Chapter 1

General introduction

The Succulent Karoo stretches along the western side of South Africa and Namibia and is recognised as one of the global hotspots of diversity (Myers et al. 2000, Critical Ecosystem Partnership Fund 2003), being one of only two hotspots that are entirely arid (Conservation International – website 2006). Despite a general lack of structural diversity, plant species diversity at both local and regional scales is undoubtedly the highest recorded for any arid region in the world (Cowling et al. 1989).

To the south the Succulent Karoo lies adjacent to South Africa's Cape Floristic Region (CFR), a region that has one of the highest species densities and levels of endemism at both local and regional scales for any temperate or tropical continental region (Cowling et al. 1989, 1992). The Cape Floristic Region has the distinction of being the world's smallest floristic kingdom (Good 1947) and is also recognised as a global hotspot of diversity (Cowling & Hilton-Taylor 1994). On a biome scale the major part of the CFR is classified as the Fynbos Biome (Low & Rebelo 1996, Mucina et al. 2005, Rutherford et al. 2006).

In 2002 the Succulent Karoo Ecosystem Plan (SKEP) initiative was launched (with the sponsorship of the Critical Ecosystem Partnership Fund (CEPF)) to identify and generate consensus for a 20-year conservation and sustainable land-use strategy for the Succulent Karoo hotspot of biodiversity (Conservation International – website 2006). For management purposes, the SKEP planning domain was subdivided into four subregions, one of which was formed by the Hantam-Tanqua-Roggeveld. As little information was available on the biodiversity of the subregion that could be used for future planning, conservation and development (Cilliers et al. 2002, Critical Ecosystem Partnership Fund 2003) collecting botanical data for the subregion was of paramount importance.

The inclusion of the Roggeveld area into the SKEP planning domain (Succulent Karoo) can be questioned because many authors classify the vegetation as part of the Fynbos Biome and not the Succulent Karoo Biome (Low & Rebelo 1996, Mucina et al. 2005, Rutherford et al. 2006). However, there is also a group of researchers that contend that the Roggeveld is a part of the Succulent Karoo Biome (Hilton-Taylor 1994, Jürgens 1997, Van Wyk & Smith 2001) and yet others that classify it as part of the Nama Karoo Biome (Acocks 1988, Rutherford & Westfall 1994). At the time the SKEP initiative was launched it was included in the SKEP domain primarily because it had not been included in the Cape Action Plan for the Environment (C.A.P.E) which was a similar programme to SKEP but focused on the CFR. However, there is a strong relationship between the Succulent Karoo Biome and the Fynbos Biome. The close relationship between these two biomes was advocated by Jürgens (1997) who proposed the recognition of the Floristic Kingdom of the Greater Cape Flora including at least two partial areas, i.e. the Cape Floristic Region and the Succulent Karoo Region. Born et al. (2007) recently investigated support for an area named the Greater Cape Floristic Region which includes the whole winter rainfall area (arid and mesic climates).

Amongst the earliest references to the botanical wealth of the Hantam-Tanqua-Roggeveld subregion dates from the early 1900s when Diels (1909) mentions the high levels of endemism on the Hantam Mountain. Both Marloth (1908) and Weimarck (1941) expand on the unique character of the vegetation in the subregion. In his phytogeographical analysis Weimarck (1941) treated the Hantam-Roggeveld as a subcentre of his North-Western Centre stating that the subcentre constituted the last outlier of the Cape element in the inner parts of western South Africa. Hilton-Taylor (1994) identified three centres of endemism within his Western Cape Domain, namely: the Western Mountain Karoo, Roggeveld and Tanqua Karoo which all occur within the study area. The botanical importance of the Hantam-Roggeveld was later emphasised by Van Wyk and Smith (2001) who identified it as one of 13 principal centres of plant endemism in southern Africa.

Identification, classification and description of vegetation units across the landscape comprise the first critical steps to improve understanding, protection and management of natural resources. As the first step in the current botanical study of the Hantam-Tanqua-Roggeveld subregion, a broad scale vegetation survey of the entire subregion of approximately three million hectares was undertaken. This vegetation survey, identifying eight plant associations (Van der Merwe et al. 2008a, 2008b), was used as the basis for further detailed botanical investigations.

Since biodiversity hotspots are biologically the richest, yet among the most threatened places on earth, because large numbers of endemic species are undergoing exceptional loss of habitat (Broennimann et al. 2006), a study to investigate various diversity parameters (i.e. species richness, evenness, Shannon and Simpson index of diversity) was initiated. Diversity has two components: species richness, or the number of plant species in a given area, and species evenness, or how well abundance or biomass is distributed among species within a community (Whittaker 1977, Shmida 1984, Magurran 1988, Stohlgren et al. 1995, Wilsey & Potvin 2000). Numerous indices exist which use either species richness or evenness as well as a combination of these two components (Shmida 1984, Magurran 1988, Clinebell et al. 1995, Stirling & Wilsey 2001). In spite of various criticisms, these indices have sparked renewed interest in handling problems associated with the conservation of natural heritage or the changes in global ecology (Mouillot & Leprêtre 1999).

Species richness is currently the most widely used diversity measure (Magurran 1988, Mouillot & Leprêtre 1999, Wilsey & Potvin 2000, Gotelli & Colwell 2001, Stirling & Wilsey

2001) because it is relatively easy to measure, is comparable across communities, and is well understood by researchers, managers, and the public (Hellman & Fowler 1999). However, species richness *per se* does not imply any standardisation of sampling area (Whittaker 1977, Whittaker et al. 2001). By adding a spatial scale, species-area curves and species accumulation curves can provide more information on the nature of the differences between vegetation types in different geographical areas than mere measures of species richness (Lomolino 2000, Cam et al. 2002, Ugland et al. 2003, Colwell et al. 2004, Drakare, et al., 2006). In recent years species-area curves have been applied successfully to examine the effects of habitat loss on species diversity (Pimm et al. 1995), the effect of invasions on species diversity (Vitousek et al. 1996), the identification of hotspots (Veech 2000), and to set baseline targets for conservation (Desmet & Cowling 2004).

Life forms (and life history patterns) give preliminary information concerning the habitat and the adaptive suite of plant traits and indicate that certain life forms are restricted to growing in particular habitats (Barbour et al. 1999). The most common, parsimonious and accepted plant life form classification is Raunkiaer's (1934) (Van Rooyen et al. 1990, Pavón et al. 2000) who suggested that the location of a plant's renewal buds, as differentiated in various life forms, best expresses its adaptation to the unfavourable season for plant life (Danin & Orshan 1990). Life form studies have shown that the distribution and abundance of different plant life forms have well defined limits along an altitudinal gradient studied and suggest that environmental heterogeneity in semi-arid environments was important for the establishment of the different life forms, thus affecting community physiognomy and structure (Pavón et al. 2000). Additionally, assessing effects of land-use change and climate change by life form or plant functional types (PFTs) should facilitate the identification of future trends in ecosystem structure (Smith et al. 1997, Epstein et al. 2002, Broennimann et al. 2006).

Within the study area, the first European farmers settled along the northern slopes of the Roggeveld Mountains in the 1740s (Van der Merwe 1938). These first farmers cultivated crops on a small scale to be self-sustainable. In later years the farmers ploughed large tracts of land to cultivate crops since the Roggeveld has a higher rainfall than the surrounding Succulent Karoo areas. An increase in production costs have forced farmers to cultivate fewer crops leading to the abandonment of various croplands throughout the Roggeveld. Plant community succession is one of the most important aspects of vegetation ecology (Zhang 2005) since successional plant communities provide a model system for testing a variety of ecological hypotheses regarding the controls on biodiversity that could be applied to the management and restoration of plant communities (Huberty et al. 1998). Additionally, with the current predictions of climate change the study of plant succession and vegetation recovery take on an even stronger urgency (Bazzaz 2000). Climate change will add another layer of complexity to the restoration of old fields and could exacerbate the ecological thresholds to plant community assembly (Cramer et al. 2007).

Although fire is not a key environmental parameter in the Succulent Karoo the renosterveld is fire-prone. Mediterranean-type shrublands belong to the world's major fire-prone biomes with fire a crucial process whereby gaps are created controlling vegetation dynamics and structure (Capitanio & Carcaillet 2008). Various studies have found that in such fire-prone ecosystems species composition and structure rapidly recover after fire (Hanes 1971, Lloret & Vilá 2003). Classifying species into fire life forms or fire response type has been found to provide a useful framework for describing post-fire chaparral succession because these response groups affect ecosystem processes in some predictable ways and may also reflect the underlying environmental changes after fire (Guo 2001).

Due to the lack of botanical information in the Hantam-Tanqua-Roggeveld subregion the main objectives of the current study were to:

a) gather botanical information on a regional scale by identifying, classifying and describing plant associations and subassociations present in the Hantam-Tanqua-Roggeveld subregion;
b) gain information on plant diversity in each of the vegetation units by studying species richness and species-area relationships;
c) analyse patterns of plant diversity using various diversity parameters such as species richness, evenness, Shannon's index of diversity and Simpson's index of diversity;
d) compare life forms at a species and vegetation cover level on a broad vegetation scale in an attempt to provide clarity on the Succulent Karoo vs. Fynbos Biome status of the subregion;
e) follow the recovery of vegetation on abandoned croplands in the Mountain Renosterveld vegetation of the Roggeveld by evaluating the rate of recovery in terms of species composition and various parameters of species and life form diversity; and
f) report on post-fire vegetation trends over a 10-year period in the Mountain Renosterveld of the Roggeveld using changes in species numbers, vegetation cover and life form categories.

The main body of this thesis is presented in the form of papers. Chapters 4 and 5 are two published articles that have been included in their published format. Chapters 6 to 10 are to be submitted for publication in various scientific journals and thus the formatting differs between them. Since these chapters have been prepared as independent articles some degree of repetition is inevitable. Except for the papers, a general introduction, study area, materials and methods, general discussion and synthesis, summary, acknowledgements and combined reference list are included. A CD containing various vegetation maps are included for larger scale printing purposes.

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Chapter 2

Study area

2.1 Location and topography

The Hantam-Tanqua-Roggeveld subregion, an area of approximately 3 million hectares, is situated within the predominately winter rainfall region of the Northern and Western Cape Provinces of the Republic of South Africa (Figure 2.1). The southwestern border of the study area is found just east of the Cederberg Mountains from where it stretches northwards along the eastern fringe of the Bokkeveld Mountains to just north of Loeriesfontein. Escarpment forming mountains such as the Roggeveld, Komsberg, Klein Roggeveld and Nuweveld Mountains to just southwest of Fraserburg delineate the eastern boundary. The southern limit includes the Tanqua and Ceres Karoo to where the Swartrug and Bontberg Mountains meet north of Ceres.

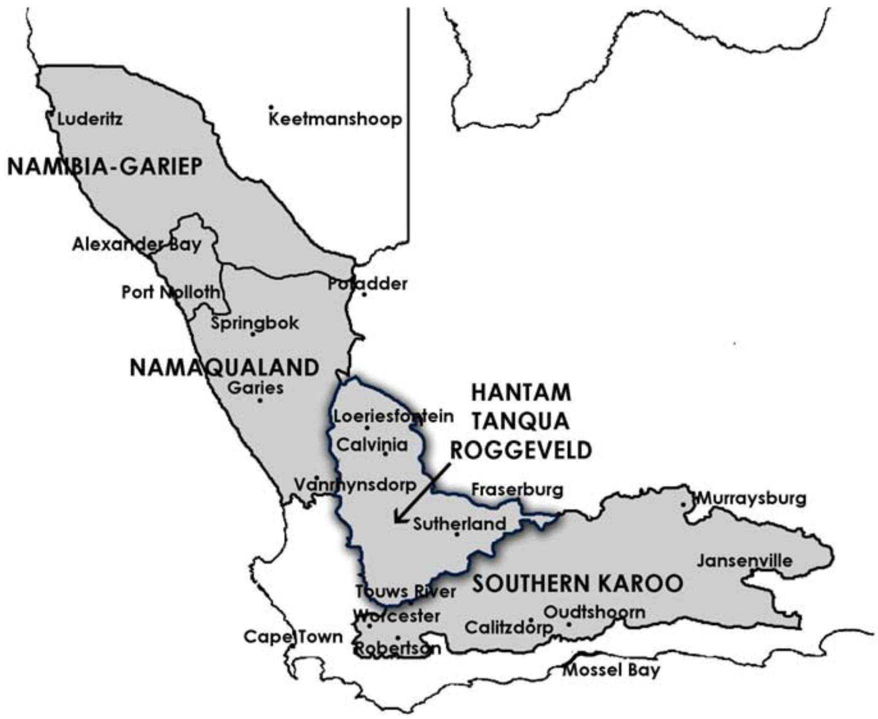


Figure 2.1 Subregions in the SKEP planning domain (Critical Ecosystem Partnership Fund 2003).

Topographically the physical geography of the Hantam, Tanqua and Roggeveld areas varies greatly. From the level plains of the Tanqua Karoo (Figure 2.2a – c) at about 290 m above sea level, the landscape rises steeply up the escarpment formed by the Roggeveld, Komsberg and Nuweveld Mountains (to approximately 1800 m above sea level) onto the inland plateau of South Africa (Figure 2.3a – c). The Hantam area is characterised by a gently undulating to steeply rolling topography (Figure 2.4a – c).

The Hantam is known for its Hantam Mountain which is situated to the north of the town of Calvinia, the Tanqua Karoo is known for its aridity and barren landscapes while the star-gazing town of Sutherland is situated in the Roggeveld. The name Roggeveld was derived from the 'wilde rog' or wild rye (*Secale strictum* subsp. *africanum*) which used to abound in the area, but is now on the brink of extinction.

2.2 Geology and soils

Geologically, the study area is dominated by the Ecca Group (Rubidge & Hancox 1999, Council for Geoscience 1973, 1983, 1989, 1991, 1997, 2001, 2008, Johnson et al. 2006). In the east, mudstones of the Abrahamskraal Formation in the Beaufort Group are found, while in the west the Dwyka Group (tillite, sandstone, mudstone and shale) crops out. The Ecca Group includes sediments of the Tierberg (shale), Prince Albert (mudrock), Kookfontein (shale, siltstone and sandstone) and Skoorsteenberg Formations (mudstone, siltstone and sandstone). Igneous intrusions of dolerite occur throughout the subregion, being easily recognisable as very hard dark grey to nearly black rocks (Van Wyk & Smith 2001). An array of land types are found in the study area (Agricultural Research Council 1986a, 1986b, 1995, 1999a, 1999b, 2002, 2003), with some of the prominent land types being Ag, Da, Db, Dc, Fb, Fc, Ia and Ib (Du Plessis 1987).

Soils of the Tanqua Karoo are shallow lithosols that often include a desert pavement and deep unconsolidated deposits in the alluvial parts. To the west of Calvinia, the Hantam is characterised by shallow lithosols and duplex soils, but where dolerite occurs the soils are red structured and red vertic clays. The Hantam Mountain and mountains of the great escarpment are shallow stony lithosol soils, and duplex soils are found in the occasional lowlands (Francis et al. 2007).

a)

b)

c)

Figure 2.2 A general impression of the low-lying Tanqua Karoo: a) An unusual scene, the Tanqua Karoo covered in carpets of annual flowers; b) the usually barren landscape of the Tanqua Karoo; and c) Tanqua Karoo low-lying plains covered with annuals in an extraordinarily good rainfall year.

a)

b)

c)

Figure 2.3 Scenes of the high-lying Roggeveld Mountains: a) the Roggeveld escarpment and plains of the Tanqua Karoo; b) Roggeveld vegetation receives a higher rainfall than the surrounding areas; and c) the typical vegetation of the Sutherland area dominated by *Rosenia oppositifolia*.

a)

b)

c)

Figure 2.4 A photographic impression of the Hantam: a) fallow lands covered in the annuals of the Hantam; b) annuals interspersed with perennial shrubs in the Hantam following good rains; and c) red dolerite derived Hantam soils rich in geophytes and annuals.

2.3 Climate

Rainfall ranges from 50 to 300 mm a year with a mean of 228 mm measured at Calvinia and 266 mm measured at Sutherland (Weather Bureau 1988). A maximum of 472 mm in 1976 for Calvinia and 467 mm for Sutherland in 1976 have been recorded (Weather Bureau 1988). The majority of the rainfall is received in winter, however, a few summer thunderstorms do contribute to the total annual rainfall. The mean annual precipitation for the Tanqua Karoo ranges from <100 mm to 200 mm, while the Hantam receives between 100 mm and 400 mm per year and the Roggeveld between 200 mm and 400 mm annually (Schulze 1997). The coefficient of variation of the annual precipitation for the Tanqua Karoo and Hantam is generally 35% to 40% and a few isolated areas with a coefficient of variation of >40% (Schulze 1997). The Roggeveld's coefficient of variation for the annual precipitation is also between 35% to 40% however, the higher-lying areas have a coefficient of variation of between 25% and 30% (Schulze 1997). Snowfalls usually occur on the high-lying areas and over a 20-year period a mean of one snow day per year was recorded for Calvinia and over a 24-year period, a mean of six snow days per year were recorded for Sutherland (Weather Bureau 1988).

January and February have a mean daily maximum of 30.8°C, with an extreme maximum of 41.2°C recorded for Calvinia in February 1990. The summer month of January is the warmest month in Sutherland with a mean daily maximum of 27.1°C and an extreme maximum of 35.5°C recorded in January 1980 (Weather Bureau 1988). For Calvinia, the coldest months are June and July, with a mean daily minimum of 4.4°C and mean daily maximum of 17.1°C for June and for July a mean daily minimum of 3.5°C and mean daily maximum of 17.2°C (Weather Bureau 1988). June and July are also the coldest months in Sutherland with a mean daily minimum of -1.2°C and mean daily maximum of 12.7°C for June, while July's mean daily minimum is -2.4°C and mean daily maximum 12.8°C (Weather Bureau 1988). The lowest temperature recorded for Calvinia was -6.5°C in June 1978 and for Sutherland -13.6°C in July 1970 and August 1978 (Weather Bureau 1988).

Walter diagrams (Figure 2.5) were constructed using data obtained from the Weather Bureau (1998) and electronic data extracted by the South African National Biodiversity Institute from the following two reports: 1) Lynch, S.D. 2004. Development of a raster database of annual, monthly and daily rainfall for southern Africa. WRC Report No. 1156/1/04. School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg, South Africa. 78 pp. CD included in report; and 2) Schulze, R.E & Maharaj, M. 2004. Development of a database of gridded daily temperatures for southern Africa. WRC Report No. 1156/2/04. School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg, South Africa. 82 pp. CD included in report.

a)

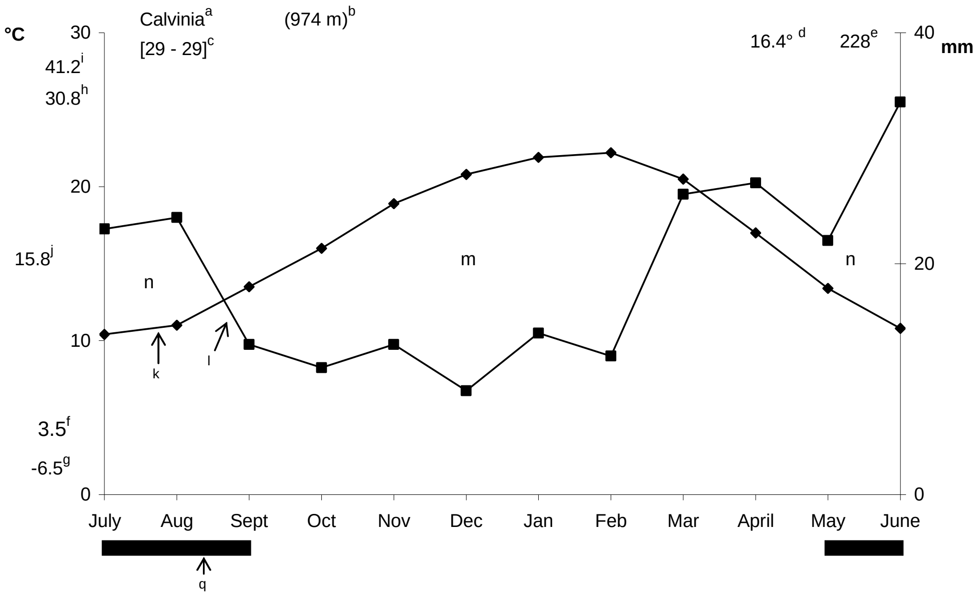
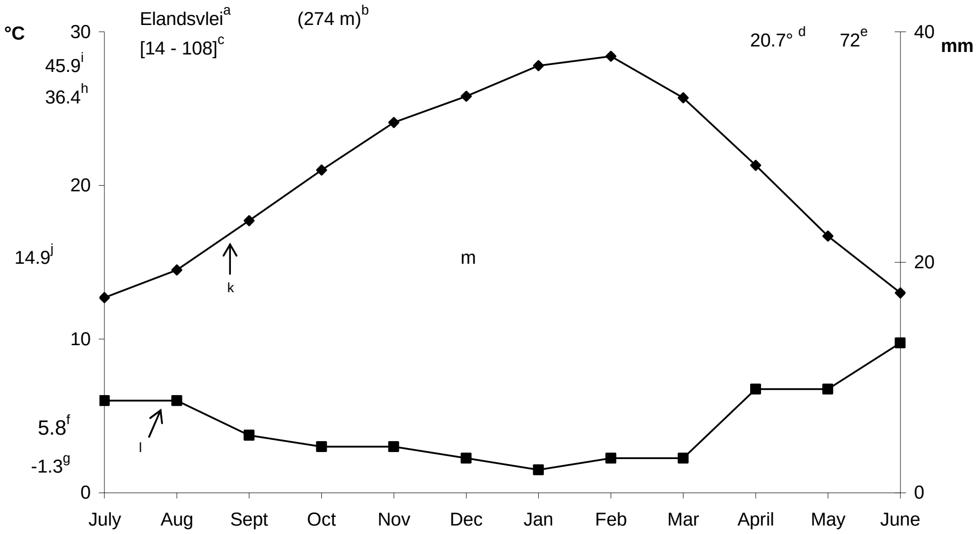


Figure 2.5 Walter diagrams for a) Calvinia (Hantam); b) Elandsvlei (Tanqua Karoo); and c) Sutherland (Roggeveld). Superscripts denote the following: a = station, b = height above sea level, c = durations of observations in years (of two figures the first indicates temperature, the second precipitation), d = mean annual temperature in °C, e = mean annual precipitation in mm, f = mean daily minimum of the coldest month, g = lowest temperature recorded, h = mean daily maximum for the warmest month, I = highest temperature recorded, j = mean daily temperature variations, k = curve of mean monthly temperature, l = curve of mean monthly precipitation, m = relative period of drought, n = relative humid season and q = months with mean daily minimum below 0°C. Some values are missing, where no data is available for the stations (After Cox and Moore 1994).

b)



c)

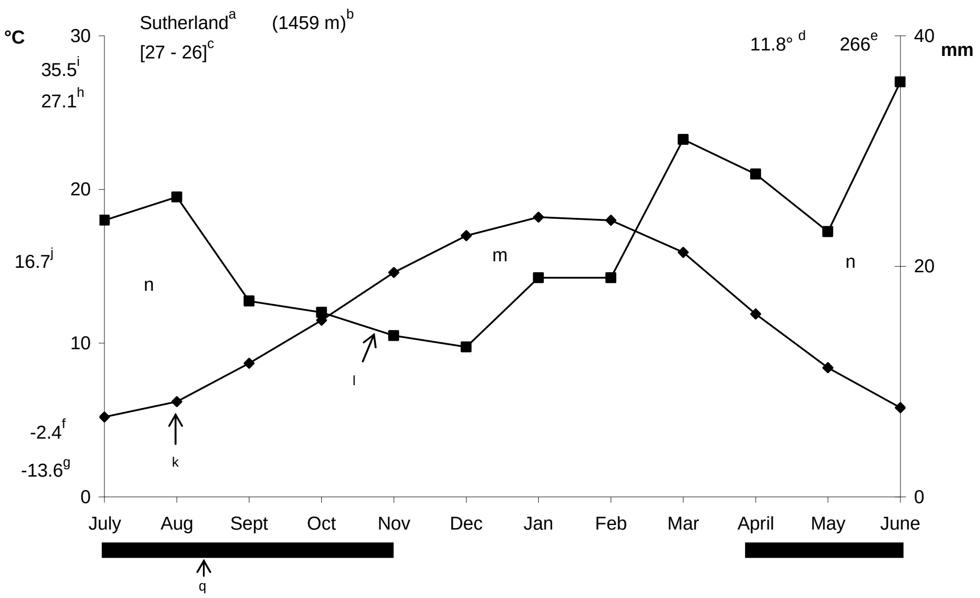


Figure 2.5 (continued)

An interesting climatic characteristic of the Roggeveld is the low number of heat units (degree days) that are encountered during a year. The concept of the heat unit (or degree day) revolves around the development of a plant or organism being dependent upon the total heat to which it was subjected during its lifetime, or else during a certain developmental stage (Schulze 1997). Heat units are expressed as degree days, where these are an accumulation of mean temperatures above a certain lower threshold value (below which active development is considered not to take place) and below an upper limit (above which growth is considered to remain static or even decline) over a period of time (Schulze 1997). The degree days for October to March above 10°C vary in the Roggeveld from 1400 to 1800 however, for April to September these degree days vary from <200 to 400, some of the lowest values for the entire South Africa (Schulze 1997).

Some plants, which have a dormant season during winter, may have to accumulate chill units with temperatures below a threshold in order to stimulate growth, develop leaves, flowers or set fruit (Steyn et al. 1996, Schulze 1997). The required amount of chilling for completion of the rest period varies between species, cultivars and different locations. Chill units have been derived from models using threshold temperatures. Positive chill units for the Roggeveld for May range from 200 to >250, June 300 to >350, August 300 to >350 and September 150 to >250. The accumulated positive chill units from May to September range from 1250 to >1750, some of the highest values for the entire South Africa (Schulze 1997).

2.4 Vegetation

2.4.1 Succulent Karoo Biome

In the Succulent Karoo Biome, succulents and non-succulent chamaephytes, geophytes and therophytes are unusually common relative to trees and grasses (Milton et al. 1997). The Succulent Karoo has a remarkable dominance and unique diversity of short to medium-lived leaf-succulent shrubs as well as a rich geophyte flora (Jürgens et al. 1999, Esler et al. 1999a). The high diversity of dwarf leaf-succulent shrubs is the biome's most distinctive character (Mucina et al. 2006) with most of the species contained in two families i.e. Mesembryanthemaceae and Crassulaceae (Milton et al. 1997). While geophytes are as successful in the Succulent Karoo Biome as they are in the Fynbos Biome in terms of abundance and diversity (Snijman & Perry 1987, Esler et al. 1999b, Mucina et al. 2006). A feature of the Succulent Karoo Biome are the spring floral displays of winter-growing annuals (Milton et al. 1997), that are relatively predictable and often extravagant (Cowling et al. 1999, Van Rooyen 1999).

Many of the biologically unique features of the Succulent Karoo Biome have been attributed to its climatic conditions (Cowling et al. 1999, Mucina et al. 2006). Firstly, the highly effective and relatively predictable seasonal rainfall (Desmet & Cowling 1999) and secondly, the relatively moderate winter and early spring temperatures (Mucina et al. 2006). Globally there are few other places what can claim to be as biologically distinct as the Succulent Karoo Biome with the biome experiencing numerous adaptive radiations and associated endemism for a wide range of faunal and floral groups (Mucina et al. 2006).

2.4.2 Fynbos Biome

Fynbos is the predominant vegetation type in the Fynbos Biome (Cowling et al. 1997) however, the Fynbos Biome strictly comprises three quite different, naturally fragmented vegetation types (fynbos, renosterveld and strandveld) that occur in the winter and summer rainfall areas, are dominated by small-leaved, evergreen shrubs and whose generation is intimately related to fire (Rebelo et al. 2006).

Renosterveld is an evergreen, fire-prone vegetation dominated by small-leaved, asteraceous shrubs (especially *Dicerothamnus rhinocerotis*, renosterbos) and has an understory of Poaceae and geophytes (Moll et al. 1984, Cowling et al. 1997). Moll et al. (1984) differentiated renosterveld into four, more or less biogeographically defined types, however, these exclude the escarpment types, which show strong karroid affiliations (Rebelo et al. 2006).

Four factors separate the Fynbos Biome from the other biomes of southern Africa. These are: 1) nutrient-poor soils supporting fynbos; 2) hot, dry summers alternating with cool, wet winters; 3) recurrent fires at five to 50 year intervals in fynbos and two to 10 year intervals in renosterveld (in comparison to no regularly occurring annual fires or the absence of fire); and 4) a complex of plant-animal interactions (Rebelo et al. 2006).

2.4.3 Phytogeographical affinities

The phytogeographical affinities of the Hantam-Tanqua-Roggeveld area have been under revision for more than a century and still remain uncertain. Some of the first detailed accounts of the area were provided by Marloth (1908) and Diels (1909).

Marloth (1908) placed the Tanqua Karoo within his ‘Karroo’ phytogeographic guild describing it as a semi-desert steppe with a dominance of dwarf shrubs and succulents, and dry riverbeds lined with trees of *Acacia* spp. and *Searsia* spp. Additionally, he divided this ‘Karroo’ into four zones one of which he called the Bokkeveld and Tanqua Karoo, which was synonymous to the historically delineated western Karoo and what we would today consider to be the Tanqua Karoo. The great escarpment was used by Marloth (1908) to separate the ‘Karoo’ guild from the ‘Karroides Hochland’ (Karoo highland) thereby placing the Roggeveld and Roggeveld Karoo areas into the 'Karroides Hochland' phytogeographic guild. Marloth (1908) considered the vegetation of the three subdivisions of the Roggeveld (Klein, Middel and Lower Roggeveld) similar, yet different from the vegetation of the Nuweveld Mountains. The Hantam is not specifically mentioned by Marloth (1908), however, his map of the phytogeographic guilds indicates the Hantam included into the 'Karroides Hochland' guild.

Diels (1909) visited the Hantam in 1900 which was a good rainfall year and provided additional information on the area. He concurred with Thunberg that as soon as the Bokkeveld ended the landscape became more arid and that the further one traveled it eventually became completely Karoo. As Marloth (1908), Diels (1909) stated that the Karoo vegetation was sparse and that it was characterised by succulents and Asteraceae (Compositae).

This early traveller, Diels (1909), gave a very specific account of his investigations up the Hantam Mountain broadly stating the following: 1) the perennial vegetation above 1000 m above sea level was not found at lower altitudes; 2) on south-facing slopes, at approximately 1400 m above sea level, many new species were encountered including the *Cliffortia arborea* mentioned in Marloth's (1908) descriptions of the Roggeveld vegetation; and 3) the highest parts of the mountain were similar to the Cape flora, however, Diels (1909) was not able to sight any Proteaceae or Ericaceae but found Restionaceae and the *Cliffortia arborea*. Diels (1909) suggested that the Hantam Mountain was perhaps one of the last outliers of the south-western flora (Cape flora), however, stated that this would have to be researched. Additionally, the mountains to the north, towards Loeriesfontein, and into Namaqualand would have to be studied since these areas were totally unknown at the time. The flora of the Hantam Mountain showed links with the flora he found on Roepmyniet and the flora described by Marloth (1908) for the Roggeveld Mountains.

Weimarck (1941) proposed a classification of the Cape species into five phytogeographical groups and treated the Hantam-Roggeveld as a subcentre of his North-Western Centre and stated that the subcentre constituted the last outlier of the Cape element in the inner parts of western South Africa. He did this somewhat hesitantly, as he stated that perhaps this region did not deserve to be classified as a subcentre on its own, as the species belonging to the Cape element are comparatively few. But the types represented in the Hantam-Roggeveld are so peculiar and often systematically so singular, that such a view could be admitted (Weimark 1941, Van Wyk & Smith 2001).

In his book, Veld types of South Africa, Acocks (1988) included a map of the vegetation in A.D. 1400? stating that there was no direct historical evidence to work with yet, he compiled a map he considered to indicate the vegetation of South Africa at that time. Acocks (1988) placed the Hantam and slopes of the Roggeveld escarpment within a Karoo veld type (including Karroid Bushveld), the Tanqua Karoo within the Succulent Karoo and the Roggeveld, including the Hantam Mountain and Nuweveld Mountains, within a Scrubby Mixed Grassveld veld type (Nama Karoo Biome). A second map of the vegetation in A.D. 1950, no longer places the Hantam and Roggeveld vegetation as a type of shrubby grassland but within the Karoo veld types and the Tanqua Karoo within the Succulent Karoo and Desert veld types.

The Fynbos Biome Project (1977-1980) resulted in a report on the description of the major vegetation categories in and adjacent to the Fynbos Biome (Moll et al. 1984). Unfortunately, this document did not include all the areas mapped by Acocks, specifically, the Roggeveld and Kamiesberg mountains covered by Mountain Renosterveld (Moll & Bossi 1984).

Rutherford and Westfall (1994) placed the Hantam and Tanqua Karoo within the Succulent Karoo Biome and the Roggeveld within the Nama Karoo Biome stating that one of the four anomalies found while classifying the biomes was an area of Mountain Renosterveld which was physically outside the Fynbos Biome on the Roggeveld escarpment. These limited areas contained vegetation different to the surrounding biomes and were only marginally similar in vegetation structure to that of the Fynbos Biome but showed some floristic affinity to the Fynbos Biome (Olivier et al. 1983 in Rutherford & Westfall 1994). They contend that the life form combination nevertheless precluded this area from being considered as part of the Fynbos Biome (Rutherford and Westfall 1994).

Low and Rebelo (1996) placed the Hantam and Tanqua Karoo within the Succulent Karoo Biome with its low presence of winter rainfall and extreme summer aridity while, the Roggeveld was included within their renosterveld vegetation group of the Fynbos Biome. Furthermore, Low and Rebelo (1996) confirm that the Cape Floral Kingdom traditionally does not include the fynbos and renosterveld outliers to the north and east.

Jürgens (1997) mapped the entire Hantam-Tanqua-Roggeveld subregion as belonging to the Succulent Karoo Biome and listed various studies indicating that some relationships exist between the Karoo and Cape flora arguing for the recognition of the Floristic Kingdom of the Greater Cape Flora with two subdivisions, the Cape Floristic Region and the Succulent Karoo Region.

Mucina et al. (2005), Rebelo et al. (2006), Rutherford et al. (2006) and Mucina et al. (2006) place the Hantam and Tanqua Karoo within the Succulent Karoo Biome and the Roggeveld within the Fynbos Biome. However, they clearly state that they did not apply the explicit and globally derived definition of a biome and only considered botanical elements (Rutherford et al. 2006).

A recent study by Born et al. (2007) evaluates the floristic support for expanding the delimitation of the CFR to include the whole winter-rainfall area into a Greater Cape Floristic Region. Their main conclusions were that the CFR constitutes a valid floristic region, however, the total endemism is higher for the whole winter-rainfall area and this supports the recognition of the larger (Greater Cape Floristic Region) unit. If floristic regions were to be delimited only on endemism, then the Greater Cape Floristic Region is to be preferred (Born et al. 2007).

2.4.4 Vegetation classification

Three of Acocks's (1953) vegetation types are found within the study area namely: Mountain Renosterveld, Succulent Karoo and Western Mountain Karoo (Acocks 1988). Acocks's Mountain Renosterveld is equivalent to the Escarpment Mountain Renosterveld of Low and Rebelo (1996), and his Succulent Karoo and Western Mountain Karoo form part of the Lowland Succulent Karoo and Upland Succulent Karoo of Low and Rebelo (1996) respectively. Mucina et al. (2005) and Mucina and Rutherford (2006) recognised twelve vegetation types in the study area which include: the Nieuwoudtville Shale Renosterveld (FRs 2), Roggeveld Shale Renosterveld (FRs 3), Central Mountain Shale Renosterveld (FRs 5), Nieuwoudtville Roggeveld Dolerite Renosterveld (FRd 1), Hantam Plateau Dolerite Renosterveld (FRd 2), Roggeveld Karoo (SKt 3), Hantam Karoo (SKt 2), Tanqua Escarpment Shrubland (SKv 4), Tanqua Karoo (Skv 5), Tanqua Wash Riviere (AZi 7), Namaqualand Riviere (AZi 1) and Bushmanland Vloere (AZi 5).

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