetation was used for livestock grazing.

3.2.1.2 Geology, soil and land types

The relatively heterogeneous geology is represented by the Witwatersrand and Ventersdorp Supergroups and the Transvaal Sequence, with isolated occurrences of old Archaic granites and Karoo Sequence sediments (Daemane *et al*., 2010). Quartzite ridges of the Witwatersrand Supergroup and the Pretoria Group, as well as the Selons River Formation of the Rooiberg Group, support soil of various quality (shallow Glenrosa and Mispah forms especially on rocky ridges) (Mucina and Rutherford, 2006). Soils in the study area are heterogeneous and vary from sandy to clayey, due to great variation in parent rock material (Daemane *et al*., 2010).

3.2.1.3 Climate

Potchefstroom experiences strong seasonal summer-rainfall, warm-temperate summers, and very cold and dry winters (Mucina and Rutherford, 2006). Daily mean temperatures may exceed 32 °C in January (Daemane *et al*., 2010). Mean annual precipitation is 654 mm, ranging between 570 mm and 730 mm between years, and decreasing towards the west (Mucina and Rutherford, 2006). Exceptional occurrences of more than 900 mm per annum have been recorded (Daemane *et al*., 2010). Occurrence of frost is frequent (Mucina and Rutherford, 2006).

3.2.1.4 Vegetation and landscape features

A highly variable landscape with extensively sloping plains and a series of ridges slightly elevated over undulating surrounding landscape (Mucina and Rutherford, 2006). The main vegetation unit is Rand Highveld Grassland which is a species-rich, wiry, sour grassland alternating with low, sour shrubland on rocky outcrops and steeper slopes.

Most common grasses on the plains belong to the genera *Themeda, Eragrostis, Heteropogon* and *Elionurus.* High diversity of herbs, many of which belong to the Asteraceae, is also a typical feature (Mucina and Rutherford, 2006).

3.2.2 Amersfoort

Fieldwork was carried out at two sites, Blomfontein and Maquabe near Amersfoort, Mpumalanga Province, South Africa (26° 57'S, 29° 59'E, altitude 1689-1747 m). The study area falls in the Pixley Ka Seme Local Municipality within the Gert Sibande District Municipality. The Local Municipality comprises an area which includes the following major towns: Amersfoort, Perdekop, Volksrust and Wakkerstroom (DALA, 2005).

3.2.2.1 Maize cultivation

Maize crops are planted in spring in this region and crops are harvested in July/August. This study area lies in a commercial high-input production system. Mpumalanga Province is the leading commercial maize producer in South Africa, with about 2 875 t produced in 2007/08 season (Table 3.1). The distance between rows of maize is about 0.9-1.0 m. Dirt roads and fences serve as boundaries between maize fields and surrounding vegetation, mainly because the major use of surrounding vegetation is for livestock grazing.

3.2.2.2 Geology, soil and land types

Soils of the region are restricted to vertic clay soils derived from dolerite that is intrusive in the Karoo sediments of the Madzaringwe Formation in the north and the Volksrust Formation and the Adelaide Subgroup in the south (Mucina and Rutherford, 2006). Large parts of Mpumalanga province grasslands occur on deep fertile soils of high agricultural value (Ferrar and Lötter, 2007).

3.2.2.3 Climate

Winters are cold and summers mild (Mucina and Rutherford, 2006). Rainfall occurs mainly in early summer, ranging between 620 mm in the west to 830 mm in the east (mean annual precipitation is 694 mm) (Mucina and Rutherford, 2006). Mean annual temperature is 14°C (Mucina and Rutherford, 2006). The seasons of no cultivation are characterized by cool and dry conditions, during which time most foliage is removed or killed by frost, and plants die back to ground level (Ferrar and Lötter, 2007).

3.2.2.4 Vegetation and landscape features

The landscape comprised of undulating grassland plains, with small scattered patches of dolerite outcrops in areas (Mucina and Rutherford, 2006). The area lies within the Amersfoort Highveld Clay Grassland vegetation unit (Mucina and Rutherford, 2006). The vegetation is comprised of short closed grassland, largely dominated by a dense *Themeda triandra* sward, often severely grazed to form short lawn dominated by various *Helichrysum* species (Mucina and Rutherford, 2006). Overgrazing leads to invasion of *Seriphium plumosum* L.

3.2.3 Jozini

The fieldwork was carried out at two sites in Makhathini flats near Jozini, South Africa (27° 26'S, 32° 09'E, altitude 72-112 m), which is considered to be low-input small farming systems. The Pongola River, which flows through Makhathini, was dammed in 1974 with the objective of controlling floods and the provision of water for irrigation (Morse *et al*., 2006). The construction of the Jozini Dam created a vast flat and fertile area of 1888 km^2 with reduced flooding incidence in the region (Morse *et al*., 2006). It falls in the Jozini Local Municipality within the uMkhanyakude District Municipality. Jozini Municipality comprises an area which includes the following rural towns: Ingwavuma, Jozini, uBombo, Bhambanana, uMkuze and Ndumo (JLM, 2008).

3.2.3.1 Maize cultivation

At this site maize is intercropped with pumpkins (*Cucurbita* species) and in some fields with sweet potato (*Ipomoea batatas* (L.) Lam.). Most of the maize is cultivated under irrigation in this region throughout the year. Farmers at the Makhathini flats (Jozini) received much attention in recent years for adopting Bt cotton (Hofs *et al*., 2008; Morse *et al*., 2006) although maize, which is the main crop, has not followed the same route. The KwaZulu-Natal province produced about 489 t of maize in the 2007/08 season (Table 3.1). The distance between rows of maize at this site was between 0.9-1.0 m. Intercrops often spread to cover large patches between rows. Dirt roads and fences act as boundaries between maize fields and surrounding vegetation. Surrounding vegetation of field margins is used for different purposes since it provides fire wood for fuel, building materials for shelter, and livestock grazing.

3.2.3.2 Geology, soil and land types

The underlying geology at this site comprises Cretaceous shallow-marine and coastal sediments, siltstones and conglomerates of the Zululand Group and minor rhyolites of the Jozini Formation (Karoo Supergroup) (Mucina and Rutherford, 2006). Dominant or zonal soils of this vegetation unit are latosols comprising of red sandy clay loam to red clay soils and non-duplex, brown, calcimorphic soils comprising yellow-brown sandy clay, sandy loam to clay loams (Mucina and Rutherford, 2006).

3.2.3.3 Climate

Rainfall occurs in summer with dry winters. Annual mean precipitation is about 500 to 750 mm per annum (Mucina and Rutherford, 2006). Mean monthly maximum and minimum temperatures are 39.5°C and 3.1°C for January and July respectively (Mucina and Rutherford, 2006).

3.2.3.4 Vegetation and landscape features

The Makhathini Flats comprises a mixed vegetation of mainly compound-leaved, short (5-10 m) woodlands and wooded grasslands. It occurs on the crest, upper and midslopes of gently undulating terrain (Mucina and Rutherford, 2006). The vegetation unit of this area is the Western Maputaland Clay Bushveld (Mucina & Rutherford (2006). This vegetation unit is dissected by two large alluvial flood-plains associated with the Mkuze and Pongola Rivers (Mucina and Rutherford, 2006). The landscape consists of fragmented patches of bushveld where successional shrubs and small trees dominate (*Dichrostachys cinerea* and *Acacia* spp.), with understory graminoid species, including *Panicum maximum* and *Dactyloctenium australe* (Hofs *et al.,* 2008).

3.2.4 Thohoyandou

The field work was carried out in Venda at Mutshenzheni and Tshiombo, both near Thohoyandou (Vhembe District), Limpopo Province, South Africa (22°47´S and 30°29`

E, altitude 613-680 m). The study sites are located in the Thulamela Municipality. The municipality covers vast tract of lands, mainly tribal, and Thohoyandou include the following small towns Malamulele, Makonde, Tshikombani, Tshaulu, Lwamondo and Saselemane (TLM, 2008).

3.2.4.1 Maize cultivation

In this low-input maize production system, maize is intercropped with pumpkins, sweet potato and peanuts (*Arachis hypogaea* L.). Maize is cultivated under irrigation due to the dry conditions of the region. Under irrigation more than one harvest is reaped every year. Limpopo has a low commercial maize production compared to Mpumalanga, North-West and KwaZulu-Natal (Table 3.1). The distance between rows of maize at this site was 1.0 m, although pumpkins, sweet potato and peanuts can spread over and cover the bare patches between rows. A small water canal in Mutshenzheni acts as a boundary between maize fields and surrounding vegetation. In the Tshiombo site dirt roads act as a boundary. Large parts of the natural vegetation on the field margins were recently cleared and burnt. Most of the surrounding natural woodland is used for fuel wood, shelter and other uses. The major use of natural vegetation is for livestock grazing.

3.2.4.2 Geology, soil and land types

Soils are generally deep sands and shallow sandy lithosols (Venter and Witkowski, 2010). The Soutpansberg Group of sandstones with lesser amounts of conglomerate, shale and basalt is mostly exposed in this area (Mucina and Rutherford, 2006). Some Karoo Supergroup rocks are also present. Most of the area has deep sands to shallow sandy lithosols (Mucina and Rutherford, 2006).

3.2.4.3 Climate

The Venda region experiences semi-arid summer rainfall with very dry winters (Mucina and Rutherford, 2006), characterized by hot summers and mild winters with mean annual precipitation of between 334 and 423 mm (Venter and Witkowski, 2010). Annual precipitation is highly variable, with a 35-40% coefficient of variation (Venter and Witkowski, 2010) and frost rarely occurs (Mucina and Rutherford, 2006).

3.2.4.4 Vegetation and landscape features

The variable landscape comprised of low mountains to extremely irregular plains and hills (Mucina and Rutherford, 2006). The main vegetation unit is Makuleke Sandy Bushveld (Mucina and Rutherford, 2006). A tree savanna (or tall shrub in places) occurs on the deep sands with trees such as *Terminalia sericea, Burkea africana, Guibourtia conjugata* and *Peltophorum africana* and a moderate to dense ground layer containing grasses, for example, *Andropogon gayanus* and *Digitaria eriantha* (Mucina and Rutherford, 2006). On stony soil the tree savanna includes *Kirkia acuminata, Croton gratissimus, Combretum apiculatum* and *Diplorhynchus condylocarpon, while* the ground layer is dominated by the grasses *Panicum maximum* and *Pogonarthria squarrosa* (Mucina and Rutherford, 2006).

Table 3.1: Maize grain production in the four study areas per province.

Production Year	Production[1]			
	KwaZulu-Natal	Limpopo	Mpumalanga	North-west
	1 000 t			
2004/05	400	120	2 807	2 862
2005/06	310	58	1 615	1 690
2006/07	359	131	1 490	1 392
2007/08	489	224	2 875	2 829

[1] Commercial production only

Source: Department of Agriculture; only the values for provinces having study areas were extracted.

Table 3.2: Climate and altitude of Mesic Highveld Grassland and Lowveld Bioregion units of the four study sites.

Bioregion	**Vegetation unit**	**Altitude (M) a.s.l.**	**Mean annual precipitation (MM)**	**Mean annual temperature (˚C)**	**Mean frost days**
Mesic highveld grassland	Gm 11 Rand highveld grassland	1 300-1 635	654	15.8	28
Mesic highveld grassland	Gm 13 Amersfoort highveld clay grassland	1 580-1 860	694	14.0	42
Lowveld	SVl 20 Western Maputaland clay bushveld	20-200	597	21.8	0
Lowveld	SVl 1 Makuleke sandy bushveld	300-700	489	21.7	1

Chapter 4: Plant species diversity and composition along maize field-field margin gradients in grassland and savanna in South Africa

4.1. Introduction

Human development is considered as the primary force behind landscape change and subsequent biodiversity loss (Fairbanks, 2004). The loss of biodiversity is a global concern affecting all biomes (O'Connor, 2005). As stated in Chapter 2, a high proportion of South Africa's biodiversity is not contained within designated conservation areas (O'Connor, 2005), but in agricultural lands (Wessels *et al*., 2003). Therefore, much attention should be directed towards agro-ecosystems for the formulation of strategies and policy that favour biodiversity conservation, management and sustainable agriculture. It has also been shown that agricultural expansion is associated with a decrease in biological diversity, so biodiversity management in agriculture is critical for the successful conservation of these ecosystems (Tscharntke *et al.*, 2005; Mponela *et al.*, 2010).

Patterns of biodiversity are of increasing concern for various reasons, such as conservation (Jiang *et al*., 2007). It is therefore important to prioritise conservation activities (Lovett *et al.,* 2000). Distribution patterns may also reflect underlying ecological processes that are important for biodiversity management and therefore an appropriate biodiversity management strategy should take this into account (Lovell *et al*., 2000). Management strategies are planned to develop sustainable agriculture and to promote environmentally friendly practices for nature conservation (Burel *et al*., 1998).

Appropriate management strategies are dependent on species richness and diversity values to assess ecosystems (Burel *et al.*, 1998). Species diversity has two basic components. Richness, or number of species in a given area, and evenness, or how relative abundance or biomass is distributed among species (Wilsey and Stirling, 2007). Plant species composition and species numbers may vary considerably among areas bordering fields (in this case maize fields) due to differences in ecological conditions and agricultural management practices (Hovd and Skogen, 2005).

Several studies have recorded positive or negative effects of agricultural land-use on species richness/diversity along a vegetation gradient. For example, Burel *et al*. (1998) in comparing biodiversity along a gradient of agricultural landscapes, found that intensification of agriculture does not always lead to a decrease in species richness, but to several functional responses according to taxonomic groups. Shackleton (2000) compared plant diversity in protected and communal lands in lowveld savanna and found that protected areas were characterized by significantly fewer species than the adjacent highly utilized, communal lands. This confirms that high biodiversity in South Africa is not contained within the designated areas, but in unprotected lands. Todd and Hoffman (1999) investigated changes in plant species richness and community composition across a fence separating heavily grazed communal and lightly grazed commercial farming systems in Namaqualand, and recorded no significant differences in plant species richness between communal and commercial farming systems, either locally within individual plots or overall across all plots.

To contribute to our understanding of plant diversity patterns in agro-ecosystems, this study investigated plant diversity patterns along maize field-field margin gradients (MAFMAG) to address the following questions:

- how do plant diversity patterns differ along MAFMAG, measured as diversity indices, in terms of locality and distance from maize field?
- how do plant species compositions along MAFMAG differ in terms of locality and plant community?

4.2. Material and Methods

4.2.1 Vegetation sampling

Surveys were conducted at four study areas in the major maize producing regions of South Africa during the 2009/10 season (see Chapter 3, Figure 3.1). Surveys were scheduled to coincide with the regional flowering times of maize to ensure sufficient sampling of insects (see Chapter 5). Two study sites were selected at each locality (study area), ± 5 km apart in order to avoid pseudoreplication. Two transects, comprising six sample points each, were placed ±200 m apart at each study site. At each sample point a plot of 100 m^2 (10 x 10 m) was placed. Inside each sample plot, five line transects of 10m each were placed, with the first line transect 1m inside the sampling plot and the remaining line transects spaced 2 m apart (Figure 4.1). Along each line transect the nearest tree, shrub, forb and grass species was recorded at intervals of 1 m. If no plant occurred within 0.5 m before or after the point a bare area was noted. In total 96 plots were sampled (24 plots per locality).

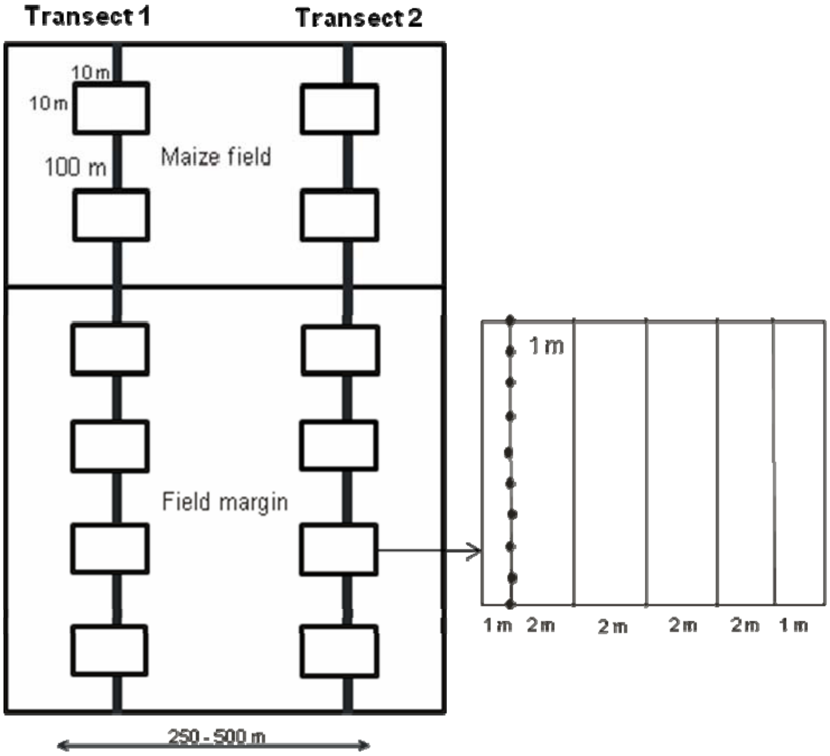

Figure 4.1: Transect layout of a single study site.

4.2.2 Data analysis

Species diversity indices were chosen to analyse the patterns of plant diversity along MAFMAG to consider both the richness and abundance of species (Magurran, 1988). Species richness and Evenness act as diversity components and diversity should be measured using a compound statistic, such as the Shannon-Wiener index, albeit that its performance and meaning is questionable (Stirling and Wilsey, 2001; Wilsey and Stirling, 2007). To broaden the scope of diversity measures the following indices were used:

Simpson index of diversity ($\check{D}$) = $\sum [n_i (n_i - 1)/N (N - 1)] - 1$, where **N** is the total number of individuals (all species) and **ni** is the number of individuals for the i*th* species.

Shannon-Wiener diversity index (H') = $-\sum (p_i . \ln p_i)$, where **p_i** is the relative abundance of the i*th* species.

Pielou's evenness (J') = $H'/H'max = H'/\ln S$, where **H'** is the Shannon-Wiener diversity index value and **S** is the species richness of the sample.

Margalef's species richness index (d) = $(S-1)/\ln N$, where **S** is the number of species recorded for the sample and **N** is the total number of individuals in all samples.

Species richness (S) is the number of species recorded for the sample and ignores relative abundances.

Statistical significant difference in plant diversity patterns was tested for with One-Way Repeated-Measures ANOVA (Analysis of Variance) in Statistica (StatSoft, 2009). P-values were obtained for distance from fields, different localities, as well as interactions (between distance and locality; combined rate of change along the gradient and between localities). To illustrate the compositional relationship of plant species between maize field and field margins of the four maize regions, data was subjected to Non-metric Multidimensional Scaling (NMDS) (samples clustered based on Bray-Curtis dissimilarity, PRIMER 5). This analysis visually represents the similarities between the species assemblages, but without attaching a specific meaning to the graph axes (Procheş and Cowling, 2007).

4.3. Results

4.3.1 General observation plant diversity patterns

Analysis of pooled data from all sites indicated that plant species diversity, richness and evenness for MAFMAG in South Africa generally increased with increasing distance from maize fields (Figure 4.2). The maize fields had the lowest value for all measurements (Figure 4.2A, B, C, D, E). The four diversity indices and species richness showed a similar pattern along MAFMAG. At 400 m outside the maize field there seemed to be a slight decrease for all indices (Figure 4.2).

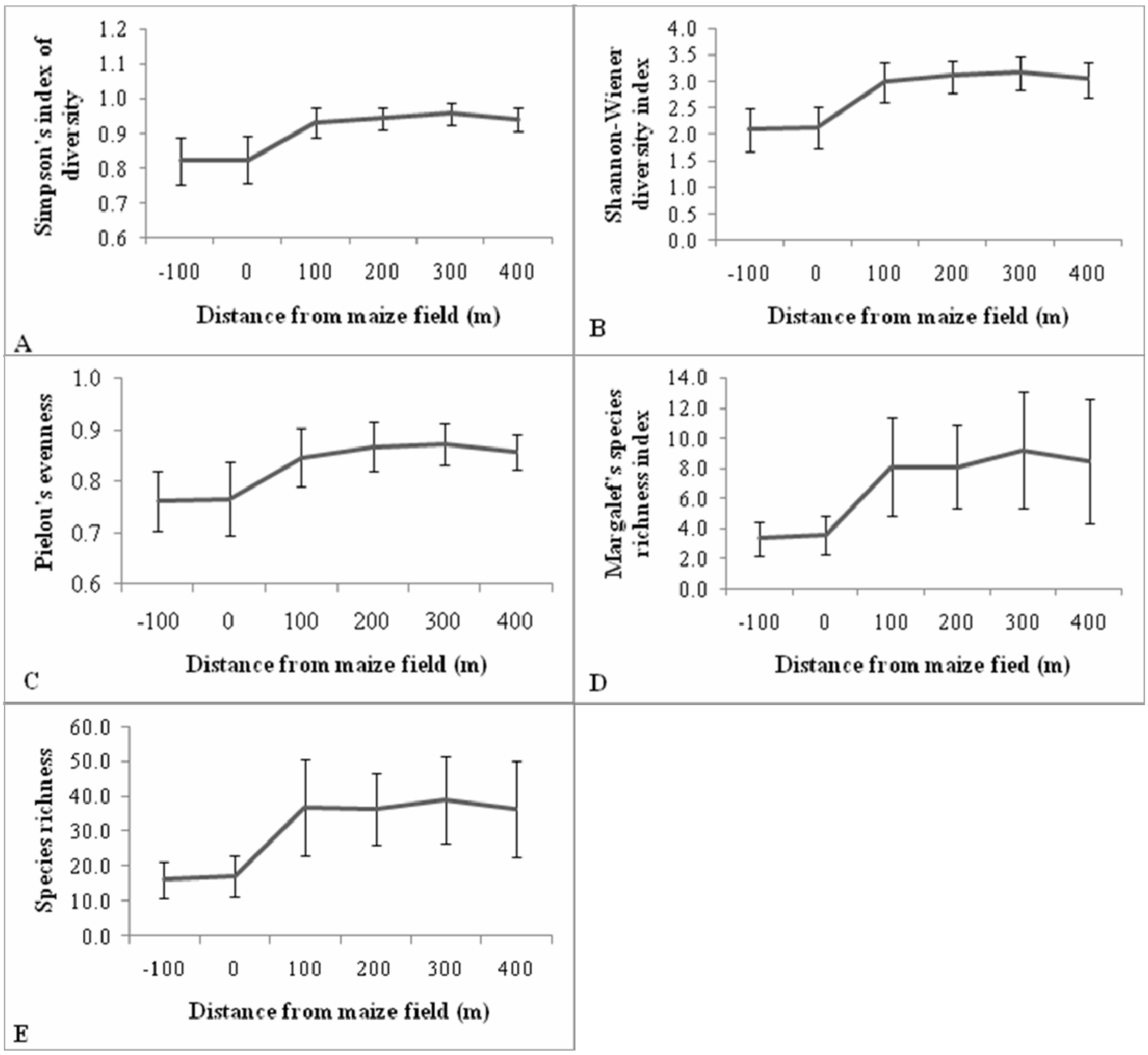

Figure 4.2: Mean diversity index ± Standard deviation values for plots along a MAFMAG in South Africa (A) Simpson's index of diversity; (B) Shannon-Wiener diversity index; (C) Pielou's evenness; (D) Margalef's species richness index; and (E) Species richness. Distances: -100 and 0 m sampled inside the maize field; 100-400 m sampled in the field margin.

4.3.2 Plant species diversity patterns per biome

The Savanna and Grassland Biomes showed similar patterns of plant diversity along the MAFMAG. However, the Savanna Biome had higher values per plot for both maize fields and field margins (Figure 4.3). Ď and H’ showed a similar pattern, but with higher values for Savanna (Figure 4.3). A statistically significance difference was recorded between both the biomes and the distance from maize fields ($p< 0.05$) (Table 4.1). As no significant difference was recorded for interaction, it is assumed that the diversity patterns are similar across biomes and the MAFMAG.

J’ was the only measurement showing lower values for the Savanna Biome, but only at 200 and 300 m (Figure 4.3C). At 400 m the Grassland Biome experienced a sudden decrease in evenness (Figure 4.3C). There was a significant difference in distance from maize fields for J’ ($P< 0.05$), but not between the biomes (Table 4.1).

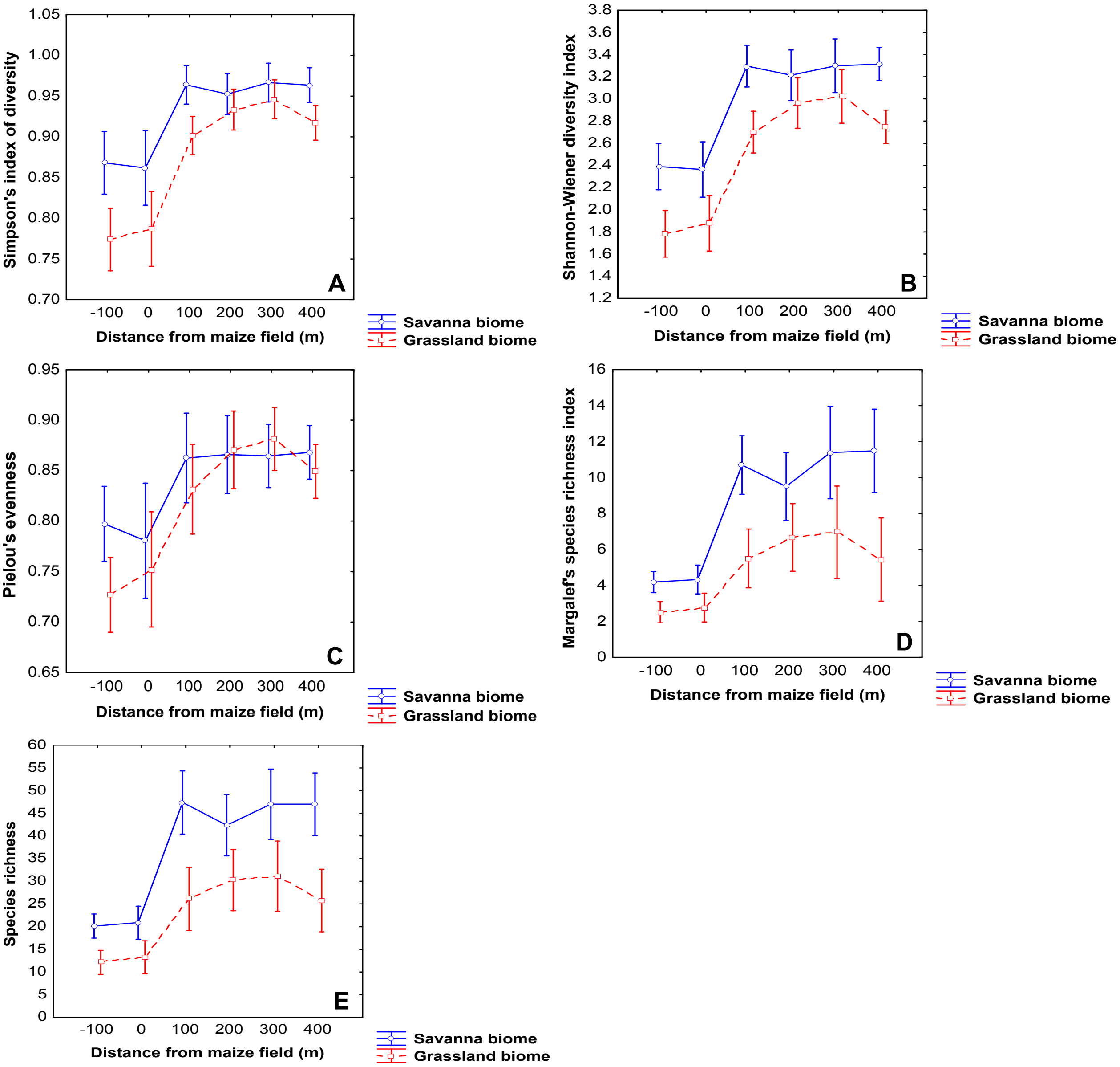

Figure 4.3: Mean (A) Simpson's index of diversity, (B) Shannon-Wiener diversity index, (C) Pielou's evenness, (D) Margalef's species richness index, and (E) Species richness values per plot (n=8) along MAFMAG in the Grassland and Savanna Biomes. Vertical bars denote 0.95 confidence intervals.

Table 4.1: P-values of Repeated Measures ANOVA for differences between biomes (Savanna and Grassland), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Biome and Distance). *indicates significant difference (P< 0.05) (n=8). Refer to Appendix A for complete statistical values.

Index	Biome	Distance	Interaction
Simpson`s index of diversity (Ď)	0.00061*	0.0*	0.056396
Shannon-Wiener diversity index (H′)	0.000038*	0.0*	0.181141
Pielou’s evenness index (J′)	0.089534	0.0*	0.249344
Margalef`s species richness index (d)	0.000556*	0.0*	0.002685*
Species richness (S)	0.000077*	0.0*	0.008665*

S and d were consistently higher for Savanna (Figure 4.3) and there was statistical significant differences between biomes, distances from maize fields and the interaction (P< 0.05) (Table 4.1). The difference in interaction suggests that grassland and savanna have specific richness patterns along the MAFMAG, peaking at 300 m from maize fields for the former. Thereafter, considering the limited length of the transect, the grassland diversity seems to decrease and the savanna diversity seems to stabilise.

The Savanna Biome had the highest mean numbers of species richness per distance (highest value = 47 species) (Figure 4.3E). In contrast, the Grassland Biome had the lowest mean number of species richness less than 31 between all sampled distances (Figure 4.3E; see Table 4.2 for further comparison).

Table 4.2: Highest, lowest and mean species richness for Savanna maize, Savanna margin, Grassland maize, and Grassland margin between all sampled distances.

Species richness	**Savanna maize**	**Savanna margin**	**Grassland maize**	**Grassland margin**
Highest species richness	29	69	21	39
Lowest species richness	16	25	6	18
Mean species richness	21	56	13	28

4.3.3 Plant species diversity patterns per locality

Ď and H' showed that maize fields had lower plant diversity than maize field margins (Figures 4.4A and 4.4B), a significant difference (Table 4.3). No significant difference was recorded for the interaction between locality and distance suggesting that trends are the same for all treatments ($P< 0.05$) (Table 4.3) and that diversity varies similarly across a MAFMAG at different localities. Both indices showed patterns of increasing plant diversity from Grassland to Savanna (Figures 4.4), also supported by a significant difference ($P< 0.05$) (Table 4.3). The indices revealed that Amersfoort and Potchefstroom (Grassland Biome) had lower plant diversity than Thohoyandou and Jozini (Savanna Biome). The Potchefstroom data showed a downward trend after 400 m for both indices, which can be more likely attributed to overgrazing.

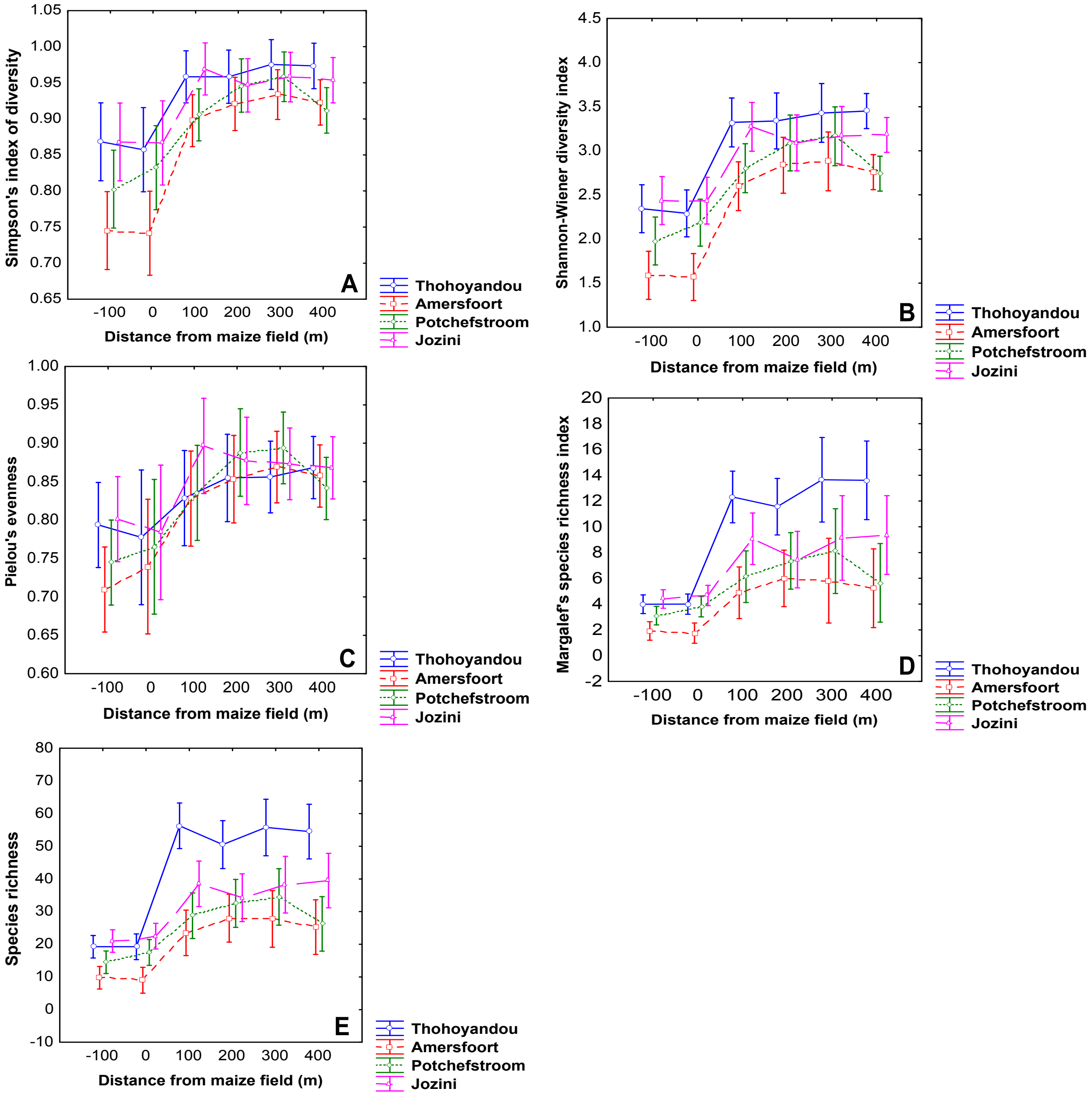

Figure 4.4: Mean (A) Simpson's index of diversity, (B) Shannon-Wiener diversity index, (C) Pielou's evenness, (D) Margalef's species richness index, and (E) Species richness values per plot (n=4) along MAFMAG for four maize producing regions in South African Biomes. Vertical bars denote 0.95 confidence intervals.

Table 4.3: P-values of Repeated Measures ANOVA for differences between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (-100, 0, 100, 200, 300, 400) and Interaction (Locality and Distance). *indicates significant difference (P< 0.05) (n=4). Refer to Appendix A for complete statistical values.

Index	Locality	Distance	Interaction
Simpson`s index of diversity (Ď)	0.000066*	0.0*	0.188693
Shannon-Wiener diversity index (H′)	0.000014*	0.0*	0.193690
Pielou's evenness index (J′)	0.142628	0.0*	0.837800
Margalef`s species richness index (d)	0.000386*	0.0*	0.001566*
Species richness (S)	0.000002*	0.0*	0.000282*

J' followed a similar pattern as the diversity indices, with lower evenness in maize fields and higher in field margins (distance from maize field was significant at P< 0.05) (Table 4.3; Figure 4.4C). At Jozini a higher evenness was observed compared to other regions (Figure 4.4C), but differences between localities were not significant. In Potchefstroom, an unanticipated decrease in evenness at 400m can be attributed to different impacts of livestock grazing. Weed control in maize fields, favouring the crop species, was responsible for the decrease of evenness at 0 m. Plant richness increased into the field margin with increasing distance from maize fields. S and d showed that Thohoyandou had the highest relative species richness, followed by Jozini, Potchefstroom and Amersfoort (Figure 4.4D and 4.4E). Subsequently the statistical results revealed a significant difference in Locality and Distance (P< 0.05) (Table 4.3). A significant difference in the Interaction of Locality and Distance (Table 4.3), suggesting that variation in species richness does not follow a common trend. Plant species richness was, as would be expected for near-monocultures, lower in maize fields compared to untransformed areas, which is probably due to bare patches of land attributed to land-use activities in the vicinity of fields (i.e. grazing and overharvesting of natural resources). Grassland localities showed a steady increase in species richness up to 300 m after which a decrease was recorded (Figure 4.4E).

4.3.4 Plant species composition per locality

All the Non-metric multidimensional scaling (NMDS) analyses had low stress values and therefore provided a meaningful representation of the samples with no prospect of misinterpretation (Clarke, 1993). In all NMDS analyses, the maize field plots grouped together and the field margin plots group according to locality (Figure 4.5).

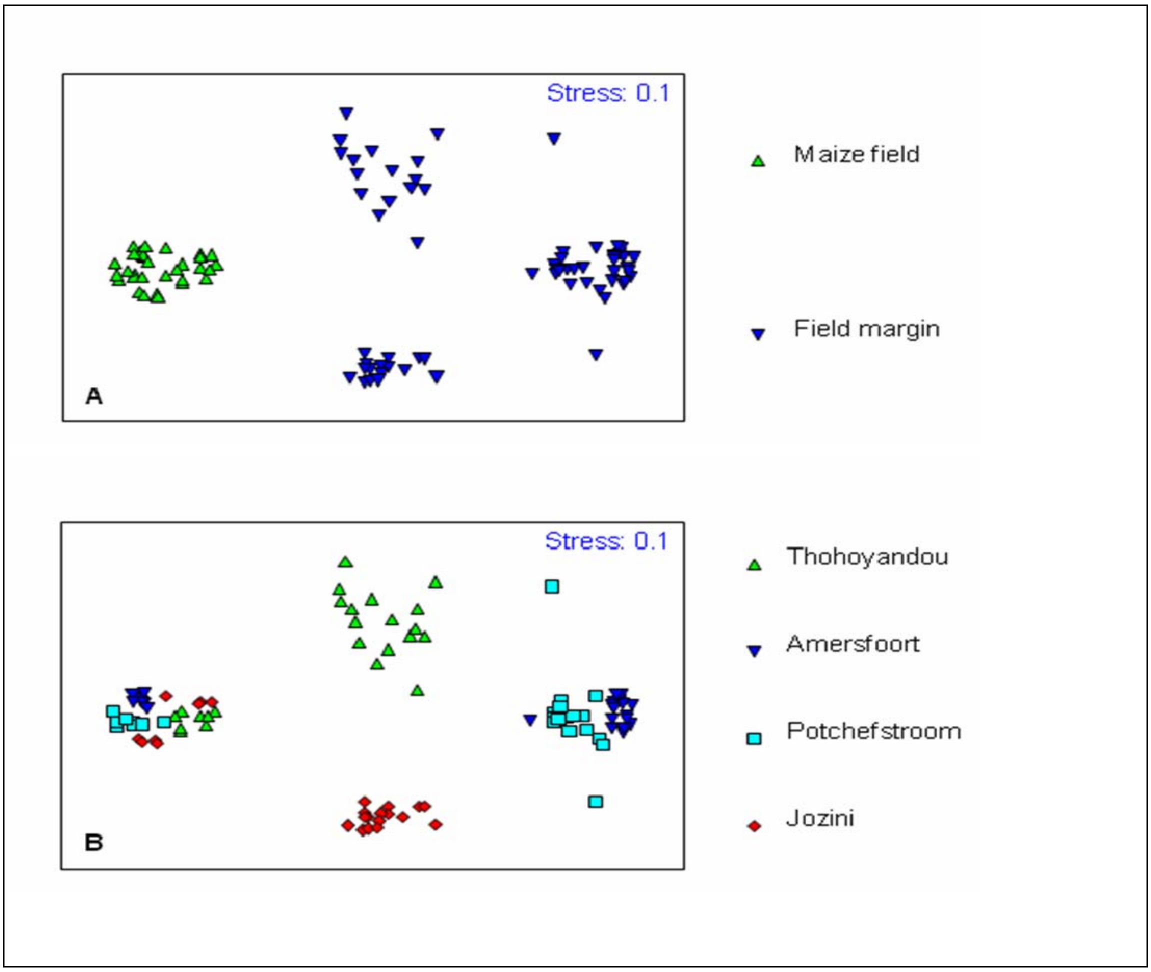

Figure 4.5: Non-metric multidimensional scaling analyses based on total species collected at all sites: (A) maize fields and field margins; and (B) four maize producing regions of South Africa.

4.3.5 Plant species composition per biome

Maize field plots in the Grassland Biome grouped together (Figure 4.6). This suggests that maize fields had similar plant species assemblages. Field margins for both Amersfoort and Potchefstroom grouped together in separated clusters, suggesting shared species assemblages.

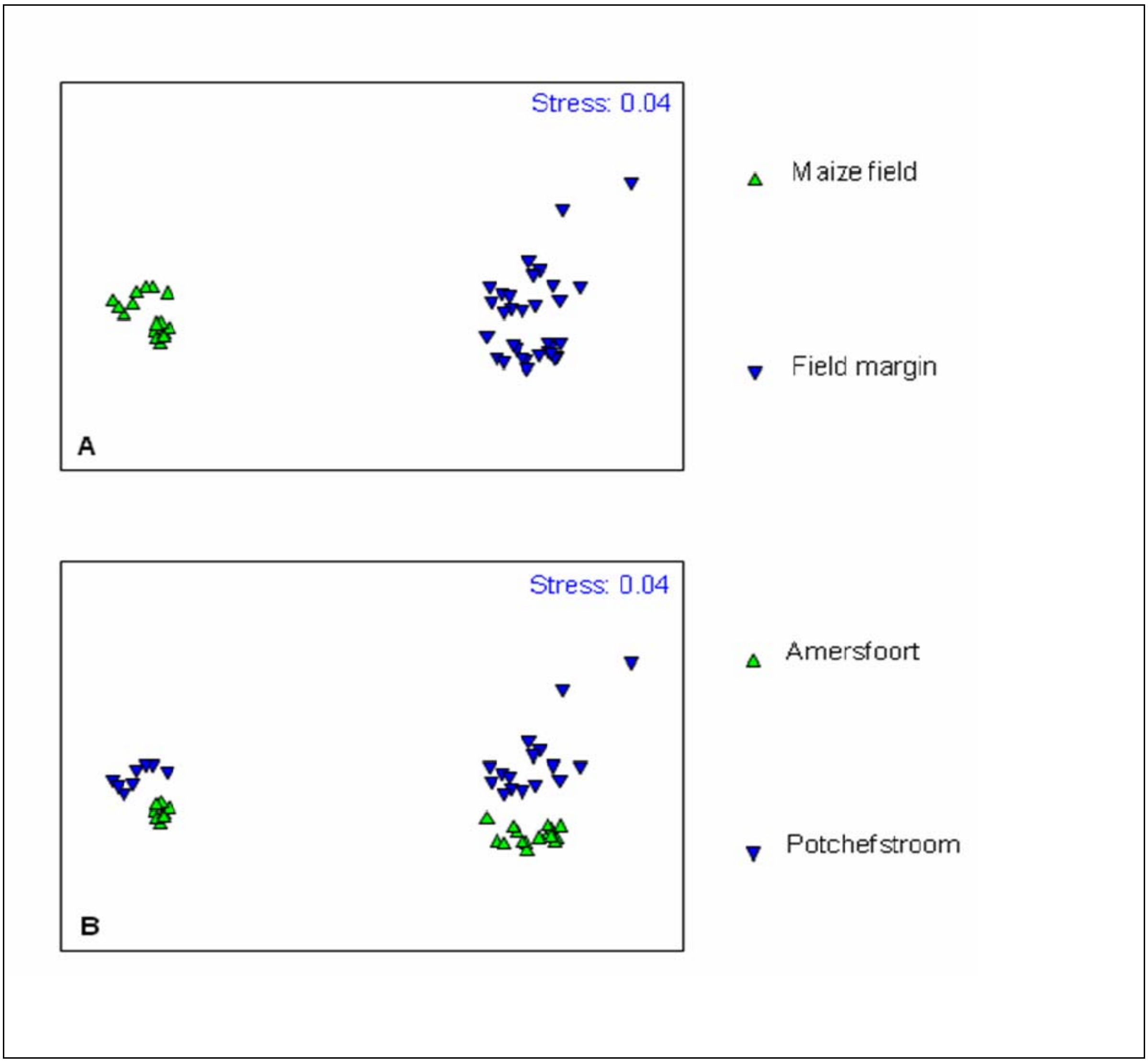

Figure 4.6: Non-metric multidimensional scaling analyses based on total species collected at all sites: (A) maize fields and field margins; and (B) Amersfoort and Potchefstroom grasslands.

Maize field plots in the Savanna Biome grouped together (Figure 4.7). Clustering of field margin plots was weaker than the margins of grasslands, suggesting higher beta-diversity regionally for savanna.

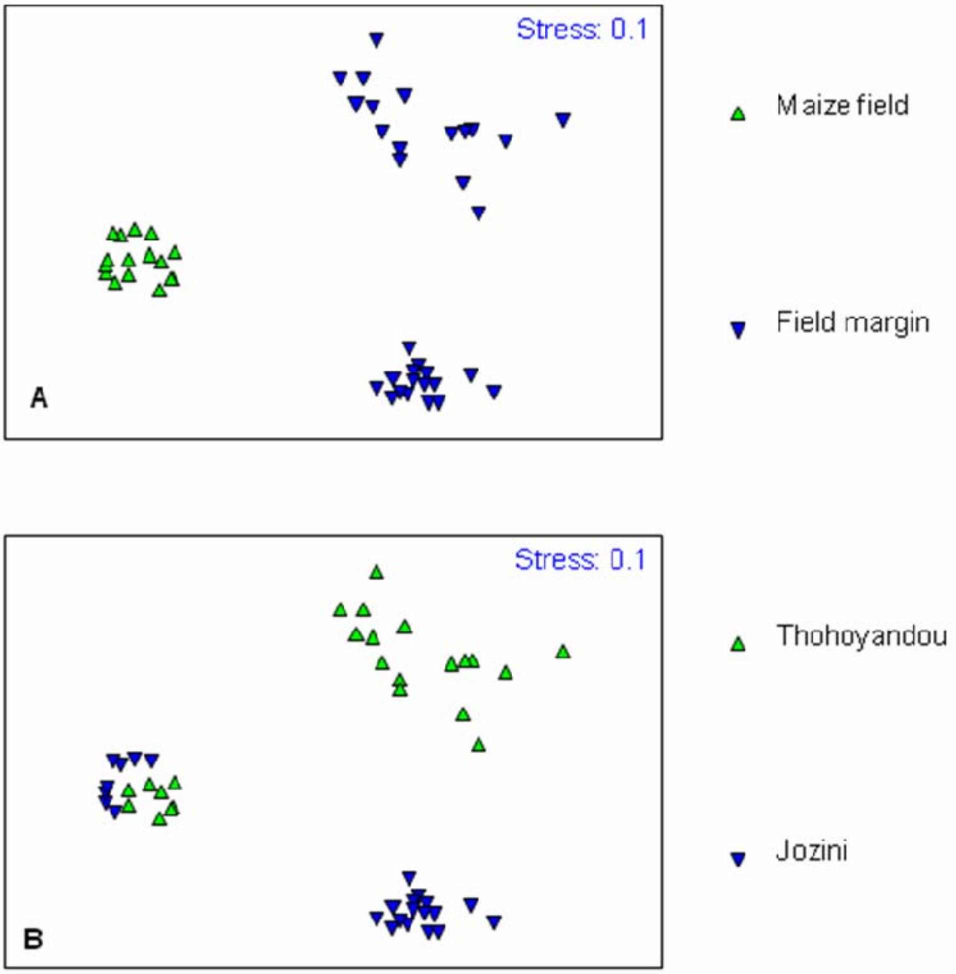

Figure 4.7: Non-metric multidimensional scaling analyses based on total species collected at all sites: (A) maize fields and field margins; and (B) Thohoyandou and Jozini savannas.

4.4 Discussion

4.4.1 Plant species diversity along MAFMAG

The main findings of this study revealed that plant species diversity, richness and evenness for MAFMAG in South Africa increase with increasing distance from maize fields, with maize fields revealing the lowest value for all measurements. This trend was expected as several northern hemisphere studies of field margins have shown that species diversity decreased with increasing management intensity (Marshall and Arnold, 1995; Buhk *et al.*, 2007; Niedrist *et al.*, 2009; Hamre *et al.*, 2010). At the edge of the field margin, 400 m away from the maize field along the MAFMAG, there seems to be a slight drop in all diversity measures. Although untested in this study, the decrease can probably be ascribed to the 'intermediate disturbance hypothesis' of Huston (1979) that suggests highly disturbed (maize fields) or slightly disturbed (400 m away from maize field) sites have lower species diversity than intermediately disturbed sites (field margin). This is, however, difficult to quantify as plant species distribution patterns are linked to the different kinds of landscape use in general (Wania *et al.*, 2007).

The lower level of species diversity in maize fields compared to field margins can be attributed to relationships between changes in species richness and a gradient of nutrient availability. Species richness is low at low nutrient levels, increases to a peak at intermediate levels and declines more gradually at high nutrient levels (Pausas and Austin, 2001) as is evident from the trends recorded for species diversity changes over distance from maize fields in this study. Maize field edges are subjected to drift of fertilisers, therefore maize field edges have intermediate nutrient levels and highest species diversity. At higher nutrient levels, such as in the maize field, a few highly competitive weedy species may become dominant, suppressing other species. This competitive exclusion causes a decline in species richness (Pausas and Austin, 2001). According to Meek *et al.* (2010), increased nutrient inputs from agricultural fields give alien species a competitive advantage over natives and this may result in more homogenous communities near maize field borders. This was observed in the present study that one or more species became dominant inside maize fields, but not on the maize field edges.

4.4.2 Plant species diversity of the Biomes

The Savanna and Grassland Biomes showed similar patterns of plant diversity along the MAFMAG, with the Savanna Biome having significantly higher values per plot for both maize fields and field margins. This agrees with our hypothesis that biodiversity of Lowveld agro-ecosystems is much higher than the Highveld. These higher values were expected as this increase for woodland field margins is ascribable to vegetation height, as multi-structured vegetation allows for more species per unit area (Schadek *et al.*, 2008) and coexistence of trees and grasses (Hassler *et al*., 2010). Also, the agricultural margins of the savanna localities were surrounded by natural vegetation which generally results in higher species diversity in field margins (Ma, 2005).

4.4.3 Plant species diversity patterns per locality

Weed control in maize fields, which favours the diversity of the crop species, is responsible for the low evenness. Evenness therefore increases at all localities with increasing distance from the fields and farming practices. However, in Potchefstroom, an unanticipated decrease in evenness at 400 m occurred. This was at a local scale, but is meaningless since highly fragmented agricultural systems, such is the case for the commercial farming areas around Potchefstroom, are subjected to an increase in disturbance types and therefore an increase in species evenness in the landscape overall (Ma, 2005).

Thohoyandou had the highest relative species diversity, followed by Jozini, Potchefstroom and Amersfoort. The species diversity of the Thohoyandou and Jozini study sites can be ascribed to these localities being situated in regions of exceptional plant species richness (Mostert *et al.,* 2008; Morgenthal *et al*., 2006). Also, the MAFMAG studied at these localities lie in communal areas which are known to have above average species diversity even when subjected to disturbance (Shackleton, 2000). Although the grassland study sites had lower diversity, it must be considered that the MAFMAG sampled were on commercial farms which lie in a highly transformed landscape where the declining species pool of the surrounding landscape results in species richness loss at local scales (Bruun, 2006). For comparative purposes, the diversity of field margins was higher and the diversity of maize fields was lower than that of road verges in Potchefstroom (Cilliers and Bredenkamp, 2000).

Overall the variation in species richness does not follow a common trend along the MAFMAG among the localities due to different disturbance intensities and landscape factors. In the field margins of Jozini and Thohoyandou the plant species richness showed a decrease at 200 m, probably due to land-use activities, such as selective and intensive harvesting of resources in the vicinity of fields (Shackleton *et al.*, 1994), followed by an upward trend towards 400 m. Grassland showed a steady increase in species richness up to 300 m after which a decrease was recorded where grazing becomes more intense. An increase of grazing intensity leads to a reduction in species diversity in grassland and woodland (Friedel, 1997; Kruess and Tscharntke, 2002; O'Connor, 2005; Sheridan *et al*., 2008).

4.4.4 Plant species composition per locality

In all NMDS analyses, the maize field plots grouped together and the field margin plots grouped according to biome. The tight grouping of the maize fields was independent of locality, confirming that maize fields are characterised by lower beta diversity than field margins. Maize field floras are, due to intensive management, made up of a limited species pool of annual weedy species. Field margin floras are much larger, comprising the maize field flora and the species pool of the specific locality's surrounding vegetation.

The field margins from the Grassland and Savanna Biomes were dissimilar. Field margins for Amersfoort and Potchefstroom (grassland) were more similar in species composition than the savanna localities, suggesting higher beta diversity regionally for savanna field margins. Beta diversity of this magnitude can be ascribed to Jozini and Thohoyandou's location in two of the regional centres of endemism of the Savanna Biome (van Wyk and Smith, 2001) resulting in extreme variation in plant composition due to the presence of numerous limited range species per locality.

4.5 Summary

The general floristic pattern follows a similar trend in the Lowveld and Highveld regions of South Africa, namely that diversity of plants increases as the distance increases away from maize fields, which confirms that diversity of plants is higher in the less disturbed field margins. Maize fields and field margins in the Grassland Biome have lower plant diversity compared to the Savanna Biome. Maize fields in both commercial and small rural-based agronomies have similar trends in diversity patterns of plant species. On this basis study constitutes baseline information for future research in agro-ecosystems. Agriculture development should not only focus on maximizing production, but should also take into consideration management strategies of biodiversity.

Chapter 5: Insect species diversity and composition along maize field-field margin gradients in grassland and savanna in South Africa

5.1 Introduction

Invertebrates are widespread, numerous, species-rich, easily sampled, and functionally diverse and they often respond to environmental changes more rapidly than do vascular plants or vertebrates (Oliver and Beattie, 1996). These organisms are threatened by increasing agricultural intensification, which includes the loss of natural and semi-natural habitats, extensive monoculture plantings, and increased pesticide and herbicide use (Winfree *et al*., 2008). Invertebrates are valuable as surrogates to evaluate species diversity patterns, as these organisms are motile and sensitive to environmental change, and therefore provide data more useful to environmental monitoring, impact assessment, and conservation practice than inventories of other taxonomic groups (Oliver and Beattie, 1996).

No information is available on invertebrate diversity along an agricultural natural-ecosystem gradient in southern Africa. Therefore, this chapter addresses the current lack of knowledge by considering one such a system, namely the maize field-field margin gradient (MAFMAG). This study is part of a larger project aimed at providing facts for the GM debate in Africa (Asante, 2008). Therefore, the current study was stimulated by the advent of Bt maize (see Chapter 1) and suggests that there is a risk that non-target organisms that occur mainly outside maize fields, may be exposed to plant material of GM maize, both inside and outside maize fields, due to insect movements. Obrist *et al*. (2006) confirmed that the Bt toxin can be transferred to predators via insect herbivores.

As explained in Chapter 4, species diversity has two basic components: richness and evenness (Reitalu *et al*., 2009). These components vary across ecosystems, independent of one another, due to differences in ecological conditions, as well as agricultural management strategies (Hovd and Skogen, 2005). Species richness and diversity are therefore measures that are employed for conservation purposes and to assess ecosystem integrity (Burel *et al*., 1998). Hence, the main theme of this study is to investigate insect diversity patterns along a MAFMAG to address the following questions:

- how do insect diversity patterns differ along MAFMAG, measured as diversity indices, in terms of locality and distance from a maize field?
- how does insect species composition along MAFMAG differ in terms of locality and insect assemblage?

5.2 Material and Methods

5.2.1 Invertebrate sampling

Surveys were conducted at four study areas in four of the major maize producing provinces during the 2009/10 cropping season (see Chapter 3 for a detailed description of localities, Figure 3.1). Surveys were scheduled to coincide with the regional flowering times of maize to ensure sufficient sampling of insects as arthropod diversity on maize is known to increase after flowering of plants (van Wyk *et al.*, 2008). Two study sites, approximately 5 km apart, were selected at each of the study areas. Two transects, comprising six sample points each, were placed ±200 m apart at each study site (Figure 5.1). In total 96 plots were sampled (24 plots per study area). Plots were 25 m^2 (5 x 5 m) at each sample point. Sample points were placed 100 m apart along each transect, 400 m into the field margin and 100 m into the field. Assemblage composition for invertebrates changes gradually over distances of up to 400 m either side of the edge and the distance to a recognizable change in composition is taxon dependent (Dangerfield *et al.*, 2003).

The D-Vac method (Kruger *et al.*, 2008) was used for insect collection as suction sampling is known to show marked differences in arthropod diversity between fields and field margins (Thomas and Marshall, 1999). The D-Vac machine was moved slowly over the surface of all plant material in each plot. Approximately seven swaths per plot were done, following a zig-zag pattern with the D-Vac in each of the swaths. In cases where there was higher vegetation such as shrubs and trees present in the plots, these were also sampled by means of the D-Vac. The apparatus was moved over the trunk, as well as lower branches of the trees.

The contents collected inside each plot were placed in a single sample bottle of alcohol for preservation. Each sample was later sifted with a kitchen sieve to remove plant material. All samples were then divided into fine and rough sub-sample to separate larger insects and remaining plant material from small insects. Samples were placed in a glass petri-dish and inspected with a stereo microscope. Insects were sorted and indentified up to morphospecies level at the Entomology laboratory of the North-West University. Oliver and Beattie (1996) have found that morphospecies may be used as surrogates for species in environmental monitoring where estimates of richness and the assessment of turnover is concerned.

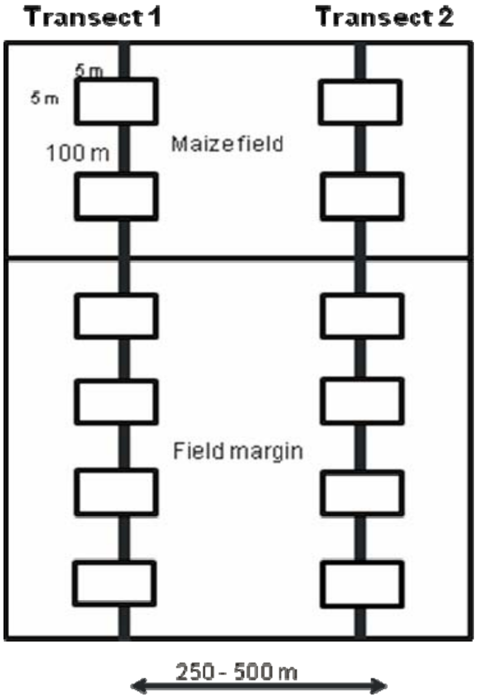

Figure 5.1: Transect layout for insect collection.

5.2.2 Data Analysis

Species diversity indices were chosen to analyse the patterns of insect diversity along MAFMAG to consider both species richness and abundance (Magurran, 1988). Species richness and evenness act like diversity components and diversity should be measured using a compound statistic, such as the Shannon-Wiener index, albeit that its performance and meaning being questionable (Stirling and Wilsey, 2001; Wilsey and Stirling, 2007). To broaden the scope of diversity measures the following indices were used:

Simpson index of diversity ($\check{D}$) = $\sum [n_i (n_i - 1)/N (N - 1)] - 1$, where **N** is the total number of individuals (all species) and **ni** is the number of individuals for the i*th* species.

Shannon-Wiener diversity index (H') = $-\sum (p_i.\ln p_i)$, where p_i is the relative abundance of the i*th* species.

Pielou's evenness (J') = $H'/H'max = H'/\ln S$, where **H'** is the Shannon-Wiener diversity index value and **S** is the species richness of the sample.

Margalef's species richness index (d) = $(S-1)/\ln N$, where **S** is the number of species recorded for the sample and **N** is the total number of individuals in all samples.

Species richness (S) is the number of species recorded for the sample and ignores relative abundances.

Statistical significant differences in insect diversity patterns were tested for with One-Way Repeated-Measures ANOVA (Analysis of Variance) in Statistica (StatSoft, 2009). P-values were obtained for distance from fields, different localities, as well as interactions (between distance and locality; combined rate of change along the gradient and between localities). To illustrate the compositional relationships of insect species between maize fields and edges of the four maize regions, data was subjected to Non-metric Multidimensional Scaling (NMDS) (samples clustered based on Bray-Curtis dissimilarity, PRIMER 5). This method provides a good way of visually representing the similarities between the invertebrate species assemblages, but without attaching a specific meaning to the graph axes (Procheş and Cowling, 2007).

5.3 Results

5.3.1 General observation insect diversity patterns

Analysis of pooled data from all sites indicated that insect diversity increased with increasing distance along MAFMAG (Figure 5.2). All the diversity indices showed a similar drastic increase 100 m into the field margin, thereafter a drop with species diversity values reaching a final high at 400 m away from the maize fields (Figure 5.2).

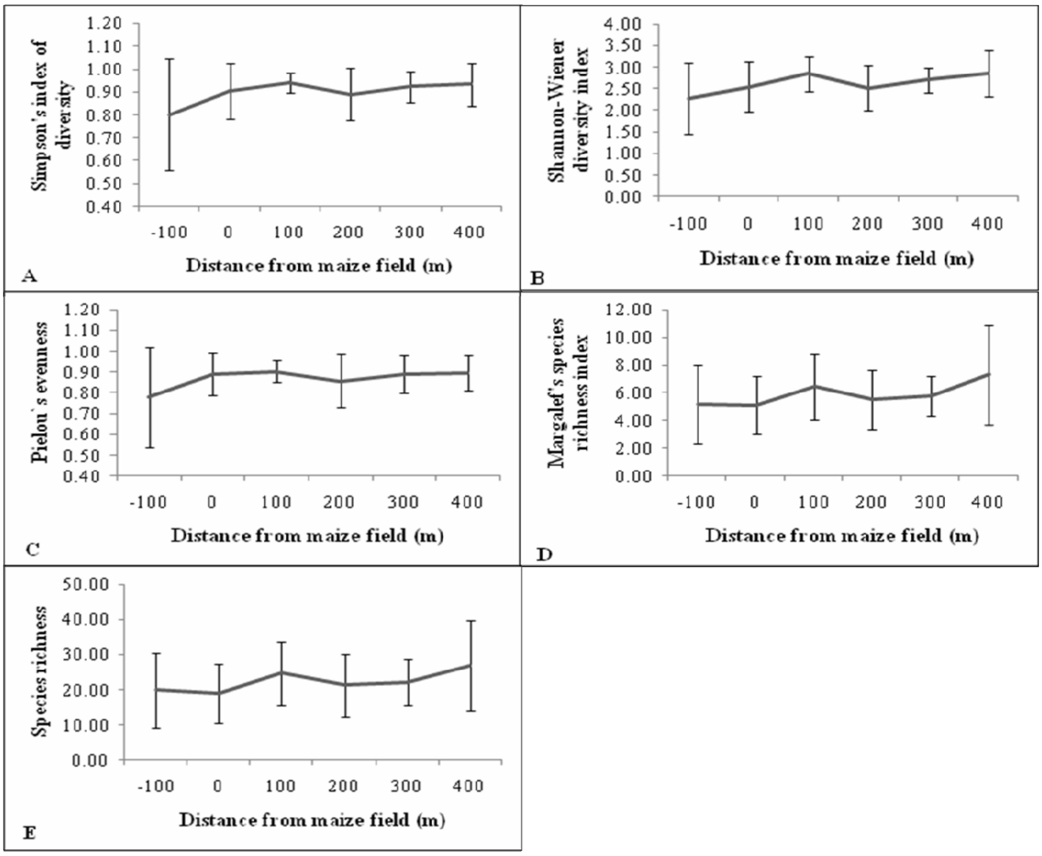

Figure 5.2: Mean diversity index values for plots along a MAFMAG in South Africa: (A) Simpson's index of diversity; (B) Shannon-Wiener diversity index; (C) Pielou's evenness; (D) Margalef's species richness index; and (E) Species richness. Mean number ± Standard deviation (n=16). Distances: -100 and 0 m sampled inside the maize field; 100-400 m sampled in the field margin.

5.3.2 Insect species diversity patterns per biome

The Savanna Biome in general showed higher insect diversity and richness than the Grassland Biome. All the indices showed a constant increase in insect diversity and richness from maize fields to field margins in Savanna. In all cases the diversity and richness peaked at 100 m into the field margin, then decreasing and peaking again at highest values 400 m into the margin. Grassland diversity, richness and evenness trends were different from the Savanna patterns in that highest values were reached 100 m into the field margin. This peak was followed by a decrease in values and then a general increase from 200 to 400 m.

In terms of diversity and richness, all the indices had a statistically significant difference for biome and distance. This suggests that the richness and diversity of invertebrates differed meaningfully between biomes along a MAFMAG and that biomes have their own invertebrate diversity patterns (Figure 5.3). The richness and diversity of invertebrates also differed between points along a MAFMAG, suggesting specifically that along the MAFMAG there are points with higher or lower diversity than other points. Evenness had no significant difference for any tests. Also, no significant difference was recorded for interaction, suggesting that the trends experienced across the biomes were similar.

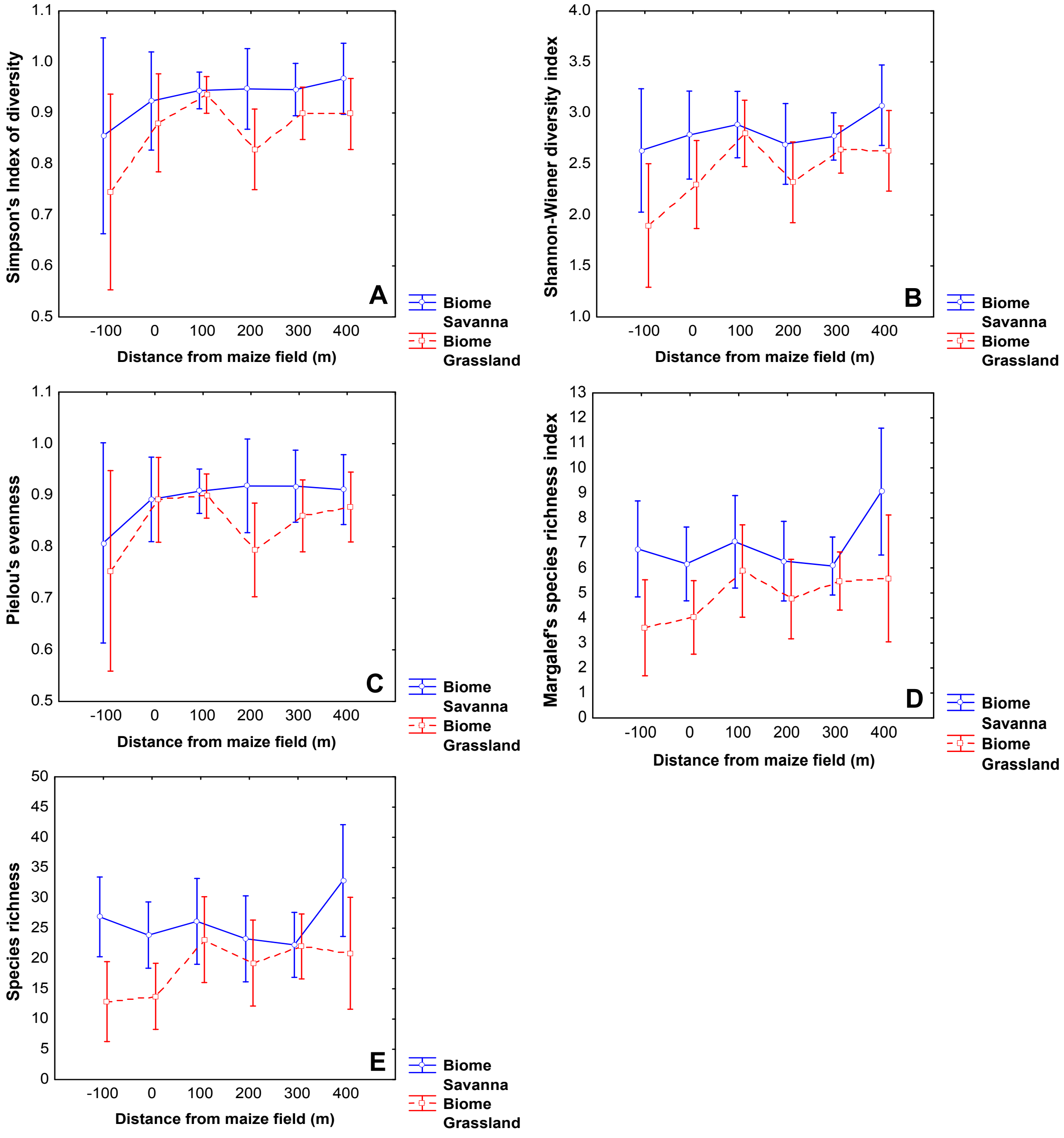

Figure 5.3: Mean (A) Simpson's index of diversity, (B) Shannon-Wiener diversity index, (C) Pielou's evenness, (D) Margalef's species richness index, and (E) Species richness values per plot (n=8) along MAFMAG in the Grassland and Savanna Biomes. Vertical bars denote 0.95 confidence intervals.

Margalef's species richness indices indicated that there was a significant difference ($P < 0.05$) in richness between different biomes, as well as different distances along a gradient (Table 5.1). Margalef's species richness in Savanna showed an increase at 100 m outside the maize field and again at 400 m into the edge (Figure 5.3D). In Grassland it showed a continuous increase in insect diversity towards areas 300-400 m outside maize fields (Figure 5.3B).

Table 5.1: P-values of Repeated Measures ANOVA for differences between biomes (Savanna and Grassland), Distance (-100, 0, 100, 200, 300, 400) and Interaction (Biome and Distance). *indicates significant difference ($P < 0.05$) ($n=8$). Refer to Appendix B for complete statistical values.

Index	Biome	Distance	Interaction
Simpson`s index of diversity (Ď)	0.025549*	0.048362*	0.847839
Shannon-Wiener diversity index (H′)	0.016109*	0.014191*	0.499094
Pielou’s evenness index (J′)	0.117552	0.114267	0.829325
Margalef`s species richness index (d)	0.019225*	0.019587*	0.288799
Species richness (S)	0.03302*	0.030739*	0.06102

Species richness (S) showed a gradual increase towards 100 m, followed by a decrease at 200 m and then a gradual increase towards 400 m along the MAFMAG (Figure 5.3E). There was significant difference in S between biomes and distance from maize fields ($P < 0.05$) (Table 5.1). In none of the cases were any significant differences observed in the interaction of locality and distance, suggesting that the overall trends were similar in both biomes.

5.3.3 Insect species diversity patterns per locality

According to Ď, the Lowveld localities generally have higher insect diversity along MAFMAG compared to the Highveld localities (Figure 5.4). However, no significant differences were recorded, suggesting that the insect diversity was comparable in the different biomes (Table 5.2). H’ values recorded for Jozini showed higher insect diversity compared to Amersfoort, Potchefstroom and Thohoyandou (Figure 5.4B). The other three maize regions showed a decrease in insect diversity at 200m, while at Jozini a decrease only occurred at 300 m away from maize field (see Figure 5.4A and 5.4B). There was a significant difference between locality and distance ($P < 0.05$) (Table 5.2).

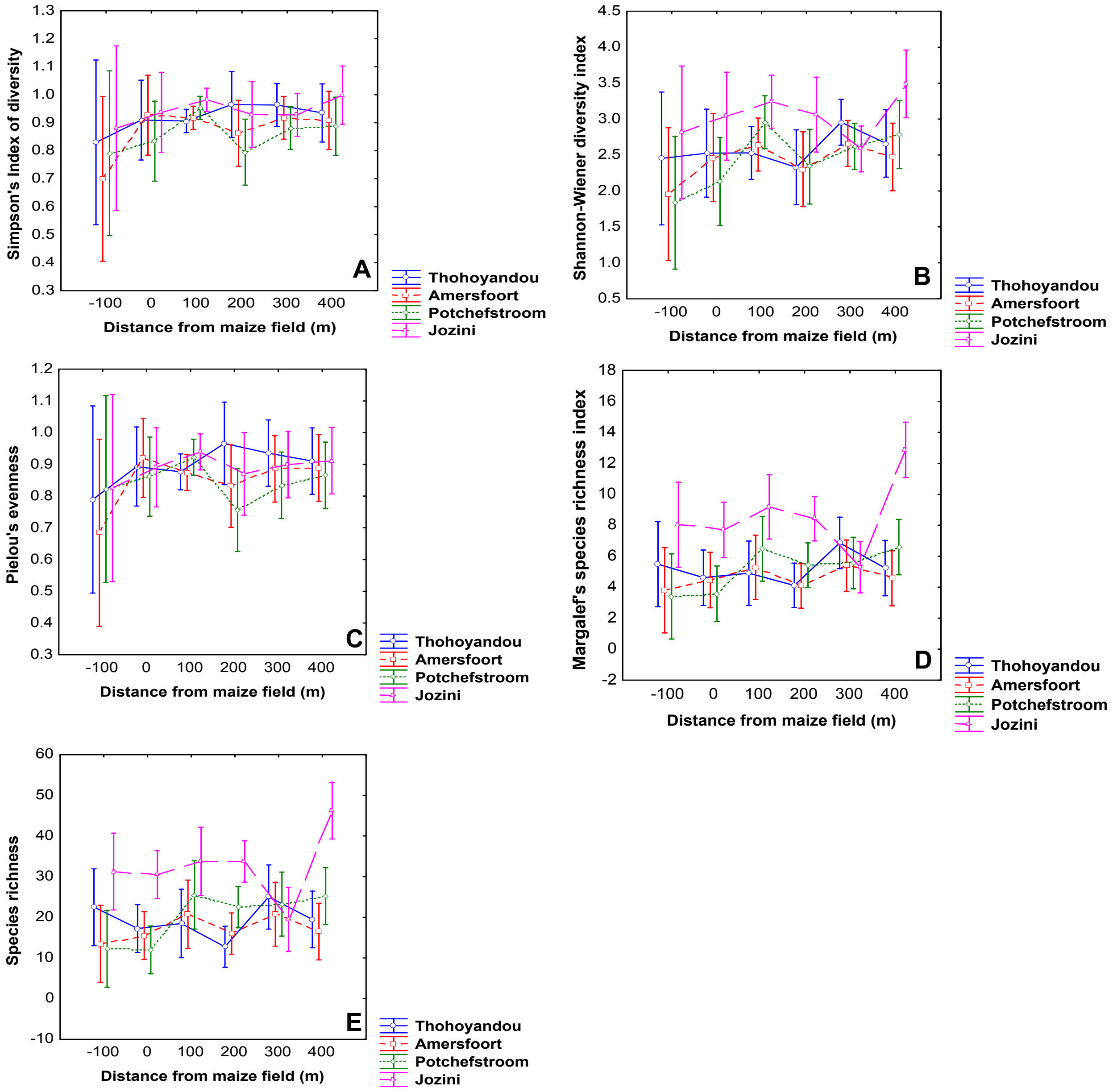

Figure 5.4: Mean (A) Simpson's index of diversity, (B) Shannon-Wiener diversity index, (C) Pielou's evenness, (D) Margalef's species richness index, and (E) Species richness values per plot (n=4) along MAFMAG for four maize producing regions in South African biomes. Vertical bars denote 0.95 confidence intervals.

Table 5.2: P-values of Repeated Measures ANOVA for differences between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (-100, 0, 100, 200, 300, 400) and Interaction (Locality and Distance). *indicates significant difference (P< 0.05) (n=4). Refer to Appendix B for complete statistical values.

Index	Locality	Distance	Interaction
Simpson`s index of diversity (Ď)	0.161894	0.071863	0.984386
Shannon-Wiener diversity index (H′)	0.008058*	0.015515*	0.525868
Pielou's evenness index (J′)	0.514576	0.14472	0.951536
Margalef`s species richness index (d)	0.000097*	0.004003*	0.0021*
Species richness (S)	0.000236*	0.006361*	0.000338*

J' generally showed a slight, but non-significant increase along the MAFMAG. Thohoyandou had the highest measured evenness and this was in the field margin. Amersfoort's highest evenness was recorded within the maize field (Figure 5.4C). Potchefstroom showed the lowest insect evenness in the field margins (Figure 5.4C). The outcomes of the d and S were similar. Both measures revealed that Jozini had the highest species richness, although showing a sharp decrease at 200 and 300 m. The patterns of insect richness appear to be similar in all maize regions, although Amersfoort and Thohoyandou had a slight decrease in richness at 400 m (Figure 5.4E), whereas the other two localities showed an upward trend at this point. For both measures there was a significant difference (P <0.05) between locality and distance, suggesting that one or more of the localities had non-comparable richness and that one or more points along a MAFMAG showed non-comparable increase or decrease in richness. Analyses of trends in diversity also showed the curve patterns were statistically different between locality and over distance, hence P <0.05 (Table 5.2), which indicates that insect richness did not follow a similar trend across localities.

5.3.4 Insect species composition per locality

All the Non-metric multidimensional scaling (NMDS) analyses delivered results with stress values between 0.16 and 0.26, which would normally render the resulting plots unusable (Procheş and Cowling, 2007). However, the good relationship between these and the NMDS analysis of plants with low stress values (see Chapter 4), suggest that these ordinations were a reasonably good representation of the relationship between samples and will be discussed**.**

The NMDS analysis results at a country level showed clustering of plots and a high degree of species were shared (Figure 5.5A) between maize fields and edges. However, at such a coarse scale it is difficult to make assumptions. Considering the NMDS analysis of biomes, the plots from maize fields and field margins in the Grassland Biome were separately grouped together (Figure 5.7). In contrast, the plots from maize fields and field margins in the Savanna Biome were clustered (Figure 5.8). In regions with high insect diversity there was also a high degree of shared insect species between maize fields and edges (Figure 5.6C, D).

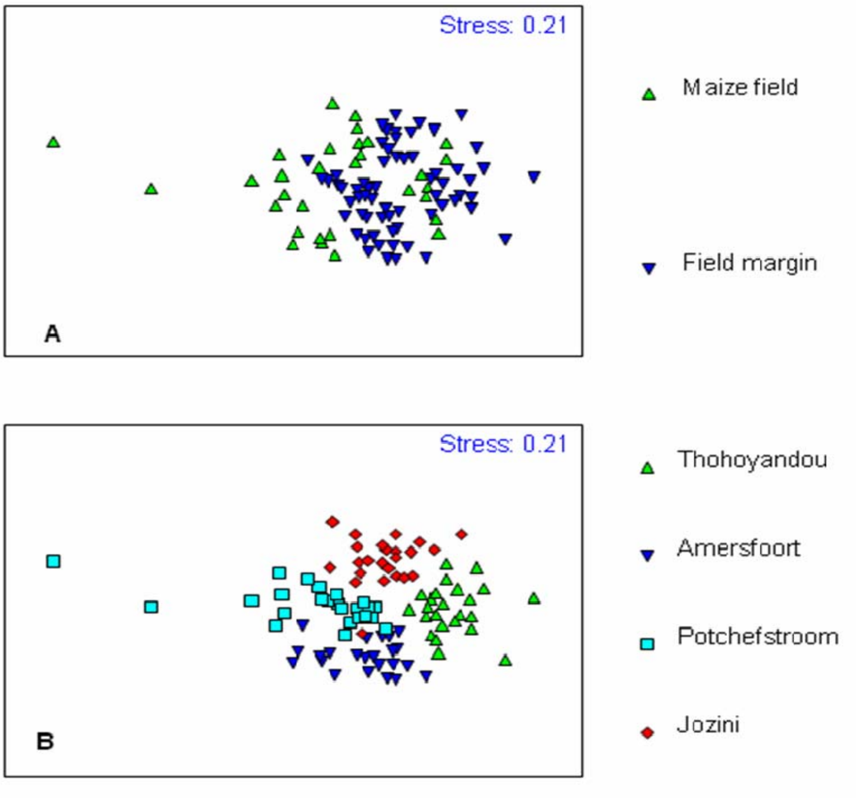

Figure 5.5: Non-metric multidimensional scaling analyses based on total species collected at all sites: (A) maize fields and field margins; and (B) four localities of major maize producing regions of South Africa.

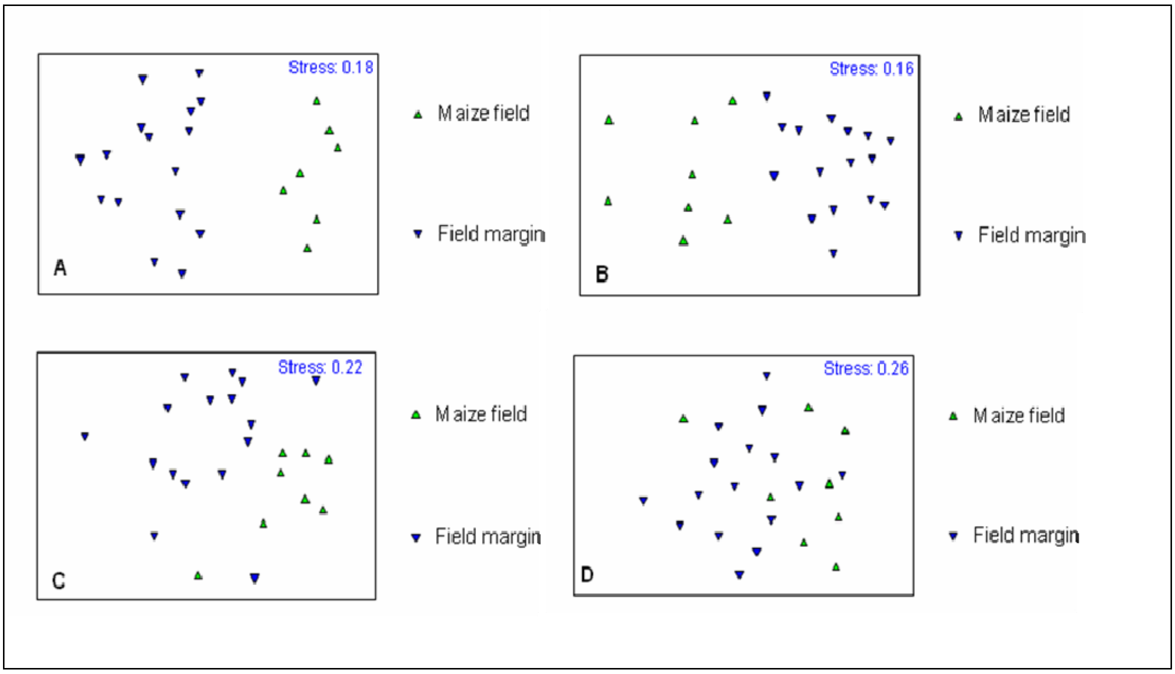

Figure 5.6: Non-metric multidimensional scaling analyses based on total species collected at all sites: (A) Amersfoort; (B) Potchefstroom; (C) Jozini; and (D) Thohoyandou.

5.3.4.1 Insect species composition per biome

Insect assemblages of maize fields and field margins were clearly separated for the Grassland Biome, suggesting that few insect species occur both inside and outside maize fields (Figure 5.7A). However, the locality data is separated, suggesting a degree of locality-specific insect assemblages.

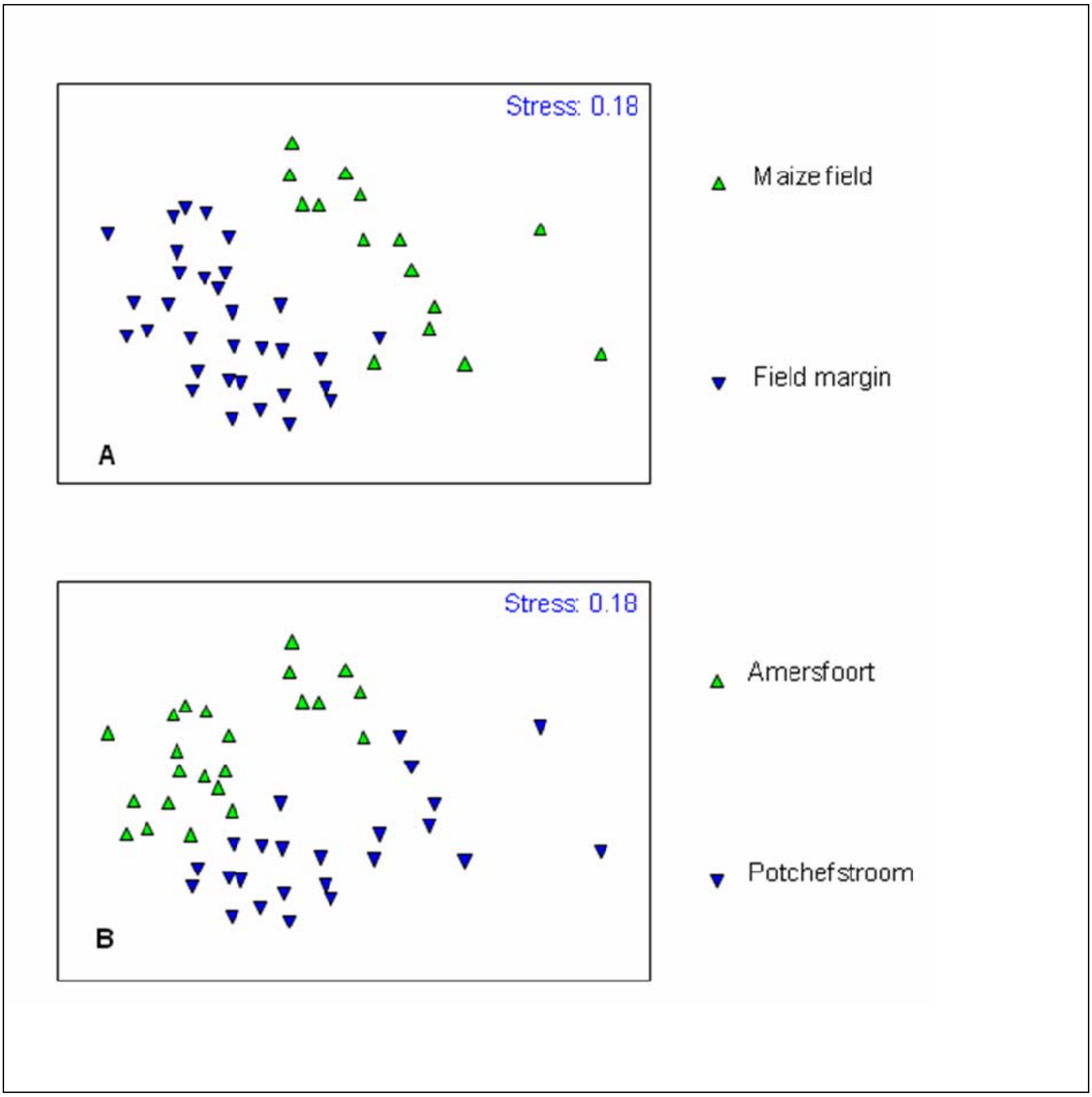

Figure 5.7: Non-metric multidimensional scaling analyses based on total species collected at all sites for the Grassland Biome: (A) maize fields and field margins; and (B) Amersfoort and Potchefstroom grasslands.

In the Savanna Biome a clear separation in terms of locality specific insect assemblages is evident. However, overlap of insect assemblages, suggesting that maize field and field margins share insects, was evident (Figure 5.8A). This suggests that insect species move between maize fields and margins. This was especially pronounced at the Thohoyandou locality.

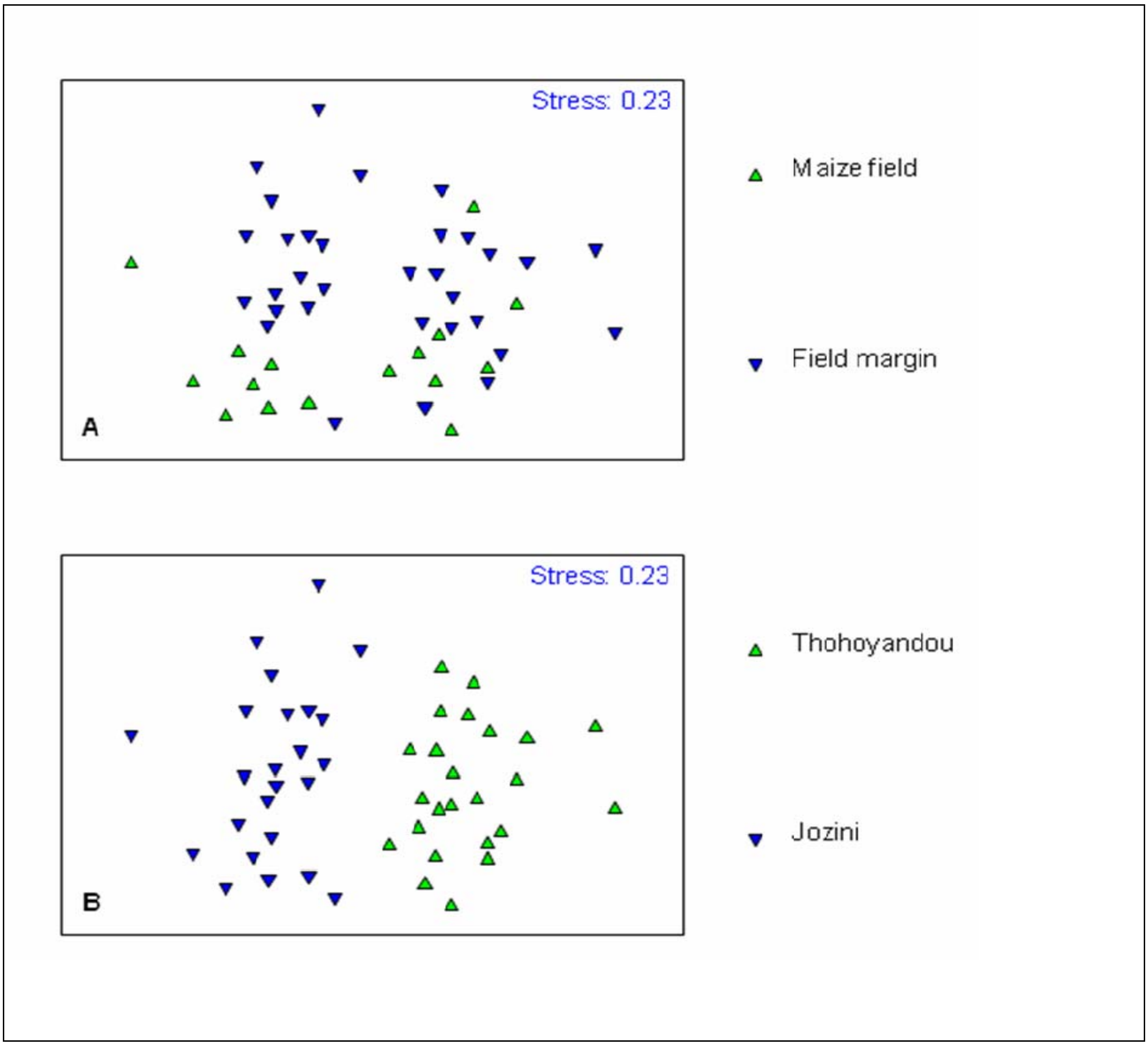

Figure 5.8: Non-metric multidimensional scaling analyses based on total species collected at all sites: (A) maize fields and field margins; and (B) Thohoyandou and Jozini savanna.

5.4 Discussion

5.4.1 Insect species diversity along MAFMAG

This study showed that insect diversity is generally lower inside maize fields than in field margins. Most of the diversity indices used in this study showed a decrease in insect diversity at 200 m away from maize fields. Reasons for this decrease in diversity is highly speculative at this point and could be ascribed to patches of land subjected to overgrazing (Debano, 2006), management intensity, e.g. clearing (Marini *et al.,* 2009) and alien plant invasions (Steenkamp and Chown, 1996).

Species richness values gradually increased along the MAFMAG. However, species richness values in Savanna showed a decrease on maize field margins due to the removal of woody species. Thomas and Marshall (1999) studied arthropod abundance and diversity in differently vegetated margins and observed arthropod diversity to be lowest in the field (crop), low inside the field edge, higher in the more diverse edge outside the field and highest in the margin with untransformed vegetation. Field margins are generally more heterogeneous they provide more niches and suit more species than inside the field (Ingham and Samways, 1996). Hendrickx *et al*. (2007) found that untransformed habitats embedded in an agricultural matrix contain the majority of the spider species inhabiting the agricultural fields plus a supplement of species bound to the more natural habitat patches.

We found that species richness/diversity increases as the distance increases along a MAFMAG. Therefore insect diversity increased as the distance increased from the maize field towards untransformed adjoining areas. Dangerfield *et al*. (2003) found that assemblage composition of invertebrates changed gradually over distance and that the distance to a recognizable change in composition was taxon dependent. Blair and Launer (1997) found that the distribution and abundance of butterflies was sensitive to changes brought about by development and disturbance that increasing loss of species from sites which are more intensively developed occurs. Hendrickx *et al*. (2007) showed that the total species richness of arthropods in agricultural landscapes decreased with increasing management intensity of the agricultural fields and an altered landscape structure. This was also evident from this study where the commercial fields (Amersfoort and Potchefstroom) had a much lower insect diversity than fields managed by subsistence farmers (Thohoyandou and Jozini).

5.4.2 Insect species diversity of the Biomes

The Savanna Biome had, as expected (Seymour and Dean, 1999; Holland and Fahrig, 2000; Whitmore *et al*., 2002; Moore and Palmer, 2005; Lachat *et al*., 2006; Söderström *et al*., 2006) a higher insect diversity and richness than the Grassland Biome. Insect diversity increased away from the maize field into the field margins of the Savanna. Savannas are characterized by having a continuous, well-developed grass layer and an open, discontinuous layer of shrubs or trees (Knoop and Walker, 1985).

However, a slight downward tendency in insect diversity outside the field in the field margin was evident for the Grassland Biome. Possible reasons were given (in 5.4.1), but it must also be considered that fields are high productivity systems, and that field margins act as sinks to recolonize fields (Duelli and Obrist, 2003; Tscharntke *et al*., 2005). Considering the time of sampling, the maize flowering season when fields were at their most productive, and that maize field structure and life forms correspond to surrounding grassland, it could be that the insect diversity closest to the field was drawn into the maize. Savanna adjacent to maize fields is somewhat buffered against this type of seasonal fluctuation in insect diversity by being multi-structured and play an important role in maintaining insect diversity in agro-ecosystems (Holland and Fahrig, 2000). Also, Savanna entomofauna represents a combination of grassland and woodland diversity (Procheş and Cowling, 2006), buffering the seasonal effect of grassland insect diversity loss to maize fields.

Trees have a great niche diversification because of structural complexity (Krüger and McGavin, 1997). Procheş and Cowling (2006) found that Grassland plots has insect diversity values similar to those of fynbos and subtropical thicket and that typical African Savanna would probably be richer in insect diversity than any of the biomes (fynbos, grassland, subtropical thicket, and Nama-karoo) considered in their study. This study showed that albeit in a disturbed ecosystem, Savannas were richer in insect diversity than grassland. This is in accordance with studies on the arachnids (Whitmore *et al*., 2002) that suggest that savannas harbour a surprising diversity of spiders when compared to other biomes surveyed in South Africa.

So what factors enhance the insect diversity of field margins in savanna? Firstly, the most studied factor is plant cover. As plant cover increases, the species richness for most arthropod taxa increases (Seymour and Dean, 1999; Holland and Fahrig, 2000; Moore and Palmer, 2005; Söderström *et al*., 2006). Secondly, plant species richness of field margins is important, with Lachat *et al.* (2006) finding that arthropod diversity is enhanced by species-rich understorey vegetation and Sparks and Parish (1995), showing that butterfly diversity is enhanced where floristic diversity is the greatest.

5.4.3 Insect species diversity patterns per locality

Lowveld localities had a higher insect diversity along MAFMAG compared to the Highveld localities. Considering that the Highveld localities were situated in grassland, with field margins extensively grazed, the finding could have been predicted as Debano (2006), in a study in the United States, reported that the abundance of insects was lower on grazed grasslands, and certain insect orders appeared to be negatively affected.

The higher insect diversity in the Lowveld sites can also be further explained by geographical aspects. Küper *et al*. (2005) has shown that the centres of species richness for vascular plants and phytophagous beetles overlap in Sub-Saharan Africa, explaining the higher invertebrate diversity of the Thohoyandou and Jozini sites which are respectively located in the Soutpansberg and Maputaland centres of vascular plant endemism and diversity (van Wyk and Smith, 2001).

A further explanation is the woody borders in the landscape. The results of a study by Holland and Fahrig, 2000) suggest that woody borders increase diversity of herbivorous insects within agro-ecosystems. Also since the Lowveld farms are managed by subsistence farmers, they are more organic compared to the Highveld farms where high inputs in terms of organic fertilizer, pesticides and herbicides are commonly used. Feber *et al*. (1997) has shown that more non-pest lepidopteran species were recorded on organic than on conventional farmland, and more non-pest lepidopteran species were recorded in the uncropped field (semi-transformed).

The higher insect diversity recorded for Potchefstroom than Amersfoort is because taller grassland (or maize) supports more individuals and a greater diversity of arthropods than short swards both in the field and the field margin (Murdoch *et al*. 1972; Morris, 2000). Also, the Amersfoort grasslands more invasive exotic species occurred in the side field margins, which are known to have substantial negative impacts on arthropod diversity (Coetzee *et al.,* 2007).

5.4.4 Insect species composition per locality

At a country level there is clear partitioning of species assemblages for maize fields and edges. However, at this coarse scale it was already evident that there was also clear partitioning of species assemblages for the different regions studied with insect diversity of the maize fields in the grassland localities grouping separately from the savanna localities. The same groupings were repeated for the field margins. This suggests that the surrounding species pool has a direct effect on the insect species assemblages of fields and field margins.

Along MAFMAG changes in species composition were evident. Dauber and Wolters (2004), has shown that margins in agricultural landscapes change the community structure of arthropod assemblages. The factors that drive the insect composition at a local scale are therefore complex, and hence, the partitioning of species assemblages. Species assemblages in fields and field margins can be influenced by landscape habitat diversity and management practices (Jeanneret *et al*., 2003; Woodcock *et al*., 2010), management intensity (Grandchamp *et al.,* 2005), floral display (Vanparys *et al.,* 2008), ability of insects to use other pollen sources (Colville *et al*., 2002), extent of control of herbivore populations by predators (Lang *et al.,* 1999), availability of shelter and nectar resources (Pywell *et al.,* 2004), levels of disturbance (Blair and Launer, 1997) and degree of invasion by alien plants (Samways *et al.,* 1996).

However, the question that remains is whether insects move between fields and field margins. In South Africa, Ingham and Samways (1996) found that most species were capable of transgressing borders of landscape elements. The species assemblages of savanna plots, especially at Thohoyandou, showed a high degree of similarity in composition of insect species assemblages in the field and field margins. This could possibly indicate that insect species move from maize fields to margins and vice versa. Dangerfield *et al*. (2003) has shown that along an edge many taxa are either present consistently in both habitats or are mostly found in one habitat, but ‘leak’ several hundred meters across into the other. Few taxa are unique to either habitat. Even sharp habitat edges, as defined by discrete changes in soils and plants (e.g. fields and field margins), are not edges but broad transition zones for many invertebrate taxa.

5.5 Summary

Results of this study suggest that insect diversity increased with increasing distance away from maize fields along the MAFMAG. The Savanna Biome had the higher insect diversity compared to the Grassland Biome for both maize fields and edges. Richness and diversity of invertebrates differed meaningfully between biomes along a MAFMAG and biomes have their own invertebrate diversity patterns that are dependent on the regional species pool. Insect species assemblages in the Savanna Biome were to some degree shared between maize fields and edges. Further research is needed to determine what functional groups of insects are shared between maize fields and margins. Also, as Bt toxin can be transferred to predators via insect herbivores on Bt maize as food sources, there is a necessity to construct foodwebs of MAFMAG to highlight potential pathways to transfer Bt.

Chapter 6: Insect-plant diversity relationships of a maize field-field margin gradient

6.1. Introduction

South Africa is rich in biota and is signatory to the Convention on Biological Diversity (Samways *et al*., 1996). This biodiversity is important in agro-ecosystems where it influences ecological functions that are vital for both crop production in sustainable agriculture systems and the surrounding environment (van Wyk *et al*., 2007). In agro-ecosystems, species assemblages fulfil a variety of ecosystem functions that may be harmed if changes occur in these assemblages (van Wyk *et al*., 2007). Therefore it is imperative to study the plant-insect relationship in agro-ecosystems and the type of vegetation management which may also influence invertebrate species assemblages (Samways *et al*., 1996). According to Blair and Launer (1997), both the species richness and diversity of butterflies peaked at intermediately disturbed sites, suggesting that diversity (and evenness) patterns are somehow connected. However, rejuvenation of ecosystem function requires restoration of invertebrate species evenness, rather than just richness (Crowder *et al.,* 2010). For example, the abundance, but not the richness, of small bee species was less than expected at ruderal sites (Kwaiser and Hendrix, 2008).

Recent studies by Procheş and Cowling (2006) compared the patterns of insect diversity in fynbos and three neighbouring biomes. Again Procheş and Cowling (2007) used the same data set to assess the compositional similarities and differences between the insect assemblages from those biomes. They found that insect samples from the same biome generally group together in multidimensional scaling analyses. Structural biodiversity in agricultural areas appears to be correlated with functional and organismal biodiversity of the above-ground insect fauna (Duelli *et al.,* 1999). According to Schweiger *et al.* (2005), decreasing spatial or stress factors of land-use intensity seems to facilitate more complex food webs and thus may favour natural pest regulation. Currently in southern Africa there is no information available that describes and compares plant-insect diversity along a maize field-field margin gradient

(MAFMAG). There is no simple linear relationship between intensification of agricultural land use and loss of species (Burel *et al.,* 1998).

This study aims to unfold the current lack of knowledge in plant-insect relationships along MAFMAG. Hence the following objectives were addressed;

- compare insect and plant diversity between treatments (maize field, semi-transformed and untransformed) and;
- test for a general relationship between plant and insect diversity along MAFMAG.

6.2. Material and Methods

6.2.1 Sampling method

Insect collecting and plant surveys were conducted at four localities in four provinces of South Africa during 2009/10 season (Table 6.1; see Chapter 3, Figure 3.1). Surveys were scheduled to coincide with the regional flowering times of maize to ensure sufficient sampling of insects.

Table 6.1: Province, nearest town and associated vegetation type for each of the study sites.

	Site 1	**Site 2**	**Site 3**	**Site 4**
Province	North-west	Mpumalanga	KwaZulu-Natal	Limpopo
District	Dr. Kenneth Kaunda	Gert Sibande	uMkhanyakude	Vhembe
Town	Potchefstroom	Amersfoort	Jozini	Thohoyandou
Biome	Grassland	Grassland	Savanna	Savanna
Bioregion	Mesic highveld grassland	Mesic highveld grassland	Lowveld	Lowveld
Vegetation unit	Gm 11 Rand highveld grassland	Gm 13 Amersfoort highveld clay grassland	SVl 20 Western Maputaland clay bushveld	SVl 1 Makuleke sandy bushveld

Two sites were selected in each province, approximately 5 km apart. Twelve points according to a grid system (two rows with six points per row) was placed 100-200 m apart at each site. The first two points of each row was placed inside the maize field. For the plant survey, sampling plots were 10 x 10 m in size at each grid point. Inside each sampling plot five line transects were placed to gather frequency data, with the first transect 1 m inside the sampling plot and the rest of the transects spaced 2 m apart (Figure 6.1). Along each transect the nearest tree, shrub, forb and grass species, at intervals of 1 m was identified and recorded. If no plants occurred within 0.5 m before or after the point, a bare area was noted. A total floristic list up to species level was compiled for each plot.

The D-Vac method (Kruger *et al*., 2008) was used to collect insects in 5 x 5 m plots, in the center of each of the 10 x 10 m vegetation sampling plots. The D-Vac was moved slowly in each plot following a zig-zag pattern. The contents of the D-Vac bag from each plot were emptied into a bottle containing alcohol for preservation. In the laboratory each sample was sifted with a kitchen sieve after removing plant material from the sample. All samples were divided into a fine and a rough sample to separate larger insects and plant material from small insects. Samples were inspected in a glass Petri dish using a stereomicroscope. Insects were sorted and indentified up to morphospecies level. In total 96 plots were sampled (24 plots per bioregion).

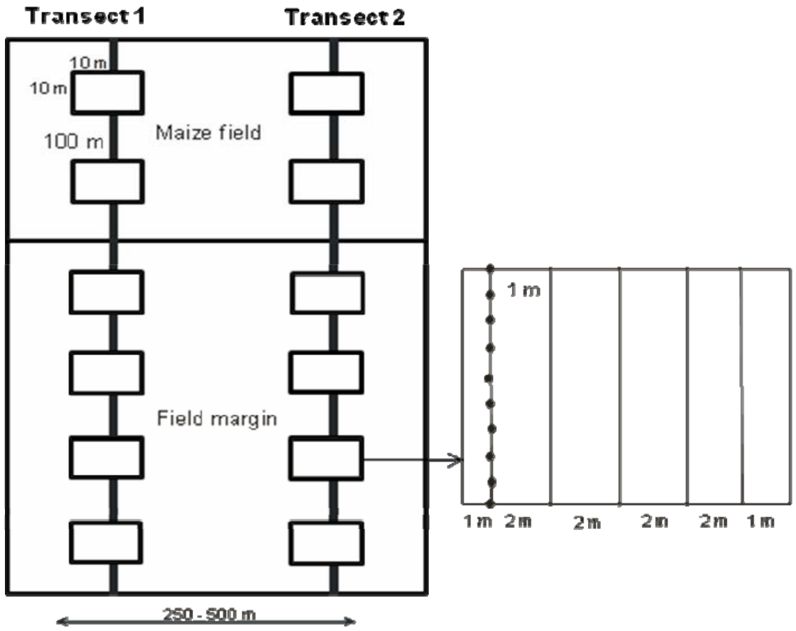

Figure 6.1: Transect layout of survey at each site.

6.2.2 Data analysis

Diversity indices were used to analyse the patterns of insect and plant diversity across treatments (maize field (0-100 m), semi-natural (200-300 m edge) and untransformed (400-600 m edge), as these indices consider both species richness and abundance (Magurran, 1988) :

Shannon-Wiener diversity index $(H') = -\sum (p_i.\ln p_i)$, where p_i is the relative abundance of the i*th* species. This index provides a rough measure of diversity, which is much less biased by sample size than species richness.

Pielou's evenness $(J') = H'/H'max = H'/\ln S$, where H' is the Shannon index and S is species richness.

Species richness (S) is the number of species recorded and ignores relative abundances.

Two-way factorial Analysis of Variance (ANOVA) with Statistica was applied to the data to test whether there is a statistically significant difference in insect and plant diversity patterns on treatments (StatSoft Inc. 2009). To compare species diversity, species richness and evenness for the four localities, we used plant and insect frequency data in a Kruskal-Wallis test (non-parametric test) of whether more than two independent groups differ. To test for general plant-insect diversity relationship, we used Pearson`s and Spearman`s correlation coefficients.

Spearman`s correlation coefficient** is a standardized measure of the strength of relationship between two variables that does not rely on the assumptions of *parametric tests* (Field, 2005). **Pearson`s correlation coefficient is a standardized measure of the strength of relationship between variables (Field, 2005).

6.3. Results

6.3.1 Plant species diversity in maize field, semi-transformed edges and untransformed areas

The Shannon-Wiener diversity index differed significantly between treatments and localities ($P<0.05$) (Table 6.2). In terms of treatment, maize fields had lower plant diversity than semi-transformed and untransformed areas (Figure 6.2 A). Analysis of locality revealed that Jozini and Thohoyandou had the highest plant diversity. Amersfoort had the lowest plant diversity across all treatments.

Maize fields had lower plant species evenness compared to semi-transformed and untransformed areas (Figure 6.2B). Jozini had the highest plant species evenness, but this was not significantly higher than other localities (Figure 6.2B). Plant species richness was significantly higher in Thohoyandou (approximately 50-60 species per 100 m^2 for semi-transformed and untransformed areas) and lowest in Amersfoort (approximately 10-25 per 100 m^2 across treatments) (Figure 6.2C). Untransformed areas had the highest species richness and maize fields had significantly lower richness. There was a significant difference in interaction ($P< 0.05$) (Table 6.2), between the Species richness (S) for plant diversity in localities, suggesting that species turnover across the gradient was not similar for the different localities.

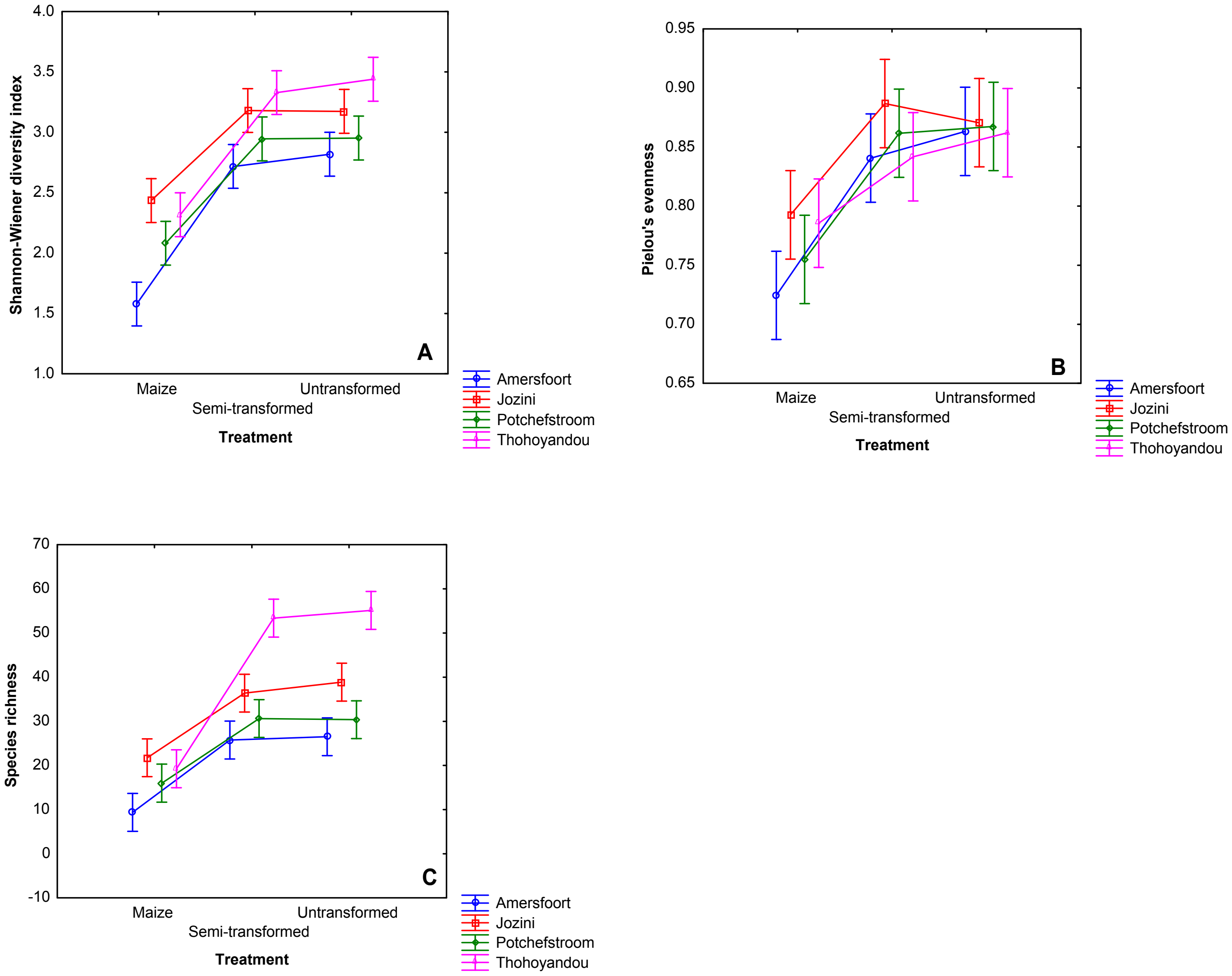

Figure 6.2: Mean (A) Shannon-Wiener diversity index, (B) Pielou's evenness, and (C) Species richness values per treatment (n=32) for plant species along MAFMAG in four maize producing regions in South Africa. Vertical bars denote 0.95 confidence intervals.

Table 6.2: P-values of two-way factorial ANOVA for differences between localities (Amersfoort, Potchefstroom, Jozini and Thohoyandou), between treatments (maize field, semi-transformed and untransformed), as well as interactions (locality and treatments). *indicates significant difference (P< 0.05) (n=32). Refer to Appendix C for complete statistical values.

Index	Locality	Treatment	Interaction
Shannon-Wiener diversity index (H′)	0.0*	0.0*	0.127520
Pielou's evenness index (J')	0.079896	0.0*	0.499593
Species richness (S)	0.0*	0.0*	0.000007*

6.3.2 Insect species diversity in maize fields, semi-transformed edges and untransformed areas

There were statistically significant differences between localities, as well as treatments (P< 0.05) (Table 6.3). The Shannon-Wiener diversity index showed that Jozini had a significantly higher insect diversity compared to other three localities. There was also a significant insect diversity increase across treatments from the maize fields to the untransformed areas furtherest along the edge gradient (ranging between 2.0 and 3.0) (Figure 6.3A). Thohoyandou is the only locality that showed a decrease in insect diversity between maize and semi-untransformed areas (Figure 6.3A).

Pielou`s evenness showed that maize fields generally had a lower evenness than untransformed areas (Figure 6.3B), but the difference was not significant (Table 6.3) which suggests that insect evenness was equally distributed along maize fields, semi-transformed and untransformed areas (Figure 6.3B). Potchefstroom evenness showed a showed a constant increased (Figure 6.2B). Insect species richness was significantly higher in Jozini (ranging from 30 to 35 in all treatments) (P< 0.05) (Figure 6.3C). Thohoyandou showed the lowest insect species richness in semi-transformed areas (Figure 6.3C).

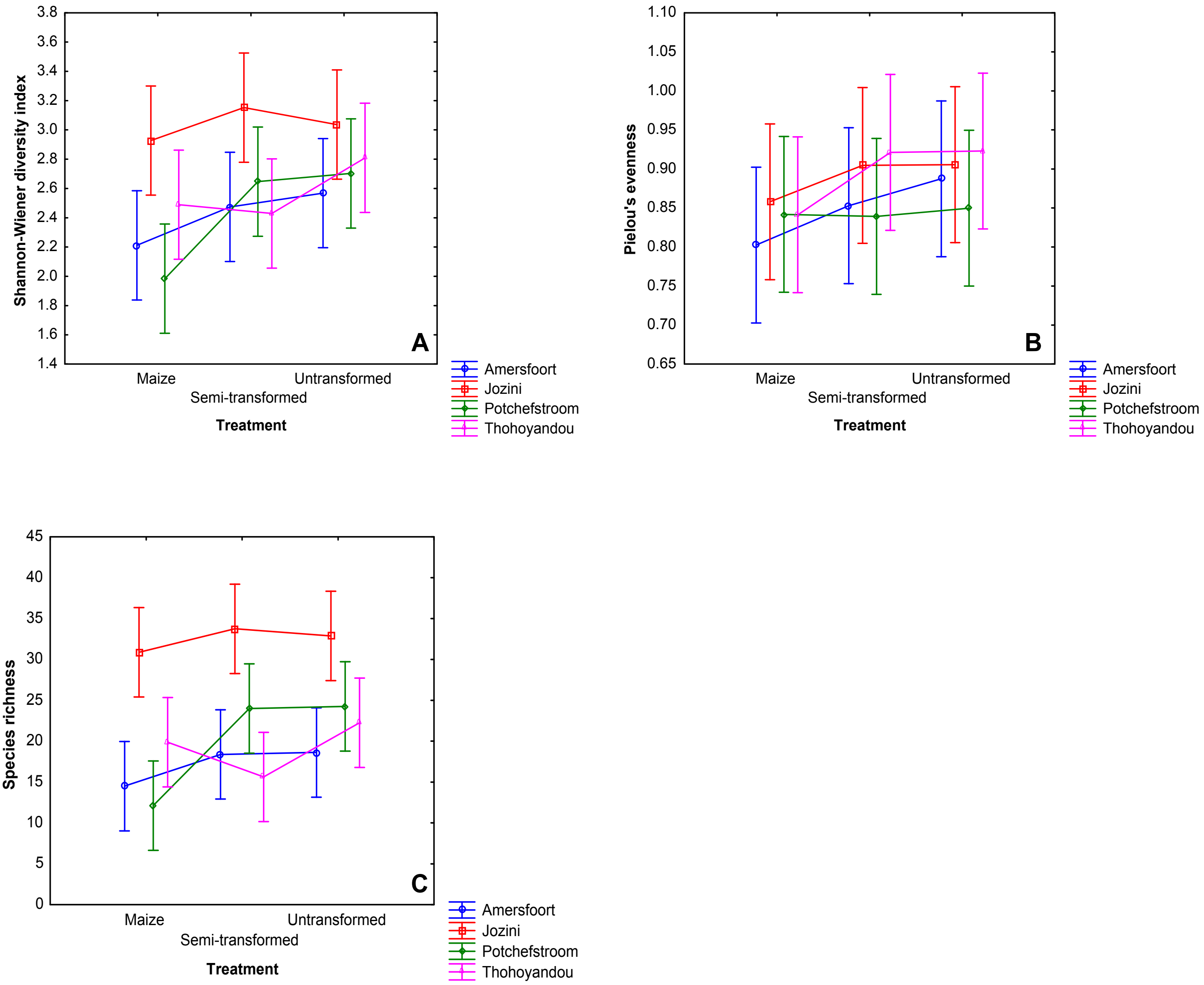

Figure 6.3: Mean (A) Shannon-Wiener diversity index, (B) Pielou's evenness, and (C) Species richness values per treatment (n=32) for insect species MAFMAG in four maize producing regions in South Africa. Vertical bars denote 0.95 confidence intervals.

Table 6.3: P-values of two-way factorial ANOVA for differences between localities (Amersfoort, Potchefstroom, Jozini and Thohoyandou), between treatments (maize field, semi-transformed and untransformed) as well as interactions (locality and treatments). *indicates significant difference ($P< 0.05$) (n=32). Refer to Appendix C for complete statistical values.

Index	Locality	Treatment	Interaction
Shannon-Wiener diversity index (H′)	0.000269*	0.016771*	0.484251
Pielou’s evenness index (J′)	0.458784	0.263479	0.981916
Species richness (S)	0.0*	0.028783*	0.127671

6.3.3 Comparison of species diversity for the four localities (Amersfoort, Jozini, Potchefstroom and Thohoyandou)

Shannon-Wiener diversity index for plant diversity showed that there was statistically significant difference between Amersfoort and the two savanna localities, Jozini and Thohoyandou (Table 6.4). The Shannon-Wiener diversity index for insect diversity showed that Jozini was significantly richer than all the other localities (Table 6.5). Pielou`s evenness for plants and insects showed no statistically significant difference between localities (Table 6.6 and 6.7). Species richness for plants showed that the savanna localities, Jozini and Thohoyandou, were significantly richer in diversity than grassland localities, Amersfoort and Potchefstroom (Table 6.8). Species richness for insects showed that Amersfoort, Potchefstroom and Thohoyandou were significantly poorer in species compared to Jozini (Table 6.9).

Table 6.4: Kruskal-Wallis test to compare p–values of localities (Amersfoort, Jozini, Potchefstroom and Thohoyandou) on Shannon-Wiener diversity index (H′) for plant diversity. *indicates significant difference (P = 0.0012) (n=96).

Depend:	Jozini	Potchefstroom	Thohoyandou
Amersfoort	0.024589*	1.0	0.001464*
Jozini	-	0.750622	0.1
Potchefstroom	-	-	1.118319

Table 6.5: Kruskal-Wallis test to compare p–values of localities (Amersfoort, Jozini, Potchefstroom and Thohoyandou) on Shannon-Wiener diversity index (H′) for insect diversity. *indicates significant difference (P = 0.0005) (n=96).

Depend:	Jozini	Potchefstroom	Thohoyandou
Amersfoort	0.000724*	1.0	1.0
Jozini	-	0.006829*	0.021550*
Potchefstroom	-	-	1.0

Table 6.6: Kruskal-Wallis test to compare values of localities (Amersfoort, Jozini, Potchefstroom and Thohoyandou) on Pielou's evenness index (J′) for plant diversity. *indicates significant difference (P = 0.3583) (n=96).

Depend:	Jozini	Potchefstroom	Thohoyandou
Amersfoort	0.484722	1.0	1.0
Jozini	-	1.0	1.0
Potchefstroom	-	-	1.0

Table 6.7: Kruskal-Wallis test to compare values of localities (Amersfoort, Jozini, Potchefstroom and Thohoyandou) on Pielou's evenness index (J′) for insect diversity. *indicates significant difference (P = 0.5299) (n=96).

Depend:	Jozini	Potchefstroom	Thohoyandou
Amersfoort	1.0	1.0	1.0
Jozini	-	1.0	1.0
Potchefstroom	-	-	1.0

Table 6.8: Kruskal-Wallis test to compare values of localities (Amersfoort, Jozini, Potchefstroom and Thohoyandou) on species richness (S) for plant diversity. *indicates significant difference (P = 0.0001) (n=96).

Depend:	Jozini	Potchefstroom	Thohoyandou
Amersfoort	0.007616*	0.872392	0.000072*
Jozini	-	0.463507	1.0
Potchefstroom	-	-	0.020846*

Table 6.9: Kruskal-Wallis test to compare values of localities (Amersfoort, Jozini, Potchefstroom and Thohoyandou) on species richness (S) for insect diversity. *indicates significant difference (P = 0.0000) (n=96).

Depend:	Jozini	Potchefstroom	Thohoyandou
Amersfoort	0.000013*	1.000000	1.000000
Jozini	-	0.003518*	0.000295*
Potchefstroom	-	-	1.000000

6.3.4 Comparison of species diversity for the three treatments (Maize field, semi-transformed edges and untransformed edges)

The Shannon-Wiener diversity index for plants showed that there was a statistically significant difference between maize fields, semi-transformed and untransformed areas (Table 6.10). Shannon-Wiener diversity index for insects showed that there was no significant difference between treatments (maize fields, semi-transformed and untransformed areas) (Table 6.11). Pielou`s evenness index for plants showed a significant difference in semi-transformed and untransformed areas compared to maize fields (Table 6.12), but insect evenness did not differ significantly between these areas (Table 6.13). Species richness of plants also showed that there was significant difference between the species rich edge (semi-transformed and untransformed) compared to the species poor maize fields (Table 6.14), however for insects there was again no significant difference between treatments (Table 6.15).

Table 6.10: Results of Kruskal-Wallis test of treatments on Shannon-Wiener diversity index (H′) for plant diversity. *indicates significant difference (P = 0.0) (n=96).

Treatment	Semi-transformed	Untransformed
Maize	0.0*	0.0*
Semi-transformed	-	1.0

Table 6.11: Results of Kruskal-Wallis test, of treatments on Shannon-Wiener diversity index (H′) for insect diversity. *indicates significant difference (P = 0.1178) (n=96).

Treatment	Semi-transformed	Untransformed
Maize	0.700535	0.118298
Semi-transformed	-	1.0

Table 6.12: Results of Kruskal-Wallis test, of treatments on Pielou's evenness index (J′) for plant diversity. *indicates significant difference (P = 0.3583) (n=96).

Treatment	Semi-transformed	Untransformed
Maize	0.0*	0.0*
Semi-transformed	-	1.0

Table 6.13: Results of Kruskal-Wallis test, of treatments on Pielou's evenness index (J′) for insect diversity. *indicates significant difference (P = 0.7684) (n=96).

Treatment	Semi-transformed	Untransformed
Maize	1.0	1.0
Semi-transformed	-	1.0

Table 6.14: Results of Kruskal-Wallis test, of treatments on Species richness (S) for plants diversity. *indicates significant difference (P = 0.0) (n=96).

Treatment	Semi-transformed	Untransformed
Maize	0.0*	0.0*
Semi-transformed	-	1.0

Table 6.15: Results of Kruskal-Wallis test, of treatments on Species richness (S) for insects diversity. *indicates significant difference (P = 0.1596) (n=96).

Treatment	Semi-transformed	Untransformed
Maize	0.437951	0.213755
Semi-transformed	-	1.0

6.3.5 Plant-insect diversity relationships

Pearson`s correlation showed that the Shannon-Wiener diversity index and species richness of insects was correlated with Shannon-Wiener diversity index of plants (Table 6.16). It also showed that Shannon-Wiener diversity index of insects was correlated with species richness of plants (Table 6.16). Species richness of insects was correlated with Pielou`s evenness of plants (Table 6.16). Spearman rank order correlation showed similar results as the Pearson`s correlation, with Species richness of insects also being correlated with Species richness of plants (Table 6.17).

Table 6.16: Results of Pearson`s correlations values between Shannon-Wiener diversity index, Pielou`s evenness and Species richness of both plant and insect species. *indicates correlations that are significant at P <0.05. (n=96).

Variable	Shannon diversity index of insects	Shannon diversity index of plants	Pielou`s evenness of insects	Pielou`s evenness of plants	Species richness of insects
Shannon diversity index (plants)	0.271995*	-	-	-	-
Pielou`s evenness (insects)	0.699566*	0.127279	-	-	-
Pielou`s evenness (plants)	0.165907	0.809341*	-0.023054	-	-
Species richness (insects)	0.777859*	0.302551*	0.186940	0.260447*	-
Species richness (plants)	0.225754*	0.881932*	0.179017	0.502734*	0.190792

Table 6.17: Results of Spearman rank order correlation values between Shannon-Wiener diversity index, Pielou`s evenness and Species richness of both plant and insect species. *indicates correlations that are significant at P <0.05. (n=96).

Variable	Shannon diversity index of insects	Shannon diversity index of plants	Pielou`s evenness of insects	Pielou`s evenness of plants	Species richness of insects
Shannon diversity index (plants)	0.201781*	-	-	-	-
Pielou`s evenness (insects)	0.517366*	0.083995	-	-	-
Pielou`s evenness (plants)	0.120709	0.811121*	-0.041522	-	-
Species richness (insects)	0.758405*	0.257228*	-0.028180	0.265286*	-
Species richness (plants)	0.219961*	0.963395*	0.121664	0.662368*	0.232217*

6.4. Discussion

6.4.1 Patterns of plant and insect species diversity

The study showed that plant and, generally also insect diversity, was lower in maize fields than in the semi-transformed and untransformed areas along the margins of maize fields. The lowest insect diversity in semi-transformed areas was recorded at Thohoyandou. However, it could be that insects of the semi-transformed areas moved to the nearby maize fields during maize flowering periods. Samways *et al*. (1996) found that the percentage of species of all taxa associated with alien vegetation was much less than that of indigenous vegetation. This is in accord with our findings that indigenous vegetation (untransformed areas) was associated with higher insect species diversity. According to the Schwab *et al*. (2002), angiosperm species present is the best single indicator of the biodiversity at a site. Angiosperm species richness is an acceptable predictor of spider and insect diversity (Schwab *et al.,* 2002), and its alien or indigenous status is an important determinant. Studies by Steenkamp and Chown (1996) found that a dense stand of an alien tree, *Prosopis glandulosa*, influenced dung beetle assemblages in southern Africa by reducing species richness and beetle diversity. Coetzee *et al*. (2007) also found significant differences in Coleoptera assemblages between grassland sites and sites invaded by *Acacia dealbata* trees. They found that Coleoptera richness was significantly lower in the invaded stands compared to grassland (Coetzee *et al*., 2007).

This study showed that untransformed areas had the highest insect species richness and maize fields had significantly lower richness. According to Duelli *et al*. (1989), the closer a maize plot is situated to a semi-transformed area, the higher the species richness of that plot. According to Crowder *et al*. (2010), species evenness has been neglected relative to species richness in recent ecological and biodiversity research, since both richness and evenness are important indicators of biodiversity and stability. For example, the study by Crowder *et al.* (2010) explained that species evenness was very important for pest control in agricultural systems.

Species richness of understory weeds decreased as crops suppressed weed growth (Poggio and Ghersa, 2011). This is in accord with our findings that inside maize fields one or more plant species became dominant, hence the lower plant species richness inside maize fields. According to Poggio and Ghersa (2011), evenness also decreased as the dominant species became increasingly productive, regardless of their identity (weeds or crops). The decrease in evenness indicates that the dominance hierarchy becomes progressively stronger as the dominant crop species becomes more productive (Poggio and Ghersa, 2011). Hence, maize fields had low plant diversity and evenness.

6.4.2 Comparison of species diversity between localities and treatments

The localities in the Savanna Biome had the highest plant diversity and species richness compared to Amersfoort and Potchefstroom. Both Amersfoort and Potchefstroom are part of the Grassland Biome where surrounding maize field-field margin vegetation is used for grazing. Low plant diversity in grassland plots can be attributed to the effect of grazing. According to Sheridan *et al.* (2008), herb species respond positively to grazing, while the response of grasses is species-specific and might not survive heavy grazing (Sheridan *et al.,* 2008). In grasslands habitats, insect diversity can be affected by habitat management, since practices such as cutting and grazing may change the associated insect community through profound alterations of plant growth, plant architecture and vegetation diversity (Kruess and Tscharntke, 2002). Overall, Jozini had the highest insect diversity compared to the other three maize producing regions. This could probably be attributed to location, as Jozini lies in the subtropical region of South Africa (Morgenthal *et al*., 2006).

The findings of this study concur with Thomas and Marshall (1999), suggesting that arthropod diversity is lowest in the crop field, low in the field margin, and higher in the least transformed areas. Maize fields had the lowest plant diversity and species richness compared to semi-transformed and untransformed areas. This confirms that semi-transformed and untransformed areas contained a higher diversity of plants. Insect diversity did not differ significantly between all treatments, suggesting that maize field insect diversity is not much different from surrounding semi-transformed and untransformed areas. This can be ascribed to the ability of insect species to move from maize fields to edges and vice versa.

6.4.3 Plant-insect diversity relationships

Diversity/species richness of insects was correlated with diversity of plants. Species richness of insects was also correlated with plant evenness. It also showed that diversity of insects was correlated with species richness of plants. Procheş and Cowling (2006) found similar results, *i.e.* a strong positive relationship between plant and insect diversity. The diversity of phytophagous insects is positively correlated with plant species diversity (Kruess and Tscharntke, 2002) and according to Haddad *et al*. (2009), the diversity of arthropods is determined by the diversity of plants. They found that species richness of herbivores was positively related to plant species richness and strongly affected by the functional groups of species represented (Haddad *et al*., 2009). Trophic structure and ecological function therefore becomes more intricate in more plant species rich communities. Asteraki (2004) also found that Auchenorrhyncha, Heteroptera and Araneae abundance were significantly correlated with plant species richness. According to Tscharntke and Greiler (1995), species richness values of bees, butterflies, phytophagous beetles, and bugs are known to be positively correlated with species richness of plants. Similarly, Toft (2001), found that richness of beetle and fungus gnat (Diptera: Mycetophilidae) species was correlated with vascular plant richness. Murdoch *et al.* (1972) studied the diversity and pattern in plants and insects on three old fields and found that within field correlations between plant and insect diversity were generally weak. However, combined data from the three fields revealed that evenness and diversity of insects were highly correlated with plant evenness and plant diversity, respectively (Murdoch *et al*., 1972). Wenniger and Inouye (2008) found that insect diversity and abundance are positively correlated with both plant diversity and irrigation. This suggests that water availability indirectly affects insect diversity and abundance. Similarly Segev (2010) found that precipitation can indirectly affect ant species richness through an increase in plant productivity and consequently an increase in food availability. However, in our study we did not test the influence of water availability/precipitation in the four maize producing regions. Our results suggest that during the dry season in semi-arid ecosystems, plant diversity may be secondary to moisture effects in influencing insect diversity and abundance (Wenninger and Inouye, 2008).

6.5. Summary

In general maize fields have lower plant and insect diversity than semi-transformed and untransformed areas. The study also showed that localities in the Savanna Biome contained higher plant and insect diversity compared to the Grassland Biome. Maize fields contained lower plant diversity compared to maize field edges. The study revealed that maize field insect diversity was similar to that in, semi-transformed and untransformed areas. Hence, it is hypothesized that during maize flowering, insects move regularly from the edges into the maize fields and back to untransformed areas. There was a relationship between plant and insect diversity. Diversity/richness of insects was correlated with plant diversity. Species richness of insects was also correlated with species richness of plants. The findings of this study agrees with Thomas and Marshall (1999), suggesting a significant positive correlation between faunal and floral diversity. The relationship between plant and insect species richness is likely to be due to both direct interactions (the plants providing primarily microhabitats and secondarily food for insects) and parallelism (both groups responding to similar environmental factors) (Procheş and Cowling, 2006). Future research should investigate whether this relationship is dependent on functional groups of arthropods.

This chapter presents evidence that there is significant overlap between biodiversity of untransformed and transformed (arable land) in South Africa and that there is an urgent need for the formulation of appropriate policies to promote biodiversity conservation on private farmland (Wessels *et al.,* 2003). Botanically diverse field margins are an important method of increasing the arthropod diversity of semi-transformed habitat in farmland (Thomas and Marshall, 1999).

Chapter 7: Conclusion and recommendations

7.1. Introduction

This dissertation described patterns of insect and plant diversity along maize field-field margin gradient in four maize producing regions of South Africa. These regions were chosen to represent both the Grassland and Savanna Biomes. It also described for the first time in South Africa the species composition inside and in the proximity of maize fields. We used the same data set to compare plant diversity and insect diversity in maize fields, semi-transformed and untransformed areas, and to test for general relationships between plant diversity and insect diversity along maize field-field margin gradients. The study bridged the current lack of knowledge of insect and plant diversity in maize-based agro-ecosystems in South Africa. These findings are of value for biodiversity conservation in agro-ecosystems and provide baseline data for possible future monitoring of changes in biodiversity patterns.

7.2. Plant diversity patterns along a maize field-field margin gradient

Plant diversity increased with increasing distance from inside maize field along a gradient towards the untransformed vegetation. Maize fields had much lower plant diversity than untransformed areas bordering maize fields. In the Savanna biome a high diversity of plants was observed compared to grasslands. Maize field-margins plant species are rarely found inside maize fields, indicating that there was high species richness/diversity outside maize fields. Maize fields in both commercial and small-scale farming systems had similar trends in diversity patterns of plant species. Decline of plant species have an effect on communal lands as these communities solely depend on natural resources for their livelihoods.

7.3. Insect diversity patterns along a maize field-field margin gradient

Insect diversity increased with increasing distance away from maize fields. As expected, inside maize fields, insect diversity was low. This observation supports the hypothesis that high diversity of plants results in high insect diversity. This is also supported by the observation that the Savanna biome showed higher insect diversity compared to grasslands. Further studies should be conducted in other crops and findings from this study need future testing using other collection methods (e.g. pitfall traps and sweep netting).

This study also affirmed our hypothesis that insect species distribution overlaps between maize fields and margins, in other words most insect species occur in both the maize fields and bordering untransformed areas. In the Savanna biome a much higher number of shared insect species occurred in maize fields and margins than in the Grassland biome. These observations could have implications in biodiversity management of agricultural systems.

Change in biodiversity patterns along maize field and field margins could have an effect in agro-ecosystems. It was mentioned in Chapter 1 that biodiversity is needed for ecosystems to function effectively, and thus to deliver services. Therefore edges provide certain ecosystem services which are important to sustain agricultural production. However, the agricultural system seems to affect the natural systems, for example, when expansion in farming areas takes place especially in ecological, sensitive areas (e.g. wetlands). Furthermore, with the advent of GM crops with insecticidal properties and herbicide tolerance, it is also possible that these technologies may influence the patterns of biodiversity observed and described in this study.

7.4. Insect-plant diversity relationships of a maize field-field margin gradient

Plant diversity was higher in untransformed areas than inside maize fields, whereas insect diversity does not differ between maize fields, semi-transformed and untransformed areas. Hence, this indicates that during maize flowering insects move between maize field and margins in a quest to make use of resources in maize fields. There was a relationship between plant diversity and insect diversity, suggesting that plant diversity enhanced insect diversity. Future research should determine if this relationship is functionally dependent. This study provided evidence that there is significant overlap between biodiversity of untransformed and transformed land. As indicated by Wessels *et al.* (2003) appropriate policies and strategies for biodiversity conservation are needed to promote biodiversity and conservation on farmland.

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Appendices

Appendix. A: Complete statistical analysis for plant diversity

Table 9.1: Repeated Measures ANOVA for the **Simpson`s index of diversity (Ď)** for differences between Biomes (Savanna and Grassland), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	78.26595	1	78.26595	37134.36	0.0*
Biome	0.06714	1	0.06714	31.85	0.00061*
Error	0.02951	14	0.00211		
Distance	0.31399	5	0.06280	39.49	0.0*
Interaction	0.01808	5	0.00362	2.27	0.056396
Error	0.11132	70	0.00159		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.2: Repeated Measures ANOVA for the **Shannon-Wiener diversity index (H′)** for differences between Biomes (Savanna and Grassland), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	724.6911	1	724.6911	4914.972	0.0*
Biome	5.1582	1	5.1582	34.983	0.000038*
Error	2.0642	14	0.1474		
Distance	20.1877	5	4.0375	61.287	0.0*
Interaction	0.5157	5	0.1031	1.566	0.181141
Error	4.6115	70	0.0659		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.3: Repeated Measures ANOVA for the **Pielou's evenness index (J′)** for differences between Biomes (Savanna and Grassland), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	66.02467	1	66.02467	20420.73	0.0*
Biome	0.01076	1	0.01076	33.33	0.089534
Error	0.04527	14	0.00323		
Distance	0.20890	5	0.04178	15.19	0.0*
Interaction	0.01873	5	0.00357	1.36	0.249344
Error	0.19254	70	0.00275		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.4: Repeated Measures ANOVA for the **Margalef`s species richness index (d)** for differences between Biomes (Savanna and Grassland), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	4424.987	1	4424.987	277.2718	0.0*
Biome	315.100	1	315.100	19.7443	0.000556*
Error	223.426	14	15.959		
Distance	547.491	5	109.498	31.5956	0.0*
Interaction	70.452	5	14.090	4.0658	0.002685*
Error	242.593	70	3.466		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.5: Repeated Measures ANOVA for **Species richness (S)** for differences between Biomes (Savanna and Grassland), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	88027.59	1	88027.59	540.4660	0.0*
Biome	4945.01	1	4945.01	30.3610	0.000077*
Error	2280.23	14	162.87		
Distance	9081.59	5	1816.32	40.7456	0.0*
Interaction	752.18	5	150.44	3.3747	0.008665*
Error	3120.40	70	44.58		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.6: Repeated Measures ANOVA for **Simpson`s index of diversity (Ď)** for differences between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Locality and Distance). *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	78.26595	1	78.26595	57081.72	0.0*
Locality	0.08019	3	0.02673	19.50	0.000066*
Error	0.01645	12	0.00137		
Distance	0.31399	5	0.06280	39.14	0.0*
Interaction	0.03313	15	0.00221	1.38	0.188693
Error	0.09627	60	0.00160		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.7: Repeated Measures ANOVA for **Shannon-Wiener diversity index (H′)** for differences between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Locality and Distance). *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	724.6911	1	724.6911	9176.308	0.0*
Locality	6.2747	3	2.0916	26.484	0.000014*
Error	0.9477	12	0.0790		
Distance	20.1877	5	4.0375	63.392	0.0*
Interaction	1.3058	15	0.0871	1.367	0.193690
Error	3.8215	60	0.0637		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.8: Repeated Measures ANOVA for **Pielou`s evenness (J′)** for differences between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Locality and Distance). *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	66.02467	1	66.02467	21869.308	0.0*
Locality	0.01980	3	0.00660	2.19	0.142628
Error	0.03623	12	0.00302		
Distance	0.20890	5	0.04178	13.74	0.0*
Interaction	0.02878	15	0.00192	0.63	0.837800
Error	0.18249	60	0.00304		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.9: Repeated Measures ANOVA for **Margalef`s species richness index (d)** for differences between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Locality and Distance). *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	4424.987	1	4424.987	429.2003	0.0*
Locality	414.808	3	138.269	13.4114	0.000386*
Error	123.718	12	10.310		
Distance	547.491	5	109.498	36.3921	0.0*
Interaction	132.515	15	8.834	2.9361	0.001566*
Error	180.531	60	3.009		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Table 9.10: Repeated Measures ANOVA for **Species richness (S)** for differences between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and Interaction (Locality and Distance). *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	88027.59	1	88027.59	1499.849	0.0*
Locality	6520.95	3	2173.65	37.035	0.000002*
Error	704.29	12	58.69		
Distance	9081.59	5	1816.32	52.648	0.0*
Interaction	1802.61	15	120.17	3.483	0.000282*
Error	2069.96	60	34.50		

SS, sum of squares; df, degrees of freedom; MS, means of squares; F, significance of F; P, significance of P.

Appendix. B: Complete statistical analysis for insect diversity

Table 9.11: Results of Repeated Measures ANOVA to test for differences between the Simpson`s index of diversity (Ď) for insect diversity in Biomes (Savanna and Grassland), between Distance (m) (-100, 0, 100, 200, 300, 400) as well as interactions (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F	P
Intercept	77.32686	1	77.32686	4627.463	0.0*
Biome	0.10430	1	0.10430	6.242	0.025549*
Error	0.23395	14	0.01671		
Distance	0.21173	5	0.04235	2.365	0.048362*
Interaction	0.03573	5	0.00715	2.399	0.847839
Error	0.25323	70	0.01790		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.12: Results of Repeated Measures ANOVA to test for differences between the Shannon-Wiener diversity index (H′) for insect diversity in Biomes (Savanna and Grassland), between Distance (m) (-100, 0, 100, 200, 300, 400) as well as interactions (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	658.5480	1	658.5480	1450.054	0.0*
Biome	3.3974	1	3.3974	7.481	0.016109*
Error	6.3582	14	0.4542		
Distance	4.0979	5	0.8196	3.086	0.014191*
Interaction	1.1689	5	0.2338	0.880	0.499094
Error	18.5932	70	0.2656		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.13: Results of Repeated Measures ANOVA to test for differences between the **Pielou's evenness index (J′)** for insect diversity in Biomes (Savanna and Grassland), between Distance (m) (-100, 0, 100, 200, 300, 400) as well as interactions (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	72.48174	1	72.48174	3864.293	0.0*
Biome	0.05218	1	0.05218	2.782	0.117552
Error	0.26260	14	0.01876		
Distance	0.17143	5	0.03429	1.850	0.114267
Interaction	0.03943	5	0.00789	0.426	0.829325
Error	1.29701	70	0.01853		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.14: Results of Repeated Measures ANOVA to test for differences between the **Margalef`s species richness index (d)** for insect diversity in Biomes (Savanna and Grassland), between Distance (m) (-100, 0, 100, 200, 300, 400) as well as interactions (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	3332.072	1	3332.072	240.7286	0.0*
Biome	96.818	1	96.818	6.9947	0.019225*
Error	193.783	14	13.842		
Distance	58.576	5	11.715	2.8968	0.019587*
Interaction	25.580	5	5.116	1.2650	0.288799
Error	283.096	70	4.044		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.15: Results of Repeated Measures ANOVA to test for differences between the **Species richness (S)** for insect diversity in Biomes (Savanna and Grassland), between Distance (m) (-100, 0, 100, 200, 300, 400) as well as interactions (Biome and Distance). *indicates significant difference (P< 0.05) (n=8).

Effect	SS	df	MS	F-value	P-value
Intercept	47570.51	1	47570.51	212.0936	0.0*
Biome	1254.26	1	1254.26	5.5921	0.03302*
Error	3140.06	14	224.29		
Distance	728.05	5	145.61	2.6324	0.030739*
Interaction	616.05	5	123.21	2.2274	0.06102
Error	3872.06	70	55.32		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.16: Results of Repeated Measures ANOVA to test differences in trend between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and interaction (Locality and Distance) on Simpson`s index of diversity (Ď) for insect diversity. *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	77.32686	1	77.32686	4142.962	0.000000*
Locality	0.11427	3	0.03809	2.041	0.161894
Error	0.22398	12	0.01866		
Distance	0.21173	5	0.04235	2.148	0.071863
Interaction	0.10613	15	0.00708	0.359	0.984386
Error	1.18283	60	0.01971		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.17: Results of Repeated Measures ANOVA to test differences in trend between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and interaction (Locality and Distance) on **Shannon-Wiener diversity index (H′)** for insect diversity. *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	658.5480	1	658.5480	2092.746	0.000000*
Locality	5.9794	3	1.9931	6.334	0.008058*
Error	3.7762	12	0.3147		
Distance	4.0979	5	0.8196	3.074	0.015515*
Interaction	3.7635	15	0.2509	0.941	0.525868
Error	15.9986	60	0.2666		

SS= sum of squares; df=degree of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.18: Results of Repeated Measures ANOVA to test differences in trend between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and interaction (Locality and Distance) on **Pielou`s evenness index (J′)** for insect diversity. *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	72.48174	1	72.48174	3319.799	0.0*
Locality	0.05277	3	0.01759	0.806	0.514576
Error	0.26200	12	0.02183		
Distance	0.17143	5	0.03429	1.716	0.14472
Interaction	0.13772	15	0.00918	0.460	0.951536
Error	1.19873	60	0.01998		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.19: Results of Repeated Measures ANOVA to test differences in trend between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and interaction (Locality and Distance) on **Margalef`s species richness index (d)** for insect diversity. *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	3332.072	1	3332.072	757.3068	0.0*
Locality	237.802	3	79.267	18.0157	0.000097*
Error	52.799	12	4.400		
Distance	58.576	5	11.715	3.8959	0.004003*
Interaction	128.254	15	8.550	2.8434	0.0021*
Error	180.423	60	3.007		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.20: Results of Repeated Measures ANOVA to test differences in trend between Locality (Amersfoort, Potchefstroom, Jozini and Thohoyandou), Distance (m) (-100, 0, 100, 200, 300, 400) and interaction (Locality and Distance) on **Species richness (S)** for insect diversity. *indicates significant difference (P< 0.05) (n=4).

Effect	SS	df	MS	F-value	P-value
Intercept	47570.51	1	47570.51	614.9426	0.0*
Locality	3466.03	3	1155.34	14.9351	0.000236*
Error	928.29	12	77.36		
Distance	728.05	5	145.61	3.6132	0.006361*
Interaction	2070.16	15	138.01	3.4246	0.000338*
Error	2417.96	60	40.30		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Appendix. C: Complete statistical analysis between treatments

Table 9.21: Results of two-way factorial ANOVA to test for differences between the **Shannon-Wiener diversity index (H′)** for plant diversity in Localities (Amersfoort, Potchefstroom, Jozini and Thohoyandou), between Treatments (maize field, semi-transformed and untransformed) as well as interactions (locality and treatments). *indicates significant difference (P< 0.05) (n=32).

Effect	SS	df	MS	F-value	P-value
Intercept	724.6911	1	724.6911	10881.66	0.0*
Locality	6.2747	3	2.0916	31.41	0.0*
Treatment	19.9832	2	9.9916	150.03	0.0*
Interaction	0.6852	6	0.1142	1.71	0.127520
Error	5.5942	84	0.0666		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.22: Results of two-way factorial ANOVA to test for differences between the **Pielou`s evenness index (J′)** for plant diversity in Localities (Amersfoort, Potchefstroom, Jozini and Thohoyandou), between Treatments (maize field, semi-transformed and untransformed) as well as interactions (locality and treatments). *indicates significant difference (P< 0.05) (n=32).

Effect	SS	df	MS	F-value	P-value
Intercept	66.02467	1	66.02467	23341.35	0.0*
Locality	0.01980	3	0.00660	2.33	0.079896
Treatment	0.20353	2	0.10177	35.98	0.0*
Interaction	0.01526	6	0.00254	0.90	0.499593
Error	0.23761	84	0.00283		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.23: Results of two-way factorial ANOVA to test for differences between the **Species richness (S)** for plant diversity in Localities (Amersfoort, Potchefstroom, Jozini and Thohoyandou), between Treatments (maize field, semi-transformed and untransformed) as well as interactions (locality and treatments). *indicates significant difference (P< 0.05) (n=32).

Effect	SS	df	MS	F-value	P-value
Intercept	88027.59	1	88027.59	2367.223	0. 0*
Locality	6520.95	3	2173.65	58.453	0. 0*
Treatment	9015.25	2	4507.62	121.218	0.0*
Interaction	1519.58	6	253.26	6.811	0.000007*
Error	3123.63	84	37.19		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.24: Results of two-way factorial ANOVA to test for differences between the **Shannon-Wiener diversity index (H′)** for insect diversity in Localities (Amersfoort, Potchefstroom, Jozini and Thohoyandou), between Treatments (maize field, semi-transformed and untransformed) as well as interactions (locality and treatments). *indicates significant difference (P< 0.05) (n=32).

Effect	SS	df	MS	F-value	P-value
Intercept	658.5480	1	658.5480	2337.949	0. 0*
Locality	5.9794	3	1.9931	7.076	0.000269*
Treatment	2.4189	2	1.2094	4.294	0.016771*
Interaction	1.5564	6	0.2594	0.921	0.484251
Error	23.6609	84	0.2817		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.25: Results of two-way factorial ANOVA to test for differences between the **Pielou`s evenness index (J′)** for insect diversity in Localities (Amersfoort, Potchefstroom, Jozini and Thohoyandou), between Treatments (maize field, semi-transformed and untransformed) as well as interactions (locality and treatments). *indicates significant difference (P< 0.05) (n=32).

Effect	SS	df	MS	F-value	P-value
Intercept	72.48174	1	72.48174	3594.994	0.0*
Locality	0.05277	3	0.01759	0.872	0.458784
Treatment	0.05465	2	0.02732	1.355	0.263479
Interaction	0.02163	6	0.00361	0.179	0.981916
Error	1.69360	84	0.02016		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.

Table 9.26: Results of two-way factorial ANOVA to test for differences between the **Species richness (S)** for insect diversity in Localities (Amersfoort, Potchefstroom, Jozini and Thohoyandou), between Treatments (maize field, semi-transformed and untransformed) as well as interactions (locality and treatments). *indicates significant difference (P< 0.05) (n=32).

Effect	SS	df	MS	F-value	P-value
Intercept	47570.51	1	47570.51	787.2770	0.0*
Locality	3466.03	3	1155.34	19.1206	0.0*
Treatment	447.40	2	223.70	3.7021	0.028783*
Interaction	621.44	6	103.57	1.7141	0.127671
Error	5075.62	84	60.42		

SS= sum of squares; df=degrees of freedom; MS=means of squares; F= significance of F; P= significance of P.