

Diversity and species turnover on an altitudinal gradient in Western Cape, South Africa: baseline data for monitoring range shifts in response to climate change

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ABSTRACT

A temperature and moisture gradient on the equator-facing slope of Jonaskop on the Riviersonderend Mountain, Western Cape has been selected as an important gradient for monitoring the effects of climate change on fynbos and the Fynbos-Succulent Karoo ecotone. This study provides a description of plant diversity patterns, growth form composition and species turnover across the gradient and the results of four years of climate monitoring at selected points along the altitudinal gradient. The aim of this study is to provide data for a focused monitoring strategy for the early detection of climate change-related shifts in species' ranges, as well as gaining a better understanding of the role of climate variability in shaping species growth responses, their distributions, and other ecosystem processes.

INTRODUCTION

The vegetation of mountain ranges of the Cape Floristic Region (CFR) is characterized by gradients of high species turnover. These gradients are associated with increasing precipitation and lower temperatures with increasing elevation, as well as edaphic diversity (Goldblatt 1997). The vegetation of Cape mountain ranges within the CFR is dominated by fynbos (Mucina & Rutherford 2006). However, in inland intermontane valleys in the Western Cape interior, fynbos is replaced by Succulent Karoo, an arid shrubland, at lower elevations with an ecotonal zone in between, called renosterveld (Cowling & Holmes 1992).

Ecotones, or areas of transition between distinct biomes or vegetation types, have been pointed out as important areas for monitoring the effects of global climate change (Kupfer & Cairns 1996). Modelling of future climate scenarios for the Western Cape indicates that large areas of fynbos will be subjected to warmer and drier climate conditions similar to what is currently associated with Succulent Karoo, and that vegetation shifts might take place resulting in a loss of distribution area of fynbos due to a southward shift of Succulent Karoo (Rutherford *et al.* 2000). Therefore vegetation gradients incorporating transitions between fynbos and Succulent Karoo are important areas to monitor for the early detection of climate change-induced biome shifts.

The elevational gradient on the equator-facing slope of Jonaskop, one of the highest peaks in the Rivier-

sonderend Mountains, Western Cape, has been identified as a key site for monitoring the effects of climate change on fynbos and the Fynbos-Succulent Karoo boundary. On the equator-facing foothills of Jonaskop, fynbos vegetation type FFs13, North Sonderend Sandstone Fynbos, intersects with Succulent Karoo vegetation type SKv7, Robertson Karoo (Mucina & Rutherford 2006) through a renosterveld ecotone. The Jonaskop gradient has been described in terms of vegetation biomass turnover (Rutherford 1978), but no formal description of the plant communities or of species diversity turnover on the gradient has been done to date. Other studies conducted at the site include investigations into *Protea* species and classic rodent pollinator interactions (Rourke & Wiens 1977; Wiens *et al.* 1983; Fleming & Nicolson 2002a, b), including rodent diets and metabolism (Johnson *et al.* 1999; 2004; 2006); a comparative study between nectar qualities of Cape and Australian Proteaceae (Nicolson & Van Wyk 1998); seed dispersal by small mammals (Midgley & Anderson 2005); lizard foraging behaviour (Cooper *et al.* 1999); leaf functional classification of a number of species in a Mediterranean context (Vile *et al.* 2005); xylem traits in relation to water stress tolerance (Jacobsen *et al.* 2007); plant phenophase responses to climate (Agenbag *et al.* 2004a); how biome boundaries might respond to climate change (Agenbag *et al.* 2004b, c); and sampling for vegetation structural changes as part of a biome-wide study (Campbell 1985). These studies mark Jonaskop as an important site for ecological research that would benefit greatly from a formal description of the biotic and abiotic environment.

The aim of this paper, therefore, is to describe the Jonaskop gradient in terms of its vegetation changes, species turnover, soil chemistry and climate and to serve as a source of reference for future monitoring.

MATERIAL AND METHODS

Study area

The Riviersonderend Mountain is situated on the western end of a chain of east-west trending moun-

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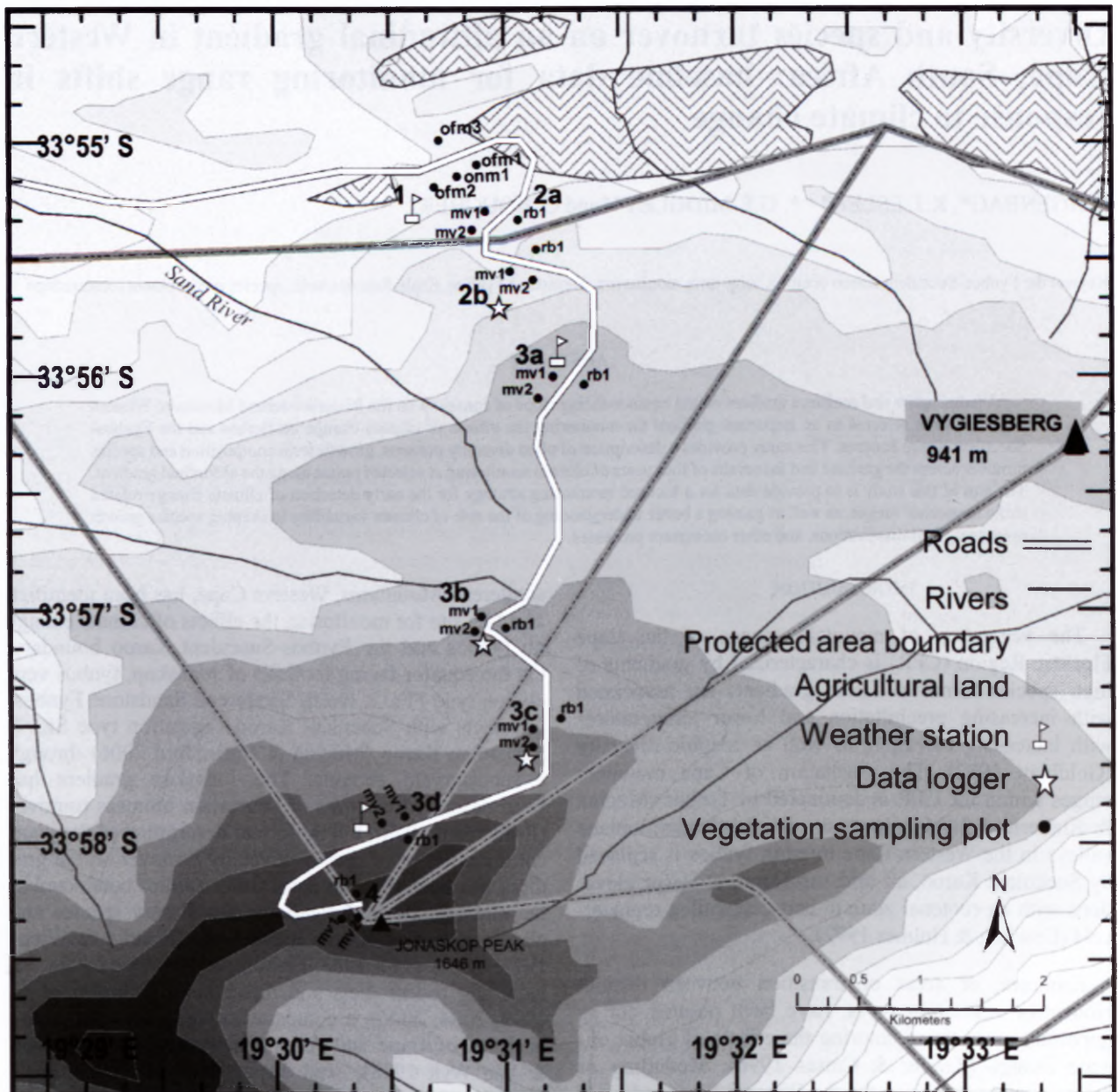


FIGURE 1.—Topographical map of study site indicating location of weather stations, data loggers and vegetation sampling plots. Contours represent 100 m intervals. 1, Karoo/ Renosterveld site, 545 m. 2, low-altitude fynbos sites: 2a, 690 m; 2b, 744 m. 3, mid-altitude fynbos sites: 3a, 953 m; 3b, 1 044 m; 3c, 1 196 m; 3d, 1 303 m. 4, high-altitude fynbos site, 1 576 m. Vegetation plot codes: onm, plot on *heuweltjie* or mima-like mound; ofm, plot in renosterveld/Karoo matrix vegetation; rb, plots in recently burnt fynbos vegetation; mv, plots in mature fynbos vegetation. GIS data provided by CapeNature, Department of Land Affairs: Surveys and Mapping, and the Department of Agriculture.

tain ranges at the southern edge of the Cape Fold Belt. Jonaskop, 33°58'00 S 19°30'00 E, altitude 1 646 m (Figure 1) is located within the Riviersonderend Mountain Catchment—a protected area that is managed by CapeNature as an important water source to the Riviersonderend River below the southern slopes and the Breede River towards the north. The protected area is bordered by privately owned agricultural land. A service road leading up to a Sentech radio mast on the mountain summit provides access to the equator-facing slope of Jonaskop.

The Jonaskop gradient spans a change of roughly 1 200 m in elevation between foothills in the Breede River Valley and Jonaskop Peak. Whereas the south-facing slope of Jonaskop is extremely steep, the equator-facing slope rises somewhat less rapidly, except for a flattened 'step' in the middle of the gradient, at ± 900 m.

Several drainage lines leading down from the northern slope converge in the Sand River, which at ± 400 m is the lowest point of the gradient. This small stream joins the Doorn River, a tributary of the Breede River, further down the valley.

Soils on the mountain are shallow and very rocky. The coarse, grey, sandy soils of the mountain slope are derived from quartzitic sandstone of the Table Mountain Group. At the foot of the mountain (below 600 m) soils are finer grained and less rocky compared to those of the Table Mountain Group. Here the geology is alternating bands of arenaceous shale and argillaceous sandstone from the Bokkeveld Group (Besans 1966).

Vegetation changes from Succulent Karoo at the very lowest elevations (± 500–600 m) through an ecotonal area of renosterveld with succulent as well as fynbos ele-

ments (roughly around 600–800 m), to fynbos from 800 m upwards. The boundary between the Succulent Karoo and ecotone coincides with the transition from shale-derived to sandstone-derived soils.

Ecotonal and fynbos vegetation on either side of the road leading to the top of the mountain differs in fire history: with few exceptions, one side burned fairly recently (2000), whereas on the other side, mature vegetation has established after the last fire in 1992.

Climate monitoring

Climate change monitoring and experimental stations have thus far been placed at six sites along the length of the gradient (Figure 1). Weather stations (Watchdog Model 600 Weather Station 3325WD), recording air temperature, relative humidity, rainfall, soil moisture and wind speed and direction, are situated at the top (1 303 m), middle (953 m) and lowest (545 m) end of the gradient, whereas data loggers (Watchdog 450 Relative Humidity/Temperature Data Logger) record relative humidity, air temperature and soil moisture at the intermediate sites (1 196 m, 1 044 m, 744 m). Weather stations have been recording climate continuously since February 2002 (with some breaks at all stations from time to time due to equipment malfunction and damage, e.g. from rodent gnawing on exposed cables. Where such breaks occurred, data were interpolated from adjacent or nearby weather stations assuming average air temperature lapse rates or average annual altitude-related rainfall trends). Readings are taken automatically every 30 minutes. Climate data were analysed to show patterns in temperature, rainfall and wind conditions across the gradient.

Soil analysis

Soil samples were taken at each of the monitoring sites along the gradient and analysed for P, Ca, Mg, K, Na, N and pH according to standard methods: to analyse for P, a 5 g sample was added to 50 ml 1 % citric acid solution. To an aliquot of the clear and colourless extract was added an acidified ammonium molybdate solution. The phosphomolybdate complex was then reduced with stannous chloride and the absorbance of the resulting blue colour measured with a spectrophotometer and compared with the absorbances obtained from standard phosphorus. To analyse for N, a known mass of soil was digested with sulphuric acid using selenium as a catalyst. The resultant ammonia was distilled into a saturated boric acid solution and titrated with standard acid. Macro elements (Ca, Mg, Na, K) were determined by measuring a 1 mol dm⁻³ ammonium acetate extraction by atomic absorption against known standards.

Field sampling methods

For the vegetation analysis, two more sites were added to the existing climate monitoring stations: one on the lower sandstone slopes of the ecotonal zone (690 m), and another one near the mountain summit (1 576 m). Vegetation sampling was done in October and November 2003. Relevés of 10 × 10 m were used, with two relevés located in mature vegetation and one in recovering vegetation at each site. Species were scored following the Braun-Blanquet cover-abundance scale (Braun-Blanquet

1928). At the Succulent Karoo site, at the lowest end of the gradient (545 m), a relevé was added to include sampling of vegetation on nutrient-enriched *heuweltjies* or mima-like mounds usually found in association with termitaria in this region (Esler & Cowling 1995).

Environmental characteristics noted at each relevé included slope, aspect, percentage rock cover, soil type and soil depth. Soil depth was determined up to 0.5 m deep at 10 points at regular intervals across one diagonal of each relevé. Soil depth for each relevé was then expressed as a range from shallow to deep, with depths of more than 0.5 m indicated by 0.5 m+.

Data analysis

Species data were assembled into a phytosociological table and sorted according to constancy and affinity to determine plant communities and their characteristic species. Braun-Blanquet scores were then converted to percentage cover values for the calculation of species diversity (See Table 1 for conversion values). The diversity of each relevé was calculated according to the Shannon-Wiener Index (Kent & Coker 1994) with the formula:

$$\text{Diversity } H' = -\sum_{i=1}^s p_i \ln p_i$$

where s is the number of species, and p_i is the proportion of the i -th species to the total vegetation cover. Diversity values of the relevés of each site were then averaged to arrive at a diversity estimate for each site. Within-site comparisons of diversity between recently burned and mature vegetation were also done for all sites except the karoo site (545 m), which did not burn.

All sampled species were classified according to growth form. Growth forms were assigned according to a scheme adapted from Cowling *et al.* (1994) (Table 2). The contribution of each growth form to total vegetation cover in each relevé was calculated by summing converted percentage cover values of all species belonging to each growth form, and expressing it as a proportion of total vegetation cover. Site specific growth form composition was then calculated by averaging cover values of the relevés of each site. Comparisons of growth form composition between recently burnt and mature vegetation were done for all sites except the lowest karoo site (545 m). Relevés of mature vegetation of all sites were lumped, and the average growth form composition was

TABLE 1.—Conversion of Braun-Blanquet scores to percentage cover values

Braun-Blanquet	Converted % cover
O	
R	1
+	1
1	3
2M	4
2A	8.5
2B	19
3	39
4	63
5	88

TABLE 2.—Categorization of growth forms, adapted from Cowling *et al.* (1994)

Main groups	Code	Subgroups
Herbs	AH	Annual herb
	PH	Perennial herb
	HV	Herbaceous vine
	PHP	Perennial herb, parasite
Dwarf shrubs (< 0.25 m)	DES	Dwarf evergreen shrub
	DSP	Dwarf shrub, parasite
Low shrubs (0.25–1 m)	LES	Low evergreen shrub
	LSP	Low shrub, parasite
Mid-high shrubs (1–2 m)	MES	Mid-high evergreen shrub
Succulents	DSS	Dwarf succulent shrub, < 0.25 m
	LSS	Low succulent shrub, 0.25–1 m
	PHS	Perennial herb with succulent leaves
	SP	Succulent parasite
Geophytes	GEO	
Graminoids	GRA	Includes all grasses, sedges and restios

compared with the average composition of all recently burnt relevés across the gradient.

Similarity of species composition of different sites were compared using Jaccard's coefficient (Kent & Coker 1994). The formula is:

$$S_j = \frac{a}{a+b+c}$$

where S_j is the Jaccard similarity coefficient, a is the number of species common to both sites compared, b is the remaining number of species present at the first site, and c is the remaining number of species present at the second site. S_j was multiplied by 100 to arrive at a percentage similarity. The average turnover rate across the gradient was determined according to the methods of Itow (1991). Log percentage similarity between every pair of sites (on y-axis) was plotted against their difference in altitude (on x-axis). The slope of the regression line fitted is taken as the average turnover rate of species per 1 m altitudinal difference.

RESULTS AND DISCUSSION

Temperature

Temperatures decrease with increasing altitude (Barry 1992); however, the rate at which temperatures decrease can vary spatially as well as seasonally (Rolland 2003). On Jonaskop, there is an average difference of 4.4°C between the highest (1 303 m) and lowest site (545 m) on the gradient (Table 3). Temperatures along this gradient generally decrease by 0.58°C with every 100 m altitude gained, as indicated by the slope of a regression line fitted to mean annual temperatures recorded at each of the monitoring sites (not shown). However, diurnal and seasonal temperature lapse rates on the mountain slope vary between -0.40°C.100 m⁻¹ for winter minimum temperatures (April to September) and -0.77°C.100 m⁻¹ for summer maximum temperatures (October to March) (Figure 2). This is consistent with patterns found in mountainous regions elsewhere (Rolland 2003 and ref-

erences therein). Complex factors contribute to seasonal and diurnal variation in lapse rates. These include wind regime, cloud cover, amount of incoming solar radiation and the moisture content of the air (Barry 1992) and it is therefore difficult to explain the variations observed on Jonaskop without detailed analysis of other meteorological patterns.

It should be noted that the middle site (953 m) is somewhat colder than the site directly above it (1 044 m) (Table 3). This effect is particularly strong at night during winter (Figure 2), when mean minimum temperatures recorded at the site are on average 1.6°C colder than the expected trend. Such local temperature inversions are generally the result of cold air drainage, and are often observed in valley bottoms (O'Hare *et al.* 2005). The fact that the middle site is located on a plateau probably results in cold air flowing downwards from the steeper slopes above and collecting at this site during the long winter nights.

Monthly mean temperature summaries indicate that August is the coldest month at the site (Figure 3), with mean minimum temperatures ranging from 3.3–6.9°C between the highest and lowest monitoring points. Highest temperatures were recorded during February, when daily maximum temperatures are on average around 30°C at the karoo site (545 m) at the lowest end of the gradient.

Rainfall

During three years of climate recording (2002–2004), the highest site (1 303 m) received an average of 719.6 mm annual precipitation, the middle site (953 m) 411.3 mm and the bottom karoo site (545 m) 315.4 mm. The highest site receives on average a slightly lower proportion of its annual rainfall in winter (Table 3, Figure 4). Higher summer rainfall at the highest site is possibly due to orographic effects, with southerly winds pushing clouds over the mountaintop and bringing rain to the highest site but not to lower sites. According to Aschmann (1973), Mediterranean climates are defined by winter rainfall constituting at least 65 % of the annual rainfall. The proportions of winter rainfall recorded across the Jonaskop gradient, which ranges from 57–66 %, therefore indicates that the study site does not fall within the strictly winter rainfall zone of the CFR. Long-term rainfall data for the Riviersonderend Mountain confirm that many large rainfall events, associated with post-frontal cut-off lows occur in summer, resulting in the

TABLE 3.—Summary of temperatures and mean annual precipitation (MAP) recorded at different altitudes on Jonaskop elevational gradient

Altitude (m)	MAT (°C)	Tmin (°C)	Tmax (°C)	MAP (mm)	% Winter
545	16.5	6.9	30.2	315.4	62
744	15.7	6.7	29.3	nr	nr
953	13.6	3.6	27.4	411.3	66
1044	14.0	4.7	27.0	nr	nr
1196	12.9	4.1	25.2	nr	nr
1303	12.1	3.3	24.6	719.6	57

MAT, mean annual temperature; Tmin, mean minimum temperature of coldest month; Tmax, mean maximum temperature of warmest month; % Winter, proportion of total MAP recorded during winter (April–Sep.); nr, not recorded.

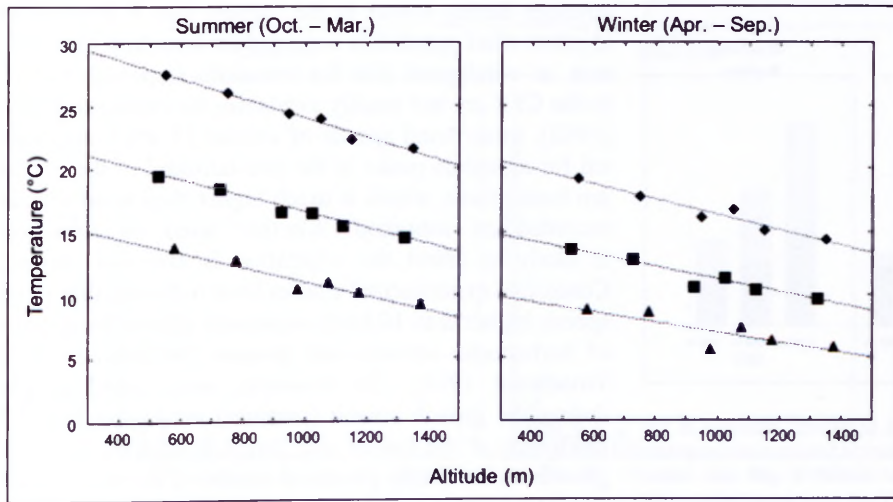


FIGURE 2.—Plot of mean daily temperatures, ■; mean daily maximum temperatures, ◆; and mean daily minimum temperatures, ▲, against altitude, showing seasonal variation in temperature decreases with increasing altitude.

area not being subjected to as severe summer droughts as elsewhere in the CFR (R.M. Cowling pers. comm.).

Monthly rainfall patterns recorded during three years of this study were very variable (Figure 5). The year 2002 had good winter rains and a relatively dry summer. The high monthly total precipitation of March 2003 was due to a single extreme rainfall event on 24 March when 174.5 mm was recorded at the highest site (1 303 m) and 103.9 mm at the lowest site (545 m). Year 2003 was an extremely dry year throughout the whole Western Cape, and the low rainfall, especially during the winter months, is reflected in the data from Jonaskop. Although 2004 had, in total, a much higher annual precipitation, it also had a very dry winter, with most of the annual precipitation recorded during October.

Cowling *et al.* (2005) highlighted the importance of rainfall reliability in terms of interannual variation in rainfall, as well as the size and structure of rainfall events, as a driver of plant traits in Mediterranean ecosystems. Rainfall data recorded at Jonaskop were, therefore, further analysed to explore seasonal pat-

terns in the size, duration and frequency of rainfall events. Whenever rain was recorded on a number of consecutive days, rainfall recorded over the period was added together as a single rainfall event. Cowling *et al.* (2005) also mentioned the importance of the regularity of rainfall events in Mediterranean climates, especially with regard to the germination of seedlings. Mustart & Cowling (1993) showed that the duration of dry periods between rainfall events is an important factor determining the successful germination of Proteaceae seeds, and that rainfall patterns during germination stages have a large impact on the distribution patterns of Proteaceae populations observed in the field. Therefore a frequency analysis of the number of days between rainfall events was also done.

At all sites, rainfall events occur most often as small (< 5 mm) events lasting only one day (Figure 6). This trend was observed during winter and summer. However, larger rainfall events (> 10 mm), and events lasting longer than two days occur much more frequently in winter than summer at all sites. In terms of the duration of dry periods between rainfall events, patterns are more diver-

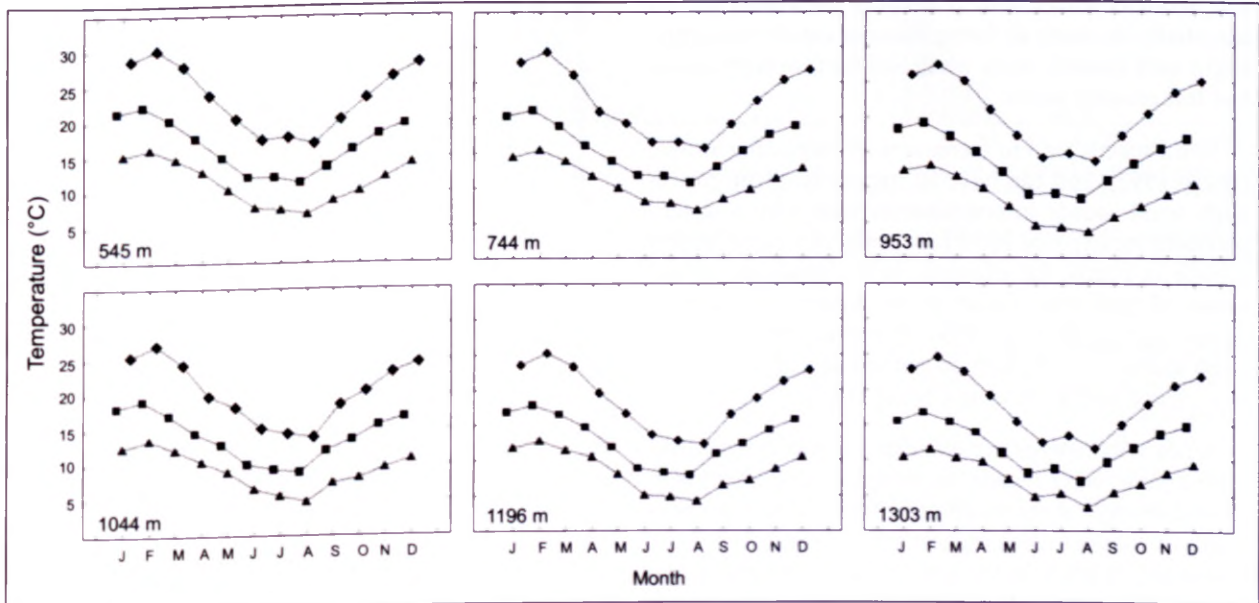


FIGURE 3.—Monthly mean daily, ■; mean daily maximum, ◆; and mean daily minimum, ▲, temperatures recorded at six sites across gradient. Numbers in lower left corner of graphs indicate altitude at which temperatures were recorded.

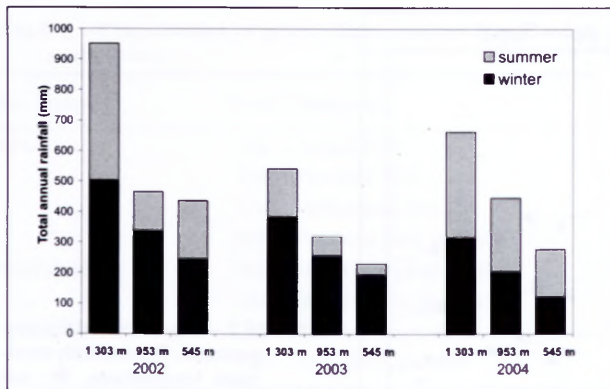


FIGURE 4.—Total annual rainfall (April to March) recorded at top (1 303 m), middle (953 m) and lower (545 m) monitoring points on Jonaskop gradient. Total annual rainfall is split into winter rainfall season (April to September) and summer growth rainfall season (October to March).

gent among sites and seasons. At the highest site (1 303 m), rainfall events were most often separated by less than four days during winter and summer. At the middle site (953 m), the winter rainfall events, in contrast, are far more frequently within four days of each other than in the summer. Summer rainfall events show a larger frequency distribution towards longer dry intervals. At the lowest site (545 m), the winters tend to have longer dry intervals at low altitudes, indicating that even during winter, rainfall at this site can be very sporadic. At this site, dry intervals of longer than 14 days are also more common during winter and summer than at the higher sites.

Wind

An analysis of wind patterns at the top (1 303 m), middle (953 m) and lowest (545 m) sites (Figure 7) shows altitudinal as well as seasonal differences. All sites experience predominantly southerly winds during summer months (October to March). During winter (April–September) wind patterns shift to predominantly northwesterly at the top site and westerly at the middle site, whereas winter wind patterns at the lowest site are essentially the same as during summer conditions, with a slight shift towards more north and northwesterly winds and less easterly winds.

Wind speeds tend to increase with increasing altitude (Barry 1992), and can have an impact on plant growth. High wind speeds in combination with very low temperatures on exposed mountain peaks can cause stunted growth in plants, for example, in the prostrate cushion forms of pine trees found in the Krummholz zone of alpine regions (Körner 1999). However, mean seasonal wind speeds on Jonaskop do not indicate an increase of wind speed with increasing altitude (Figure 8).

When wind speeds are compared across the gradient, lowest mean wind speeds are recorded during both winter and summer at the middle site (953 m). The southerly winds of summer reach highest speeds (mean 11.8 km/h, maximum 28 km/h) at the lowest site. At the middle and lowest sites, winds are stronger during summer than in winter, but the predominantly northeasterly winds associated with advancing rain-bearing cold fronts are much

stronger during winter at the highest site. It is difficult to place wind speed data recorded on Jonaskop into context, as windspeed data for mountain slopes elsewhere in the CFR are not readily available. According to Barry (1992), mean wind speeds of around 25 km/h are typical for mountain peaks in the mid-latitudes of the northern hemisphere, which is much higher than wind speeds recorded on Jonaskop. Whether wind on Jonaskop is likely to affect the vegetation is also not certain. Controlled experimental studies have indicated that wind speeds higher than 10 km/h negatively affects the growth of herbaceous annuals and grasses (Whitehead 1962; Woodward 1993). On Jonaskop, mean wind speeds during the growth season (summer) are higher than 10 km/h only at the lowest site, but it is unlikely to affect growth in the sturdy perennial shrubs of the site, except when associated with high temperatures and low relative humidity, as under berg wind conditions.

Soil characteristics

Soils on the gradient are generally very shallow and rocky, the rockiness increasing with increasing altitude (Table 4). This has an effect on soil moisture, as soils at

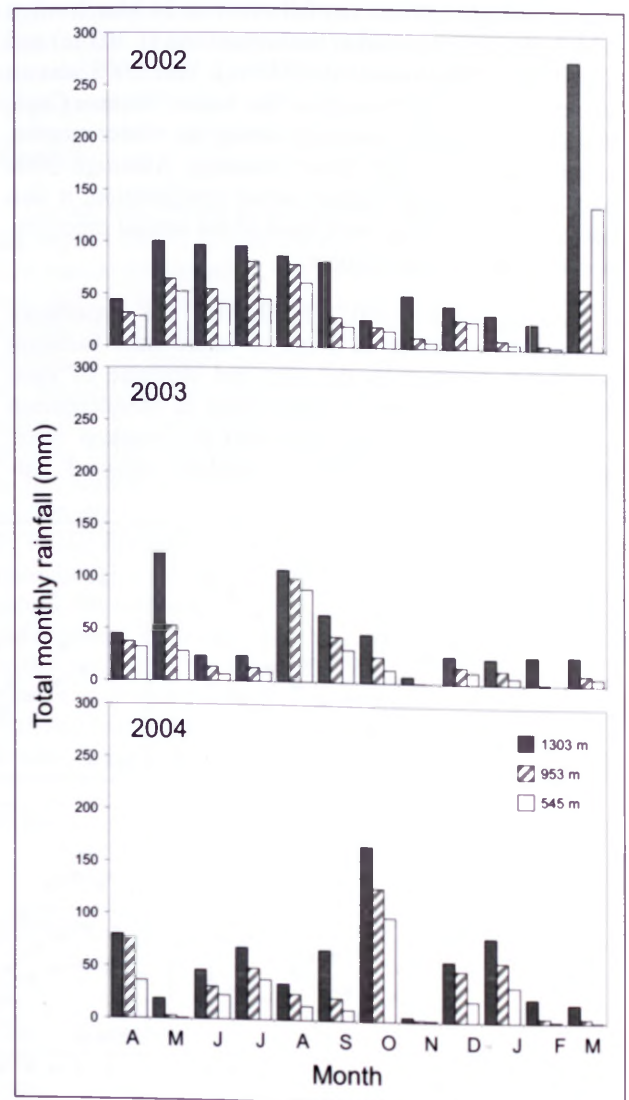


FIGURE 5.—Monthly rainfall recorded from April 2002 to March 2004 at the top (1 303 m), middle (953 m) and lower (545 m) monitoring points on the Jonaskop gradient.

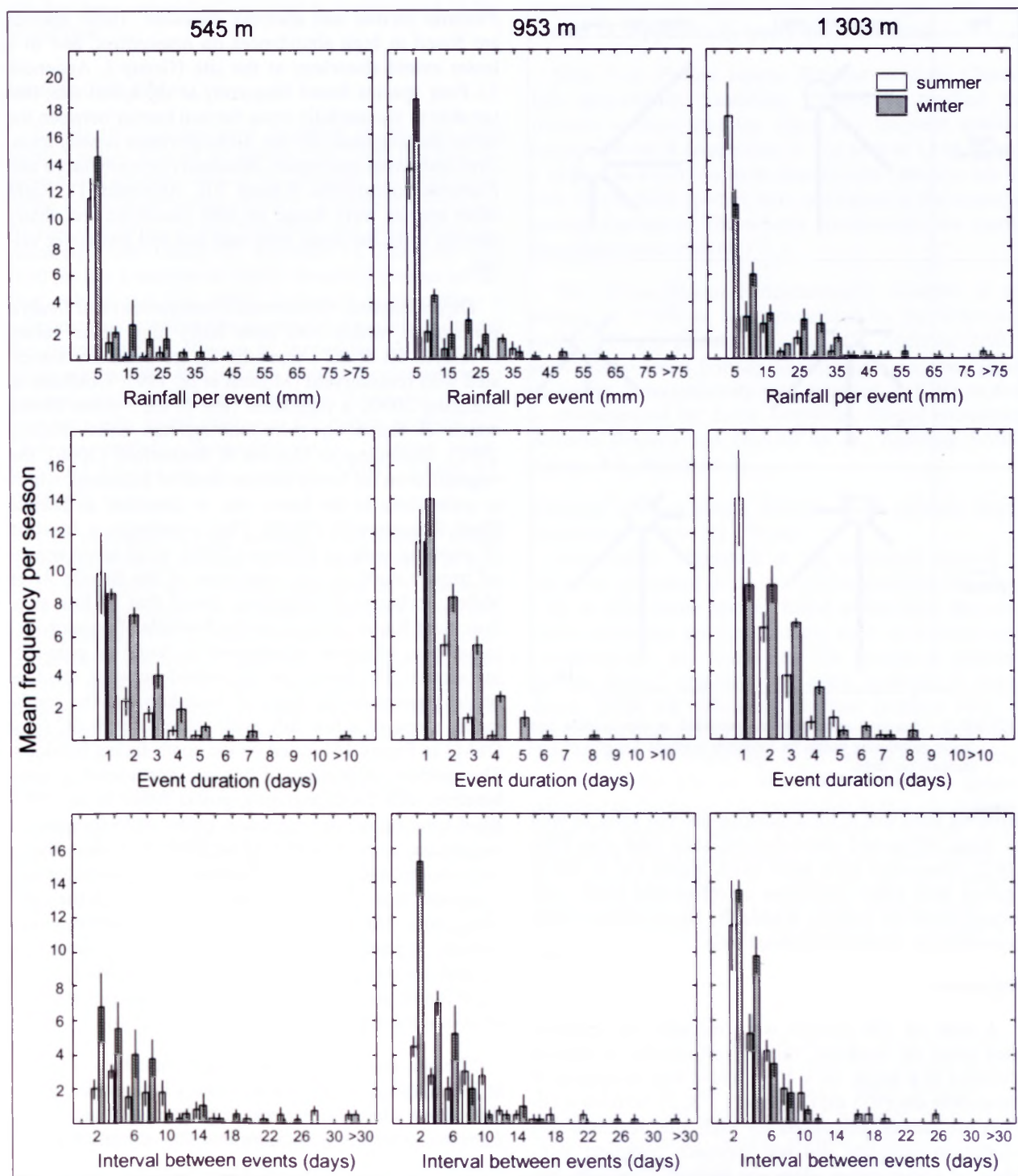


FIGURE 6.—Amount of rain per rainfall event, duration of rainfall events, and duration of dry intervals between rainfall events summarized as mean frequencies per season. Altitude where rainfall was recorded on gradient is indicated above each column. Error bars indicate 1 standard error.

the highest site (1 303 m) are generally drier than the site just below (1 196 m) (data available on request). At the 1 303 m site, slopes are steeper, and the soil is shallower and rockier than at the 1 196 m site (Table 4). These factors imply that faster drainage and runoff of rainfall occurs at the highest site, resulting in soils being drier. It is important to note that the soil moisture sensors did not record values drier than 100 kPa, and thus indicate when water was freely available, and then only in shallow surface layers of the soil. The calibrated range of the sensors was not wide enough to record the onset of stressful soil moisture conditions, which are generally associated

with soil water tensions lower than -1500 kPa (Miller & Gardiner 1998). Soil moisture values do not give an indication of water availability to deep-rooted species. However, our data (available on request) does illustrate that there is a trend toward different soil moisture dynamics at different altitudes that is related to rainfall.

The main differences in soil chemistry between shale-derived soils at the karoo site (545 m) and the sandstone-derived soils of the rest of the mountain was in terms of P, Ca and Mg, which were much higher in the shale-derived soils. Soil on the mounds (*heuweltjies*) was very

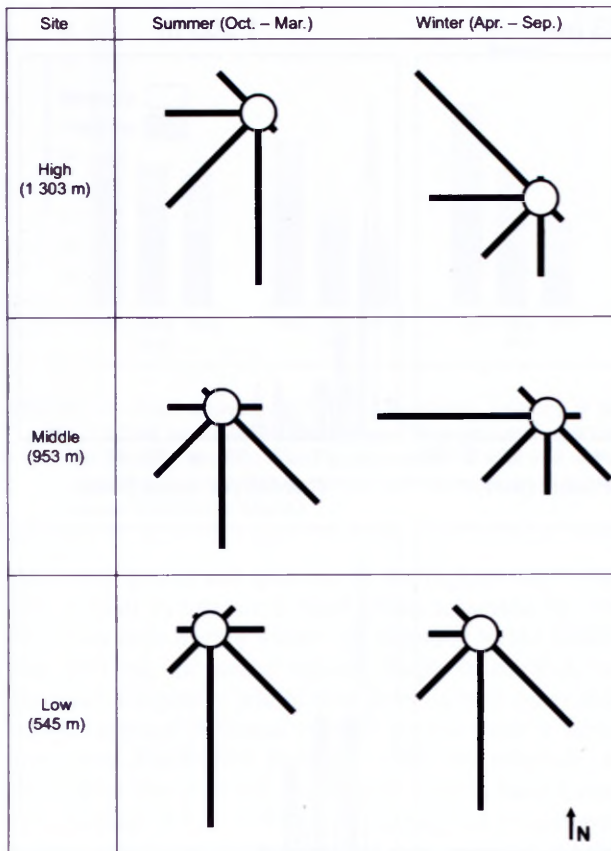


FIGURE 7.—Seasonal wind patterns recorded at top, middle and lower monitoring points on Jonaskop gradient. Lengths of bars indicate no. days.

different from that in the sandstone-derived soils, as well as from off-mound shale-derived soils (see also Ellis 2002). *Heuweltjie* soils have much higher Ca, K and N content than either sandstone or off-mound shale. Off-mound shale has roughly double the Na content of either *heuweltjie* or sandstone-derived soils.

Vegetation

A total of 286 species were recorded at sampling sites along the gradient. The highest number of species recorded in a single 10 × 10 m relevé was 50 species at the middle site (953 m) (Appendix 1 & 2). Species accumulation curves, calculated for each site, revealed that vegetation sampling did not approach complete sampling of communities (data not shown). Typically, the vegetation of the Fynbos Biome has three strata and is a mid-tall to tall shrubland (Campbell 1985). The vegetation recorded in this study differed only at the summit where extreme subalpine conditions have resulted in dwarf shrubland vegetation, less than 0.5 m tall.

Karoo site (545 m)

Out of a total of 56 species recorded at this site, 45 (80 %) occurred at no other sites on the gradient. A number of species were specific to *heuweltjies* alone (Group II, Appendix 1), namely *Galenia africana*, *Schismus barbatus* and *Galium tomentosum*. The off-mound communities are defined by the presence of *Dicerotheramnus rhinocerotis*, *Oedera squarrosa* and *Pteronia paniculata* (Group III, Appendix 1). General species typifying the vegetation at this site are *Euphorbia burmannii*,

Pteronia incana and *Ruschia lineolata*. These species are found in high abundances on *heuweltjies*, and to a lesser extent elsewhere at the site (Group I, Appendix 1). Four species found frequently at the karoo site, that are able to successfully cross the soil barrier between the karoo and ecotonal site are *Anthospermum aethiopicum*, *Drosanthemum speciosum*, *Montinia caryophyllacea* and *Passerina obtusifolia* (Group VII, Appendix 1). Eight other species were found on both sandstone and shale-derived soils, but these were rare and had low cover values.

Dicerotheramnus rhinocerotis (*renosterbos*) and *Oedera genistifolia*, which both have fairly high cover values in relevés 6B & 6C (Appendix 1), are generally associated with renosterveld (Mustart *et al.* 1997; Goldblatt & Manning 2000), a vegetation type of the Fynbos Biome which is found on more nutrient-rich soils (Rebello 1998). According to Mucina & Rutherford (2006), the vegetation on the lower eastern slope of Jonaskop, which is quite close to the karoo site, is classified as Breede Shale Renosterveld (FRs8). This is probably a function of mapping scale as Holmes (2002), in an environmental impact study on the vegetation of the Breede River Valley northeast of Jonaskop, found that in this area, Succulent Karoo is found on the foothills of equator-facing slopes, whereas renosterveld is found on pole-facing slopes. The karoo site is located between the foot of the equator-facing slope of Jonaskop and the south-facing slope of a low hill, with relevés 6B & 6C (plot OFM3 in Figure 1) located on the south-facing hillslope. The species composition of this site, considered in combination with the topography, points either to an altitudinal banding of the vegetation types, or to transitional vegetation, or to a mosaic of adjacent Succulent Karoo and renosterveld, which has resulted in an inevitable mix of species from both vegetation types found in the sampling plots. The substrate, in conjunction with the local climate, appears to be the main driving force determining the vegetation found here (Boucher & Moll 1981), but it is still unclear whether this is due to soil nutritional or soil water retention constraints.

The site also has a relatively high incidence of unpalatable asteraceous shrubs such as *Chrysocoma ciliata* (bitterbos), *Galenia africana* (kraalbos) and species of *Pteronia*, which may indicate that the vegetation at this

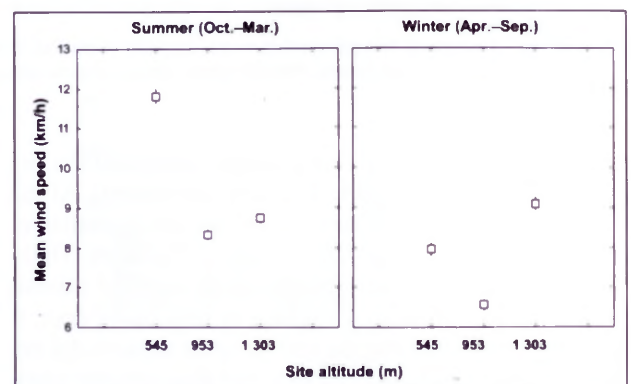


FIGURE 8.—Mean seasonal wind speeds recorded at top (1 303 m), middle (953 m) and lowest (545 m) end of Jonaskop gradient. Wind speeds measured at 1 m above soil surface. Error bars indicate 1 standard error.

site has been somewhat degraded by overgrazing in the recent past.

Ecotone (690–744 m)

In all, 105 species were recorded at the two sites located at low altitude sandstone sites. Fifty five species were found nowhere else on the gradient. Species typical of the low altitude sandstones are *Cannomois scirpoides*, *Ficinia oligantha*, *Protea humiflora* and *Ruschia* sp. (L. Agenbag 5A09, Group IV, Appendix 1). The lower site (690 m) has a number of highly abundant species occurring only at this site, which defines it as supporting a subcommunity within the ecotonal Low-altitude Inland Sandstone Fynbos (Group V, Appendix 1). They are *Cliffortia crenata*, *Ischyrolepis sieberi*, *Lachnospermum fasciculatum* and *Polygala fruticosa*. A number of species were also found unique to the higher ecotonal site (744 m), namely, *Hermannia rudis*, *Othonna ramulosa* and *Phyllica* sp. (L. Agenbag 5A03) (Group VI, Appendix 1).

The vegetation of the ecotonal Low-altitude Inland Sandstone Fynbos recorded here is very similar in species composition and physical aspects to the *Cannomois parviflora*–*Passerina obtusifolia* Shrublands described by McDonald (1993), which occurs on the lower northern slopes of the nearby Langeberg. These arid Sandstone Fynbos shrublands are also found near the transition between Table Mountain Sandstone and Bokkeveld Shales, which support Little Karoo vegetation.

Mid-altitude Sandstone Fynbos (953–1 303 m)

Although there were a number of species characteristic of different sites within the Mid-altitude Sandstone Fynbos (Groups IX, X, XI and XII, Appendix 1), as a whole, these sites seem to represent variations within a specific community (*Protea repens*–*Phaenocoma prolifera* Closed Tall Mid-altitude Sandstone Fynbos) characterized by *Edmondia sesamoides*, *Hypodiscus aristatus*, *Leucadendron laureolum*, *Phaenocoma prolifera*, *Protea amplexicaulis* and *Protea magnifica* (Group VIII, Appendix 1).

Site 4: *Protea repens*–*Tetraria flexuosa* Closed Tall Mid-altitude Sandstone Fynbos, which is located in the middle of the gradient (953 m), has by far the highest species number on the gradient, with 85 species recorded at this site alone. It has a high number of rare species which were recorded in low abundances and low fre-

quencies. *Tetraria flexuosa* and *Wahlenbergia neorigida* (Group IX, Appendix 1), typify this community.

Sites 1–3: *Protea repens*–*Tetraria ustulata* Closed Tall Mid-altitude Sandstone Fynbos, is typified by *Tetraria ustulata* and the other less frequent species listed in Group X (Appendix 1). The sites at 1 196 m and 1 303 m, however, do have characteristic species, but in both cases, these species were not found in the recently burned vegetation. These latter communities are therefore given lower ranking.

The *Elegia filacea* Subcommunity, recorded at an altitude of 1 196 m, is characterized by the following species: *Elegia filacea*, *Erica* sp. (L. Agenbag 2A02) and *Nebelia laevis* (Group XI, Appendix 1). The *Elegia racemosa* Subcommunity was recorded at 1 303 m and is characterized by *Erica longifolia*, *Elegia racemosa*, *Tetraria fasciata* and *Diosma* sp. (L. Agenbag 1A08) (Group XII, Appendix 1).

Ehrharta ramosa–*Restio triticeus* High Altitude Sandstone Dwarf Fynbos (1 576 m):

Structurally, vegetation at the mountain summit is very low compared to the rest of the gradient (less than 0.25 m tall). Some species found at this site, that also occur elsewhere on the gradient, such as *Helichrysum swartbergense*, are found near the summit as dwarfed growth forms, compared to taller individuals lower down. Soils are extremely shallow (surface rock to pockets of soil not often more than 10 cm deep) and very rocky, with an average of 75 % rock cover. Species numbers at this site are very low, with only 26 species recorded in the plots. The vegetation at this site is dominated by grasses, sedges and restios, although dwarf shrubs are present throughout. Species characteristic of this high-altitude summit vegetation include *Ehrharta ramosa*, *Metalasia* sp. (L. Agenbag 0B02), *Restio triticeus* and *Stoebe* sp. (L. Agenbag 0C04) (Group XV, Appendix 1).

Diversity

Shannon diversity indices showed highest diversity at the low to middle altitudes (690–953 m) and sites on a sandstone substrate (Figure 9A). When diversity was compared within sites between recently burned and mature vegetation, burned relevés had higher diversity in all fynbos sites (953, 1 044, 1 196 and 1 303 m) as well as at the summit (1 576 m, Figure 9B). Low-altitude inland sandstone fynbos sites (690 and 744 m)

TABLE 4.—Soil characteristics of selected sites along Jonaskop gradient

Monitoring site	Geology	Mean rock cover (%)	Soil depth range (cm)	pH	P (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	Na (mg/kg)	N (mg/kg)
545 m on	Bokkeveld Group	0	14–31	6.3	45.7	3 206.3	854.0	165.0	22.0	3 446.9
545 m off	Bokkeveld Group		5–32	4.2	36.3	651.7	620.7	87.7	53.3	1 390.5
744 m	Table Mtn Group	15	0–38	4.9	2.3	394.3	87.3	74.7	19.7	1 245.2
953 m	Table Mtn Group	13	0–50+	4.3	3.3	417.3	85.3	56.0	15.7	1 120.7
1 044 m	Table Mtn Group	22	0–50+	4.1	2.0	148.3	71.0	79.0	18.0	694.3
1 196 m	Table Mtn Group	19	4–50+	3.6	3.7	133.3	55.7	41.7	12.0	888.6
1 303 m	Table Mtn Group	43	0–34	4.0	2.0	190.7	65.7	52.7	24.7	632.3

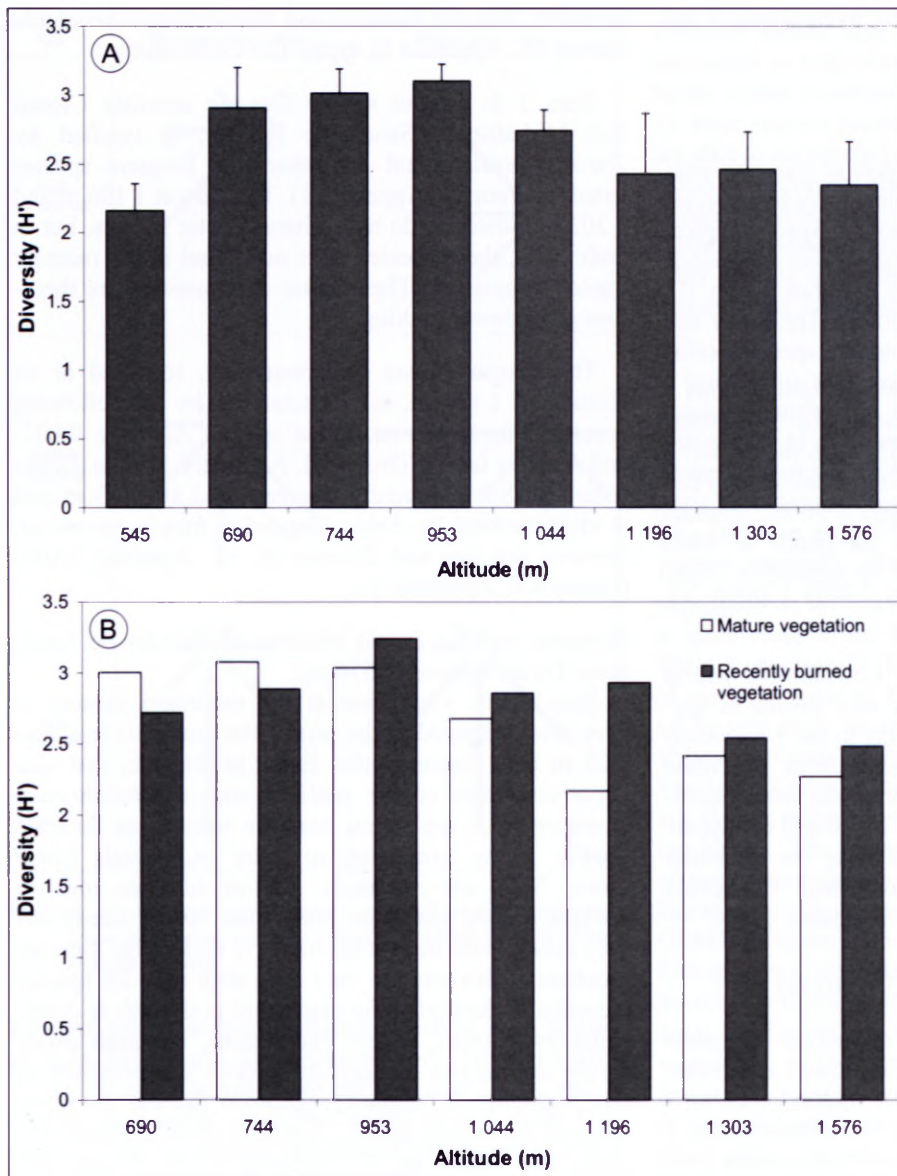


FIGURE 9.—A, Shannon-Wiener diversity indices (H') recorded across gradient. H' values for each altitude is mean of three 10×10 m relevés; B, comparative diversity indices (H') between recently burned and mature vegetation at selected altitudes along Jonaskop gradient. Diversity values for mature vegetation is mean of two 10×10 m relevés, whereas only one relevé was sampled in recently burned vegetation at each altitude. Error bars in A indicate 1 standard error.

have lower diversity in recently burned relevés. Other studies in fynbos have also found that richness is highest in the first few years after fires, due to the presence of ephemeral species (Bond & Van Wilgen 1996; Holmes & Cowling 1997).

Growth form composition

A comparison of the relative contribution of various growth forms to vegetation cover shows clear shifts in dominant growth forms across the gradient (Figure 10A). From the karoo site (545 m) up to the lowest fynbos site (953 m), vegetation is dominated by low shrubs. At the karoo site, succulents are also a significant contributor to vegetation cover, but not at any of the other sites. Above 953 m, the dominant growth form shifts to graminoids, which includes grasses, sedges and restios. The low vegetation at the summit site (1576 m) is reflected in a high proportion of vegetation cover represented by dwarf shrubs, with heights lower than 0.25 m. At this site, herbs also represent a larger proportion of the vegetation cover than at other sites.

When growth form composition between recently burned and mature vegetation is compared, ecotonal low-alti-

tude inland sandstone sites show very similar composition (Figure 10B). In mid to high-altitude fynbos sites, however, recently burned vegetation has higher cover in herbs, succulents and graminoids, whereas mature vegetation consists largely of long-lived low and mid-high shrubs, as well as graminoids.

Taking a closer look at the relative contribution of the families Cyperaceae, Poaceae and Restionaceae to graminoid cover across the gradient, more interesting patterns are revealed (Figure 11A, Appendix 3). Grasses are more common at the karoo site (545 m), and are found only in very low proportions elsewhere on the gradient, except again for the summit (1576 m), where grasses, sedges and restios make roughly equal contributions to total graminoid cover. Restionaceae show increasing dominance from the low-altitude sandstone sites upwards to 953 m, after which sedges become slightly more important. Comparing graminoid cover between recently burned and mature vegetation reveals that in fynbos, Cyperaceae dominate recently burned vegetation, whereas Restionaceae are dominant in mature vegetation (Figure 11B). In the low-altitude sandstone sites, grasses are slightly more abundant in recently burned than mature vegetation.

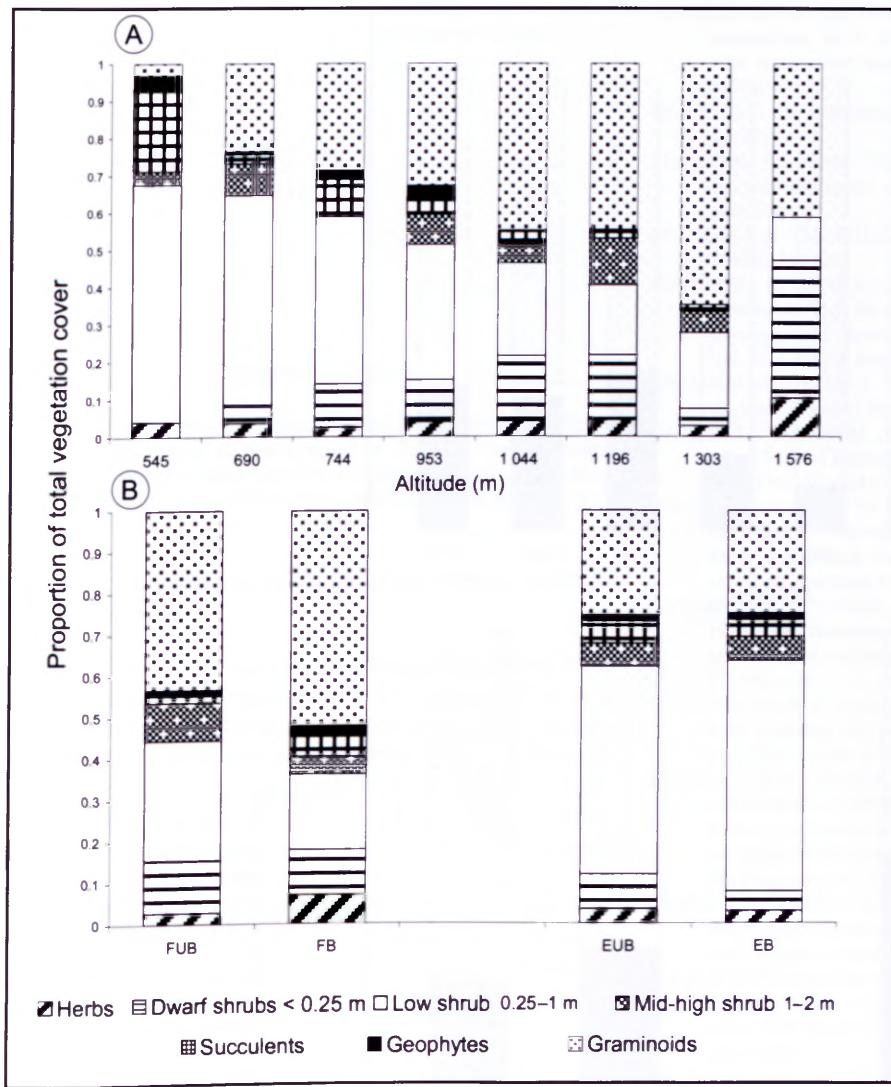


FIGURE 10.—A, comparative contributions of various growth forms to total vegetation cover at selected altitudes along gradient; B, comparative growth form composition between recently burned and mature vegetation in fynbos sites. FUB, fynbos mature vegetation; FB, recently burned fynbos; EUB, ecotone mature vegetation; EB, recently burned ecotone vegetation.

Similarity and turnover rates

Similarity between all sites is relatively low, suggesting high species turnover even between sites with similar vegetation. Similarity between the karoo site and the rest of the gradient, as well as between the summit and the rest of the gradient is the lowest (Table 5), suggesting that strong climatic and/or soil factors are limiting species distributions between these and other areas on the gradient. Highest similarities were found among the ecotonal low-altitude sandstone sites (25.6 %) and among fynbos sites (15.7–25.5 %). Similarities of 11.3 %, 17.1 % and 16.2 % between the (low-altitude sandstone) ecotone and lower mid-altitude fynbos sites (953 and 1 044 m) suggests that the low-altitude sandstone ecotonal vegetation is more closely related to fynbos than karoo, as similarities between the latter two sites are only 7.5 % (690 m) and 2.7 % (744 m). Mean turnover rate for the gradient was determined as -0.0014, with the equation fitted to the plot of difference in altitude against similarity being $\text{Log \% similarity} = -0.0014 \times \text{difference in altitude} + 1.41$, $r^2 = 0.52$ (Figure 12). Similarity values between the karoo site and other sites were generally much lower than predicted by the regression line for similar changes in altitude elsewhere along the gradient, again suggesting that the area between 545 and 690 m is governed by strong environmental factors affecting species distributions.

CONCLUSION

Climate change studies report increasing evidence that species' ranges shift higher on mountain slopes as a result of climate warming, and that high altitude species are therefore particularly vulnerable to extinction as they reach the limits of mountain summits (Grabherr *et al.* 1994; Parmesan & Yohe 2003). Therefore the summit community on the Jonaskop gradient, with its very restricted range, is almost certainly vulnerable to the warmer and drier conditions predicted for the Western Cape.

However, monitoring species for population mortality, extinctions and shifts in ranges across the entire gradient will provide valuable insights into the responses of fynbos, renosterveld and Succulent Karoo vegetation dynamics to climate change. Anecdotal evidence suggests that *Protea* species (mainly genus *Leucadendron*) may be vulnerable to drought stress on Jonaskop (Hannah *et al.* 2007). Jacobsen *et al.* (2007) studied 19 species from nine angiosperm families along the Jonaskop gradient, and found significant variation in their water stress tolerance. Species studied were not as tolerant of water stress as chaparral shrubs occurring in climatically similar California, USA. They suggested that the measurement of xylem density may be a useful tool to assess drought tolerance of large numbers of species.

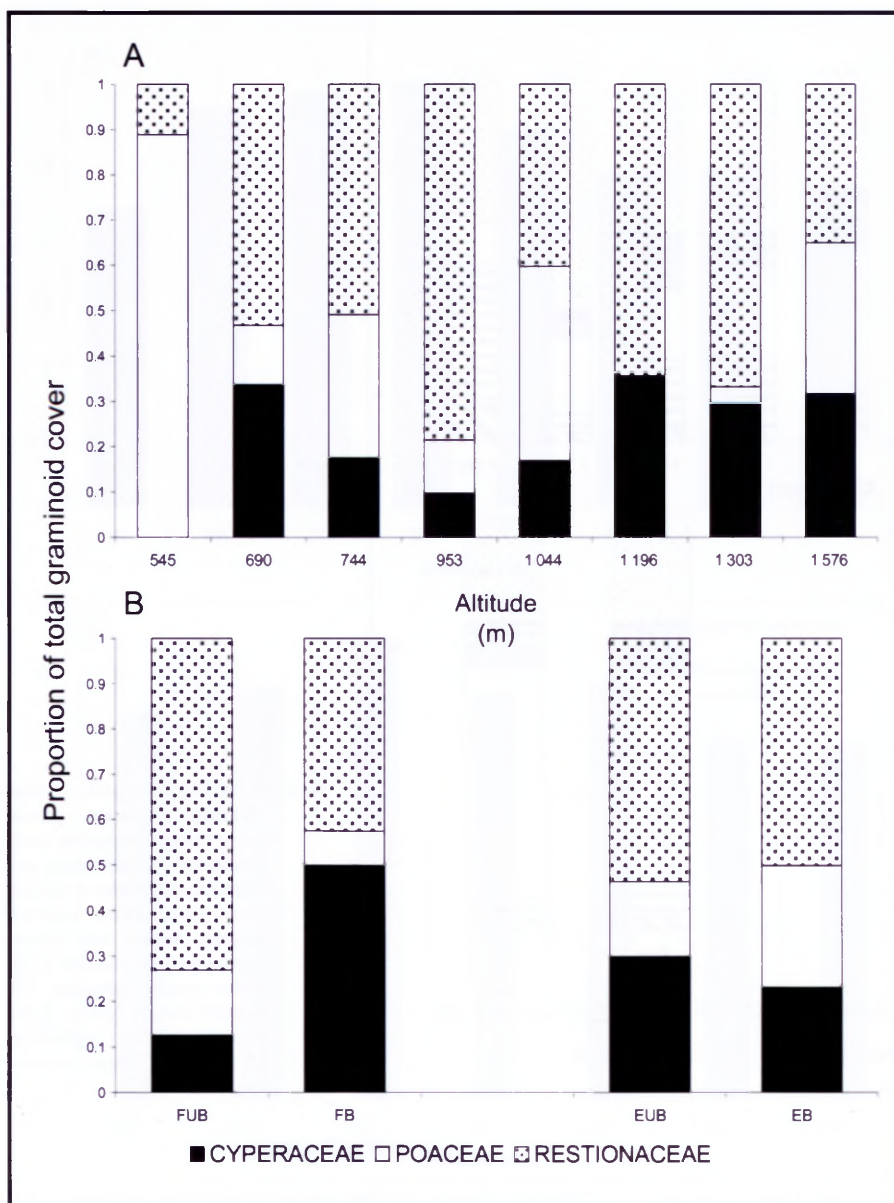


FIGURE 11.—A, relative contribution of sedges (Cyperaceae), grasses (Poaceae) and restios (Restionaceae) to total graminoid cover at selected altitudes across Jonaskop gradient; B, comparative contribution of sedges (Cyperaceae), grasses (Poaceae) and restios (Restionaceae) to total graminoid cover between recently burned and mature vegetation. FUB, fynbos mature vegetation; FB, recently burned fynbos; EUB, ecotone mature vegetation; EB, recently burned ecotone vegetation.

The area around the lower ecotonal site (550–700 m) is the most important to monitor for the first signs of shifts in species and growth form composition as indication of an upward shift of Succulent Karoo into renosterveld-fynbos territory. Since karoo vegetation is known to be distinct from the vegetation recorded in this study through analysis of species similarity, diversity and growth form composition, changes should be detected relatively easily.

Monitoring efforts should not only focus on upward shifts in species ranges, but also on contraction of ranges at the lower elevational limits of species (Hampe *et al.* 2005). Data collected in this study revealed clearly defined upper and lower altitudinal limits on the gradient for many species sampled, and thus, focusing monitoring on changes in abundance of these species at their upper and lower limits, along with continued climate data

TABLE 5.—Total no. species and no. species with single site occurrences recorded at selected sites along Jonaskop gradient, including percentage similarity values for all sites compared. Shaded diagonal represents similarity values between adjacent sites

	Altitude (m)	Karoo		Fynbos					
		Low altitude	Mid-altitude	High alt.					
Total no. spp.	56	73	59	85	56	62	53	26	
No. single spp.	45	25	11	30	11	26	14	11	
	545	690	744	953	1044	1196	1303	1576	
Karoo	545								
Ecotone	690	7.5							
	744	2.7	25.7						
Fynbos	953	1.4	11.3	17.1					
	1044	0.9	7.5	16.2	24.8				
	1196	0	3.8	7.1	15.7	25.5			
	1303	0	5.9	5.7	18.0	23.9	22.3		
Summit	1576	0	2.1	1.2	5.7	3.8	8.6	12.9	

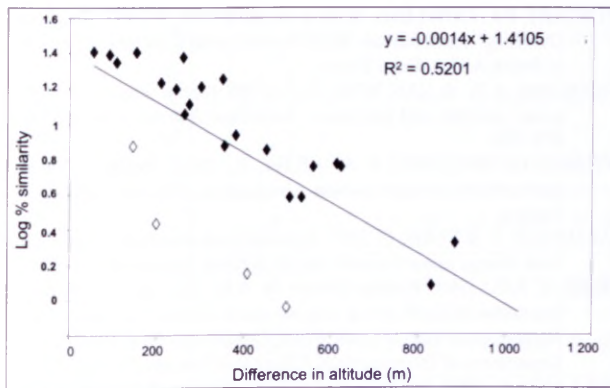


FIGURE 12.—Difference in altitude against log percentage similarity between pairs of all sites sampled, \blacklozenge . Slope of fitted regression line represents mean turnover rate across gradient. Karoo sites, \diamond ; closed symbols indicate sites elsewhere on the gradient, \blacklozenge .

recording, could reveal much about the climatic controls of species' ranges.

It is of course necessary to investigate the importance of the change in soil type between 545 m and 690 m as a potential barrier to climate change-induced shifts in species' ranges, and this is possibly best achieved through experimental studies. As Dunne *et al.* (2004) have indicated, a combination of gradient monitoring and experimental investigation strategies provide the best insights into complex ecosystem responses to climate change. We submit that this study will provide useful baseline data for a future focused and directed monitoring effort leading to a better understanding of the potential effects of climate change on fynbos and the fynbos-renosterveld-succulent karoo boundary.

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REFERENCES

- AGENBAG, L., ESLER, K.J. & MIDGLEY, G. 2004a. An environmental gradient reveals how climate influences phenophases in fynbos growth forms. In M. Arianoutsou & V.P. Papanastasis, *Proceedings of the Vth International Conference on Mediterranean Ecosystems, Rhodes, Greece*. Milpress, Rotterdam.
- AGENBAG, L., ESLER, K.J. & MIDGLEY, G. 2004b. Studies along an environmental gradient reveal how biome boundaries may respond to climate change. In M. Arianoutsou & V.P. Papanastasis, *Proceedings of the Vth International Conference on Mediterranean Ecosystems, Rhodes, Greece*. Milpress, Rotterdam.
- AGENBAG, L., RUTHERFORD, M.C., MIDGLEY, G. & ESLER, K.J. 2004c. Fundamental and realised niches of fynbos and karoo seedlings as revealed by reciprocal transplants. In M. Arianoutsou & V.P. Papanastasis, *Proceedings of the Vth International Conference on Mediterranean Ecosystems, Rhodes, Greece*. Milpress, Rotterdam.
- ASCHMANN, H. 1973. Distribution and peculiarity of Mediterranean ecosystems. In F. Di Castri & H.A. Mooney, *Mediterranean type ecosystems: origin and structure*: 11–20. Springer-Verlag, Berlin.
- BARRY, R.G. 1992. *Mountain weather and climate*: 18–107. Routledge, London.
- BESAANS, A.J. 1966. 3319C, Worcester and 3419A, Caledon, 1: 125 000 geological map. Pretoria, Department of Mines Geological Survey.
- BOND, W.J. & VAN WILGEN, B.W. 1996. *Fire and plants*. Chapman & Hall, London.
- BOUCHER, C. & MOLL, E.J. 1981. South African mediterranean shrublands. In F. Di Castri, D.W. Goodall & R.L. Specht, *Mediterranean-type shrublands*: 233–248. Ecosystems of the World, Vol. 11. Elsevier, Amsterdam.
- BRAUN-BLANQUET, J. 1928. *Pflanzensoziologie: Grundzüge der Vegetationskunde*. Springer, Berlin.
- CAMPBELL, B.M. 1985. A classification of the mountain vegetation of the Fynbos Biome. *Memoirs of the Botanical Survey of South Africa* No. 50: 1–115.
- COOPER, W.E., WHITING, M.J., VAN WYK, J.H. & MOUTON, P. LE F.N. 1999. Movement- and attack-based indices of foraging mode and ambush foraging in some gekkonid and agamine lizards from southern Africa. *Amphibia-Reptilia* 20: 391–399.
- COWLING, R.M., ESLER, K.J., MIDGLEY, G.F. & HONIG, M.A. 1994. Plant functional diversity, species diversity and climate in arid and semi-arid southern Africa. *Journal of Arid Environments* 27: 141–158.
- COWLING, R.M. & HOLMES, P.M. 1992. Flora and vegetation. In R.M. Cowling, *The ecology of fynbos: nutrients, fire and diversity*: 23–61. Oxford University Press, Cape Town.
- COWLING, R.M., OJEDA, F., LAMONT, B.B., RUNDEL, P.W. & LECHMERE-OERTEL, R. 2005. Rainfall reliability, a neglected factor in explaining convergence and divergence of plant traits in fire-prone Mediterranean-climate ecosystems. *Global Ecology & Biogeography* 14: 509–519.
- DUNNE, J.A., SALESKA, S.R., FISCHER, M.L. & HARTE, J. 2004. Integrating experimental and gradient methods in ecological climate change research. *Ecology* 85: 904–916.
- ELLIS, F. 2002. Contribution of termites to the formation of hardpans in soils of arid and semi-arid regions of South Africa. *Proceedings of the 17th World Congress of Soil Science, Bangkok, Thailand, August 2002*.
- ESLER, K.J. & COWLING, R.M. 1995. The comparison of selected life-history characteristics of Mesembryanthema species occurring on and off Mima-like mounds (*heuweltjies*) in semi arid southern Africa. *Plant Ecology* 116: 41–50.
- FLEMING, P.A. & NICOLSON, S.W. 2002a. How important is the relationship between *Protea humiflora* (Proteaceae) and its non-flying mammal pollinators? *Oecologia* 132: 361–368.
- FLEMING, P.A. & NICOLSON, S.W. 2002b. Opportunistic breeding in the Cape spiny mouse (*Acomys subspinosus*). *African Zoology* 37: 101.
- GOLDBLATT, P. 1997. Floristic diversity in the Cape flora of South Africa. *Biodiversity and Conservation* 6: 359–377.
- GOLDBLATT, P. & MANNING, J. 2000. Cape plants. A conspectus of the Cape flora of South Africa. *Strelitzia* 9. National Botanical Institute, Pretoria.
- GRABHERR, G., GOTTFRIED, M. & PAULI, H. 1994. Climate effects on mountain plants. *Nature* 369: 448.
- HAMPE, A., PETIT, R.J. & CORTUFO, F. 2005. Conserving biodiversity under climate change: the rear edge matters. *Ecology Letters* 8: 461–467.
- HANNAH, L., MIDGLEY, G.F., ANDELMAN, S., ARAÚJO, M., HUGHES, G., MARTINEZ-MEYER, E., PEARSON, R. & WILLIAMS, P. 2007. Protected area needs in a changing climate. *Frontiers in Ecology and Environment* 5: 131–138.
- HOLMES, P.M. 2002. *Specialist study on the potential impact of the proposed N1 N2 winelands toll highway project on the affected vegetation and plant species*. Report submitted to Crowther Campbell Associates on behalf of the South African National Roads Agency. Cape Ecological Services, Bergvliet.
- HOLMES, P.M. & COWLING, R.M. 1997. Diversity, composition and guild structure relationships between soil-stored seed banks and mature vegetation in alien plant-invaded South African fynbos shrublands. *Plant Ecology* 133: 107–122.
- ITOW, S. 1991. Species turnover and diversity patterns along an evergreen broad-leaved forest coenocline. *Journal of Vegetation Science* 2: 477–484.

- JACOBSEN, A.L., AGENBAG, L., ESLER, K.J., PRATT, R.B., EWERS, F.W. & DAVIS, S.D. 2007. Xylem density, biomechanics and anatomical traits correlate with water stress in 17 evergreen shrub species of the Mediterranean-type climate region of South Africa. *Journal of Ecology* 95: 171–183.
- JOHNSON, S.A., JACKSON, S., ABRATT, V.R., WOLFAARDT, G.M., CORDERO-OTERO, R. & NICOLSON, S.W. 2006. Xylose utilization and short-chain fatty acid production by selected components of the intestinal microflora of a rodent pollinator (*Aethomys namaquensis*). *Journal of Comparative Physiology* 176: 631–641.
- JOHNSON, S.A., NICOLSON, S.W. & JACKSON, S. 2004. The effect of different oral antibiotics on the gastrointestinal microflora of a wild rodent (*Aethomys namaquensis*). *Comparative Biochemistry and Physiology* 138: 475–483.
- JOHNSON, S.A., VAN TETS, T.G. & NICOLSON, S.W. 1999. Sugar preferences and xylose metabolism of a mammal pollinator, the Namaqua Rock Mouse (*Aethomys namaquensis*). *Physiological and Biochemical Zoology* 72: 438–444.
- KENT, M. & COKER, P. 1994. *Vegetation description and analysis: a practical approach*. Wiley, Chichester.
- KÖRNER, C. 1999. *Alpine plant life: functional plant ecology of high mountain ecosystems*. Springer-Verlag, Berlin.
- KUPFER, J.A. & CAIRNS, D.M. 1996. The suitability of montane ecotones as indicators of global climatic change. *Progress in Physical Geography* 20: 253–272.
- MCDONALD, D.J. 1993. The vegetation of the southern Langeberg, Cape Province. 1. The plant communities of the Boomsansbos Wilderness Area. *Bothalia* 23: 129–151.
- MIDGLEY, J.J. & ANDERSON, B. 2005. Scatterhoarding in Mediterranean shrublands of the SW Cape, South Africa. In P.M. Forget, J.E. Lambert, P.E. Hulme & S.B. Vander Wall, *Seed fate: predation, dispersal and seedling establishment*. Ciba Publishing, Wallingford.
- MILLER, R.W. & GARDINER, D.T. 1998. *Soils in our environment*. Prentice Hall, Upper Saddle River, NJ, USA.
- MUCINA, L. & RUTHERFORD, M.C. 2006. The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19. South African National Biodiversity Institute, Pretoria.
- MUSTART, P.J. & COWLING, R.M. 1993. Effects of soil and seed characteristics on seed germination and their possible roles in determining field emergence patterns of four Agulhas Plain (South Africa) Proteaceae. *Canadian Journal of Botany* 71: 1363–1368.
- MUSTART, P.J., COWLING, R.M. & ALBERTYN, J. 1997. *Southern Overberg*. South African Wild Flower Guide 8. Botanical Society of South Africa, Cape Town.
- NICOLSON, S.W. & VAN WYK, B-E. 1998. Nectar sugars in Proteaceae: patterns and processes. *Australian Journal of Botany* 46: 489–504.
- O'HARE, G., SWEENEY, J. & WILBY, R. 2005. *Weather, climate and climate change: human perspectives*. Pearson Education, Harlow.
- PARMESAN, C. & YOHE, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37–42.
- REBELO, A.G. 1998. Fynbos Biome. In A.B. Low & A.G. Rebelo, *Vegetation of South Africa, Lesotho and Swaziland: a companion to the vegetation map of South Africa, Lesotho and Swaziland*: 62–74. Department of Environmental Affairs and Tourism, Pretoria.
- ROLLAND, C. 2003. Spatial and seasonal variations of air temperature lapse rates in Alpine regions. *Journal of Climate* 16: 1032.
- ROURKE, J. & WIENS, D. 1977. Convergent floral evolution in South African and Australian Proteaceae and its possible bearing on pollination by nonflying mammals. *Annals of the Missouri Botanical Garden* 64: 1–17.
- RUTHERFORD, M.C. 1978. Karoo-fynbos biomass along an elevational gradient in the western Cape. *Bothalia* 12: 555–560.
- RUTHERFORD, M.C., MIDGLEY, G.F., BOND, W.J., POWRIE, L.W., ROBERTS, R. & ALLSOPP, J. 2000. *South African country study on climate change: plant biodiversity, vulnerability and adaptation assessment*. South African Climate Change Country Study Chapter. Government of South Africa, Pretoria.
- VILE, D., GARNIER, E., SHIPLEY, B., LAURENT, G., NAVAS, M.-L., ROUMET, C., LAVOREL, S., DIAZ, S., HODGSON, J.G., LLORET, F., MIDGLEY, G.F., POORTER, H., RUTHERFORD, M.C., WILSON, P.J. & WRIGHT, I.J. 2005. Specific leaf area and dry matter content estimate thickness in laminar leaves. *Annals of Botany* 96: 1129–1136.
- WHITEHEAD, F.H. 1962. Experimental studies on the effect of wind on plant growth and anatomy. II. *Helianthus annuus*. *New Phytologist* 61: 59–62.
- WIENS, D., ROURKE, J.P., CASPER, B.B., RICKART, E.A., LAPINE, T.R., PETERSON, C.J. & CHANNING, A. 1983. Nonflying mammal pollination of southern African proteas: a non-co-evolved system. *Annals of the Missouri Botanical Garden* 70: 1–31.
- WOODWARD, F.I. 1993. The lowland-to-upland transition—modelling plant responses to environmental change. *Ecological Applications* 3: 404–408.

APPENDIX 1.—Structured relevé table for Jonaskop altitudinal gradient in Riviersonderend Mountain Catchment of Western Cape, South Africa. Data were collected in October 2003. See Appendix 2 for species with low frequency occurrences (cont.)

VEGETATION TYPE	SUCCULENT KAROO-RENOSTERVELD MOSAIC	SANDSTONE FYNBOS																									
		LOW ALTITUDE INLAND												MID-ALTITUDE												HIGH-ALTITUDE	
		2.1			2.2			3.1			3.2.1			3.2.2			3.2.3			4							
Community no.	1.1	1.2	5.5A	5.5B	5.5C	5A	5B	5C	4A	4B	4C	3A	3B	3C	2A	2B	2C	1A	1B	1C	0A	0B	0C				
Releve no.	6A	6B	690	690	690	744	744	744	953	953	953	1044	1044	1044	1196	1196	1196	1303	1303	1303	1576	1576	1576				
Altitude (m)	545	545	690	690	690	744	744	744	953	953	953	1044	1044	1044	1196	1196	1196	1303	1303	1303	1576	1576	1576				
Aspect (°)	325	320	3	355	355	255	332	330	195	140	10	320	20	35	335	325	45	355	10	15	25	0	10				
Slope (°)	11	16	24	16	23	14	18	12	4	3	4	25	14	4	3.5	2	4.5	6	18	13	18	22	22				
Latitude South°	33.55.053	33.55.059	33.55.222	33.55.235	33.55.234	33.55.312	33.55.314	33.55.272	33.56.061	33.56.097	33.56.128	33.56.563	33.56.560	33.56.589	33.57.283	33.57.287	33.57.287	33.57.691	33.57.694	33.57.743	33.58.224	33.58.203	33.58.130				
Longitude East°	19.30.421	19.30.417	19.31.041	19.31.057	19.31.057	19.30.599	19.30.592	19.31.035	19.31.228	19.31.183	19.31.294	19.30.539	19.30.525	19.31.000	19.31.007	19.31.011	19.31.106	19.30.800	19.30.777	19.30.823	19.30.306	19.30.266	19.30.249				
Rock cover (%)	0	0	25	50	30	5	35	5	35	1	2	5	40	20	2	1	55	40	20	70	80	75	70				
Vegetation cover (%)	80	50	75	50	70	70	60	55	60	95	68	80	60	30	85	90	30	60	80	30	20	25	30				
Soil type (SH, shale; SHM, shale, heuweltjie; SA, sandstone)	SHM	SH	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA				
Soil depth range (cm)	14-31	5-23	0-33	0-7	0-12	3-38	0-37	0-36	0-10	4-53	0-37	0-39	4-30	5-50+	12-50+	4-50+	10-50+	0-23	0-34	0-23	0-49	0-46	0-16				
2. Protea humiflora–Ficinia oligantha Medium-tall Mid-dense Low-altitude Sandstone Fynbos																											
<i>Ficinia oligantha</i>			2A	I	R	R	R	R																			
<i>Ruschia</i> sp. (L. Agenbag 5A09)			R	+	1	2A	R	R																			
<i>Protea humiflora</i>			+	R	3	+	R	R																			
<i>Commomopsis scirpoides</i>			+	+	I	I	I	I																			
<i>Agathosma glandulosa</i>			R		I	R	+	I																			
<i>Seriphium incanum</i>			R			2A	+	O																			
<i>Syncarpha paniculata</i>			I	R		I	I	I																			
<i>Searsia dissecta</i>			R	O				2A																			
<i>Felicia filifolia</i>			+	+	R			R																			
<i>Lobostemon fruticosus</i>			I	2B		R		R																			
<i>Aspalathus biflora</i>			+	R		2A	R	R																			
<i>Centella triloba</i>				R		R	+																				
<i>Aspalathus spicata</i>				2A		R	R	R																			
<i>Searsia rosmarinifolia</i>					+			O																			
<i>Arctotis</i> sp. (L. Agenbag 5C03)					I			I																			
<i>Aspalathus pachyloba</i> subsp. <i>macroclada</i>			3			2A																					
<i>Cymbopogon pospischilii</i>			R	+																							
<i>Oxalis engeliana</i>				R		R		R																			
<i>Hermannia angularis</i>				+		R		R																			

APPENDIX 2.—List of species occurring only once in Appendix 1. Symbols in parentheses represent cover-abundance categories and address (original relevé number) for each record

<i>Acrosanthes teretifolia</i> Eckl. & Zeyh. (R, 4B)	<i>Geissorhiza confusa</i> Goldblatt (R, 5.5B)
<i>Adenandra uniflora</i> (L.) Willd. R (3B)	<i>Gladiolus debilis</i> Sims (R, 2C)
<i>Adenocline pauciflora</i> Turcz. (R, 5.5B)	<i>Haplocarpha lanata</i> (Thunb.) Less. (+, 2B), (R, 2C)
<i>Agathosma stipitata</i> Pillans (O, 4C)	<i>Heliophila subulata</i> Burch. ex DC. (R, 4C)
<i>Anthospermum</i> sp. (L. Agenbag 2C06) (+, 2C)	<i>Lachnaea pudens</i> Beyers (R, 4A)
<i>Antimima hamatilis</i> (L. Bolus) H.E.K. Hartmann (O, 6C)	<i>Linum acuticarpum</i> C.M. Rogers (+, 5.5B)
<i>Arctotis flaccida</i> Jacq. (R, 2C)	<i>Lobelia capillifolia</i> (C. Presl) A. DC. (R, 5.5C)
<i>Arctotis incisa</i> Thunb. (R, 4B)	<i>Lobelia jasionoides</i> (A. DC.) E. Wimm. (R, 0A)
<i>Aristea africana</i> (L.) Hoffmanns (+, 5.5B)	<i>Lobelia pinifolia</i> L. (1, 2C)
<i>Aristea juncifolia</i> Baker (R, 2C)	<i>Merxmüllera arundinacea</i> (P.J. Bergius) Conert (O, 6C)
<i>Askidiosperma paniculata</i> (Rottb.) Desv. (1, 1A)	<i>Merxmüllera stricta</i> (Schrad.) Conert (O, 5.5A)
<i>Aspalathus alpestris</i> (Benth.) R. Dahlgren (O, 6C)	<i>Metalasia montana</i> P.O. Karis (O, 0B)
<i>Aspalathus fusca</i> Thunb. (+, 3B)	<i>Muraltia muraltioides</i> (Eckl. & Zeyh.) Levyns (O, 6C)
<i>Aspalathus hirta</i> E. Mey. (+, 5.5A)	<i>Paranomis dispersus</i> Levyns (R, 5B)
<i>Aspalathus linearis</i> (Burm. f.) R. Dahlgren (+, 5A)	<i>Pelargonium alchemilloides</i> (L.) L'Hér. (O, 5.5B)
<i>Aspalathus tridentata</i> L. (R, 5A)	<i>Pelargonium caucalifolium</i> Jacq. subsp. <i>convulvulifolium</i> (R, 5.5B)
<i>Cassytha ciliolata</i> Nees (1, 5.5C)	<i>Pelargonium elegans</i> (Andrews) Willd. (O, 1C)
<i>Cheilanthes contracta</i> (Kuntze) Mett. ex Kuhn (R, 5.5A)	<i>Pelargonium hermannifolium</i> (P.J. Bergius) Jacq. (O, 2C)
<i>Cliffortia juniperina</i> L. f. (R, 1B)	<i>Pelargonium longifolium</i> (Burm. f.) Jacq. (R, 4A)
<i>Cliffortia ruscifolia</i> L. (+, 4B)	<i>Pelargonium rapaceum</i> (L.) L'Hér. (R, 5.5A)
<i>Cliffortia sericea</i> Eckl. & Zeyh. (R, 4A)	<i>Pelargonium</i> sp. (L. Agenbag 2C15) (R, 2C)
<i>Clutia alaternoides</i> L. (R, 4C)	<i>Pentastichis colorata</i> (Steud.) Staff (O, 2C)
<i>Clutia laxa</i> Eckl. ex Sond. (R, 2C)	<i>Polygala scabra</i> L. (O, 6C)
<i>Clutia polifolia</i> Jacq. (+, 2C)	<i>Protea lorifolia</i> (Salisb. ex Knight) Fourc. (1, 3A)
<i>Corymbium</i> sp. (L. Agenbag 2C13) (R, 2C)	<i>Protea neriifolia</i> R. Br. (O, 4C)
<i>Crassula capensis</i> (L.) Baill. (R, 6C)	<i>Pseudoselago serrata</i> (P.J. Bergius) Hilliard (R, 2C)
<i>Crassula nudicaulis</i> L. (O, 6C)	<i>Rafnia acuminata</i> (E. Mey.) G. J. Campbell & B-E. van Wyk (R, 5C)
<i>Crassula pubescens</i> Thunb. (R, 4A)	<i>Satyrium odorum</i> Sond. (+, 4A)
<i>Crassula</i> sp. (L. Agenbag 6D04) (O, 6C)	<i>Sebaea exacoides</i> (L.) Schinz (R, 4C)
<i>Cullumia sulcata</i> (Thunb.) Less. (+, 5.5C)	<i>Senecio acaulis</i> (L. f.) Sch. Bip. (R, 3B)
<i>Cyphia volubilis</i> (Burm. f.) Willd. (O, 2C)	<i>Senecio burchellii</i> DC. (R, 4B)
<i>Dicerotheramnium</i> sp. (L. Agenbag 3C09) (O, 3C)	<i>Stipagrostis zeyheri</i> (Nees) De Winter (+, 1C)
<i>Dilatris ixiooides</i> Lam. (O, 3C)	<i>Stoebe nervigera</i> (DC.) Sch. Bip. (R, 5.5A)
<i>Drosanthemum flammeum</i> L. Bolus (O, 5C)	<i>Struthiola myrsinites</i> Lam. (+, 4A)
<i>Drosanthemum</i> sp. (L. Agenbag 6D11) (O, 6C)	<i>Syncarpha flava</i> (Compton) B. Nord. (O, 3C)
<i>Ehrharta ottonis</i> Kunth ex Nees (O, 2C)	<i>Syncarpha gnaphaloides</i> (L.) DC. (R, 4C)
<i>Ehrharta rehmannii</i> Stapf subsp. <i>rehmannii</i> (O, 2C)	<i>Syncarpha variegata</i> (P.J. Bergius) B. Nord. (O, 1A)
<i>Ehrharta rupestris</i> Nees ex Trin. (+, 3C)	<i>Tetragonia spicata</i> L. f. (O, 6B)
<i>Erica coccinea</i> L. (O, 2A)	<i>Tritoniopsis lata</i> (L. Bolus) G. J. Lewis (R, 2B)
<i>Erica embothriifolia</i> Salisb. (O, 0C)	<i>Ursinia paleacea</i> (L.) Moench. (O, 5A)
<i>Erica lateralis</i> Willd. (+, 1A)	<i>Ursinia rigidula</i> (DC.) N.E. Br. (+, 5.5B)
<i>Erica taxifolia</i> Bauer (+, 1B)	<i>Viscum</i> sp. (O, 6C)
<i>Eriocephalus</i> sp. (1, 5A)	<i>Wahlenbergia</i> cf. <i>anerea</i> (L. Agenbag 5.5C06) (R, 5.5C)
<i>Ficinia deusta</i> (P.J. Bergius) Levyns (+, 3C)	<i>Willdenowia</i> sp. (L. Agenbag 2B06) (R, 2B)
<i>Gazania ciliaris</i> DC. (+, 4C)	<i>Willdenowia teres</i> Thunb. (R, 2A)
<i>Gazania rigida</i> (Burm. f.) Roessler (O, 2C)	

APPENDIX 3.—Checklist of species occurring on Jonaskop altitudinal gradient in Riviersonderend Mountain Catchment of Western Cape, South Africa. Growth form codes (GFC) are provided in Table 2

Species	Family	GFC
<i>Acrosanthes teretifolia</i> Eckl. & Zeyh.	Aizoaceae	LSS
<i>Adenandra uniflora</i> (L.) Willd.	Rutaceae	LES
<i>Adenandra villosa</i> (P.J. Bergius) Licht. ex Roem. & Schult.	Rutaceae	LES
<i>Adenocline pauciflora</i> Turcz.	Euphorbiaceae	AH
<i>Agathosma glandulosa</i> (Thunb.) Sond.	Rutaceae	LES
<i>Agathosma serphyllacea</i> Licht. ex Roem. & Schult.	Rutaceae	LES
<i>Agathosma stipitata</i> Pillans	Rutaceae	LES
<i>Aloe microstigma</i> Salm-Dyck	Asphodelaceae	LSS
<i>Anaxeton asperum</i> (Thunb.) DC. subsp. <i>pauciflorum</i> Lundgren	Asteraceae	DES
<i>Anthospermum aethiopicum</i> L.	Rubiaceae	LES
<i>Anthospermum galioides</i> Rchb. f.	Rubiaceae	DES
<i>Anthospermum</i> sp. (L. Agenbag 2C06)	Rubiaceae	DES
<i>Antimima hamatilis</i> (L. Bolus) H.E.K. Hartmann	Mesembryanthemaceae	DSS
<i>Arctotis acaulis</i> L.	Asteraceae	PH
<i>Arctotis flaccida</i> Jacq.	Asteraceae	PH
<i>Arctotis incisa</i> Thunb.	Asteraceae	PH
<i>Arctotis</i> sp. (L. Agenbag 5C03)	Asteraceae	PH
<i>Aristea africana</i> (L.) Hoffmanns	Iridaceae	PH
<i>Aristea juncifolia</i> Baker	Iridaceae	PH

APPENDIX 3.—Checklist for species occurring on Jonaskop altitudinal gradient in Rivieronderend Mountain Catchment of Western Cape, South Africa. Growth form codes (GFC) are provided in Table 2 (cont.)

Species	Family	GFC
<i>Aristea racemosa</i> Baker	Iridaceae	PH
<i>Aristida diffusa</i> Trin.	Poaceae	GRA
<i>Askidiosperma paniculata</i> (Rottb.) Desv.	Restionaceae	GRA
<i>Aspalathus alpestris</i> (Benth.) R.Dahlgren	Fabaceae	LES
<i>Aspalathus biflora</i> E.Mey.	Fabaceae	LES
<i>Aspalathus cordata</i> (L.) R.Dahlgren	Fabaceae	LES
<i>Aspalathus fusca</i> Thunb.	Fabaceae	LES
<i>Aspalathus hirta</i> E.Mey.	Fabaceae	LES
<i>Aspalathus juniperina</i> Thunb.	Fabaceae	LES
<i>Aspalathus leucophylla</i> R.Dahlgren	Fabaceae	LES
<i>Aspalathus linearis</i> (Burm.f.) R.Dahlgren	Fabaceae	LES
<i>Aspalathus pachyloba</i> Benth. subsp. <i>macroclada</i> R.Dahlgren	Fabaceae	LES
<i>Aspalathus</i> sp. (L. Agenbag 6B06)	Fabaceae	LES
<i>Aspalathus spicata</i> Thunb.	Fabaceae	DES
<i>Aspalathus tridentata</i> L.	Fabaceae	LES
<i>Bromus hordeaceus</i> L. subsp. <i>molliformis</i> (J.Lloyd) Maire & Weiller	Poaceae	GRA
<i>Cannomois nitida</i> (Mast.) Pillans	Restionaceae	GRA
<i>Cannomois scirpoides</i> (Kunth) Mast.	Restionaceae	GRA
<i>Cassytha ciliolata</i> Nees	Lauraceae	HV
<i>Centella</i> sp. (L. Agenbag 5.5B02)	Apiaceae	PH
<i>Centella triloba</i> (Thunb.) Drude	Apiaceae	HV
<i>Ceratocaryum argenteum</i> Kunth	Restionaceae	GRA
<i>Cheilanthes contracta</i> (Kuntze) Mett. ex Kuhn	Pteridaceae	PH
<i>Chrysocoma ciliata</i> L.	Asteraceae	LES
<i>Cliffortia crenata</i> L.f.	Rosaceae	MES
<i>Cliffortia juniperina</i> L.f.	Rosaceae	LES
<i>Cliffortia pungens</i> C.Presl	Rosaceae	LES
<i>Cliffortia ruscifolia</i> L.	Rosaceae	LES
<i>Cliffortia sericea</i> Eckl. & Zeyh.	Rosaceae	LES
<i>Clutia alaternoides</i> L.	Euphorbiaceae	LES
<i>Clutia laxa</i> Eckl. ex Sond.	Euphorbiaceae	LES
<i>Clutia polifolia</i> Jacq.	Euphorbiaceae	LES
<i>Clutia polygonoides</i> L.	Euphorbiaceae	DES
<i>Corymbium glabrum</i> L.	Asteraceae	PH
<i>Corymbium</i> sp. (L. Agenbag 2C13)	Asteraceae	PH
<i>Crassula atropurpurea</i> (Haw.) D.Dietr. var. <i>atropurpurea</i>	Crassulaceae	LSS
<i>Crassula capensis</i> (L.) Baill.	Crassulaceae	PHS
<i>Crassula fascicularis</i> Lam.	Crassulaceae	PHS
<i>Crassula nudicaulis</i> L.	Crassulaceae	PHS
<i>Crassula pubescens</i> Thunb.	Crassulaceae	DSS
<i>Crassula</i> sp. (L. Agenbag 6D04)	Crassulaceae	DSS
<i>Crassula subaphylla</i> (Eckl. & Zeyh.) Harv.	Crassulaceae	LSS
<i>Cullumia sulcata</i> (Thunb.) Less.	Asteraceae	LES
<i>Cymbopogon pospischilii</i> (K.Schum.) C.E. Hubb.	Poaceae	GRA
<i>Cyphia volubilis</i> (Burm.f.) Willd.	Lobeliaceae	HV
<i>Dicerotheramus rhinocerotis</i> (L.f.) Koekemoer	Asteraceae	LES
<i>Dilatris ixiooides</i> Lam.	Haemodoraceae	GEO
<i>Diosma</i> sp. (L. Agenbag 1A08)	Rutaceae	DES
<i>Dodonea viscosa</i> Jacq.	Sapindaceae	MES
<i>Drosanthemum flammeum</i> L.Bolus	Mesembryanthemaceae	DSS
<i>Drosanthemum</i> sp. (L. Agenbag 6D11)	Mesembryanthemaceae	LSS
<i>Drosanthemum speciosum</i> (Haw.) Schwantes	Mesembryanthemaceae	LSS
<i>Edmondia sesamoides</i> (L.) Hilliard	Asteraceae	PH
<i>Ehrharta capensis</i> Thunb.	Poaceae	GRA
<i>Ehrharta delicatula</i> (Nees) Stapf	Poaceae	GRA
<i>Ehrharta ottonis</i> Kunth ex Nees	Poaceae	GRA
<i>Ehrharta ramosa</i> (Thunb.) Thunb.	Poaceae	GRA
<i>Ehrharta rehmannii</i> Stapf subsp. <i>rehmannii</i>	Poaceae	GRA
<i>Ehrharta rupestris</i> Nees ex Trin.	Poaceae	GRA
<i>Ehrharta thunbergii</i> Gibbs Russ.	Poaceae	GRA

APPENDIX 3.—Checklist for species occurring on Jonaskop altitudinal gradient in Rivieronderend Mountain Catchment of Western Cape, South Africa. Growth form codes (GFC) are provided in Table 2 (cont.)

Species	Family	GFC
<i>Elegia filacea</i> Mast.	Restionaceae	GRA
<i>Elegia grandis</i> (Nees) Kunth	Restionaceae	GRA
<i>Elegia racemosa</i> (Poir.) Pers.	Restionaceae	GRA
<i>Elegia stokoei</i> Pillans	Restionaceae	GRA
<i>Elytropappus</i> sp. (L. Agenbag 3C09)	Asteraceae	MES
<i>Erepsia gracilis</i> (Haw.) L.Bolus	Mesembryanthemaceae	LSS
<i>Erica anguliger</i> (N.E.Br.) E.G.H.Oliv.	Ericaceae	DES
<i>Erica axillaris</i> Thunb.	Ericaceae	LES
<i>Erica cerinthoides</i> L.	Ericaceae	LES
<i>Erica coccinea</i> L.	Ericaceae	LES
<i>Erica corifolia</i> L.	Ericaceae	LES
<i>Erica embothriifolia</i> Salisb.	Ericaceae	LES
<i>Erica equisetifolia</i> Salisb.	Ericaceae	LES
<i>Erica fastigiata</i> L.	Ericaceae	LES
<i>Erica lateralis</i> Willd.	Ericaceae	LES
<i>Erica longifolia</i> Bauer	Ericaceae	MES
<i>Erica monsoniana</i> L.f.	Ericaceae	MES
<i>Erica plukenetti</i> L.	Ericaceae	LES
<i>Erica sessiliflora</i> L.f.	Ericaceae	LES
<i>Erica setacea</i> Andrews	Ericaceae	DES
<i>Erica</i> sp. (L. Agenbag 2A02)	Ericaceae	DES
<i>Erica taxifolia</i> Bauer	Ericaceae	LES
<i>Erica vestita</i> Thunb.	Ericaceae	LES
<i>Eriocephalus africanus</i> L.	Asteraceae	LES
<i>Eriocephalus</i> sp.	Asteraceae	LES
<i>Euclea undulata</i> Thunb.	Ebenaceae	MES
<i>Euphorbia burmannii</i> E.Mey. ex Boiss.	Euphorbiaceae	LSS
<i>Euryops abrotanifolius</i> (L.) DC.	Asteraceae	MES
<i>Felicia filifolia</i> (Vent.) Burtt Davy	Asteraceae	LES
<i>Ficinia deusta</i> (P.J.Bergius) Levyns	Cyperaceae	GRA
<i>Ficinia monticola</i> Kunth	Cyperaceae	GRA
<i>Ficinia nigrescens</i> (Schrad.) J.Raynal	Cyperaceae	GRA
<i>Ficinia oligantha</i> (Steud.) J.Raynal	Cyperaceae	GRA
<i>Ficinia</i> sp. (L. Agenbag 0B01)	Cyperaceae	GRA
<i>Ficinia stolonifera</i> Boeck.	Cyperaceae	GRA
<i>Galenia africana</i> L.	Aizoaceae	LES
<i>Galium tomentosum</i> Thunb.	Rubiaceae	LES
<i>Gazania ciliaris</i> DC.	Asteraceae	PH
<i>Gazania rigida</i> (Burm.f.) Roessler	Asteraceae	PH
<i>Geissorhiza confusa</i> Goldblatt	Iridaceae	GEO
<i>Geranium incanum</i> Burm.f.	Geraniaceae	PH
<i>Gladiolus debilis</i> Sims	Iridaceae	GEO
<i>Haplocarpha lanata</i> (Thunb.) Less.	Asteraceae	PH
<i>Harveya bolusii</i> Kuntze	Orobanchaceae	PH
<i>Helichrysum revolutum</i> (Thunb.) Less.	Asteraceae	LES
<i>Helichrysum zwartbergense</i> Bolus	Asteraceae	DES
<i>Heliophila scoparia</i> Burch. ex DC.	Brassicaceae	LES
<i>Heliophila subulata</i> Burch. ex DC.	Brassicaceae	PH
<i>Hermannia angularis</i> Jacq.	Sterculiaceae	LES
<i>Hermannia aspera</i> J.C.Wendl.	Sterculiaceae	LES
<i>Hermannia rudis</i> N.E.Br.	Sterculiaceae	LES
<i>Hypodiscus albo-aristatus</i> (Nees) Mast.	Restionaceae	GRA
<i>Hypodiscus aristatus</i> (Thunb.) C.Krauss	Restionaceae	GRA
<i>Hypodiscus laevigatus</i> (Kunth) H.P.Linder	Restionaceae	GRA
<i>Hypodiscus squamosus</i> Esterh.	Restionaceae	GRA
<i>Hypodiscus striatus</i> (Kunth) Mast.	Restionaceae	GRA
<i>Indigofera depressa</i> Harv.	Fabaceae	LES
<i>Indigofera porrecta</i> Eckl. & Zeyh.	Fabaceae	LES
<i>Ischyrolepis capensis</i> (L.) H.P.Linder	Restionaceae	GRA
<i>Ischyrolepis curviramis</i> (Kunth) H.P.Linder	Restionaceae	GRA

APPENDIX 3.—Checklist for species occurring on Jonaskop altitudinal gradient in Rivieronderend Mountain Catchment of Western Cape, South Africa. Growth form codes (GFC) are provided in Table 2 (cont.)

Species	Family	GFC
<i>Ischyrolepis gaudichaudiana</i> (Kunth) H.P.Linder	Restionaceae	GRA
<i>Ischyrolepis sieberi</i> (Kunth) H.P.Linder	Restionaceae	GRA
<i>Ixia longituba</i> N.E.Br. var. <i>bellenidenii</i> (R.C.Foster) M.P.de Vos	Iridaceae	GEO
<i>Lachnaea pudens</i> Beyers	Thymeleaceae	LES
<i>Lachnospermum fasciculatum</i> (Thunb.) Baillon	Asteraceae	LES
<i>Lampranthus</i> sp. (L. Agenbag 5.5A19)	Mesembryanthemaceae	LSS
<i>Leucadendron laureolum</i> (Lam.) Fourc.	Proteaceae	MES
<i>Leucadendron nervosum</i> E.Phillips & Hutch	Proteaceae	MES
<i>Leucadendron salignum</i> P.J.Bergius	Proteaceae	LES
<i>Leucospermum calligerum</i> (Salisb. ex Knight) Rourke	Proteaceae	LES
<i>Linum acuticarpum</i> C.M.Rogers	Linaceae	PH
<i>Lobelia capillifolia</i> (C.Presl) A.DC.	Lobeliaceae	LES
<i>Lobelia coronopifolia</i> L.	Lobeliaceae	PH
<i>Lobelia jasionoides</i> (A.DC.) E.Wimm.	Lobeliaceae	PH
<i>Lobelia pinifolia</i> L.	Lobeliaceae	DES
<i>Lobostemon fruticosus</i> (L.) H.Buek	Boraginaceae	LES
<i>Lobostemon gracilis</i> Levyns	Boraginaceae	LES
<i>Merxmuellera arundinacea</i> (P.J.Bergius) Conert	Poaceae	GRA
<i>Merxmuellera stricta</i> (Schrad.) Conert	Poaceae	GRA
<i>Metalasia densa</i> (Lam.) P.O.Karis	Asteraceae	LES
<i>Metalasia montana</i> P.O.Karis	Asteraceae	DES
<i>Metalasia</i> sp. (L. Agenbag 0B02)	Asteraceae	DES
<i>Microdon dubius</i> (L.) Hilliard	Scrophulariaceae	LES
<i>Montinia caryophyllacea</i> Thunb.	Montiniaceae	MES
<i>Muraltia heisteria</i> (L.) DC.	Polygalaceae	LES
<i>Muraltia muraltioides</i> (Eckl. & Zeyh.) Levyns	Polygalaceae	DES
<i>Nebelia laevis</i> (E.Mey.) Kuntze	Bruniaceae	MES
<i>Nebelia sphaerocephala</i> (Sond.) Kuntze	Bruniaceae	MES
<i>Oedera genistifolia</i> (L.) Anderb. & K.Bremer	Asteraceae	LES
<i>Oedera squarrosa</i> (L.) Anderb. & K.Bremer	Asteraceae	LES
<i>Oligocarpus calendulaceus</i> (L.f.) Less.	Asteraceae	AH
<i>Ornithogalum dubium</i> Houtt.	Hyacinthaceae	GEO
<i>Osteospermum polygaloides</i> L.	Asteraceae	DES
<i>Osteospermum polygaloides</i> L. var. <i>polygaloides</i>	Asteraceae	DES
<i>Othonna quinqueidentata</i> Thunb.	Asteraceae	MES
<i>Othonna ramulosa</i> DC.	Asteraceae	LSS
<i>Oxalis depressa</i> Eckl. & Zeyh.	Oxalidaceae	GEO
<i>Oxalis engleriana</i> Schltr.	Oxalidaceae	GEO
<i>Oxalis pes-caprae</i> L.	Oxalidaceae	GEO
<i>Paranomus dispersus</i> Levyns	Proteaceae	LES
<i>Passerina obtusifolia</i> Thoday	Thymeleaceae	LES
<i>Pelargonium alchemilloides</i> (L.) L'Hér.	Geraniaceae	DES
<i>Pelargonium caucalifolium</i> Jacq. subsp. <i>convulvifolium</i>	Geraniaceae	LES
<i>Pelargonium elegans</i> (Andrews) Willd.	Geraniaceae	DES
<i>Pelargonium hermannifolium</i> (P.J.Bergius) Jacq.	Geraniaceae	LES
<i>Pelargonium incarnatum</i> (L'Hér.) Moench	Geraniaceae	DES
<i>Pelargonium longifolium</i> (Burm.f.) Jacq.	Geraniaceae	GEO
<i>Pelargonium ovale</i> (Burm.f.) L'Hér.	Geraniaceae	DES
<i>Pelargonium rapaceum</i> (L.) L'Hér.	Geraniaceae	GEO
<i>Pelargonium</i> sp. (L. Agenbag 2C15)	Geraniaceae	DES
<i>Pelargonium</i> sp. cf. section <i>Hoarea</i> (L. Agenbag 6B07)	Geraniaceae	GEO
<i>Pentameris macrocalycina</i> (Steud.) Schweick.	Poaceae	GRA
<i>Pentaschistis colorata</i> (Steud.) Stapf	Poaceae	GRA
<i>Pentaschistis curvifolia</i> (Schrad.) Stapf	Poaceae	GRA
<i>Pentaschistis eriostoma</i> (Nees) Stapf	Poaceae	GRA
<i>Phaenocoma prolifera</i> (L.) D.Don	Asteraceae	LES
<i>Phyllica</i> sp. (L. Agenbag 5.5A08)	Rhamnaceae	LES
<i>Phyllica</i> sp. (L. Agenbag 5A03)	Rhamnaceae	LES
<i>Phyllica vulgaris</i> Pillans var. <i>major</i> Pillans	Rhamnaceae	DES
<i>Phyllobolus splendens</i> (L.) Gerbaulet subsp. <i>splendens</i>	Mesembryanthemaceae	LSS

APPENDIX 3.—Checklist for species occurring on Jonaskop altitudinal gradient in Rivieronderend Mountain Catchment of Western Cape, South Africa. Growth form codes (GFC) are provided in Table 2 (cont.)

Species	Family	GFC
<i>Podalyria</i> sp. (L. Agenbag 2C14)	Fabaceae	LES
<i>Polygala fruticosa</i> P.J.Bergius	Polygalaceae	LES
<i>Polygala scabra</i> L.	Polygalaceae	LES
<i>Protea amplexicaulis</i> (Salisb.) R.Br.	Proteaceae	LES
<i>Protea humiflora</i> Andrews	Proteaceae	LES
<i>Protea laurifolia</i> Thunb.	Proteaceae	MES
<i>Protea lorifolia</i> (Salisb. ex Knight) Fourc.	Proteaceae	LES
<i>Protea magnifica</i> Link	Proteaceae	LES
<i>Protea neriifolia</i> R.Br.	Proteaceae	MES
<i>Protea repens</i> (L.) L.	Proteaceae	MES
<i>Pseudopentameris macrantha</i> (Schrad.) Conert	Poaceae	GRA
<i>Pseudoselago serrata</i> (P.J.Bergius) Hilliard	Scrophulariaceae	LES
<i>Pteronia fasciculata</i> L.f.	Asteraceae	LES
<i>Pteronia incana</i> (Burm.) DC.	Asteraceae	LES
<i>Pteronia paniculata</i> Thunb.	Asteraceae	LES
<i>Rafnia acuminata</i> (E.Mey.) G.J.Campbell & B.-E.van Wyk	Fabaceae	DES
<i>Restio bolusii</i> Pillans	Restionaceae	GRA
<i>Restio filiformis</i> Poir.	Restionaceae	GRA
<i>Restio triticeus</i> Rottb.	Restionaceae	GRA
<i>Ruschia caroli</i> (L.Bolus) Schwantes	Mesembryanthemaceae	DSS
<i>Ruschia lineolata</i> (Haw.) Schwantes	Mesembryanthemaceae	DSS
<i>Ruschia</i> sp. (L. Agenbag 5A09)	Mesembryanthemaceae	LSS
<i>Satyrium odorum</i> Sond.	Orchidaceae	GEO
<i>Schismus barbatus</i> (Loeff. ex L.) Thell.	Poaceae	GRA
<i>Searsia dissecta</i> (Thunb.) Moffett	Anacardiaceae	LES
<i>Searsia lucida</i> (L.) F.A.Barkley	Anacardiaceae	LES
<i>Searsia rosmarinifolia</i> (Vahl) F.A.Barkley	Anacardiaceae	LES
<i>Searsia undulata</i> (Jacq.) T.S.Yi, A.J.Mill. & J.Wen	Anacardiaceae	MES
<i>Sebaea exacoides</i> (L.) Schinz	Gentianaceae	AH
<i>Selago parvibractea</i> Hilliard	Scrophulariaceae	LES
<i>Senecio acaulis</i> (L.f.) Sch.Bip.	Asteraceae	PHS
<i>Senecio burchellii</i> DC.	Asteraceae	DES
<i>Senecio paniculatus</i> P.J.Bergius	Asteraceae	PH
<i>Seriphium incanum</i> (Thunb.) Pers.	Asteraceae	LES
<i>Seriphium plumosum</i> L.	Asteraceae	LES
<i>Serruria gremialis</i> Rourke	Proteaceae	DES
<i>Stipagrostis zeyheri</i> (Nees) De Winter	Poaceae	GRA
<i>Stoebe aethiopica</i> L.	Asteraceae	LES
<i>Stoebe capitata</i> P.J.Bergius	Asteraceae	LES
<i>Stoebe montana</i> Schltr. ex Levyns	Asteraceae	DES
<i>Stoebe nervigera</i> (DC.) Sch.Bip.	Asteraceae	DES
<i>Stoebe</i> sp. (L. Agenbag 0C04)	Asteraceae	PH
<i>Struthiola myrsinites</i> Lam.	Thymeleaceae	LES
<i>Sutera caerulea</i> (L.f.) Hiern	Scrophulariaceae	AH
<i>Sutera uncinata</i> (Desr.) Hilliard	Scrophulariaceae	LES
<i>Syncarpha flava</i> (Compton) B.Nord.	Asteraceae	DES
<i>Syncarpha gnaphaloides</i> (L.) DC.	Asteraceae	DES
<i>Syncarpha paniculata</i> (L.) B.Nord.	Asteraceae	LES
<i>Syncarpha variegata</i> (P.J.Bergius) B.Nord.	Asteraceae	DES
<i>Tetragonia spicata</i> L.f.	Aizoaceae	LES
<i>Tetragonia bromoides</i> (Lam.) Pfeiff.	Cyperaceae	GRA
<i>Tetragonia fasciata</i> (Rottb.) C.B.Clarke	Cyperaceae	GRA
<i>Tetragonia flexuosa</i> (Thunb.) C.B.Clarke	Cyperaceae	GRA
<i>Tetragonia sylvatica</i> (Nees) C.B.Clarke	Cyperaceae	GRA
<i>Tetragonia ustulata</i> (L.) C.B.Clarke	Cyperaceae	GRA
<i>Thamnochortus fruticosus</i> P.J.Bergius	Restionaceae	GRA
<i>Thamnochortus lucens</i> (Poir.) H.P.Linder	Restionaceae	GRA
<i>Thesium carinatum</i> A.DC.	Santalaceae	DS,P
<i>Thesium commutatum</i> Sond.	Santalaceae	DS,P
<i>Thesium patulum</i> A.W.Hill	Santalaceae	PH,P

APPENDIX 3.—Checklist for species occurring on Jonaskop altitudinal gradient in Riviersonderend Mountain Catchment of Western Cape, South Africa. Growth form codes (GFC) are provided in Table 2 (cont.)

Species	Family	GFC
<i>Thesium</i> sp. (L. Agenbag 5B05)	Santalaceae	LS,P
<i>Thesium spicatum</i> L.	Santalaceae	DS,P
<i>Thesium strictum</i> P.J.Bergius	Santalaceae	LS,P
<i>Trachyandra muricata</i> (L.f.) Kunth.	Asphodelaceae	GEO
<i>Tribolium hispidum</i> (Thunb.) Desv.	Poaceae	GRA
<i>Tritoniopsis lata</i> (L.Bolus) G.J.Lewis	Iridaceae	GEO
<i>Tylecodon paniculatus</i> (L.f.) Toelken	Crassulaceae	LSS
<i>Ursinia anthemoides</i> (L.) Poir. subsp. <i>anthemoides</i>	Asteraceae	AH
<i>Ursinia paleacea</i> (L.) Moench.	Asteraceae	LES
<i>Ursinia rigidula</i> (DC.) N.E.Br.	Asteraceae	DES
<i>Ursinia</i> sp.	Asteraceae	DES
<i>Vellereophyton dealbatum</i> (Thunb.) Hilliard & B.L.Burt	Asteraceae	PH
<i>Viscum</i> sp.	Viscaceae	S,P
<i>Wachendorfia</i> sp.	Haemodoraceae	GEO
<i>Wahlenbergia</i> cf. <i>anerea</i> (L. Agenbag 5.5C06)	Campanulaceae	LES
<i>Wahlenbergia neorigida</i> Lammers	Campanulaceae	LES
<i>Willdenowia</i> sp. (L. Agenbag 2B06)	Restionaceae	GRA
<i>Willdenowia teres</i> Thunb.	Restionaceae	GRA
<i>Zygophyllum fulvum</i> L.	Zygophyllaceae	LES
<i>Zyrphelis lasiocarpa</i> (DC.) Kuntze	Asteraceae	DES
<i>Zyrphelis microcephala</i> (Less.) Nees	Asteraceae	DES