CHAPTER 4: MATERIALS & METHODS

4.1 Overview

Information on the status of our plant biodiversity is a growing need for the future, because without reliable information about the present threatened plant species and habitats, action is merely based on unproven assumptions that do not allow the successful conservation of our diverse flora in southern Africa (Given, 1994).

In order to get a thorough documentation of the prevailing phyto-diversity of a study area, the consultation of different data sources is a crucial step in the process of data acquisition; subsequently the organization of the gathered data into databases then forms the basis for determining conservation priorities for both, species and areas (Given, 1994).

However, because of the enormous task of plant diversity assessments, especially in large areas such as the western Central Bushveld Bioregion, the existing and sampled biodiversity information is mostly far from complete (Colwell & Coddington, 1995; Grand *et al*., 2007; Wilson *et al*., 2005).

As a result, this study consists of a two-fold approach, one of acquiring plant diversity data from different sources, and another by modelling of possible species occurrences using two predefined standardizing profiles.

4.2 Defining the western Central Bushveld

The vegetation of the Central Bushveld Bioregion covers some 100,000 km^2 of the North West and Limpopo Provinces in South Africa. For the purpose of the conservation assessment of the Heritage Park and the Impala Bafokeng Mining Complex, the bioregion has been delimited to only include the relevant vegetation units for the floristic study. The borders of the western Central Bushveld were defined using the vegetation map from Mucina & Rutherford (2006). Quarter Degree Grids were selected in order to represent the dominant vegetation types of the western Central Bushveld area. In this process 50 Quarter Degree Grids could be identified as giving essential plant species information for the phyto-diversity study.

4.3 Data collection

Existing presence data for plant species of the western Central Bushveld (WCB) has been acquired by consulting various data sources.

The National Herbarium Pretoria (PRE) Computerized Information System, called PRECIS, formed the basis to build a plant diversity database for the western Central Bushveld Bioregion. Complete species lists for each of the 50 Quarter Degree Grids were obtained from the PRECIS database held at the South African National Biodiversity Institute (SANBI) (figure 4.1).

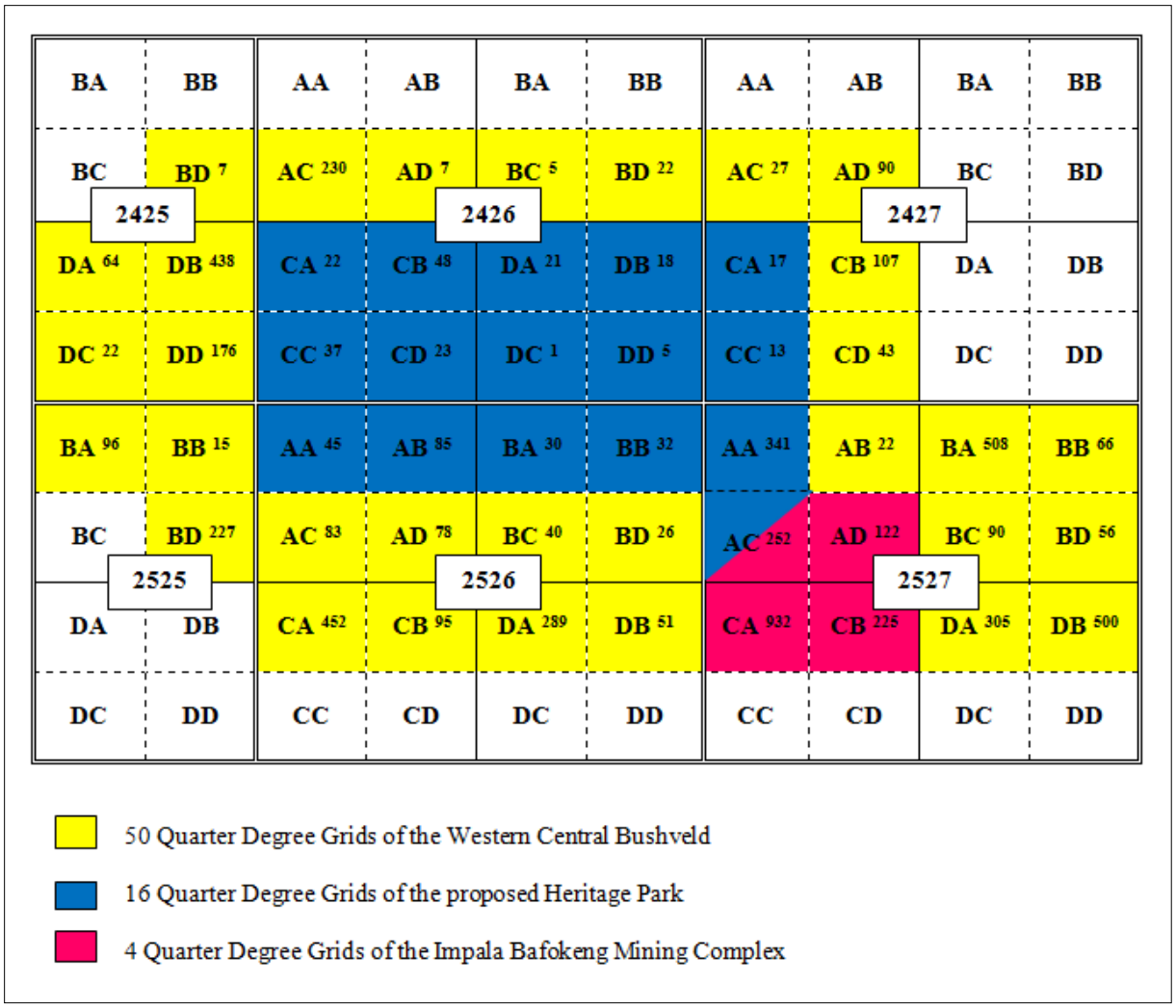


Figure 4.1: Schema displaying the 50 Quarter Degree Grids of the western Central Bushveld Bioregion with their present sampling status according to the PRECIS database.

PRECIS is an electronic database that contains information of all southern African plant species currently present in the collection of the National Herbarium. The database stores

more than 700 000 plant specimens from the Flora of Southern Africa (FSA), which includes all African countries south of the Limpopo and Kunene Rivers, namely South Africa, Namibia, Swaziland and Lesotho (Robertson & Barker, 2006; SANBI, 2009). Floristic information and nomenclature for the southern African plant taxa is accessible online via the Plants of southern Africa (POSA) website (SANBI, 2009).

To further assist the build-up of a representative species database for the western Central Bushveld, the plant species lists were augmented by species records from the AP Goosens Herbarium held at the North-West University, Potchefstroom, and by relevant published and unpublished phyto-sociological studies.

The reference collection of the AP Goosens Herbarium has been manually searched for plant specimens recorded for the Brits, Marico, Rustenburg, Swartruggens, Thabazimbi and Zeerust area. Where spatial reference was lacking in many records, the applicable Quarter Degree Grids for the locations were assigned to the plant specimens by map work.

The published phyto-sociological study of the western Transvaal Bushveld by Van der Meulen (1979) contributed important plant species data due to the fact that the study areas coincide largely. Relevé data, sampled by Van der Meulen according to the Braun Blanquet method, was provided in digital format by Dr. Bobby Westfall from the Agricultural Research Council (ARC) in Pretoria. The 515 relevés with a total of 1,002 plant species records were manually transformed into a floristic data matrix by sorting of plant species occurrences according to the 50 Quarter Degree Grids of the western Central Bushveld. Grid locations of the relevés were allocated by map work via the GPS information for each sampling plot. Plant species names have been updated using the reference work 'Plants of southern Africa: an annotated checklist' by Germishuizen & Meyer (2003).

Furthermore, plant species lists of Quarter Degree Grids have been augmented by unpublished phyto-sociological data of both the Heritage Park and Impala Bafokeng Mining Complex, which was collected by the Masters students Mari La Grange (2010) and Rikus Lamprecht (2010) from the North-West University respectively, using the Braun Blanquet method.

4.4 Data sampling

Collections of plant specimens serve not only as a basis for taxonomic reference and information, but most importantly serve as a historical reference for the geographic distribution of plant species (O'Connell *et al*., 2004).

Thus, stratified random sampling was used to do extensive plant voucher collection in the Heritage Park and the Impala Bafokeng Mining Complex to obtain good baseline data for the floristic assessment of the two study areas in the context of the western Central Bushveld. Field reconnaissance and stratification of the study areas were conducted in association with the phyto-sociological surveys (La Grange, 2010; Lamprecht, 2010) before sampling commenced, so that data collection could follow according to gap analysis.

For each plant species encountered, two specimens have been collected for accessioning into the AP Goosens Herbarium of the North-West University in Potchefstroom, and the National Herbarium in Pretoria. The specimens were immediately numbered and pressed in a field plant press, while species and habitat information were documented in a field collection book. One set of dry plant specimens has been identified and mounted in the AP Goosens Herbarium and was used to compile a species list per Quarter Degree Grid for integration into the species database.

4.4.1 Heritage Park

Data sampling in the Heritage Park took place during the summer season of 2008 and 2009 between February and April. In this period of two years, 111 sites were sampled throughout the central part of the Heritage Park extension area (figure 4.2). Plant species information for the five following Quarter Degree Grids was collected: 2426DC, 2426DD, 2427CD, 2526BA and 2526BB (figure 4.1).

The survey covered various habitats representative of the diverse landscape and flora found in the Heritage Park. The Heritage Park extension area, largely characterized by thornveld and mixed bushveld sites on the plains to the south and north of the Dwarsberg Mountain Range with occasional occurring dolomitic rocky outcrops, has been extensively sampled (Appendix A). Open clay thornveld underlain by the rocks of the Bushveld Igneous Complex was dominantly encountered in the southern part of the study area (Appendix A, 1.1). Whereas

further north, where black clay soils grade into dark brown loams, more dense and tall growing thorny and mixed bushveld was sampled (Appendix A, 1.2. and 1.3.).

The survey also included the species-rich kloofs and other mountain bushveld sites of the Dwarsberg range dominated by mesophyllous woody vegetation (Appendix A, 2.0). Further habitats sampled in the Heritage Park included vegetation disturbed through farming or mining by a cement factory. The terrain of the local cement mine mainly consists of dense, mixed bushveld with severe bush-encroachment (Appendix A, 3.1), while survey sites in the farming areas are characterized by alien and weed infestation (Appendix A, 3.2).

Additional specimens have been sampled for a social subproject focusing mainly on medicinal and useful plants (Magodielo *et al*., 2010).

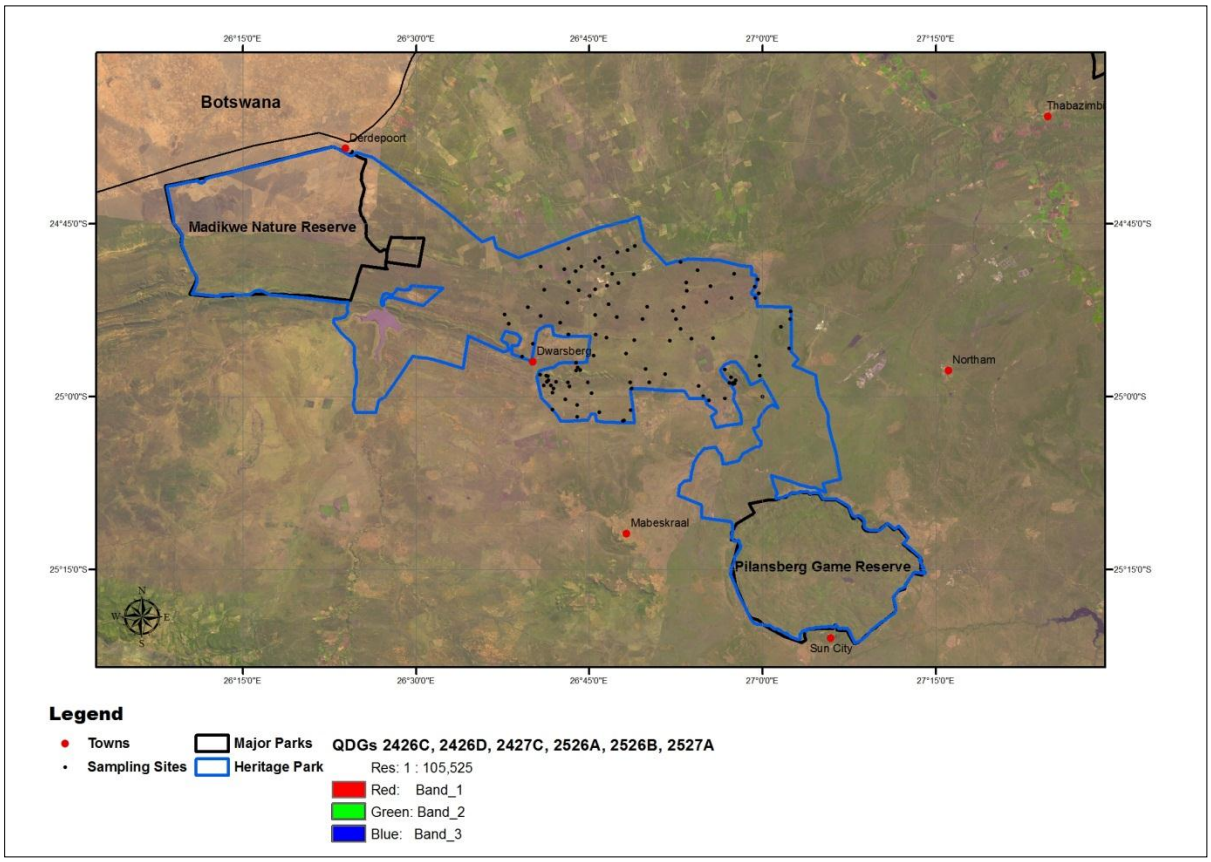


Figure 4.2: Location of the sampling sites in the central part of the extension area for the proposed Heritage Park.

4.4.2 Impala Platinum

Data sampling in the mining lease area of Impala Platinum in Rustenburg was conducted between February and May 2009. The Impala Bafokeng Mining Complex stretches over the

four Quarter Degree Grids 2527AC, 2527AD, 2527CA and 2527CB, where a total of 132 sites were sampled (figure 4.1 and 4.3).

Since the study area is situated on igneous rocks of the Rustenburg Layered Suite, the floristic exploration of the characteristic norite koppies and other noritic outcrops (Appendix B, 2.1 and 2.2), as well as the associated interspersed turf thornveld (Appendix B, 1.0), was the main focus.

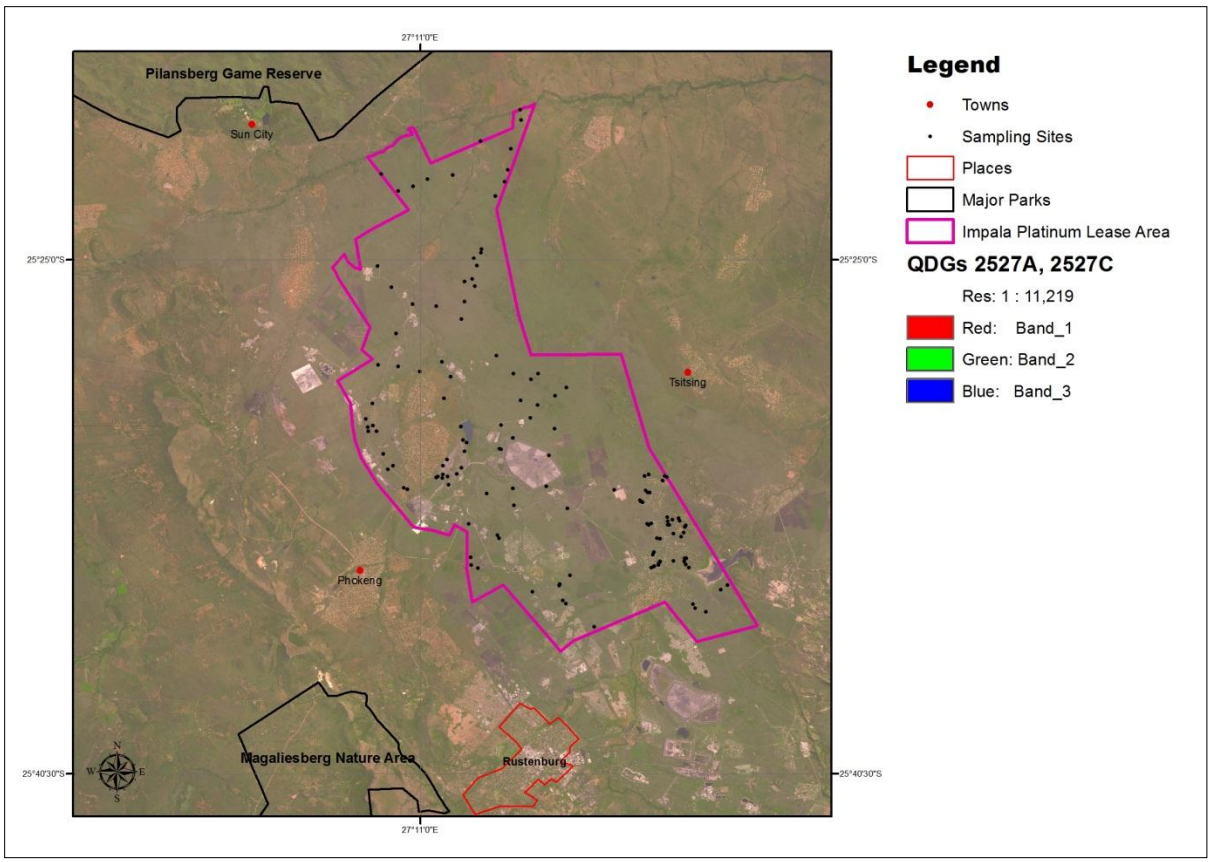


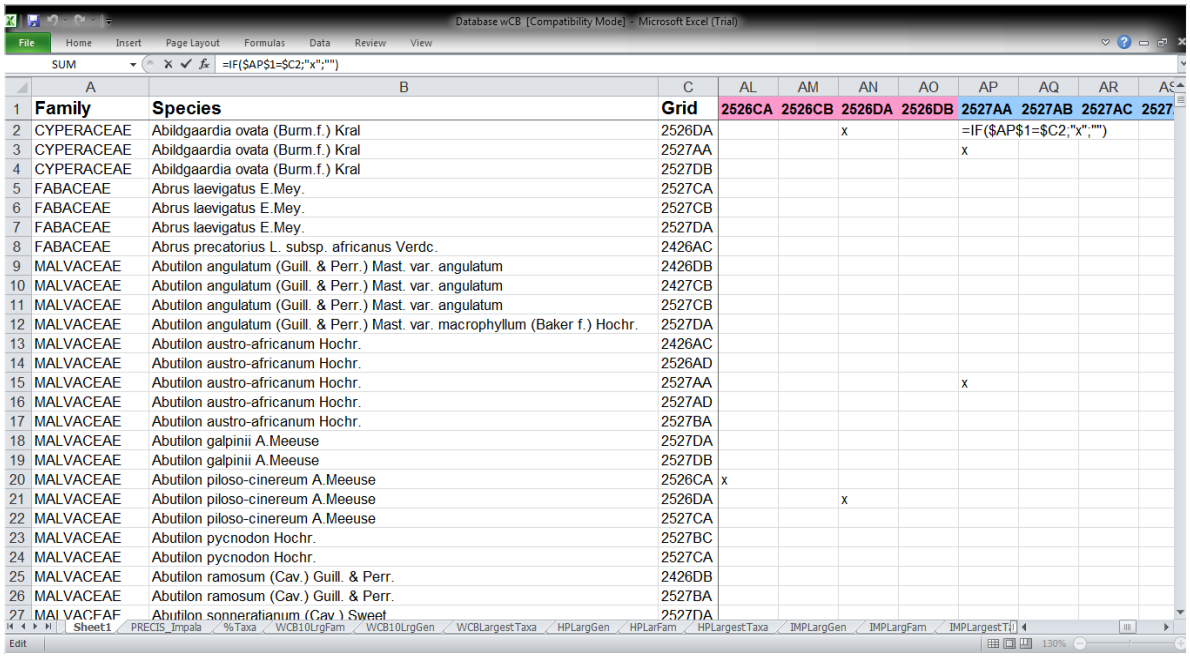
Figure 4.3: Location of the sampling sites throughout the mining lease area of Impala Platinum.

The survey also included habitat that have been influenced by mining activities. This included the already rehabilitated sedimentation dams (Appendix B, 3.0) where different techniques to re-establish vegetation were tested. Furthermore, the flora of old fields was sampled, which included fallow fields and rehabilitated thornveld (Appendix B, 4.0). Because there is a substantial influence of mining on aquatic habitats, the flora of the local riparian areas were surveyed to determine the degree of degradation.

4.5 Integration of data

Existing and sampled plant species presence-absence data for the 50 QDGs was merged into an integrative case specific Excel database. In the first step all collected plant species lists were combined into a single Excel sheet. The resulting two-way matrix was then transformed into a data matrix that recorded species occurrences as presence-absence data for each of the 50 Quarter Degree Grids.

In this process, various Excel tools and formulas were used as manual sorting of an Excel database with several thousand entries would have been a nearly insurmountable task. For example the 'IF' function was used to calculate species presence-absence for whole grid columns in the excel spreadsheet (figure 4.4).

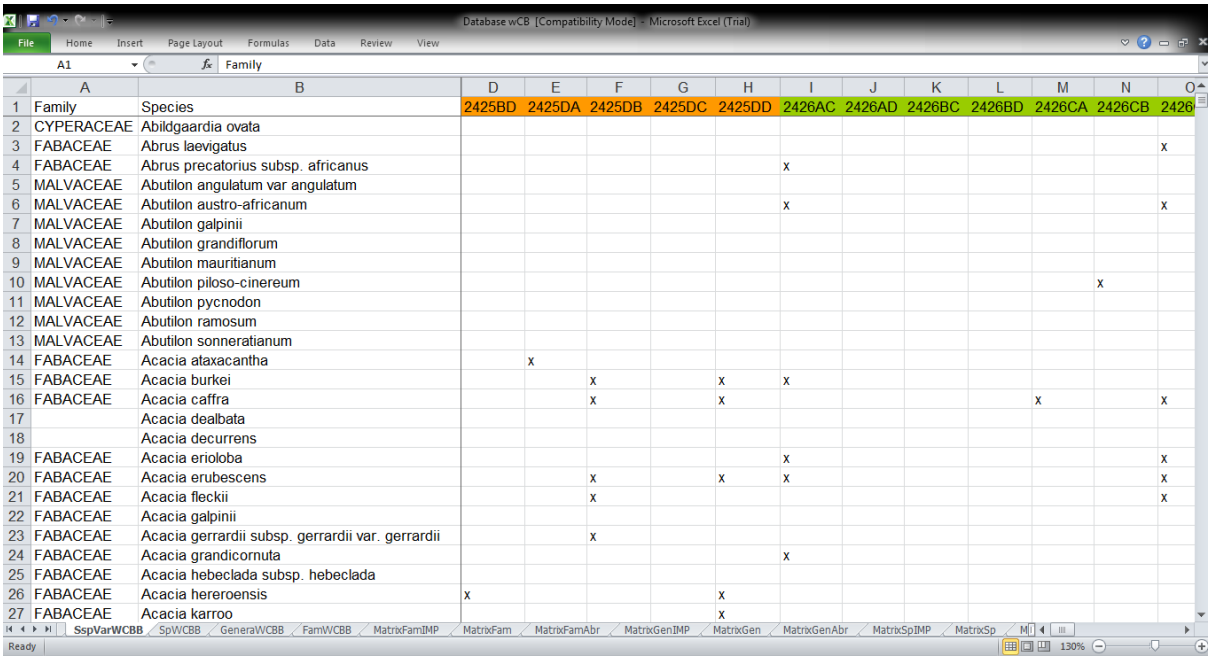


	A	B	C	AL	AM	AN	AO	AP	AQ	AR	AS
1	**Family**	**Species**	**Grid**	**2526CA**	**2526CB**	**2526DA**	**2526DB**	**2527AA**	**2527AB**	**2527AC**	**2527**
2	CYPERACEAE	Abildgaardia ovata (Burm.f.) Kral	2526DA			x		=IF(AP1=$C2;"x";"")			
3	CYPERACEAE	Abildgaardia ovata (Burm.f.) Kral	2527AA					x			
4	CYPERACEAE	Abildgaardia ovata (Burm.f.) Kral	2527DB								
5	FABACEAE	Abrus laevigatus E.Mey.	2527CA								
6	FABACEAE	Abrus laevigatus E.Mey.	2527CB								
7	FABACEAE	Abrus laevigatus E.Mey.	2527DA								
8	FABACEAE	Abrus precatorius L. subsp. africanus Verdc.	2426AC								
9	MALVACEAE	Abutilon angulatum (Guill. & Perr.) Mast. var. angulatum	2426DB								
10	MALVACEAE	Abutilon angulatum (Guill. & Perr.) Mast. var. angulatum	2427CB								
11	MALVACEAE	Abutilon angulatum (Guill. & Perr.) Mast. var. angulatum	2527CB								
12	MALVACEAE	Abutilon angulatum (Guill. & Perr.) Mast. var. macrophyllum (Baker f.) Hochr.	2527DA								
13	MALVACEAE	Abutilon austro-africanum Hochr.	2426AC								
14	MALVACEAE	Abutilon austro-africanum Hochr.	2526AD								
15	MALVACEAE	Abutilon austro-africanum Hochr.	2527AA					x			
16	MALVACEAE	Abutilon austro-africanum Hochr.	2527AD								
17	MALVACEAE	Abutilon austro-africanum Hochr.	2527BA								
18	MALVACEAE	Abutilon galpinii A.Meeuse	2527DA								
19	MALVACEAE	Abutilon galpinii A.Meeuse	2527DB								
20	MALVACEAE	Abutilon piloso-cinereum A.Meeuse	2526CA	x							
21	MALVACEAE	Abutilon piloso-cinereum A.Meeuse	2526DA			x					
22	MALVACEAE	Abutilon piloso-cinereum A.Meeuse	2527CA								
23	MALVACEAE	Abutilon pycnodon Hochr.	2527BC								
24	MALVACEAE	Abutilon pycnodon Hochr.	2527CA								
25	MALVACEAE	Abutilon ramosum (Cav.) Guill. & Perr.	2426DB								
26	MALVACEAE	Abutilon ramosum (Cav.) Guill. & Perr.	2527BA								
27	MALVACEAE	Abutilon sonneratianum (Cav.) Sweet	2527DA								

Figure 4.4: Example of using the Excel 'IF' formula to convert the two-way matrix of combined species lists into a data matrix where plant species occurrences are recorded as presence-absence data for the 50 Quarter Degree Grids.

In the next step the Van der Meulen data matrix was added to the developed species data matrix, followed by the removal of duplicate species. For this the presence-absence data was first sorted by species with the 'Sorting' tool. Then the QDG data for each species was manually merged into one row and the remaining rows were deleted from the Excel spreadsheet using the 'Remove Duplicates' tool. Finally, the author information was manually

removed from the residual PRECIS species to develop a homogeneous species data matrix (figure 4.5).



	A	B	D	E	F	G	H	I	J	K	L	M	N	O
1	Family	Species	2425BD	2425DA	2425DB	2425DC	2425DD	2426AC	2426AD	2426BC	2426BD	2426CA	2426CB	2426
2	CYPERACEAE	Abildgaardia ovata												
3	FABACEAE	Abrus laevigatus												x
4	FABACEAE	Abrus precatorius subsp. africanus						x						
5	MALVACEAE	Abutilon angulatum var angulatum												
6	MALVACEAE	Abutilon austro-africanum						x						x
7	MALVACEAE	Abutilon galpinii												
8	MALVACEAE	Abutilon grandiflorum												
9	MALVACEAE	Abutilon mauritianum												
10	MALVACEAE	Abutilon piloso-cinereum											x	
11	MALVACEAE	Abutilon pycnodon												
12	MALVACEAE	Abutilon ramosum												
13	MALVACEAE	Abutilon sonneratianum												
14	FABACEAE	Acacia ataxacantha		x										
15	FABACEAE	Acacia burkei			x		x	x						
16	FABACEAE	Acacia caffra			x		x					x		x
17		Acacia dealbata												
18		Acacia decurrens												
19	FABACEAE	Acacia erioloba						x						x
20	FABACEAE	Acacia erubescens			x		x	x						x
21	FABACEAE	Acacia fleckii			x									x
22	FABACEAE	Acacia galpinii												
23	FABACEAE	Acacia gerrardii subsp. gerrardii var. gerrardii			x									
24	FABACEAE	Acacia grandicornuta						x						
25	FABACEAE	Acacia hebeclada subsp. hebeclada												
26	FABACEAE	Acacia hereroensis	x				x							
27	FABACEAE	Acacia karroo					x							

Figure 4.5: Data matrix that displays recorded western Central Bushveld plant species at infra-specific level as presence-absence data for the 50 Quarter Degree Grids.

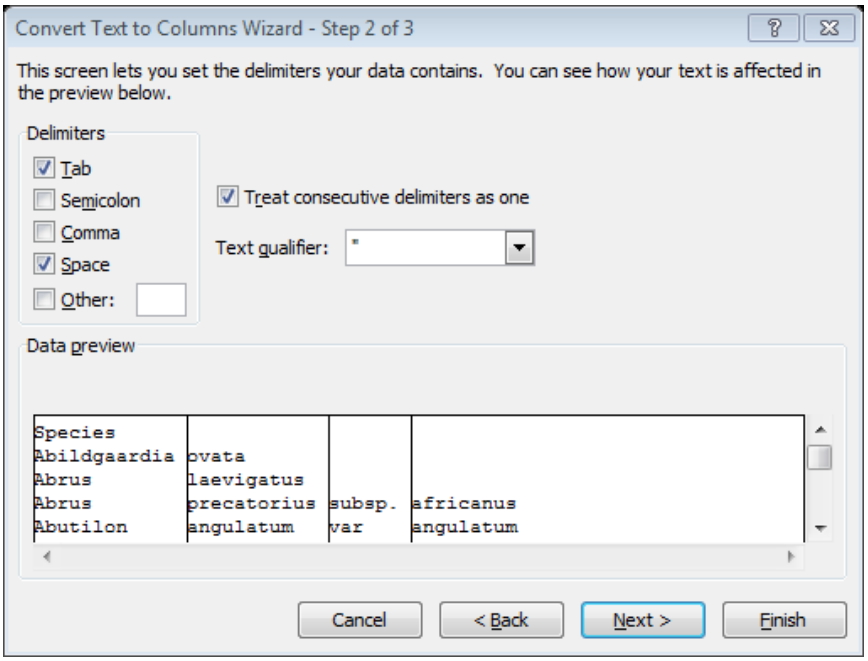
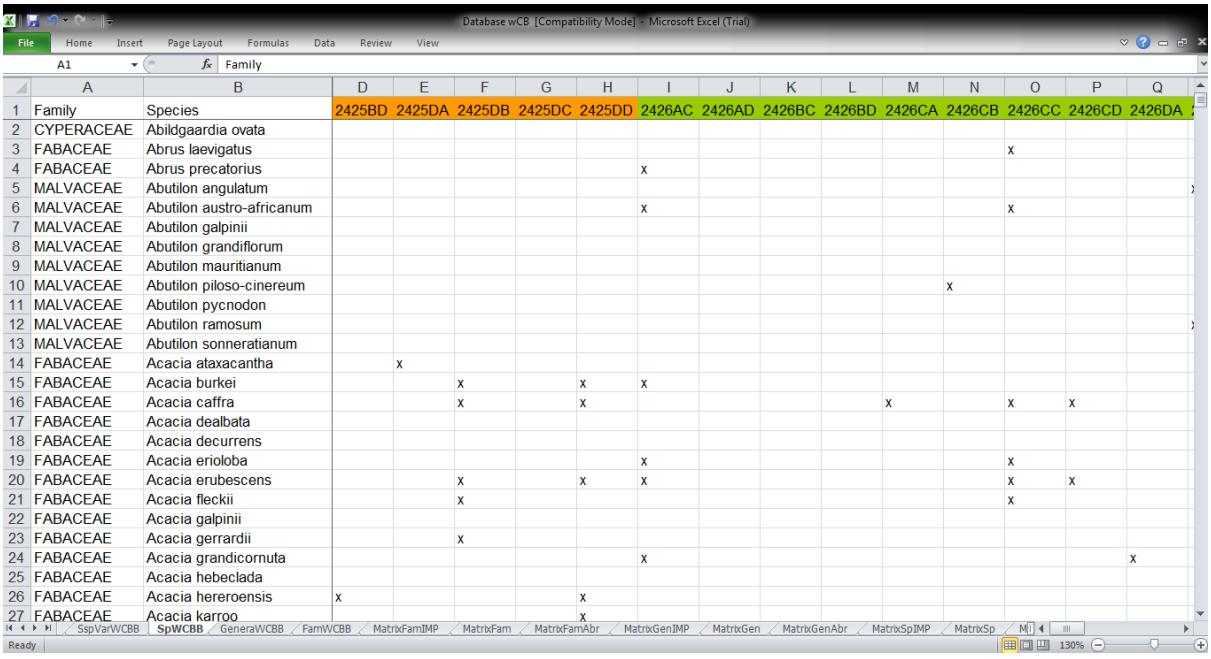


Figure 4.6: 'Text to Column' tool used to remove infra-specific and species epithets for designing the species and genus data matrix.

Further data matrices were developed for species, genus and family level (figures 4.7 to 4.9). This was done by manually merging the QDG data for species with the same species, genus or

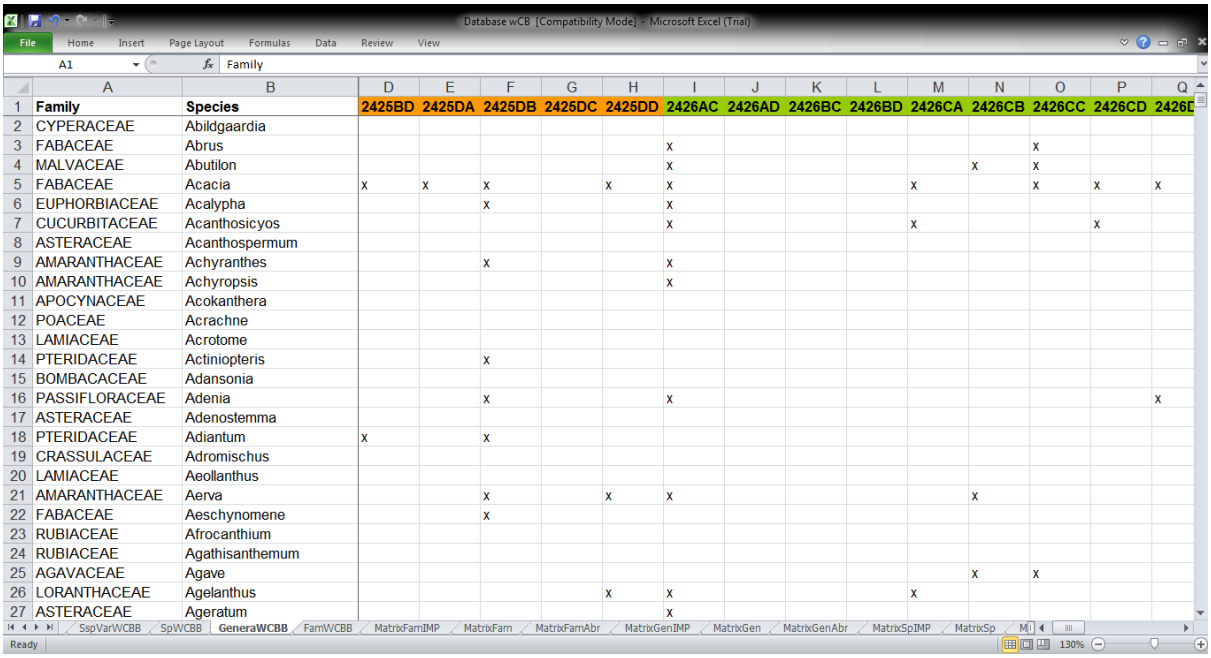
family into one row respectively, and subsequently deleting the excess rows. For the purpose of designing the species and genus data matrix, the 'Text to Column' tool was used to remove the infra-specific and species epithets (figure 4.6).

For further data analyses the presence-absence data of all plant taxa matrices were transformed into 1's and 0's. This is especially a prerequisite for multivariate ordination (see 4.7.2).



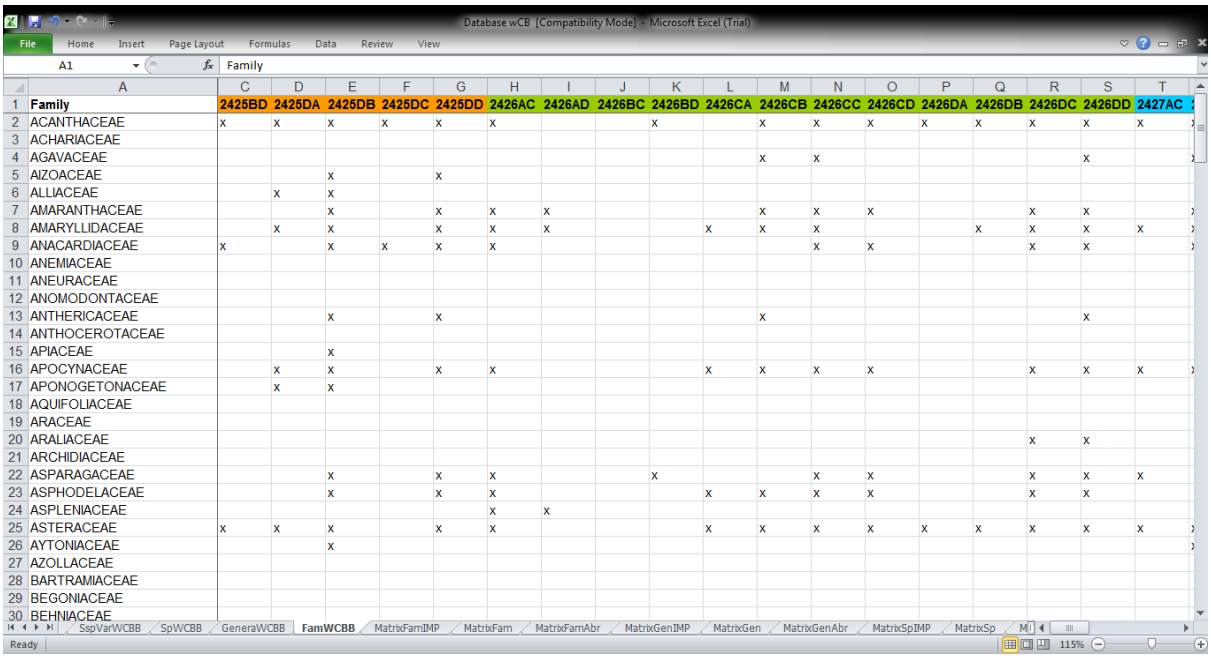
	A	B	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Family	Species	2425BD	2425DA	2425DB	2425DC	2425DD	2426AC	2426AD	2426BC	2426BD	2426CA	2426CB	2426CC	2426CD	2426DA
2	CYPERACEAE	Abildgaardia ovata														
3	FABACEAE	Abrus laevigatus												x		
4	FABACEAE	Abrus precatorius						x								
5	MALVACEAE	Abutilon angulatum														
6	MALVACEAE	Abutilon austro-africanum						x						x		
7	MALVACEAE	Abutilon galpinii														
8	MALVACEAE	Abutilon grandiflorum														
9	MALVACEAE	Abutilon mauritianum														
10	MALVACEAE	Abutilon piloso-cinereum											x			
11	MALVACEAE	Abutilon pycnodon														
12	MALVACEAE	Abutilon ramosum														
13	MALVACEAE	Abutilon sonneratianum														
14	FABACEAE	Acacia ataxacantha		x												
15	FABACEAE	Acacia burkei			x		x	x								
16	FABACEAE	Acacia caffra			x		x					x		x	x	
17	FABACEAE	Acacia dealbata														
18	FABACEAE	Acacia decurrens														
19	FABACEAE	Acacia erioloba						x						x		
20	FABACEAE	Acacia erubescens			x		x	x						x	x	
21	FABACEAE	Acacia fleckii			x									x		
22	FABACEAE	Acacia galpinii														
23	FABACEAE	Acacia gerrardii			x											
24	FABACEAE	Acacia grandicornuta						x								x
25	FABACEAE	Acacia hebeclada														
26	FABACEAE	Acacia hereroensis	x				x									
27	FABACEAE	Acacia karroo					x									

Figure 4.7: Species data matrix.



	A	B	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Family	Species	2425BD	2425DA	2425DB	2425DC	2425DD	2426AC	2426AD	2426BC	2426BD	2426CA	2426CB	2426CC	2426CD	2426D
2	CYPERACEAE	Abildgaardia														
3	FABACEAE	Abrus						x						x		
4	MALVACEAE	Abutilon						x					x	x		
5	FABACEAE	Acacia	x	x	x		x	x				x		x	x	x
6	EUPHORBIACEAE	Acalypha			x			x								
7	CUCURBITACEAE	Acanthosicyos						x				x			x	
8	ASTERACEAE	Acanthospermum														
9	AMARANTHACEAE	Achyranthes			x			x								
10	AMARANTHACEAE	Achyropsis						x								
11	APOCYNACEAE	Acokanthera														
12	POACEAE	Acrachne														
13	LAMIACEAE	Acrotome														
14	PTERIDACEAE	Actiniopteris			x											
15	BOMBACACEAE	Adansonia														
16	PASSIFLORACEAE	Adenia			x			x								x
17	ASTERACEAE	Adenostemma														
18	PTERIDACEAE	Adiantum	x		x											
19	CRASSULACEAE	Adromischus														
20	LAMIACEAE	Aeollanthus														
21	AMARANTHACEAE	Aerva			x		x	x					x			
22	FABACEAE	Aeschynomene			x											
23	RUBIACEAE	Afrocanthium														
24	RUBIACEAE	Agathisanthemum														
25	AGAVACEAE	Agave											x	x		
26	LORANTHACEAE	Agelanthus					x	x				x				
27	ASTERACEAE	Ageratum						x								

Figure 4.8: Genus data matrix.



Family	2425BD	2425DA	2425DB	2425DC	2425DD	2426AC	2426AD	2426BC	2426BD	2426CA	2426CB	2426CC	2426CD	2426DA	2426DB	2426DC	2426DD	2427AC
ACANTHACEAE	x	x	x	x	x	x			x		x	x	x	x	x	x	x	x
ACHARIACEAE																		
AGAVACEAE											x	x					x	
AIZOACEAE			x		x													
ALLIACEAE		x	x															
AMARANTHACEAE			x		x	x	x				x	x	x			x	x	
AMARYLLIDACEAE		x	x		x	x	x			x	x	x			x	x	x	x
ANACARDIACEAE	x		x	x	x	x						x	x			x	x	
ANEMIACEAE																		
ANEURACEAE																		
ANOMODONTACEAE																		
ANTHERICACEAE			x		x						x						x	
ANTHOCEROTACEAE																		
APIACEAE			x															
APOCYNACEAE		x	x		x	x				x	x	x	x			x	x	x
APONOGETONACEAE		x	x															
AQUIFOLIACEAE																		
ARACEAE																		
ARALIACEAE																x	x	
ARCHIDIACEAE																		
ASPARAGACEAE			x		x	x			x			x	x			x	x	x
ASPHODELACEAE			x		x	x				x	x	x	x			x	x	
ASPLENIACEAE						x	x											
ASTERACEAE	x	x	x		x	x				x	x	x	x	x	x	x	x	x
AYTONIACEAE			x															
AZOLLACEAE																		
BARTRAMIACEAE																		
BEGONIACEAE																		
BEHNIACEAE																		

Figure 4.9: Family data matrix.

4.6 Standardization

Despite extensive sampling of plant vouchers in the Heritage Park and the Impala Bafokeng Mining Complex, many QDGs of the western Central Bushveld are still under-sampled (figure 4.1). Because incomplete sampling across the grids of a study area results in false records of species absence and thus biased biodiversity estimation, the plant distribution data for the western Central Bushveld Bioregion has been standardized using predefined rules. For this purpose two standardizing profiles have been developed, namely the 'Centroid Grid'(figure 4.10) and the 'Integrated Grid' (figure 4.11) profile.

The 'Centroid Grid' profile involves the strengthening of under-sampled grids by extrapolating species occurrences from three adjacent grids with the most similar vegetation composition (figure 4.10). It assumes that neighbouring QDGs with similar vegetation composition will presumably share similar plant species. Thus adjacent grids will give information on new species that has not been sampled yet, but which are likely to be encountered in that grid.

Selection of the three grids for the plant data standardization according to the 'Centroid Grid' profile has been done subjectively by studying the vegetation classification for the western Central Bushveld study area (figure 4.12). Only the three most dominant vegetation types per grid were used as the selection criteria. Because there is no detailed vegetation description for

the Botswana vegetation, a conformable continuation of the vegetation pattern was assumed. The 'Centroid Grid' integration rules for the standardization of the floristic data are shown in table 4.1.

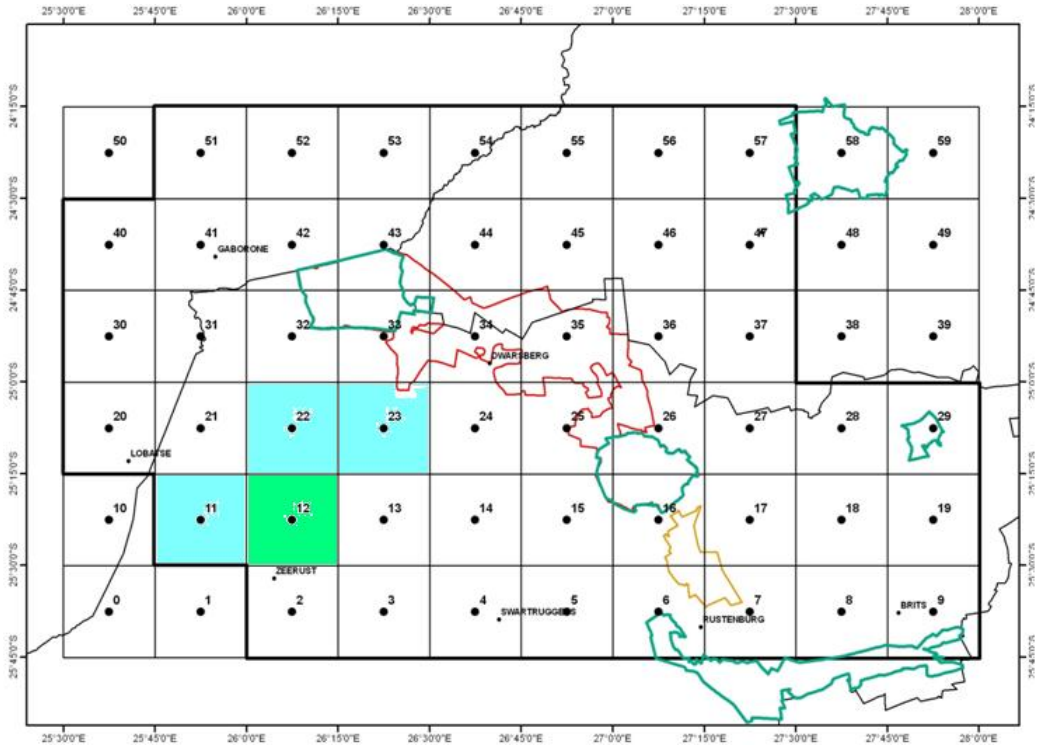


Figure 4.10: Exemplifying how the 'Centroid Grid' profile combines the species data of a target grid (green) with the species data of three adjacent grids (blue) that display the most similar vegetation composition.

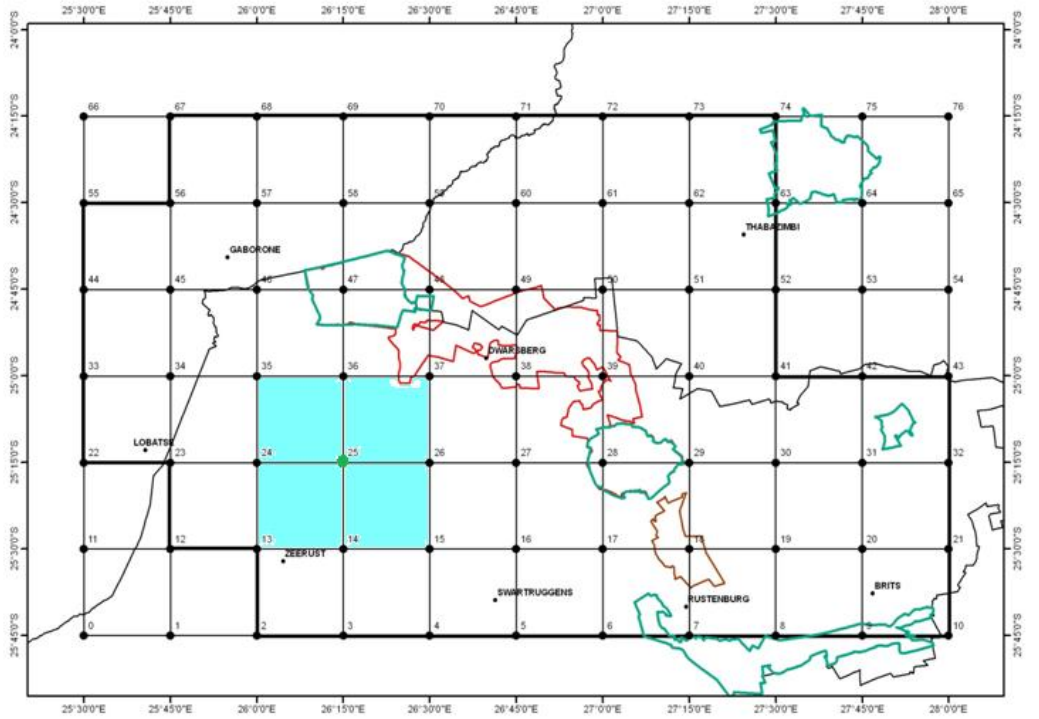


Figure 4.11: Exemplifying how the 'Integrated Grid' profile combines the species data of four grids (blue) at each reference point (green) within the study area.

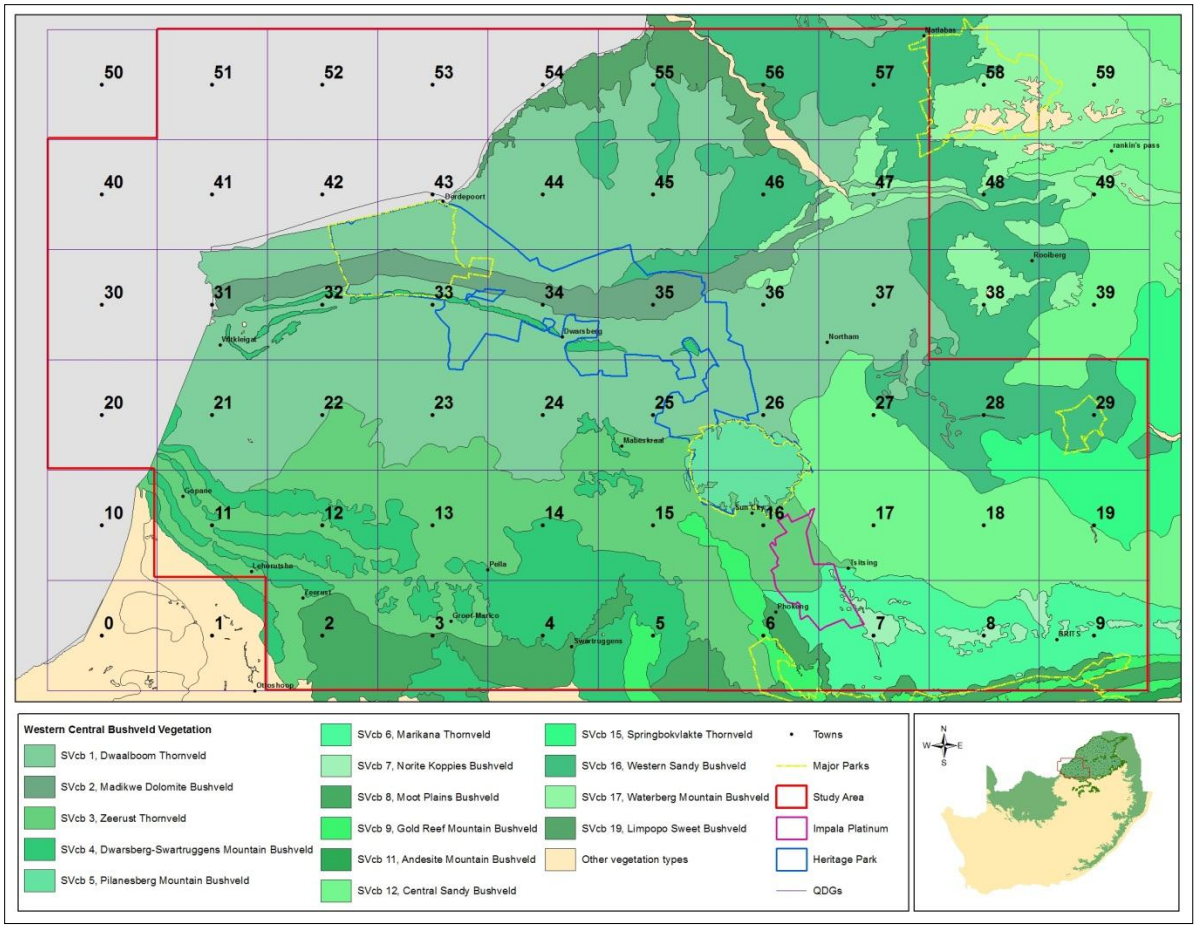


Figure 4.12: Vegetation map used to identify the grids with the most similar vegetation classification.

Table 4.1: 'Centroid Grid' integration rules used for the standardization of the western Central Bushveld plant taxa.

51	**52**	**53**	**54**	**55**	**56**	**57**	**40**	**41**	**42**
51+41+52+40	52+51+53+41	53+52+42+43	54+55+53+43	55+54+56+45	56+55+46+57	57+56+46+47	40+41+51+30	41+40+30+52	42+52+53+43
2425BD	2426AC	2426AD	2426BC	2426BD	2427AC	2427AD	2425DA	2425DB	2426CA
43	**44**	**45**	**46**	**47**	**30**	**31**	**32**	**33**	**34**
43+42+53+54	44+43+54+45	45+44+55+46	46+45+56+57	47+37+57+46	30+31+20+40	31+32+30+21	32+31+33+21	33+32+34+23	34+33+35+44
2426CB	2426DA	2426DB	2427CA	2427CB	2425DC	2425DD	2426CC	2426CD	2426DC
35	**36**	**37**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
35+34+36+45	36+35+37+46	37+36+47+26	20+21+30+11	21+20+22+11	22+23+21+13	23+22+24+13	24+23+25+14	25+24+26+15	26+25+15+16
2426DD	2427CC	2427CD	2525BA	2525BB	2526AA	2526AB	2526BA	2526BB	2527AA
27	**28**	**29**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
27+28+17+18	28+27+29+19	29+28+19+18	11+12+20+21	12+11+13+14	13+12+14+3	14+13+15+4	15+14+16+5	16+15+26+6	17+18+27+6
2527AB	2527BA	2527BB	2525BD	2526AC	2526AD	2526BC	2526BD	2527AC	2527AD
18	**19**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
18+17+19+27	19+18+17+29	2+3+12+13	3+2+4+13	4+3+5+14	5+4+6+15	6+5+7+15	7+6+8+9	8+7+9+18	9+8+18+19
2527BC	2527BD	2526CA	2526CB	2526DA	2526DB	2527CA	2527CB	2527DA	2527DB

Whereas the 'Integrated Grid' profile integrates plant diversity data of the four QDGs that intersect at each grid point (figure 4.11). This approach assumes that adjacent grids share similar species due to the presence of a common regional flora. As a result each integral grid reference point generates regional and overlapping plant information made up of four QDGs.

Data standardization was done for all taxonomic levels for which plant data matrices were prepared. Figure 4.13 to 4.16 illustrates the standardization process for the species level data matrix as an example.

For each grid reference point the plant data (e.g. species, genera and family names) has been merged in Excel according to the respective standardization rule. The QDG data was first extracted from the original plant data matrix by sorting according to the relevant QDGs, and then copied and pasted into a new Excel sheet. With the 'Remove Duplicates' tool multiple occurring plant species were removed to finally obtain the new standardized plant lists for each grid reference point. The number of plant taxa for each standardized grid has been calculated for later use in spatial analysis.

In the following step the standardized plant lists for the different taxonomic levels have been transformed into data matrices. For this the original data matrices were copied as templates into a new spreadsheet and the grid reference points of the respective profile were assigned to the corresponding QDGs. The presence-absence data for the standardized grids were calculated with the aid of case-specific Excel formulas using the 'IF' and 'COUNTIF' functions (figure 4.13 and 4.15).

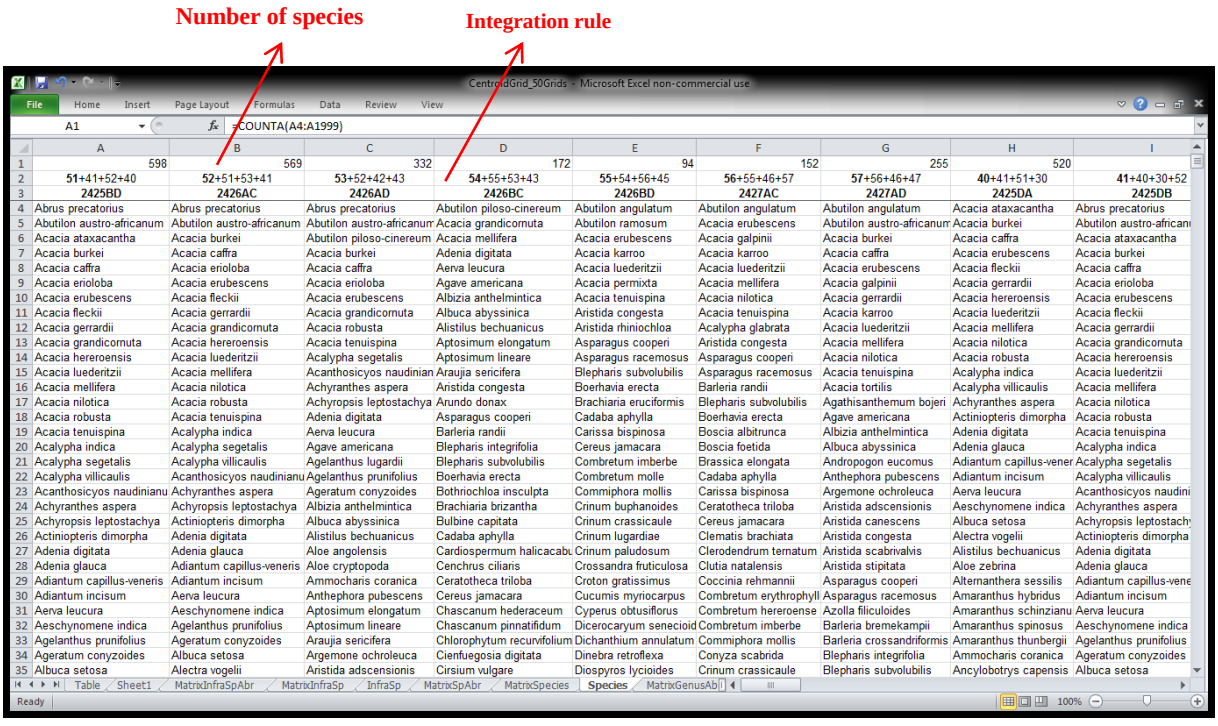
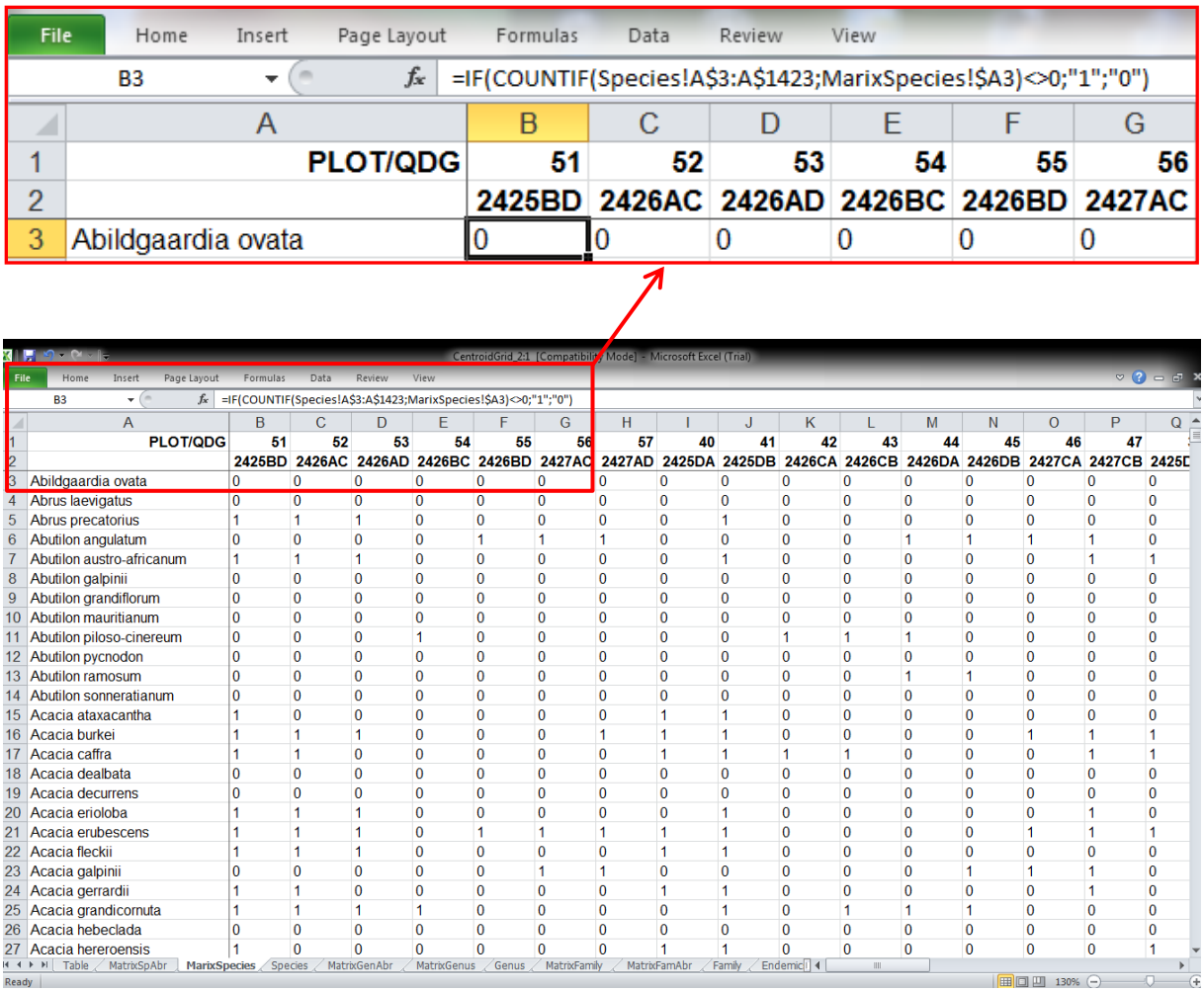
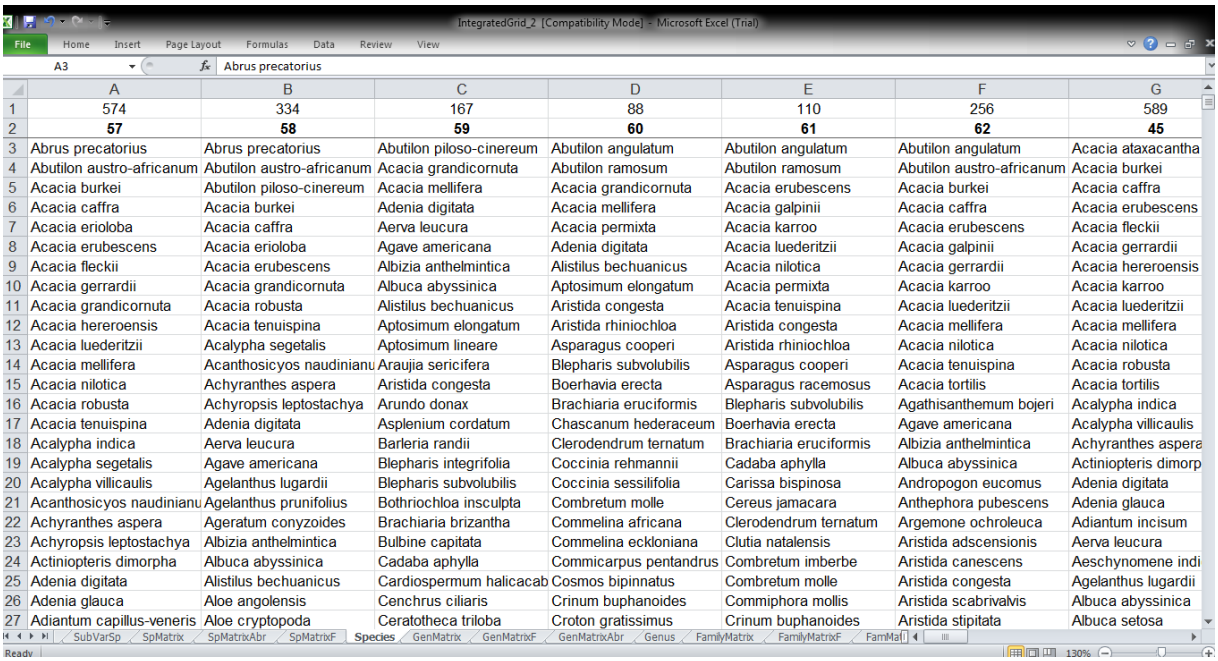


Figure 4.13: Standardized species data derived from the 'Centroid Grid' profile.



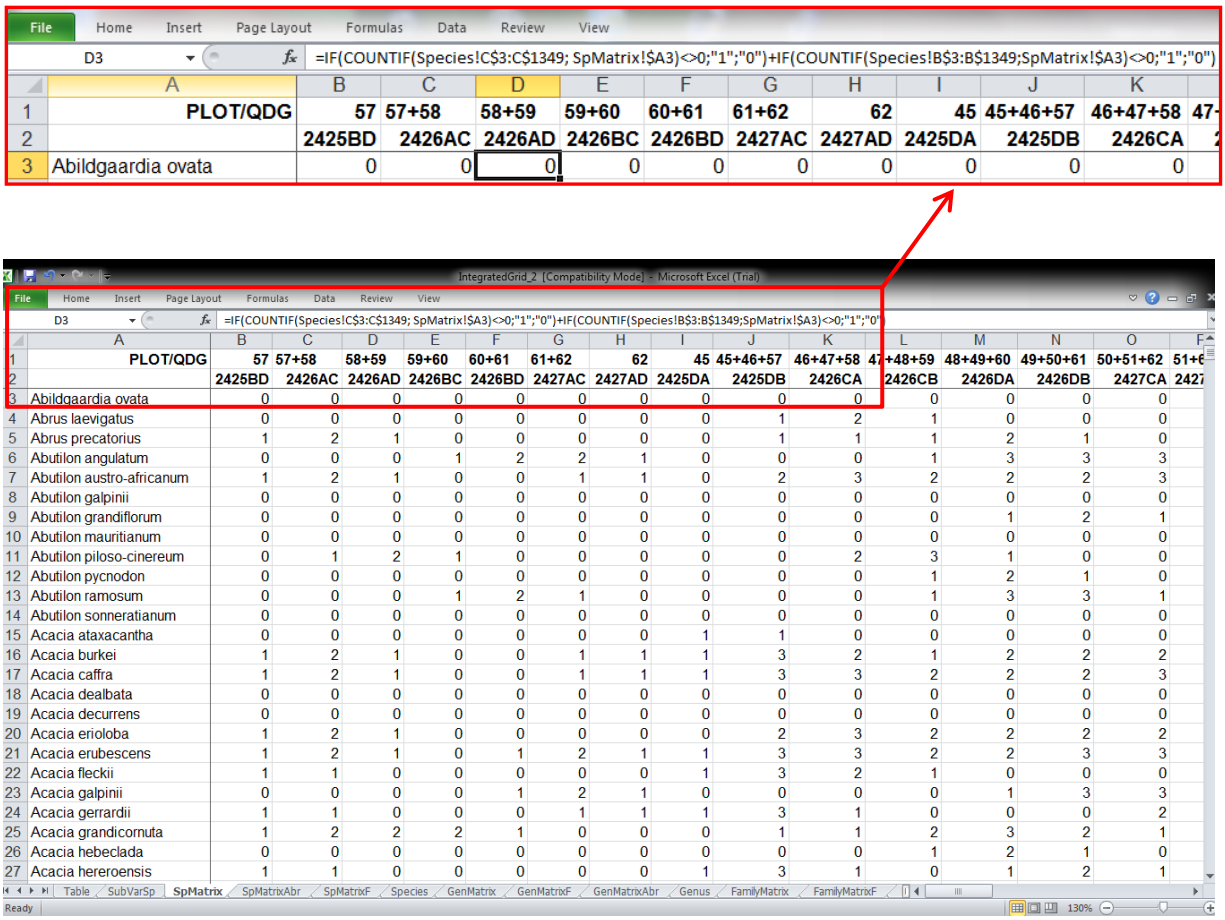
	A	B	C	D	E	F	G
1	PLOT/QDG	51	52	53	54	55	56
2		2425BD	2426AC	2426AD	2426BC	2426BD	2427AC
3	Abildgaardia ovata	0	0	0	0	0	0

Figure 4.14: Standardized species data matrix derived from the 'Centroid Grid' profile with a calculation example for *Abildgaardia ovata* for the QDG 2425BD from the plant taxa information of grid reference point 51 in the 'Species' spreadsheet.



	A	B	C	D	E	F	G
1	574	334	167	88	110	256	589
2	57	58	59	60	61	62	45
3	Abrus precatorius	Abrus precatorius	Abutilon piloso-cinereum	Abutilon angulatum	Abutilon angulatum	Abutilon angulatum	Acacia ataxacantha
4	Abutilon austro-africanum	Abutilon austro-africanum	Acacia grandicornuta	Abutilon ramosum	Abutilon ramosum	Abutilon austro-africanum	Acacia burkei
5	Acacia burkei	Abutilon piloso-cinereum	Acacia mellifera	Acacia grandicornuta	Acacia erubescens	Acacia burkei	Acacia caffra
6	Acacia caffra	Acacia burkei	Adenia digitata	Acacia mellifera	Acacia galpinii	Acacia caffra	Acacia erubescens
7	Acacia erioloba	Acacia caffra	Aerva leucura	Acacia permixta	Acacia karroo	Acacia erubescens	Acacia fleckii
8	Acacia erubescens	Acacia erioloba	Agave americana	Adenia digitata	Acacia luederitzii	Acacia galpinii	Acacia gerrardii
9	Acacia fleckii	Acacia erubescens	Albizia anthelmintica	Alistilus bechuanicus	Acacia nilotica	Acacia gerrardii	Acacia hereroensis
10	Acacia gerrardii	Acacia grandicornuta	Albuca abyssinica	Aptosimum elongatum	Acacia permixta	Acacia karroo	Acacia karroo
11	Acacia grandicornuta	Acacia robusta	Alistilus bechuanicus	Aristida congesta	Acacia tenuispina	Acacia luederitzii	Acacia luederitzii
12	Acacia hereroensis	Acacia tenuispina	Aptosimum elongatum	Aristida rhiniochloa	Aristida congesta	Acacia mellifera	Acacia mellifera
13	Acacia luederitzii	Acalypha segetalis	Aptosimum lineare	Asparagus cooperi	Aristida rhiniochloa	Acacia nilotica	Acacia nilotica
14	Acacia mellifera	Acanthosicyos naudinianu	Araujia sericifera	Blepharis subvolubilis	Asparagus cooperi	Acacia tenuispina	Acacia robusta
15	Acacia nilotica	Achyranthes aspera	Aristida congesta	Boerhavia erecta	Asparagus racemosus	Acacia tortilis	Acacia tortilis
16	Acacia robusta	Achyropsis leptostachya	Arundo donax	Brachiaria eruciformis	Blepharis subvolubilis	Agathisanthemum bojeri	Acalypha indica
17	Acacia tenuispina	Adenia digitata	Asplenium cordatum	Chascanum hederaceum	Boerhavia erecta	Agave americana	Acalypha villicaulis
18	Acalypha indica	Aerva leucura	Barleria randii	Clerodendrum ternatum	Brachiaria eruciformis	Albizia anthelmintica	Achyranthes aspera
19	Acalypha segetalis	Agave americana	Blepharis integrifolia	Coccinia rehmannii	Cadaba aphylla	Albuca abyssinica	Actiniopteris dimorp
20	Acalypha villicaulis	Agelanthus lugardii	Blepharis subvolubilis	Coccinia sessilifolia	Carissa bispinosa	Andropogon eucomus	Adenia digitata
21	Acanthosicyos naudinianu	Agelanthus prunifolius	Bothriochloa insculpta	Combretum molle	Cereus jamacara	Anthephora pubescens	Adenia glauca
22	Achyranthes aspera	Ageratum conyzoides	Brachiaria brizantha	Commelina africana	Clerodendrum ternatum	Argemone ochroleuca	Adiantum incisum
23	Achyropsis leptostachya	Albizia anthelmintica	Bulbine capitata	Commelina eckloniana	Clutia natalensis	Aristida adscensionis	Aerva leucura
24	Actiniopteris dimorpha	Albuca abyssinica	Cadaba aphylla	Commicarpus pentandrus	Combretum imberbe	Aristida canescens	Aeschynomene indi
25	Adenia digitata	Alistilus bechuanicus	Cardiospermum halicacab	Cosmos bipinnatus	Combretum molle	Aristida congesta	Agelanthus lugardii
26	Adenia glauca	Aloe angolensis	Cenchrus ciliaris	Crinum buphanoides	Commiphora mollis	Aristida scabrivalvis	Albuca abyssinica
27	Adiantum capillus-veneris	Aloe cryptopoda	Ceratotheca triloba	Croton gratissimus	Crinum buphanoides	Aristida stipitata	Albuca setosa

Figure 4.15: Standardized species data derived from the 'Integrated Grid' profile.



	A	B	C	D	E	F	G	H	I	J	K
1	PLOT/QDG	57	57+58	58+59	59+60	60+61	61+62	62	45	45+46+57	46+47+58
2		2425BD	2426AC	2426AD	2426BC	2426BD	2427AC	2427AD	2425DA	2425DB	2426CA
3	Abildgaardia ovata	0	0	0	0	0	0	0	0	0	0

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	PLOT/QDG	57	57+58	58+59	59+60	60+61	61+62	62	45	45+46+57	46+47+58	+48+59	48+49+60	49+50+61	50+51+62
2		2425BD	2426AC	2426AD	2426BC	2426BD	2427AC	2427AD	2425DA	2425DB	2426CA	2426CB	2426DA	2426DB	2427CA
3	Abildgaardia ovata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Abrus laevigatus	0	0	0	0	0	0	0	0	1	2	1	0	0	0
5	Abrus precatorius	1	2	1	0	0	0	0	0	1	1	1	2	1	0
6	Abutilon angulatum	0	0	0	1	2	2	1	0	0	0	1	3	3	3
7	Abutilon austro-africanum	1	2	1	0	0	1	1	0	2	3	2	2	2	3
8	Abutilon galpinii	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Abutilon grandiflorum	0	0	0	0	0	0	0	0	0	0	0	1	2	1
10	Abutilon mauritianum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Abutilon piloso-cinereum	0	1	2	1	0	0	0	0	0	2	3	1	0	0
12	Abutilon pycnodon	0	0	0	0	0	0	0	0	0	0	1	2	1	0
13	Abutilon ramosum	0	0	0	1	2	1	0	0	0	0	1	3	3	1
14	Abutilon sonneratianum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Acacia ataxacantha	0	0	0	0	0	0	0	1	1	0	0	0	0	0
16	Acacia burkei	1	2	1	0	0	1	1	1	3	2	1	2	2	2
17	Acacia caffra	1	2	1	0	0	1	1	1	3	3	2	2	2	3
18	Acacia dealbata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Acacia decurrens	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Acacia erioloba	1	2	1	0	0	0	0	0	2	3	2	2	2	2
21	Acacia erubescens	1	2	1	0	1	2	1	1	3	3	2	2	3	3
22	Acacia fleckii	1	1	0	0	0	0	0	1	3	2	1	0	0	0
23	Acacia galpinii	0	0	0	0	1	2	1	0	0	0	0	1	3	3
24	Acacia gerrardii	1	1	0	0	0	1	1	1	3	1	0	0	0	2
25	Acacia grandicornuta	1	2	2	2	1	0	0	0	1	1	2	3	2	1
26	Acacia hebeclada	0	0	0	0	0	0	0	0	0	0	1	2	1	0
27	Acacia hereroensis	1	1	0	0	0	0	0	1	3	1	0	1	2	1

Figure 4.16: Standardized species data matrix derived from the 'Integrated Grid' profile with a calculation example for *Abildgaardia ovata* for the QDG 2426AD from the plant taxa information of grid reference point 58 and 59 in the 'Species' spreadsheet.

4.7 Data analysis

4.7.1 Desktop study

First, floristically important plant taxa (IPT) found in the western Central Bushveld flora was identified using various reference works and lists:

Red Data plants

- PRECIS species lists for North West, Limpopo and Botswana from the online checklist of the Plants of Southern Africa (POSA) and Red List of South African species version 2009 (SANBI, 2009).
- IUCN list of Red Data plants for the NW Province (NWDACE, 2008)

Endemics

- PRECIS species lists for North West, Limpopo and Botswana from the online checklist of the Plants of Southern Africa (POSA) (SANBI, 2009)

– ‘The vegetation of South Africa, Lesotho and Swaziland’ (Mucina & Rutherford, 2006)

Protected Trees

– List of Protected Trees according to the National Forest Act (Act 84 of 1998) (SANBI, 2009)

Useful & Medical Plants

– ‘People’s plants: a guide to useful plants of Southern Africa’ (Van Wyk & Gericke, 2000)

– ‘Medicinal plants of South Africa’ (Van Wyk *et al.*, 1997)

Problem Plants

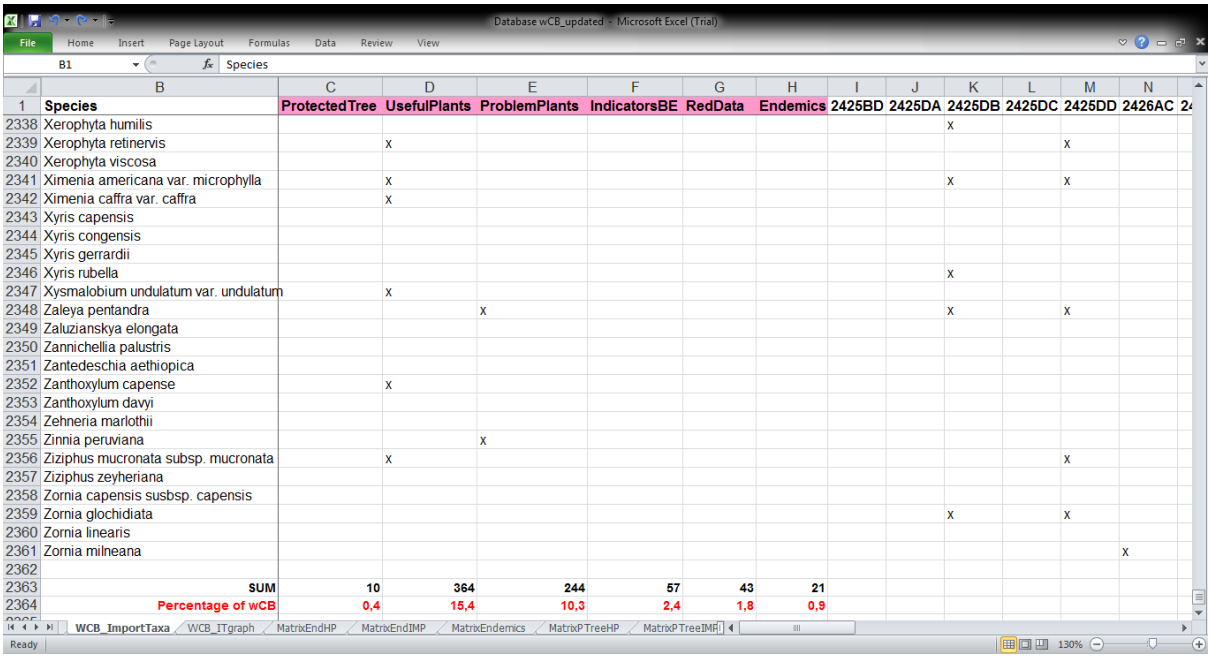
– ‘Problem plants of South Africa: a guide to the identification and control of more than 300 invasive plants and other weeds’ (Bromilow, 2001)

– Declared weeds in the NW Province according to the Conservation of Agricultural Resources Act (Act No 43 of 1983) (NWDACE, 2008).

Bush encroachment Indicators

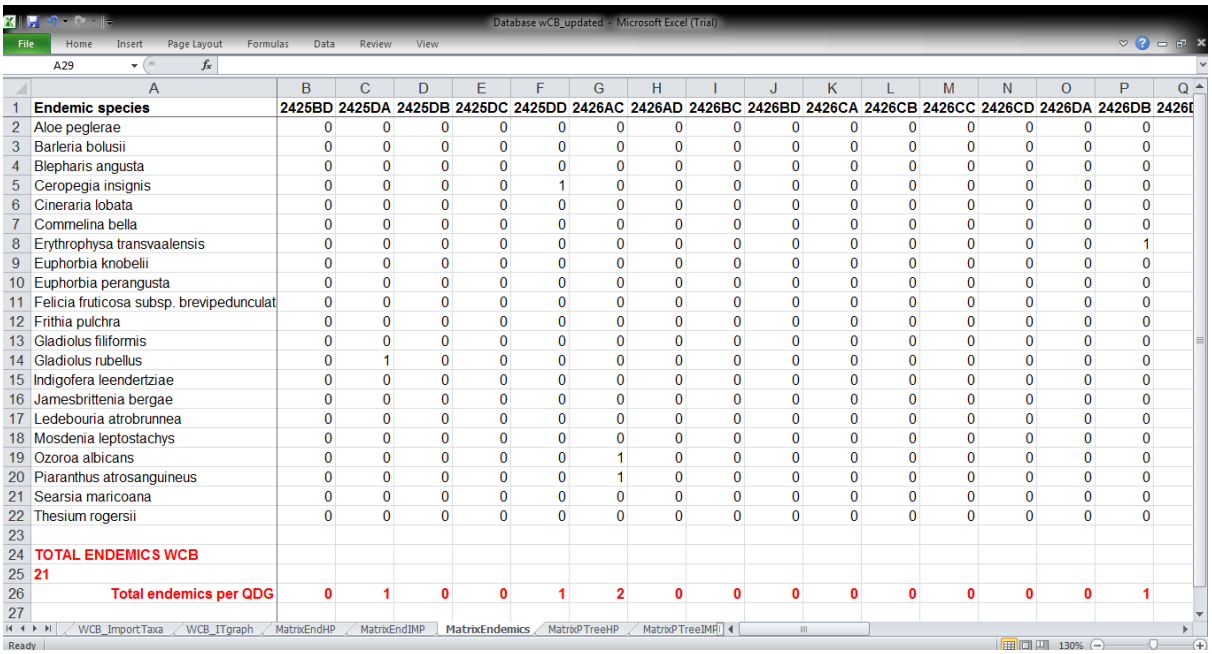
– Declared indicators of bush encroachment in the NW Province (Conservation of Agricultural Resources Act (Act No 43 of 1983)) cited in the ‘North West Province Environment Outlook 2008’ (NWDACE, 2008).

Analysis has been done in the species database at infra-specific level to facilitate later extraction of single data matrices for the different IPT groups (figure 4.17). Data matrices have been prepared for the western Central Bushveld (figure 4.18), as well as for the two study areas, Heritage Park (figure 4.19) and Impala Platinum (figure 4.20).



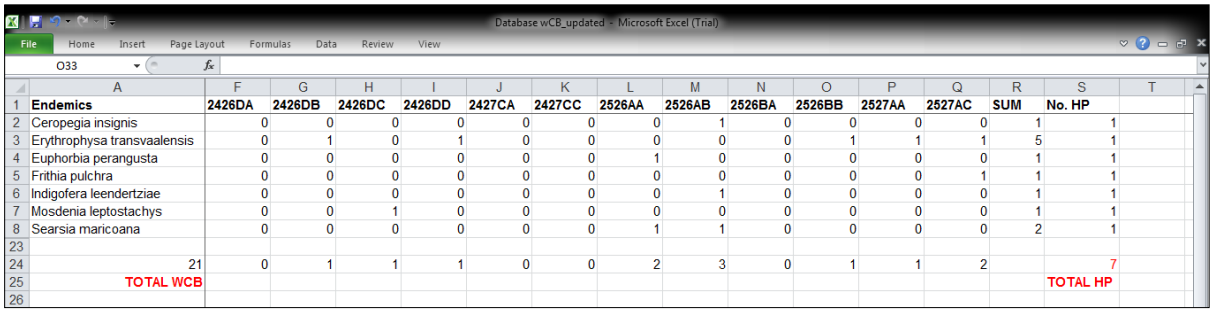
	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Species	ProtectedTree	UsefulPlants	ProblemPlants	IndicatorsBE	RedData	Endemics	2425BD	2425DA	2425DB	2425DC	2425DD	2426AC
2338	Xerophyta humilis									x			
2339	Xerophyta retinervis		x									x	
2340	Xerophyta viscosa												
2341	Ximenia americana var. microphylla		x							x		x	
2342	Ximenia caffra var. caffra		x										
2343	Xyris capensis												
2344	Xyris congensis												
2345	Xyris gerrardii												
2346	Xyris rubella									x			
2347	Xysmalobium undulatum var. undulatum		x										
2348	Zaleya pentandra			x						x		x	
2349	Zaluzianskya elongata												
2350	Zannichellia palustris												
2351	Zantedeschia aethiopica												
2352	Zanthoxylum capense		x										
2353	Zanthoxylum davyi												
2354	Zehneria marlothii												
2355	Zinnia peruviana			x									
2356	Ziziphus mucronata subsp. mucronata		x									x	
2357	Ziziphus zeyheriana												
2358	Zornia capensis susbsp. capensis												
2359	Zornia glochidiata									x		x	
2360	Zornia linearis												
2361	Zornia milneana												x
2362													
2363	SUM	10	364	244	57	43	21						
2364	Percentage of wCB	0,4	15,4	10,3	2,4	1,8	0,9						

Figure 4.17: Analysis of the western Central Bushveld database for Important Plant Taxa.



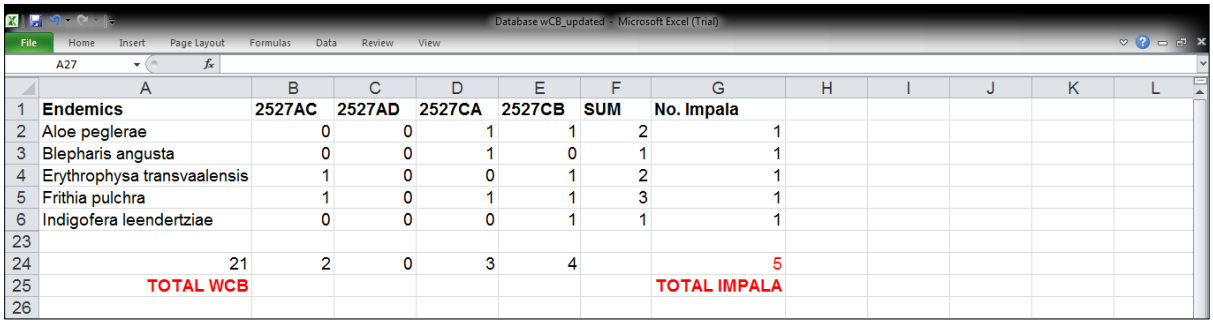
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	**Endemic species**	**2425BD**	**2425DA**	**2425DB**	**2425DC**	**2425DD**	**2426AC**	**2426AD**	**2426BC**	**2426BD**	**2426CA**	**2426CB**	**2426CC**	**2426CD**	**2426DA**	**2426DB**	**2426D**
2	Aloe peglerae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	Barleria bolusii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	Blepharis angusta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	Ceropegia insignis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
6	Cineraria lobata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	Commelina bella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	Erythrophysa transvaalensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
9	Euphorbia knobelii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10	Euphorbia perangusta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	Felicia fruticosa subsp. brevipeduncular	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	Frithia pulchra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13	Gladiolus filiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	Gladiolus rubellus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	Indigofera leendertziae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	Jamesbrittenia bergae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17	Ledebouria atrobrunnea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	Mosdenia leptostachys	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	Ozoroa albicans	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
20	Piaranthus atrosanguineus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
21	Searsia maricoana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	Thesium rogersii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23																	
24	TOTAL ENDEMICS WCB																
25	21																
26	Total endemics per QDG	0	1	0	0	1	2	0	0	0	0	0	0	0	0	1	
27																	

Figure 4.18: Example of data matrix for western Central Bushveld endemic species.



	A	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	**Endemics**	**2426DA**	**2426DB**	**2426DC**	**2426DD**	**2427CA**	**2427CC**	**2526AA**	**2526AB**	**2526BA**	**2526BB**	**2527AA**	**2527AC**	**SUM**	**No. HP**	
2	Ceropegia insignis	0	0	0	0	0	0	0	1	0	0	0	0	1	1	
3	Erythrophysa transvaalensis	0	1	0	1	0	0	0	0	0	1	1	1	5	1	
4	Euphorbia perangusta	0	0	0	0	0	0	1	0	0	0	0	0	1	1	
5	Frithia pulchra	0	0	0	0	0	0	0	0	0	0	0	1	1	1	
6	Indigofera leendertziae	0	0	0	0	0	0	0	1	0	0	0	0	1	1	
7	Mosdenia leptostachys	0	0	1	0	0	0	0	0	0	0	0	0	1	1	
8	Searsia maricoana	0	0	0	0	0	0	1	1	0	0	0	0	2	1	
23																
24	21	0	1	1	1	0	0	2	3	0	1	1	2		7	
25	TOTAL WCB														TOTAL HP	
26																

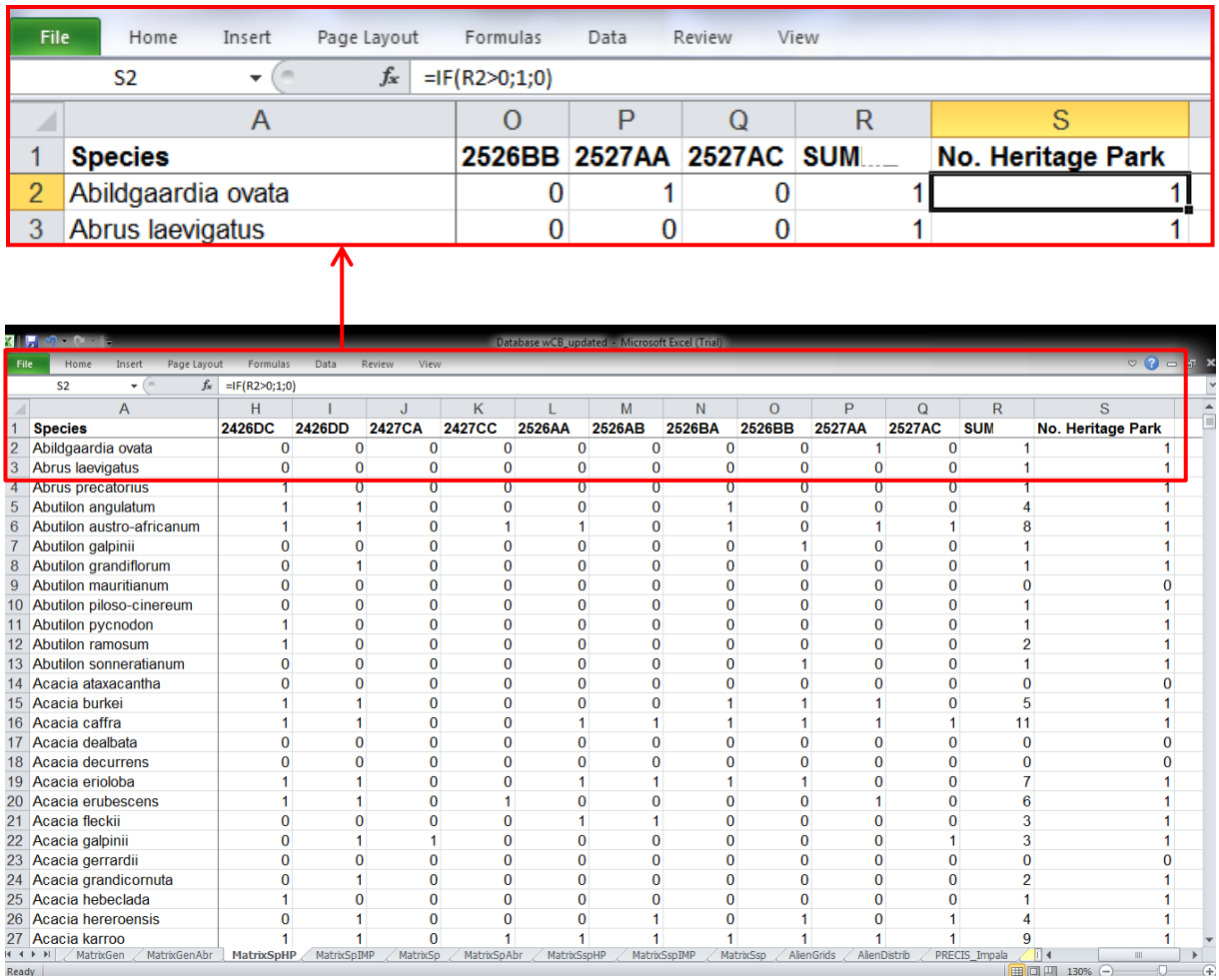
Figure 4.19: Example of data matrix for western Central Bushveld endemics occurring in the Heritage Park.



	A	B	C	D	E	F	G	H	I	J	K	L
1	**Endemics**	**2527AC**	**2527AD**	**2527CA**	**2527CB**	**SUM**	**No. Impala**					
2	Aloe peglerae	0	0	1	1	2	1					
3	Blepharis angusta	0	0	1	0	1	1					
4	Erythrophysa transvaalensis	1	0	0	1	2	1					
5	Frithia pulchra	1	0	1	1	3	1					
6	Indigofera leendertziae	0	0	0	1	1	1					
23												
24	21	2	0	3	4		5					
25	TOTAL WCB						TOTAL IMPALA					
26												

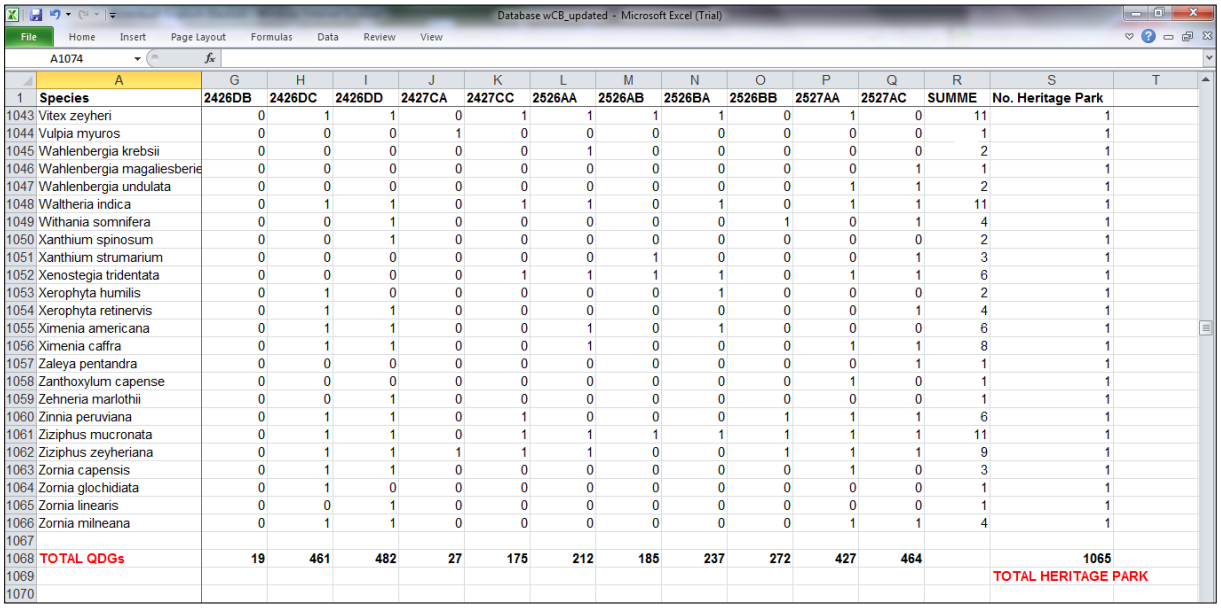
Figure 4.20: Example of endemics data matrix for Impala Bafokeng Mining Complex.

Following this, the number of recorded plant taxa (i.e. species, genera, families and ITPs) and the 10 largest genera and families for the western Central Bushveld were determined; as well as for the Heritage Park and Impala Platinum with the aim of discussing their relevance for phyto-diversity conservation in the bioregion.



	A	O	P	Q	R	S
1	Species	2526BB	2527AA	2527AC	SUM	No. Heritage Park
2	Abildgaardia ovata	0	1	0	1	1
3	Abrus laevigatus	0	0	0	1	1

Figure 4.21: Example of species database for the Heritage Park study area extracted from the original WCB data matrix.

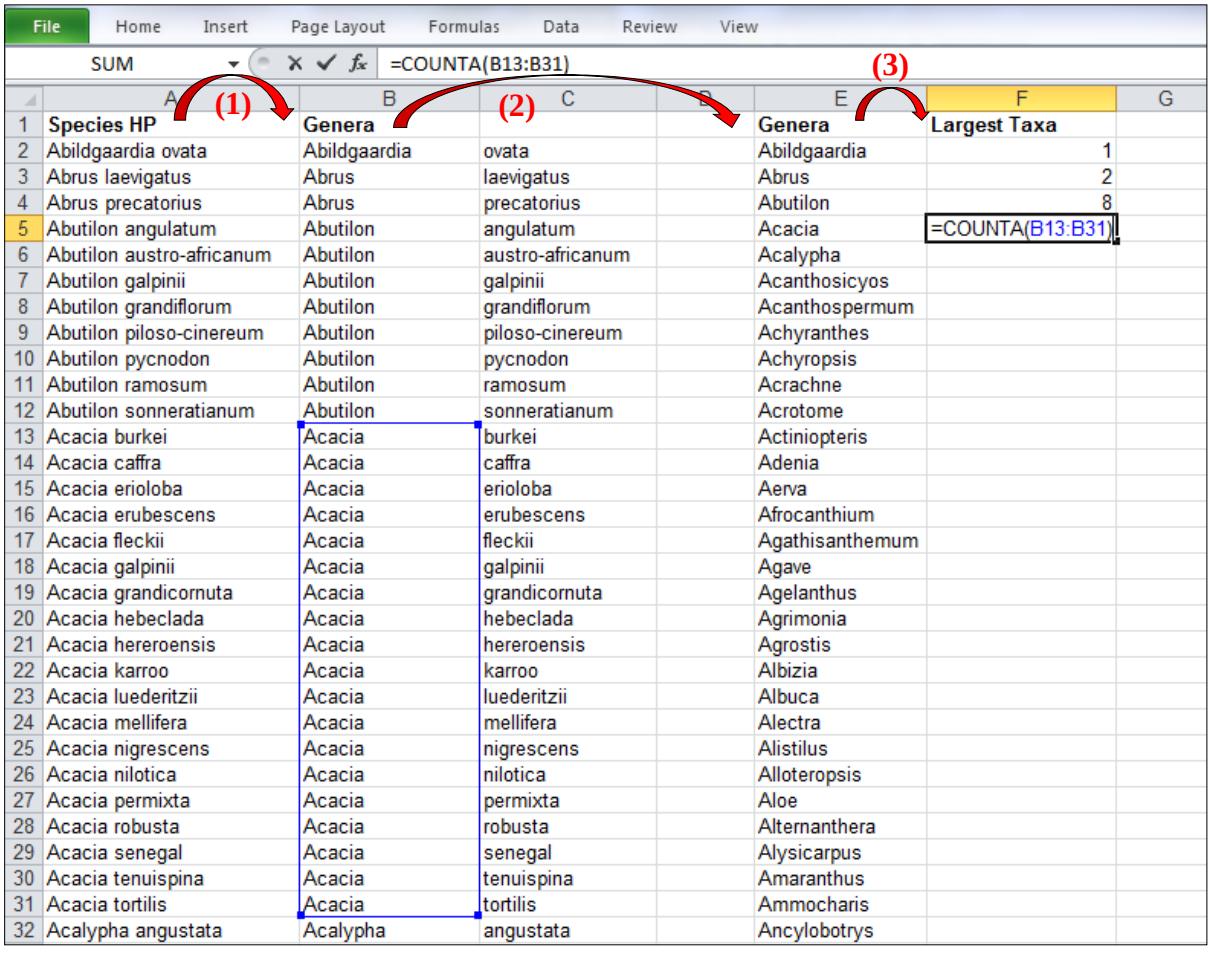


	Species	2426DB	2426DC	2426DD	2427CA	2427CC	2526AA	2526AB	2526BA	2526BB	2527AA	2527AC	SUMME	No. Heritage Park
1043	Vitex zeyheri	0	1	1	0	1	1	1	1	0	1	0	11	1
1044	Vulpia myuros	0	0	0	1	0	0	0	0	0	0	0	1	1
1045	Wahlenbergia krebsii	0	0	0	0	0	1	0	0	0	0	0	2	1
1046	Wahlenbergia magaliesberie	0	0	0	0	0	0	0	0	0	0	1	1	1
1047	Wahlenbergia undulata	0	0	0	0	0	0	0	0	0	1	1	2	1
1048	Waltheria indica	0	1	1	0	1	1	0	1	0	1	1	11	1
1049	Withania somnifera	0	0	1	0	0	0	0	0	1	0	1	4	1
1050	Xanthium spinosum	0	0	1	0	0	0	0	0	0	0	0	2	1
1051	Xanthium strumarium	0	0	0	0	0	0	1	0	0	0	1	3	1
1052	Xenostegia tridentata	0	0	0	0	1	1	1	1	0	1	1	6	1
1053	Xerophyta humilis	0	1	0	0	0	0	0	1	0	0	0	2	1
1054	Xerophyta retinervis	0	1	1	0	0	0	0	0	0	0	1	4	1
1055	Ximenia americana	0	1	1	0	0	1	0	1	0	0	0	6	1
1056	Ximenia caffra	0	1	1	0	0	1	0	0	0	1	1	8	1
1057	Zaleya pentandra	0	0	0	0	0	0	0	0	0	0	1	1	1
1058	Zanthoxylum capense	0	0	0	0	0	0	0	0	0	1	0	1	1
1059	Zehneria marlothii	0	0	1	0	0	0	0	0	0	0	0	1	1
1060	Zinnia peruviana	0	1	1	0	1	0	0	0	1	1	1	6	1
1061	Ziziphus mucronata	0	1	1	0	1	1	1	1	1	1	1	11	1
1062	Ziziphus zeyheriana	0	1	1	1	1	1	0	0	1	1	1	9	1
1063	Zornia capensis	0	1	1	0	0	0	0	0	0	1	0	3	1
1064	Zornia glochidiata	0	1	0	0	0	0	0	0	0	0	0	1	1
1065	Zornia linearis	0	0	1	0	0	0	0	0	0	0	0	1	1
1066	Zornia milneana	0	1	1	0	0	0	0	0	0	1	1	4	1
1067														
1068	TOTAL QDGs	19	461	482	27	175	212	185	237	272	427	464		1065
1069														TOTAL HERITAGE PARK
1070														

Figure 4.22: Final Heritage Park species data matrix.

To count the plant taxa present in the two specific study areas, the relevant QDGs were extracted from the original data matrices and pasted into a new spreadsheet to form new data matrices. To filter the new databases for the plant taxa actually occurring in the study areas, the species occurrences were summed and the presence-absence calculated using the 'IF' function, as shown in figure 4.21 for the Heritage Park species data matrix. Plant taxa with '0' occurrence in the study areas were deleted from the database for the final Heritage Park data matrix (figure 4.22).

Figure 4.23 shows an example of how the 10 largest genera of the Heritage Park study area were determined. The Heritage Park species list was copied from the data matrix and pasted into a new Excel sheet where it was edited using the 'Text to Columns' and 'Remove Duplicates' tools (figure 4.23, (1) and (2) respectively). Finally the number of species recorded for each genus was calculated using the 'COUNTA' function (figure 4.23, (3)).



	A	B	C	D	E	F	G
1	**Species HP**	**Genera**			**Genera**	**Largest Taxa**	
2	Abildgaardia ovata	Abildgaardia	ovata		Abildgaardia	1	
3	Abrus laevigatus	Abrus	laevigatus		Abrus	2	
4	Abrus precatorius	Abrus	precatorius		Abutilon	8	
5	Abutilon angulatum	Abutilon	angulatum		Acacia	=COUNTA(B13:B31)	
6	Abutilon austro-africanum	Abutilon	austro-africanum		Acalypha		
7	Abutilon galpinii	Abutilon	galpinii		Acanthosicyos		
8	Abutilon grandiflorum	Abutilon	grandiflorum		Acanthospermum		
9	Abutilon piloso-cinereum	Abutilon	piloso-cinereum		Achyranthes		
10	Abutilon pycnodon	Abutilon	pycnodon		Achyropsis		
11	Abutilon ramosum	Abutilon	ramosum		Acrachne		
12	Abutilon sonneratianum	Abutilon	sonneratianum		Acrotome		
13	Acacia burkei	Acacia	burkei		Actiniopteris		
14	Acacia caffra	Acacia	caffra		Adenia		
15	Acacia erioloba	Acacia	erioloba		Aerva		
16	Acacia erubescens	Acacia	erubescens		Afrocanthium		
17	Acacia fleckii	Acacia	fleckii		Agathisanthemum		
18	Acacia galpinii	Acacia	galpinii		Agave		
19	Acacia grandicornuta	Acacia	grandicornuta		Agelanthus		
20	Acacia hebeclada	Acacia	hebeclada		Agrimonia		
21	Acacia hereroensis	Acacia	hereroensis		Agrostis		
22	Acacia karroo	Acacia	karroo		Albizia		
23	Acacia luederitzii	Acacia	luederitzii		Albuca		
24	Acacia mellifera	Acacia	mellifera		Alectra		
25	Acacia nigrescens	Acacia	nigrescens		Alistilus		
26	Acacia nilotica	Acacia	nilotica		Alloteropsis		
27	Acacia permixta	Acacia	permixta		Aloe		
28	Acacia robusta	Acacia	robusta		Alternanthera		
29	Acacia senegal	Acacia	senegal		Alysicarpus		
30	Acacia tenuispina	Acacia	tenuispina		Amaranthus		
31	Acacia tortilis	Acacia	tortilis		Ammocharis		
32	Acalypha angustata	Acalypha	angustata		Ancylobotrys		

Figure 4.23: Calculation of the 10 largest genera for the Heritage Park using the Excel tools 'Text to Columns' (1), 'Delete Duplicates' (2) and the 'COUNTA' function (3).

4.7.2 Ordination

The floristic patterns across the western Central Bushveld were explored with ordination techniques using the software package CANOCO 4.5 (Ter Braak & Smilauer, 2002). The aim was to extract ecological relationships hidden in the extensive floristic dataset of this study (Mathema, 2005). Ordination arranges floristic samples in relation to each other on the basis of their similarity of plant taxa composition, and positions them along an environmental gradient in ordination space (Kent & Coker, 1992; Leps & Smilauer, 1999).

Indirect gradient analysis (PCA and DCA) was applied as the ordination tool, since only floristic data is available for analysis. This means, that samples are arranged along a hypothetical environmental gradient in the ordination graph. Relationships may then be interpreted in terms of known environmental patterns (Ter Braak & Prentice, 1988).

The suitability of the different indirect ordination methods (Principal Component Analysis (PCA) and Detrended Correspondence Analysis (DCA)) for the plant data of this study has been tested. According to Wilson (1981), the successful use of ordination depends on how well an ordination technique performs with the collected field data, i.e. how interpretable the results are.

4.7.2.1 Selection of the appropriate ordination method

The response of species to environmental gradients can be classified into two models, that is either linear or unimodal (Leps & Smilauer, 1999).

The linear response model assumes a linear species turnover which can be observed along short sections of an environmental gradient (Ter Braak & Prentice, 1988). Thus ordination methods based on linear models, such as PCA, are applicable for datasets that capture only a partial range of the environmental variation (Ter Braak & Prentice, 1988; Mathema, 2005). As the name PCA implies, the ordination technique tries to identify the hidden factors or components along which the samples vary with regard to taxa composition (Palmer, 2011). The contribution of each component (ordination axis) to the total variation within the dataset is represented by the eigenvalues.

According to McLaughlin (1994), PCA—also called factor analysis—is the most commonly applied ordination technique in floristic studies, explained by the fact that the factors produced by the Q-mode analysis can be associated with floristic elements, while those from the R-mode can be related to floristic areas. The latter relates to the goal of this study, and thus PCA is considered as a good approach in identifying the floristic groups of the western Central Bushveld.

In contrast to the linear model, the unimodal response model expects species to follow a bell-shaped or Gaussian curve (figure 4.24) due to the fact that most species have an optimum on an environmental gradient (Kent & Coker, 1992; Leps & Smilauer, 1999). This curvilinear distribution of species would result into distortion (horseshoe effect) in PCA ordination space (Palmer, 2011). Consequently, ordination methods based on unimodal relation between species and environmental gradients are more appropriate for datasets that capture a broader range of the environment (Mathema, 2005).

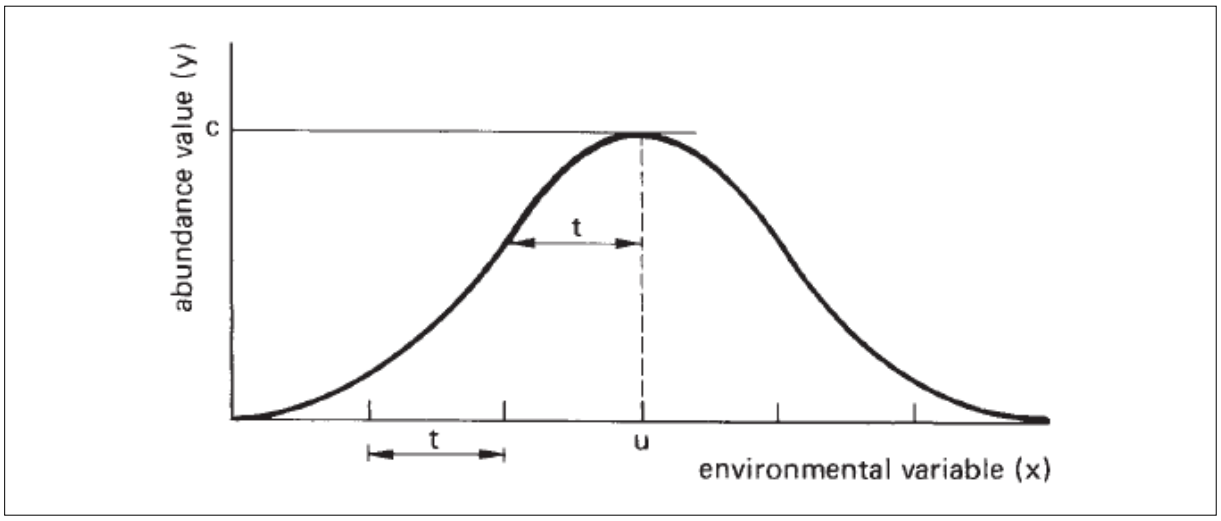


Figure 4.24: The Gaussian curve illustrates the unimodal relationship between a species (y) and an environmental variable (x) using the quadratic function log $y = a - 0.5 (x - u)^2/t^2$, where u = optimum, t = tolerance and c = maximum. Source: Ter Braak & Prentice (1988).

For example Detrended Correspondence Analysis (DCA) is widely used as an indirect gradient analysis for species data following the Gaussian curve. Distortion of the data (e.g. arch effect and compression at the axes) by the underlying quadratic mathematical relationship is prevented by dividing the first axis into segments and re-centering of samples on the axis. The axes are scaled in units of mean standard deviation (SD) of species turnover; for example a complete compositional turnover of a sample occurs in 4 SD (Eilertsen, 1990;

Kent & Coker, 1992). In this way the samples are shifted to equalize beta-diversity, which makes DCA ordination a useful tool for the measurement of beta-diversity (Palmer, 2011).

As a result, DCA ordination is used to test which indirect ordination technique suits the western Central Bushveld floristic data, and to determine beta-diversity across the Quarter Degree Grids of the study area.

4.7.2.2 Performance of indirect ordination methods for the floristic analysis

Good performance of an ordination means first of all ***accuracy***, namely the results should mirror correctly the underlying structure, and secondly ***consistence*** in the results for replicate samples (Wilson, 1981).

Therefore three criteria were chosen to determine the right ordination technique for the floristic data of this study: (1) the amount of variance explained by the ordination axes (Wilson, 1981; Mathema, 2005), (2) the length of the DCA ordination axes as a measure of how unimodal the response is (Mathema, 2005), and (3) the consistency of floristic groupings across the different hierarchical levels of plant taxa.

VARIANCE EXPLAINED BY THE ORDINATION METHODS

Figure 4.25 illustrates the ability of the two indirect ordination methods to describe the existing variance in the floristic data. For this the eigenvalues of the first four ordination axes were plotted for unstandardized and standardized data at species, genus and family level.

The graphs clearly demonstrate that PCA is more suitable to explain floristic similarities of the samples (QDGs) than DCA, especially for increasing hierarchical level of plant taxa, but also for standardized data.

The higher the percentage of variance explained by the ordination axes, especially where more of the information is concentrated on the first axis, the better the ordination performs (Wilson, 1981). For unstandardized higher and standardized plant taxa data the PCA eigenvalues are larger than the DCA eigenvalues, and show a marked concentration for the first ordination axis. Only the unstandardized species data shows DCA eigenvalues larger than PCA eigenvalues, due to following a unimodal response curve. For that reason PCA is

regarded as the suitable ordination method for exploring floristic patterns across the western Central Bushveld.

GRADIENT LENGTH AS A MEASURE OF UNIMODALITY

The unimodal model has been approved to be the ecologically more realistic method to describe the response of species to environmental factors (Kent & Coker, 1992; Mathema, 2005; Palmer, 2011). Therefore, Detrended Correspondence Analysis (DCA) is at present the most widely used ordination technique (Eilertsen, 1990).

However, standardization reduces the gradient length, implying that standardization decreases the unimodal response of species along environmental gradients in the study area (table 4.2). Mathema (2005) advocates the use of linear methods (PCA) rather than unimodal methods if DCA ordination axes are shorter than 4 SD. In view of the fact that the gradient lengths are generally well below 4 SD particularly at higher taxa levels, PCA was chosen to explore the floristic patterns of plant taxa in the western Central Bushveld was selected. Studies of Del Moral (1980) and Kessel & Whittaker (1976) proofed that PCA ordination gives reliable results if beta-diversity is low.

Table 4.2: Gradient length obtained from DCA ordination in units of standard deviation (SD)

DCA Gradient	Axis 1	Axis 2	Axis 3	Axis 4
Species Unstandardized	3,137	**5,494**	**7,477**	**8,274**
Species 'Centroid Grid'	2,397	1,594	2,530	1,451
Species 'Integrated Grid'	2,104	1,861	1,628	1,481
Genera Unstandardized	2,110	2,682	2,813	4,271
Genera 'Centroid Grid'	1,872	1,289	1,765	1,221
Genera 'Integrated Grid'	1,460	1,820	1,077	0,970
Families Unstandardized	2,359	2,011	2,343	1,308
Families 'Centroid Grid'	1,557	1,560	0,984	1,129
Families 'Integrated Grid'	1,208	1,440	0,987	0,739

CONSISTENCY OF FLORISTIC GROUPINGS

Test graphs have been created for the plant data of the different taxonomic levels using both PCA and DCA ordination. PCA ordination resulted in ordination graphs showing distinct floristic groupings, which are relatively consistent from species through to family level. On

the other side, DCA ordination proofed neither to show clear floristic groupings, nor consistency in the grouping of samples.

4.7.2.3 Principal Component Analysis

Based on the ordination performance test above, PCA was employed to look for floristic spatial patterns across the western Central Bushveld Bioregion. In order for the ordination to show the true floristic pattern, the option ‘center and standardize’ for the sample data has been chosen as advised by Mohler (1981) and Palmer (2011). The default option center by species would result in giving all species the same variation, i.e. the standard deviation of 1, and thus wouldn’t discriminate samples according to the true underlying floristic variation; for example it would not consider a species occurrence of 1,000 more variable than 200 (Palmer, 2011). Furthermore, species centered PCA leads to a misplacement of samples and thus to a distortion of the true sample pattern (Del Moral, 1980; Mohler, 1981).

4.7.2.3 Detrended Correspondence Analysis

Although DCA didn’t perform well for the exploration of spatial patterns of the western Central Bushveld flora, the ordination method was used to look at the compositional diversity (beta-diversity) of the study area at different levels of taxonomic organization.

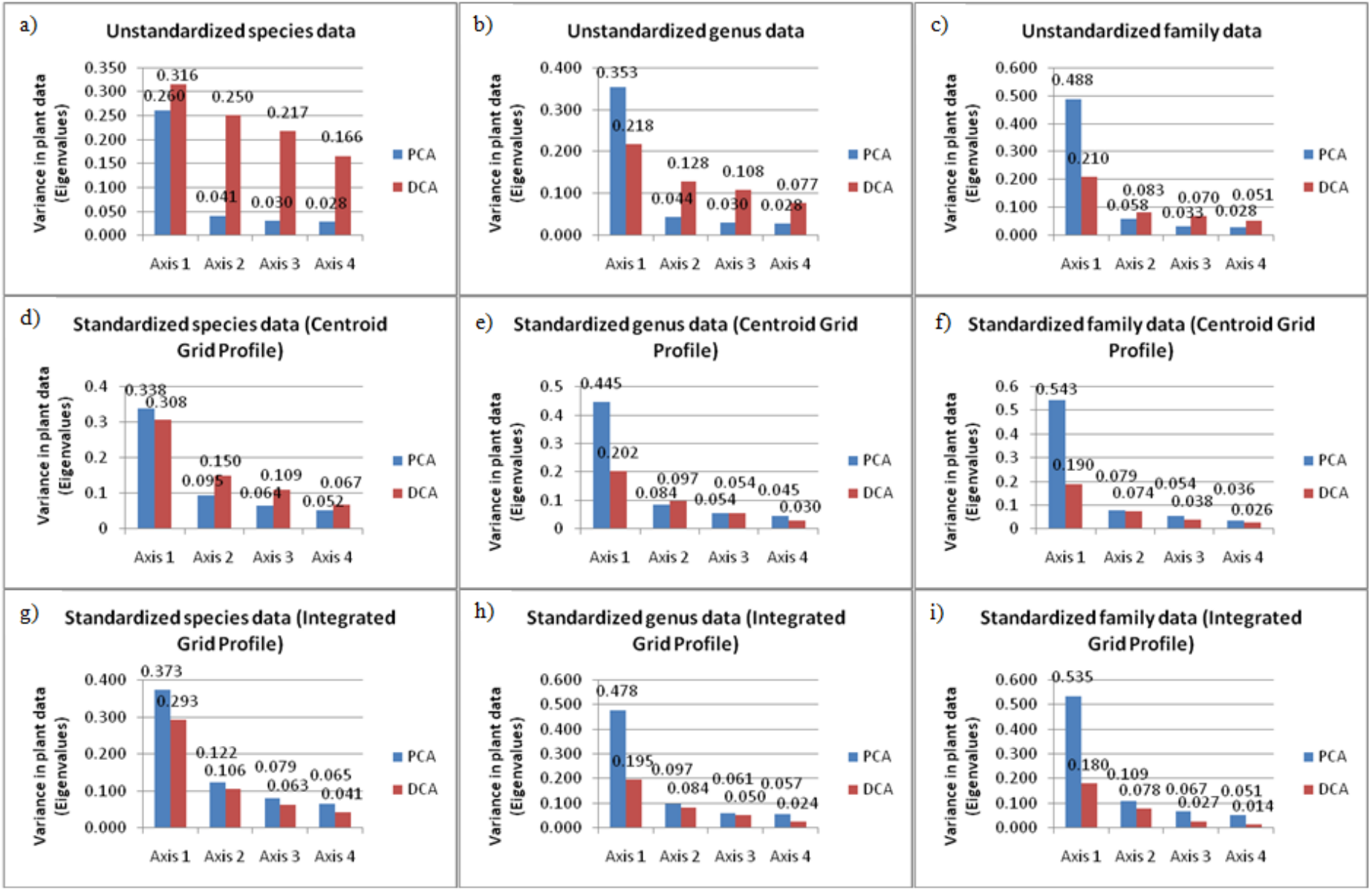


Figure 4.25: Performance of the indirect ordination methods PCA and DCA for explaining the variance of the floristic data from species to family level

4.7.3 Spatial analysis

4.7.3.1 Interpolation

Spatial analysis has been performed to illustrate the distribution of phyto-diversity in the western Central Bushveld Bioregion in the form of plant richness maps. Richness maps have been created by interpolation of the generated floristic data in ArcMap 10 (ESRI, 2010). The spatial analysis covered unstandardized and standardized data for the different plant taxa.

The first step in creating phyto-diversity maps was to digitize the grid system of the study area and responding grid points to feed them with the floristic data for spatial analysis. Two different grids were generated using the 'Create Fishnet' option of the 'Data Management Tool' in the ArcTool Box, namely the 'QDG_Centroid' and 'QDG_Integrated' representing the two different spatial standardization methods.

In the following step the floristic data of each dataset (unstandardized, 'Centroid Grid' and 'Integrated Grid' profile) was extracted from the data matrices. This was done by summing the plant taxa presence data for each grid point. Then the floristic data of each dataset was manually loaded into the attribute table of the respective grid layer by adding new fields for the different plant taxa.

The unstandardized and 'Centroid Grid' data has been added to the 'QDG_Centroid' layer as they share the same spatial reference, whereas the 'Integrated Grid' data has been treated in two different ways. First, the data that integrates floristic information of four QDGs into a shared grid point has been entered into the attribute table of the 'QDG_Integrated' layer. And second, the data that integrates floristic information on QDG level due to overlap of floristic data from the 'Integrated Grid' profile was entered into the attribute table of the 'QDG_Centroid' layer.

Grid points that contain zero values as they fall outside the study area were deleted from the attribute tables. Interpolation test runs have shown that zero values negatively influence the outcome of the spatial analysis.

Then the floristic data was interpolated using the 'Inverse Distance Weight' (IDW) of the ArcMap spatial analyst tool. The IDW method assumes that each measured point has a local influence that decreases with distance; thus IDW interpolates the variable to be mapped by

giving points closer to the prediction location a greater weight than those further away (ERSI, 2010).

The interpolated data has been classified according to 'Natural Breaks (Jenks)', which defines class breaks based on natural groupings inherent in the data; features are divided into classes by best grouping similar values and setting boundaries where there are big differences in the data values, so as to maximize the differences between the groups (ESRI, 2010).

4.7.3.2 Correlation with environmental factors

The observed spatial distribution of plant taxa in the western Central Bushveld has been correlated with various environmental factors. Analysis has been performed using the zonal spatial analyst tool in ArcMap 10 (ESRI, 2010).

Only the unstandardized plant interpolation raster maps were used for the analysis, as they represent the current observed plant distribution pattern in the real world. Floristic patterns have been correlated with the following environmental factors: temperature, rainfall, evaporation, geology, soil, terrain morphology, landcover and landuse. The climate feature datasets were downloaded from the Agricultural Geo-referenced Information System homepage (AGIS, 2010); while the other spatial feature datasets were obtained from the Environmental Potential Atlas issued by the Department of Environmental Affairs and Tourism (Breedlove & Jordaan, 2001).

First, the correlation between environmental factors and floristic patterns was displayed graphically using the 'Zonal Statistics' tool. It computes statistics on the values of a raster within the zones of another raster or a feature dataset, and plots the output as a zonal statistics raster (ESRI, 2010). ESRI (2010) defines a zone as all areas within the input spatial data that share the same value. The statistics type selected for the analysis was the mean, as it summarizes the average number of plant taxa present for each zone of an environmental factor. Second, the 'Zonal Statistics as Table' tool has been used to give information on the minimum, maximum and mean number of plant taxa for each zone, in order to outline the range of plant taxa richness for each zone and to identify the zones with the highest plant taxa richness.

4.7.3.3 Hotspot analysis

Hotspot analysis was applied to identify Important Plant Areas (IPAs) for conservation. IPAs were categorized either as areas of exceptional floristic richness, or as sites that provide habitat for a wide variety of threatened species in compliance with the criteria set out by Plantlife International (2004). Conservation hotspots were identified by the degree of endangerment from human environmental change. For the context of this study human threat was defined as existing threats that originate from the current landuse patterns, and as future threats from a likely expansion of cultivation on still unused soils with agricultural potential.

The richness hotspots (species, Red Data and endemic) were digitized from the unstandardized species interpolation maps (figure 5.37a, 5.40a and 5.41a; chapter 5). Conservation hotspot analysis was performed by overlaying the relevant GIS layers using the 'Intersect' and 'Union' tool in ArcMap 2010 (ESRI, 2010).