CHAPTER 6: FLORISTIC PATTERNS OF THE WESTERN CENTRAL BUSHVELD

6.1 Floristic importance of the western Central Bushveld flora

The rising concern regarding accelerated extinction of plant species due to vegetation transformation and habitat destruction has reawakened an interest in describing, understanding and predicting patterns of species richness (Cowling *et al.*, 1989). This has become a prerequisite for the successful conservation of plant diversity in our today's human dominated landscape. It aids in pinpointing areas of high biodiversity value and threats.

In this context, the taxonomic diversity (alpha diversity) of the western Central Bushveld (WCB) flora and the distribution patterns of its taxa (beta diversity) has been the main objective of this study.

6.1.1 Species

6.1.1.1 Species richness

Southern Africa has the highest plant species density at the subcontinental level (Cowling *et al.*, 1989). But how does the study area rank among the species richest areas in southern Africa?

In the African context, the southern African savanna is considered as an important centre of speciation for many genera contributing to species-rich plant communities (Gibbs Russell, 1987). Thus it cannot be regarded as a depauperate intrusion of the Sudano-Zambesian flora as proposed by White (1983) as indicated by Cowling *et al.* (1989). The vast savanna core area of 632,000 km^2 (45% of total biome) that contains the study area, has been found to provide habitat for 5,788 plant species, compared to studies of Exell (1971) who recorded only about 6, 000 species for other African countries that are largely covered by savanna but comprise areas four times greater than the savanna core area (Cowling *et al.*, 1989).

Analyses performed in this study confirmed the above postulation of Gibbs Russell (1987). Even though the study area contains only 3% of the savanna core area, it harbours 41% of its species richness and has a species/area ratio of 0.07 (table 5.1; chapter 5). This high gamma diversity in such a small area can be explained by a low beta diversity between the species rich communities of the savanna and consequently of the WCB. Whittaker (1972) defines beta diversity as the extent of differentiation between communities along an environmental gradient. The total diversity of a landscape, the gamma diversity, results from the alpha diversity of its communities and the amount of beta differentiation (beta diversity) among them.

Cowling *et al.* (1989) observed that 91% of the savanna flora is recorded by sampling of only 10% of the savanna core area, although the savanna species/area ratio totals only 0.01 species per km^2. These figures show that there is a low species turnover between the range of habitats along the geographic gradient in the savanna and the WCB (Whittaker, 1972; Cowling *et al.*, 1989). The rather low differentiation between the habitats results in a low beta diversity, while alpha diversity of the local plant communities is high.

The same trend can be also observed for the two specific study areas. The Heritage Park and the Impala mining area constitutes only 0.4% and 0.05% of the savanna core area, but encompasses 20% and 24% of the savanna flora respectively. Likewise, the species/area relationship increases to 0.41 species per km^2 for the Heritage Park to 4.7 species per km^2 for Impala Platinum (table 5.1; chapter 5), which again confirms a high alpha diversity combined with low beta diversity within the study area.

6.1.1.2 Distribution pattern

However, likewise to the FSA region, the species richness in the study area is not equally distributed, some areas are clearly more species rich than others (Cowling & Hilton-Taylor, 1994). It has been found that the dry and topographically uniform plains (figure 5.2; chapter 5) of the WCB basin is underlain mainly by sedimentary rocks (figure 5.53; chapter 5) and has the lowest mean species diversity ($\bar{x}$ = 209) (table 5.18; chapter 5). Generally, species richness increases along an N–S and NW–SE gradient as indicated in the species interpolation maps (figures 5.38 and 5.39; chapter 5), with the highest mean species richness in areas with high variation in relief: 1) hills and lowlands ($\bar{x}$ = 444), 2) slightly undulating plains ($\bar{x}$ = 404) and 3) lowlands with parallel hills ($\bar{x}$ = 335) (figure 5.52, table 5.18; chapter 5). The same distribution pattern was observed for the genus and family level.

Environmental factors that give some indication on the distribution pattern of plant taxa richness in the WCB will be discussed in more detail (see 6.2).

6.1.2 Genera and families

6.1.2.1 Family richness

Looking at the largest families of flowering plants in the WCB, 11 of the WCB top 30 families have been found to rank among the top 30 families of the Flora of Southern Africa (table 6.1) (Cowling & Hilton-Taylor, 1994). A particular high correspondence exists between the two families Fabaceae and Asteraceae, which belong to the top three families in both floras.

The majority of families in the WCB have a cosmopolitan or pantropical origin (Goldblatt, 1978). Only the family Aizoaceae with two representative genera in the study area (*Galenia procumbens and Zaleya pentandra*) is a floristic group with its centre of speciation in southern Africa, while the following families are found that have undergone extensive radiation in southern Africa: Asteraceae (80 genera), Iridaceae (8 genera), Geraniaceae (*3 genera*), Oxalidaceae (*Oxalis*), Rutaceae (4 genera), Scrophulariaceae (20 genera), Thymelaeaceae (*Gnidia*) and Zygophyllaceae (*Tribulus*) (Goldblatt, 1978).

Two families exhibit taxa with African origin, namely Myrothamnaceae (*Myrothamnus flabellifolius*) and Selaginaceae (*Selaginella*); and Afro-Madagascan origins, namely Kirkiaceae (*Kirkia wilmsii*) and Oliniaceae (*Olinia emarginata*), (Goldblatt, 1978).

Furthermore, three families of African-Eurasian relationships occur. These are Pedaliaceae (six genera), Resedaceae (*Oligomeris dregeana*) and Vahliaceae (*Vahlia*), and two families of African-New World relationship, namely Turneraceae (three genera) and Velloziaceae (*Xerophyta)* (Goldblatt, 1978).

6.1.2.2 Genera richness

The above pattern of family ranking could be confirmed during examination of the largest genera within the study area. The most dominant genera have been found among the top 4 families as shown in table 6.2 (rank in brackets): the Fabaceae (*Indigofera* (1.), *Acacia* (5.)

and *Rhynchosia* (9.)), the Poaceae (*Eragrostis* (3.)), the Asteraceae (*Helichrysum* (4.) and *Senecio* (6.)) and the Cyperaceae (*Cyperus* (2.)). Other dominant taxa of the top 10 genera in the WCB are: *Euphorbia* (7.) of the Euphorbiaceae, *Ipomoea* (8.) of the Convolvulaceae and *Hibiscus* (10.) of the Malvaceae family.

Attributed to a massive evolutionary radiation in a range of isolated herbaceous and woody genera, several very large genera developed in the flora of southern Africa with an outstanding high species per genera ratio (Goldblatt, 1978). Five of the largest genera determined for the flora of southern Africa by Goldblatt (1978) have been found to be the dominant genera in the WCB too: *Indigofera* (42 species), *Senecio* (28 species), *Helichrysum* (31 species), *Euphorbia* (22 species) and *Hermannia* (17 species) (table 6.2).

Likewise, unparalleled climatic and topographic diversity of the southern African region produced high levels of endemism among the genera (29% according to Goldblatt, 1978). Several endemic genera could be identified for the WCB. Table 6.4 shows fifteen southern African endemics that were recorded for the study area. Additional seven half-endemic genera have been determined: 1) the two genera *Dimorphotheca* (Asteraceae) and *Leucosidea* (Rosaceae) have their major distribution in southern Africa, with a few species locally spreading into the tropical regions of Africa; 2) the seven genera *Euryops*, *Felicia* (Asteraceae), *Dierama*, *Hesperantha*, *Moraea* (Iridaceae), *Cliffortia* (Rosaceae) and *Selago* (Selaginaceae) have their endemic hotspot in the Cape flora, but occur throughout eastern South Africa and few species spread as far as East Africa; 3) the genus *Osteospermum* (Asteraceae) is mainly endemic to southern Africa, but a few species are found in the Mediterranean and the Middle East (Goldblatt, 1978).

Table 6.1: The 20 largest families of the western Central Bushveld compared to the top 30 families of the Flora of southern Africa as defined by Gibbs Russell (1985). Source: Cowling & Hilton-Taylor (1994).

Families	Rank WCB	Rank FSA
FABACEAE	1.	3.
POACEAE	2.	7.
ASTERACEAE	3.	2.
CYPERACEAE	4.	10.
ACANTHACEAE	5.	14.
APOCYNACEAE	6.	-
EUPHORBIACEAE	7.	11.
LAMIACEAE	8.	19.
MALVACEAE	9.	-
RUBIACEAE	10.	22.
SCROPHULARIACEAE	11.	9.
HYACINTHACEAE	12.	-
CONVOLVULACEAE	13.	-
SOLANACEAE	14.	-
ANACARDIACEAE CUCURBITACEAE	15.	- -
IRIDACEAE	16.	5.
AMARANTHACEAE STERCULIACEAE	17.	- 30.
PTERIDACEAE	18.	-
VITACEAE	19.	-
ASPHODELACEAE	20.	-

Table 6.2: The 10 largest genera of the western Central Bushveld relative to the largest genera of the Flora of southern Africa (Goldblatt, 1978; Gibbs Russell, 1985, 1987). Source: Cowling & Hilton-Taylor (1997).

Genera	Rank WCB	Number of species	Rank FSA	Number of species
Indigofera	1.	42	9.	209
Helichrysum	4.	31	5.	245
Senecio	6.	28	3.	285
Euphorbia	7.	22	6.	235
Hermannia	10.	17	17.	146

Table 6.3: The 10 largest genera occurring in the western Central Bushveld (WCB).

Family	Largest Genera	No. subsp.	Rank
FABACEAE	*Indigofera*	42	1.
CYPERACEAE	*Cyperus*	40	2.
POACEAE	*Eragrostis*	36	3.
ASTERACEAE	*Helichrysum*	31	4.
FABACEAE	*Acacia*	30	5.
ASTERACEAE	*Senecio*	28	6.
EUPHORBIACEAE CONVOLVULACEAE FABACEAE	*Euphorbia* *Ipomoea* *Rhynchosia*	22	7.
MALVACEAE	*Hibiscus*	20	8.
POACEAE ASPARAGACEAE ANACARDIACEAE	*Aristida* *Asparagus* *Searsia*	19	9.
STERCULIACAEA SOLANACEAE	*Hermannia* *Solanum*	17	10.

Table 6.4: Plant genera endemic to southern Africa which are found in the western Central Bushveld flora (Goldblatt, 1978).

Familiy	Endemic genera	Region
ACANTHACEAE	*Chaetacanthus*	Natal to S Cape, Free State, Transvaal
AMARYLLIDACEAE	*Haemanthus*	Widespread
AMARYLLIDACEAE	*Nerine*	Widespread, mainly Transvaal to E Cape
CAMPANULACEAE	*Prismatocarpus*	E Cape, SW Cape to Namaqualand
CRASSULACEAE	*Andromischus*	Widespread
IRIDACEAE	*Freesia*	SW & E Cape, W Transvaal to Karoo
FABACEAE	*Aspalathus*	E Cape, SW Cape to Namaqualand, Natal
FABACEAE	*Melolobium*	Widespread in arid areas
FABACEAE	*Sutherlandia*	Widespread
FABACEAE	*Xerocladia*	Namaqualand, Namibia
NEURADACEAE	*Neuradopsis*	Botswana, Cape, Namibia
POACEAE	*Harpochloa*	Highveld
POACEAE	*Mosdenia*	Transvaal
POACEAE	*Tarigidia*	N Cape, Namibia, Free State
SCROPHULARIACEAE	*Antherothamnus*	Cape to Namibia, Transvaal
SCROPHULARIACEAE	*Teedia*	E Cape, SW Cape, Namaqualand

6.1.3 Important plant taxa

'*There is no single indicator for biodiversity*' (Duelli & Obrist, 2003). Plant diversity has many facets; therefore various floristically important taxa have been determined for the WCB to describe the critical habitats for conservation. Especially the presence of endemic and Red Data plants plays an important role in the selection of conservation areas.

6.1.3.1 Endemic species

A total of 21 (0.9%) endemic species has been recorded for the WCB (figure 5.2; chapter 5), about half of the 43 (1.8%) endemic species that are predicted to occur in the WCB flora (table 6.5). Compared to the Succulent Karoo, which is comparable in size (40,931 km^2) and climate (semi-arid) to the study area but counting 397 (20%) endemic species, the degree of endemism in the WCB flora is comparatively low (Cowling & Hilton-Taylor, 1994).

However, most of the WCB endemic species are rare (e.g. *Gladiolus filiformis*) and several are threatened with extinction (e.g. *Aloe peglerae*) and thus their habitats must be protected (table 6.6). Hotspots of the current documented endemic species in the study area are mainly in the Rustenburg area and to the south of Zeerust (figure 5.42a; chapter 5).

Many parts of the WCB are not well collected, so the hotspots of endemic plants could differ from the current picture, as demonstrated by standardization of data with the Centroid and 'Integrated Grid' Profile (figures 5.42b–d; chapter 5). The Rustenburg endemic hotspot is predicted to cover a greater area expanding towards Pilanesberg and Brits and the Zeerust hotspot is expected to actually stretch in a broad band north-west into the western part of the Heritage Park.

The highest mean endemic species richness was measured in areas of intensive human use such as mines and quarries ($\bar{x} = 1.5$), cultivated grassland ($\bar{x} = 1.7$), commercial ($\bar{x} = 1.7$) and industrial built-up land ($\bar{x} = 1.9$), and associated degraded grasslands ($\bar{x} = 2.1$) (table 5.30; chapter 5). Natural areas comprise a comparatively lower mean endemic plant diversity, except grassland ($\bar{x} = 1.5$). Among the wilderness areas in the WCB the thicket and bushland show the highest local count of endemic plant species (max = 4).

Table 6.5: Predicted endemics for the western Central Bushveld flora and their geographical range, with actually recorded species highlighted with an asterisk (*).

Region[1]	Endemic Species
Botswana	*Aristida wildii*
Botswana	*Blepharis petalidioides*
Botswana	*Cleome kalachariensis*
Botswana	*Eragrostis subglandulosa*
Botswana	*Eriospermum seineri*
Botswana	*Erlangea remifolia*
Botswana	*Euphorbia venteri*
Botswana	*Gladiolus rubellus**
Botswana	*Jatropha botswanica*
Botswana	*Nesaea minima*
Botswana	*Neuradopsis bechuanensis*
Botswana	*Panicum coloratum* var. *makarikariense*
Central Bushveld	*Acacia theronii*
Central Bushveld	*Erythrophysa transvaalensis**
Central Bushveld	*Ledebouria crispa*
Central Bushveld	*Mosdenia leptostachys**
Central Bushveld	*Orthosiphon fruticosus*
Central Bushveld	*Oxygonum dregeanum* subsp. *canescens* var. *dissectum*
Central Bushveld	*Petalidium oblongifolium*
Central Bushveld	*Piaranthus atrosanguineus**
Dwarsberg-Swartruggens Mountain Bushveld	*Euphorbia perangusta**
Goldreef Mountain Bushveld	*Aloe peglerae**
Goldreef Mountain Bushveld	*Frithia pulchra**
Loskop Mountain Bushveld	*Gladiolus pole-evansii*
Loskop Mountain Bushveld	*Haworthia koelmaniorum*
North West	*Brachystelma canum*
North West	*Brachystelma gracillimum*
North West	*Brachystelma incanum*
North West	*Ceropegia insignis**
North West	*Commelina bella**
North West	*Euphorbia knobelii **

North West	*Euphorbia perangusta**
North West	*Gladiolus filiformis**
North West	*Ledebouria atrobrunnea**
North West	*Rhus maricoana*
Northern Sourveld	*Asparagus fourei*
Northern Sourveld	*Chorisochora transvaalensis*
Northern Sourveld	*Dracaena transvaalensis*
Northern Sourveld	*Encephalartos eugene-maraisii*
Northern Sourveld	*Haemanthus pauculifolius*
South Africa	*Barleria bolusii**
South Africa	*Blepharis angusta**
South Africa	*Cineria lobata**
South Africa	*Felicia fruticosa* subsp. *brevipedunculata**
South Africa	*Gladiolus rubellus**
South Africa	*Indigofera leendertziae**
South Africa	*Jamesbrittenia bergae**
South Africa	*Ozoroa albicans**
South Africa	*Searsia maricoana**
South Africa	*Thesium rogersii**
Waterberg Mountain Bushveld	*Grewia rogersii*
Waterberg Mountain Bushveld	*Oxygonum dregeanum* subsp. *canescens* var. *pilosum*
Waterberg Mountain Bushveld	*Pachystigma triflorum*
Zeerust Thornveld	*Rhus maricoana*

[1]Source: Mucina & Rutherford (2006) and SANBI (2009).

6.1.3.2 Red Data species

Furthermore, some 43 (1.8%) Red Data species have been recorded for the WCB (figure 5.2; chapter 5). This is a low percentage in contrast to the Flora of Southern Africa (FSA) with 15% of its species holding a Red Data status (Protea Atlas Project, 2010).

But 21% of the Red Data species face an immediate threat of extinction (table 6.6), and thus it is of utmost importance to preserve them. On top of this, 25% of the Red data species in the study area are endemic plants with a limited distribution range (e.g. Goldreef Mountain Bushveld Endemics *Aloe peglerae* and *Frithia pulchra*), and consequently under severe pressure by land-use change. Land-use change has confirmed to be a realistic threat to both endemic and Red Data plants.

The Rustenburg area bordering the Magaliesberg Nature Reserve has been identified as the major hotspot for Red Data species in the WCB (figure 5.43a; chapter 5). But the Red Data hotspot is expected to cover a much wider range according to the Centroid and ‘Integrated Grid’ Profile (figures 5.43b–d; chapter 5). Further sampling might identify the greater Rustenburg district as a hotspot with the inclusion of the Impala Bafokeng Complex (figure 5.43c; chapter 5), and even ranging as far as Swartruggens and Pilanesberg (figure 5.43b; chapter 5).

As for endemic plants, a high mean richness of Red Data species was documented for areas under severe pressure from human use, including residential areas (x̄ = 4.0), mines and quarries (x̄ = 4.0), eroded land (x̄ = 4.2), degraded grassland (x̄ = 4.4), exotic plantations (x̄ = 4.7), as well as industrial (x̄ = 5.3) and commercial (x̄ = 5.5) built-up land (table 5.32; chapter 5). Although the natural areas may have a local high diversity of Red Data species, the average species diversity is comparatively low. For example a maximum number of 12 Red Data plants have been recorded for some areas of the woodlands, but the mean species richness for the total area amounts only to x̄ = 2.5 (table 5.32; chapter 5).

6.1.3.3 Useful and medicinal plants

An additional threat to about 25% of the endemic and Red Data species in the study area derives from anthropogenic use of plants for various purposes such as building material and medicine. A total of 364 useful and medicinal plant species (16%) have been found in the study area, making up 15% of the WCB flora (figure 5.2; chapter 5). Because of their significant cultural, spiritual and medicinal value, these species receives protection in the WCB.

Table 6.6: Red Data species of the western Central Bushveld flora sorted according to the IUCN threat categories (EN = endangered, VU = vulnerable, NT = near threatened, DDT = data deficient – taxonomically problematic). Source: SANBI (2009).

Species	RedData
Aloe peglerae	EN
Euphorbia perangusta	EN
Hermannia procumbens subsp. *myrrhifolia*	EN
Dioscorea sylvatica	VU
Jamesbrittenia bergae	VU
Ledebouria atrobrunnea	VU
Marsilea farinosa subsp. *arrecta*	VU
Prunus africana	VU
Searsia maricoana	VU
Adromischus umbraticola subsp. *umbraticola*	NT
Cleome conrathii	NT
Cyphostemma flaviflorum	NT
Delosperma leendertziae	NT
Drimia sanguinea	NT
Elaeodendron transvaalense	NT
Eucomis pallidiflora	NT
Kniphofia typhoides	NT
Lithops lesliei subsp. lesliei	NT
Stenostelma umbelluliferum	NT
Gladiolus filiformis	Critically Rare
Ornithogalum juncifolium	Critically Rare

Ceropegia insignis	Rare
Freylinia tropica	Rare
Frithia pulchra	Rare
Helichrysum rotundatum	Rare
Isoetes schweinfurthii	Rare
Cineraria lobata	Rare/NT
Acacia erioloba	Declining
Boophone disticha	Declining
Crinum macowanii	Declining
Drimia altissima	Declining
Eucomis autumnalis subsp. *clavata*	Declining
Gunnera perpensa	Declining
Hypoxis hemerocallidea	Declining
Ilex mitis var. mitis	Declining
Rapanea melanophloeos	Declining
Acalypha caperonioides	DDT
Commelina bella	DDT
Drimia elata	DDT
Euphorbia knobelii	DDT
Indigofera leendertziae	DDT
Myrothamnus flabellifolius	DDT
Salsola capensis	DDT

Hotspots of recorded useful and medicinal plants have been found to be concentrated in the southernmost part of the study area, mainly in proximity of the towns of Zeerust, Swartruggens, Rustenburg and Brits; additionally, the sampled central Heritage Park area emerged to be a hotspot for useful and medicinal plants (figure 5.45a; chapter 5). The patterns of plant species richness predicted by the Centroid and ‘Integrated Grid’ Profile strengthen the indicated hotspots in the south of the study area forming a band between Zeerust and Brits that expands northwards into the Heritage Park (figures 5.45b–d; chapter 5).

Statistical analyses point out that natural landscapes in the WCB hold high numbers of useful plant species: thicket and bushland (max = 203), grassland with (max = 202), and woodland (max = 181) (table 5.40; chapter 5). However, human dominated areas have on average a higher richness of useful and medicinal plants than natural areas (table 5.40, chapter 5). Therefore, it is not enough to conserve plant species in remote natural areas, but also species-rich zones in the human dominated landscapes.

6.1.3.4 Protected Tree species

Likewise, 90% of the ten Protected Trees found in the study area are extensively used by people, mostly as timber and firewood. As a result many Protected Tree species become rare and are threatened with extinction (e.g. *Prunus africana*) (table 6.7). However, many Protected Tree species are keystone species in the ecosystem in which they occur and are of significant cultural or spiritual value for local people (DWAF, 2011).

According to present knowledge about the distribution of Protected Tree species richness in the WCB, hotspots are found in the greater Zeerust area, the Rustenburg district, and the central part of the Heritage Park (figure 5.44a; chapter 5). Yet, the analyses have shown that the hotspots of Protected Tree species have most probably much larger spatial range. Specifically the hotspot in Rustenburg is predicted by the Centroid and 'Integrated Grid' Profile to extend in a band towards Swartruggens and Brits, and stretching upwards to include the western and central part of the Heritage Park (figure 5.44b-d; chapter 5).

The highest count of Protected Tree species richness was observed to occur in land covered with thicket and bushland along with woodland, each having a maximum of 7 species (table 5.34; chapter 5). Nevertheless, degraded grassland ($\bar{x}$ = 4.0), commercial ($\bar{x}$ = 3.5) and residential built-up land ($\bar{x}$ = 3.4) contain on average a larger richness of Protected Trees. Only the grassland among natural landcover classes have proven to have a significant mean species richness of Protected Tree species ($\bar{x}$ = 3.4), in contrast to thicket and bushland terrain ($\bar{x}$ = 2.8) and woodlands ($\bar{x}$ = 2.6) (table 5.34, chapter 5).

Table 6.7: Protected Tree species of the western Central Bushveld flora (IUCN categories: LC = Least Concern, NT = Near Threatened, VU = Vulnerable). Source: DWAF (2011).

Protected Tree species	Common name	Red List status
Acacia erioloba	Camel thorn	Declining
Adansonia digitata	Baobab	LC
Boscia albitrunca	Shepherd's tree	LC
Combretum imberbe	Leadwood	LC
Elaeodendron transvaalense	Bushveld saffron	NT
Erythrophysa transvaalensis	Bushveld red balloon	LC
Pittosporum viridiflorum	Cheesewood	LC
Prunus africana	Red stinkwood	VU
Sclerocarya birrea subsp. *caffra*	Marula	LC
Securidaca longepedunculata var. *longepedunculata*	Violet tree	LC

6.1.3.5 Problem plants and bush encroachment indicators

Conversely, the richness of problem plant and bush encroachment indicator species in an area gives information about the degradation threat of the local native flora through vegetation change. In the study area 244 problem plant species exist, which constitutes 10% of the total

WCB flora, and another 2.4% of the flora (57 species) is represented by indicators of bush encroachment (figure 5.2; chapter 5).

Hotspots of problem and bush encroachment species generally occur in highly built-up regions; for bush encroachment indicators additional hotspots have been identified in vacant land such as in the central Heritage Park (figures 5.46a and 5.47a; chapter 5).

The statistical analyses on the correlation with landcover exposed that the richness of problem plants is concentrated primarily in industrial built-up land ($\bar{x} = 78$), but also in commercial built-up land ($\bar{x} = 65$), degraded grassland ($\bar{x} = 62$) and cultivated grassland ($\bar{x} = 59$) (table 5.36; chapter 5). Conversely, the highest count of problem plants were calculated for commercially cultivated land (max = 121) and residential areas (max = 119) in terms of human dominated landscape, and for thicket and bushland (max = 121) and grassland (max = 120) in relation to the natural land classes.

Similarly, bush encroachment indicators are located mainly in industrial ($\bar{x} = 22$) and commercial ($\bar{x} = 21$) built-up land, but also common in degraded forest and woodland ($\bar{x} = 19$) and degraded grassland ($\bar{x} = 19$) (table 5.37; chapter 5). But locally high numbers have been identified for unspoiled land, especially grasslands (max = 30), thicket and bushland (max = 30) and woodlands ($\bar{x} = 28$).

6.2 Correlation of the distribution of plant richness in the study area with environmental and anthropogenic factors

The occurrence and floristic composition of savanna vegetation are largely determined by the interplay between climate, topography, geology and soil (Cole, 1996; Solbrig *et al*., 1996). Solbrig (1996) holds that on regional scale savanna flora is mainly controlled by differences in climate and soil, whereas at local level the topography and its associated geomorphological history are the determining factors.

However, the African savanna has also been shaped by its long history of human land-use. As a result of the sensitivity of plant communities to habitat conditions, human activities (e.g. settlements, animal grazing, veld burning and cultivation) are seen as a secondary determinants governing vegetation change and thus local composition of savanna flora (Cole, 1996). Therefore, landcover and land-use data allows for the identification of highly transformed areas and areas of conservation concern.

6.2.1 Climate

Local fluctuations in temperature and rainfall with changing latitude, altitude and topography largely influence the distribution of plant taxa richness in the WCB. In general, the study area has a typical savanna climate characterized by a seasonal but predictable rainfall regime that provides moisture during the warm season where most of the plant growth occurs; but in the dry and cooler winter months low temperatures may approach freezing point, and moisture deficiencies cause plant stress and limit plant growth which prevents the development of dense forests (Cole, 1996).

6.2.1.1 Mean annual minimum and maximum temperature

Plant taxa richness has been found to be positively correlated with low to moderate annual mean temperatures, while a significantly lower range of plant species is able to thrive in areas of high annual mean temperatures where high evaporation levels exist.

On average the highest species richness occurs in the southern and south-western part of the study area (figures 5.38 and 5.39), bordering the cooler and more species-rich grassland biome, associated with elevated terrain (figure 5.52; chapter 5) and generally lower annual minimum and maximum temperatures than for the plains of the bushveld basin (figures 5.48 and 5.49; chapter 5).

The hills in the south-west are characterized by a moderate low annual minimum temperature of 0.1 to 2ºC (figure 5.48; chapter 5) which support on average the highest species richness in the WCB ($\bar{x}$ = 390, max = 952) (table 5.2; chapter 5). Species richness decreases north-eastwards with annual minimum temperatures rising up to 4.1–6 ºC in the plains of the WCB ($\bar{x}$ = 253; max = 609). Yet, the highest count of plant species has been recorded locally for the plains in the Rustenburg district (max = 1,063).

Likewise, the hilly terrain with its associated lowlands and undulating plains show a moderate annual maximum temperature of 29.1 to 31ºC (figure 5.49; chapter 5) that supports the highest mean and maximum species richness in the study area ($\bar{x}$ = 388, max = 1063) (table

5.3; chapter 5). In contrast to this, the warmer plains of the bushveld basin, with maximum summer temperatures principally ranging from 31.1 to 33 ºC, harbour a lower mean and maximum species richness (x̄ = 264, max = 854). Particularly the area north-east of Derdepoort with annual maximum temperatures approaching 33.1 to 35 ºC show a rather low species richness (x̄ = 57, max = 218).

6.2.1.2 Mean annual rainfall and evaporation

The annual rainfall for most of the study area amounts to 401–600mm, with only the southernmost part together with Pilanesberg and Thabazimbi receiving 601–800mm rainfall (figure 5.50; chapter 5). Analyses proved that plant species richness in the WCB is correlated with the amount of rainfall and its efficiency influenced by evaporation. Annual evaporation varies between 1,801–2,000mm and >2,400mm depending on temperature and the length of the dry season which can last up to eight months (Cole, 1996). Evaporation increases from the south and south-east towards the Botswana border (figure 5.51; chapter 5).

The highest species richness is found where rainfall is high (x̄ = 394, max = 1,063) and evaporation moderate to low (x̄ = 379, max = 1,063) (tables 5.10 and 5.11; chapter 5). This is particularly true for the south between Zeerust and Brits and from there northwards in the direction of the Borakalalo National Park. A lesser species richness was again found in the warmer and dryer plains of the bushveld basin where lower rainfall (x̄ = 278, max = 844) and increased evaporation (x̄ = 275 and max = 975 for 2,201–2,400mm) limits species diversity. The lowest species richness was found in and around Madikwe Game Reserve due to the highest maximum temperatures and evaporation rate (x̄ = 130, max = 498 for >2,400mm) in the study area.

6.2.2 Soil type and geology

Mucina & Rutherford (2006) point out that a close relationship exists between soils and vegetation in dry regions, where water is the limiting growth factor: in low-rainfall areas such as the WCB, the floristic composition of vegetation is greatly influenced by those physical factors that determine the rainfall efficiency, foremost the prevailing soils. Soil properties such as drainage and water-holding capacity that control the soil-water balance and nutrient status are crucial for plant growth, thus determining how many and which species grow in a region (Cole, 1996).

But soils are the legacy of the past geological history and climate of an area. As stated by Cole (1996), both the nature and distribution of the major soil types within the savanna region are closely related to the landscapes features and underlying geological rocks.

Large areas of the WCB are dominated by shallow soils (20–30 cm) on hard or weathering rock, mainly of Glenrosa and Mispah forms, which are associated with low and inefficient rainfall (Soil Classification Working Group, 1991; Fox, 2000). Despite limited pedological development and nutrient status, shallow soils show the highest mean species richness ($\bar{x} > 350$) in the study area (figure 5.54, table 5.24; chapter 5).

These soils originate largely from coarse-grained and quartz-rich parent materials, namely shale ($\bar{x} = 388$), andesite ($\bar{x} = 364$), quartzite ($\bar{x} = 344$) and dolomite ($\bar{x} = 339$) that weather slowly under the present unfavourable moisture conditions (figure 5.53, table 5.21; chapter 5) (Fox, 2000), and thus producing the topographic diverse hills and lowlands of the south-western study area that provide habitat for a rich phyto-diversity (figure 5.52; chapter 5). Shale is the dominant rock of this species rich terrain which accounts for most of the high plant species richness (max = 1,063) recorded between Zeerust and Rustenburg (figure 5.53, table 5.21; chapter 5). Shallow soils with low pedological development (figure 5.54; chapter 5) were also found in the eastern study area overlaying mainly granite, but with a lower associated plant species richness ($\bar{x} = 256$, max = 561) (figure 5.53, table 5.21; chapter 5).

But several smaller dolerite outcrops within the band of shale show a strong correlation with plant species richness as well (figure 5.53, chapter 5). The highest mean species richness has been recorded for dolerite rocks ($\bar{x} = 538$) weathering into red soils that are more fertile and stable against erosion than soils from the surrounding sedimentary rocks (table 5.21; chapter 5) (Fox, 2000). High species diversity has been found on the deeper (> 30 cm) red-yellow apedal and freely drained soils with a high base status (max = 990) (table 5.24; chapter 5).

Important to mention is also Pilanesberg National Park that is made up largely of rocky terrain with miscellaneous soils, for which the highest maximum species richness was recorded (max = 1,063) (figure 5.54, table 5.24; chapter 5). The analyses indicate that this exceptional species richness is most probably associated with clinopyroxenite rocks (max = 1,055) that make up the bulk of the Pilanesberg ring complex and is correlated with a high count of plant species (figure 5.53, table 5.21; chapter 5).

However, extraordinary numbers of plant species were also noted for highly weathered and well-drained clayey to loamy soils with a high base status (figure 5.54, table 5.24; chapter 5). Most noteworthy in this regard are the vertic, melanic and red-structured soils with a high clay content (max = 1,055). They cover basic igneous rocks in the centre and south-east of the study area, mainly gabbro (x̄ = 449, max = 783) and norite (x̄ = 402, max = 879) of the Rustenburg Layered Suite, which have been found to be connected with high number of plant species (figure 5.53, table 5.21; chapter 5).

High plant species numbers could be related to nutrient-rich eutrophic red soils with a plinthic catena (max = 1,045) (table 5.24). These mostly soft plinthite soils derive from deep aeolian sands covering dense clay formed from underlying geological materials in flat terrain of the western study area (Fox, 2000).

On the other hand, sedimentary rocks (x̄ = 199, max = 509) that constitute the dominant geologic formation in the study area show a rather low correlation with species richness (figure 5.53, table 5.21; chapter 5).

6.3.3 Soil potential, landuse and landcover

Soil potential, landuse and landcover are intrinsically linked to biodiversity as they jointly determine the output of ecosystem services; therefore a comprehensive understanding of the relationships between landuse and biodiversity is essential in order to cope with the problems of human-induced environmental changes (Haines-Young, 2009).

In southern Africa increasing population growth and associated land-use change puts a great pressure on plant diversity. Transformation of natural vegetation cover to other land-uses (figures 5.55 and 5.56), first and foremost crop cultivation and urban development, presents the leading threat to phyto-diversity as proposed by Wessels *et al.* (2003). Analyses of land utilisation confirmed that cultivated land (max = 1,061) and residential areas (max = 1,045) rank among the species richest tracts of land in the study area (table 5.27; chapter 5).

But in the specific case of the WCB Bioregion, commercial and industrial developments (x̄ = 540), mining (x̄ = 421) as well as urbanization (x̄ = 403) constitute the prime threat to phyto-diversity (table 5.27; chapter 5). Compared to vacant land (x̄ = 297) and land set aside for conservation (x̄ = 257) these areas harbour the highest average plant species richness.

However, the presence of non-indigenous plants makes up a large portion of the species richness in those human dominated areas.

The analyses clearly demonstrate that a significant part of the WCB plant diversity occurs outside of conservation areas. Nature Reserves in the WCB collectively support a maximum of 1060 plant species (table 5.27; chapter 5). However, considerable plant species richness is also found in agricultural land which makes up 11% (area = 0,321) of the study area, significantly more than the 8% (area = 0,235) of land that is set aside for official conservation (table 5.27; chapter 5). With respect to commercially cultivated land that makes up two-thirds of the agricultural land, a total of 1,061 plant species were recorded, while land used for subsistence farming counts only 898 plant species (table 5.28; chapter 5).

This high species diversity of the human-dominated landscapes in the study area can be partly related to high numbers of problem plants. Industrial ($\bar{x}$ = 78) and commercial ($\bar{x}$ = 65) built-up land show the greatest average problem plant infestation, followed by mines and quarries ($\bar{x}$ = 58) (table 5.36; chapter 5). High counts of weed and invader plant species were also documented locally for commercial cultivated land (max = 121), residential areas (max = 119) and subsistence farmland (max = 105).

But on the other side, the high levels of plant species richness can also be explained by the complex heterogeneous land-cover and land-use matrix providing multifaceted habitats that are able to sustain a wide range of plant species (figures 5.55 and 5.56; chapter 5); for example the marginal lands in the northern Provinces of South Africa are mainly used by a mix of semi-commercial and subsistence-level farming that does not transform the vegetation to the same extent as pure large-scale commercial farming (Wessels *et al.*, 2003).

Nevertheless, the highest species richness was counted for vacant land (max = 1,063), which makes up 79% of the study area. The unused land is covered by 64% thicket and bushland, 32% woodland and forest, and 4% grassland, although considerable portions of these natural vegetation types have been degraded already (table 6.8). Vegetation degradation is accompanied by considerable losses of the original species richness as indicated in table 5.28 (chapter 5).

The analyses show that vegetation transformation can be mainly attributed to invasion by problem plants and bush encroachment linked with a substantial loss in plant species richness (table 5.36 and 5.38; chapter 5).

Degraded grassland show with 52% the most striking loss of plant species richness (max = 503), which can be ascribed largely to the extensive invasion of problem plants (max = 120) and bush encroachers (max = 30) into natural grassland (max = 1055) that replace native species (table 5.36, 5.38 and 5.28 respectively; chapter 5). For example the increase in woody cover leads to a decrease in the species diversity of the ground layer (Eriksen & Watson, 2009). Furthermore, a shift from pastoralism to intensive animal grazing in grasslands that are considered marginal in the WCB, has become a major threat to phyto-diversity as it disrupts plant species composition (Darkoh, 2003).

However, the greatest habitat transformation in terms of area was detected for savanna woodland and forest with 9% of its natural area transformed followed by thicket and bushland with 7%. Rapid population growth in the rural areas of the WCB drives settlers and farming into areas that are agro-ecologically unsuitable for crop cultivation. These areas belong to the species richest in the WCB ($\bar{x}$ = 359; max = 1,063) (table 5.41; chapter 5). Deforestation and continued burning of shifting farming systems results on the one side into a decline in native woody and herbaceous species, but on the other side may lead to bush encroachment in association with overgrazing (Darkoh, 2003; Eriksen & Watson, 2009). As a result, savanna thicket and bushland (max = 1063) display a species loss of 42% (max = 617), and woodland and forest (max = 917) display a species loss of 38% (max = 572) (table 5.28; chapter 5).

Darkoh (2003) recognizes habitat alteration and degradation as a major cause for the decline in phyto-diversity, as plant species fail to adjust to the new ecological setting in the modified environment. In the study area, habitat loss and alteration does not only result from the expansion of mining and commercial agriculture, but is also caused by tree cutting and the collection of wild plants, which play a significant role in the subsistence economy of African drylands (Darkoh, 2003).

Table 6.8: The percentage of transformation calculated for the natural vegetation cover classes in the western Central Bushveld.

Landcover	Proportion of vacant land (%)	Degradation (%)	Species richness		Loss of plant species (%)
			Natural	Degraded	
Grassland	4%	0.1%	max = 1,055	max = 503	52%
Woodland & forest	32%	9%	max = 917	max = 572	38%
Thicket & bushland	64%	7%	max = 1,063	max = 617	42%

The natural vegetation of the WCB contains a wide range of wild food, medicinal and other useful plants (max = 203) traditionally used by native people (table 5.39; chapter 5). For example the Tswana people are known to live as agro-pastoral hunter-gatherers in the semi-arid drylands of the eastern Kalahari extending into the WCB (Grivetti, 1979). Especially in times of drought, the nutritional success of the Tswana is supported by a diversified food base with emphasis on wild food plants and animal grazing, baring the landscape under the high pressure of human and animal densities in these agricultural marginal areas (Darkoh, 2003).

6.3 Spatial pattern of the western Central Bushveld flora

6.3.1 Evaluation of significance

The analysis of plant data using ordination was employed to identify floristic areas in the WCB Bioregion and their spatial variance on different taxonomic levels. The groupings of the floristic elements were each investigated for unstandardized and standardized datasets. Ordination of standardized data gave information on the significance of standardization for the improvement of spatial sampling.

As suggested by McLaughlin (1994), the phytogeographic classification of the WCB flora has been evaluated by applying two different ordination methods and comparing them for consistency. Principal Component Analysis (PCA) and Detrended Correspondence Analysis (DCA) resulted in groups of nearly identical composition, although detrending in DCA caused distortion of the floristic data and led to a weak natural clustering. The spatial arrangement of floristic groups at each taxonomic level stays relative constant and becomes more pronounced through standardization. Therefore, the congruence in spatial arrangement of the sample plots for the two ordination methods allows the conclusion that there is an inherent pattern in the floristic data (McLaughlin, 1994).

6.3.2 PCA

Principal Component Analysis proved to be the most suitable ordination method for exploring the phytogeography of the study area as only a fraction of the Central Bushveld flora and associated environmental gradient was sampled.

The ordination resulted into spatially distinct floristic groupings, particularly for the standardized datasets, for example as seen in figures 5.14 and 5.16 (chapter 5) for the species level.

Standardization improves the sampling status across the study area, but explicitly for quarter degree grids with low floristic sampling. Improved sampling status of the under-sampled Quarter Degree Grids resulted into improved floristic clustering of sample plots in the northern part of the WCB across all taxonomic levels (figures 5.12 to 5.28; chapter 5).

In general, standardization resulted into a clearer spatial arrangement of floristic groups which becomes more distinct with increasing taxonomic level. Figures 5.20 and 5.26 (chapter 5) illustrate enhanced floristic grouping for genus and family data standardized with the 'Centroid Grid' profile. Standardization with the 'Integrated Grid' Profile shows the most pronounced spatial clustering as the datasets of each four grids have been merged to a regional flora (figure 5.16, 5.22 and 5.28; chapter 5).

The floristic pattern of standardized species data could be related to the climatic and physical environmental gradients of the WCB. No visible correlation could be identified for unstandardized species data.

6.3.2.1 Standardization with the 'Centroid Grid' profile

The 'Centroid Grid' profile involved the extrapolation of species occurrences from three adjacent grids with the most similar vegetation composition assuming that neighbouring QDGs with similar vegetation composition will share similar plant species. Therefore, it was expected that the floristic areas resulting from the ordination of the species level data should largely coincide with the dominant vegetation types of the western Central Bushveld.

The comparison between the spatial groupings of the western Central Bushveld species (figure 5.14; chapter 5) and the vegetation pattern defined by Mucina & Rutherford (2006) (figure 4.12; chapter 4) confirmed a spatial relationship. Furthermore, the spatial structure of plant species could be related to the physical environmental gradients present in the study area (table 6.9). The floristic areas show a strong relationship to terrain morphology and associated geological and soil patterns (figure 5.52, 5.53 and 5.54; chapter 5).

There is a clear floristic variance between areas dominated by mountain ranges, undulating hills and koppies, and plains. All have their own characteristic geological and soil formations.

The plains of the Transvaal basin in the north of the study area are characterized by granite, sedimentary rocks and migmatite in the north-east, overlain by red-yellow loams, vertic or melanic clay, and soils with a plinthic catena. Floristic group 1 associated with the Dwaalboom Thornveld (SVcB 1) are found in the north-western plains bordering Botswana, whereas floristic group 2 associated with the Western Sandy Bushveld (SVcB 16) and Limpopo Sweet Bushveld (SVcB 19) covers the Limpopo plains in the study area.

However, the bottomlands of the bushveld basin are featured by different rocks and soils that formed from the igneous processes of the Bushveld Complex supporting a somewhat different plant life than the plains in the north. The flora of the bushveld basin (floristic group 4) consists of two sub-groups. Sub-group 1 dominated by vegetation of the Dwaalboom Thornveld (SVcB 1) is located in the flat bottomlands in the west of the study area. The flora seems to be associated with sedimentary and other rocks of volcanic origin (clinopyroxenite and pyroclastic) covered by red-yellow loams and clay soils. On the other side, the flora of sub-group 2 is found in the undulating plains of the east. Its spatial pattern coincides with vegetation of the Central Sandy Bushveld (SVcB 12) and the Springbokvlakte Thornveld (SVcB 15). It appears to be associated with the bushveld granites underlying vast stretches of soil of the Glenrosa and Mispah form.

The spatial pattern of floristic group 3 corresponds with that of the Marikana Dolomite Bushveld (SVcB 2), covering the parallel running hills and lowlands of the northern Bankenveld, which are characterized by Glenrosa and Mispah soils and a rocky underground of dolomite, shale and quartzite.

In contrast, the hills and lowlands of the southern Bankenveld support the heterogeneous floristic group 5 that is characterized by several vegetation types: Zeerust Thornveld (SVcB 3), Dwarsberg-Swartruggens Mountain Bushveld (SVcB 4), Pilanesberg Mountain Bushveld (SVcB 5) and Moot Plains Bushveld (SVcB 8). The flora is linked with rocks of the Transvaal Supergroup— mainly shale, andesite and quartzite—overlain by rocky soils on the mountain ranges and Glenrosa, Mispah and red-yellow loams in the lowlands.

Table 6.9: Floristic groupings of species data standardized with the 'Centroid Grid' Profile correlated with the underlying vegetational and physical environmental gradients.

Floristic group	Corresponding vegetation types according to Mucina & Rutherford (2006)	Terrain morphology	Geology	Soil
Group 1	SVcB1 Dwaalboom Thornveld	Plains of the Transvaal Basin	Granite, sedimentary	Red-yellow loam, vertic/ melanic clay, soils with a plinthic catena
Group 2	SVcB 16 Western Sandy Bushveld SVcB 19 Limpopo Sweet Bushveld	Plains of the Transvaal Basin	Granite, sedimentary, migmatite	Red-yellow loam, vertic/ melanic clay, soils with a plinthic catena
Group 3	SVcB 2 Madikwe Dolomite Bushveld	Parallel hills and lowlands (northern Bankenveld)	Dolomite, shale, quartzite	Glenrosa/Mispah, soils with a plinthic catena, rocky soils
Group 4	I: SVcB 1 Dwaalboom Thornveld II: SVcB 12 Central Sandy Bushveld SVcB 15 Springbokvlakte Thornveld	I: Plains of Bushveld Basin II: Undulating plains with koppies	I: Sedimentary, clinopyroxenite, pyroclastic II: Granite, dolomite, shale, mudstone	I: Red-yellow loams, vertic/ melanic clay II: Glenrosa/Mispah, red-yellow loam
Group 5	SVcB 3 Zeerust Thornveld SVcB 4 Dwarsberg-Swartruggens Mountain Bushveld SVcB 5 Pilanesberg Mountain Bushveld SVcB 8 Moot Plains Bushveld	Hills and lowlands (southern Bankenveld)	Shale, andesite, quartzite	Red-yellow loam, Glenrosa/ Mispah, rocky soil, soils with a plinthic catena
Group 6	SVcB 6 Marikana Thornveld SVcB 7 Waterberg Mountain Bushveld	Undulating plains with hills and koppies	Gabbro, norite, clinopyroxenite	Vertic/ melanic clay, rocky soils

6.3.2.2 Standardization with the 'Integrated Grid' Profile

The 'Integrated Grid' profile assumes that neighbouring Quarter Degree Grids share a regional flora. Thus, floristic data was extrapolated by merging floristic occurrences of each four intersecting grids.

Because the approach throws together the floras of adjacent grids, the formation of regional floristic areas was expected. Therefore, the resultant floristic groups do not show a relationship to the vegetational and environmental patterns of the western Central Bushveld, but demonstrate a correlation with the climatic patterns in the study area.

In the study area there is an evident NW–SE climatic gradient, where annual rainfall increases towards the south and south-east (figure 5.50; chapter 5) accompanied with a decrease in annual maximum temperature and evaporation (figure 5.49 and 5.51; chapter 5). Thus, the most drought and heat resistant plant species are predicted to be located in the north-west along the Botswana border, whereas plant species with lower tolerances for heat and water deficiencies are expected to be present in the southern and south-eastern floras.

A comparison of species data standardized with the 'Integrated Grid' profile confirmed the above speculations (figure 5.16; chapter 5). The spatial pattern of floristic groups shows a correlation with the climatic gradient.

Phytogeographic group 1 and 2 in the north-west seem to be drought resistant floristic groups that withstand high temperatures and evaporation levels together with low rainfall levels due to an erratic precipitation pattern in the study area (figures 5.48 to 5.51; chapter 5). Floristic group 3 forms a transitional flora with a medium high drought tolerance; in the bushveld basin high evaporation levels may exist locally.

Similar to the 'Centroid Grid' profile, floristic group 4 splits into two subgroups (figure 5.16; chapter 5). One adapted to the moister and cooler upland climate of the southern Bankenveld, where temperatures in winter may drop below 0°C (figure 5.48; chapter 5). And another adapted to the moderate climate of the eastern bushveld basin plains, with medium temperatures and evaporation levels in summer and mild winters (figures 5.48 and 5.49; chapter 5).

And finally floristic group 5 and 6 displays a flora that is adapted to a moist and warm climate. The highest levels of rainfall occur here (figure 5.50; chapter 5) coupled with low evaporation and the lowest annual maximum temperatures (figure 5.49 and 5.51; chapter 5).

Additionally to the climatic gradient, the floristic pattern of plant species data standardized with the ‘Integrated Grid’ profile could be correlated with the spatial patterns of species richness.

In the study area species richness increases towards the south-east (figure 5.39d; chapter 5) associated with rising precipitation and decreasing annual maximum temperatures and evaporation. High temperatures and evaporation coupled with lower effective rainfall seems to be a limiting factor for plant species diversity in the western Central Bushveld. Floristic group 1 to 3 (figure 5.16; chapter 5) displays the lowest phyto-diversity with a species richness ranging between 25% and 50% of the total western Central Bushveld flora (figure 5.39d; chapter 5). The moist and warm areas in the south and south-east show the highest plant diversity. Floristic group 5 and 6 are the species richest with 70% to 100% of the phyto-diversity recorded for the study area.

6.3.2.3 Success of standardization

Standardization proved to enhance the sampling status of under-sampled plots which enlarged beta-diversity in the study area. This resulted into a clearer spatial arrangement of floristic groups for both standardization methods. Thus, standardization significantly improved the spatial clustering of plant taxa into phytogeographic floras, especially with increasing taxonomic level.

The standardization with the ‘Centroid Grid’ profile demonstrated to be the more appropriate method since the resultant floristic areas show an evident congruence with the spatial structure of vegetation and physical environmental factors. Furthermore, the spatial pattern of floristic areas derived from the ‘Centroid Grid’ profile stays relative constant on higher, more inclusive taxonomic levels (figures 5.20 and 5.26; chapter 5).

On the other side the standardization with the ‘Integrated Grid’ profile appears to be the less appropriate method to explore the phytogeography of the study area. Because the method throws together the floras of adjacent grids, a regional equalized flora results that ignores the dependence of plant species occurrences on regional, varying environmental patterns, such as terrain morphology, soil and geology that determine the structure and species composition of vegetation. On family level this gave rise to the formation of large governing floristic groupings as standardization strengthens dominant plant groups (figure 5.28; chapter 5).

However, to develop a better picture on the true phytogeography of the western Central Bushveld, a larger area needs to be analysed. Preferable would be to study the plant geography on the level of the Central Bushveld Bioregion where the creation of artificial borders could be minimized.

6.3.3 DCA

Detrended Correspondence Analysis was used to look at the degree of beta-diversity between the sample plots of the study area, which is expressed as the cumulative variance in ordination space. Beta-diversity was compared for unstandardized and standardized plant data.

Ordination of the unstandardized datasets resulted into a rather diffuse spatial clustering which suggests a low beta-diversity for the western Central Bushveld flora (figures 5.12, 5.18 and 5.24; chapter 5). Low beta-diversity is an indicator of low species variation between the habitats (QDGS) of the study area.

Table 6.10: Increase of beta-diversity through standardization measured as cumulative variance in ordination space.

Percentage Change of Cumulative Variance		
	'Centroid Grid' Profile	***'Integrated Grid' Profile***
Species data	11%	19%
Genus data	12%	21%
Family data	13%	23%

However, the low species diversity between the habitats proved to be at least partially attributable to the lack of plant data for many grids of the study area. This was demonstrated by the standardization of plant data. Standardization augmented quarter degree grids with new plant species information and thereby increased beta-diversity between the sample plots. Consequently the DCA ordination of standardized data shows an improved spatial clustering, especially for plant data standardized with the 'Integrated Grid' profile (figures 5.16, 5.22 and 5.28; chapter 5).

Table 6.10 gives the percentage increase of between habitat diversity for the western Central Bushveld flora through standardization. Inter-habitat variation rises around 10% and 20% through standardization with the ‘Centroid Grid’ and ‘Integrated Grid’ profile respectively.

6.4 Summary

The floristic pattern of the western Central Bushveld (WCB) is characterized by a high alpha diversity of its local plant communities. However, beta diversity has been found to be low as a result of low species turnover between the habitats along the environmental gradients. This means a large number of plant species are recorded in relative small sampling units. Thus, the WCB habitats are exceptional species rich in the context of the Savanna Biome. Although the study area samples only 3% of the savanna core area, the WCB flora represents 41% of the savanna flora, about half of which is represented each in the Heritage Park (20%) and Impala Platinum (24%) conservation areas.

Within the species rich plant communities of the WCB the Fabaceae, Poaceae and Asteraceae have been identified as the most dominant plant families. In addition, the WCB flora contains numerous species rich genera and several genera endemic to South Africa that thrive in the climatic and topographically diverse habitats of the study area.

Although the degree of endemism (0.9%) is comparatively low in the WCB, most of the encountered 21 endemic plant species are rare and have a limited distribution pattern within the Central Bushveld Bioregion. Nine endemic and 12 other rare plant species with Red Data status face an immediate risk of extinction. Hotspots for those endemic and Red Data species are mainly the greater Rustenburg and Zeerust area.

Furthermore, the WCB has been recognized as a hotspot for useful and medicinal plant species, many with an important cultural and socio-economic value in southern Africa. However, several of the 364 useful and medicinal plants are Protected Trees or have Red Data status due to intensive human use.

Exhaustive human use of natural capital in the WCB and associated transformation and degradation of natural vegetation has led to a significant increase in problem plant and bush encroachment indicator species. Already 10% of the WCB flora consists of weed and invader species.

Despite low inter-habitat diversity, the distribution of species richness and floristic groupings in the WCB show a clear pattern. The spatial maps of species richness display an increase in plant diversity from the north-west towards the south and south-east. This rise in phyto-diversity can be mainly attributed to present climatic (temperature, rainfall and evaporation) and physical environmental (topography, geology and soil) gradients in the study area.

Besides environmental factors, human activities have proved to be important determinants of local vegetation composition and thus influence floristic patterns and the distribution of plant species richness. The highest average species richness was reported for hotspots of anthropogenic use, particularly for industrial, commercial and residential built-up land including mining areas. However, the highest phyto-diversity is still safeguarded in undegraded natural areas.

PCA was the ordination method used to explore the phytogeographic patterning inherent to the WCB flora. Ordination resulted into spatially distinct floristic groupings for the standardized datasets. Improved spatial clustering in comparison to the unstandardized floristic data can be explained by the upgrading of the under-sampled Quarter Degree Grids through standardization.

The floristic patterns of standardized species data could be related to the environmental gradients present in the WCB. Floristic areas derived from the ‘Centroid Grid’ profile show a strong correlation to topographical landscape variations and concomitant geologic and soil characteristics. Since vegetation patterns are known to reflect underlying environmental factors, floristic areas have been found to correspond with the dominant vegetation types of the Central Bushveld Bioregion (Mucina & Rutherford, 2006). As opposed to the 'Centroid Grid' profile, standardization with the ‘Integrated Grid’ profile gave rise to a floristic patterning that displays a correlation to the climatic gradients in the study area.

The ‘Centroid Grid’ profile is regarded as the suitable method for standardization as resultant floristic groupings best reflect the environmental patterns, while the ‘Integrated Grid’ profile has shown to result into a regional equalized flora that seem not to apply to natural gradients.