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Preliminary floristic analysis of the major biomes in southern Africa

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Keywords: biomes, Desert, Fynbos, Grassland, Karoo, Nama-Karoo, Savanna, species diversity, Succulent Karoo

ABSTRACT

Over 24 000 plant taxa are known to occur in the southern African flora, which is extraordinarily rich on a species/area basis. Lists of species and infraspecific taxa recorded for the six major biomes, Fynbos, Savanna, Grassland, Nama-Karoo, Succulent Karoo and Desert, were obtained from the PRECIS specimen database. These lists were analysed by numbers of unique and shared species and infraspecific taxa, by differential occurrence and life forms of large genera, and by differential occurrence of families. Each biome is floristically distinct except Nama-Karoo. The biomes form two main groupings, those with winter rainfall and those with summer rainfall. Succulent Karoo is most similar to Fynbos and Nama-Karoo is most similar to Savanna.

UITTREKSEL

Dit is bekend dat meer as 24 000 planttaksons in die suider-Afrikaanse flora voorkom, wat op 'n spesies/area-grondslag buitengewoon ryk is. Lyste van spesies en infraspesifieke taksons van die ses hoofbiome, Fynbos, Savanne, Grasveld, Nama-Karoo, Sukkulente Karoo en Woestyn, is vanaf die PRECIS-eksemplaardatabasis verkry. Hierdie lyste is ontleed in terme van unieke en gemeenskaplike spesies en infraspesifieke taksons, differensiële voorkoms en lewensvorme van groot genusse, en die differensiële voorkoms van families. Elke bioom behalwe Nama-Karoo, is floristies kenmerkend. Die biome vorm twee hoofgroeperings, dié met winterreënval en dié met somerreënval. Sukkulente Karoo toon die meeste ooreenkoms met Fynbos en Nama-Karoo toon die meeste ooreenkoms met Savanne.

CONTENTS

INTRODUCTION

The southern African flora is extremely species-rich in terms of species/area ratios, with 0,0081 species/km^2 overall (Figure 1). This value is higher than those recorded for humid tropical floras such as Brazil (0,0044) and Asia (0,0041) (Gibbs Russell 1985b). The winter rainfall Cape Floral Kingdom is well known to be extremely species-rich (Goldblatt 1978). However, even when the Cape flora is excluded from calculation, the species/area ratio for the rest of the southern African flora (0,0061) is still considerably higher than that of the humid tropics, and nearly twice that of Australia (0,0032), which also includes both tropical and temperate areas.

These species/area ratios indicate in a superficial way that the remarkable species richness of the southern African flora is not restricted to the Cape Floral Kingdom. The aim of this study is to investigate the floristic richness of the major biomes and to explore floristic relationships between these biomes using distribution data for families, genera and species.

At the present time, the PRECIS (Pretoria National Herbarium Computerized Information System) specimen database is by far the most comprehensive source of information on the distribution of plant taxa in southern Africa. Although PRECIS has certain limitations (see Methods), this preliminary study forms a base against which more detailed studies of particular biomes can be put in context, and which will allow the generation of hypotheses to guide future studies. A re-evaluation should be done when more complete checklists, based on co-operative herbarium studies and intensive field work, have been compiled for all the biomes.

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FIGURE 1. — Species/area ratios for large regions. The number of species and areas in km^2 for each region follow Gibbs Russell (1985b).

METHODS

This study is based on checklists compiled from PRECIS for quarter degree latitude and longitude grids representing the major biomes for southern Africa. The biomes adopted were determined by superimposing five recent treatments of southern African vegetation using floristic, structural and environmental criteria (Werger 1978; Scheepers 1982 based on Acocks 1975; White 1983; Huntley 1984; Rutherford & Westfall 1986). The resulting composite map showed six major regions that were recognized as entities, even though none of the studies agreed on exact boundaries. Elimination of all areas of disagreement, and of areas smaller than a quarter degree, yielded the regions accepted as the core biomes for this investigation (Figure 2). Important environmental characteristics of the core biomes are shown in Table 1.

The lack of agreement between the treatments occurred at three levels: 1, exact boundaries at quar-

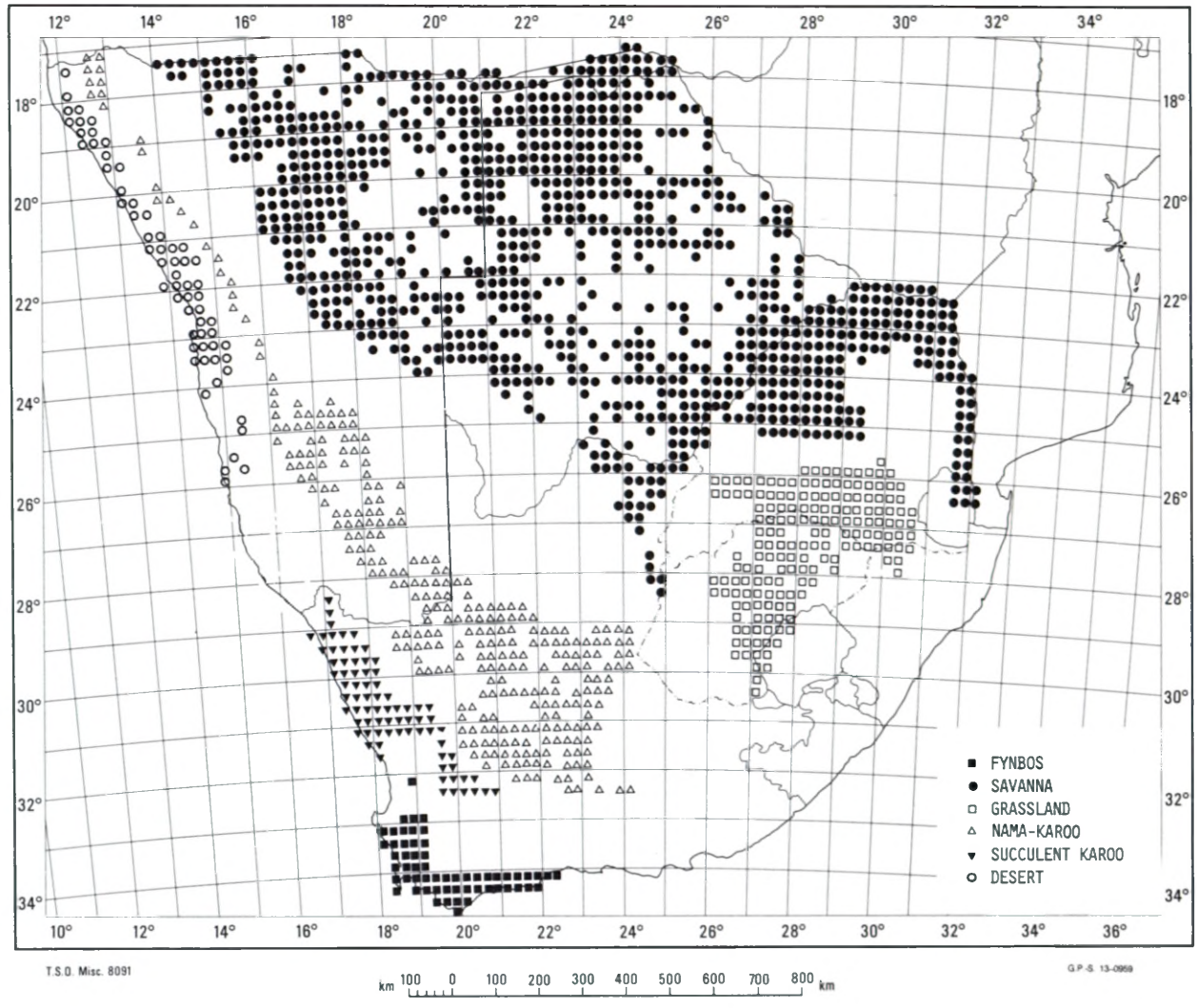

FIGURE 2. — Quarter degree grids searched in PRECIS for each biome.

TABLE 1.—Characteristics of the biomes

Biome	Rainfall amount*	Rainfall season*	Dominant life forms*	Structural characteristics
Fynbos	Mesic (210–3 000 mm)	Winter	Chamaephytes Phanerophytes Cryptophytes	Evergreen sclerophyllous heathland and shrubland†
Savanna	Mesic (above 235 mm)	Summer	Hemicryptophytes Phanerophytes	Wooded C_4 grasslands†
Grassland	Mesic (400–2 000 mm)	Summer	Hemicryptophytes	Grassland, woody plants absent or rare†
Nama-Karoo	Arid (100–520 mm)	Summer (to all year)	Chamaephytes Hemicryptophytes	Dwarf and low open shrublands†
Succulent Karoo	Arid (20–290 mm)	Winter (to all year)	Chamaephytes	Dwarf and low open succulent shrublands†
Desert	Arid (13–70 mm)	Summer	Therophytes	Ephemeral, with many annuals

* Rutherford & Westfall (1986)
† Huntley (1974)

ter degree scale; 2, areas of transition between karroid and savanna regions; and 3, areas of complicated vegetation relationships, such as the eastern Transvaal, Natal and the eastern Cape. The two 'karroid' biomes accepted here were recognized at the highest level of classification only by Rutherford & Westfall (1986), on grounds of differences in dominant plant life form and environmental conditions. Their Succulent Karoo Biome roughly coincided with the Western Cape Domain of the Karoo-Namib Region defined by Werger (1978) at a secondary level of classification on phytochorological grounds. The other three vegetation studies treated the entire karroid vegetation as a single entity at the highest level. In this investigation, Succulent Karoo was separated from Nama-Karoo, and a secondary aim of the study was to examine the floristic relationship between them.

Besides the six core biomes adopted for this study, all the treatments recognized the high altitude vegetation of the Drakensberg, and the forests of the southern Cape. However, these small irregularly shaped areas were not accessible to computer search at the scale of quarter degree grid reference, and could therefore not be included.

The PRECIS specimen database records label information for ± 610 000 specimens in the National Herbarium (PRE). The overall operation and implementation of PRECIS have been reported several times (Gibbs Russell & Gonsalves 1984; Gibbs Russell 1985a). More recently, new programming has allowed compilation from the database of checklists of plant species and infraspecific taxa from any combination of quarter degree grids. Several special programmes were written to compare the checklists by providing lists of unique taxa, lists of shared taxa, and a matrix of all taxa with the biomes from which they were recorded.

The total numbers of unique and shared taxa, obtained by employing these programmes, were used to calculate Sorenson's (1948) coefficients of similarity, and percentages of unique taxa and taxa shared between biomes. The ranking of families for each biome, the identification of widespread taxa, and the determination of centres of diversity for 'large' genera with 10 or more species and infraspecific taxa were obtained by manual searches of printout. A biome was considered to be a centre of diversity for a genus if it contained 50% or more of the taxa reported for the genus. In a few cases, slightly less than half (to 45%) was accepted in biomes of low collecting intensity. Life forms follow the definitions of Raunkiaer (1934) as stated by Rutherford & Westfall (1986), but with the inclusion of 'Succulent', and were determined from Dyer (1975, 1976) and herbarium specimens. At all stages of work, doubtful records encountered on PRECIS listings were checked in PRE.

An inherent weakness in the method used is the uneven collecting intensity for the different biomes. Gibbs Russell *et al.* (1984) showed that the collecting intensity represented in PRECIS for the eastern and southern mesic areas is far higher than for the western arid areas. Therefore, the checklists used here undoubtedly differ in completeness, and it must be emphasized that these results are preliminary. Table 2 illustrates the differences in collecting intensity between the biomes by comparing the specimens and the taxa per km^2 as well as the specimens per taxon recorded in PRECIS for each biome. Although Fynbos, and to a lesser degree Grassland, appear to be better collected than the other biomes on a specimens/km^2 or taxa/km^2 basis, Savanna in fact exhibits more 'repeat' collections than either. However, it is apparent that mesic Fynbos, Savanna and Grassland are better collected than arid Nama-Karoo, Succulent Karoo and Desert.

PRECIS is known to have errors in about 7% of specimen identifications and quarter degree grid references. Until these errors can be corrected, an ongoing process in system management, results must be used with discretion. In this study, identifications directly from PRECIS are used only at the level of family and genus, while at the level of species and infraspecific taxa, only total numbers, and not identifications, are used unless the records were checked

TABLE 2.—Collecting intensity reported from PRECIS for each biome. Area was determined from the number of quarter degree grids searched (and 'average' quarter degree covers 666 km²)

	No. specimens	No. taxa	Area (km²)	Specimens/km²	Taxa/km²	Specimens/taxon
Fynbos	52650	7316	36628	1,36	0,19	7,2
Savanna	50460	5788	632034	0,08	0,01	8,7
Grassland	27685	3788	111888	0,25	0,03	7,3
Nama-Karoo	7685	2147	198468	0,04	0,01	3,6
Succulent Karoo	6484	2125	50616	0,13	0,04	3,1
Desert	1334	497	41292	0,03	0,01	2,7

in PRE. For the same reason, distribution is given only at biome level, and not to individual quarter degree grids.

Despite the limitations imposed by differences in collecting intensity and by the accuracy of individual PRECIS records, at the present time PRECIS is the most reliable and complete source of information about the distribution of taxa throughout the southern African flora. Publication of these preliminary results is therefore considered worthwhile.

Throughout the study, the number of species and infraspecific taxa, rather than species alone, were used in comparisons because of taxonomic uncertainty about the correct level of treatment for many of these entities, as explained in detail in Gibbs Russell (1985b). For the sake of brevity, the term 'taxa' in this context is used in place of the longer phrase 'species and infraspecific taxa'.

RESULTS AND DISCUSSION

Area, taxa and specimens

The area, taxa and specimens covered in this study are summarized in Table 3. The five recent vegetation treatments used to determine the biomes for this study agreed on about 40% of the total area of southern Africa at a scale available for computer search. About 60% of all southern African taxa represented in PRECIS were reported from the area designated. Certain taxa were not included in the study for the following reasons: 1, they are known only outside the areas of the core biomes; 2, they are not represented in PRECIS; or 3, they are represented in PRECIS, but the distribution is not recorded as a quarter degree grid. Only about 25% of the specimens in PRECIS are reported in the study. This low figure results from the uneven collecting intensity in the National Herbarium mentioned above.

TABLE 3.—Total size of sample reported for all biomes

Number of specimens	146 298
Out of 610 000 in PRECIS	24%
Out of ±2 000 000 in southern African herbaria	7%
Number of taxa	14 391
Out of 24 000 in southern Africa	60%
Area covered (1 611 quarter degree grids @666 km² per quarter degree)	1 072 926 km²
Out of 2 573 000 km² for southern Africa	42%

Comparison of biomes by numbers of species and infraspecific taxa

Widely differing numbers of taxa have been recorded for the six biomes, and the differences in taxon numbers are not related to the area sampled (Table 2). Fynbos has the most taxa although it is the smallest in area. Savanna, which covers by far the largest area, has about 1 500 fewer taxa than Fynbos. Similarly, Grassland has about 1 700 more taxa than Nama-Karoo, although Nama-Karoo covers about twice the area of Grassland. Nama-Karoo and Succulent Karoo have similar numbers of taxa, but Nama-Karoo covers about four times the area of Succulent Karoo. The number of taxa recorded for Desert is extremely low even though its area is slightly larger than that of Fynbos.

The checklists for each biome were compared both by Sorenson's (1948) coefficient of similarity, and by percentage comparisons within each biome. Sorenson's coefficients give comparable values for checklists of different length. Low Sorenson's coefficients signify low similarity between lists of taxa, while higher values show a greater similarity. The percentage comparisons show the proportion of taxa within each biome that are unique and that are shared with other biomes.

Sorenson's coefficients of similarity

The Sorenson's coefficients of similarity between the six major biomes are shown in Figure 3. The values for the coefficients are generally low (30 or less), indicating that each biome has its own flora which is quite distinct from that of the others. The exception is the coefficient between Savanna and Grassland, which is considerably higher than any other.

For Savanna, the highest Sorenson's coefficients occur with Grassland and with Nama-Karoo, and the values are low (less than 20) for the other biomes. Grassland, which has the strongest similarity to Savanna, has very low Sorenson's coefficients with Desert and with Succulent Karoo, and somewhat higher values with Fynbos and Nama-Karoo. Desert has very low values with all biomes except Nama-Karoo. Fynbos has low Sorenson's coefficients with all biomes except Succulent Karoo. Succulent Karoo and Nama-Karoo show opposite relationships. Excluding the Sorenson's coefficient between the two 'karroid' biomes, Succulent Karoo has its highest value with Fynbos, and very low values with Desert,

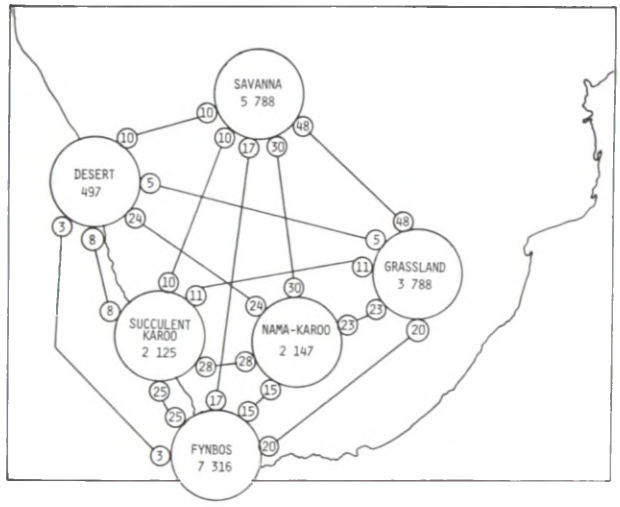

FIGURE 3. — Number of taxa and Sorenson's coefficients of similarity for the biomes. The number in each large circle is the number of species and infraspecific taxa reported for the biome. The number in each small circle is the Sorenson's coefficient of similarity between pairs of biomes.

Savanna and Grassland, whereas Nama-Karoo has its highest value with Savanna, high values with Desert and Grassland, and a low value with Fynbos.

Percentages of unique and shared taxa

The percentages of taxa unique to each biome and shared between biomes are shown in Figure 4. The biomes vary greatly in percentages of unique taxa. Fynbos has the highest percentage (which is consistent with a value of 68% given by Bond & Goldblatt (1984)), and Savanna is also well above the others. Grassland and Succulent Karoo are similar, and Desert and Nama-Karoo have similar and very low percentages of unique taxa.

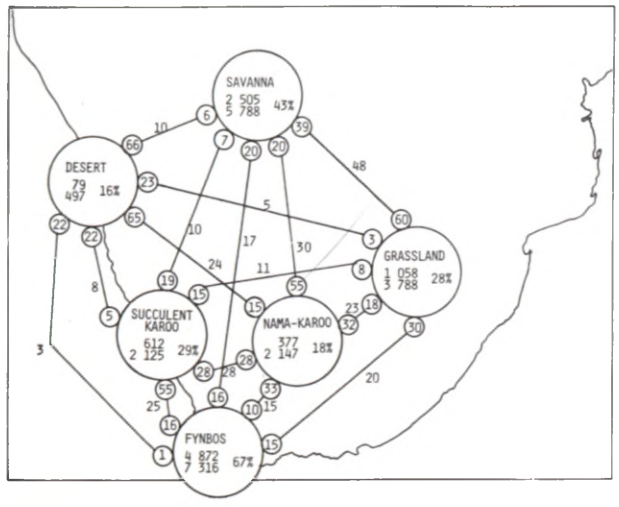

FIGURE 4. — Number and percentage of species and infraspecific taxa unique to and shared between biomes. In each large circle, the upper number is the number of unique taxa, the lower number is the total number of taxa for the biome, and the percentage is the percentage of taxa unique for the biome. The number in each small circle is the percentage of taxa shared between pairs of biomes, and the number on the line connecting a pair is the Sorenson's coefficient of similarity.

The percentage of taxa shared between the biomes amplifies the relationships shown by the Sorenson's coefficients. The few apparent contradictions result from comparing taxon lists of very different length: where one list is long and the other short, the percentage of shared taxa differs markedly from the Sorenson's values.

The close floristic relationships between Savanna and Grassland and Savanna and Nama-Karoo shown by the Sorenson's coefficients are borne out by the high percentage of Grassland and Nama-Karoo taxa that is shared with Savanna. Savanna itself shares most taxa with Grassland, shares the same percentage of its taxa with Nama-Karoo as with Fynbos, and shares a very low percentage of its taxa with Succulent Karoo and Desert. Grassland shares a very high percentage of its taxa with Savanna, and is similar to Savanna in that its lowest percentage of shared taxa is with Succulent Karoo and Desert, but Grassland shares a considerably higher percentage of taxa with Fynbos than with Nama-Karoo. Desert, which because of its small flora shows very low Sorenson's values with all biomes except Nama-Karoo, shares about the same very high percentage of its taxa with Savanna as with Nama-Karoo. Desert has a very low percentage of unique taxa, and shares more than 20% of its taxa with Grassland, with Succulent Karoo and with Fynbos. In contrast, Fynbos, which has a high percentage of unique taxa, does not share more than 20% of its taxa with any other biome. The close relationships of Succulent Karoo to Fynbos and of Nama-Karoo to Savanna, already indicated by Sorenson's coefficients, are borne out by the high percentage of Succulent Karoo taxa shared with Fynbos, and the high percentage of Nama-Karoo taxa shared with Savanna. Both of the 'karroid' biomes share the lowest percentage of taxa with Desert and an intermediate percentage with Grassland.

Comparison of biomes by important families and large genera

Differential occurrence of important families

Forty-six families comprise 1% or more of the taxa in at least one biome. In each biome there are between 22 and 28 families that comprise 1% or more of the taxa, and that together account for between 55 and 60% of the total number of taxa. Each of these families can be used to distinguish and/or link the biomes (Table 4).

In order to compare the biomes in this way, these important families are ranked for every biome by number of taxa from largest (rank of 1) to smallest (rank of 22 to 28). Ranking is necessary for comparison at family level because the biomes differ so greatly in number of taxa. A family well represented in a species-poor biome may in fact have fewer taxa in that biome than the same family has in a biome with a rich flora, even though the family is a negligible component of the more species-rich biome (Gibbs Russell 1975, 1985b). The families are ranked in three groups in the discussion: the largest families (1–3 in bold type in Table 4); the next rank (4–10 in italics in Table 4); and the lowest rank (from

11 onwards in roman type in Table 4). The biomes are characterized by the presence, absence or difference in rank of certain large families, and the occurrence of some families can be linked to simple environmental parameters characteristic of certain combinations of biomes.

The seven plant families that comprise 1% or more of the taxa in all of the biomes are shown in Table 4a. Three families, Asteraceae, Poaceae and Fabaceae are the three largest in all biomes (with the exception of Poaceae in Succulent Karoo and Fynbos), and either Asteraceae or Poaceae is the largest family in all biomes. Asteraceae and not Poaceae is the largest family in Grassland.

The six biomes are briefly discussed in turn below:

Fynbos (Table 4b) is distinguished by eight families that are important in no other biome. Of these, Ericaceae is one of the three largest families, and

TABLE 4.—Families represented by more than 1% of the total number of taxa in any one of the biomes. Sv, Savanna; G, Grassland; D, Desert; N-K, Nama-Karoo; SK, Succulent Karoo; F, Fynbos. The number in the matrix is the rank according to number of taxa in the family in a given biome, with '1' signifying the largest family in the biome

	Sv	G	D	N-K	SK	F
4a. Families comprising more than 1% of the total number of taxa in all biomes						
Asteraceae	3	1	2	1	1	1
Poaceae	1	2	1	2	*4*	*5*
Fabaceae	2	3	3	3	3	2
Liliaceae	*5*	*4*	*10*	*4*	*5*	*7*
Scrophulariaceae	*10*	*6*	*7*	*5*	*6*	12
Cyperaceae	*6*	*5*	12	13	20	*9*
Euphorbiaceae	*8*	12	11	*9*	19	24
4b. Families that distinguish Fynbos						
Presence of:						
Ericaceae						3
Restionaceae						*8*
Rutaceae						*10*
Polygalaceae						14
Thymelaeaceae						15
Rhamnaceae						20
Rosaceae						22
Lobeliaceae						28
High rank of:						
Proteaceae					17	*6*
Absence or low rank of:						
Asclepiadaceae	*9*	*7*	13	*10*	15	
Scrophulariaceae	*10*	*6*	*7*	*5*	*6*	12
4c. Families that distinguish Savanna						
Presence of:						
Verbenaceae	21					
High rank of:						
Rubiaceae	*4*	11				
Absence of:						
Mesembryanthemaceae		13	*8*	*8*	*7*	13
4d. Families that distinguish Grassland						
High rank of:						
Orchidaceae	14	*8*				11
Lamiaceae	11	*9*		20		
Absence of:						
Sterculiaceae	16		14	11	14	27
Aizoaceae	15		*4*	*7*	*8*	23
4e. Families that distinguish Nama-Karoo						
No families form more than 1% of flora only in Nama-Karoo.						
No families have high rank only in Nama-Karoo.						
No families are absent only from Nama-Karoo.						
4f. Families that distinguish Succulent Karoo						
High rank of:						
Iridaceae	17	*10*		14	2	*4*
Crassulaceae		14		12	*9*	19
Geraniaceae			23	16	*10*	16

	Sv	G	D	N-K	SK	F
4g. Families that distinguish Desert						
Presence of:						
Pedaliaceae			17			
Burseraceae			20			
High rank of:						
Chenopodiaceae			*5*	15	18	
Capparaceae			*9*	24		
Absence of:						
Iridaceae	17	*10*		14	2	*4*
4h. Families that link summer rainfall biomes						
Presence of:						
Acanthaceae	*7*	19	*6*	*6*		
Malvaceae	12	17	21	19		
Lamiaceae	11	*9*		20		
Cucurbitaceae	19		22	22		
Amaranthaceae	18		16			
Rubiaceae	*4*	11				
Convolvulaceae	13	15				
Anacardiaceae	20	20				
Solanaceae		22	19	21		
Capparaceae			*9*	24		
Boraginaceae			18	23		
4i. Families that link winter rainfall biomes						
Presence of:						
Proteaceae					17	*6*
Oxalidaceae					11	21
Campanulaceae					21	18
Low rank of:						
Poaceae	1	2	1	2	*4*	*5*
Euphorbiaceae	*8*	12	11	*9*	19	24
4j. Families that link arid biomes						
Presence of:						
Chenopodiaceae			*5*	15	18	
Zygophyllaceae			15	17	22	
High rank of:						
Aizoaceae	15		*4*	*7*	*8*	23
Mesembryanthemaceae		13	*8*	*8*	*7*	13
4k. Families that link Grassland and/or Nama-Karoo to Succulent Karoo and/or Fynbos						
Presence of:						
Crassulaceae		14		12	*9*	19
Brassicaceae		23		18	13	25
Selaginaceae		21		25	12	26
Geraniaceae			23	16	*10*	16
Amaryllidaceae		16			16	
Apiaceae		18				17
High rank of:						
Iridaceae	17	*10*		14	2	*4*
Orchidaceae	14	*8*				11

Restionaceae, Rutaceae and Proteaceae among the ten largest families in Fynbos only. In contrast, Asclepiadaceae is not important, and only in Fynbos is Scrophulariaceae not one of the ten largest families. *Savanna* (Table 4c) is distinguished by one important family, Verbenaceae, one family, Rubiaceae, that ranks among the ten largest in no other biome, and one family, Mesembryanthemaceae, that does not occur among the important families. *Grassland* (Table 4d) is distinguished by the high rank of Orchidaceae and Lamiaceae, which are among the ten largest families only in this biome, and only here are Sterculiaceae and Aizoaceae absent from the important families. *Nama-Karoo* (Table 4e) is the only biome which is not distinguished from the others by differential occurrence of families. *Succulent Karoo* (Table 4f) is distinguished by the high rank of Iridaceae, which is one of the three largest families, and Crassulaceae and Geraniaceae, which are among the ten largest families only in this biome. *Desert* (Table 4g) is distinguished by the occurrence of Pedaliaceae and Burseraceae as important families, by the occurrence of Chenopodiaceae and Capparaceae among the ten largest families, and by the absence of Iridaceae as an important family.

A number of families indicate floristic relationships between biomes with different rainfall seasonality and amount. The four summer rainfall biomes (Table 4h) are variously linked by 11 families that do not occur as an important component of the winter rainfall biomes. Winter rainfall biomes (Table 4i) are linked by the occurrence of three families, Proteaceae, Oxalidaceae and Campanulaceae, that are not important in summer rainfall areas, and one family, Poaceae, that ranks first or second in summer rainfall biomes, but has a lower rank in the winter rainfall areas.

In contrast to the above groupings based on rainfall seasonality, other families link biomes with similar amounts of rainfall. The arid biomes are linked by four families (Table 4j). Chenopodiaceae and Zygophyllaceae are important, and Aizoaceae and Mesembryanthemaceae are among the ten largest families only in the arid biomes. Finally, a group of six families, all with low ranking, weakly links the summer rainfall biomes Grassland and Nama-Karoo to the winter rainfall biomes (Table 4k). Savanna is not linked to the winter rainfall biomes at family level.

Centres of diversity of large genera

The large genera (with 10 or more taxa) with centres of diversity in one, two or three biomes are listed in Appendices 1–3. The large genera with no apparent centre of diversity are listed in Appendix 4. Figure 5 summarizes this information by showing the numbers and percentages of large genera with centres of diversity within and shared between the biomes.

Only in the case of Fynbos and Savanna are more than half the large genera centred in a single biome, whereas each of the other four biomes shares more than half its large genera with another biome. The highest number of large genera have their centre of

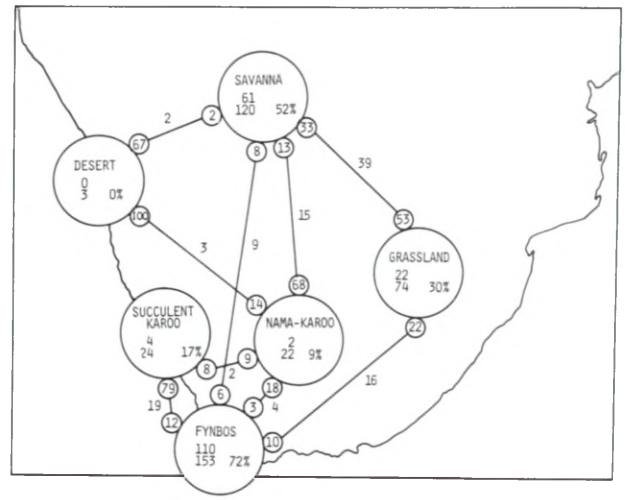

FIGURE 5. — Number and percentage of large genera (10 or more taxa) with centres of diversity in each biome and shared between biomes. In each large circle, the upper number is the number of large genera with a centre of diversity only in that biome, the lower number is the total number of large genera with a centre of diversity in that biome, and the percentage is the percentage of large genera with a centre of diversity only in that biome. The number in each small circle is the percentage of genera shared between pairs of biomes, and the number on the line between a pair is the number of genera with shared centres of diversity. Absence of linkage lines indicates no large genera in common.

diversity in Fynbos, and 72% of these genera are centred only in Fynbos. Fynbos is a shared centre of diversity for similar numbers of genera with Succulent Karoo and with Grassland, and for low numbers with Savanna and with Nama-Karoo. No genera have centres of diversity in both Fynbos and Desert. In Savanna, as in Fynbos, over half the large genera have centres of diversity in no other biome, and Savanna also shares genera with centres of diversity in four other biomes. No genera have centres of diversity in both Savanna and Succulent Karoo. For Grassland, over half the large genera share their centres of diversity with Savanna, and nearly a quarter share their centres of diversity with Fynbos. Grassland shares large genera only with Savanna and Fynbos, and no genera have centres of diversity in both Grassland and Nama-Karoo, Grassland and Succulent Karoo or Grassland and Desert. A very low percentage of large genera have their centre of diversity in Nama-Karoo alone. Over two-thirds of large genera in Nama-Karoo share their centre of diversity with Savanna, and Nama-Karoo shares genera with centres of diversity in all biomes except Grassland. In Succulent Karoo, a very high percentage of large genera shares a centre of diversity with Fynbos, and a low percentage shares a centre of diversity with Nama-Karoo. Succulent Karoo shares large genera only with Fynbos and Nama-Karoo, and no genera have centres of diversity in both Succulent Karoo and Savanna, Succulent Karoo and Grassland or Succulent Karoo and Desert. Only two genera have their diversity centred in both of the 'karroid' biomes, and this is the lowest percentage of shared large genera for either Nama-Karoo or Succulent Karoo. Only three large genera have a centre of diversity in Desert, and all three are shared with

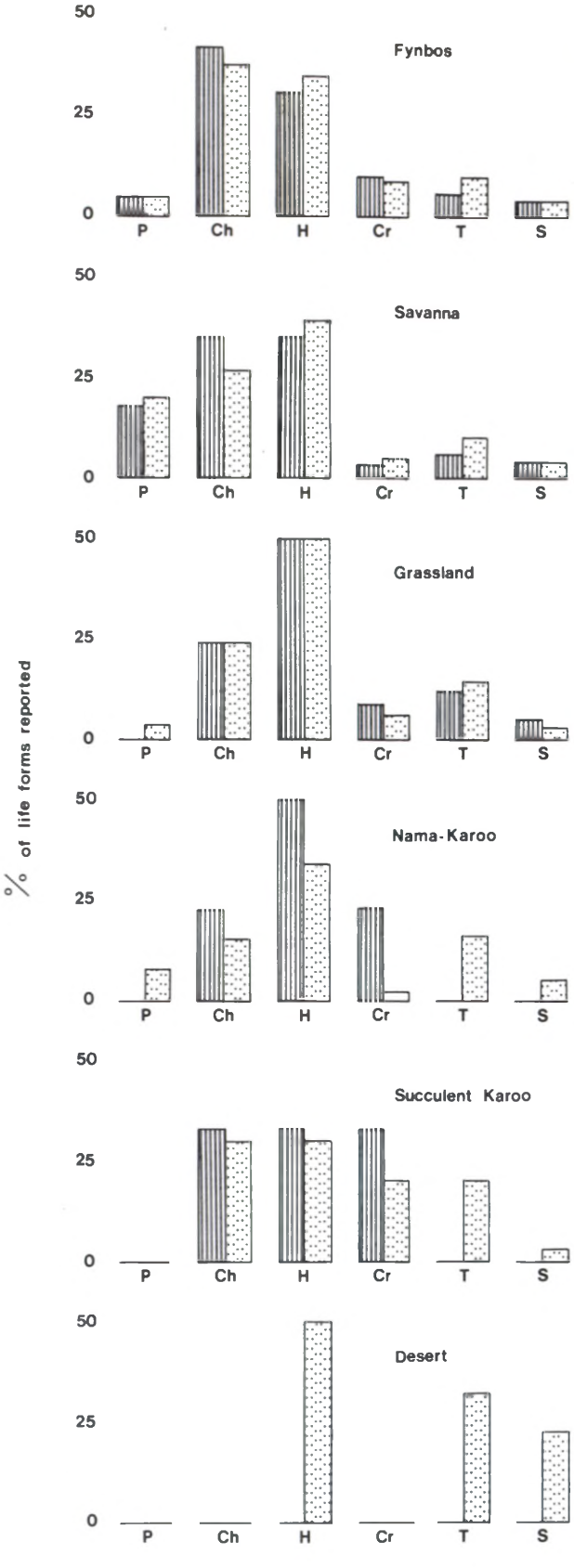

FIGURE 6. — Life form spectra of large genera (10 or more taxa) for each biome. Life forms of genera with centres of diversity only in a particular biome are shown by stripes, and life forms in all genera with centres of diversity in a particular as well as in other biomes are shown by stippling. Life forms are indicated by the following symbols: P = phanerophytes; Ch = chamaephytes; H = hemicryptophytes; Cr = cryptophytes; T = therophytes; S = succulents.

Savanna or with Nama-Karoo. No genera have centres of diversity in both Desert and Grassland, Desert and Succulent Karoo, or Desert and Fynbos.

Life forms and centres of diversity of large genera

Figure 6 shows life form spectra for large genera with centres of diversity either only in one or in more than one biome. The basis for plant classification is that floral characters are conservative at family and genus level, whereas vegetative characters can be variable between members of a higher category. Raunkiaer's life forms indicate broad basic differences in vegetative states, depending on the position of the perennating bud, and indicate differences in utilization of resources. The fact that a genus has many species and infraspecific taxa in a certain biome suggests that the adaptations displayed by the taxa are compatible with the environment of that biome. Thus the differences in characteristics of the genera, as illustrated by life forms, can show convergent adaptations in a number of separate evolutionary lines to the conditions in the biome. However, a centre of diversity for a genus in a particular biome does not imply that speciation occurred either in that biome, or under current environmental conditions.

The biomes are characterized by differences in the life forms reported in the large genera. In Fynbos, chamaephytes are the most commonly reported life form in the large genera. In Savanna, phanerophytes are reported more frequently than in any other biome. For Grassland, nearly half the life forms reported are hemicryptophytes. Grassland differs from Savanna by having fewer phanerophytes and chamaephytes (the woody component), and from Nama-Karoo by having fewer cryptophytes. Nama-Karoo is similar to Grassland, but with more cryptophytes reported among the few genera with their centre of diversity in Nama-Karoo only. Succulent Karoo is remarkable because it has similar values for chamaephytes, hemicryptophytes and cryptophytes. The comparative value for cryptophytes is far higher than for any other biome, and phanerophytes are not reported at all. The life form spectrum for Desert may be misleading because it is based on three genera only, and therefore it is not considered further.

The differences in occurrence of each of the life forms in the biomes can also be examined. Phanerophytes appear only in genera with a centre of diversity in Fynbos or Savanna. Chamaephytes and hemicryptophytes show a basic difference between the summer and the winter rainfall biomes. Chamaephytes are reported most often in winter rainfall Fynbos and Succulent Karoo. Hemicryptophytes are the most abundant life form in the summer rainfall Savanna, Grassland, Nama-Karoo and Desert. Cryptophytes occur in low numbers in all the biomes, but are reported often only in genera with their centre of diversity in Succulent Karoo, and to a lesser extent, Nama-Karoo. Therophytes are reported in all biomes, but are less frequently reported in genera of which the centre of diversity is confined to a single biome, and are more frequently reported in genera with centres in more than one

biome. Succulents are reported in all biomes, but the mesic biomes Fynbos, Savanna and Grassland, have succulents reported in genera with centres in each one, while the more arid Succulent Karoo and Nama-Karoo have succulents reported only in genera with centres of diversity in more than one biome.

Floristic characteristics and relationships of the biomes

Fynbos

Fynbos has the largest number of taxa, the highest percent of unique taxa, the largest number of important families that do not occur in any other biome, and the greatest number of centres of diversity for large genera. At species level, the Sorenson's coefficient of similarity and the percentage of shared taxa show that Fynbos is most closely related to Succulent Karoo, the other winter rainfall biome. At the generic level, Fynbos shares more centres of diversity for large genera with Succulent Karoo than with any other biome. At the family level, Fynbos is linked only to Succulent Karoo by four important families. The less-marked relationship between Fynbos and Grassland will be discussed under Grassland below.

Savanna

Savanna is second to Fynbos in number of taxa, percentage of unique taxa, and in number of centres of diversity for large genera. However, Savanna is distinguished at family level by only three families, while it is linked to the other summer rainfall biomes by eight families. The closest relationship of Savanna is to Grassland, as shown by the very high Sorenson's coefficient of similarity and the percentage of shared taxa, the number of large genera with centres of diversity in both Savanna and Grassland, and the six families that link them, three of which are important only in Savanna and Grassland. A weaker relationship between Savanna and Nama-Karoo is shown by a high Sorenson's coefficient and the percentage of shared taxa, a considerable number of large genera with centres of diversity in both Savanna and Nama-Karoo, and by four families that link them.

Grassland

A moderately large number of taxa is reported for Grassland, which is distinguished by four families. Its relationship with Savanna is the closest demonstrated in this study, as discussed above. Grassland shows similar moderate Sorenson's coefficients with both Nama-Karoo and Fynbos, but other comparisons show that Grassland is in fact more closely related to Fynbos than to Nama-Karoo. The percentage of Grassland taxa shared with Fynbos is far higher than the percentage shared with Nama-Karoo, and a number of large genera, nearly all hemicryptophytes, have centres of diversity in both Grassland and Fynbos, while no large genera have centres of diversity in both Grassland and Nama-Karoo. At family level, Grassland is linked to Nama-Karoo only by families that also link it to Savanna (Table 4h) or to Fynbos (Table 4k), while it is linked independently to Fynbos by two families (Table 4k).

Nama-Karoo

Nama-Karoo is not well defined floristically in this study. At species level, its number of taxa is low, particularly with respect to its large area, and the percentage of unique taxa is very low, hardly higher than that of Desert. Nama-Karoo is the only biome for which all Sorenson's coefficients except one (to Fynbos) are greater than 20. Over half of Nama-Karoo taxa are shared with Savanna, about a third are shared with Grassland and another third with Fynbos. At generic level, few large genera have a centre of diversity in Nama-Karoo, and of these, more have a shared centre of diversity with Savanna, with Fynbos or with Desert than are centred in Nama-Karoo alone. At family level, Nama-Karoo is the only biome that cannot be defined by differential occurrence of important families. It is linked to all the other summer rainfall biomes, and also to the winter rainfall Succulent Karoo through the arid biomes.

Succulent Karoo

The number of taxa reported for Succulent Karoo is similar to that of Nama-Karoo, but the area covered is about a quarter as large, and Succulent Karoo has more unique taxa. It is distinguished from other biomes by three important families. Succulent Karoo is shown by Sorenson's coefficients, by percentage of shared taxa and by centres of diversity of large genera to be related floristically both to Fynbos and Nama-Karoo. The much higher values in every case show that the relationship is strongest to Fynbos (see *Fynbos* above). Over half the Succulent Karoo taxa and over three quarters of the large genera are shared with Fynbos. At family level, the strong links of Succulent Karoo to Fynbos are shown by four families that are important only in these two biomes, whereas at family level Succulent Karoo is linked to Nama-Karoo only through the group of families that links the three arid biomes.

Desert

A very small number of taxa are reported for Desert, and the percentage of unique taxa is lower than for any other biome. There are no large genera with a centre of diversity in Desert alone. However, Desert is distinguished by four important families. Relationships of the Desert flora are shown by Sorenson's coefficients and by the percentage of shared taxa, to be highest with Savanna and with Nama-Karoo, and it is only with these two biomes that Desert shares centres of diversity for large genera. In addition, Desert is linked to Nama-Karoo by ten families, two of which are important only in Desert and Nama-Karoo, and it is linked to Savanna by four families, one of which is important only in Desert and Savanna. Desert is also linked to the arid but winter rainfall Succulent Karoo by four families.

Relationships

The distribution of species, genera and families and the life form spectra shows that the biomes fall floristically into two groups, which correspond to the summer rainfall region (Savanna, Grassland, Nama-Karoo, Desert) and the winter rainfall region (Fynbos, Succulent Karoo). The present analysis of 14 000 taxa therefore supports and extends the 'winter rainfall biome' concept first put forward on the basis of a few genera by Bayer (1984). A detailed study of grass subfamily distributions also shows a similar basic division, with Chloridoideae and Panicoideae most abundant in summer rainfall areas and Arundinoideae most abundant in winter rainfall areas (Gibbs Russell 1986).

Nama-Karoo and Succulent Karoo, which have previously been placed together at highest level in all vegetation studies except that of Rutherford & Westfall (1986), are not closely related floristically. Nama-Karoo is more closely related to Savanna than to Succulent Karoo, and Succulent Karoo is more closely related to Fynbos than to Nama-Karoo.

Within the summer rainfall group, at species level, the strongest relationship is between Savanna and Grassland, with a weaker relationship between Savanna and Nama-Karoo. The same relationships are shown at generic level, and the distinctness of Nama-Karoo from Grassland and of Desert from Succulent Karoo is emphasized. At family level, particular families link and demarcate the summer rainfall biomes and the winter rainfall biomes, but another group of families complicates this simple difference by linking the arid biomes of both summer and winter rainfall regimes.

Secondary links connect the two major groups through Nama-Karoo, which lies between the other biomes geographically. Nama-Karoo is ill-defined as an entity, and is strongly linked at species, genus and family level to Savanna and Desert; it is more weakly linked at species and family level to Succulent Karoo and at genus level to Fynbos. Grassland, which is very strongly allied to Savanna, shows a secondary link to Fynbos, independent of Nama-Karoo, at species, genus and family level.

CONCLUSIONS

At the highest level of floristic comparison the winter rainfall biomes and the summer rainfall biomes form two separate groups. Within these groups, each biome is floristically distinct at the level of species and infraspecific taxa, whether measured by Sorenson's coefficient of similarity or by percentage of shared taxa, and each biome (except Desert) is rich in taxa. Each is a centre of diversity for certain large genera, and the life form spectrum for these genera is different for each biome. Each (except Nama-Karoo) is distinguished by differences in the occurrence of important plant families.

The floristic distinctness of the biomes, coupled with high taxon numbers, implies that each should be studied and managed as a separate entity. Because of the high numbers of species and infraspecific taxa, it is unlikely that conservation of limited areas in nature reserves will protect a large proportion of the taxa in any one biome.

This study is hampered by the dearth of specimen records from arid areas, and for this reason it may be criticized for being too preliminary. However, the trends indicated should serve as stimulus to more precise analyses. Unfortunately precision can only be achieved when primary data are available to compile more complete and accurate checklists. This should be done through bringing together records from many herbaria and from literature, and most important, through rationally planned specimen collecting designed to cover all biomes adequately.

The conclusions are based on plant distributions as they are now known, that result from interactions over a long geological, climatological and evolutionary history. It is not apparent to what extent these distributions have been influenced by present or past environments. However, listing and comparing the taxa in each biome is the first step in unravelling the events that have led to the formation of its characteristic flora. PRECIS has given us a preliminary look that will allow the generation of hypotheses for more rigorous testing using stronger data sets and more refined techniques.

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APPENDIX 1.—Large genera (10 taxa or more) with centre of diversity in one biome. * = genera reported only from a single biome. Life forms are abbreviated: P, phanerophyte; Ch, chamaephyte; H, hemicryptophyte; Cr, cryptophyte; T, therophyte; S, succulent

a. Large genera with centre of diversity reported for Fynbos only

Family and genus	Total no. of taxa reported	% of the reported taxa in Fynbos	Life form
Pottiaceae			
Tortula	12	83	H
Poaceae			
Merxmuellera	12	66	H
Pentaschistis	47	82	H
Cyperaceae			
Ficinia	54	98	H
Isolepis	19	78	H
Tetraria	35	97	H
Restionaceae			
Restio	109	94	H
Chondropetalum*	19	100	H
Elegia*	36	100	H
Leptocarpus	22	100	H
Thamnochortus	29	100	H
Hypodiscus*	12	100	H
Juncaceae			
Juncus	19	89	H
Liliaceae *s.l.*			
Wurmbea	12	91	Cr
Trachyandra	44	54	Cr
Haworthia	22	63	H, S
Ornithogalum	44	59	Cr
Lachenalia	46	82	Cr
Hypoxidaceae			
Spiloxene	15	86	Cr
Iridaceae			
Romulea	51	62	Cr
Galaxia	11	81	Cr
Moraea	62	64	Cr
Homeria	22	63	Cr
Bobartia*	12	100	H
Aristea	29	82	H
Geissorhiza	58	98	Cr
Ixia	41	97	Cr
Tritonia	17	58	Cr
Gladiolus	103	72	Cr
Tritoniopsis*	13	100	Cr
Watsonia	16	81	Cr
Orchidaceae			
Holothrix	13	69	H
Satyrium	32	75	H
Disa	59	79	H
Monadenia	12	91	H
Corycium	13	69	H
Proteaceae			
Paranomus	13	100	P, Ch
Serruria	57	100	Ch
Spatalla	15	100	Ch
Protea	62	87	P, Ch
Leucospermum	39	97	P, Ch
Leucadendron	64	93	P, Ch
Santalaceae			
Thesium	95	54	Ch, H
Mesembryanthemaceae			
Drosanthemum	17	64	Ch, S
Erepsia*	12	100	Ch, S
Lampranthus	43	86	Ch, S
Caryophyllaceae			
Silene	12	91	H
Droseraceae			
Drosera	16	75	H
Crassulaceae			
Crassula	137	54	Ch, H, S
Adromischus	15	53	Ch, S
Bruniaceae			
Raspalia	10	100	Ch
Berzelia	10	100	Ch
Rosaceae			
Cliffortia	77	96	P, Ch
Fabaceae			
Cyclopia*	17	100	Ch
Podalyria	12	100	Ch
Priestleya	16	100	Ch
Rafnia	18	100	Ch, H
Lebeckia	24	70	Ch, H
Aspalathus	220	97	P, Ch
Geraniaceae			
Pelargonium	121	89	Ch, H, Cr, T
Oxalidaceae			
Oxalis	135	68	Ch, H, Cr, T
Rutaceae			
Agathosma	68	100	Ch
Adenandra*	23	100	Ch
Acmadenia*	11	100	Ch
Diosma	20	100	Ch
Euchaetis	20	100	Ch
Polygalaceae			
Polygala	50	58	Ch, H
Muraltia	91	95	Ch
Euphorbiaceae			
Clutia	24	75	Ch
Rhamnaceae			
Phylica	93	97	P, Ch
Malvaceae			
Anisodontea	12	83	Ch, H
Sterculiaceae			
Hermannia	145	46	Ch, H
Thymelaeaceae			
Gnidia	64	71	Ch
Struthiola	25	100	Ch
Lachnaea	20	100	Ch
Passerina	14	92	Ch
Apiaceae			
Centella	34	100	H
Peucedanum	15	53	Ch, H
Ericaceae			
Erica	460	96	P, Ch
Blaeria*	12	100	Ch
Grisebachia	10	70	Ch
Simocheilus*	17	100	Ch
Syndesmanthus*	11	100	Ch
Schyphogyne*	12	100	Ch
Plumbaginaceae			
Limonium	16	87	Ch, H
Gentianaceae			
Chironia	15	66	Ch, H
Boraginaceae			
Lobostemon	21	100	Ch

Scrophulariaceae			
Polycarena	23	60	H, T
Harveya	15	73	H
Selaginaceae			
Selago	61	63	Ch
Rubiaceae			
Anthospermum	17	70	Ch
Campanulaceae			
Roella*	23	100	Ch, H
Prismatocarpus	21	90	Ch, H
Lightfootia	35	77	Ch, H
Lobeliaceae			
Cyphia	27	55	H, Cr
Lobelia	51	70	Ch, H, T
Monopsis	13	92	H, T
Asteraceae			
Mairea	12	100	Ch, H
Felicia	62	66	Ch, H
Helipterum	11	100	H, T
Stoebe	21	100	Ch
Metalasia	23	91	Ch
Relhania	18	77	Ch, T
Athanasia	25	88	Ch
Cotula	22	59	H, T
Senecio	182	48	Ch, H, S
Euryops	46	54	Ch, H, T
Osteospermum	56	66	Ch, H
Ursinia	37	78	Ch, H, T
Cullumia	13	92	Ch

b. Large genera with centre of diversity reported for Savanna only

Family and genus	Total no. of taxa reported	% of the reported taxa in Savanna	Life form
Ricciaceae			
Riccia	20	55	H
Marsileaceae			
Marsilea	11	90	H
Adiantaceae			
Cheilanthes	26	57	H
Zamiaceae			
Encephalartos	10	70	P, Ch
Poaceae			
Brachiaria	19	100	H
Panicum	35	97	H
Pennisetum	14	64	H
Sporobolus	38	89	H
Eragrostis	81	88	H
Cyperaceae			
Mariscus	32	90	H
Fuirena	13	76	H
Eleocharis	10	90	H
Liliaceae *s.l.*			
Chlorophytum	11	54	Cr
Urginea	17	47	Cr
Dipcadi	14	92	Cr
Protasparagus	41	63	Ch
Amaryllidaceae			
Crinum	18	94	Cr
Moraceae			
Ficus	18	100	P
Loranthaceae			
Tapinanthus	16	100	Ch
Viscaceae			
Viscum	13	61	Ch
Amaranthaceae			
Amaranthus	12	83	T
Capparaceae			
Maerua	12	83	P, Ch
Fabaceae			
Albizia	10	90	P, Ch
Acacia	63	79	P, Ch
Cassia	22	90	P, Ch, H
Crotalaria	50	90	Ch, H
Indigofera	170	52	Ch, H
Psoralea	38	97	Ch, H
Tephrosia	49	88	Ch, H
Sesbania	17	82	P, Ch, H
Aeschynomene	10	80	Ch, H, T
Rhynchosia	44	73	Ch, H
Vigna	14	100	H
Euphorbiaceae			
Phyllanthus	14	78	P, Ch, H
Croton	10	100	P, Ch, H
Jatropha	15	86	Ch, H
Euphorbia	123	46	P, Ch, H, S
Anacardiaceae			
Ozoroa	13	84	P, Ch
Vitaceae			
Cyphostemma	23	78	Ch, H
Tiliaceae			
Corchorus	12	100	Ch, H
Grewia	24	91	P, Ch
Triumfetta	11	91	Ch, H
Malvaceae			
Abutilon	16	93	P, Ch, H
Pavonia	11	72	Ch, H
Hibiscus	45	93	P, Ch, H, T
Sterculiaceae			
Melhania	10	100	Ch, H
Ochnaceae			
Ochna	10	90	P, Ch
Elatinaceae			
Bergia	10	90	Ch, H
Lythraceae			
Nesaea	16	87	Ch, H, T
Combretaceae			
Combretum	32	96	P, Ch
Ebenaceae			
Diospyros	19	73	P, Ch
Asclepiadaceae			
Ceropegia	21	95	H, S
Huernia	17	82	H, S
Convolvulaceae			
Ipomoea	43	90	Ch, H, T
Verbenaceae			
Clerodendrum	10	100	P, Ch, H
Lamiaceae			
Leonotis	11	91	Ch, H
Lentibulariaceae			
Utricularia	14	92	H
Acanthaceae			
Barleria	47	85	Ch
Blepharis	35	65	Ch, H, T
Justicia	24	87	Ch, H
Rubiaceae			
Kohautia	14	85	Ch, H, T
Oldenlandia	13	100	Ch, H
Canthium	14	92	P, Ch
Asteraceae			
Geigeria	14	92	Ch, H
Dicoma	14	78	Ch, H

c. Large genera with centre of diversity reported for Grassland only

Family and genus	Total no. of taxa reported	% of the reported taxa in Grassland	Life form
Cyperaceae			
Carex	13	69	H
Liliaceae *s.l.*			
Kniphofia	23	73	H
Agapanthus	11	63	H
Tulbaghia	12	75	H
Amaryllidaceae			
Nerine	14	57	Cr
Cyrtanthus	20	55	Cr
Iridaceae			
Dierama	10	100	Cr
Mesembryanthemaceae			
Delosperma	24	79	Ch, H, S
Portulacaceae			
Anacampseros	11	45	Ch, H, S
Brassicaceae			
Lepidium	13	53	Ch, H, T

Fabaceae			
Lotononis	33	45	Ch, H
Pearsonia	10	90	Ch, H
Onagraceae			
Oenothera	12	91	Ch, H, T
Apiaceae			
Alepidea	13	92	H
Asclepiadaceae			
Aspidoglossum	12	83	H
Pachycarpus	13	84	H
Lamiaceae			
Stachys	29	51	Ch, H, T
Salvia	25	60	Ch, H
Scrophulariaceae			
Zaluzianskya	10	45	H, T
Gesneriaceae			
Streptocarpus	10	50	H
Asteraceae			
Helichrysum	147	55	Ch, H
Gerbera	12	50	H

d. Large genera with centre of diversity reported for Succulent Karoo only

Family and genus	Total no. of taxa reported	% of the reported taxa in Succulent Karoo	Life form
Liliaceae *s.l.*			
Androcymbium	21	57	Cr
Iridaceae			
Lapeirousia	13	48	Cr
Aizoaceae			
Galenia	26	61	Ch, H
Crassulaceae			
Tylecodon	13	76	Ch, H, S

e. Large genera with centre of diversity reported for Nama-Karoo only

Family and genus	Total no. of taxa reported	% of the reported taxa in Nama-Karoo	Life form
Mesembryanthemaceae			
Lithops	12	83	H, S
Asteraceae			
Pentzia	25	60	Ch, H

APPENDIX 2.—Large genera (10 taxa or more) with centres of diversity in two biomes. Life forms are abbreviated: P, phanerophyte; Ch, chamaephyte; H, hemicryptophyte; Cr, cryptophyte; T, therophyte; S, succulent

a. Large genera with centre of diversity reported for Savanna and Grassland

Family and genus	Total no. of taxa reported	% of reported taxa in: Savanna	Grassland	Life form
Aspleniaceae				
Asplenium	13	62	62	H
Poaceae				
Andropogon	12	67	83	H
Hyparrhenia	17	100	65	H
Digitaria	29	93	62	H
Setaria	17	88	59	H
Aristida	38	92	55	H, T
Cyperaceae				
Cyperus	63	84	54	H, T
Pycreus	18	89	56	H, T
Kyllinga	10	70	80	H, T
Schoenoplectus	17	76	71	H, T
Bulbostylis	10	90	90	H, T
Scleria*	13	85	46	H
Commelinaceae				
Commelina	19	95	53	H, T
Liliaceae *s.l.*				
Anthericum	17	88	53	Cr
Ledebouria	12	92	83	Cr
Hypoxidaceae				
Hypoxis	20	50	80	Cr
Dioscoreaceae				
Dioscorea	16	88	50	Ch, H, Cr
Orchidaceae				
Habenaria	18	50	61	H, Cr
Eulophia	35	66	51	H
Polygonaceae				
Polygonum	15	66	60	Ch, H
Chenopodiaceae				
Chenopodium	21	76	52	H, T
Fabaceae				
Eriosema	22	68	64	Ch, H
Euphorbiaceae				
Acalypha	16	94	62	P, Ch, H
Chamaesyce	10	90	50	H
Anacardiaceae				
Rhus	61	52	48	P, Ch
Malvaceae				
Sida	13	92	54	Ch, H
Oleaceae				
Jasminum	10	70	50	Ch
Asclepiadaceae				
Asclepias	37	57	81	Ch, H
Brachystelma	20	70	45	H
Convolvulaceae				
Convolvulus	20	60	70	H
Verbenaceae				
Chascanum	13	69	62	Ch, H
Lamiaceae				
Plectranthus	29	76	48	Ch, H, T
Hemizygia	15	67	47	Ch, H
Solanaceae				
Solanum	38	68	53	P, Ch, H
Scrophulariaceae				
Alectra	11	73	55	H, T
Rubiaceae				
Pavetta	14	93	50	P, Ch

b. Large genera with centres of diversity reported for Savanna and Nama-Karoo

Family and genus	Total no. of taxa reported	% of reported taxa in: Savanna	Nama-Karoo	Life form
Aizoaceae				
Limeum	28	75	50	Ch, H, T
Capparaceae				
Cleome	19	89	50	H, T
Boscia	10	70	50	P, Ch
Fabaceae				
Melolobium	15	53	53	Ch
Burseraceae				
Commiphora	27	67	55	P, Ch
Boraginaceae				
Heliotropium	15	80	73	Ch, H
Solanaceae				
Lycium	14	64	57	P, Ch
Scrophulariaceae				
Aptosimum	15	93	67	Ch, H
Selaginaceae				
Walafrida	14	50	57	Ch, H, T
Acanthaceae				
Petalidium	25	52	72	Ch, H
Monechma	22	59	68	Ch
Cucurbitaceae				
Cucumis	15	87	47	H, T

c. Large genera with centres of diversity reported for Savanna and Fynbos

Family and genus	Total no. of taxa reported	% of reported taxa in: Savanna	Fynbos	Life form
Dicranaceae				
Campylopus	13	62	77	H
Crassulaceae				
Cotyledon	11	45	55	Ch, H, S
Celastraceae				
Cassine	12	50	75	P, Ch
Ebenaceae				
Euclea	18	67	61	P, Ch
Asclepiadaceae				
Cynanchum	10	50	50	Ch, H

d. Large genera with centres of diversity reported for Fynbos and Grassland

Family and genus	Total no. of taxa reported	% of reported taxa in: Fynbos	Grassland	Life form
Bryaceae				
Bryum	15	60	73	H
Poaceae				
Agrostis	13	54	54	H
Orchidaceae				
Disperis	17	47	47	H
Polygonaceae				
Rumex	13	77	77	Ch, H
Chenopodiaceae				
Atriplex	10	50	70	Ch, H
Caryophyllaceae				
Dianthus	18	44	50	H, T
Fabaceae				
Argyrolobium	22	50	59	Ch, H
Trifolium	18	61	55	H
Geraniaceae				
Geranium	12	50	50	H, T
Gentianaceae				
Sebaea	35	54	46	H, T
Asclepiadaceae				
Schizoglossum	13	46	62	H
Rubiaceae				
Galium	13	77	54	Ch, H
Asteraceae				
Cineraria	20	50	60	Ch, H

e. Large genera with centres of diversity reported for Fynbos and Succulent Karoo

Family and genus	Total no. of taxa reported	% of reported taxa in: Fynbos	Succulent Karoo	Life form
Poaceae				
Ehrharta	29	90	45	H
Liliaceae				
Bulbine	23	65	48	Cr
Albuca	22	55	55	Cr
Amaryllidaceae				
Haemanthus	16	56	56	Cr
Gethyllis	11	82	45	Cr
Iridaceae				
Hesperantha	25	48	60	Cr
Babiana	51	57	49	Cr
Aizoaceae				
Pharnaceum	22	77	55	Ch, H, T
Tetragonia	27	56	67	Ch, H, T
Brassicaceae				
Heliophila	60	72	47	Ch, H, T
Fabaceae				
Wiborgia	10	70	80	Ch
Scrophulariaceae				
Diascia	11	45	50	H, T
Nemesia	39	62	46	Ch, H, T
Manulea	32	50	50	Ch, H, T
Selaginaceae				
Hebenstretia	23	57	48	Ch, H, T
Asteraceae				
Othonna	55	55	58	Ch, H, S
Arctotis	34	68	53	H
Gazania	18	61	61	H, T

f. Large genera with centres of diversity reported for Fynbos and Nama-Karoo

Family and genus	Total no. of taxa reported	% of reported taxa in: Fynbos	Nama-Karoo	Life form
Chenopodiaceae				
Salsola	24	58	63	Ch, H
Asteraceae				
Pteronia	52	46	42	Ch

g. Large genus with centres of diversity reported for Nama-Karoo and Succulent Karoo

Family and genus	Total no. of taxa reported	% of reported taxa in: Nama-Karoo	Succulent Karoo	Life form
Asteraceae				
Eriocephalus	19	63	58	Ch

h. Large genus with centres of diversity reported for Nama-Karoo and Desert

Family and genus	Total no. of taxa reported	% of reported taxa in: Nama-Karoo	Desert	Life form
Mesembryanthemaceae				
Psilocaulon	19	47	32	H, T

APPENDIX 3.—Large genera (10 taxa or more) with centres of diversity in three biomes. Life forms are abbreviated: P, phanerophyte; Ch, chamaephyte; H, hemicryptophyte; Cr, cryptophyte; T, therophyte; S, succulent

a. Large genera with centres of diversity reported for Savanna, Grassland and Fynbos

Family and genus	Total no. of taxa reported	% of reported taxa in: Savanna	Grassland	Fynbos;	Life form
Fissidentaceae					
Fissidens	23	52	52	70	H
Celastraceae					
Maytenus	17	71	47	59	P, Ch
Asteraceae					
Conyza	13	62	54	92	Ch, H, T

b. Large genera with centres of diversity reported for Savanna, Nama-Karoo and Desert

Family and genus	Total no. of taxa reported	% of reported taxa in: Savanna	Nama-Karoo	Desert	Life form
Poaceae					
Stipagrostis	34	50	65	68	H
Pedaliaceae					
Sesamum	14	71	50	50	H, T

c. Large genus with centres of diversity reported for Fynbos, Succulent Karoo and Nama-Karoo

Family and genus	Total no. of taxa reported	% of reported taxa in: Fynbos	Succulent Karoo	Nama-Karoo	Life form
Zygophyllaceae					
Zygophyllum	30	50	53	57	Ch

d. Large genus with centres of diversity reported for Fynbos, Savanna and Nama-Karoo

Family and genus	Total no. of taxa reported	%of reported taxa in: Fynbos	Savanna	Nama-Karoo	Life form
Geraniaceae					
Monsonia	10	50	50	50	Ch, H, T, S

APPENDIX 4.—Large genera (10 taxa or more) with no apparent centre of diversity. Life forms are abbreviated: P, phanerophyte; Ch, chamaephyte; H, hemicryptophyte; Cr, cryptophyte; T, therophyte; S, succulent

Family and genus	Total no.	Vegetation type with largest % of taxa	%	Life form
Liliaceae *s.l.*				
Eriospermum	39	Savanna	41	Cr
Aloe	98	Savanna	44	Ch, S
Iridaceae				
Brunsvigia	11	Fynbos	36	Cr
Mesembryanthemaceae				
Ruschia	55	Fynbos	40	Ch, S
Fabaceae				
Lessertia	33	Fynbos	42	Ch, H
Asclepiadaceae				
Stapelia	27	Fynbos	44	H, S
Scrophulariaceae				
Sutera	72	Savanna	42	Ch, H, T
Campanulaceae				
Wahlenbergia	46	Grassland	35	H, T
Asteraceae				
Berkheya	43	Grassland	47	Ch, H