THE INFLUENCE OF ENVIRONMENT AND LIVESTOCK GRAZING ON THE MOUNTAIN VEGETATION OF LESOTHO

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PREFACE

The experimental work described in this dissertation was originally carried out in the Department of Grassland Science of the erstwhile University of Natal from 1988 to 1990 under the supervision of Professor Neil Tainton. The thesis was submitted for examination in June 1994 and the degree of MSc (Agric) was conferred, but not awarded, in 1995 with an option to upgrade to a PhD chosen. Professor Kevin Kirkman was subsequently appointed as supervisor. This thesis is an unaltered facsimile of the original thesis examined and passed in 1995, and the research methods, analytical procedures and interpretation of the results are within the context of the socio-environmental conditions prevalent in Lesotho in the late 1980s to early 1990s. The scientific methodology employed for data collection and analysis and interpretation of the results are contingent on the techniques as well as the body of scientific knowledge and theory available at that time.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any university. Where use has been made of the work of others it is duly acknowledged in the text.

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C.D. Morris (candidate).

Signed:

Professor K.P Kirkman (supervisor).

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ACKNOWLEDGEMENTS

ABSTRACT

The mountains of Lesotho form the catchments for the Lesotho Highlands Water Project (LHWP), which is presently under construction, and their condition will determine the longevity of the LHWP. The mountain rangelands also support an extensive livestock system. However, there is concern that grazing is negatively affecting the mountain vegetation to the detriment of both livestock production and catchment function. Therefore, the impact of environment and grazing on the vegetation was investigated to aid the development of management policy for the conservation of the grazing, floristic and water resources of the mountains.

Vegetation surveys were conducted in the mountains in the east (Study Area 1: 2 625 - 3 350 m a.s.l.) and in the west (Study Area 2: 2 240 - 3 125 m a.s.l.). Indirect gradient analysis (IGA) and classification were used to investigate the influence of environment on vegetation pattern. Results of the IGA indicated that variation in species composition in the mountains is related primarily to topographic variation, in particular elevation and aspect. Five vegetation communities were identified in Study Area 1 and seven in Study Area 2. These communities occurred consistently in specific topographic positions in the landscape and were arranged along a temperate/subtropical grass species continuum which was associated with a gradient in elevation and aspect. In Study Area 1, the elevation boundary between the high-lying temperate grasslands and the lower subtropical grasslands corresponded with the generally recognised boundary between the Alpine and Subalpine vegetation belts (*viz. c.* 2 950 m a.s.l. on northerly aspects and *c.* 2 750 m a.s.l. on southerly aspects). This boundary was lower in Study Area 2 (*viz. c.* 2 800 m a.s.l. on northerly aspects and *c.* 2 300 m a.s.l. on southerly aspects).

Vegetation-insolation relationships were investigated in Study Area 1 using a model for simulating solar radiation, temperature and potential evaporation patterns on sloping terrain (RADSLOPE). The spatial distribution of the identified vegetation communities and the ratio of temperate (C_3) and subtropical (C_4) grasses in the sward were related to solar irradiance patterns, as influenced by topography. Results suggest that exposure, which increases with altitude, is probably also an important determinant of vegetation pattern in the mountains.

The influence of grazing on the vegetation was studied by examining changes in species composition and cover that were associated with gradients in grazing intensity

that exist around cattleposts in the mountains. There was little evidence of a shift in species composition and cover under grazing in the Alpine Belt but there was an identifiable grazing gradient in the Subalpine belt. There, short dense grasslands, dominated by palatable species, degrade to a dwarf karroid shrubland with sparse cover under prolonged, intense grazing. The optimum position along the grazing gradient of the more abundant species was identified. It was proposed that the relative positions, or scores, of these species along the grazing gradient can be used in a weighted scoring procedure to provide an index for monitoring the response of the mountain vegetation to grazing. However, the species' scores still require verification.

The need for monitoring temporal changes in vegetation composition and cover in order to assess the possible effects of the LHWP and other development initiatives was noted. Such monitoring should be undertaken in conjunction with an overall programme to assess the dynamics of the socio-economy in the mountains. Therefore, interdisciplinary monitoring programmes are required to achieve this. These programmes should be focused in a few key study locations rather than spread over a wide area.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Background

The high elevation mountain catchments of Lesotho have recently become the focus of international attention. These mountain catchments are the catchments of the giant Lesotho Highlands Water Project (LHWP), which is presently under construction in the interior of the country. The overall aim of the LHWP is to transfer water from the Senqu (Orange) river and its tributaries in Lesotho to the industrial heartland of South Africa in the Pretoria-Witwatersrand-Vereeniging (PWV) region (Anon. 1985a). Although the highland region of Lesotho constitutes only about 5% of the total catchment of the Orange river (excluding the Vaal system), it provides about 50% of the catchment run-off (Anon. 1986). The potential for tapping this valuable water source has long been realised (Staples & Hudson 1938).

The export of Lesotho's "white gold" via the LHWP will provide an economic injection into the economy of Lesotho (Anon 1985a). The investment by Government and private agencies in infrastructure and related developments in the initial phase of the LHWP (Phase IA) is already large, and the projected cost (at 1985 prices) of the project by its completion in the year 2019 will be over R4 000 million (Anon 1985a). Altogether, five main reservoirs are to be built on the Senqu river and its tributaries and the water stored in these dams will be transferred north via 200 km of tunnels to deliver an eventual 70 m^3 s^{-1} into the Ash river in the Orange Free State, which is a tributary of the Vaal river (Anon. 1985b) (Figure 1.1). Hydroelectric power (72 MW) will be generated at the outlet of the main transfer tunnel which will deliver water from the Katse dam on the Malibamatso river to the Sentelina holding pond, 50 km away. Lesotho's economy will receive an enormous boost from the sale of water to the Republic of South Africa and the generation of electricity for local use (Anon 1985a).
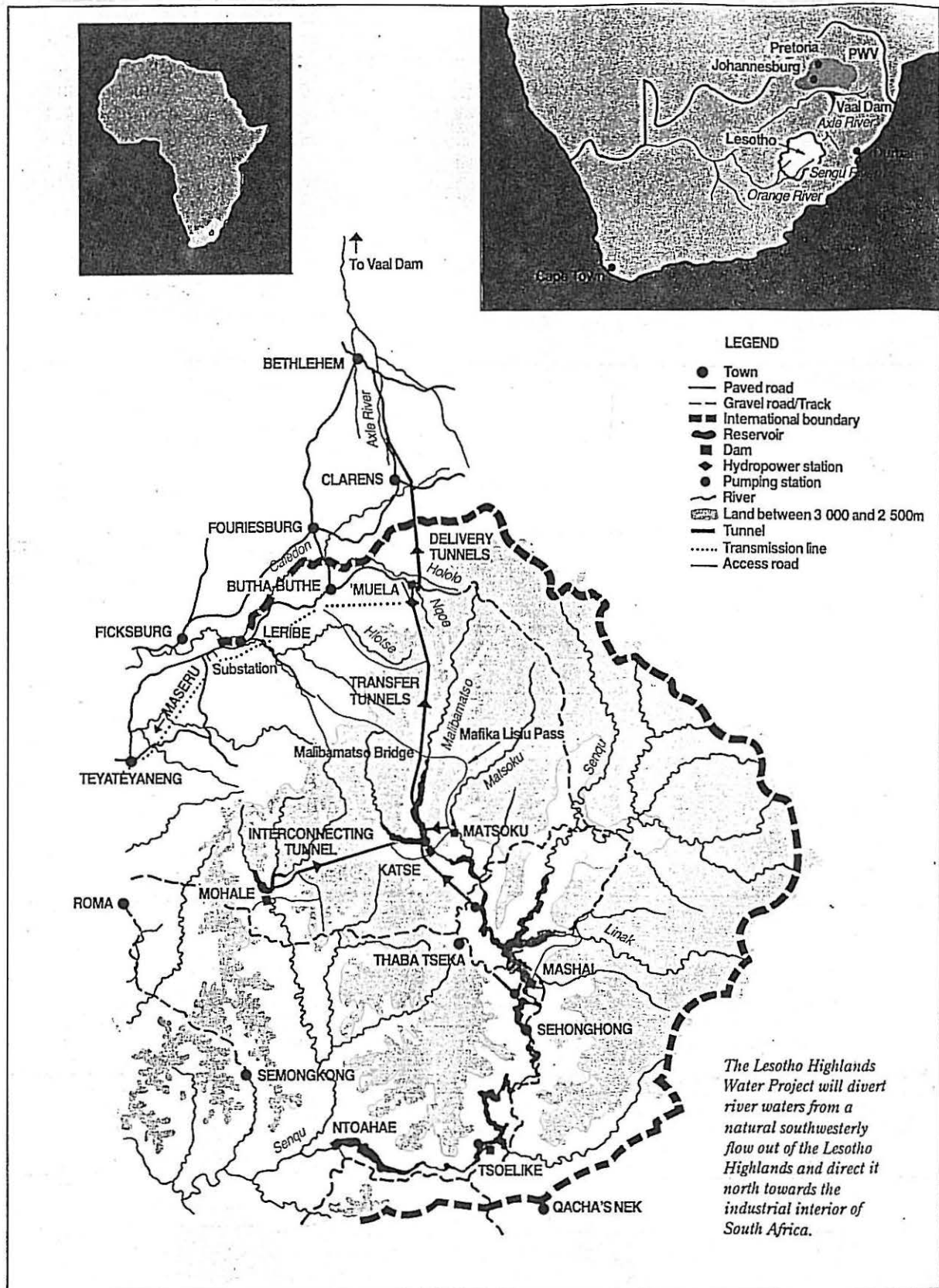
Figure 1.1   The location of the Lesotho Highlands Water Project in Lesotho
(after Wallis 1992).

The mountains of Lesotho have another important function. The mountain rangelands form the basis of an extensive livestock production system (Phororo 1979). The mountain vegetation has been grazed by domestic livestock since early this century when Basotho first moved into the mountainous interior of the country. It is likely that the mountain rangelands will continue to be utilized in the foreseeable future because livestock (cattle, sheep, goats & equines) play a fundamental role in the socio-economy of the Basotho, both for subsistence needs and for commercial purposes (Anon. 1990c).

Concern has repeatedly been expressed, both recently and in the past, that overstocking of the mountain rangelands is detrimentally affecting the function of the catchments and the productivity of the livestock system (e.g. Staples & Hudson 1939; Darkoh 1984; Anon. 1990c) and that excessive silt production resulting from overgrazing may shorten the lifespan of the LHWP (Anon. 1986; Anon. 1989). These reports concur with studies concluding that heavy grazing in catchment regions has undesirable hydrological consequences (Love 1958; Smeins 1975). Grazing in watersheds may directly conflict with the objective function of catchments, namely the production of quality water (van Zinderen Bakker 1981; Mark 1986). Therefore, management of land-use in the catchments is required in order to ensure the sustainable production of forage for livestock while maintaining the functional ability of the catchments to produce water (Bainbridge et al. 1991).

Recently, two integrated environmental studies have been conducted in the mountains of Lesotho with the aim of gaining a better understanding of the socio-ecology of the mountain region and the impacts that are being imposed on the system (Bainbridge et al. 1991; Anon. 1993).

The first of these studies, known as the Drakensberg/Maluti Mountain Catchment Conservation Programme (D/MCCP), was initiated in 1982 as a collaborative intergovernmental project of the governments of the Republic of South Africa and the Kingdom of Lesotho (Bainbridge et al. 1991). The Programme was directed towards ensuring the long-term conservation of the mountain catchments of the

LHWP for the production of optimum volumes of high quality water, while maintaining sustained forage production for livestock. The Programme also recognised the need to protect the unique floral and scenic resources of the mountain landscape for tourism. A survey of the high-lying catchments (>2 750 m a.s.l.) east of Mokhotlong (Figure 1.1) was undertaken in 1988 to investigate the environmental characteristics, the floral and faunal diversity, the human economy and land-use practices within the area. The nine specific research areas within the Programme were: plant taxonomy; terrain analysis; wetlands; the impact of fire and grazing on the vegetation; the socio-economy; alien and indigenous fish; fauna; climate & hydrology; and data management. The vegetation (excluding the mountain wetlands) of the study area was surveyed by the Fire and Grazing Team of the Department of Grassland Science, University of Natal, Pietermaritzburg (Morris *et al*. 1989). The objective of this project was to describe the vegetation communities occurring in the area and to quantify the effects of grazing and fire on their composition, structure and productivity.

On completion of the D/MCCP, it was recommended that the eastern mountain catchments be protected under the auspices of a Managed Resource Area (MRA) (Bainbridge *et al*. 1991). This recommendation was subsequently adopted by the Government of Lesotho (Anon. 1990c). The MRA is a conservation category of the International Union for the Conservation of Nature (IUCN) which aims to ensure the protection of the biota and the physical features of the environment while allowing controlled utilisation of the resources (IUCN 1978). A monitoring programme to assess the effectiveness of the conservation programme was recommended (Morris *et al*. 1989). However, permanent monitoring sites were not established during the D/MCCP.

In 1990 the Lesotho Highlands Development Authority (LHDA), who administer the LHWP, commissioned a baseline biological survey of the Katse subcatchment in the Phase IA area of the LHWP (Figure 1.1) (Anon 1990a). The objective of the survey was to collect quantitative data on the distribution and relative abundance of the flora and fauna to serve as a baseline for determining the long-term impacts of the

LHWP. Aspects included in the survey were: the flora; small mammals; reptiles; fish; amphibians; birds; insects; and soil invertebrates (Anon. 1993). The specific objective of the vegetation survey, which was undertaken by the Department of Grassland Science (University of Natal), was to provide a quantitative description of the major vegetation types of the Katse study area and to establish a vegetation monitoring programme.

In this thesis the influence of environmental factors and grazing on vegetation pattern in the mountain catchments are considered. The overall objective of the thesis is to provide a quantitative analysis of vegetation pattern to increase the understanding of the mountain ecology and to aid conservation management in the mountains. The thesis includes an analysis of the vegetation data collected in the study areas of the D/MCCP and the Baseline Biological Survey of Phase IA of the LHWP.

1.2 Objectives

1. To outline previous work done in Lesotho concerning the vegetation.
2. To investigate the influence of environmental factors on floristic variation in the mountains.
3. To identify and describe the composition and topographic distribution of the major vegetation types occurring in the two study areas.
4. To describe the influence of livestock on the vegetation and to identify species that are responsive to grazing and which can be used as indicator species in a vegetation monitoring programme.
5. To consider the implications of livestock grazing on the condition and function of the mountain catchments.

CHAPTER 2

STUDY AREA

2.1 Location

The study area for the Drakensberg/Maluti Mountain Catchment Conservation Programme (D/MCCP) - hereafter referred to as Study Area 1 - was located in the eastern mountains of Lesotho in a major part of the catchment for the Senqu (Orange) river (Figure 2.1) (Bainbridge *et al.* 1991). It was approximately 200 000 ha in extent. It extended from the source of the Senqu river in the north (28°53'S) to just past Sani Pass in the south (29°42'S). The study area bordered Natal in the east, along the Drakensberg escarpment, and extended west as far as Mokhotlong and Molumong (29°00'E). The lower boundary of the study area was defined as the 2 750 m contour line in order to exclude all villages and to incorporate the summer cattlepost areas. The highest point in the study area was Thabana Ntlenyana, which at 3 482 m a.s.l., is the highest mountain in southern Africa. Due to limited accessibility in the northern reaches of the study area, vegetation, faunal and socio-economic sub-projects of the D/MCCP concentrated their efforts more towards the central and southern regions of Study Area 1.

The study area for the baseline biological survey of the Phase IA catchment - hereafter referred to as Study Area 2 - was defined as the local catchment of the Malibamatso river, on which the Katse reservoir is being built (Figure 2.1). It was approximately 62 500 ha in extent and excluded the area that is to be inundated (3 227 ha) (Anon. 1990a). The upper Bokong catchment (28°17'E) formed its western boundary and the ridge between the Malibamatso and the Matsoku rivers, its eastern border. It extended north just past the confluence of the Pelaneng and Malibamatso rivers (29°03'S) and its southern perimeter was along the ridge south of Katse village (29°21'S). The altitudinal range within Study Area 2 was 1 085 m, from 2 040 m a.s.l. at the site of the Katse dam wall to 3 125 m a.s.l. at the source of the Lepaqoa river.
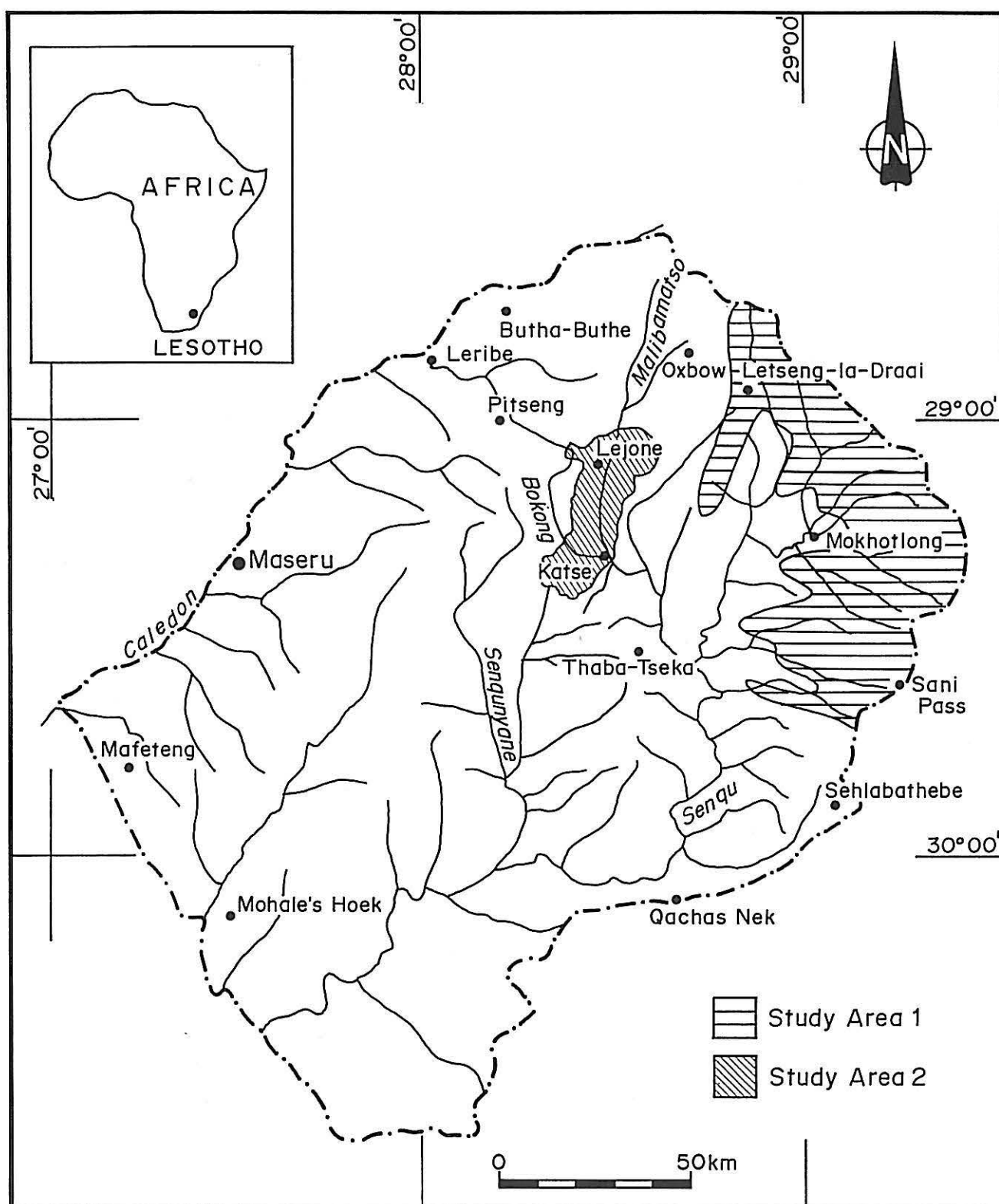
Figure 2.1   The location of Study Area 1 and Study Area 2 in Lesotho, southern
Africa.

2.2   The physical environment

The following is a general description of the physical environment pertaining to both Study Area 1 and Study Area 2.   Where there are important differences between the two study areas, they are discussed.

2.2.1 Geology and topography

Lesotho can be divided into four major topographic zones, namely, the Lowlands, the Foothills, the Mountains and the Senqu River Valley (Schmitz 1984).   The Lowlands (1 300 - 1 800 m a.s.l.), which cover *c.* 12% of the country, are located along the western and southern edge of Lesotho.   The Foothills (1 800 - 2 100 m a.s.l.) are transitional between the Lowlands and the Mountains and occupy *c.* 15% of the land.   The Mountains (2 100 - 3 482 m a.s.l.) comprise the largest proportion of the country (*c.* 65%) whereas the Senqu River Valley in the south is only *c.* 8% of total land area in Lesotho.

Lesotho can be divided further into land regions based on geological structure, lithology and topography (Schmitz 1984).   Both study areas were located in the Mountains and incorporated the Higher Mountain Region, the Lower Mountain Slopes and the Lower Mountain Flats.   The following description of the geology and geomorphology of the Mountains is derived from Wieland (1982), Schmitz & Rooyani (1987) and Klug *et al.* (1989).

The underlying geology of the Mountains is basalt of the Drakensberg Formation. This basalt is the youngest strata of the Karoo sequence and was laid down as a succession of separate lava flows, up to 50 m thick, during the early Jurassic. Dolerite sills and dykes that cut through the basalt are found in places in both study areas and kimberlite pipes occur sporadically in Study Area 2.

The Mountains are a vast tableland dissected by deep river valleys carved out by fast flowing streams.   Basalt buttresses and sheer cliffs predominate, with steep slopes below.   The accidented topography is a product of past geological and geomorphological processes.   Natal and Lesotho have been subject to number of

episodes of uplifting and monoclinal warping in the past which have rejuvenated erosion processes (King 1982). As a result the landscape is in a youthful stage of geomorphological development. The mountain summits represent the lowered remnants of the original post-Gondwanaland basalt surface. There are three mountain ranges in Lesotho (collectively known as the Maluti), running roughly from north to south. The Thaba-Putsoa Range forms the western escarpment, the Central Range lies to the east of the Thaba-Putsoa Range and the Drakensberg escarpment, further east, forms the border between Natal and Lesotho. The Drakensberg is the highest of the three ranges. The Senqu river divides the Central Range and the Drakensberg whereas the Senqunyane river, its main tributary, flows between the Central and Thaba-Putsoa ranges.

Valleys are steep to very steep and display marked asymmetry (Meiklejohn 1992). South-facing slopes are considerably steeper than northerly aspects. This has been ascribed to varying rates of soil formation and removal as a consequence of aspect induced temperature differences. Hillslopes are typically stepped with basalt benches with small scarps that protrude at regular intervals down the slope. This is a result of differential weathering of the discrete basalt layers. The horizontal upper surfaces of the basalt benches are broader and have a shallower soil layer on northerly aspects than on south-facing slopes. The soil mantle has been severely eroded on many of these protruding basalt ledges, especially on the warmer slopes, as a result of grazing and trampling by livestock.

Flat areas of any extent are uncommon in the Mountains and are found only at the headwaters of certain streams (e.g. the Sani flats) and on the elevated benches above some major rivers (e.g. the Mokhotlong and Bokong rivers). These benches, which are remnants of earlier river valley bottoms, are extensively cultivated. In Study Area 1, rivers generally flow from east to west, into the Senqu river. In Study Area 2, rivers are shorter and steeper than those in Study Area 1 and they drain both from the east and from the west into the Malibamatso river. Wetlands have developed under conditions of permanent soil saturation in seepage zones on the mountain slopes and in the flat basins at river sources. These wetlands can

be up to a few hectares in extent, e.g. on the Sani flats in Study Area 1. Large wetlands are uncommon in Study Area 2 due to a paucity of flat areas. However, there are wetlands of appreciable size at the headwaters of the Bokong and Lepaqoa rivers.

2.2.2 Soils

The soils of the mountains of Lesotho have been described by several authors (Venter 1938; Bascomb & Carroll 1967; Bawden & Carroll 1968; Killick 1978b; Conservation Division 1979; Wieland 1982; Schmitz & Rooyani 1987; Klug *et al*. 1989). The following discussion is a summary of these reports with an emphasis on soil characteristics that are relevant to the ecology of the mountain flora.

The climate and the terrain of the mountains are such as to favour soil removal rather than soil deposition (Darkoh 1984; Anon. 1993). Therefore, the mountain soils are juvenile and generally shallow (<45 cm). Most of the soils occurring in the mountains are mineral soils, in that they consist largely of a mineral fraction with some organic matter. However, the organic matter fraction may be as high as 20%. Low temperatures, soil moisture accumulation and a dense vegetation cover resulting from fertile soils and high rainfall, are factors favouring organic matter accumulation in the solum. The majority of the soils occurring in both study areas belong to the Mollisol order (U.S.D.A. Soil Taxonomy; Soil Survey Staff 1975). Mollisols have a mollic epipedon, or surface horizon, and are young soils commonly formed under grassland vegetation. They are dark, well structured soils with a thick (>17.5 cm) humus rich topsoil. Their heavy texture and high cation exchange capacity - with a base saturation of more than 50% - is a result of the basaltic parent material. The calcium content of Mollisols in Lesotho is high, also a consequence of the mineralogy of the parent basalt and this is reflected in elevated calcium levels in the vegetation growing on such soils (Morris *et al*. 1989). Soils are neutral to slightly acidic with pH values (in water) in the region of 6.

Entisols and Histisols also occur in the mountains. Entisols, also known as

Lithosols, are found on the mountain summits and protruding basalt benches. They are shallow soils, less than 15 cm in depth, with a fairly high organic matter content. Histisols, or soils containing an organic (histic) horizon, have been reported to occur in wetlands at high altitudes where drainage is impeded and where low temperatures limit microbial degradation of organic matter (Mack 1981; Backeus 1988; Schwabe *et al.* 1989). Klug *et al.* (1989) noted that the organic matter content of soil profiles that they examined in the wetlands of Study Area 1 was below the required limit for the histic epipedon (i.e. <30%) and they doubted that true bogs containing peat occur in Lesotho. However, they did encounter a Palaeo-Histisol in a wetland near Sani Pass which was buried under a relatively recent Mollisol and which was most likely formed under climatic conditions different to that of the present. They classified the soils of the wetlands as Haplaquolls (belonging to the subgroup Aquolls), i.e. Mollisols with an aquic moisture regime and a relatively young (cambic) B horizon.

Soil moisture and soil temperature are the two climatic parameters that are used to classify soils at the suborder level in Soil Taxonomy (Soil Survey Staff 1975). Three soil moisture and two soil temperature regimes have been recognised for the mountains in Lesotho (Table 2.1). Aquic soils are the saturated soils of the wetlands (Table 2.1). An ustic soil moisture regime occurs in the low, warm valleys of Study Area 2. These soils occasionally experience a negative water balance during the growing season which could inhibit plant growth. Udic soils are found at high altitudes, especially near the Drakensberg and western Maluti escarpments, where evapotranspiration is low and precipitation is high. Plant growth in those areas is limited by low temperatures rather than by soil moisture deficits. The high lying soils and those on southerly aspects experience a frigid temperature regime whereas the temperature regime prevailing on the northerly slopes at low altitudes is mesic (Table 2.1). Udic Mollisols with a mesic temperature regime are potentially the most productive soils in the mountains (Wieland 1982).

Table 2.1   Soil moisture and soil temperature regimes used to classify soils in Lesotho at the suborder level of Soil Taxonomy (after Soil Survey Staff 1975).

Soil moisture regime	
Category	Description
aquic	Soil experiences a reducing regime that is virtually free of dissolved oxygen because of saturation with ground water or by water of a capillary fringe.
udic (humid)	In most years the soil is not dry in any part for as long as 90 days (cumulative) and is not dry in all parts for as long as 45 consecutive days in the four months following the summer solstice.
ustic	In most years the soil is dry in some or all parts for 90 or more cumulative days and is not dry in all parts for as long as 45 consecutive days in the four months following the summer solstice.
Soil temperature regime	
mesic	Mean annual soil temperature of between 8 and 15°C (mean air temperature 7-14°C). The difference between the mean and winter soil temperatures is >5°C.
frigid	Mean annual soil temperature of between 0 and 8°C. The difference between the mean and winter soil temperatures is >5°C.

Soil moisture dynamics and soil temperatures vary according to aspect and this results in differential rates of chemical weathering. Venter (1938) described the soils of southerly aspects as being blacker, moister and containing more K_2O, P_2O_5 and organic matter than those of the north-facing slopes. However, these marked aspectal differences in mineralogical and chemical soil characteristics were not observed by later researchers (Herbst & Roberts 1974a; Klug et al. 1989). Klug et al. (1989) did note that the coloration of the basaltic parent material and the subsurface soil layer, where present, differed between aspects and they attributed this to differential rates of iron oxide mobilisation. On south-facing slopes, the subsurface soils were yellow and the basalt was dark grey to black. In contrast,

on the north-facing slopes, the soils and the surface and near-surface basalt were red in colour, indicating a faster rate of chemical weathering than on the cooler, southerly slopes.

The conspicuously different pattern of accelerated soil erosion on different aspects is a feature of the landscape in both study areas. Soil loss has been higher on the north than on the south-facing slopes. The warmer northerly slopes are preferred settlement and grazing areas, and as a consequence, herbaceous vegetation cover is denuded on these slopes in places, especially along bridle paths and in the vicinity of cattleposts. Surface wash, causing sheet and rill erosion, and mass movement of soil are the two primary mechanisms of erosion in the mountains. Rills, exposed subsurface rock and small dongas are erosion features of the northerly slopes whereas on the southerly aspects, numerous terracettes have formed through soil creep initiated by livestock trampling. Stream channels in wetlands are often incised as a result of excessive livestock pressure. Denudation of the vegetation and soil on steep slopes in the vicinity of mountain villages and around cattleposts is a distinctive feature of the mountains (Staples & Hudson 1938; Anon. 1989). Nevertheless, it is remarkable that accelerated erosion is not further advanced than it is in the mountains given the purported extent of overstocking (Jacot-Guillarmod 1971; Herbst & Roberts 1974a; Klug *et al.* 1989).

Mountain soils, which are derived from basalt, are less erodible than the sandstone derived soils of the Lowlands (Anon. 1989). The erodibility of the mountain soils is low when they are wet due to the viscosity imparted by humic materials in the surface epipedon. However, the soils are loose and friable when dry and they then erode readily when exposed to high intensity summer rainstorms. In addition, the soil mantle on the steep mountain slopes is inherently thin and freeze/thaw processes destabilize the soil surface, especially on northerly slopes which are subject to large temperature fluctuations. Consequently, there is a potential for extensive soil loss in the mountains. Recovery of degraded areas in the severe climatic conditions of the mountains is very slow (Staples & Hudson 1938; Herbst & Roberts 1974a; Tiedeman 1983b; Weaver 1987).

2.2.3 Climate

The climate of the mountains has been described by various authors (Carter 1967; Bawden & Carroll 1968; Binnie & Partners 1972; Killick 1978a, 1978c; Wieland 1982; Mokuku 1992; Anon. 1993). There are no permanent weather stations in Study Area 1 and only two weather stations in Study Area 2. However, reliable long-term climatic data were not available from these two stations. Therefore, a general description of expected climatic conditions was surmised from neighbouring areas with a similar physical environment.

Lesotho's climate can be described as being continental (Schulze 1947). It is cool and subhumid with a dry winter. It should be noted, however, that overall climate, or macroclimate, has little ecological relevance because climatic variables such as soil moisture, air temperature and solar insolation vary extensively over the rugged topography. Microclimatic conditions at or near the ground largely determine plant distribution and productivity (Barry & van Wie 1974).

2.2.3.1 Precipitation

Rainfall in the mountains is high, with many areas receiving over 1 000 mm a^{-1}. Precipitation is influenced by topography and is highest on the western and eastern escarpments, which receive orographic rainfall. Mean annual rainfall at the summits of the Organ Pipes and Sani passes, on the Drakensberg escarpment, is 1 609 mm and 996 mm, respectively (Killick 1978a). Rainfall declines rapidly towards the interior of the mountains due to the rain-shadow effect of the escarpment (Killick 1963). At Mokhotlong (altitude 2 230 m), 35 km west of the Drakensberg escarpment, mean annual precipitation is only 575 mm (Killick 1978a). At Pelaneng, in the lower reaches of the Malibamatso river valley (Study Area 2), the mean annual rainfall is 694 mm whereas Rampai, on the western escarpment less than 10 km away, receives an annual rainfall of 1 177 mm (Anon. 1993).

The variability of rainfall from year to year is high with an average CV of between 40 to 50%. Droughts occur periodically. Precipitation occurs mostly in the form

of high intensity thunderstorms of short duration and scattered distribution. These thunderstorms are often accompanied by lightning and hail. Almost 80% of the annual precipitation falls between October and March. Summer is also the season with the highest relative humidity. During the summer, misty mornings are commonplace along the escarpment and afternoons are frequently cloudy due to thunderstorm activity. In contrast, winter days are clear between periodic frontal systems that move up from the south-western Cape. These dry, cold winter months are the period of greatest stress for plant and animal life. At high altitudes, low temperatures delay the onset of spring growth in the grasslands in spite of sufficient moisture being available from melting snow (Hilliard & Burtt 1987). Evapotranspiration is lowest at high altitudes and increases rapidly with a decline in elevation as a result of increasing temperatures.

2.2.3.2 Temperature

Temperatures in the mountains vary according to altitude and aspect. Estimates of temperature lapse rates range from 6.5°C km-1 to 7.7°C km-1. The mean annual temperature at Letsêng-la-Draai (3 050 m a.s.l.), Kao Mine (2 560 m a.s.l.) and at Mokhotlong (2 230 m a.s.l.) is 5.7°C, 10.1°C and 12°C, respectively (Wieland 1982). Summers are cool to mild with occasional hot days (>30°C) whereas winters are cold, with minimum temperatures frequently below 0°C (Figure 2.2). The mean temperature in January (the warmest month of the year) is c. 10°C at high altitudes and c. 17°C at the lowest elevation extremes of the mountains. Mean temperatures during June are just above freezing at high altitudes and c. 5°C at low altitudes. The lowest recorded temperature at Letsêng-la-Draai was -20.4°C, recorded in June 1967 (Killick 1978a).

The growing season in the mountains is short as the vegetation experiences temperature induced dormancy during the winter months. It has been estimated that the higher altitude extremes of the mountains experience up to 300 frost days a year (Binnie & Partners 1972). However, the mean number of frost days per annum recorded at Letsêng-la-Draai was only 183 (Killick 1978a). An average of 100 frost days a-1 have been recorded at Mokhotlong (Killick 1978a). Although

moisture may be present on the soil surface and in the soil profile during the winter, it is often frozen and therefore unavailable for plant growth. Hence, the vegetation is said to experience physiological drought (Hilliard & Burtt 1987). This explains the xeromorphic features exhibited by many plants growing at high altitudes in Lesotho, such as a rosette leaf arrangement, a cushion-like growth form and filiform or hairy leaves.
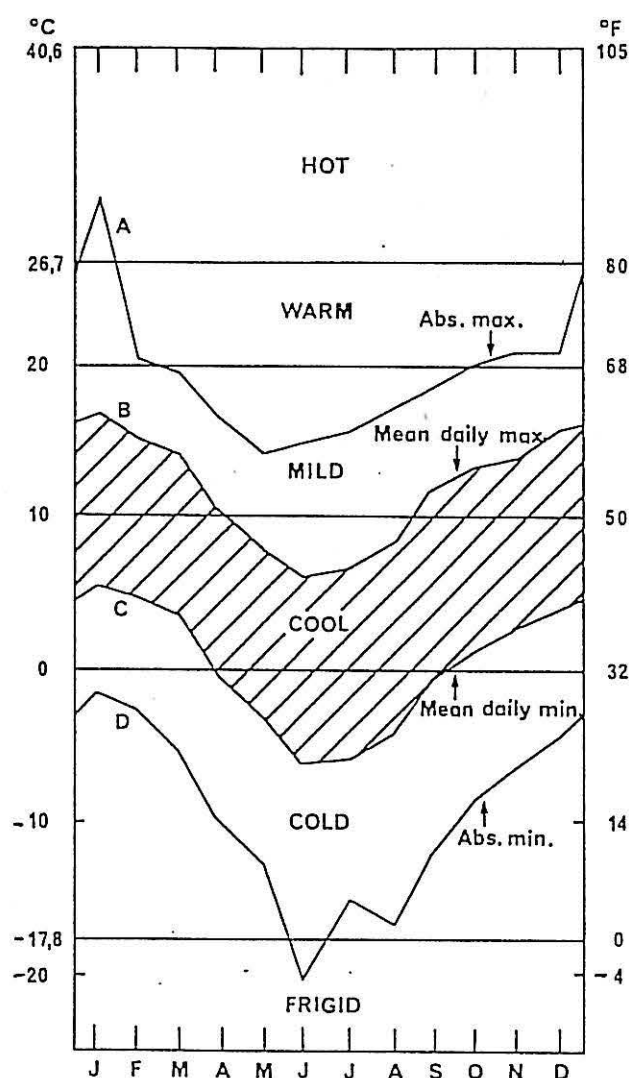
Figure 2.2   Temperature chart for Letsêng-la-Draai in north-eastern Lesotho (Killick 1978a).

There is a pronounced diurnal variation in temperature in the mountains, especially at high altitudes and in early spring. Daily maxima can be 2-4 times greater than the corresponding minima. Although the soil surface at high elevations does not remain frozen throughout the year as suggested by van Zinderen Bakker & Werger (1974), nightly minimum temperatures during summer are low (*c.* 4°C) and daily maxima are frequently high. Soils experience a wide temperature fluctuation, especially on the north-facing slopes, and this results in a highly stressful environment for plant growth. Freezing and thawing of the soil during the cooler months of the year creates a loose, powdery soil surface that erodes easily. It also causes mechanical injury to plants by severing plant roots. Herbaceous and grass cover serves to moderate diurnal and seasonal ground temperature fluctuations, thereby reducing frost-heaving.

2.2.3.3 Snow

The ecological effects of snow on the alpine vegetation have been described by Killick (1963). Snowfalls are possible at all times of the year but are most likely to occur during June and July. Snow falls eight times a year on average. It melts after a few days on the warmer slopes but may cover the vegetation on southern slopes for up to two months after a fall. A snow blanket is beneficial to the vegetation in that it provides protection from extreme cold and drying winds, it prevents the soil from freezing and it is a source of available moisture for spring growth when it melts (Barry & van Wie 1974). However, the nett effect of snow is to shorten the growing season.

2.2.3.4 Cryogenic phenomena

Certain soil features that are characteristic of cold mountain climates where regular freezing occurs, are found at high altitudes in Lesotho (van Zinderen Bakker & Werger 1974). Frost-raised mounds ('thufur') are regular features of the alpine wetlands (Grab 1994). Numerous hollow patches of bare soil are encountered on the highest summits and on flat areas along the northern Drakensberg escarpment. Snow accumulates in these hollows and their surface is characterized by narrow, parallel soil ridges caused by the simultaneous action of frost and wind. Small

stone polygons are occasionally observed. Needle ice forms in the topsoil of the surrounding grasslands and lifts the soil surface. Solifluction, as a result of frost heaving, serves to initiate soil erosion.

2.2.3.5 Solar radiation

Insolation levels at high altitudes in Lesotho are high. This is as a result of the rarefied atmosphere at high elevations, where atmospheric pressure and the concentration of pollutants are low. At Oxbow, the average incoming insolation at ground level is 582 cal cm^{-2} day^{-1} in January and 285 cal cm^{-2} day^{-1} in June (Wieland 1982). Plants growing at the higher altitudes have to withstand high levels of ultra-violet radiation. Dwarfness, a characteristic feature of alpine plants (Hedberg 1964), may be due to elevated levels of ultra-violet radiation. Certain species occurring at high altitudes in Lesotho possess a grey or white indumentum on their leaves which is said to be a means of reducing the amount of absorbed radiation (Killick 1963).

Topography influences insolation patterns in mountainous areas. The amount of radiant energy received by any land surface is a function of solar altitude, slope orientation and slope inclination (Schulze 1975). Steep, north and south facing slopes can differ up to 500% in the amount of insolation incident during winter, when the solar angle is low (Granger & Schulze 1977). Radiant energy patterns largely determine soil temperatures, soil moisture dynamics, rates of weathering and erosion, as well as snow cover duration (Barry & van Wie 1974). North-facing aspects experience a greater degree of natural erosion than the cool and moist southerly aspects. Vegetation patterns in mountains have been shown to be related to insolation patterns (Granger & Schulze 1977; Holland et al. 1977). Certain species, especially temperate grasses, are confined in their distribution to the mesic southerly slopes. Succession may also be more advanced on these aspects than on the xeric north-facing slopes (Granger & Schulze 1977).

2.2.3.6 Wind

Plants growing at high altitudes in Lesotho are exposed to cold, drying winds. The

escarpment edge and mountain summits experience high velocity winds throughout the year. Generally, however, late winter and spring are the windiest months in the mountains and this coincides with the period when moisture for plant growth is frequently limited. The average windspeed measured at Mokhotlong was 8 km hr^{-1} (Wieland 1982). October is the windiest month of the year and May the least windy. The prevailing wind direction during the summer is easterly, associated with the summer rain, whereas in winter the wind direction is generally from the west.

CHAPTER 3

THE VEGETATION

3.1   Phytogeography

The Drakensberg, the Maluti and the lower lying mountains of the Eastern Cape (the Witteberge) were recognized by Phillips (1917) as a phytogeographical entity in southern Africa, termed 'the Eastern Mountain Region'. The Eastern Mountain Region also has affinities with other flora, both southwards in the Cape and in the eastern and central mountains of Africa (Hilliard & Burtt 1987). Links to the Afroalpine flora of the high mountains north of Tanzania have been emphasized by researchers in Lesotho and South Africa (Killick 1978b; Wieland 1982; Martin 1986). Recently, however, doubts have arisen as to the validity of the phytogeographical association between the mountain vegetation of Lesotho and the Afroalpine flora (Hedberg 1986; Hilliard & Burtt 1987).

The term 'Afroalpine' was first coined by Hauman (1933, cited by Killick 1963) to describe the high altitude vegetation of the central and eastern African mountains. Hedberg (1961), Coetzee (1967) and van Zinderen Bakker & Werger (1974) regarded the mountains of Lesotho and the Drakensberg as being a southerly outlier of the Afroalpine mountain archipelago (i.e. the Ethiopian Highlands, Ruwenzori, Mount Kenya, Kilimanjaro, Mount Mlanje and others). The vegetation occurring above 1 800 m a.s.l. in the Drakensberg and Lesotho was subsequently included in the Afroalpine phytochorion by Killick (1978b) as an southern (austral) variant of the Afroalpine region - the 'Austral-Afroalpine' region.

The reason for classifying the southern alpine vegetation in the same phytochorion as the central and eastern African mountains was that a fair number of genera and species were common to both areas (18 species and 84 genera; Killick 1978b). However, almost all these species and genera are widely distributed throughout other non-Afroalpine areas in Africa (Hilliard & Burtt 1987). Further, certain species characteristic of the tropical Afroalpine vegetation, e.g. giant Senecios and

Lobelias, are absent from the high mountains in southern Africa. Hilliard and Burtt (1987), as well as Hedberg (1986) and Backeus (1988), considered the botanical links between the southern mountain flora and the Afroalpine phytochorion to be too meagre to warrant their recognition as a combined phytogeographical region. White (1983) recognised a separate mapping unit for the southern African mountain vegetation - the 'South African altimontane vegetation' - to distinguish it from the vegetation of the tropical mountains further north.

Hilliard and Burtt (1987) proposed that the vegetation of the Drakensberg/Maluti mountains should be classified according to White's classification (1976) as a Regional Mosaic - more specifically 'the South-eastern Mountain Regional Mosaic'. Although endemism is high in the region (almost 30% of the species occurring at high altitudes are endemic), the flora represents a zone of transition between the temperate flora of the southern Cape mountains and the subtropical and tropical African flora. Affinities to the temperate flora of the Cape include the genera: *Merxmuellera*; *Rhodohypoxis*; *Pentaschistis*; and *Glumicalyx* species (Hilliard & Burtt 1987). The Fynbos elements that are represented in Lesotho (e.g. *Erica* spp. & *Helichrysum trilineatum*) are considered to be isolated populations of fynbos that are relics of a past climate when the boundary between the winter and summer rainfall regions was further east than it is at present (Deacon *et al.* 1983). Temperate grass species - which photosynthesize via the C_3 pathway - occur predominantly on cool microsites (high elevations and southerly aspects) in the mountains whereas subtropical grasses, with a C_4 photosynthetic pathway, are prevalent on warm aspects and at lower elevations (Vogel *et al.* 1978). Many of the subtropical grass species occurring in the mountains of Lesotho (e.g. *Themeda triandra*, *Harpochloa falx* & *Eragrostis curvula*) also occur in Natal, the eastern Orange Free State and the Eastern Cape (Killick 1963; Hilliard & Burtt 1987).

Although the vegetation of Lesotho's mountains has floristic links with vegetation elsewhere in Africa, it is fairly unique in composition and structure. The dwarf *Erica-Helichrysum* heathland of the Drakensberg and Maluti summits as well as the dense, mat-like vegetation of the mountain wetlands, occur nowhere else in

southern or central Africa. This is most likely a consequence of the particular combination of climatic and edaphic conditions occurring in the mountains of Lesotho. In spite of its floristic uniqueness there have been relatively few detailed taxonomic and ecological studies of the mountain vegetation.

3.2. Previous ecological studies in Lesotho.

3.2.1 Early descriptions.

Wieland (1982) summarized previous vegetation classifications in Lesotho by comparing the various vegetation zones recognized by researchers (Table 3.1). Other descriptions of the vegetation have been presented in various texts (Thode 1901; Staples & Hudson 1938; Rhodes University 1960; Edwards 1963; Killick 1963; Edwards 1967; Bawden & Carroll 1968; Jacot-Guillarmod 1971; Herbst & Roberts 1974a & 1974b; Acocks 1975; Killick 1978b & 1978c; Killick 1979; van Zinderen Bakker 1981; Martin 1986; Hilliard & Burtt 1987; Meakins *et al.* 1988; Morris *et al.* 1989; Mokoku 1992; Anon. 1993). The phytogeography, limnology and ecology of the mountain wetlands have also been described (Jacot-Guillarmod 1962 & 1963; van Zinderen Bakker & Werger 1974; Backeus 1988; Schwabe *et al.* 1989).

Thode's (1901) described the vegetation of the 'Upper Mountain Region' as being similar in character to alpine vegetation elsewhere in the world. He noted that the Compositae, especially *Helichrysum* and *Senecio* species, comprised a large proportion (>27%) of the species occurring there. Heaths (*Erica* species) were also common, as were orchids. 'Southern Africa's Switzerland' was a paradise for the ardent nature lover (Thode 1901).

In 1937 Staples and Hudson undertook an ecological survey of the mountains in order to inventory the rangelands before major settlements developed in the mountains (Staples & Hudson 1938). They described two extensive grasslands occurring in the mountains, known locally as the *seboku* and *letsiri* grasslands (Table 3.1), whose development and maintenance they ascribed to regular 'firing'.

Table 3.1 Vegetation zonation in Lesotho according to previous workers (Wieland 1982).

Elev. metres	Staples and Hudson, 1938 Reconnaissance Lesotho Mountains (1)		Acocks, 1953 and 1975 Veld Types, based on Abundance, South Africa (2)	Killick, 1963 Climatic Climax Types Monoclimax Hypothesis Cathedral Peak, Natal	Jacot Guillarmod, 1971 Vegetation Belts Observation Lesotho	Molumong Prototype, 1981 Vegetation Associations and Soil Suborders Ecosystem Approach Polyclimax Hypothesis (3)
3 500	North Aspect Letsiri	South Aspect	*Themeda - Festuca* High elevation variation Veld Type No. 58	*Erica - Helichrysum* Heath Alpine Belt	Alpine belt	*Merxmuellera drakensbergensis* phase Alpine Zone (3) *Festuca caprina - Merxmuellera disticha* h.t. Soils: Borolls
3 000	Sehalahala		Invading karroid spp.			
2 500	___2 740___	Letsiri	??? *Themeda Festuca* Sweet veld to mixed variation	___2 865___ *Passerina - Phillipia Widdringtonia* Fynbos Subalpine belt	___2 900___ Subalpine belt	Cattlepost: *Chrysocoma tenuifolia* ___2 900___ Subalpine Zone *Themeda triandra - Harpochloa flax* h.t. Soils : Udolls
2 000	Seboku ___2 130___ Seboku		Veld Type No. 58 ___1 850 - 2 150___		___2 286___ ·Foothills	___2 400___ Montane Zone *Cymbopogon pluriodis - Eragrostis* spp. h.t. Soils : Ustolls
1 500	_1981 - (1)_		*Cymbopogon - Themeda* Southern variation Veld Type No. 48 (2)	___1 830___ *Podocarpus latifolius* Forest Montane Belt	· 1 830 ___ Lowlands ___1 530___	___1 950___ Lower boundary of Prototype
1 000				___1 280___		

(1) Staples and Hudson pointed out. "Below about 6 500ft (1 982m) in mountain valleys as in the lowlands. *Themeda triandra* probably was never so completely dominant as it is in the best mountain pastures of this type."

(2) Acocks does not give a lower elevation limit for the *Cymbopogon-Themeda* veld. However this veld merges with the Dry *Cymbopogon-Themeda* Veld Type no. 50 at lower elevations.

(3) Aspect is recognised as a variable that will affect the Zone/Type boundaries. Because the Prototype has few southern aspects, the boundaries have been set according to the northern, dominant aspect. For southern aspects the zone boundaries should be set at 2 740m instead of 2 900m and 2 290m instead of 2 400m.

Seboku, or 'sweetveld' grassland, occurred primarily on the warmer slopes of the mountains between 2 000 and 2 700 m a.s.l. and was dominated by *T. triandra*. In contrast, *letsiri* grassland, which was dominated by grasses with a temperate affinity (*Merxmuellera disticha, Festuca caprina, Koeleria capensis* & *Pentaschistis* spp.), occurred at high altitudes and on southerly aspects. A third vegetation type, namely *Sehalahala* ('small shrub'), was also recognized. This was a dwarf shrubland dominated by *Chrysocoma ciliata* and other dwarf shrubs that commonly occurred in the Karoo (*Pentzia cooperi* & *Felicia filifolia*). Overgrazing by domestic livestock was imputed to lead to the replacement of *letsiri* and *seboku* grasslands by *sehalahala*. Staples and Hudson (1938) estimated that a total of 13% of the Mountain Province had been invaded by *sehalahala*.

The vegetation types discussed above were recognized by later workers as being valid vegetation zones although altitudinal boundaries between zones were redefined and zones were named according to international terminology (Table 3.1). The five vegetation belts recognised in tropical mountain ecology are: Tropical; Montane; Subalpine; Alpine; and Nival (Killick 1963). In Lesotho the Tropical and the Nival (i.e. with permanent snow cover) belts are absent. The region above the tree-line, i.e. the Alpine Belt, has been divided into two belts in Lesotho based on climatic features as well as the subtropical/temperate nature of the grassland (Jacot-Guillarmod 1971; Killick 1978b). These are the Subalpine and Alpine Belts (Table 3.1). The Montane Belt is located below the Subalpine Belt (i.e. <1 830 m a.s.l.).

Killick (1963; 1978b; 1979) described the climax vegetation communities for the Montane, Subalpine and Alpine Belts of the Natal Drakensberg and Lesotho. The climax vegetation community, according to the mono-climax hypothesis of Clements (1916), is the community that ultimately develops in a particular climatic region in the absence of recurrent disturbances such as fire or grazing, *viz.* the 'climatic climax'. An *Erica-Helichrysum* (*E. dominans* & *H. trilineatum*) dwarf heathland is suggested to be the mono-climax community of the Alpine Belt (Edwards 1967; Killick 1978b). It generally occurs only in rocky areas where

protection from fire is afforded (Killick 1978b). The Subalpine vegetation of the Natal Drakensberg and the Maluti is a 'fire-climax' grassland that is maintained in its present state by regular, intense fires (Killick 1963; Jacot-Guillarmod 1971). In the absence of fire in the Subalpine Belt of the Natal Drakensberg, succession proceeds to a tall shrubland dominated by *Passerina filiformis*, *Philippia evansii* and *Widdringtonia dracomontana* (Killick 1963). These sclerophyllous shrub species are rare in the Subalpine Belt of Lesotho and, in the absence of regular burning, dwarf shrubs of karroid affinity that are intolerant of fire (e.g. *C. ciliata* & *P. cooperi*) proliferate (Jacot-Guillarmod 1971; Killick 1978b). The Montane Belt in Lesotho is also a fire-climax grassland with patches of scrub forest *(Leucosidea sericia*, *Rhamnus prinoides*, *Halleria lucida* and other tall shrub species) confined to sheltered ravines and steep rocky slopes (Jacot-Guillarmod 1971). *Podocarpus latifolius* forest, which develops in protected habitats in the Montane Belt in the Natal Drakensberg, does not occur in Lesotho. Fire and human exploitation may have limited the development of forest in the Montane Belt of Lesotho to some extent but there is no evidence that forests were ever widespread (Martin 1986).

Acocks (1975) classified the high-lying vegetation of the Lesotho mountains as *Themeda-Festuca* Alpine Veld (veld type no. 58) and that occurring in the lower river valleys as the southern variation of *Cymbopogon-Themeda* Veld (veld type no. 48) (Table 3.1). Had Acocks visited Lesotho he might have classified the vegetation as *Merxmuellera-Themeda* Veld rather than *Themeda-Festuca* veld because *Merxmuellera disticha*, rather than *Festuca caprina*, is the dominant grass at high elevations (Herbst & Roberts 1974b; Morris *et al.* 1989). Acocks (1975) also warned of the loss of extensive areas of valuable rangeland to Karroid False Fynbos (i.e. *sehalahala*).

3.2.2 Quantitative studies

A quantitative survey of the vegetation of the mountains was conducted by Herbst and Roberts in the Tsehlanyane valley of the Oxbow area, an important catchment of the Malibamatso river (Herbst 1971; Roberts 1971; Herbst & Roberts 1974a & 1974b). Their study area (6 600 ha) extended from 2 590 - 3 050 m a.s.l. and

included parts of both the Subalpine and Alpine Belts. Species composition was recorded in 102 plots using a wheel-point apparatus (Tidmarsh & Havenga 1955). In their analyses they examined the relationships between cover components (plant basal cover, litter, bare soil, rock & dung), soil chemical characteristics and physiographic factors (altitude, slope & aspect).

A total of 126 species were collected in the survey, with 80 species being recorded in the sample plots. They noted that the alpha diversity (i.e. the number of species encountered at a site) was relatively low compared to grasslands elsewhere in southern Africa. Grasses comprised *c.* 65% of the vegetative cover, with only 10 species contributing over 70% of the total grass cover. Most grasses were of temperate affinity, with the exception of *T. triandra*, *H. falx* and *Eragrostis caesia*. *Tristachya leucothrix* and *Trachypogon spicatus*, which occur at similar altitudes in the Natal Drakensberg (Killick 1963), were absent from the sward in Tsehlanyane. Sclerophyllous fynbos shrubs, especially *Erica* spp., were common at high altitudes. Mean plant basal cover in the Tsehlanyane catchment was 29% and did not vary significantly over the landscape. The catchment was considered to be in good condition in terms of vegetative cover and species composition in spite of a history of continuous grazing during summer.

Wieland (1982) classified the vegetation of the Molumong area (20 km south-west of Mokhotlong), an area he considered to be similar in landform, vegetation and land-use to other areas in the Mountain Province. A total of 46 sample plots were surveyed using microplots (Tiedeman & Wieland 1983) to obtain estimates of the relative proportion of cover components as well as species frequencies. The data were sorted into an association table displaying vegetation communities that had a consistent association with particular soil and climatic conditions.

Wieland (1982) identified three vegetation zones occurring at Molumong (Table 3.1). At high altitudes, within the Alpine Belt, slopes were dominated by *M. disticha* and *F. caprina*, whereas *M. drakensbergensis* formed dense stands in seepage zones and along stream banks. The sward in the Subalpine and Montane

Belts comprised mainly subtropical grasses such as *T. triandra*, *H. falx* and *Cymbopogon plurinodis*. *Eragrostis* and *Aristida* species occurred on shallow soils in the Montane Belt. Vegetation degradation and accelerated soil erosion that was observed in the area was attributed to overstocking, which was estimated to be as high as 77%.

A National Range Inventory was conducted in Lesotho from 1983 to 1986 by the Division of Range Management of the Government of Lesotho (Martin 1984a). It was the first detailed range inventory for the country as a whole. The objectives of the inventory were to provide the following (Martin 1984a):

1. a classification of the various plant communities and associated environments;
2. a map of ecologically significant units;
3. an estimate of forage production for each unit; and
4. management plans for the national range based upon sound ecological principles.

Satellite imagery (Landsat) was initially used to define the major ecological units of the country and these were mapped by Martin (1984b) at a scale of 1:250 000. During the subsequent reconnaissance phase, species composition data were collected from as many of the major ecological units as possible. Ratings of species importance, based on a visual estimate of canopy cover and prominence, were obtained from relevès (i.e. plotless samples) within each major ecological unit. The composition data were then manually sorted into vegetation communities which appeared to be consistently associated with particular habitats. These were termed 'ecological sites' and were mapped in the field, with the assistance of aerial photographs, at a scale of 1:50 000 (Martin & Ntale 1984).

In the third phase of the National Range Inventory numerical species composition data were collected to provide a baseline for long term monitoring of vegetation condition and trend (Hickey 1986). Relative species abundance (by crown cover)

and total standing herbage were estimated in metric belt transects (Schmutz *et al.* 1982) on selected ecological sites. Floristically similar ecological sites were grouped together into 12 vegetation types (Range Management Division n.d.). These are listed below.

1.   *Hyparrhenia* & *Cymbopogon* and associated species.
2.   *Eragrostis* & *Aristida* species.
3.   *Themeda triandra* & *Elionurus muticus*.
4.   *Festuca caprina* and other grasslands.
5.   *Chrysocoma* & *Artemisia* species.
6.   *Leucosidea sericea* mixed shrub complex.
7.   *Rhus* and other bush species.
8.   *Merxmuellera* species.
9.   Land with limited vegetation, shallow soil and rockland.
10.   Residential area.
11.   Cultivated fields and forests.
12.   Natural waters and boglands.

Martin (1986) classified the 1 546 plots surveyed during the reconnaissance phase of the National Range Inventory into 68 community types using PHYTOTAB (Westfall & Dednam 1981), an agglomerative computer classification technique. Representative stands from each community type were then ordinated using Detrended Correspondence Analysis (Hill 1979a) in order to examine relationships between gradients in species composition and the environment. Spatial gradients in composition appeared to be related to altitude and rainfall gradients and, in certain cases, disturbance. However, no statistical tests were employed to test the relationship between environmental variables and composition gradients.

Ordination and classification were also used by Morris *et al.* (1989) to examine vegetation-environment relationships in the eastern mountain catchments (i.e. Study Area 1). Species composition data were collected in 136 plots (30 x 30 m) using the nearest-plant, point technique (Foran *et al.* 1978), with 200 points

recorded per plot. Altitude and aspect were identified as the two primary determinants of vegetation pattern. Classification via Two-way Indicator Species Analysis (TWINSPAN; Hill 1979b) resulted in the identification of four main vegetation communities that were separated on the basis of altitude. Altitude boundaries between vegetation communities varied according to aspect and were generally lower on southerly slopes than on northern aspects. The four vegetation communities are listed below.

1. *Helichrysum/Erica* heathland and temperate grassland (mean altitude of 3 020 m);

2. *Festuca caprina/Merxmuellera disticha* temperate grassland (mean altitude of 2 960 m);

3. *Themeda triandra/Festuca caprina/Harpochloa falx* mixed grassland (mean altitude of 2 890 m); and

4. *Chrysocoma ciliata/Pentzia cooperi* dwarf shrubland (mean altitude of 2 750 m).

No quantitative phytosociological surveys have been undertaken in Study Area 2. Meakins *et al.* (1988) listed the species encountered at 18 sites in the Phase IA area. They recommended that the wetland of the upper Bokong basin as well as the adjacent cliff area be declared a nature reserve in order to protect the Bearded Vulture (Lammergeier - *Gypaetus barbatus*) as well as species of *Rhodohypoxis* growing on moist gravel patches adjacent to the wetland. A LHDA report (Jenkins 1990) assessed the present and possible future impact of works within the Phase IA area on the vegetation. The report concluded that there were no rare or endangered plant species occurring within the Phase IA area.

Recently, Mokuku (1992) conducted a survey of the vegetation of the upper Bokong basin at Mafika-Lisiu, which is adjacent to the north-west corner of Study Area 2. His study area comprised 3 000 ha at an altitude of between 2 900 m and 3 125 m, i.e. in the Alpine Belt. Species frequency, density and cover were measured in 30 transects using quadrats and the nearest-plant technique (Foran

et al. 1978). Vegetation patterns were examined using ordination and classification.

Mokuku (1992) concluded that the species composition gradients in the area were not related to any single environmental factor but rather to a complex environmental gradient running downslope; from xeric sites on the rocky mountain summits through to the moist soils in bottomland positions. Soil depth, soil organic matter content and soil moisture were measurable components of this gradient. Vegetation pattern was unrelated to soil nutrient status. It was noted that heavy grazing pressure at Mafika-Lisiu during the summer had resulted in a marked deterioration in the hydrologic and floristic condition of the Bokong wetland. Mokuku also recommended that grazing should be disallowed on the mountain summits due to their inherent fragility.

3.3 The dynamics of the vegetation under different disturbance regimes

Grazing by domestic livestock and fire are the two major man-induced disturbance factors in the mountain rangelands of Lesotho (Staples & Hudson 1938; Phororo 1979; Limbach 1986; Morris *et al.* 1989). The nature and the effects of these impacts are discussed below. Other anthropogenic impacts on the vegetation include: cultivation; cutting of grass for thatch; harvesting of woody shrubs for fuelwood; and gathering of a variety of plants for medicinal and other uses (Shoup 1987).

The effects of cultivation on the vegetation are clear. Cultivation reduces the extent of grazing land, thereby increasing stocking rates on the range (Schmitz 1984; Weaver 1987). However, this may have little effect on the overall carrying capacity of the area as crop stover from cultivated areas is a source of forage for livestock during winter (Makhanya 1979). Cultivation of marginal areas in the mountains (*viz.* on steep slopes and/or on shallow soils) leads to accelerated soil erosion (Anon. 1989), especially if maize is grown rather than wheat because maize provides little protective cover for the soil (Staples & Hudson 1938). The potential for erosion on cropland is exacerbated by the removal, through grazing,

of the protective cover provided by crop stover (Darkoh 1984). The organic matter content of cropland soils is also reduced through grazing of crop residues and the removal of dung for fuel (Anon. 1989). As a result of declining fertility, increased erosion and occasional severe droughts, crop yields in the mountains have declined since the 1970s and most farmers are now unable to meet their own subsistence needs through cropping (Anon. 1989). The long-term sustainability of cultivation in marginal areas in the mountains is questionable (Anon. 1993).

The impact of harvesting of plant resources for fuel or other purposes is difficult to assess. Shrubs such as *C. ciliata*, *H. trilineatum* and *P. cooperi*, are the only source of fuel in the mountains, apart from dried manure. Harvesting of invasive shrubs by hand-pulling has been demonstrated to be an effective means of reducing shrub density in shrub infested areas (Beckman 1977; Tiedeman *et al*. 1983). However, the overall effect on shrub populations of regular harvesting for fuelwood has not been quantified. Also unknown, is the extent of the threat to wild populations of plant species that are gathered regularly for medicinal or ceremonial purposes. An example of a plant species that has become endangered by indiscriminate collection is *Aloe polyphylla*, which now exists only in a few isolated communities in the mountains (Schmitz 1982; Jenkins 1990).

3.3.1 The impact of livestock

The majority of ecological studies conducted in Lesotho have reported that the vegetation in many areas of the mountains has been modified by livestock (e.g. Wieland 1982; Tiedeman & Wieland 1983; Martin 1984a; Morris *et al*. 1989). Overstocking and uncontrolled grazing has reportedly led to the replacement of palatable and productive grass species by less palatable grasses, unpalatable herbs and shrubs (Schmitz 1984; Limbach 1986; Morris *et al*. 1989). These changes were usually accompanied by a denudation of herbaceous cover, resulting in accelerated soil erosion. Overgrazing has been cited as the main cause of accelerated erosion on rangeland and adjacent croplands (Darkoh 1984; Anon. 1989). It has been estimated that erosion rates are extremely high on 60% of the mountain slopes (>27 tons ha^{-1}) and that only 27% of the area is not undergoing

accelerated erosion (Anon. 1989). It has repeatedly been imputed that traditional land tenure and pastoral practices are responsible for vegetation degradation in the mountains and it has been recommended that the traditional pastoral system needs to be amended in order to halt the degradation of the soil-plant continuum (Sayce 1924; Staples & Hudson 1938; Darkoh 1984; Martin 1984a; Tiedeman 1985; Anon. 1990b; Anon. 1990c; Bainbridge et al. 1991).

The effects of grazing and trampling of livestock on the composition and cover of vegetation are examined in detail in a later chapter (Chapter 6). However, the ecological effects of the impact of livestock cannot be examined in isolation from the socio-economic context and it is necessary to clearly understand the complexities of the mountain pastoral system when considering the influence of livestock on the mountain ecosystem.

The nature and the extent of the impact of livestock in the mountains is determined by the prevailing livestock management system. Stock numbers, stock movement and local grazing patterns are determined by a suite of factors including national and international economic forces, social customs, tribal and national laws and ecological considerations (Quinlan & Morris in prep). There are certain features of the traditional pastoral system that make it unique, at least in southern Africa. A brief description of the characteristics of the grazing system in Lesotho follows, derived from reports by Phororo (1979), Dobb (1985b), Quinlan & Matobo (1989), Anon. (1990b), Motsamai (1991), and Quinlan & Morris (in prep).

3.3.1.1.   The livestock economy

Livestock play a fundamental role in the socio-economy of the Basotho, both in the Lowlands and in the Mountains. More than half of all households in Lesotho own some livestock and in the Mountains, over 75% of households are stockowners (Schmitz 1984; Anon. 1990c). Grazing livestock include cattle, merino sheep, angora goats, horses, donkeys and mules. Smallstock (sheep & goats) constitute over 85% of the stock in the Mountains, the majority of which are sheep (almost 60% of all livestock) (Schmitz 1984; Anon 1990b). There has been in increase in

the ratio of goats to sheep since national independence in 1966, most likely in response to an increase of the price of mohair relative to wool (Hunter 1987). There are twice as many cattle in the Mountains as there are donkeys, horses and mules (Schmitz 1984).

Cattle are indispensable for draught in the mountains and provide milk, meat and dung for fuel. They also are a 'store of wealth' (Doran *et al.* 1979) for occasions when cash is needed for purchases or school fees . Therefore, cattle can be seen as form of savings, providing a hedge against inflation. Smallstock, apart from providing a cash income through the sale of wool, mohair and animals, are also a source of hides and skins as well as providing some meat and milk for herders at cattleposts. Horses are a means of transport in the mountains, where roads are few and generally poor. Donkeys and mules are used to transport food, supplies and building materials. Animal products such as hides and fleeces as well as various animal organs are utilized by the community for ceremonial and other purposes. The benefits derived from livestock and their products cannot easily be replaced by a cash economy.

Apart from their contribution to the subsistence needs of the Basotho, livestock play an important role in the economy of Lesotho. Although Lesotho's economy is mostly dependent on wage remittances from the Republic of South Africa, livestock enterprises contribute significantly to the national income (*c.* 23% of Gross Domestic Product in 1986; Hunter 1987) and comprise up to 40% of export earnings (Anon. 1990c). The largest share of export revenue is derived from the sale of wool and mohair which comprise 75% of domestically generated cash income (Lawry 1986b; Swallow & Brokken 1987). Historically, Lesotho was known for the quality of its wool and mohair clip. However, there has been a decline in fleece quality and yield (per animal) since the 1960s (Anon. 1990c). Average fleece yields in Lesotho (i.e. 2.4 kg animal^{-1} for sheep & 0.7 kg animal^{-1} for goats) are substantially lower than average yields in South Africa (Hunter 1987). Poor productivity has been blamed on poor breeding and animal husbandry practices, a neglect of culling as well as on poor nutrition from overgrazed

rangelands (Hunter 1987; Anon. 1990c). Offtake of cattle for slaughter through formal channels is also low (0.56% of the national herd) and Lesotho is a net importer of livestock for meat (Meyers *et al.* 1987; Anon 1990c).

3.3.1.2   Livestock ownership

Livestock ownership in Lesotho is skewed in that a few livestock owners own the majority of the stock and the majority of stockowners have small livestock holdings. Half of the nations' cattle, sheep and goats are owned by 10.9%, 2.1% and 3.8% of the total farm households in Lesotho, respectively (LASA 1982). Most livestock owning households in the mountains have small herds and flocks, as indicated by a survey of livestock ownership in an area east of the Malibamatso river (14 000 ha) in Study Area 2 (Artz 1992) (Table 3.2). Similar livestock ownership profiles have been reported from other areas in Lesotho (Dobb 1985b; Lawry 1986b; Shoup 1987; Quinlan & Matobo 1989; Tshabalala & Turner 1989; Buzzard & Ntlale 1991). The recent trend in the mountains is towards increased concentration of sheep and goat ownership and an increase in the average flock size, which may indicate increased commercialization of smallstock production (Hunter 1987). Large sheep and goat herds are not merely maintained for status as a 'sign of wealth' (Darkoh 1984), but rather for commercial purposes (Hunter 1987).

Although livestock ownership in the mountains is unevenly distributed, various customs and practices ensure that the benefits of livestock are distributed widely throughout the community. One of these customs is the common practice of *mafisa*. *Mafisa* is the practice whereby a stockowner loans livestock on a long-term basis to another member of the community. During the period of the loan the borrower has rights to the products of the livestock (milk, wool or mohair) as well as use of any *mafisa'd* cattle for draught. Products from any animals that die by accident are also available to the borrower. In return, the stockowner obtains free herding for his stock. On completion of the loan, all stock plus their offspring are returned to their owner. This practice serves to make livestock accessible to a wide spectrum of the community and enables stockowners to overcome labour

Table 3.2   The frequency distribution of livestock ownership by animal type and holding-size in an area east of the Malibamatso river in Lesotho (after Artz 1992).

Animal type	Animals		Households	
	%	Cum. %	%	Cum. %
Cattle (n = 891)				
0 head	0	0	33	33
1-5 head	22	22	34	67
6-25 head	65	87	31	98
26-75 head	14	100	2	100
Sheep (n = 4687)				
0 head	0	0	55	55
1-5 head	1	1	10	65
6-25 head	12	13	21	86
26-75 head	9	22	6	92
75-150 head	17	39	4	96
>150 head	61	100	4	100
Goats (n = 1430)				
0 head	0	0	64	64
1-5 head	5	5	12	76
6-25 head	26	31	16	92
26-75 head	36	67	6	98
76-150 head	16	83	1	99
>150 head	18	100	1	100
Horses/donkeys/ mules (n = 404)				
0 head	0	0	38	38
1-5 head	60	60	53	91
6-25 head	34	94	8	99
26-75 head	7	100	1	100
Total (n = 7412)				
0 head	0	0	21	21
1-5 head	1	1	21	42
6-25 head	10	11	29	71
26-75 head	19	30	19	90
76-150 head	7	37	3	93
>150 head	62	100	7	100

constraints. It is estimated that 20% of livestock owning households in Lesotho are involved in *mafisa* arrangements and that 25% of households not owning livestock, have *mafisa* stock (Phororo 1979). Sharing of tillage equipment, labour, as well as draught animals is also a common practice in the mountains. Livestock of various sorts are still used to pay *labolla* (bride price), although cash is increasingly being used as part of the payment.

All livestock owners, whether they are commercial or subsistence farmers, seek access to grazing to support their stock. Therefore, the land tenure arrangements that operate in the mountains have been developed to facilitate equitable access to rangeland and other natural resources.

3.3.1.3   Communal range use
No land is privately owned in Lesotho but all land "belongs to the King in trust for the Nation" (Makhanya 1979). Under Basotho law every married male has the right to be allocated a portion of arable land in the area where he resides for his exclusive use (Sheddick 1954). Following the harvest of crops, all fields, excluding vegetable gardens, are declared open to the community and livestock can graze crop residues left on the land. The administration of land is vested in Land Allocation Committees which are chaired by chiefs.

Rangeland, unlike arable lands, is common property and there are no individual rights to rangeland, although there may be some area and time restrictions on grazing (Ashton 1967). Rangelands in the vicinity of villages are under the jurisdiction of village chiefs and are reserved for the use of local residents. Rangelands further away from the villages are under the jurisdiction of the a Ward or Principal chief who allocates rights to establish cattleposts in his or her area. A cattlepost (*motebong*) typically consists of a stone kraal (corral) for enclosing smallstock at night and a thatch-roofed stone hut for herders. Once allocated, cattlepost rights are inheritable. Cattleposts are sometimes shared by herds and flocks of a number of stockowners, each with their own herder.

In spring, when winter grazing in the villages is depleted and the snow in the high mountains has melted, herders drive livestock into the cattlepost grazing areas for the duration of the summer grazing period. They return again to the villages in autumn. This seasonal transhumance is a feature of the pastoral system in Lesotho.

3.3.1.4   Seasonal transhumance

Livestock are sent to the cattlepost areas during the summer, both to utilize the extensive mountain rangelands and to prevent the destruction of crops in the vicinity of villages by livestock. Livestock are usually overwintered in villages or in cattleposts close to the villages where the risk of stock deaths due to the weather is reduced. Crop stubble and village rangelands provide forage for the winter period.

Under customary law, only a few milk cows and work-oxen are permitted to remain in the village during summer. Grazing is prohibited on village rangelands during summer in order to conserve forage for the winter months as well as to protect other natural resources from grazing, e.g. thatch grass areas, reedbeds and woodlots. This practice of designating areas for rest to conserve vegetation is known as *leboella* ('spareveld') (Phororo 1979). Chiefs are empowered under the Range Management and Grazing Control Regulations (Legal Notice No. 39 of 1980) to impound livestock found in a *leboella* area and to impose fines. Grassland in the vicinity of cultivated lands are often in good condition and this has been attributed to the regular seasonal *leboella* imposed on them (Staples & Hudson 1938; Phororo 1979; Weaver 1987). In contrast, the vegetation in the summer cattlepost areas receives little relief from grazing during the growing season and is effectively continuously grazed for six months or more each year.

The timing of the commencement of stock movement from the village areas to the mountain cattleposts is set by the Principal Chief in consultation with the local chiefs and agricultural officer. The dates may vary between areas and are dictated, amongst other things, by the cessation of snowfalls in the mountains, the state of

regrowth of the range in the cattlepost areas and completion of tillage in the village croplands. Smallstock are sent to the cattleposts once lambs and kids have been born. Transhumance may begin as early as the end of September, under favourable conditions, but the median date is mid November (Quinlan & Matobo 1989). Peak stock numbers in the summer cattlepost areas are usually reached by the end of December. In autumn (April) cattle are brought back to the villages while smallstock remain in the summer cattlepost areas until the end of May or June. However, in certain valleys, sheep remain in the summer cattlepost areas throughout the year (Dobb 1985a). Horses, when not in use in the village, usually also stay in the summer cattlepost areas for the whole year.

The traditional pattern of seasonal transhumance in the mountains forms the basis of the grazing management plan developed for the Range Management Areas in Lesotho (Weaver 1987; Buzzard & Ntlale 1991). A Range Management Area (RMA) is an area that has been set aside for the exclusive use of residents within the area and is managed cooperatively under the guidance of the Division of Range Management (Weaver 1991). The RMA grazing management plan comprises a simple deferred rotation grazing system, where grazing in a particular area is deferred until its 'optimum' time of use (Weaver 1987). The rationale behind the system is to enforce seasonal *leboella* in order to maintain the vigour and productivity of the village and cattlepost rangelands.

The grazing management plan requires all livestock that are not needed in the villages during summer to vacate the village areas and move into the summer cattlepost areas by a particular date in spring. This date varies between the different RMAs and between years, according to the state of regrowth of the range in the summer cattlepost areas. Livestock are required to return to the villages in late autumn. The summer cattlepost areas may also be divided into two altitudinal regions which are utilized at different times during the growing season (e.g. in the Sehlabathebe RMA; Weaver 1987). The lower-lying grasslands, which are comprised mostly of subtropical grass species, are open for grazing during spring and summer and are rested during autumn to allow the accumulation of energy

reserves in the crown and roots of the grass plants (Tainton 1981b; Weaver 1987). The higher lying temperate grasslands are utilized in late summer and autumn. These grasslands receive a rest in spring and summer. Weaver and Sekoto (1991) reported that the implementation of the grazing management plan in the Sehlabathebe RMA had resulted in an improvement in the species composition of the range as well as an increase in vegetative cover (both crown and basal cover) and species diversity over a seven year period.

The transhumance system in the mountains has developed in response to the needs of the community and the particular characteristics of the mountain environment. However, today, traditional grazing systems are under stress due to increased population pressure in the mountains (Lawry 1988) and management options available to the traditional 'managers' of rangelands, i.e. the chiefs, are declining (Dahlberg 1988; Anon. 1993). Consequently, there is increased degradation of the natural resources in the region (Anon. 1990c) and new land-use practices are developing in response to increasing scarcity of resources. It is becoming common practice for stockowners to treat the crop stover from their fields as a private resource (Anon. 1990b; Motsamai 1991). Some farmers even remove the stover from the fields to feed their own livestock during winter (Artz 1993; Quinlan & Morris in prep). Cattleposts are increasingly being built in the zone between the villages and summer cattlepost areas for overwintering of livestock (Quinlan & Morris in prep). A general increase in stock numbers in the mountains coupled with a recent trend for families with small stock holdings to keep their animals in the village environs throughout the year has lead to a decline in the availability of winter forage in the village areas. In response, stockowners are building winter cattleposts to utilize the rangelands in the lower valleys between the high summer cattlepost area and the villages. The possible ecological consequences of this practice are discussed in Chapter 7.

3.3.1.5   Overstocking

It has frequently been reported that the rangelands of Lesotho are overstocked (Chapter 3.3.1.). Estimates of the degree of overstocking in Lesotho vary

considerably, from 30% to almost 300% (Dobb 1985b; Anon. 1990c). The initial estimate of overstocking arising from the National Range Inventory was pessimistic (i.e. 212%) and this was subsequently altered to account for a possible overestimation of stock numbers and a probable underestimate of forage production from the range (Anon 1990c). A figure of 50% overstocking for the country as a whole is currently quoted (Anon. 1990b; Anon. 1990c). Estimates of overstocking, which are based on the ratio of actual stock numbers per unit area (i.e stocking rate) to a perceived permissable level of stocking (i.e. carrying capacity), vary widely because of uncertainty surrounding the actual stocking rates in the mountains as well as the potential carrying capacity of the range.

3.3.1.5.1 Stocking rates

The actual stocking rate on the range is difficult to establish with any precision because livestock census figures in Lesotho are unreliable (LASA 1982; Dobb 1985b; Quinlan & Matobo 1989; Anon. 1990c). This imprecision is partly due to inconsistencies in the survey methodology used to census livestock (Dobb 1985b; Hunter 1987). The difficulties associated with trying to census livestock in rugged, inaccessible terrain as well as the reluctance of livestock owners to divulge their true livestock holdings also contribute to the variation in the data. Further, measurements of land area obtained from one dimensional maps for the calculation of stocking rates underestimate the true land area due to the convoluted nature of the terrain (Anon. 1990c).

The available livestock statistics indicate that the size of the national herd has remained fairly constant since the 1930s, with fluctuations around the long term average of 982 089 Large Stock Units[1] (LSU) (BOS 1986; Hunter 1987). This approximates to a nationwide stocking rate (on range and croplands) of 3.48 ha LSU^{-1}. Stocking rates are approximately twice as high in the Lowland districts than they are in the Mountains, although some seasonal transhumance does occur from

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[1] Conversion factors from animal numbers to Large Stock Units are: cattle 0.8; horses & mules 0.7; donkeys 0.5; and sheep & goats 0.2 (LASA 1978).

the Lowlands to the Mountains (Dobb 1985b). The carrying capacity of the Mountains is estimated to be higher than that of the Lowland areas, resulting in a greater degree of apparent overstocking in the Lowlands than in the Mountains (Dobb 1985b).

3.3.1.5.2. Carrying capacity

Estimates of overstocking in Lesotho vary because there is little consensus as to the carrying capacity of the rangelands (Dobb 1985b; Morris *et al*. 1989). Carrying capacity can be defined as "the potential of an area to support livestock through grazing and/or browsing and/or fodder production over an extended number of years without deterioration to the overall ecosystem" (Trollope *et al*. 1990 after Danckwerts 1981). Estimates of carrying capacity for the summer cattlepost areas (for a maximum of 6 months of grazing) range from between 0.167 to 0.250 Animal Units[2] (AU) ha^{-1} (4-6 ha AU^{-1}) (Wieland 1982; Tiedeman 1983a). Herbst and Roberts (1974a) estimated the carrying capacity of the Tsehlanyane valley (a summer cattlepost area) to be as high as 0.5-1.0 ha AU^{-1}, provided the area received a regular summer rest. The average carrying capacity of poor condition range as well as winter grazing areas (including croplands) is estimated to be *c.* 7 ha AU^{-1} (Phororo 1979; Wieland 1982; van der Geer 1984).

In order to establish the carrying capacity of an area the average productivity of the range (and any other forage sources) needs to be known as well as an estimate of the extent to which the vegetation can be utilized by herbivores without prejudicing the long-term productivity and stability of the range. However, the measurement of both parameters is difficult.

There are no reliable data on primary production for the different vegetation types in Lesotho (Morris *et al*. 1989). Estimates of production for the 12 vegetation

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[2] Conversion factors from animal numbers to Animal Units: cattle & horses 1.0; donkeys 0.8; and sheep & goats 0.2 (Range Management and Grazing Control Regulations 1980. Legal Notice no. 39 of 1980).

types identified by the National Range Inventory (Chapter 3.2.2.) were derived from a once-off measure of standing biomass (using metric belt transects) on range that was subject to grazing (Hickey 1986). Therefore, these data underestimate the total production over a full growing season (Morris *et al.* 1989; Anon. 1990c). The amount of useable forage in each metric belt transect, in each vegetation type, was obtained by multiplying the amount of forage available from each species in the transect by a 'proper use factor' (PUF) for each species (LCRD 1986a). The PUF assigned to a particular species is the allowable percentage use of the top-growth of the species which will supposedly not detrimentally affect its long-term vigour and persistence (Limbach 1986). Proper use factors are dependent on the relative palatability of species as well as the relative resilience of species under grazing (Weaver 1987). Proper use factors range from: 40-60 for 'Desirable' forage species (e.g. 50 for *T. triandra*); 30-40 for species of 'Intermediate' value (e.g. 40 for *E. caesia*); and 10-30 for 'Undesirable' grasses and shrubs (e.g. 15 for *M. drakensbergensis*) (Limbach 1986; Weaver 1987). These PUFs are merely estimates and are not based on empirical evidence.

In the calculation of stocking rates and carrying capacities, livestock numbers are usually expressed in terms of a standard animal unit to facilitate comparisons between different species and classes of animals. Both the Large Stock Unit (LSU) equivalent (LASA 1978) as well as the Animal Unit (AU) equivalent (LCRD 1986a) have been used in Lesotho. Although both the AU and LSU equivalent are based on comparisons with a 450 kg animal with a dry matter feed requirement of *c.* 2.75% of its body liveweight, the conversion factors for different livestock species differ between the two standards. For example, cattle and horses are considered to be equivalent to 1.0 AU (LCRD 1986a) whereas the conversion factors to LSUs for cattle and horses are 0.8 and 0.7, respectively (LASA 1978). This disparity makes comparisons between stocking rate and carrying capacity estimates difficult when they are based on the two different standards (Dobb 1985b; Quinlan 1994). Meissner (1989) considered the conversion factors used for the calculation of AUs and LSUs in Lesotho to be inappropriate for two reasons. First, the actual average liveweights of all species of livestock in Lesotho are significantly lower than those

implied in the conversion to AUs or LSUs. Second, the dry matter requirements of livestock in Lesotho have been overestimated because most livestock in Lesotho are at maintenance rather than productive levels. This is in keeping with the suggestion that the livestock population in Lesotho has equilibrated at a point known as the 'ecological carrying capacity' (Caughley 1976), where recruitment is balanced by mortality and nett production from the system is minimal (Dobb 1985b; Tiedeman 1983a & 1985; Anon. 1993).

3.3.1.5.3. Ecological versus economic carrying capacity

The ecological carrying capacity is the stocking rate at which the herbivore-plant system is at an equilibrium and there is no harvest from the system (Caughley 1976 & 1979). At ecological carrying capacity most of the forage produced by the range is used for the maintenance of the stock population, leaving few nutrients for production. In contrast, the economic carrying capacity is the stocking rate at which sustained offtake from the system is achieved. The stocking rate at the economic carrying capacity is low enough to ensure adequate reproduction and performance of the livestock population. Financial considerations, such as the relative costs of animals, land and labour as well as market prices for livestock products, will determine the exact position of the economic carrying capacity in a commercial livestock enterprise (Workman 1986). The economic carrying capacity, according to the Jones-Sandland model describing the relationship between animal performance and stocking rate (Jones & Sandland 1974), generally occurs at a stocking rate of about one half to one third of the stocking rate at which animal performance is zero (viz. the ecological carrying capacity) (Anon. 1993). The estimates of carrying capacity presented in Chapter 3.3.1.5.2 are all estimates of economic carrying capacity.

An equilibrium between livestock and the vegetation can arise in a system where the livestock are totally dependent on forage produced within the system (i.e. from range & croplands) and there is little or no live offtake or importation of animals into the system (Caughley 1976). Reproductive rates are dependent on forage availability and, in high-rainfall years, the livestock population will increase. The

population may then 'overshoot' the capacity of the forage base to support it, resulting in increased mortality and an eventual decline in the livestock population. This will bring respite to the range, allowing forage to accumulate again. The cycle will continue, with animal numbers oscillating around an equilibrium level. Range degradation will most likely also occur in response to increased stocking rates. Grazing-intolerant species will be replaced by grazing-tolerant species and vegetative cover may be denuded. These changes will also serve to limit the size of the livestock population. The position of the livestock-vegetation equilibrium may also shift over time in response to long-term climatic changes or as a result of accelerated soil erosion.

There is evidence to suggest that the rangelands of Lesotho are stocked at, or near, ecological carrying capacity (Dobb 1985b; Tiedeman 1983a & 1985). The size of the national herd has remained fairly constant since 1930 (Schmitz 1984; Tiedeman 1983a; Hunter 1987). Livestock productivity is low and annual death rates almost equal annual birth rates (Phororo 1979; Dobb 1985a; Lawry 1986b; Anon. 1990b). Poor nutrition, under inclement and stressful climatic conditions, combined with an unfavourable herd and flock structure (the male to female ratio is high) have resulted in low reproductive rates, high infant mortality and poor wool and mohair productivity (Anon. 1990b). The ecological carrying capacity is approximated by the current stocking rate, which for the whole of Lesotho is *c.* 3.5 ha LSU^{-1} (Anon. 1990c). Estimates of the ecological carrying capacity in the mountains range from 2.0 ha LSU^{-1} in the Katse local catchment (Anon. 1993) to 3.5 ha LSU^{-1} at Molumong (Wieland 1982).

It should be noted, however, that the concept of ecological carrying capacity may not be totally applicable to the livestock system in Lesotho for two reasons. First, the system in not 'closed' as in 'natural' wildlife situations - for which the concept of ecological carrying capacity was originally developed - and significant numbers of livestock (mainly cattle) are imported into Lesotho from South Africa (Meyers *et al. 1987)*. Second, it is contended that range degradation (in the form of changes in floristic composition) is continuing under the present stocking regime

(Anon. 1990c) and this is not consistent with the concept of a range/animal equilibrium. However, data from long-term monitoring programmes are not available to determine whether changes in range composition in Lesotho have equilibrated or are still continuing.

It is argued that the ecological carrying capacity is the logical stocking rate for traditional pastoral systems to operate at (Mentis 1984a; Tiedeman 1983a). According to the traditional pastoralism paradigm, the grazier is more concerned with maintaining sufficient animals on the range to maximise production of non-consumptive livestock products (i.e. draft, dung & milk) for subsistence purposes rather than maximising cash-flow through the sale of animals and animal products (e.g. meat & fibre) (Mentis 1984a; Behnke & Scoones 1993). The quantity of livestock rather than their quality is important (Tiedeman 1983a). To achieve their objective, traditional pastoralists run as many livestock as the range will carry, *viz.* the range is stocked at ecological carrying capacity. Maintenance of large herds and flocks has also been seen as an effective means of risk management in a capricious environment (Sandford 1983; Quinlan & Morris in prep). Under such conditions the grazier is seeking to guarantee a minimum level of production rather than an uncertain maximum (Brunschwing 1991). However, it is important to note that not all livestock owners in Lesotho are purely subsistence farmers and that the objective of a number of stockowners (mostly smallstock owners) is to maximise the economic performance of their herds and flocks (Hunter 1987). These commercial farmers would benefit if they could stock the range at a level below ecological carrying capacity. However, rangeland in Lesotho is common-property and the individual stockowner would not benefit if he or she alone destocks (Hardin 1968; Dobb 1985b).

According to theory (Caughley 1981), a system operating at ecological carrying capacity will be fairly stable and not prone to the sudden collapse that has been predicted (Darkoh 1984). Nevertheless, a gradual attrition of the soil resource is occurring in Lesotho under the present stocking regime (Anon. 1988; Anon. 1989) and the long term sustainability of the traditional livestock system has been

questioned (Anon. 1990c; Anon. 1993). A National Livestock Policy Implementation Plan was drawn up in 1990 by the Government of Lesotho to address the problems of range degradation and declining livestock productivity in Lesotho (Anon. 1990c; Motsamai 1991). The long-term goal (over 15 years) of the plan is to reduce livestock numbers to the carrying capacity of the range (i.e. the economic carrying capacity), while simultaneously increasing the carrying capacity of the rangeland through enhanced management. Livestock numbers will be reduced by a combination of a national culling programme, increased livestock marketing and the implementation of grazing fees. To compensate for decreased animal numbers an attempt will be made to increase the productivity of animals by improving animal management and breeding practices as well as through an animal exchange programme. The various options available for reducing stock numbers and enhancing range productivity will be discussed in Chapter 7.

3.3.2 Fire

It is generally believed that fire has been part of the mountain ecosystem ever since the climate included a dry season (Killick 1979). Before the advent of man in the area, fires were mainly ignited by lightning (Edwards 1984). Today, however, fires are largely initiated by man and may be more frequent than they were in the past (Jacot-Guillarmod 1971; Mentis et al. 1974; Anon. 1993). Descriptions in the literature attest to the prevalence of widespread fires in the mountains, especially during winter and early spring (Killick 1963; Jacot-Guillarmod 1971; Weaver 1987). Such fires apparently burnt for many days.

Although widespread fires have been reported to occur regularly along the Drakensberg escarpment and in the other areas of the Maluti, a lack of fuel as well as the broken nature of the topography will limit their extent, rate of spread and intensity (Morris et al. 1989). Livestock remove a large proportion of annual herbage production leaving little material available for fuel (Phororo 1979). Morris et al. (1989) estimated that sufficient herbage was present on the northerly slopes at Sani Top at the end of winter to carry a fire (viz. c. 2 000 kg ha^{-1}). However, this fuel, which comprised largely of the mat-forming grass H. falx, was situated

in a compact layer close to the ground and may not burn readily. Fuel loads are highest on southern slopes where the temperate species such as *F. caprina* and *M. disticha* form large tussocks if not defoliated regularly (Jacot-Guillarmod 1971).

Fire influences vegetation dynamics in the mountains (Killick 1963; Morris *et al.* 1989). The grasslands of the Maluti and Drakensberg have developed under fire and are considered to be fire-climax grasslands (Chapter 3.2.1; Killick 1963; Jacot-Guillarmod 1971). The role of fire in arresting vegetation succession in the Subalpine and Alpine grasslands of the Drakensberg and Maluti has been discussed by Killick (1963 & 1978b) and Edwards (1967). The climax community of the Alpine Belt, the *Erica-Helichrysum* heathland, is vulnerable to fire and occurs only in sites where a lack of herbaceous fuel limits the incidence and intensity of fires (e.g. boulder beds, rocky slopes and mountain summits). In contrast, many of the herbaceous plant species (especially grasses) occurring in the mountain grasslands are adapted to fire. Certain grasses, e.g. *T. triandra*, respond positively to periodic fires, which remove senescent material and stimulate tiller development (Everson & Tainton 1985). It has been shown that exclusion of fire from humid grasslands leads to a decline in the abundance of fire-tolerant grasses and their replacement by taller, coarser grass species and woody shrubs that are not adapted to fire (Killick 1963; Granger 1976; Everson & Tainton 1984). This change in species composition is accompanied by a decline in vegetation basal cover and an increased potential for soil erosion (Granger 1976).

Uncontrolled burning is seen as being detrimental to the mountain vegetation (Phororo 1979; Anon. 1989; Motsamai 1991). Herders often set fires in winter or early spring to initiate unseasonal growth in order to obtain fresh, nutritious forage for livestock (Jacot-Guillarmod 1971; Weaver 1987). This practice is seen as being particularly undesirable if burning is followed by prolonged, intense grazing (Tainton 1981a). Herders also often burn the large tufts of *M. drakensbergensis*, apparently to scare away predators from cattleposts and to warm themselves (Morris *et al.* 1989). This may result in severe localized erosion (Jacot-Guillarmod 1971). Current legislation in Lesotho prohibits unauthorized burning of grass in the

village and cattlepost areas in order to prevent untimely grazing of recently burnt range and to avoid valuable forage being destroyed by fire (Range Management and Grazing Control Regulations legal Notice No. 39 of 1980). Offenders are liable to a substantial fine. However, the legislation has proved impossible to enforce (Motsamai 1991).

Regular burning to remove residual material is not required in the village and cattlepost areas in the mountains as little of the current seasons growth remains at the end of winter. Where deferred grazing is applied (e.g. within an RMA) and excess herbage forage accumulates, then periodic burning may be needed to remove excess material and to maintain the vigour and productivity of the sward.

Fire has been proposed as a tool for the reclamation of areas, invaded by undesirable woody shrubs, to grassland (Staples & Hudson 1938; Beckman 1977; Phororo 1979; Morris *et al.* 1989). The wood of many fynbos and karroid dwarf shrubs (e.g. *Erica* spp., *H. trilineatum, Eumorphia sericia, Inulanthera thodei, C. ciliata & P. cooperi*) is resinous and will burn readily once ignited. Intense fire will kill these shrubs (Morris *et al.* 1989). Trials have been conducted at various places in Lesotho to evaluate the effectiveness of fire as a shrub control agent when used alone or in combination with other management practices (Staples & Hudson 1938; Beckman 1977; Tiedeman *et al.* 1983; Morris *et al.* 1989). In all of the trials, burning killed a large proportion of the shrub population. For example, at Sehlabathebe, an intense fire set in a shrub-infested area that had been rested the previous two years, resulted in a 91% mortality of *C. ciliata* shrubs (Morris *et al.* 1989). When examined a year after the burn, none of the dead *C. ciliata* plants had resprouted at the base. There was no evidence of a flush of shrub seedlings which has been observed to occur in *C. ciliata* shrubland in the Karoo after fire (Staples & Hudson 1938; Beckmann 1977).

In the above mentioned trials, treatment of shrub-infested areas with herbicides had varying success in reducing shrub density, with the non-hormonal herbicides (Tordon 155 & Roundup) being more effective than hormonal based herbicides

(Beckman 1977; Tiedeman *et al*. 1983). Hand-pulling also proved to be a sure, albeit extremely labour intensive, means of eradicating invasive shrubs. Resting to restore the competitiveness of the herbaceous layer also reduced shrub density (Beckman 1977; Tiedeman *et al*. 1983). However, a period of at least six years of complete rest would be required to reduce shrub densities to levels commensurate with those achieved by burning (Tiedeman *et al*. 1983). Thus, it appears that fire is the most cost effective means of shrub control in the mountains.

Pre-fire and post-fire management is important in order to maximise the effectiveness of the burn. Guidelines for the correct application of fire for shrub control and the required post-fire management are given in Tiedeman *et al*. (1983) and Morris *et al*. (1989). In *sehalahala* dominated shrublands the grass fuel may often be too thinly dispersed to carry a fire through the shrubland and the area may have to be rested for a period prior to burning to build up a sufficient fuel load for an intense fire (Staples & Hudson 1938). A cool fire may kill only the aerial portions of shrubs and coppicing will occur from buds in the crown of the plant. This was observed in Study Area 2 (Anon. 1993). Large tracts of *sehalahala* shrubland that had been burnt in uncontrolled fires appeared superficially to be dead, but on closer inspection, it was observed that there was extensive resprouting at the base of many plants.

Grazing should be disallowed for a period following the burn to allow the herbaceous layer to recover. The time period required will depend on the condition of the particular site. Thereafter, excessive grazing should be avoided as this will deplete the vigour of the sward and reduce vegetal cover, thereby facilitating the re-establishment and growth of invasive shrubs. Fire will be effective in controlling shrub populations only if the stocking rate in the area is permanently reduced (Tiedeman 1983a; Anon. 1993).

CHAPTER 4

GRADIENT ANALYSIS AND CLASSIFICATION OF THE VEGETATION

4.1   Introduction

Mountains are regions of extreme topographic and climatic heterogeneity (Barry & van Wie 1974). Large changes in altitude, aspect and slope angle can occur over short distances. This spatial heterogeneity is usually associated with considerable variation in the composition, structure and productivity of the mountain vegetation (Whittaker 1956 & 1960; Killick 1963; Beals 1969; Hamilton 1975; Baruch 1984; Cambell 1986). Such variations also occur in Lesotho, as described by Staples and Hudson (1938), who stated that "variations in the botanical composition, apart from those caused by overgrazing, which exist in the mountain pastures, were primarily due to climatic changes owing to the great range in elevation and differences in aspect."

The altitudinal range in mountains often exceeds the average range occupied by most species (Druitt *et al.* 1990) and distinctive vegetation 'belts' that are associated with a particular elevation zones are recognisable (e.g. Hedberg 1961; Killick 1963). Because of the large altitudinal range encompassed by the two study areas (almost 1.5 km) it is expected that floristic variation across the landscape would be considerable and that particular vegetation associations would be confined to specific elevation zones. In the present study, gradient analysis was employed to analyse and describe this variation and classification was used to provide a stratification of the vegetation for management and monitoring purposes.

Gradient analysis is the study of spatial patterns of vegetation in relation to underlying environmental gradients (Whittaker 1967). It was popularized by the studies of Whittaker in the Great Smoky Mountains of Tennesee (Whittaker 1956) and those of Curtis in the prairies and forests of Wisconson (Curtis & McIntosh 1951; Curtis 1959). However, the concept and methods of gradient analysis were

developed earlier this century by Gleason (1917; 1926) and Ramensky (1930, cited by Whittaker 1967).

The underlying principle of gradient analysis is that vegetation comprises a complex continuum of species populations that are arranged along environmental gradients according to the genetic structure, physiological characteristics and population dynamics of the individual species (Whittaker 1967). Because species differ in these characteristics no two species would have exactly the same distribution along the environmental gradients and vegetation communities (associations) would intergrade continuously across the landscape. This theory, known as the 'individualistic concept of the plant association' (Gleason 1926), was contrary to the dogma of the time concerning plant communities. The generally accepted theory at that time, which was later termed the 'community-unit theory' by Whittaker (1956), held that plant communities comprised distinct entities that were separated from each other in the landscape by sharp discontinuities in composition. These communities were understood to be products of a deterministic and predictable pathway of succession towards a mono-climax community (Clements 1916 & 1936).

Gradient analysis can be conducted in two ways. Sample sites and species can be arranged according to their relative position along measured environmental gradients. This is known as direct gradient analysis (DGA; Whittaker 1967). The environmental variables that are chosen for the analysis are those that are deemed to be important in controlling plant species distribution. Alternatively, samples (and species) can be arranged along axes of variation in floristic composition by various ordering (ordination) procedures (Whittaker 1978; Gauch 1982). These axes can then be interpreted in the light of the measured environmental gradients. Because the relationship between species gradients and environmental gradients is inferential and not direct, this type of analysis is known as indirect gradient analysis (IGA; Whittaker 1967).

The advantage of DGA lies in its explicitness (ter Braak 1987a). What is known

about the relationship between vegetation and the environment can be clearly expressed in an interpretable way (Whittaker 1967). However, preconceived ideas regarding the relationship between the vegetation and the environmental will influence the direction of investigation and the effects of unmeasured environmental variables cannot be accounted for (Whittaker 1967; Gauch 1982). In contrast, IGA techniques do not make *apriori* assumptions concerning the influence of environmental factors on community composition (Gauch 1982). The major directions (dimensions) of variation in the data may or may not be related to the measured abiotic gradients and IGA should indicate the relative importance of measured and unknown environmental factors in influencing species composition (Gauch 1982). Environmental factors that may have been overlooked in DGA may be identified as having some importance (ter Braak 1987a).

Vegetation pattern in the mountains was also examined using numerical classification. The aim of gradient analysis is to describe the floristic continuum in the landscape, whereas classification seeks to identify discontinuities in the data (Howard 1991). Classification, also known as cluster analysis, is the process whereby objects (sites and species) are placed into groups or classes according to their similarity (Gordon 1981). Its aim is to provide information on the co-occurrence of species and to establish community types for description and/or mapping (Greig-Smith 1980). A further goal may be to investigate relations between vegetation communities and the environment (van Tongeren 1987). Community types derived from classification are abstractions from the landscape pattern and they represent the 'colours' that man recognises in the vegetational spectrum (Brown & Curtis 1952).

Traditionally, classification and gradient analysis were regarded as being mutually exclusive approaches because they were perceived to represent the two schools of thought concerning the nature of vegetation pattern in the landscape, i.e. the community-unit and the individualistic hypotheses (Whittaker 1962, 1978; Kent & Ballard 1988). The vegetation continuum was regarded by many as being unclassifiable (McIntosh 1967; Whittaker 1967). Nowadays, however,

classification and gradient analysis (via ordination) are no longer regarded as completely separate exercises (Prentice 1980; Kent & Ballard 1988). Used together, they can reveal different aspects of pattern in the data (e.g. Martin 1986; Walker 1987; Morris *et al*. 1989; Burgess 1991; Mokuku 1992). Ordination can reveal clusters or discontinuities in the data whereas cluster analysis can usefully partition a multidimensional continuum (Greig-Smith 1980; van Tongeren 1987). Communication and comprehension is often easier when vegetation pattern is expressed in terms of a limited number of classes or community types rather than as floristic gradients.

In the present study the term 'community' is used to describe classified units, with the stated understanding that communities are part of the structure of the classification rather than integral 'organic' units (*sensu* Clements 1916) that are part of the structure of the vegetation.

4.1.1 Objectives
The following questions were addressed for both study areas.

1. What is the nature and the magnitude of the major floristic gradients in the area?
2. How are these floristic gradients related to the measured environmental variables?
3. What are the major vegetation community types?
4. Where do these vegetation communities occur in the landscape?

4.2 Methods
The procedure adopted to collect floristic data differed, in parts, between the two study areas because the specific objectives of the two programmes conducted in the two study areas (i.e the Drakensberg/Maluti Mountain Catchment Conservation Programme (D/MCCP) in Study Area 1 and the Baseline Biological Survey in Study Area 2) were different. In Study Area 2, a description of the vegetation as well as baseline data for a long-term monitoring programme were required. The D/MCCP

did not incorporate a monitoring programme. Therefore, the floristic data collected in Study Area 1 were only for descriptive purposes.

4.2.1 Data collection.

4.2.1.1 Study Area 1

1. Plant species composition was recorded in 88 plots located in the central and southern regions of the study area. Access was limited to the northern reaches of the study area. Therefore, the results presented in this study do not necessarily pertain to that region. A map showing the areas where sampling was undertaken is presented in Figure 4.1. Although the lower limit of Study Area 1 was defined as the 2 750 m contour (Bainbridge *et al.* 1991) sites were sampled down to an altitude of 2 625 m in order to include the full extent of the summer cattlepost area.

2. Plots were located on representative vegetation over the full range of altitude, aspect and landscape positions in the area. Ideally sites should be randomly located to ensure a representative and unbiased sample (Green 1979). However, obviously disturbed areas need to be avoided when sampling. Further, not all localities were accessible for sampling. Judgmental sampling is considered adequate for studies aimed at seeking broad patterns in vegetation (Crovello 1970; Barnett 1974; Whittaker 1978).

3. A plot size of 30 x 30 m (*c.* 0.1 ha) was used as a sampling unit. There are no clear guidelines as to the area that a sampling plot should encompass (Brockett & Holton 1986). However, a 30 x 30 m plot, which is the standard plot size used to sample grassland in southern Africa (Mentis 1984b), is considered large enough to include most of the local heterogeneity in a grassland and yet not too large to incorporate any extra variability that is associated with spatial environmental heterogeneity (Brockett & Holton 1986; Stalmans & Mentis 1993).

4. Plots were sited at three positions along a slope (Herbst & Roberts 1974a). These were mid-slope, lower-slope (within 200 m of the river) and upper-slope (within 200 m of the summit). Plots were located at a distance of at least 120 m from any cattlepost to avoid the influence of disturbance due to livestock concentration.

5. The nearest-plant method was used to record species composition within each plot (Foran *et al.* 1978). A metal spike was used to systematically locate 200 sampling points at 1 m intervals within each plot. At each point, the nearest rooted plant was identified to species level where possible. This technique is a modified form of the wheel-point (Tidmarsh & Havenga 1955) and step-point (Mentis 1981) methods and is an efficient means of quantifying proportional composition (Mentis 1981; Everson & Clarke 1987). Two hundred points have been shown to provide a sufficiently precise estimate of species composition in grassland for monitoring and descriptive purposes (Hardy & Walker 1991; Stalmans & Mentis 1993).

6. Plants with inflorescences were collected for identification by the Botanical Research Institute (BRI), Pretoria and the herbarium of the University of Natal, Pietermaritzburg. Species which were indistinguishable vegetatively were identified at the genus level (e.g. *Senecio* spp. & *Aristida* spp.). Nomenclature was according to Gibbs-Russell *et al.* (1985) and Gibbs-Russell *et al.* (1990).

7. Environmental data were collected at each site (Appendix 1). The following variables were recorded.
    1. Altitude - to the nearest 25 m - read from a topocadastral map.
    2. Aspect - compass bearing. These data were corrected for true north and then converted to a linear scale ranging from 0 to 180 degrees using the following conversion: aspect = aspect, for aspects up to 180°; and aspect = 360 - aspect, for aspects >180° (Walker 1987). This conversion was necessary for the employment of

correlation analysis, regression and other statistical procedures.

3.   Slope - measured in degrees using an Abney level.

4.   Visual surface features e.g. rockiness, permanent moisture, soil depth
        etc.

4.2.1.2   Study Area 2

Transects rather than plots were used as sampling units in Study Area 2. These transects were located parallel to the hillslope, running uphill from the foot of the slope to the summit. The reason that transects were placed parallel to the altitude gradient was to facilitate detection of floristic changes along an elevation gradient. According to previous studies in Lesotho (Chapter 3) altitude has a major influence on species composition in the mountains. Any programme designed to monitor temporal changes in composition also needs to take altitude into account because the intensity of grazing by livestock in the mountains varies with altitude (Morris *et al.* 1989).

The following sampling strategy was employed.

1.   Nine study areas were selected to encompass the geographical range within
        Study Area 2 (Figure 4.2). Village grazing as well as winter and summer
        cattlepost areas were included within the eight study areas. The area that
        is to be inundated by the Katse reservoir was not included in the survey.

2.   A total of fifty transects were located in Study Area 2. Transects were
        located on different aspects within each of the nine study areas. Where
        possible, transects were placed on opposite aspects within the same valley.
        Sampling was prohibited in certain valleys where male-initiation ceremonies
        were being conducted or where *Cannabis sativa* was being cultivated.

3.   Transects were permanently marked for monitoring purposes. Both ends of
        each transect were demarcated by painting embedded rocks with white
        paint. Various points along the transect were also marked with paint to
        facilitate resiting the transect. The positions of the transects were marked

on 1:20 000 colour aerial photographs (1989) and 1:50 000 topocadastral maps (nos: 2928AB; 2928AD; 2928BA; & 2928BC).

4.   Proportional species composition was measured in each transect using the nearest-plant technique (Chapter 4.2.1.1).   Points were placed systematically, at two metre intervals, along the full length of the transect. The total number of points in a transect was dependent on the length of the transect and ranged from 92 to 634 points (Appendix 2). The total of 11 050 point positions were recorded in Study Area 2, at an average of 221 points per transect.

5.   In addition to identifying the plant nearest to each point, the distance from the point to the base of the plant was measured in centimetres - rounded up to the nearest centimetre - using a metre rule. This was done to provide a measure of the amount of area unoccupied by plants - termed the 'bare area index' (BAI) - which is a function of the basal cover of the vegetation (Hardy & Tainton 1993). Average plant size, the other component of basal cover, cannot be easily determined in the grasslands of Lesotho as certain species (e.g. *Harpochloa falx*) are stoloniferous and do not form easily recognisable tufts.

The 'bare area index' was calculated for segments of transects (see Chapter 4.2.2) as the mean point-to-plant distance within each segment, with the distance values transformed to natural logarithms (In).   Logarithmic transformation (Rayner 1967) was used to reduce the bias introduced by the few large distances that were encountered in most transects.

6.   The environmental data collected at each transect were the same as those recorded in Study Area 1 (Appendix 2).
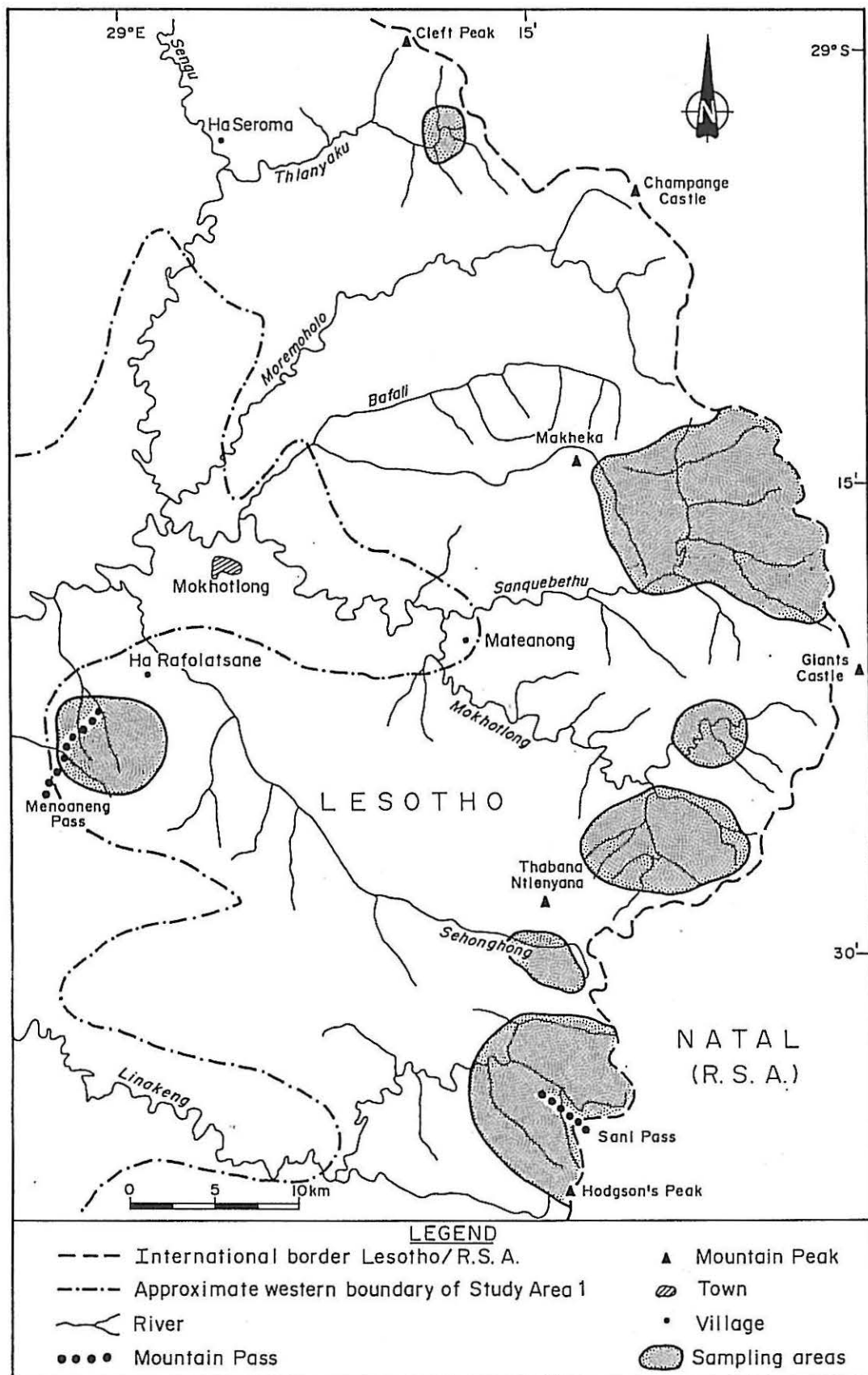
Figure 4.1   Areas where vegetation sampling was undertaken in Study Area 1, eastern Lesotho.
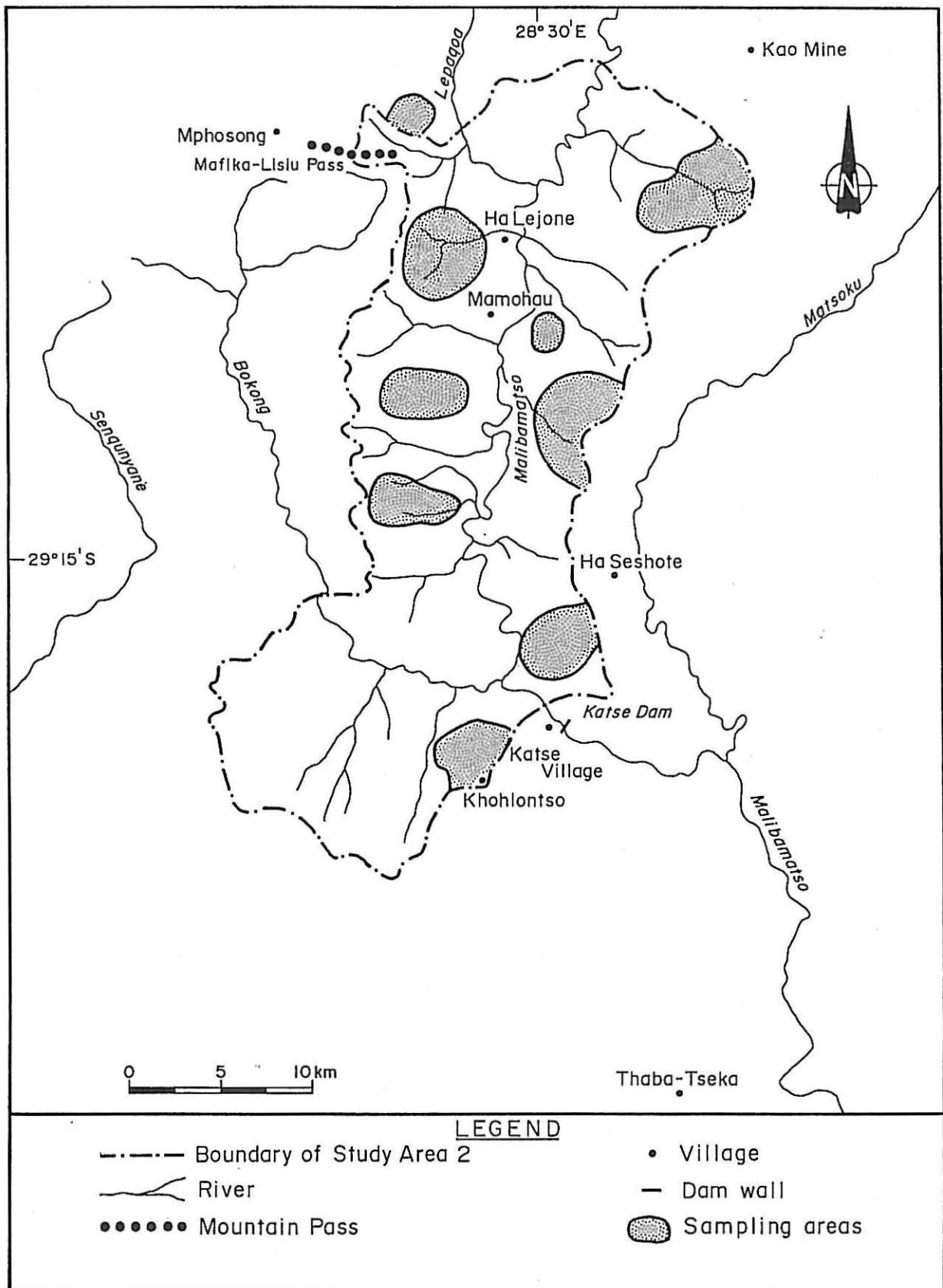
Figure 4.2   Areas where vegetation sampling was undertaken in Study Area 2, western Lesotho.

4.2.2 Data analysis

Proportional species composition, based on 200 points, was calculated for each of the 88 plots surveyed in Study Area 1. In Study Area 2, the transects were divided into successive overlapping data segments and proportional composition and BAI was calculated for each segment (Friedel & Blackmore 1988). Segments comprised 75 successive data points, overlapping adjacent segments by 50 points. The segmenting of transects into overlapping data 'windows' is a form of moving mean that enables the detection of composition changes along the elevation gradient. A total of 362 segments were used in the analyses. Species composition data in Study Area 2, based on 75 point segments, are less precise than those derived from 200 points in Study Area 1 (Everson *et al.* 1990). However, this lack of precision was compensated for by a large sample size that was distributed over a wide range of environmental conditions.

The analytical procedures employed in gradient analysis and classification of the species composition data from both study areas are outlined below.

4.2.2.1   Gradient analysis

Indirect Gradient analysis was conducted using ordination to extract the major gradients in community composition from the data. Ordination effectively reduces the variability in the data to a few dimensions (axes) of variability in order to graphically display the relationship between sample sites in terms of their species composition. In the resultant ordination diagram, sites that are similar in composition are plotted close together whereas sites that are very different are plotted far apart in ordination space. The similarity between species in terms of their distribution across the sample sites can also be displayed in the ordination plot in a similar way to that of the sites. Ordination does not provide a rigorous statistical test of the influence of environmental factors on species composition but rather an exploratory, hypothesis generating description of the relationship between vegetation pattern and the environment (Howard 1991).

Detrended Correspondence Analysis (DCA; Hill & Gauch 1980) was used via the

computer program DECORANA (Hill 1979a). Detrended Correspondence Analysis is an ordination technique that is a modification of Correspondence Analysis (CA). Correspondence analysis, which is usually achieved by the algorithm of Reciprocal Averaging (RA; Hill 1973; 1974), has two conspicuous faults. First, site scores along a particular ordination axis often show a quadratic relationship with those of the preceding axis, an effect known as the 'arch effect' (Hill & Gauch 1980). The arch effect is a mathematical artifact and does not represent real structure in the data. A second fault of CA is that the sites scores towards the ends of the ordination axes are compressed relative to those near the middle of the axes.

Detrended Correspondence Analysis employs certain mathematical manipulations to correct for the faults of CA (Hill & Gauch 1980). The arch effect is removed by a process known as detrending, whereby the first ordination axis is divided into a number of running segments and site scores on the second ordination axis, within each segment, are adjusted so that their mean on the second axis is zero. This is done for each subsequent pair of ordination axes. Nonlinear rescaling of site scores is employed to equalize the dispersion of site along ordination axes. Detrended Correspondence Analysis is also designed to cope with non-linear (i.e. Gaussian) species response curves (ter Braak 1987a).

It has been argued that detrending and rescaling may occasionally result in a loss of ecological information and a distortion of the underlying composition gradient (Minchen 1987; Wartenberg et al. 1987; Oksanen 1988; Howard 1991). However, in most cases DCA provides a clear and interpretable representation of the pattern within the data set (Gauch 1982; Peet et al. 1988).

The option for down-weighting rare species in DECORANA was chosen when performing DCA because species of low abundance and infrequent occurrence may unduly influence the ordination (ter Braak 1987a). Further, the abundance of rare species is measured with low precision when using the nearest-plant technique (Everson et al. 1990).

Rank correlation (Spearman's rank correlation) was employed to identify environmental factors that were associated with the ordination axes (Siegel 1956; ter Braak 1987a). Correlation does not necessarily indicate causality. However, it does serve to highlight those environmental variables that may be influencing vegetation pattern, directly or indirectly.

The photosynthetic pathway (C_3 or C_4) (Hatch & Slack 1970) of the grasses encountered in the survey was identified from the literature (Brown 1958; Ellis 1977) and the variation in the C_3/C_4 ratio between sites was correlated with ordination axes. The proportional mix of C_3 and C_4 grasses in the herbaceous layer is indicative of particular environmental conditions (Downton 1971; Vogel *et al.* 1978).

4.2.2.2   Classification

The species composition data were classified using Two-Way Indicator Species Analysis (TWINSPAN), a hierarchical, divisive classification procedure (Hill 1979b). The classification algorithm is divisive in that all sites are initially placed in a single group which is progressively divided into smaller classes. Classification is based on dichotomous division of the first axis of an RA ordination of the composition data followed by discriminant analysis to identify species that are useful for distinguishing between the two groups. These species are termed 'indicator species' (Hill 1979b). The process of ordination partitioning followed by indicator species identification is repeated for each group in the dichotomy in order to construct a hierarchical classification dendrogram.

The identification of indicator species in TWINSPAN is facilitated by transforming the quantitative species abundance data to a semi-quantitative measure of abundance. A number of 'pseudo-species' are defined for each species, based on predefined percentage cut levels, and the abundance of species are then recorded in terms of the presence or absence of pseudo-species. Percentage cut levels of 0, 2, 5, 10 and 20 were used for the definition of pseudo-species in the analysis. In the analysis, only the latter four pseudo-species were specified as being available

as indicator species and they were given twice the weight of the first pseudo-species. This was done in order to prevent the less abundant species from being used as indicators to describe the dichotomies and to minimise their influence in the classification procedure[1]. Hierarchical division was continued until groups had a membership of no less than 10 sites in order to ensure that groups were well represented in the field.

TWINSPAN is the most widely used classification procedure in the ecological discipline as it is robust and it provides an informative species and sites classification (Gauch & Whittaker 1981; Kent & Ballard 1988). The algorithm used in TWINSPAN is less computationally demanding than agglomerate cluster procedures like TABORD or PHYTOTAB (van der Maarel et al. 1978; Westfall & Dednam 1981), where sites are fused into progressively larger classes, finally resulting in a single group containing all sites. Both TWINSPAN and PHYTOTAB have been used to classify vegetation in Lesotho (Martin 1986; Morris et al. 1989; Mokuku 1992). However, what was lacking in these studies was a clear and objective interpretation of the classification in terms of the relationship between the identified vegetation communities and the environment. Vegetation classification has little practical value without an environmental interpretation (van Tongeren 1987; Fuls 1990).

In the present study, the relationship between vegetation communities and the measured environmental variables was investigated using two-group, linear discriminant analysis, performed at each dichotomy of the dendrogram (ter Braak 1982). The primary aim of these investigations was to describe the identified plant communities in terms of simple environmental parameters that could be easily identified on a map or in the field. Linear discriminant analysis involves the construction of a weighted linear function of environmental variables that best

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[1] In an earlier TWINSPAN analysis of floristic data from Study Area 1 (Morris et al. (1989)) all pseudo-species were specified as being available as indicators and given equal weight in the analysis.

predicts the dichotomy (Cooley & Lohnes 1971). It is a means of identifying those environmental variables that are most useful for differentiating between vegetation clusters (van Tongeren 1987). Discriminant analysis has been successfully used in ecology and other disciplines to interpret the results of a cluster analysis (e.g. Heyck & Klecka 1973; Sowell 1985; Cambell 1986).

An examination of the standardised coefficients (standardised to zero mean and a standard deviation of 1) of each environmental variable in the discriminant function facilitates an interpretation of the function, a process similar to the use of standardized variable weights in a multiple regression function (Montgomery & Peck 1982). The environmental variable that has the largest standardized coefficient in the discriminant function (irrespective of the sign of the coefficient) contributes most to differentiation along that function (Tabachnick & Fidell 1989).

Differences between identified vegetation communities in terms of the proportional representation of C_3 grasses and bare area index were tested using a Kruskall-Wallis test of group medians (Steel & Torrie 1981). Asymmetrical data distribution necessitated the use of a non-parametric procedure.

4.3 Results

The results of the classification of the vegetation of Study Area 1 have been published by Morris *et al.* (1993). Gradient analysis and classification of the vegetation in Study Area 2 is reported in Anon. (1993).

The total number of species encountered in plots in Study area 1 and transects in Study Area 2 was 98 and 132, respectively. A list of species names is presented in Appendix 3.

4.3.1 Gradient analysis

In an ordination solution the relative amount of variability (also termed inertia) incorporated in each axis is represented by the eigenvalue (Gauch 1982). The

eigenvalues for the first four DCA axes for both study areas are presented in Table 4.1. These eigenvalues can also be expressed as a proportion of the total variability in the data (calculated as the sum of the eigenvalues for all possible ordination axes[2]) to indicate the relative importance of each axis in representing pattern within the data set (Table 4.1).

The amount of species turnover along each ordination axis, termed 'beta diversity' (Whittaker 1960), is indicated by the range of site scores along the axis (Wilson & Mohler 1983; ter Braak 1987a). In DCA, axes lengths are expressed in multiples of 'standard deviation units' (Hill & Gauch 1980). An axis length of four standard deviation units represents one complete species turnover and, in such cases, sites on opposite ends of the axis will have no species in common. The lengths of the first four DCA axes for both study areas are presented in Table 4.1.

Beta diversity was large in both study areas (Table 4.1). There was more than a complete species turnover in Study Area 2 and just under a full species turnover in Study Area 1. This contrasts with the low beta diversity encountered by Walker (1988) and Hurt (1989) in the Highland Sourveld in Natal, who reported a species turnover along DCA axis 1 of 2.3 s.d. and <2.3 s.d., respectively. Topographic variation as well as livestock and human impacts contribute to the high beta diversity in the mountain grasslands of Lesotho.

In both study areas the eigenvalue of the first ordination axis was more than twice the magnitude of that of the second axis (Table 4.1). Axes 3 and 4 accounted for less than half the variability of the first two axes. Therefore, a plot of the species and site configurations in ordination space, defined by DCA axes 1 and 2, will provide an adequate representation of the predominant pattern in species composition in both study areas (Figures 4.3a & b; 4.4a & b).

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[2]The total number of ordination axes in a data set is equal to the number of species or sites, whichever is the smaller (Gauch 1982).

Table 4.1   Eigenvalues and gradient lengths (in standard deviations of species turnover (SD)) for each of the first four Detrended Correspondence Analysis (DCA) axes in Study area 1 and Study Area 2 in Lesotho.

	DCA Axis				Total inertia
	1	2	3	4	
Study Area 1					
Eigenvalue	0.522	0.266	0.193	0.130	3.830
Length (SD)	3.604	3.186	2.369	2.341	
Study Area 2					
Eigenvalue	0.597	0.212	0.149	0.111	3.852
Length (SD)	4.515	3.449	2.225	2.059	

Sites in Study Area 1 were distributed evenly across the ordination plot with no distinct grouping of sites (Figure 4.3b). In Study Area 2 there was a divergence in the ordination configuration towards the right-hand side of the ordination plot (Figure 4.4). Sites with high eigen scores along DCA axes 1 and 2 were dominated by *Catalepis gracilis* and *Monsonia brevirostrata*, with *Karoochloa purpurea*, *Polevansia rigida* and *Tetrachne dregei* occurring at low abundance (Figure 4.4a). *Cymbopogon plurinodis*, in association with *Hyparrhenia hirta*, *Heteropogon contortus* and *Elionurus muticus*, was dominant in sites forming the other branch in the ordination plot (Figure 4.4a).

In Study Area 1 there was a significant (P<0.001) negative correlation between site positions along the first ordination axis and altitude (Table 4.2). Sites positioned towards the left of the ordination plot were high altitude sites whereas the lower lying sites occurred towards the right-hand end of DCA axis 1. Aspect was also significantly correlated with axis 1 (P<0.01) and axis 3 (P<0.001). However, the correlations were weak. Axis 4 was weakly correlated with slope inclination (P<0.05). There were no significant correlations between environmental variables.
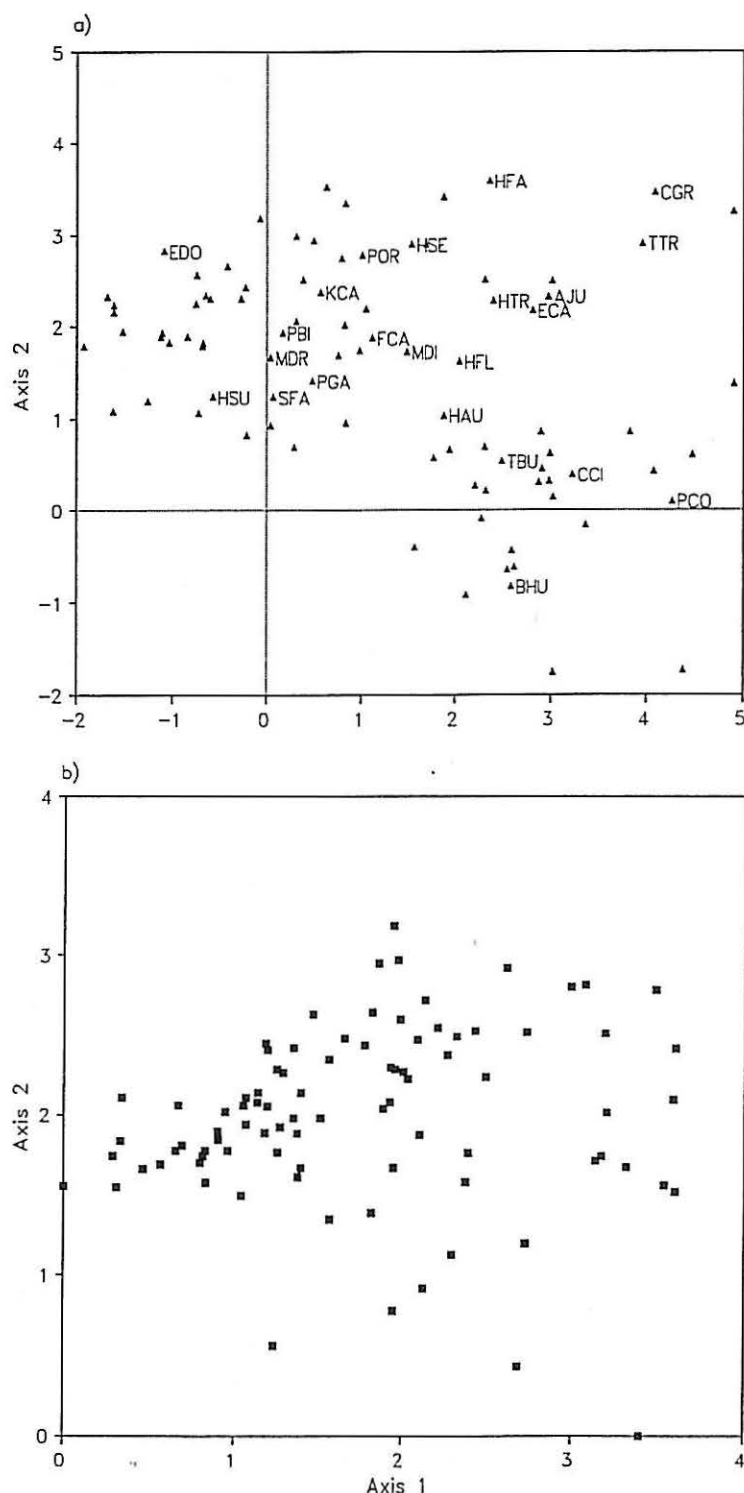
Figure 4.3   A plot of the position of species (a) and sites (b) in ordination space defined by the first two axes of a Detrended Correspondence Analysis of species composition data from Study Area 1 in eastern Lesotho. Only the more abundant species (i.e mean abundance > 1%) are labelled, as follows: AJU = *Aristida junciformis* subsp. *galpinii*; BHU = *Bulbostylis humilis*; CCI = *Chrysocoma ciliata*; CGR = *Catalepis gracilis*; ECA = *Eragrostis caesia*; EDO = *Erica dominans*; FCA = *Festuca caprina*; HAU = *Helichrysum aureum*; HFA = *Harpochloa falx*; HFL = *Helichrysum flanaganii*; HSE = *H. sessilioides*; HSU = *H. subglomeratum*; HTR = *H. trilineatum*; KCA = *Koeleria capensis*; MDI = *Merxmuellera disticha*; MDR = *M. drakensbergensis*; PBI = *Poa binata*; PCO = *Pentzia cooperi*; PGA = *Pentaschistis galpinii*; POR = *P. oreodoxa*; SFA = *Scirpus falsus*; TBU = *Trifolium burchellianum*; and TTR = *Themeda triandra*.
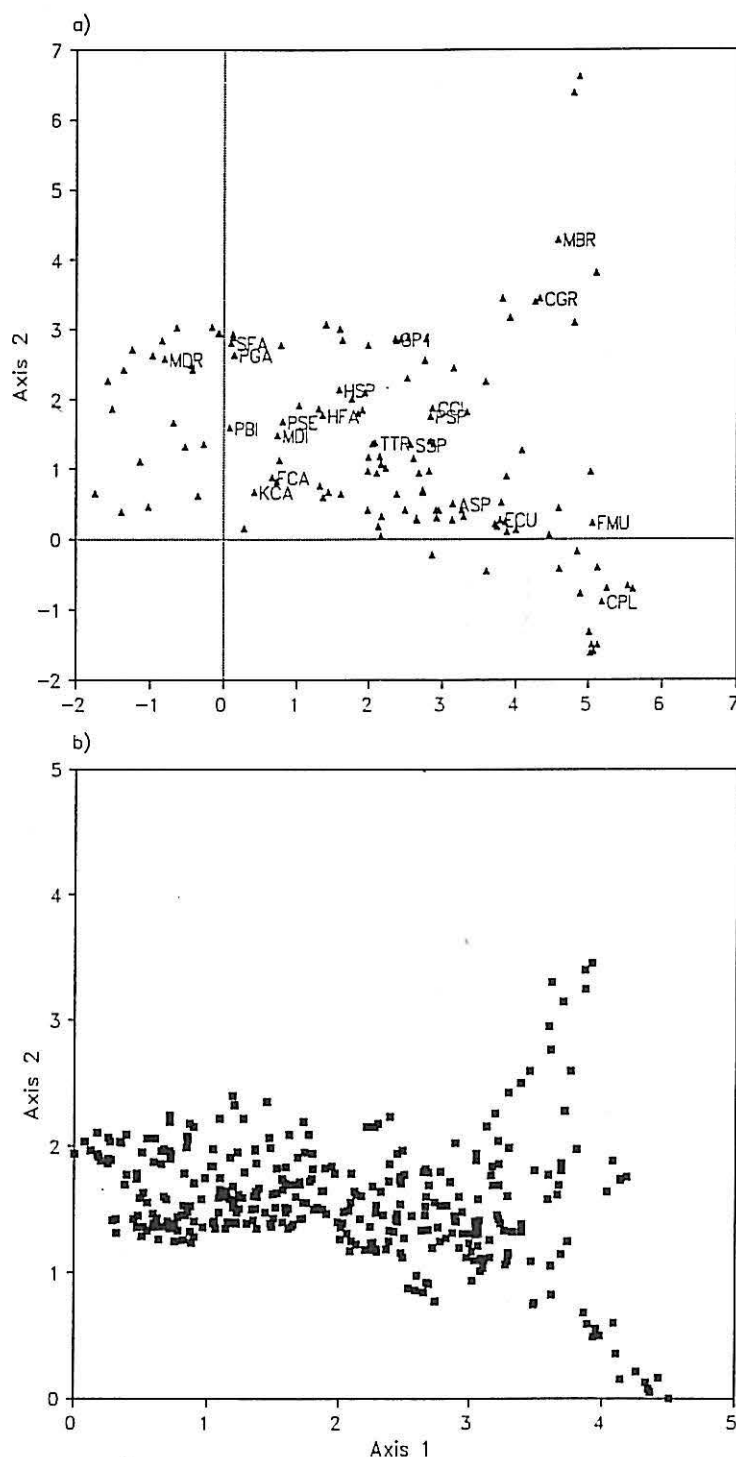
Figure 4.4 A plot of the position of species (a) and sites (b) in ordination space defined by the first two axes of a Detrended Correspondence Analysis of species composition data from Study Area 2 in western Lesotho. Only the more abundant species (i.e mean abundance >1%) are labelled, as follows: ASP = *Aristida* spp.; CCI = *Chrysocoma ciliata*; CGR = *Catalepis gracilis*; CPL = *Cymbopogon plurinodis*; ECU = *Eragrostis curvula*; FCA = *Festuca caprina*; FMU = *Felicia muricata* subsp. *muricata*; GP1 = {*Bulbostylis humilis, Crassula* spp., *Gymnopentzia bifurcata*, Sedge spp.}; HFA = *Harpochloa falx*; HSP = *Helichrysum* spp.; KCA = *Koeleria capensis*; MBR = *Monsonia brevirostrata*; MDI = *Merxmuellera disticha*; MDR = *M. drakensbergensis*; PBI = *Poa binata*; PGA = *Pentaschistis galpinii*; PSE = *P. setifolia*; PSP = *Pennisetum sphacelatum*; SFA = *Scirpus falsus*; SSP = *Senecio* spp.; and TTR = *Themeda triandra*.

Table 4.2   Correlations (Spearman's rank coefficient) between environmental variables measured at each site and the positions of sites along the first four axes of a Detrended Correspondence Analysis (DCA) of species composition data from Study Area 1, eastern Lesotho.

Variables	DCA Axis			
	1	2	3	4
Altitude	-0.633***	-0.163ns	-0.209ns	0.169ns
Aspect	-0.291**	0.107ns	0.508***	-0.041ns
Slope	0.153ns	-0.185ns	0.131ns	0.247*

ns   = non significant
*   = significant (P ≤ 0.05)
* *   = significant (P < 0.01)
* * *   = significant (P < 0.001)

In Study Area 2 a number of correlations between variables were statistically significant (Table 4.3). However, this may be largely due to the large sample size employed in the analysis (n = 362). Therefore, only moderate and strong correlations are worth consideration. Axis 1 was negatively correlated with altitude ($P < 0.001$) and aspect ($P < 0.001$). The high-lying sites on southerly aspects had the lowest eigen scores along axis 1. Altitude was also correlated with axis 2 ($P < 0.001$). Slope angle was not strongly correlated with any of the floristic gradients. Slope was positively correlated with aspect ($r = 0.481$; $P < 0.001$), *viz.* the southerly slopes were steeper than north-facing aspects. This is a consequence of asymmetrical geomorphological processes in the mountains (Chapter 2). There were moderate to weak correlations between BAI and Axis 1 ($P < 0.001$) as well as between altitude, aspect and BAI ($P < 0.001$). Cover tended to improve with increasing altitude and on cooler aspects (Table 4.3).

Table 4.3   Correlations (Spearman's rank coefficient) between environmental variables measured at each site and the positions of sites along the first four axes of a Detrended Correspondence Analysis (DCA) of species composition data from Study Area 2, western Lesotho.

Variables	DCA axis				Cover (BAI[1])
	1	2	3	4	
Altitude	-0.723***	0.509***	0.118*	-0.098ns	-0.284***
Aspect	-0.507***	-0.257***	0.415***	0.262***	-0.297***
Slope	-0.108*	-0.139**	0.117*	0.160**	-0.178***
BAI	0.478***	-0.036NS	-0.248***	-0.295***	

[1]BAI = 'bare area index' (see text for details)
ns   = non significant
*   = significant (P≤0.05)
**   = significant (P<0.01)
*** = significant (P<0.001)

The predominant floristic gradient (i.e. DCA axis 1) in both study areas was highly correlated (P<0.001) with the proportion of C_3 (temperate) grasses in the sward (Table 4.4).   Temperate grasses (e.g. *Merxmuellera, Festuca* & *Pentaschistis* species) dominated the sward in sites positioned towards the left of the ordination plots, whereas subtropical grasses (e.g. *Themeda triandra, Harpochloa falx, Aristida* & *Eragrostis* species) were more abundant in sites towards the right of the ordinations (Figures 4.3a & 4.4a).   The gradient from temperate to subtropical grasses was associated with a decline in altitude as well as a shift from south-facing aspects towards more northerly aspects (Table 4.4).

Table 4.4   The correlation (Spearman's rank coefficient) between floristic gradients (Detrended Correspondence Analysis (DCA) axes), environmental variables and the proportion of C_3 grasses at each site in Study Area 1 and Study Area 2 in Lesotho.

Variables	C_3 grass proportion	
	Study Area 1	Study Area 2
DCA axis 1	-0.877***	-0.948***
DCA axis 2	-0.389***	0.249***
DCA axis 3	0.263*	0.527***
DCA axis 4	-0.004ns	-0.088ns
Altitude	0.553***	0.667***
Aspect	0.361***	0.508***
Slope	-0.069ns	0.121*

ns   = non significant
*   = significant ($P \leq 0.05$)
**   = significant ($P < 0.01$)
*** = significant ($P < 0.001$)

4.3.2 Classification

4.3.2.1   Study Area 1

Hierarchical classification of the vegetation is presented in the form of a dendrogram in Figure 4.5. Division was continued until the third level resulting in the identification of five vegetation communities (numbered VC1 to VC5).

The mean abundance of the species in each of the five vegetation communities is presented in Table 4.5. The species are ordered in Table 4.5 according to their order in the two-way table produced by the TWINSPAN analysis. A table ordered in this way facilitates the identification of species that are limited in their distribution to a particular vegetation community.
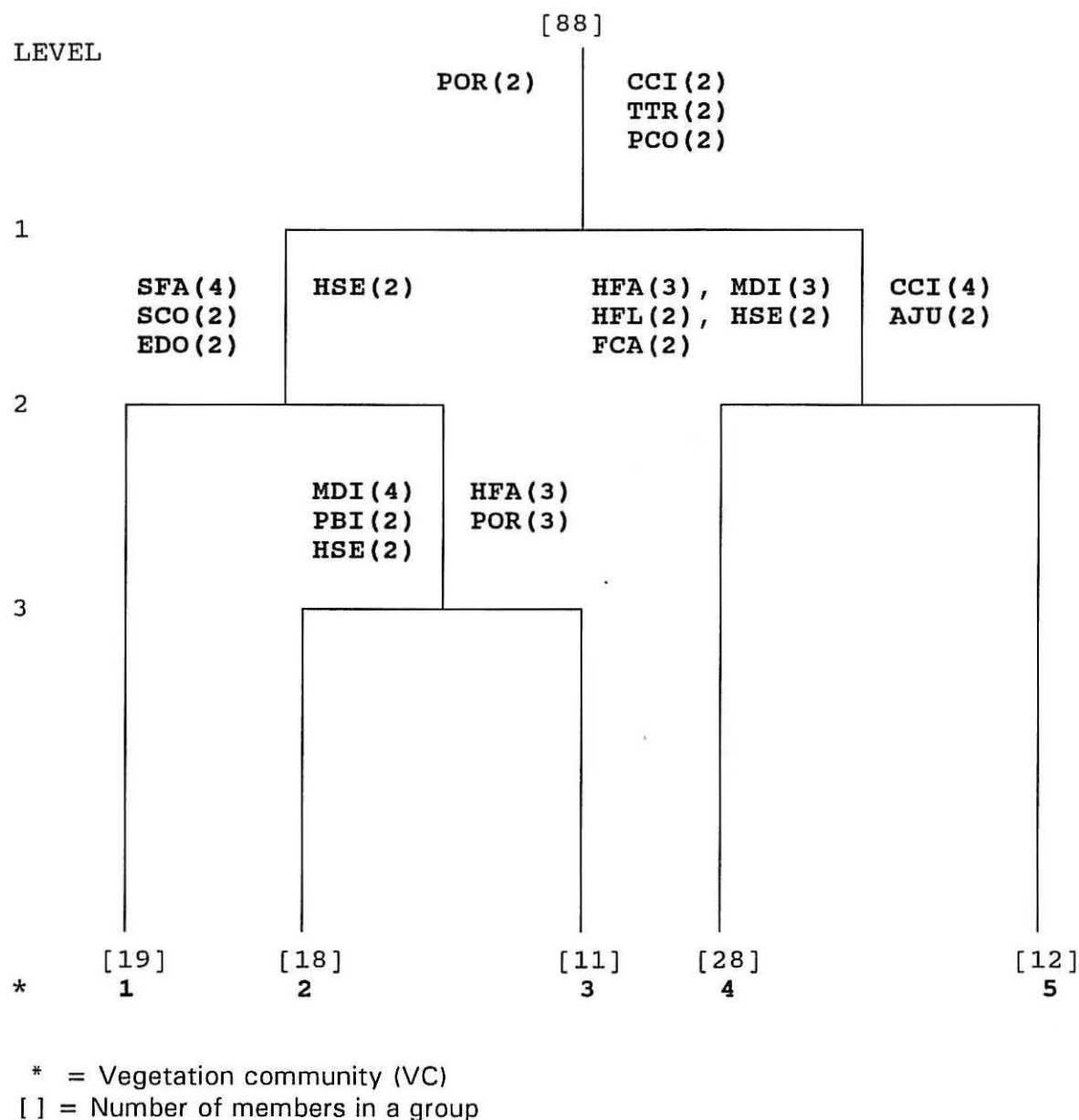
Figure 4.5 A dendrogram of the TWINSPAN classification of the vegetation in Study Area 1, eastern Lesotho. The indicator pseudo-species at each dichotomy are displayed as follows: AJU = *Aristida junciformis* subsp. *galpinii*; CCI = *Chrysocoma ciliata*; EDO = *Erica dominans*; FCA = *Festuca caprina*; HFA = *Harpochloa falx*; HFL = *Helichrysum flanaganii*; HSE = *Helichrysum sessilioides*; MDI = *Merxmuellera disticha*; PBI = *Poa binata*; PCO = *Pentzia cooperi*; POR = *Pentaschistis oreodoxa*; SCO = *Scabiosa columbaria*; SFA = *Scirpus falsus*; and TTR = *Themeda triandra*.

Table 4.5 The mean abundance (%) of species within each vegetation community type in Study Area 1, eastern Lesotho.

Vegetation community	1	2	3	4	5
No. of sites	19	18	11	28	12
Species					
Anthoxanthum ecklonii	0.4				
Clutia nana	0.4				
Cotula radicalis	1.1	0.1			
Crassula natalensis	0.1				
Erica algida	1.7	0.3	0.0		0.0
Erica dominans	4.8		0.0		
Erica frigida	0.1				
Erica glaphyra	0.2				
Helichrysum marginatum	1.2				
Helichrysum witbergense	0.3				
Merxmuellera macowanii	0.1				
Moraea spp.	0.3				
Rodohypoxis sp.	0.8				
Sebaea natalensis	0.8				
Unidentified forb1	0.6		0.6		
Craterocapsa congesta	1.1	0.2	0.0		
Helichrysum basalticum			0.2		
Helichrysum subglomeratum	3.3	1.3	0.6		
Luzula africana	0.4	0.0			
Unidentified forb3	1.3	0.3	0.5		
Anthospermum monticola	0.7				
Carex glomerabilis	1.9	1.2	0.7	0.2	0.8
Crassula setulosa	0.4	0.1	0.0		
Merxmuellera drakensbergensis	4.8	2.2	2.9	0.9	
Pentaschistis galpinii	1.9	0.7	4.1	0.1	0.0
Psammotropha mucronata	0.7	0.2	0.4	0.0	
Scirpus falsus	14.5	3.1	6.6	1.4	1.4
Berkheya cirsiifolia	1.2	0.2		0.3	0.0
Ehrharta longigluma	0.2	0.7	0.2	0.0	
Geum capense	1.1	0.6			
Poa annua	0.1	0.1	0.0		
Ursinia montana	1.0	2.1	0.6	0.0	
Basutica propiniqua		0.2			
Unidentified forb2	1.3	0.4	2.3	0.0	0.0
Moraea alticola			0.2		
Polygala hispida	0.1	0.0	0.5		
Senecio parascitus		0.4	0.2		
Unidentified forb4			0.2		
Zaluzianskya spp.			0.2		
Chenopodium sp.	0.0	0.3	0.2		0.0
Cotula hispida	0.0	1.0	0.6	0.1	
Eumorphia sericea		0.2	0.0	0.1	
Poa binata	2.5	6.6	0.6	0.8	
Pentaschistis oreodoxa	4.6	2.4	10.5	1.4	0.0
Scabiosa columbaria	1.9		0.5	0.6	0.0
Festuca scabra	0.4		0.2		0.2
Merxmuellera stereophylla	1.1			0.0	2.4
Cerastium spp.	0.2			0.1	
Festuca caprina	9.0	11.2	5.3	5.3	3.3
Helichrysum aureum	1.4	0.9	1.3	0.7	1.0
Koeleria capensis	2.8	3.2	1.0	0.9	0.3
Merxmuellera disticha	10.5	23.8	10.8	13.3	2.3
Dianthus basuticus	1.6	0.6	0.4		
Helichrysum flanaganii	0.6	5.6	1.7	3.9	0.4
Helichrysum sessilioides	1.0	15.3	2.3	7.0	

Table 4.5 continued.

Vegetation community	1	2	3	4	5
Species					
Senecio seminiveus	0.2		0.6	0.3	
Crassula sp.	0.7	0.8	0.6	1.0	0.7
Helichrysum trilineatum	0.6	2.8	0.7	2.5	2.0
Trifolium burchellianum	0.3	1.9	1.3	2.0	2.3
Delosperma spp.	0.0		0.3	0.0	0.0
Erica alopecurus	0.0				
Athrixia spp.	0.0	0.0		0.1	0.0
Oxalis obliquifolia	0.3	0.2	1.6	0.5	0.7
Geranium spp.	0.2		0.0	0.1	1.0
Senecio spp.	1.6	0.2	0.5	0.7	2.3
Felicia filifolia				0.2	
Harpochloa falx	3.1	1.9	29.3	18.0	1.6
Eragrostis caesia	0.4	0.6	1.3	1.6	3.0
Aristida junciformis subsp. *galpinii*	0.7	0.1	0.6	1.1	3.7
Asclepias sp.			0.3	0.1	1.2
Bulbostylis humilis	2.4	0.2	0.2	1.3	4.1
Gazania spp.	0.0	0.2	0.6	0.8	1.8
Legume spp.	0.0	0.0	0.6	0.3	1.1
Senecio spp1.	0.1 ·		0.3	1.2	0.2
Pentzia cooperi			0.2	1.6	5.8
Chrysocoma ciliata	0.0	0.0	0.7	4.3	11.4
Fingerhuthia sesleriiformis	0.2			0.8	2.3
Karoochloa purpurea			0.2	0.5	0.8
Lessertia sp.				0.0	
Pennisetum sphacelatum				1.3	1.1
Pentaschistis sp.				0.0	
Gymnopentzia bifurcata	0.0	0.0		0.9	1.6
Senecio spp2				0.3	0.7
Sutera pristisepala				0.3	0.4
Themeda triandra			0.5	13.9	20.3
Unidentified forb5					0.0
Brachypodium bolusii					0.3
Bromus catharticus			0.2	0.1	0.7
Catalepis gracilis				1.7	5.3
Cynodon hirsutus					0.7
Deschampsia cespitosa					0.0
Eragrostis curvula				0.2	2.8
Eragrostis sp.					1.2
Helictotrichon turgidulum					0.6
Melica decumbens					0.7
Mentha sp.					0.2
Selago spp.	0.0				1.8
Taraxacum spp.				0.0	0.3

Note: an abundance of 0.0 indicates that a species is present at a mean abundance of <0.1%.

Merxmuellera disticha was the most abundant species in the study area, especially at high altitudes (VCs 1,2 & 3; Table 4.5). The dominant species in VC1 was the sedge *Scirpus falsus*, whereas the most abundant grass in VC1 was *M. disticha*. Other abundant species in VC1 included *Erica dominans, M. drakensbergensis, Pentaschistis oreodoxa* and *Festuca caprina*. *Erica dominans, Helichrysum trilineatum* and *Eumorphia sericea* were not as abundant in the study area as they

are on the escarpment of the northern Drakensberg (Killick 1963).

In VC2, *M. disticha* was the dominant species with *H. sessilioides* and *F. caprina* as subdominants. Other common species in VC2 were *Poa binata* and *H. flanaganii*. *Harpochloa falx* and *P. oreodoxa* were the two indicator species for the division between VC2 and VC3 (Figure 4.5). They were two of the most abundant species in VC3, along with *S. falsus*, *F. caprina* and *M. disticha*.

Vegetation communities 4 and 5 were separated from the other three communities at level one of the dendrogram (Figure 4.5). The indicator species for these two communities at this dichotomy were *Chrysocoma ciliata*, *T. triandra* and *Pentzia cooperi*. *Pentaschistis oreodoxa*, the indicator species for the other branch of the dichotomy at level one of the dendrogram, was found infrequently and at low abundances in VC4 and VC5. In VC4, *H. falx*, *T. triandra* and *M. disticha* were the most abundant species (Table 4.5). *Helichrysum sessilioides* and *F. caprina* were also common in VC4. Sites in VC5 were dominated either by *T. triandra* or the karroid dwarf shrub *C. ciliata*. *Pentzia cooperi*, a dwarf shrub of karroid affinity, was also abundant in certain sites in VC5. The mat-forming grass, *Catalepis gracilis* occurred in the vicinity of cattleposts and on basalt benches in VC5.

The relationship between the five VCs in terms of their species composition can be displayed by plotting the distribution of sites belonging to each community in two-dimensional ordination space defined by DCA axis 1 and DCA axis 2 (Figure 4.6).
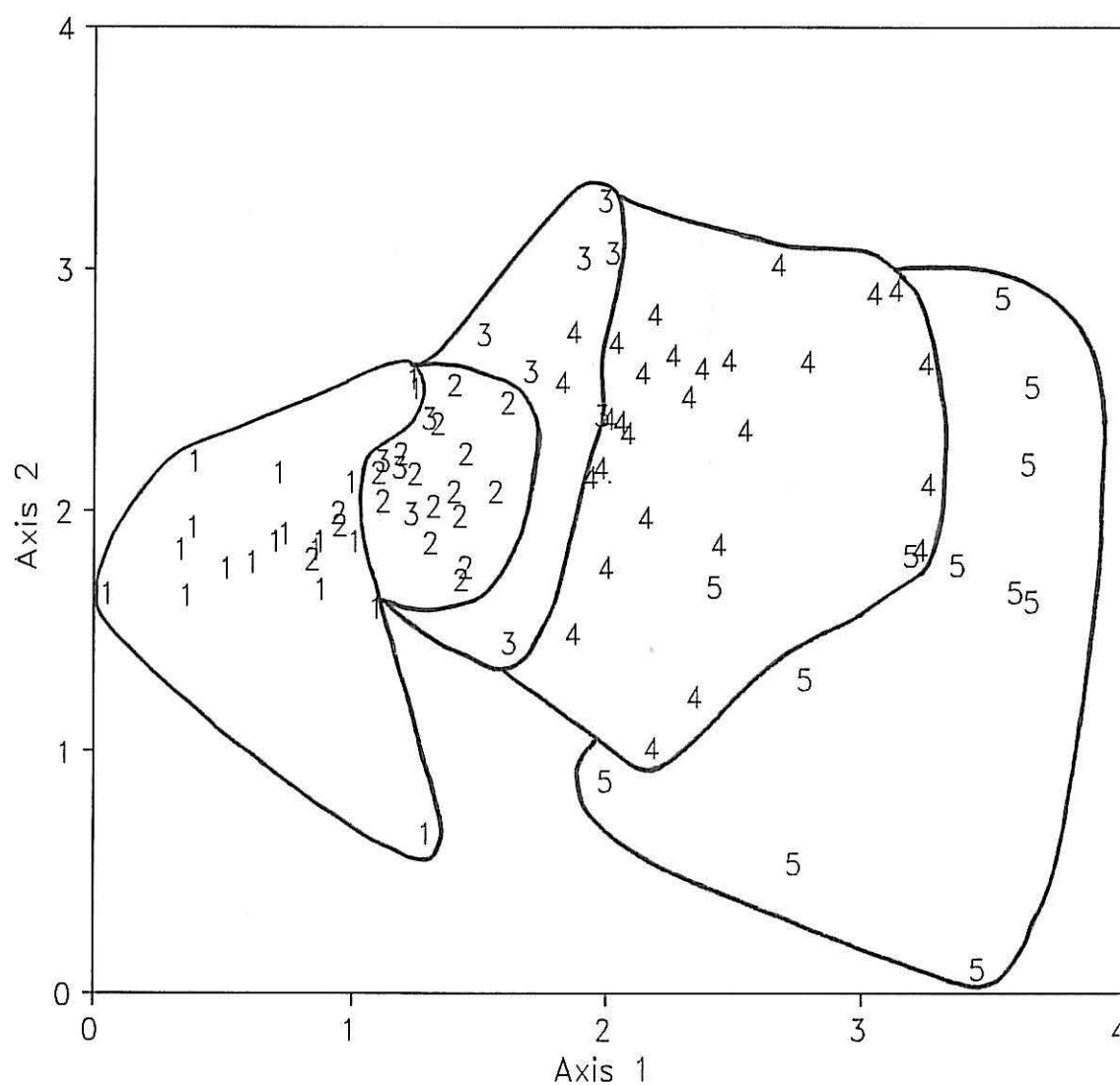
Figure 4.6   The distribution of the five vegetation communities identified in Study
Area   1,   eastern   Lesotho,   in   two-dimensional   Detrended
Correspondence Analysis ordination space.

The first division of the TWINSPAN dendrogram, i.e. the division between VCs 1, 2, 3 and 4 & 5, occurred approximately half-way along DCA axis 1 (Figure 4.6). This was not surprising because TWINSPAN is based on the division of the first axis of a RA ordination of the data at or near the centroid of the site positions along that axis (Hill 1979b) and DCA is merely a special form of RA (Gauch 1982). The five VCs occupied successive positions along DCA axis 1, from VC1 on the left of the ordination plot through to VC5 on the right (Figure 4.6). There were no obvious discontinuities between the vegetation communities and the boundaries defined by the TWINSPAN analysis did not completely separate the communities in ordination space.

The five communities differed significantly in the median proportion of C_3 grass species in their herbaceous layer (P<0.001). There was a gradient in the proportion of temperate grass species in the sward, from a median proportion of 98% and 99% in communities 1 and 2 through the mixed grassland of community 3 (54%), to the subtropical swards of communities 4 and 5 with 63% and 90% subtropical (C_4) grass species, respectively (Figure 4.7).

The five communities were named after their dominant and subdominant indicator species as well as the temperate/subtropical nature of the grass sward. The vegetation communities, as listed below, were referred to as grasslands because grasses were dominant - with the exception of VC1 which was dominated by the sedge *S. falsus* - and because dwarf shrubs were abundant only in some sites of certain communities (e.g. *E. dominans* & *C. ciliata*).

VC1 - *Scirpus falsus* temperate sedgeland.

VC2 - *Merxmuellera disticha/Helichrysum sessilioides/Festuca caprina* temperate grassland.

VC3 - *Harpochloa falx/Pentaschistis oreodoxa* mixed grassland.

VC4 - *Harpochloa falx/Themeda triandra/Merxmuellera disticha* subtropical grassland.

VC5 - *Themeda triandra/Chrysocoma ciliata* subtropical grassland.
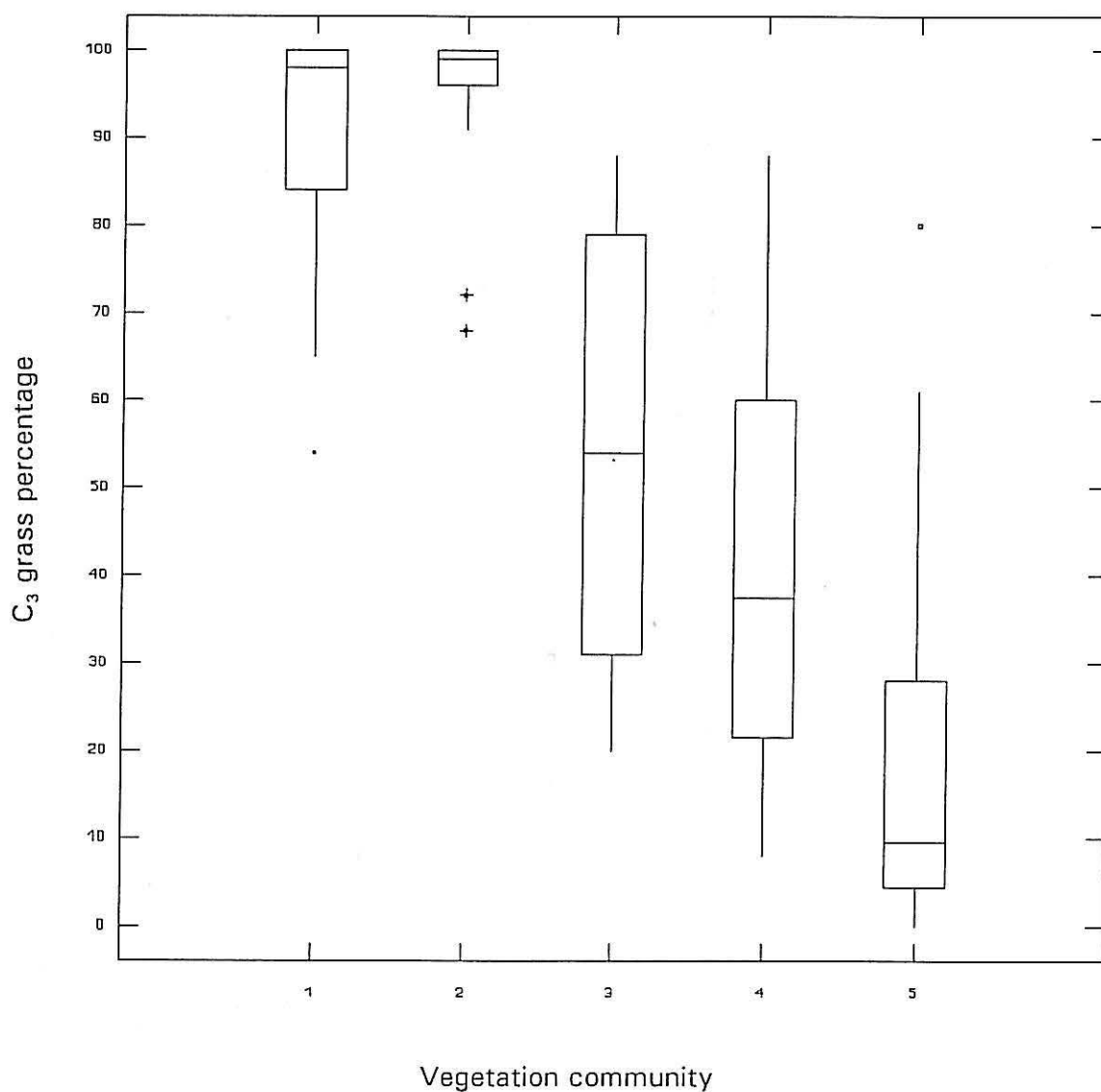
Figure 4.7   A Box and Whisper plot of the proportion of temperate (C$_3$) grasses in each of the five vegetation communities identified in Study Area 1, eastern Lesotho.   The horizontal bar represents the median, the middle two quartiles are enclosed within the box and the vertical line indicates the data range.   Outliers are also indicated.

The results of the two-group discriminant analyses performed at each dichotomy of the TWINSPAN dendrogram are presented in Figure 4.8. The mean and standard error for each of the measured environmental variables in each of the five vegetation communities are given in Table 4.6.

Table 4.6   The mean and standard error (mean) for each of the measured environmental variables in the five vegetation community types in Study Area 1, eastern lesotho.

Vegetation community	Environmental variable					
	Altitude (m a.s.l.)		Aspect (degrees - linear scale[1])		Slope (degrees)	
	Mean	SE	Mean	SE	Mean	SE
1	3 054.0	22.07	100.6	13.95	15.4	1.95
2	2 959.8	34.13	132.1	12.93	15.4	1.64
3	3 004.6	18.10	38.4	8.78	15.7	2.52
4	2 849.1	26.65	93.8	7.68	17.8	1.37
5	2 795.8	34.24	40.5	11.56	18.9	1.56

[1]Aspect converted to linear scale as follows: aspect = aspect, for aspect $\leq 180°$; aspect = 360-aspect, for aspect $> 180°$.

Altitude and aspect were the two environmental variable that could be used to differentiate between groups at various levels of the TWINSPAN dendrogram (Figure 4.8). Slope angle added little discriminating power to the functions. The first division of the 88 sites at level one of the dendrogram was between low elevation sites on the right of the dendrogram (VCs 4 & 5) and high elevation sites on the left (VCs 1, 2 & 3). The standardised coefficient for altitude at that dichotomy was almost twice the magnitude of that of aspect and slope. The discriminant function at that division was able to correctly predict group membership for a high proportion of the sites (Figure 4.8).

Figure 4.8   A dendrogram of the TWINSPAN classification of the vegetation in Study Area 1, eastern Lesotho, showing the most discriminating environmental variable at each dichotomy (highlighted) along with the standardized coefficients for the environmental variables used in the analysis (ALT = Altitude, ASP = Aspect, SLP = slope). The percentage of sites in each group that were correctly classified by the discriminant function is given at each dichotomy.

The altitudinal boundary between the two groups at level one of the dendrogram varied according to aspect (Figure 4.9). On northerly aspects this boundary was at *c.* 2 950 m a.s.l. whereas on the south-facing slopes it was as low as 2 750 m a.s.l. There was some variation around this boundary, with a few sites from VC3 and VC4 occurring at high altitudes on northerly aspects. The diagonal altitudinal distribution of vegetation belts across different aspects, as displayed in Figure 4.9, is a well documented feature of mountain landscapes (e.g. Staples & Hudson 1938; Killick 1963; Whittaker 1967; Wieland 1982; Druitt *et al.* 1990).

The two major vegetation groups at level one of the dendrogram could also be distinguished by the nature of the herbaceous layer. The high elevation vegetation belt (VCs 1, 2 & 3) was temperate in nature with a median proportion C_3 grass species of 96%. In the lower elevation vegetation belt (VCs 4 & 5) the median C_3 grass proportion was only 28.5%, indicating the subtropical nature of the sward.

The two vegetation belts represented in Figure 4.9 correspond with the Alpine Belt (*viz.* the temperate grassland) and the Subalpine Belt (*viz.* the subtropical grassland) as recognised by previous workers in Lesotho (Chapter 3.2). The altitude boundary between the Alpine and Subalpine belts has been set at 2 900 m for northerly aspects (Jacot-Guillarmod 1971; Wieland 1982) and 2 740 m for southerly aspects (Wieland 1982). However, on north-facing slopes in Study Area 1, Subalpine vegetation occurred regularly up to an altitudes of 3 000 m and Alpine grassland occurred below 2 950 m a.s.l. (Figure 4.9). Given that there were no distinct altitudinal boundaries between the two vegetation belts in the field and that the delineation of the two vegetation belts in this study represented the division of a continuum in species composition rather than a disjunction in the data, a precise border between vegetation belts could not be described. However, the boundary described in Figure 4.9 is a useful stratification for monitoring and management purposes.
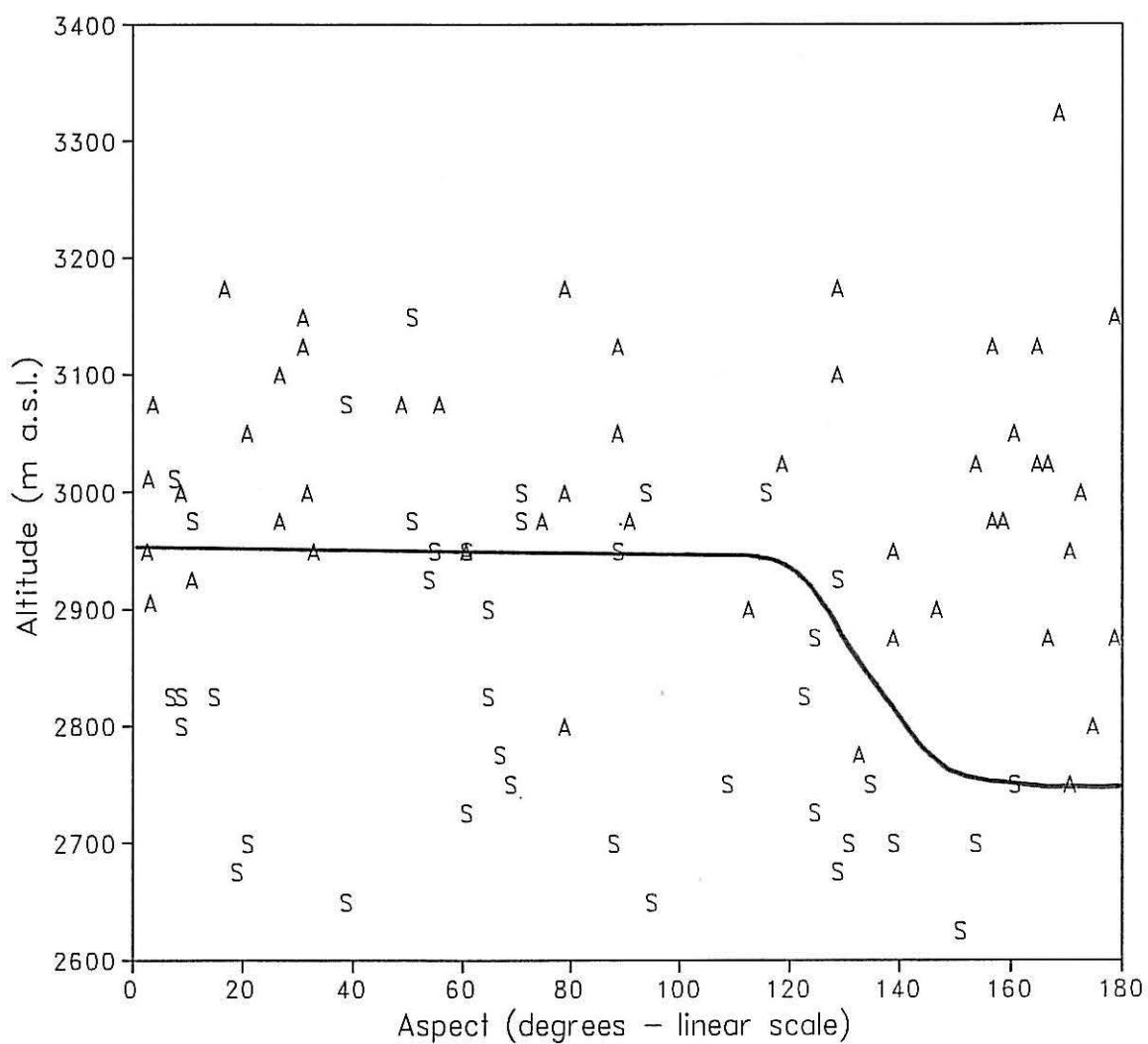
Figure 4.9   The approximate altitude boundary between the two vegetation belts identified at level 1 of a TWINSPAN analysis of species composition data from Study Area 1, eastern Lesotho. A = Alpine Belt and S = Subalpine Belt.

Soil temperature regimes in the Study Area 1 are reported to follow a similar distribution to that of the two vegetation belts identified above (Chapter 2; Wieland 1982; Klug *et al.* 1989). A mesic regime, in which the mean annual soil temperature is between 8°C and 15°C, prevails in the subtropical Subalpine Belt, whereas the higher, Alpine grasslands experience frigid temperatures (mean annual soil temperature of between 0°C and 8°C). It has been proposed that low temperatures during the growing season, in particular nightly minima of <8°C, may serve to limit the distribution of C_4 grasses to the warm microsites in the landscape (Vogel *et al.* 1978).

Aspect could be used to differentiate between communities within the two vegetation belts (Figure 4.8). The exception was the division at level 2 between VC1 and VCs 2 & 3, where altitude had the largest standardised coefficient (Figure 4.8). Although the average elevation of sites belonging to VC1 was slightly higher than that of sites from VCs 2 & 3 (Table 4.6), their altitude distributions overlapped and the discriminant function was a poor descriptor of the dichotomy (Figure 4.8). Sites of VC1 commonly occurred immediately above and below the scarps of the exposed basalt benches and on the plateaus of the mountain summits. Those thin-soiled, rocky habitats were usually associated with seepage zones (Klug *et al.* 1989).

Vegetation communities 2 and 3 occupied the deeper soils between the basalt benches in the Alpine Belt. There, the vegetation was short and dense. *Helichrysum sessilioides* formed large mats on the cooler aspects whereas a rhizomatous form of *H. falx* contributed to the high vegetation cover on the north and east-facing slopes above 2 950 m a.s.l. The two communities within the Subalpine Belt could also be distinguished by their respective aspectal distributions (Figure 4.8). *Themeda triandra*, which was the dominant grass on the warmer aspects within the Subalpine Belt (VC5), was replaced by a shrubby community (*C. ciliata* & *P. cooperi*) associated with poor cover, in overgrazed areas (Morris *et al.* 1989). *Chrysocoma ciliata* and *P. cooperi* did not readily invade the cooler aspects at this altitude (i.e. VC4).

A schematic diagram depicting the topographic distribution of the five vegetation communities is presented in Figure 4.10. It is recognised that the boundaries drawn between communities represent only the average topographical ranges of the communities and that floristic changes between communities in the landscape may be gradual. However, sharp transitions between communities did occur where environmental gradients were steep, e.g. on ridges and in valley bottoms where aspect changed abruptly.
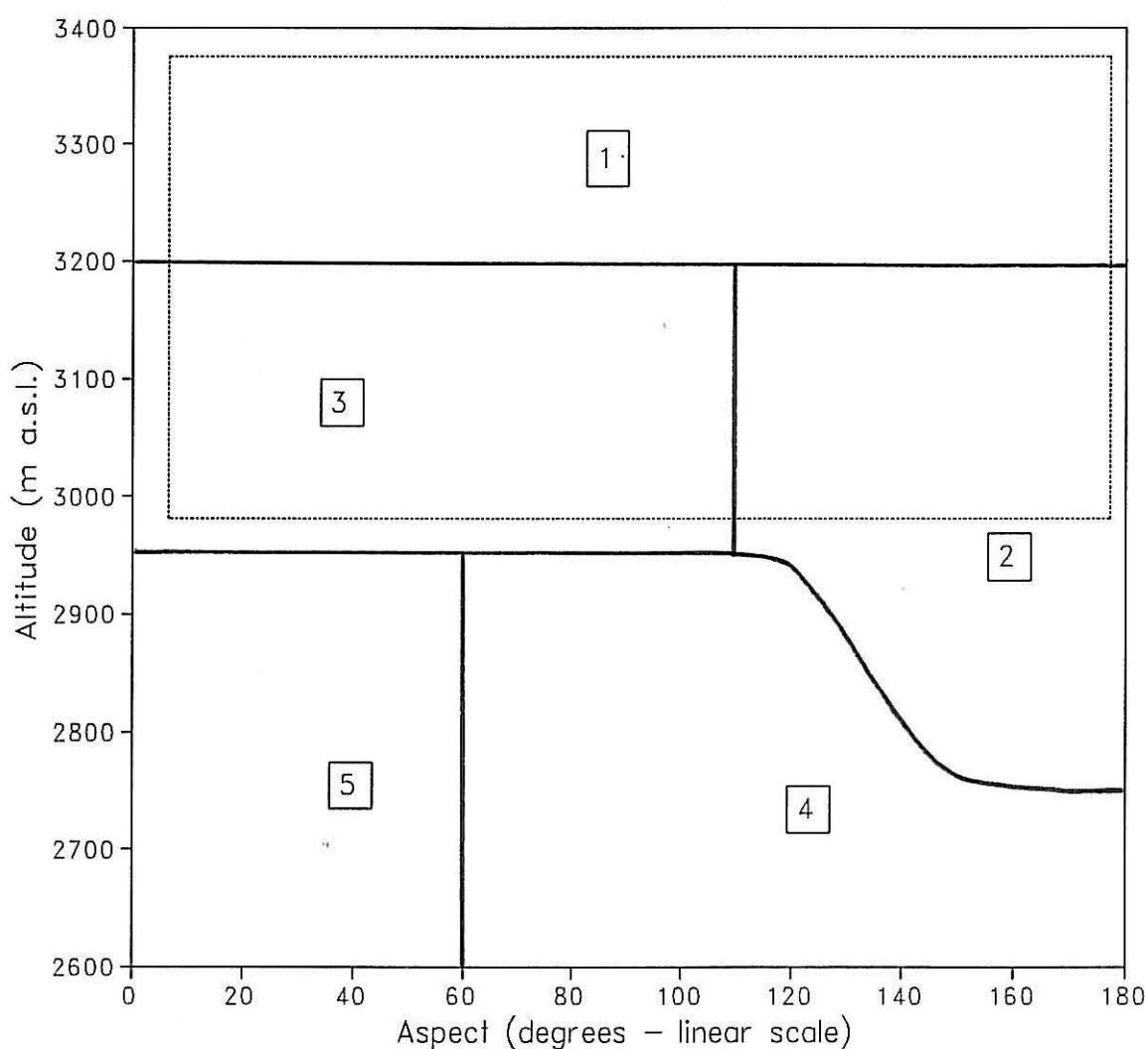
Figure 4.10 A schematic diagram depicting the topographic distribution of the five vegetation communities identified in Study Area 1, eastern Lesotho.

4.3.2.2   Study Area 2

Hierarchical classification of the vegetation is presented in the form of a dendrogram in Figure 4.11. Division was continued until the third level resulting in the identification of seven vegetation communities (numbered VC1 to VC7). The mean abundance of species in each of the communities is presented in Table 4.7.

A plot of the distribution of the sites belonging to each of the seven vegetation communities in two dimensional DCA ordination space illustrates the relationships between the communities in terms of their species composition (Figure 4.12). The four groups at level two of the TWINSPAN dendrogram (Figure 4.11) occupied contiguous positions along DCA axis 1 (Figure 4.12). The communities within these four groups were separated along DCA axis 2, especially towards the right of the ordination plot (i.e. VC6 & VC7).

Merxmuellera disticha was the dominant or subdominant species in communities 1 to 4 (Table 4.7) and it was an indicator species for those communities at level one of the classification dendrogram (Figure 4.11). Another *Merxmuellera* species, the large tufted *M. drakensbergensis*, was abundant in VC1, especially in drainage areas and alongside streams. *Poa binata, S. falsus, F. caprina* and various *Helichrysum* species were abundant in VC1. Temperate grasses were also abundant in VC2 (Table 4.7).

Themeda triandra was co-dominant with *M. disticha* in VC3 (Table 4.7). Other abundant species in VC3 were *H. falx* and *F. caprina*. *Merxmuellera disticha, T. triandra* and *H. falx* were the principal constituents of VC4, along with *P. galpinii, S. falsus* and *Aristida* spp. (*A. junciformis* subsp. *galpinii, A. diffusa* & *A. congesta* subsp. *congesta*). *Eragrostis curvula* was abundant in communities which constituted the right-hand group of the dichotomy at level one of the dendrogram (VCs 5, 6 & 7; Figure 4.11). Within that group, *M. disticha* and *F. caprina* occurred only in VC5, and there only at a low abundance. Other abundant species in VC5 included *T. triandra, Pennisetum sphacelatum* and *Senecio* spp.

LEVEL

[362]

MDI(3)   ECU(3)
PBI(2)   CGR(2)
FCA(2)   SSP(3)
KCA(2)

1

FCA(3)   TTR(3)   SSP(3)   FMU(2)
PBI(3)   HFA(2)   TTR(2)   MBR(2)
        ASP(2)   CCI(2)   CPL(2)
                              MDI(2)

2

MDR(3) MDI(5)   KCA(2) PGA(2)
HSP(2)   FCA(3) ASP(2)
                SSP(2) MSP(2)   CPL

3   MDR(2)   (4)

[26]   [56]   [67]   [45]   [127]   [25]   [16]
* 1.   2.   3.   4.   5.   6.   7.

* = Vegetation community (VC)
[ ] = Number of members in a group
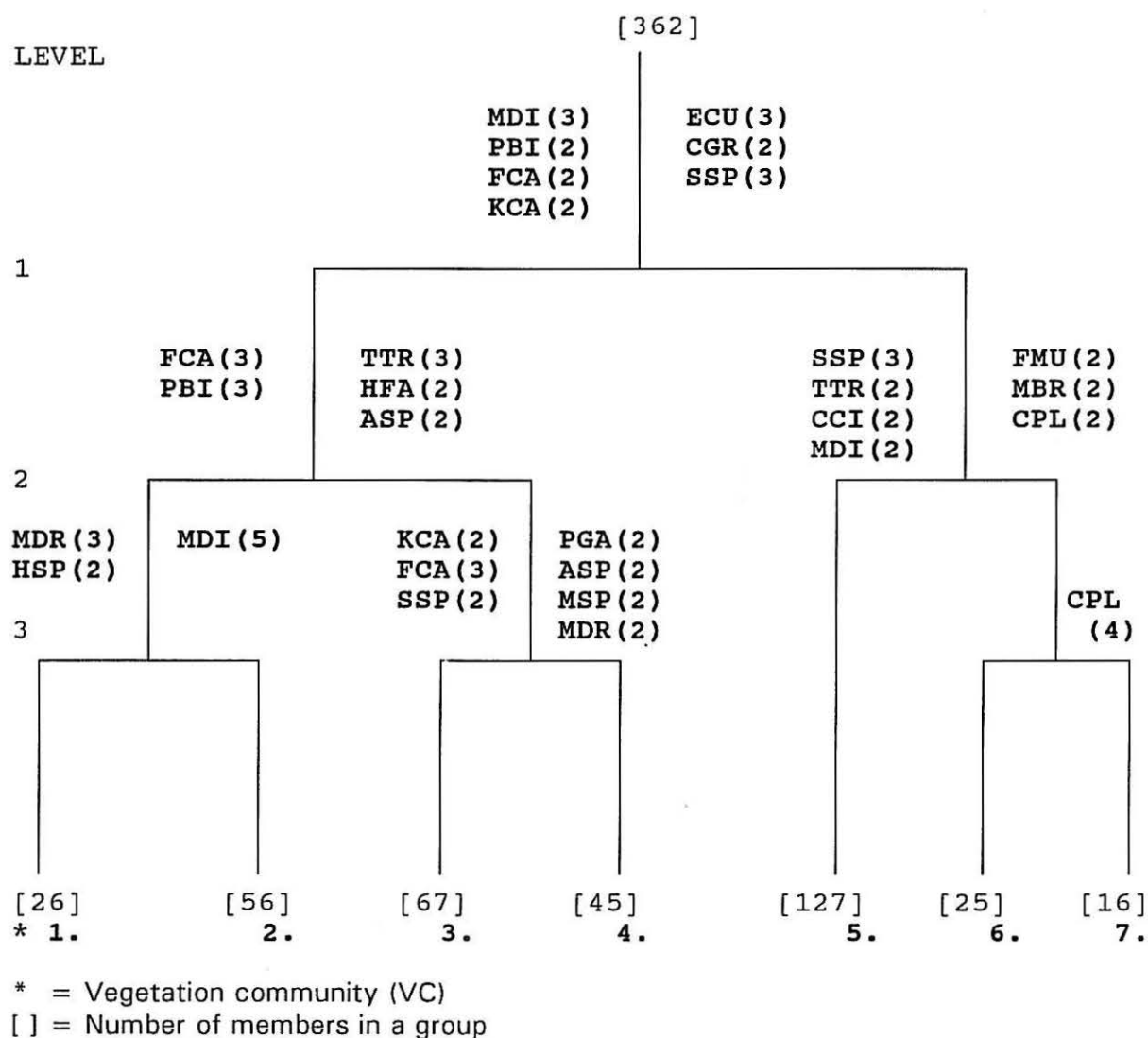
Figure 4.11 A dendrogram of the TWINSPAN classification of the vegetation in Study Area 2, western Lesotho. The indicator pseudo-species at each dichotomy are displayed as follows: ASP = *Aristida* spp.; CCI = *Chrysocoma ciliata*; CGR = *Catalepis gracilis*; CPL = *Cymbopogon plurinodis*; ECU = *Eragrostis curvula*; FCA = *Festuca caprina*; FMU = *Felicia muricata* subsp. *muricata*; HFA = *Harpochloa falx*; HSP = *Helichrysum* spp.; KCA = *Koeleria capensis*; MBR = *Monsonia brevirostrata*; MDI = *Merxmuellera disticha*; MDR = *M. drakensbergensis*; MSP = *Moraea* spp.; PBI = *Poa binata*; PGA = *Pentaschistis galpinii*; SSP = *Senecio* spp.; and TTR = *Themeda triandra*.

Table 4.7   The mean abundance (%) of species within each vegetation community type in Study Area 2, western Lesotho.

Vegetation community	1	2	3	4	5	6	7
No. of sites	26	56	67	45	127	25	16
Species							
Alepidea spp.	1.1	0.2	0.0		0.0	0.0	0.0
Erica dominans	1.3	0.3	0.1				
Aster erucifolius		0.1					
Festuca scabra		0.1					
Geum capense	0.5		0.0				
Helichrysum flanaganii	0.6	2.6	0.3	0.0	0.1		
Helichrysum sessilioides	0.2	0.6	0.0	0.0			
Luzula africana		0.0					
Merxmuellera drakensbergensis	18.2	1.4	0.2	2.9	0.3		
Merxmuellera guillarmodiae	0.4						
Senecio macrocephalus	0.6	0.1					
Ranunculus multifidus		0.1					
Agrostis barbuligera	3.0	0.8	0.6	0.1	0.1		
Erica frigida	1.8	0.2	0.2	0.3	0.0		
Helichrysum subglomeratum	3.4	0.8		0.0			
Craterocapsa congesta		0.0	0.0				
Poa binata	15.4	9.0	6.2	2.1	0.6		
Aster bakeranus	0.0	0.0	0.0	0.2			
Pentaschistis galpinii	2.6	3.4	0.5	5.4	0.0		
Polygala hispida	0.0	0.2	0.0	0.1			
Scirpus falsus	4.0	2.9	1.5	8.1	0.2		
Sebaea natalensis	0.2	0.0	0.0	0.4			
Oxalis obliquifolia		0.1	0.3				
Barbarea verna		0.0	0.3				
Koeleria capensis	4.4	5.7	4.2	1.0	0.6		
Inulanthera thodei	0.0	0.0			0.0		
Festuca caprina	8.0	17.6	5.9	2.8	2.6		
Merxmuellera disticha	16.1	31.6	18.7	12.9	3.8		
Pentaschistis setifolia	0.9	2.2	1.6	2.1	0.4		
Scabiosa columbaria	1.6	1.0	1.0	0.0	0.2	0.0	0.0
Cerastium spp.	0.1	0.4	0.4		0.0		
Helichrysum spp.	5.1	0.5	1.2	3.0	1.1		0.2
Gazania spp.	0.5	0.3	1.1	1.0	0.3	0.2	0.4
Helichrysum trilineatum		0.1	0.4	0.3	0.0		
Psammotropha mucronata	0.1	0.4	0.6	0.7	0.2		
Eragrostis caesia		0.4	2.1	1.6	0.5	0.5	
Juncus dregeanus		0.0	0.4	0.2	0.0		
Harpochloa falx	0.0	2.2	8.0	10.6	1.0		
Moraea spp.			0.0	2.4	0.0	0.1	
Alloteropsis semialata		0.0		0.3			
Anthoxanthum ecklonii	0.2			0.4			
Brachypodium bolusii				0.6			
Dierama robustum				0.0			
Helichrysum marginatum				0.0			
Kniphofia caulescens			0.0	0.0			
Ledebouria cooperi				0.0			
Senecio seminiveus				0.5		0.1	
Gunnera perpensa			0.0	0.0			
Panicum schinzii			0.0				
Taraxacum spp.		0.0	0.2				
Berkheya cirsiifolia	0.6		0.1	0.3	0.1	0.2	
Helictotrichon longifolium		0.0	0.5	1.1	0.4		
Merxmuellera macowanii			0.3	0.4	0.0		
Anthospermum sp.				0.3	0.0		
Trifolium burchellianum	0.0	0.7	1.0	0.6	0.7		
Ursinia montana	0.2	0.1	0.1		0.0		

Table 4.7 continued.

Vegetation community	1	2	3	4	5	6	7
Species							
Cotula hispida	0.3	0.3	0.3	0.0	0.6		
Arctotis microcephala		0.2	0.0		0.0		
Scirpus ficinioides		0.1			0.0		
Geranium spp.	0.0	0.4	0.3		0.3		0.0
Silene sp.				0.2	0.1	0.1	
Delosperma spp.	0.0	0.0	0.0	0.1	0.0		
Themeda triandra	0.2	2.7	17.2	9.4	10.4		1.4
Agrostis lachnantha		0.0	0.6	0.0	0.4	0.0	
Crassula spp.	0.6	1.0	1.2	2.6	2.6	2.9	0.6
Sedge spp.	5.2	1.5	2.8	3.8	2.7	8.5	1.4
Dianthus basuticus		0.2	0.2		0.2		0.0
Gymnopentzia bifurcata		0.2	0.6	2.8	3.1		
Sutera pristisepala			0.0	0.0	0.0		
Wahlenbergia undulata				0.6	0.3		
Fingerhuthia sesleriiformis			0.3		0.1		
Aristida spp.		0.0	2.1	5.5	3.6	7.6	8.7
Bulbostylis humilis	0.8	0.5	1.9	4.6	3.6	8.5	2.6
Bromus catharticus			0.4	0.1	0.6		
Galium capense		0.4	0.4		0.6	0.6	0.4
Mohria caffrorum		0.0	0.0	0.2	0.2	0.5	0.4
Unidentified forb			0.0		0.1	0.4	0.2
Lotononis sericophylla		0.2			0.1	0.0	0.4
Senecio spp.	1.2	2.1	4.1	1.6	8.6	1.1	1.4
Hebenstretia comosa			0.0	0.1	0.1		0.0
Helictotrichon turgidulum		0.1	0.6	0.3	1.1	0.2	0.9
Zaluzianskya spp.		0.0	0.0		0.0		
Osteospermum jucundum			0.0		0.1		0.2
Pelargonium spp.	0.1				0.0		
Pennisetum sphacelatum		0.5	1.8	1.2	6.2	1.4	1.3
Chrysocoma ciliata		0.2	1.3	1.7	6.0	0.6	
Trachypogon spicatus			0.0	0.1	0.2		
Andropogon appendiculatus					0.0		
Brachiaria eruciformis					0.0		
Anthospermum monticola					0.0	0.1	
Cotula radicalis			0.0		0.0		
Cotyledon orbiculata					0.1		
Euphorbia ericoides			0.0		0.1		
Helichrysum odoratissimum					0.5	0.3	0.0
Hypoxis sp.					0.0		
Rhus pyroides					0.0		
Thesium durum					0.0		
Andropogon amethystinus					0.2		
Bidens pilosa					0.0		
Convolvulus thunbergii					0.2	0.2	
Cynodon hirsutus			0.0	0.0	0.7	0.3	0.0
Digitaria ternata					0.0		
Stachys tysonii			0.0	0.4	1.2	0.4	
Pentzia cooperi		0.0	0.0		0.9	0.2	
Selago spp.			0.0		0.4	0.2	0.2
Euphorbia clavarioides					0.1	0.2	
Catalepis gracilis		0.0	0.6	0.3	5.8	23.9	1.2
Artemisia afra					0.0		0.3
Eragrostis capensis			0.0		0.3		3.2
Eragrostis curvula		0.0	3.0	0.4	21.3	11.8	18.1
Melica decumbens					0.1	0.3	0.2
Polevansia rigida					0.1	0.3	0.2
Brachiaria serrata					0.0		0.2
Elionurus muticus			0.0		0.3	0.2	6.1
Athrixia spp.			0.0				0.8
Cymbopogon plurinodis		0.2				1.1	20.7
Digitaria eriantha					0.0	0.7	2.2
Eragrostis racemosa					0.0	0.1	4.8

Table 4.7 continued.

Vegetation community	1	2	3	4	5	6	7
Species							
Felicia filifolia						0.1	
Felicia muricata					0.2	10.7	13.0
Heteropogon contortus							1.1
Hyparrhenia hirta					0.0		1.7
Tagetes minuta						0.1	1.3
Argyrolobium pumilum							0.0
Legume spp.						1.1	
Microchloa caffra						0.3	1.0
Stachys rugosa						0.6	
Tragus racemosus					0.0	0.5	0.7
Trichoneura grandiglumis							0.2
Karoochloa purpurea						0.8	
Tetrachne dregei						0.2	
Monsonia brevirostrata			0.2		0.5	11.7	1.5

Note: an abundance of 0.0 indicates that a species is present at a mean abundance of <0.1%.

In VC6, *C. gracilis* formed large dense mats on the thin-soiled basalt benches, ridgetops and other flat areas. Those habitats were associated with seepage zones and an accumulation of water in the soil profile as a result of the underlying impermeable basalt rock (Klug *et al.* 1989). *Bulbostylis humilis* and the low-growing herb, *M. brevirostrata* proliferated in those environments (Table 4.7). *Cymbopogon plurinodis* was an indicator species for the dichotomy between VC6 and VC7 (Figure 4.11) and was the dominant species in VC7 (Table 4.7). *Aristida* spp. and *Felicia muricata* subsp. *muricata* were also abundant in VC7. None of the temperate grass species that were common in communities 1 to 4, occurred in VC6 and VC7.

The seven vegetation communities lay along a temperate to subtropical gradient similar to that encountered in Study Area 1 (Figure 4.7). The seven communities differed significantly in the proportion of C_3 grass species in their herbaceous layer (P<0.001). Communities 1 and 2 were temperate grasslands, with a median proportion C_3 grasses of 100% and 94.5%, respectively (Figure 4.13). Temperate and subtropical grasses were equally represented in communities 3 and 4 (53.1% & 47.1% C_3 grasses) whereas communities 5 to 7 were dominated by subtropical grasses, with 89%, 100% and 100% C_4 grasses, respectively.
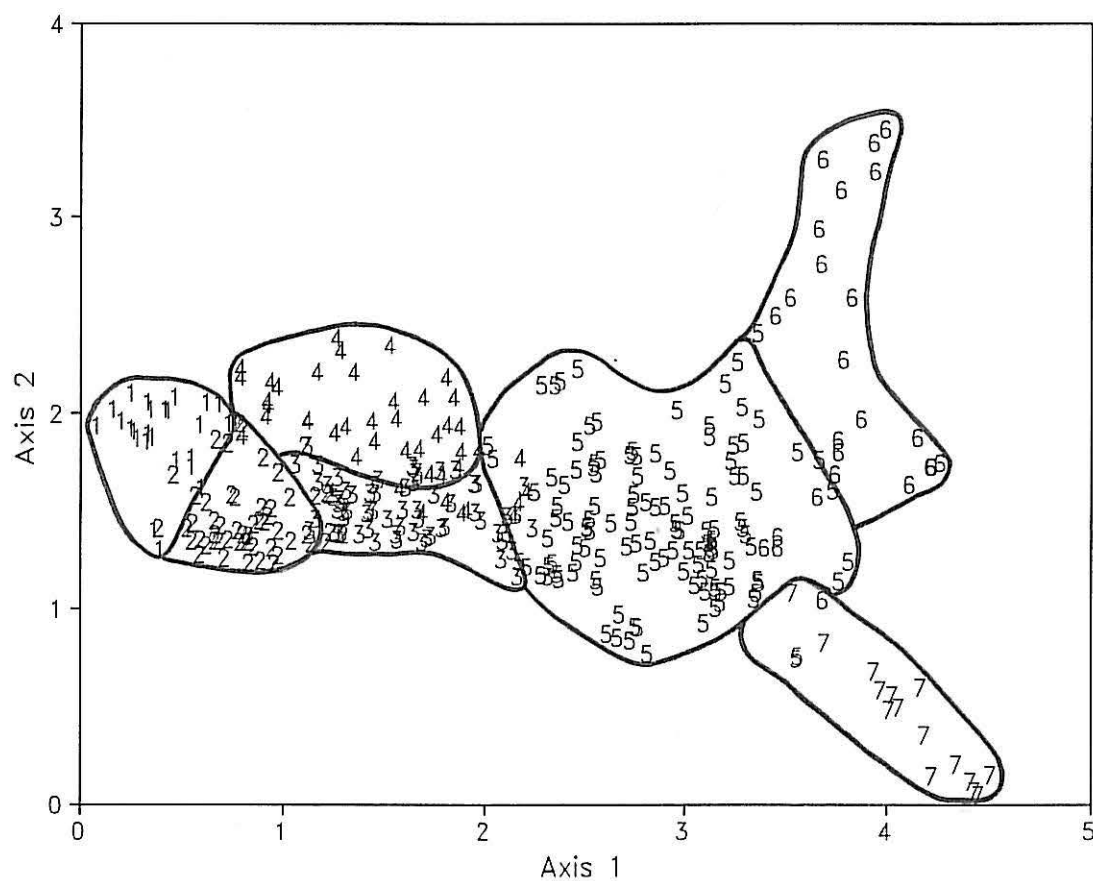
Figure 4.12 The distribution of the seven vegetation communities identified in Study Area 2, western Lesotho, in two-dimensional Detrended Correspondence Analysis ordination space.
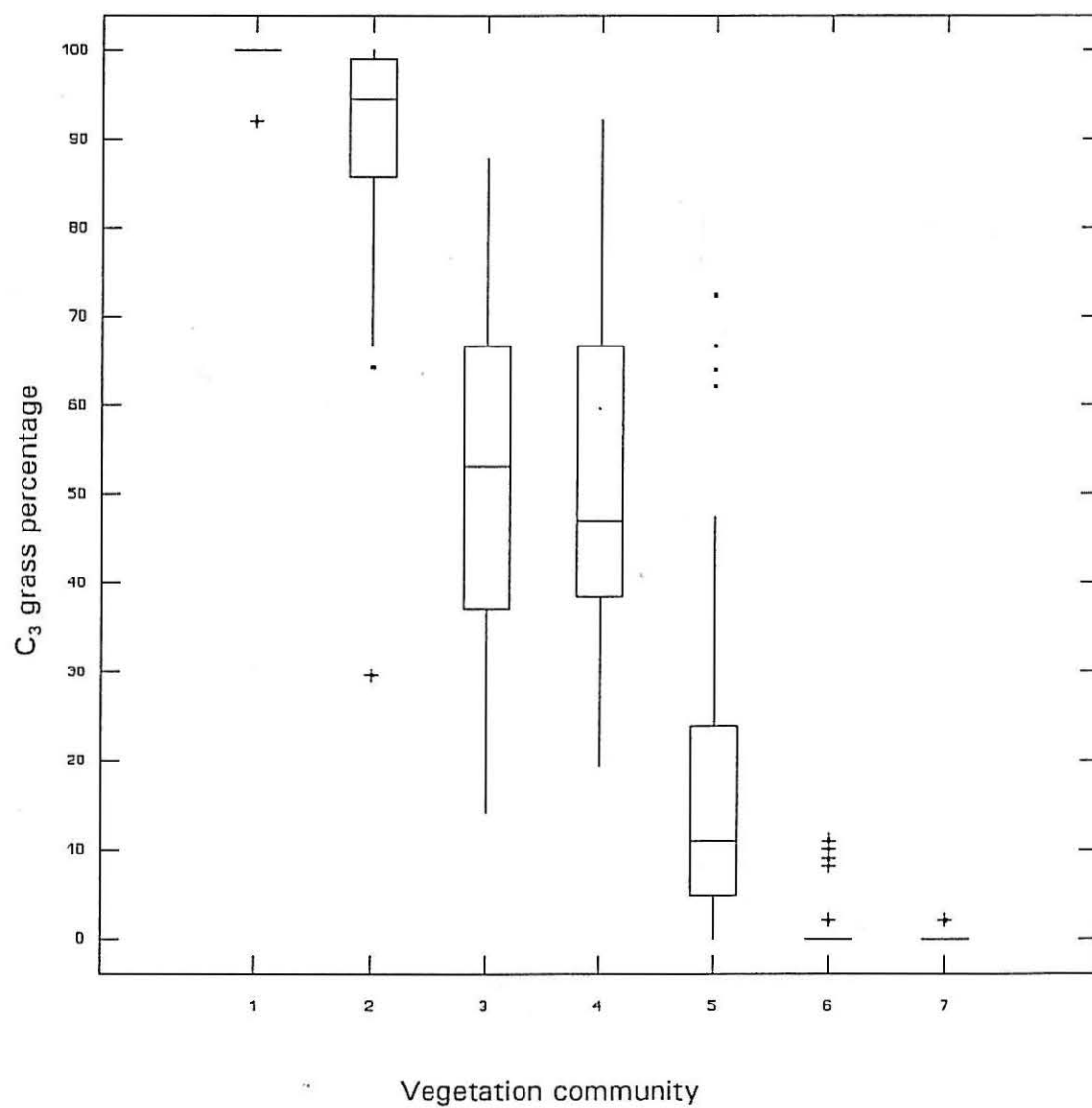
Figure 4.13 A Box and Whisper plot of the proportion of temperate (C_3) grasses in each of the seven vegetation communities identified in Study Area 2, western Lesotho. The horizontal bar represents the median, the middle two quartiles are enclosed within the box and the vertical line indicates the data range. Outliers are also indicated.

The names of the seven vegetation communities are listed below.

VC1 - *Merxmuellera* temperate grassland

VC2 - *Merxmuellera disticha/Festuca caprina* temperate grassland

VC3 - *Merxmuellera disticha/Themeda triandra* mixed grassland

VC4 - *Merxmuellera disticha/Harpochloa falx* mixed grassland

VC5 - *Themeda triandra/Eragrostis curvula* subtropical grassland

VC6 - *Catalepis gracilis* subtropical grassland

VC7 - *Cymbopogon plurinodis* subtropical grassland

The results of the two-group linear discriminant analyses conducted at each dichotomy of the classification dendrogram are presented in Figure 4.14. The means for the measured environmental variables in each of the seven vegetation communities are given in Table 4.8.

Table 4.8   The mean and standard error (mean) for each of the measured environmental variables in the five vegetation community types in Study Area 2, western Lesotho.

Vegetation community	Environmental variable					
	Altitude (m a.s.l.)		Aspect (degrees - linear scale[1])		Slope (degrees)	
	Mean	SE	Mean	SE	Mean	SE
1	2 982.8	18.34	114.2	7.29	21.0	2.01
2	2 736.2	18.78	153.5	3.48	23.9	0.50
3	2 636.3	20.61	122.6	6.15	24.7	0.50
4	2 863.6	11.65	42.1	4.38	22.5	0.56
5	2 552.1	15.34	64.1	4.62	23.9	0.38
6	2 375.7	10.48	28.4	6.21	14.0	2.17
7	2 290.5	24.98	57.6	5.77	19.3	0.42

[1]Aspect converted to linear scale as follows: aspect = aspect, for aspect ≤ 180°; aspect = 360-aspect, for aspect > 180°.
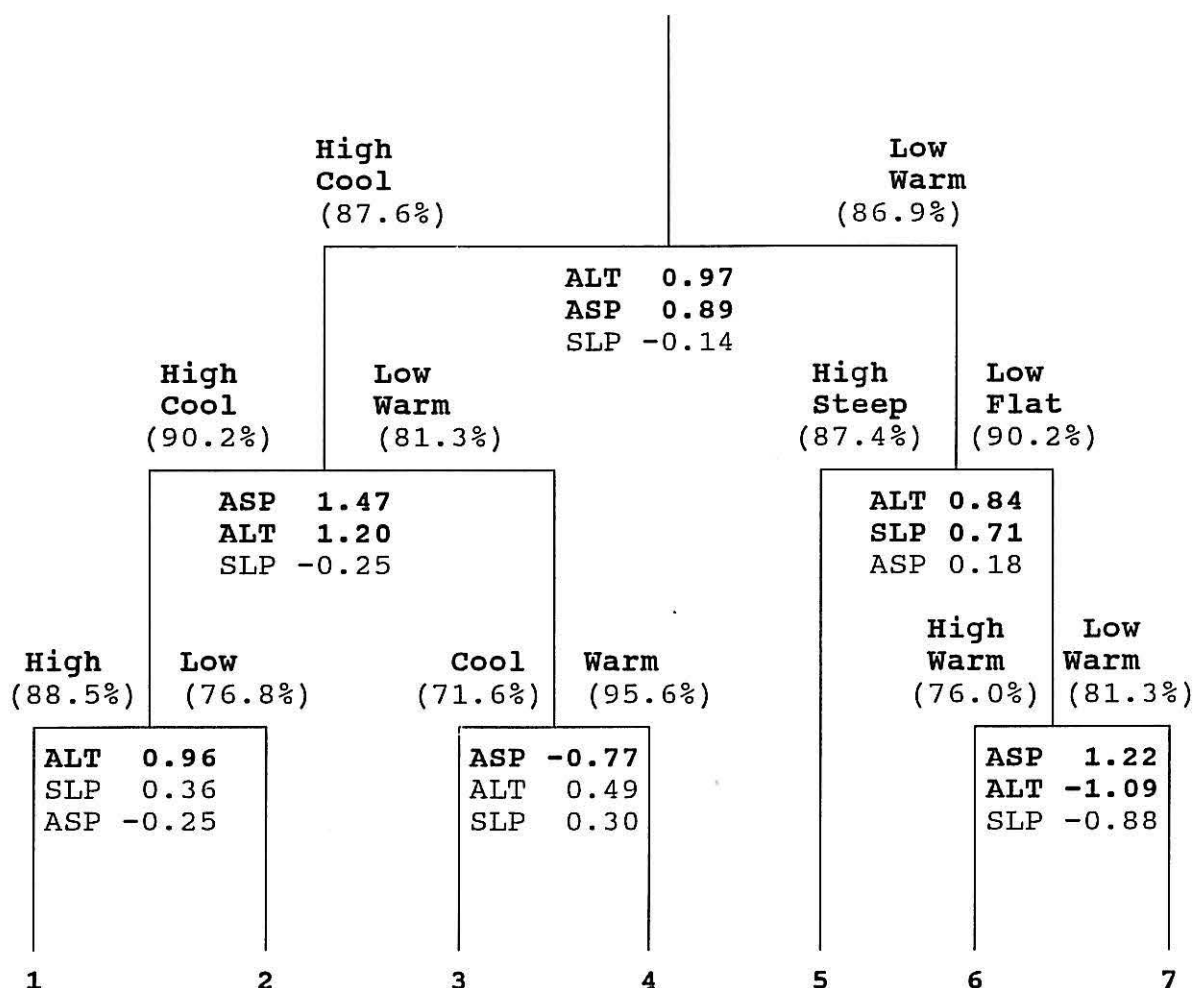
Figure 4.14 A dendrogram of the TWINSPAN classification of the vegetation in Study Area 2, western Lesotho, showing the most discriminating environmental variable at each dichotomy (highlighted) along with the standardized coefficients for the environmental variables used in the analysis (ALT = Altitude, ASP = Aspect, SLP = slope). The percentage of sites in each group that were correctly classified by the discriminant function is given at each dichotomy.

There was clear discrimination between groups at all dichotomies of the dendrogram, as indicated by the high percentage of sites that were correctly classified by the discriminant functions (Figure 4.14). In the initial TWINSPAN classification, VC5 was separated into two groups (n = 104 & n = 23) at level three of the dendrogram and discriminant analysis indicated that aspect and altitude were the most important discriminating variables for that division. However, the dichotomy was poorly described by the discriminant function (canonical correlation coefficient = 0.412; percentage correctly classified sites = 61%). Further, inspection of the data revealed that one of the groups (n = 23), characterized by the presence of *P. cooperi* and *Mentha* spp., was poorly represented in the data set and occurred only in four localised disturbed areas. For these reasons VC5 was not subdivided and was maintained as a discrete community.

The division at level one of the dendrogram (Figure 4.14) was between high altitude sites on southerly aspects and sites that occurred at lower altitudes on northern aspects (Figure 4.15). The altitude distribution of the two vegetation groups at this level of the dendrogram was skewed according to aspect, in a pattern similar to that which occurred in Study Area 1 (Figure 4.9). It was difficult to delineate a precise elevation boundary between the two vegetation groups because they overlapped in their altitude distribution on northerly aspects (Figure 4.15).

The upper elevation limit of sites in the low elevation group (VCs. 5-7: group 1) was *c.* 2 800 m. a.s.l. on north-facing aspects (Figure 4.15). Sites belonging to the high elevation group (VCs 1-4: group 0) descended down to 2 675 m a.s.l. on similar aspects. The elevation cutoff between the two groups on south-facing aspects occurred at *c.* 2 300 m a.s.l. Unlike Study Area 1, this primary division of the floristic data did not correspond with the recognised boundary between the temperate Alpine Belt and the subtropical Subalpine Belt (Chapter 3.2 & Figure 4.9). Although the indicator species for group 0 were temperate grass species and subtropical species characterized group 1 (Figure 4.11), there were sites in group 0, especially those in VC3 and VC4, whose swards were dominated by subtropical
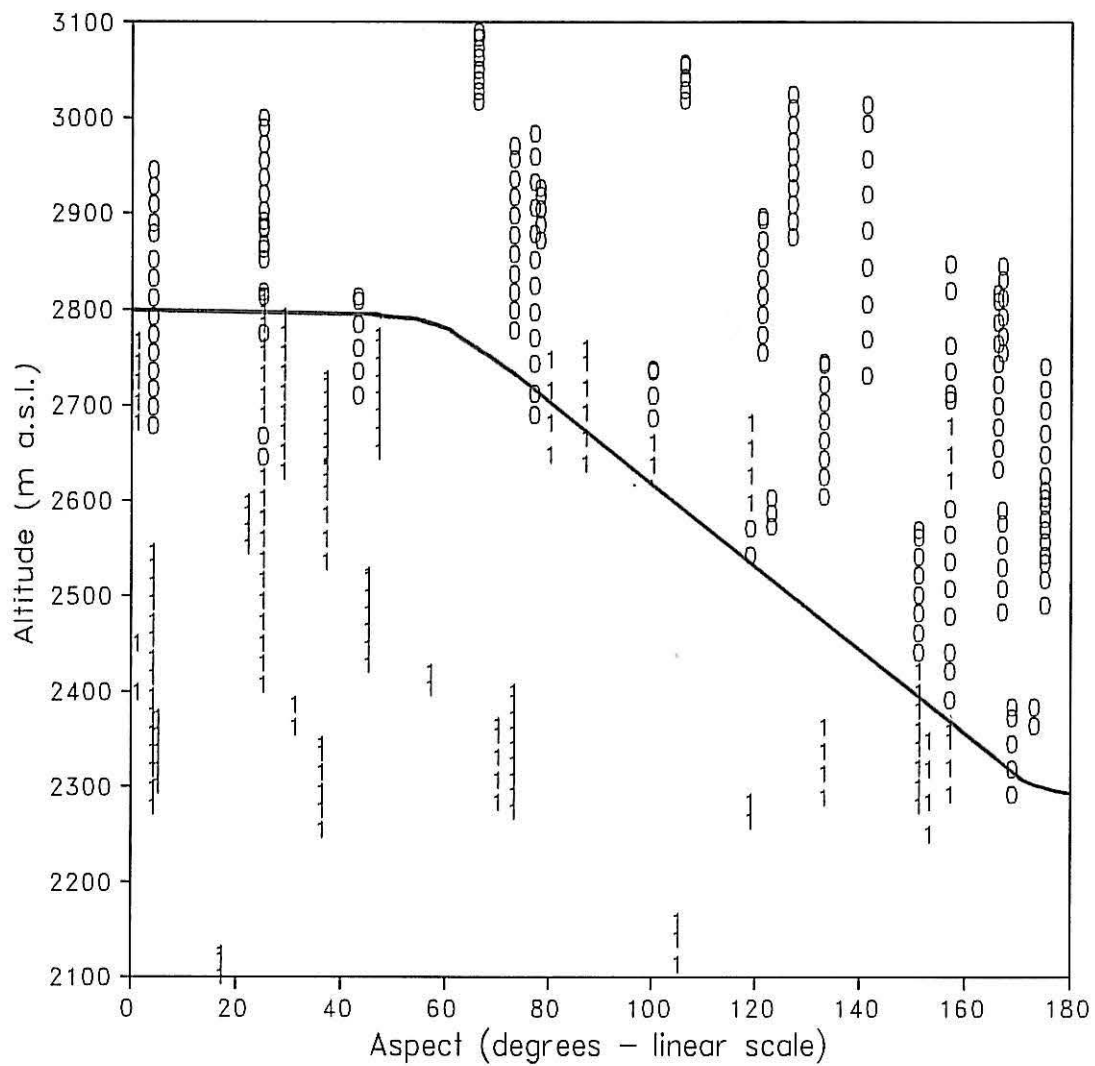
Figure 4.15 The approximate elevation boundary between the two vegetation groups (0 & 1) identified at level 1 of the TWINSPAN classification of species composition data from Study Area 2, western Lesotho.

species (Figure 4.13). The median proportion of C_3 grass species in group 0 was 69.6% (with a range of 14-100%), and in group 1 it was 7.5% (with a range of 0-72%). This confirmed that the classification was an artificial division of a floristic continuum that occurred gradually across the landscape.

Altitude, usually in combination with aspect, was the environmental variable that could be used to discriminate between groups at most of the dichotomies of the classification dendrogram (Figure 4.14). The exceptions were: (1) the split between VC3 and VC4, which was characterized by differences in aspect (Table 4.8); and (2) the division between VC5 and VCs 6 & 7, where slope and altitude were the best discriminating variables (Figure 4.14).

The four vegetation groups at level two of the dendrogram (Figure 4.11) occupied successively lower elevation zones in the study area. The mean altitude of each of these four groups, from left to right in the dendrogram, was: 2 814 m; 2 728 m; 2 552 m; and 2 342 m, respectively. The vegetation in each group descended to lower elevations on southern than on the northern aspects. A schematic diagram depicting the topographic distribution of the seven vegetation communities within these four vegetation/elevation belts is presented in Figure 4.16. The estimated area occupied by the seven vegetation communities and the expected extent of flooding of each community by the Katse reservoir is given in Table 4.9 (Anon. 1993).

The *Themeda triandra/Eragrostis curvula* subtropical grassland (VC5) was the most extensive vegetation community in Study Area 2 (Table 4.9). It was found on all aspects within a specific elevation zone (Figure 4.16). In contrast, the *Merxmuellera* temperate grassland (VC1) occupied only a small proportion of the study area and was confined in its distribution to areas above 3 000 m a.s.l. on east and west-facing slopes and above 2 800 m a.s.l. on cooler aspects (Figure 4.16). There was little high-elevation land in Study Area 2 compared to Study Area 1. Consequently, temperate grasslands (VCs 1 & 2) were less extensive in Study 2 than they were in Study Area 1. Also limited in its distribution in the

study area, was the *Catalepis gracilis* subtropical grassland (VC6), which occurred only on the flatter areas in the elevation zone between 2 300 m and 2 425 m (Figure 4.16).
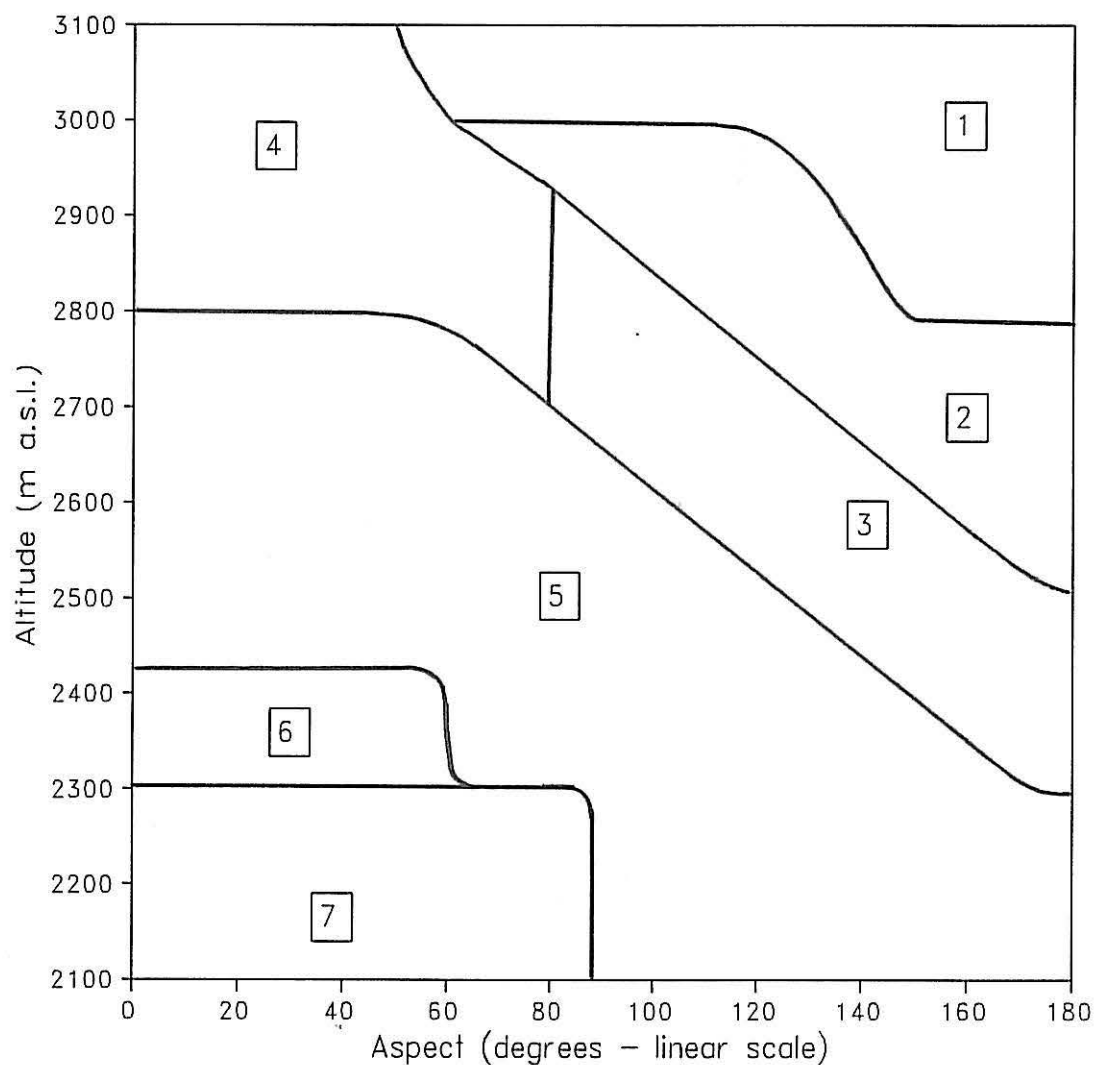
Figure 4.16 A schematic diagram depicting the topographic distribution of the seven vegetation communities identified in Study Area 2, western Lesotho.

Table 4.9   The area occupied by the seven vegetation community types and the
estimated extent of flooding of each vegetation community by the
Katse reservoir in Study Area 2, western Lesotho.

	Vegetation community						
	1	2	3	4	5	6	7
Total area (ha)	1 444	3 262	5 642	2 304	28 313	5 710	14 147
Percentage of study area	2.4	5.4	9.3	3.8	46.6	9.4	23.3
Area to be flooded (ha)	0	0	0	0	1 362	0	2 219
Percentage to be flooded	0	0	0	0	4.8	0	15.7

The *Cymbopogon plurinodis* subtropical grassland (VC7) was the second largest
vegetation community in the study area and it is the community which will be most
extensively flooded on completion of the Katse dam (Table 4.9). It occurred in the
river valleys below 2 300 m a.s.l. (Figure 4.16). Those low, warm valleys, which
are often steep-sided, are inherently prone to accelerated soil erosion as a
consequence of a prevailing ustic soil moisture regime, where plants may
experience a soil water deficit during the growing season (Chapter 2). Due to their
proximity to villages, these valleys are extensively cultivated (*c.* 35% of the total
area of VC7; Anon. 1993) and are subject to excessive grazing pressure, resulting
in severe soil erosion in places (Anon. 1989; Anon. 1993). In contrast, there was
little sign of accelerated soil erosion in the high-elevation temperate grasslands
(VC1 & VC2), where high vegetation cover afforded adequate protection for the
soil (Anon. 1989; Anon. 1993).

There was a significant difference (P<0.001) in vegetative basal cover (as indexed
by BAI) between the seven vegetation communities. In general, the trend in BAI
between communities was one of increasing BAI (and hence declining cover) with
a decrease in altitude and a shift in aspect from southerly to north-facing slopes
(Figure 4.17). The exception was VC6, which had lower BAI values than other

communities at comparable elevations and aspects. Cover in this community was largely afforded by *C. gracilis*, which forms dense mats. Cover was consistently high in the high-lying temperate grasslands (VCs 1 & 2) and particularly low in many sites in VC5, especially those occurring on northerly aspects.
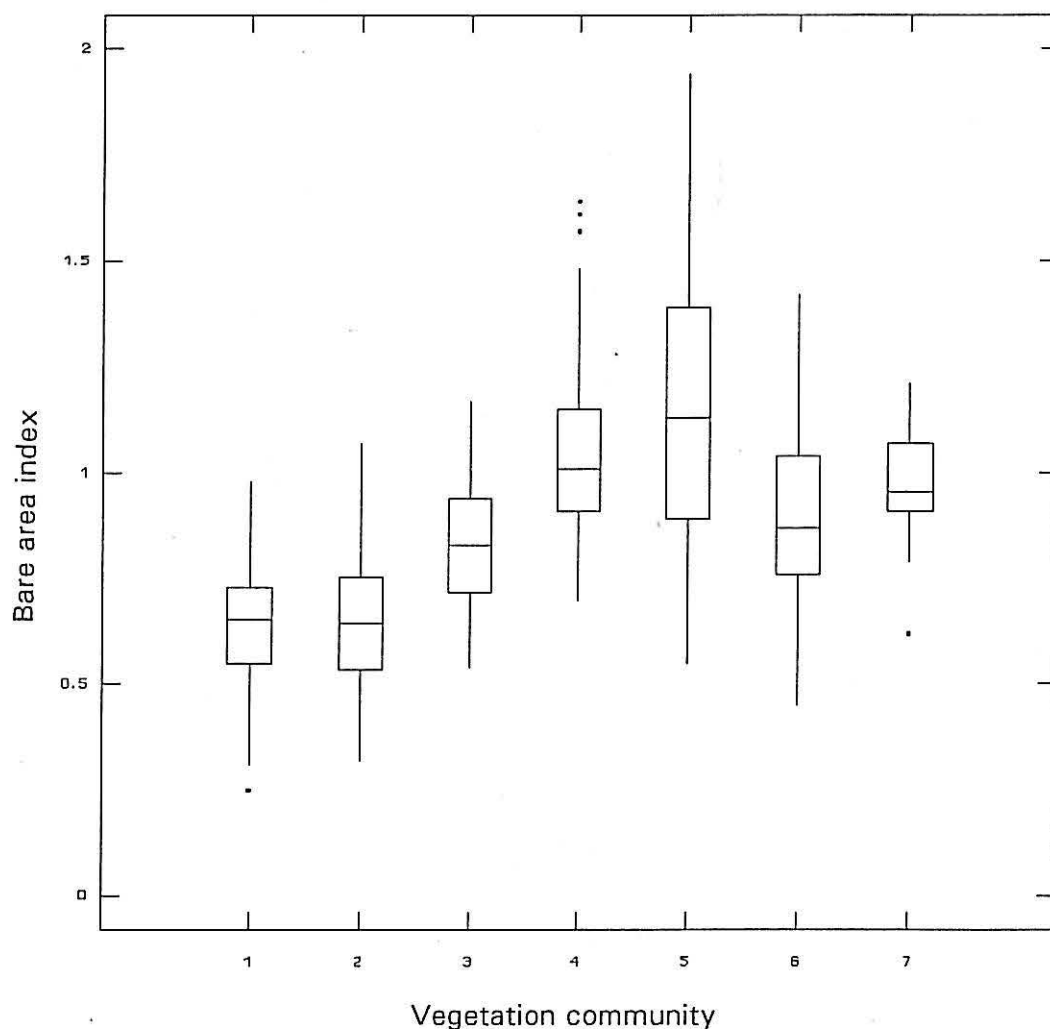
Figure 4.17 A Box and Whisper plot of the variation in cover (indexed by the 'bare area index' (BAI)) in each of the seven vegetation communities identified in Study Area 2, western Lesotho. The horizontal bar represents the median, the middle two quartiles are enclosed within the box and the vertical line indicates the data range. Outliers are also indicated.

4.4 Discussion

The results of gradient analysis in both study areas indicate that topography, especially elevation, has a large influence on species composition variation in the mountains. This has been recognised in previous ecological surveys conducted in Lesotho (Chapter 3.2.) and in the Natal Drakensberg (Killick 1963; Walker 1988; Burgess 1991). Therefore, vegetation strata can be defined primarily on the basis of elevation.

There is no direct correspondence between previous vegetation classifications in Lesotho and those presented in this study. Neither do the classifications for the two study areas completely coincide. The primary reason for these disparities is that each data set was classified independently and the resultant classification is optimal for the particular area. Consequently, vegetation classes may not correspond between classifications. Further, studies differed in terms of the sampling methodology and sampling intensity employed. Individual species also differed in abundance between areas, for example *H. sessilioides* was an indicator species in Study Area 1 (Figure 4.5) where it was abundant in the high elevation temperate grassland (Table 4.5). In contrast, *H. sessilioides*, occurred at only low abundances in Study Area 2 (Table 4.7).

However, there are some general similarities between classifications. The vegetation communities in both study areas are arranged along a temperate/subtropical grass species continuum which is associated with a gradient in elevation and aspect. This pattern, which has previously been described in Lesotho (Staples & Hudson 1938; Jacot-Guillarmod 1971; Wieland 1982) and in mountains elsewhere in the world (Livingstone & Clayton 1980; Rundel 1980), is implicit in the local categorization of the mountain grasslands as *letsiri* (temperate) and *seboku* (subtropical) grasslands (Chapter 3). The recognised elevation boundary between the temperate Alpine Belt and the subtropical Subalpine Belt coincides with the primary division of the floristic data in Study Area 1 but not in Study Area 2.

The topographic variables (altitude, aspect & slope) that were used to differentiate between vegetation communities in the present study are variables that are themselves associated with a suite of other interconnected variables (Whittaker 1967; Baruch 1984). Therefore, they are known as complex variables (Austin *et al*. 1984). Elevation varies concomitantly with temperature, growing season duration, precipitation, humidity, wind velocity, atmospheric pressure and evaporation (Whittaker 1967). Aspect has a marked effect on soil moisture and soil temperature regimes (Granger & Schulze 1977). Further, altitude and aspect do not have a direct physiological effect on plant growth and survival (Austin & Cunningham 1981). They merely serve to modify factors that directly determine the growth and performance of plants, *viz.* nutrients, water, temperature and light (Austin *et al*. 1984). The relationships between the indirect environmental variables and direct plant growth factors may be location specific (Austin & Cunningham 1981). Consequently, the relationship between plant species gradients and complex variables such as altitude and aspect may vary between areas and boundaries between vegetation communities may be location specific (Margules & Austin 1991). This appears to be the case in the present study.

Depending on the purpose of the study, it may be sufficient to use indirect environmental variables to predict the distribution of individual plant species or vegetation communities. However, it has been argued that predictability can be increased if indirect environmental variables are expressed in terms of gradients in resource availability (e.g. nutrient availability, soil moisture, light etc) (Austin *et al*. 1984; Scholes & Walker 1993). To do this, resource levels have to either be measured in the field - which is difficult and expensive - or scalars need to be derived that represent resource availability (e.g. Waring & Major 1964; Austin 1987). However, it is also difficult to calculate scalars that realistically represent levels of resource availability at the immediate interface with the plant (Austin *et al*. 1984).

An alternative approach is to model the spatial and temporal variation of factors that provide direct input of resources into the ecosystem, *viz.* rainfall and solar

radiation. In the mountains of Lesotho, where the soil nutrients are uniformly distributed across the landscape through leaching (Anon. 1993) and where the soil parent material is invariable (Klug et al. 1989), solar radiation (insolation) and rainfall patterns are expected to have a major influence on vegetation pattern. Insolation patterns may be especially important in determining plant distribution in mountainous terrain because light and temperature regimes as well as soil moisture dynamics are governed by insolation (Chapter 2). The modelling of spatial insolation patterns in the mountains in order to investigate the relationship between insolation and vegetation pattern is presented in the following chapter.

4.5   Conclusions

1.   Changes in the species composition of the vegetation in the mountains of Lesotho occur primarily along altitude and aspect gradients. These topographic variables are interconnected with a suite of environmental variables and they themselves do not have a direct physiological effect on plant growth and distribution. Therefore, the use of environmental factors that have greater relevance to plant performance and distribution (e.g. insolation) may improve the understanding of vegetation pattern in the mountains.

2.   Floristic change in the mountains occurs gradually across the landscape and classification imposes an artificial structure onto the data. However, the communities identified in each study area occur consistently in particular topographic positions in the landscape and the classification provides a useful stratification for description as well as for management and monitoring purposes.

CHAPTER 5

THE INFLUENCE OF SOLAR RADIATION ON VEGETATION PATTERN

5.1   Introduction

In the previous chapter it was demonstrated that floristic pattern in the mountains of Lesotho is closely allied to topographic variation and that vegetation communities occupy specific topographic positions in the landscape.   It was proposed that modelling solar radiation (insolation) patterns may serve to explain the distribution of vegetation communities because insolation is a climatic factor that has a direct influence on plant growth and survival

Insolation is a fundamental variable in the plant/soil continuum (Barry & van Wie 1974; Yoshino 1975; Granger & Schulze 1977; Scholes & Savage 1989). Insolation and rainfall are the forces driving plant growth (Lee 1963; Austin *et al*. 1984). Insolation directly determines the light and temperature regime experienced by plants and affects soil moisture dynamics through its influence on evapotranspiration (Schulze 1974). Therefore, the distribution and productivity of plant communities are expected to be closely related to the spatial distribution of insolation (Barry & van Wie 1974; Granger & Schulze 1977).

Radiant energy is also a driving force in the hydrological cycle (Lambson 1988), affecting both soil moisture balances and streamflow response (Lee 1963; Lambson 1988).   Geomorphological processes, such as fluvial erosion and cryogenesis, are also influenced by insolation (Schulze 1975).   Differential insolation loadings on opposite aspects has been implicated as a causal mechanism for the valley asymmetry observed in Lesotho and the Drakensberg (Klug *et al*. 1989; Meiklejohn 1992).

The considerable spatial and temporal variation in insolation in mountainous terrain results in a corresponding variance in ground and air temperatures (Schulze 1975; Yoshino 1975).   Inhabitants of such areas have long since appreciated this as

evidenced by their settlement and land-use patterns (Garnett 1935). Sunny ('warm') slopes are preferred by both man and livestock to the shaded, 'cooler' slopes. On landscape positions where insolation loads are high, snowmelt rates are high and frost duration is limited, resulting in a longer growing season than on slopes with a lower insolation receipt (Barry & van Wie 1974) .

Insolation loadings on sloping terrain at a particular time are largely determined by the inclination and the orientation (aspect) of the slope (Schulze 1975). It is significant that the word 'climate' in its original Greek form meant "to slope or incline" (Geiger 1957). Aspect and slope effects on insolation are greatest at mid-latitudes and least at the equator and the poles (Holland & Steyn 1975). The amount of insolation incident on a slope is also a function of its elevation, which determines the path length of incident solar beams through the atmosphere and hence the degree of attenuation by atmospheric factors, e.g. dust and water vapour (Schulze 1975). Even microrelief can have a marked influence on temperature patterns. For example, Grab (1992) measured a difference of 9.1 °C between the sun-facing and the shaded side of frost-hummocks (c. 0.35 m high) in a high altitude wetland in Lesotho. This temperature differential persisted to 30 cm below the hummock. Because topography, through its influence on insolation, extensively modifies the local climate of the area, the term 'topoclimate' has been suggested (Thornthwaite 1954) to describe the effect of topography on climatic variables such as insolation, temperature and wind patterns.

It has been extensively reported that certain plant species and vegetation communities occur exclusively on slopes of specific orientation and inclination and that vegetation on opposing aspects can be markedly different (Chapter 3; Holland & Steyn 1975; Cowling 1983). At high altitudes, vegetation differences on opposite aspects are particularly pronounced (Holland & Steyn 1975) but such differences are apparent even at low altitudes. For example, outside Pietermaritzburg at an altitude of c. 700 m, closed canopy bush is confined to steep south-facing slopes whereas the north-facing aspects and the adjacent flat areas are occupied by open savanna (Aitken 1922). Most authors have implied or

stated that such differences in vegetation on different aspects can be attributed to insolation induced differentials in temperature and/or soil moisture (e.g. Staples & Hudson 1938; Wieland 1982; Walker 1987). Consequently, attempts have been made to model the spatial distribution of solar radiation to explain observed vegetation patterns (Granger & Schulze 1977; Holland *et al*. 1977; Kirkpatrick & Nunez 1980; Austin & Cunningham 1981; Kirkpatrick *et al*. 1988).

5.1.1 Modelling the spatial distribution of insolation

Various tables, algorithms and computer programs of varying complexity have been used by geographers, hydrologists and ecologists to calculate insolation budgets at given points in time and space (e.g. Frank & Lee 1966; Garnier 1968; Rouse & Wilson 1969; Fuggle 1970; Schulze 1974 & 1975; Swift 1976; Granger & Schulze 1977; Schulze & Lambson 1986a). These models employ unit co-ordinate vectors to express the geometric relationships between incoming solar rays and slopes of varying aspect orientation and inclination. The following is a brief description of the basic conceptual framework of these models (Schulze 1975).

Total incoming (global) shortwave insolation comprises both direct and diffuse (scattered) components. The intensity of direct insolation received by a horizontal surface is dependent on: (1) the intensity of incoming insolation at the top of the atmosphere, i.e. extraterrestrial solar radiation (a function of the solar constant and the earth's distance from the sun); (2) attenuation by the earth's atmosphere (a function of site elevation, water vapour and aerosols, e.g. dust and pollutants); (3) attenuation by clouds; and (4) the angle of incidence of the solar beam on the earth's surface (a function of latitude, time of year and time of day). The intensity of diffuse radiation is primarily a function of solar angle and cloud cover.

On sloping terrain one component changes, i.e. the angle of incidence of the solar beam on the slope. This angle is determined by the inclination and orientation (aspect) of the slope as well as solar altitude. The slope may receive only diffuse radiation during cloudy times during the day or when the sun disappears behind the skyline and the slope is shaded.

A logical extension to modelling insolation patterns in mountainous terrain is the calculation of the effects of insolation on closely related climatic variables, *viz.* temperature and potential evaporation (PE), as these factors also affect plant growth. In order to do this, energy budgets need to be computed, accounting for incoming shortwave insolation, reflected shortwave insolation as well as outgoing longwave radiation. These radiant energy loadings can then be used in a radiation-based equation for estimating PE (Schulze & Lambson 1986a). Surface temperatures, which influence PE and the emission of longwave radiation by the surface, can also be calculated from incoming insolation (adjusted for slope and aspect) as there is a linear relationship between daily incoming insolation and daily temperature (Chang 1971 cited by Schulze & Lambson 1986a).

Schulze and Lambson (1986a), in a review of radiation simulation models, noted that many models contain various omissions, oversimplifications and assumptions that reduce their accuracy. In particular, they do not adequately account for attenuation of incoming insolation by the atmosphere and clouds, the shading and reflective effects of surrounding topography and the reflective properties of the surface (albedo), which exhibits seasonal and diurnal variation. A radiation simulation computer model, known as RADSLOPE, has been developed by Schulze and Lambson (1986a) to correct for assumptions and simplifications inherent in earlier tables and models. In addition, RADSLOPE calculates surface temperatures from radiant energy loadings as well as PE (Schulze & Lambson 1986a).

5.1.2 The RADSLOPE simulation model

RADSLOPE is a user oriented computer model for the simulation of insolation budgets on sloping terrain (Schulze & Lambson 1986a). It requires only modest climatic and site topographic information input. The features incorporated in RADSLOPE to improve on earlier radiation models include:

1. improved estimation of atmospheric transitivity and attenuation of incoming insolation by cloud cover;

2. estimation of the effect of topographic shading on sunshine duration - this

effect can be considerable in deeply dissected terrain (Turner 1966 cited by Schulze & Lambson 1986a);

3.   accounting for the contribution of reflected radiation from surrounding terrain; and

4.   the estimation of surface temperatures, outgoing longwave radiation fluxes and PE.

RADSLOPE requires only basic climatic data from a nearby reference climate station, *viz.* screen air temperature, relative humidity and wind. The topographic information required by RADSLOPE for each study site includes elevation, aspect, slope gradient, and a description of the horizon profile in the vicinity of the site for the estimation of topographic shading effects.

The theoretical background as well as details of the algorithms, equations and computer subroutines employed in RADSLOPE are given by Schulze & Lambson (1986a & 1986b) and Pike (1991). The basic formulation of RADSLOPE is outlined below.

5.1.2.1 Model formulation

In RADSLOPE the available incoming insolation for a particular day of the year is computed for short iterative periods (15 or 60 minutes) between sunrise and sunset and then summed to obtain a daily total radiation flux density ($J\ m^{-2}\ day^{-1}$). The total available incoming radiation (RAAL) for a given iterative period of time (I) of a day is calculated as:

RAAL(I) =   [SCONST*MINS*sinALTI*(ATDIM/DCF)*(XX(I)+(1-(I))*CLOUDP)+
DIFUS]*(1-ALBEDO) + RADOP(I)

where:

SCONST   =   value of the solar constant (1 374 $W\ m^{-2}$);

MINS   =   number of minutes per iterative period;

ALTI   =   angle of incidence between the sun's rays and the inclined surface;

ATDIM   =   coefficient of atmospheric transmissivity;

DCF	=	earth's radius vector, i.e. an expression of the variable distance between the sun and the earth;
CLOUDP	=	attenuation of incoming radiation by clouds;
DIFUS	=	diffuse radiation;
ALBEDO	=	reflection coefficient of the surface;
XX(I)	=	fraction of sunshine for period I; and
RADOP	=	reflected shortwave radiation from surrounding surfaces.

The angle between the suns rays and the inclined slope (ALTI) at a particular site is a determinant of when topographic shading will occur. Topographic shading involves both shading of the slope by itself (i.e. when the sun is behind the slope and the angle ALTI is less than that of the slope gradient) or shading of the slope by the skyline. When this happens only diffuse radiation is received at the site. The horizon profile at each site is described by an array of angles between the site and the skyline, measured at 20 degree intervals, clockwise from north. These angles are obtained from a topocadastral map.

Atmospheric transitivity (ATDIM) is usually given an assumed constant in radiation models. However, in RADSLOPE it is calculated as a function of: (1) the optical air mass (i.e. an expression of the relative length of the solar beam passing through the atmosphere at a given angle); (2) aerosol particle concentration; (3) atmospheric pressure (a function of altitude); and (4) total precipitable water vapour content in the atmosphere (derived from temperature and humidity data recorded at a nearby climatic reference station).

The attenuation of incoming insolation by clouds (CLOUDP) is calculated for eight cloud types, each with a different transmission coefficient. Diffuse radiation (DIFUS), which is influenced by cloudiness, is derived from empirical relationships between solar altitude and diffuse radiation and is corrected for its depletion on sloping terrain.

The amount of incoming shortwave radiation that is reflected by a particular

surface depends on the reflective properties of the surface and the angle of incidence of the solar beam (i.e. time of day). The reflective properties of the surface are characterised by the value of albedo for different surface types (ALBEDO). In accounting for shortwave radiation reflected from surrounding terrain onto the point of interest (RADOP), the surrounding terrain is assumed to have the same reflection coefficient and slope gradient as the point, but an opposing aspect (by 180°).

Outgoing longwave radiation from the sloping surface is calculated as a function of the following: (1) the relative emissivity of the surface; (2) a factor to account for atmospheric counter-radiation of longwave radiation - the ratio of global to extraterrestrial radiation; (3) actual vapour pressure; and (4) the estimated temperature of the sloping surface. The surrounding terrain will intercept outgoing longwave radiation, hence longwave radiation estimates need to be reduced by the amount of longwave radiation intercepted by the surrounding terrain. This is done in a manner similar to that used to correct for reflected shortwave radiation from surrounding topography.

The net radiation loading at a site, i.e. the difference between incoming shortwave radiation and outgoing longwave radiation, is used in the Penman (1948) combination equation to estimate PE. Therefore, temporal and spatial variation in PE in sloping terrain will be closely allied to variation in radiation. Other climatic variables that influence PE are wind and vapour pressure (which is a function of temperature).

The surface temperatures (mean screen air temperatures) used to calculate outgoing longwave radiation fluxes are obtained from a nearby reference climatic station. Because the reference station is usually situated on a unobstructed horizontal surface, temperatures need to be adjusted to account for differences in altitude, slope and aspect, between the point of interest and the reference climate station. The prevailing lapse rate is used to make the temperature adjustment for altitude. To account for temperature differences due to aspect and slope, the

linear relationship between daily global insolation and daily temperature is employed. The specific relationship between temperature and radiation varies between the major climate regions of Köppen (Köppen & Geiger 1936 cited by Strahler 1975). Functions predicting temperature from global insolation are available for each Köppen region (Chang 1971 cited by Schulze & Lambson 1986a).

5.1.2.2 Model verification

RADSLOPE has been incorporated as a subroutine into the Kentucky Watershed Model for the prediction of snowmelt (Lambson 1988) and into a spatial analysis model (terrain analysis model) for the automated calculation of insolation and PE fluxes in watersheds (Pike 1991). Verification tests conducted on flat terrain at Pietermaritzburg in Natal (Schulze & Lambson 1986a), and in steep canyon-like terrain in Utah (Pike 1991), indicated that RADSLOPE accurately simulates global insolation intensities on clear days ($r^2 > 0.95$). However, on cloudy days, RADSLOPE performs poorly (r^2 values often < 0.1). Inaccurate cloud type assessment as well as difficulty in specifying cloud thickness and layering, contribute to the poor simulation of insolation on cloudy days (Pike 1991). However, it is more important to accurately predict insolation patterns during the autumn, winter and spring periods, when insolation differences due to slope and aspect in mountainous terrain are at a maximum and skies are usually clear, than during the cloudy summer months when insolation differences between aspects are at a minimum (Schulze 1975; Granger & Schulze 1977). Further, insolation on cloudy days is largely diffuse and at low intensities.

5.1.3 Objectives

RADSLOPE was used to simulate seasonal patterns of potential insolation, temperature and PE at each study site in Study Area 1 in order to address the following questions:

1. Do the vegetation communities in Study Area 1 experience different insolation, temperature and PE regimes?
2. At what time of the year are these differences at a maximum?
3. Is the balance of subtropical (C_4) and temperate (C_3) grasses in the herbaceous layer related to insolation determined, temperature differences?
4. Does the use of a direct plant growth factor like insolation, rather than an indirect environment variable (*viz.* altitude, aspect or slope) improve the prediction of vegetation pattern?

5.2 Methods

Insolation loadings for each of the 88 plots in Study Area 1 were simulated using RADSLOPE (Schulze & Lambson 1986a). Study Area 1 was chosen to test the relationship between vegetation and insolation patterns because the plots in Study Area 1 were widely dispersed over the landscape, thereby providing a range in possible insolation conditions. The horizon profile in the vicinity of each site, which is used in RADSLOPE to estimate skyline shading effects, could be readily determined for each site in Study Area 1 from a topocadastral map (1:50 000). The composition data from Study Area 2 were not included in the analysis because the sampling unit in Study Area 2 comprised overlapping segments of transects (Chapter 4). Because transects, rather than individual segments, were marked on the 1:50 000 topocadastral map, determination of the horizon profile for individual segments would be difficult and inaccurate.

5.2.1 Model input

The reference meteorological station used to provide climatic data for RADSLOPE is located at Letsêng-la-Draai (28°58'S, 28°52'E, 3 050 m a.s.l.), approximately 50 km north-west of Mokhotlong (Figure 2.1). Letsêng-la-Draai is situated in the

northern regions of Study Area 1 within the altitudinal limits of the study area. The only other climatic station that is close to Study Area 1 is located at Mokhotlong (2 377 m a.s.l.). However, this station is located below the lower limit of the study area (i.e. < 2 750 m a.s.l.) and is in the relatively warm and dry Senqu valley (Killick 1978a).

The climatic data required by RADSLOPE are monthly means for maximum and minimum temperatures and relative humidity. In RADSLOPE, mean daily temperatures for a particular month are derived from mean maxima and minima (*viz.* Tmean = (Tmax-Tmin)/2). These data have been recorded at Letsêng-la-Draai for an uninterrupted period of 18 years (1965-1982; Fincham *et al.* 1989). However, only 16 years of data are available for certain months. The mean monthly minimum and maximum temperatures used in the RADSLOPE simulations are given in Table 5.1. These temperature data are considered reliable (Killick 1978a; Fincham *et al.* 1989). However, the relative humidity data recorded at Letsêng-la-Draai displayed considerable variation between years and the seasonal humidity pattern was not consistent with altitude (Killick 1978a). Therefore, the default value for relative humidity in RADSLOPE (i.e. 50%) was used in the simulations.

The default values that were used in RADSLOPE for those parameters where unreliable data, or no data, were available were: (1) an atmospheric aerosol concentration of 0.4 particles cm^{-3} for the computation of atmospheric transmissivity; (2) a daily windrun, at a height of 2 m, of 100 km day^{-1}; (3) a local lapse rate of 6.5°C/1 000 m; (4) a surface reflectance value of 2.0 - typical of grassed surfaces - used to compute the percentage of direct radiation reflected by the surface (i.e. albedo); and (5) an emissivity coefficient of 0.98 used to calculate the skyward emission of longwave radiation by a 'non-black' surface (grassed surfaces typically have an emissivity coefficient of 0.98).

Table 5.1   Mean monthly temperatures (recorded at Letsêng-la-Draai) used in the
RADSLOPE simulation model (after Fincham *et al.* 1989).

Month	Temperature (°C)	
	Minimum	Maximum
January	5.4	16.5
February	4.8	15.2
March	3.6	13.7
April	-1.2	10.9
May	-3.3	8.6
June	-6.1	6.5
July	-6.0	7.1
August	-4.4	8.9
September	-1.0	11.9
October	1.0	13.0
November	2.6	13.3
December	3.1	15.5

RADSLOPE was run for clear-sky conditions only, thereby simulating potential insolation, potential temperatures and potential PE.   As discussed earlier, RADSLOPE performs poorly under cloudy conditions due to the problems of obtaining an adequate description of the timing and characteristics of the cloud layer.   There are no data describing the nature and timing of cloudiness in the Lesotho mountains.   The only available data are from the Cathedral Peak meteorological station in the Natal Drakensberg where the seasonal pattern of sunshine duration has been recorded (Schulze 1974).   These data were not considered to represent conditions in Study Area 1 because the extent and timing of cloudiness on the Lesotho side of the Drakensberg differs substantially from that occurring at Cathedral Peak due to the orographic effect of the escarpment (Killick 1978a).   Further, the data recorded at Cathedral Peak did not include a description of cloud type.

In the mountains of Lesotho, extensive cloudiness usually only occurs during summer when the topographically induced radiation variations are at a minimum (Killick 1978a; Granger & Schulze 1977). Consequently, the assumption of cloudless conditions would not have a marked effect on the calculation of

insolation loadings on different aspects.

RADSLOPE was run for each site for one day of each month of the year (the 15th day). Insolation was simulated for 60 minute intervals during the day and then summed to obtain daily global insolation flux density (MJ m^{-2} day^{-1}), mean daily temperature (°C) and PE (mm day^{-1}).

5.2.2 Data analysis

Analysis of variance (Steel & Torrie 1981) was used to test for differences, at each month, between the five vegetation communities in Study Area 1 in terms of their mean insolation loading, mean temperature and mean PE. Correlation analysis (Pearson's correlation coefficient) was used to investigate relationships between insolation, temperature, PE and topographic variables (altitude, aspect & slope) as well as the influence of monthly temperatures on the proportional representation of C_3 grasses in the herbaceous layer.

Canonical Correspondence Analysis (CCA) (ter Braak 1986) was used to describe the relative influence of altitude, aspect, slope and temperature on floristic and C_3 grass composition. Canonical Correspondence Analysis was performed via the program CANOCO (ter Braak 1985).

Canonical Correspondence Analysis is an ordination technique whereby species composition gradients are related directly to environmental variables rather than indirectly, as in most ordination procedures (Chapter 4.1). It is a multiple direct gradient analysis procedure that calculates the weighted linear combination of environmental variables (via multiple regression) that best explains each of the axes (dimensions) of variation in species composition. This is done during the reciprocal averaging process used to derive species and sample axes. The result is that the ordination axes depict the variation in species composition that can be directly attributed to the environmental variables. This differs from Correspondence Analysis (CA) in that ordination axes in CA represent dimensions of variation within the data, irrespective of the environmental variables (ter Braak 1987a). The

relationship between CA axes and the measured environmental variables is only established (via correlation analysis or multiple regression) subsequent to the ordination analysis.

In a CCA ordination diagram the relationship between the distribution of species and the environmental variables is displayed. The direction of influence of each environmental is represented in the ordination diagram by an arrow whose magnitude indicates the strength of the correlation between that variable and the ordination axes. As in CA, the importance of CCA ordination axes in depicting pattern within the data is indicated by their respective eigenvalues. Eigenvalues in CCA may be lower than those derived from a CA ordination of the data because the particular set of environmental variables that were measured may not explain all variation within the data set and some variation may be attributable to unmeasured factors or noise (ter Braak 1986). However, even if a CCA ordination explains a low percentage of the total variation in the data set, it can still provide an informative description of the relationship between species and the environment (ter Braak 1987a).

5.3 Results

The five vegetation communities identified in Study Area 1 (see Chapter 4) differed significantly in their mean insolation loads, mean temperatures and mean PE values during certain months of the year (Table 5.2). Differences between the communities in terms of their mean insolation loadings occurred during the non-summer months, whereas the communities experienced different temperature regimes throughout the year. The communities did not differ in PE during December and January.

Table 5.2   The F-ratio and associated significance level derived from an ANOVA between the five vegetation communities identified in Study Area 1, eastern Lesotho, in terms of monthly insolation, temperature and potential evaporation (PE).

Month	Insolation	Temperature	PE
January	0.436 ns	4.235 *	1.220 ns
February	3.503 *	10.504 ***	7.345 ***
March	7.170 ***	13.356 ***	11.238 ***
April	9.059 ***	13.680 ***	11.909 ***
May	9.775 ***	12.870 ***	11.632 ***
June	9.383 ***	12.033 ***	10.285 ***
July	9.724 ***	12.976 ***	11.654 ***
August	9.255 ***	13.065 ***	11.540 ***
September	8.461 ***	13.876 ***	11.669 ***
October	5.974 ***	13.098 ***	10.727 ***
November	0.662 ns	6.339 ***	2.881 *
December	1.494 ns	3.364 *	0.942 ns

ns   = non significant
*   = significant $(P \le 0.05)$
* *   = significant $(P < 0.01)$
* * *   = significant $(P < 0.001)$

The insolation, temperature and PE seasonal profiles in the five vegetation communities generally mirrored each other (Figures 5.1a,b & c). This was because incoming insolation receipts are used in RADSLOPE to calculate temperature and PE. Insolation differences between the five communities were at a maximum during winter (June) and minimal during summer (Figure 5.1a). The same was true for the seasonal temperature and PE patterns in the five communities (Figure 5.1b & c). The mean insolation flux density in June for the community which received the highest insolation load (VC5) was 1.7 times larger than the mean insolation in the community with the lowest winter insolation load (VC2). The temperature difference between these two communities in June was 9.6°C and the mean PE in VC5 was 2.3 times higher than that of VC2.
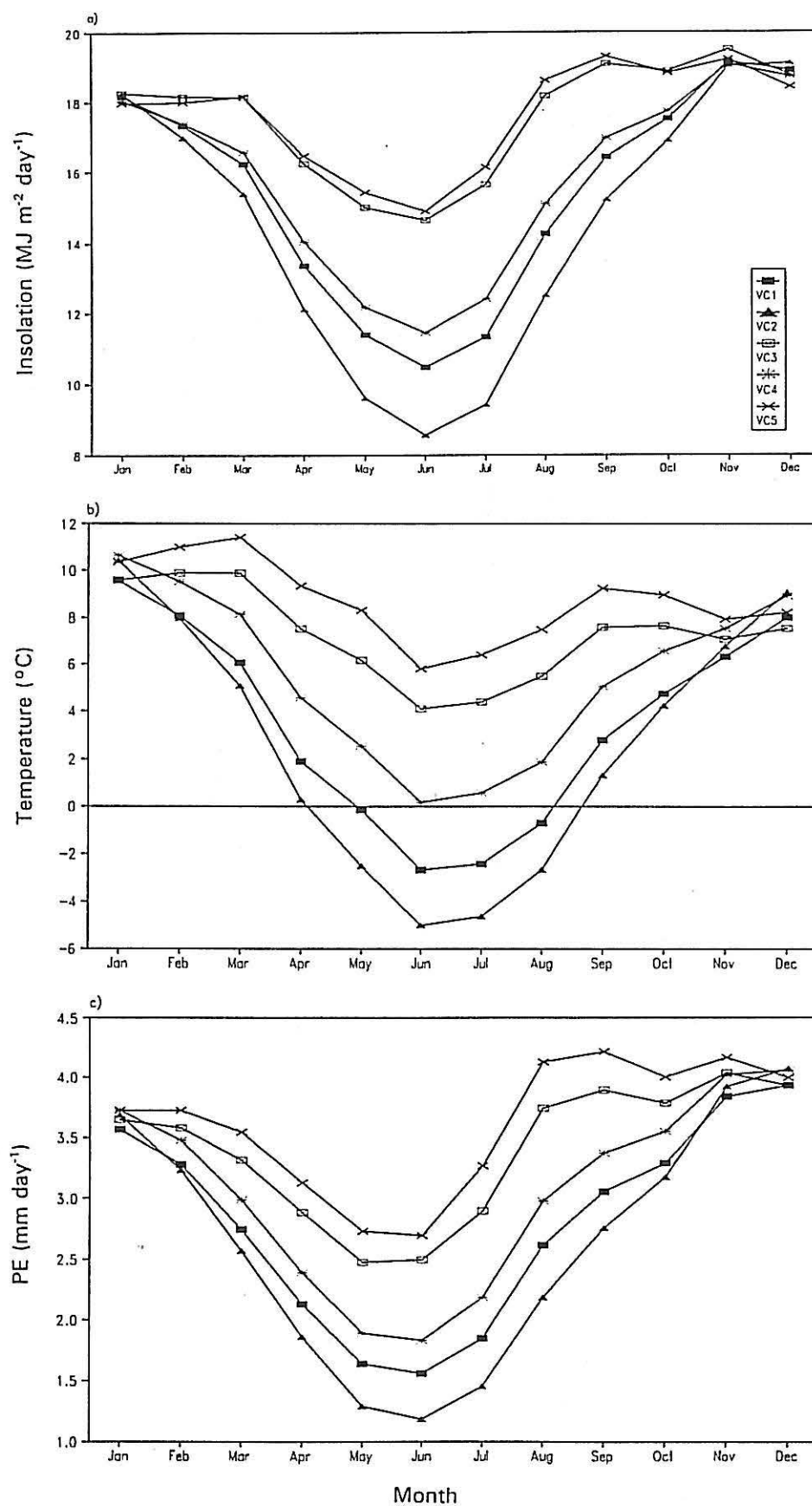
Figure 5.1   The seasonal trend in insolation (a), temperature (b) and potential evaporation (PE) simulated by the RADSLOPE model for the five vegetation communities (VCs) in Study Area 1, eastern Lesotho.

There was a large range in the June insolation loadings in the 88 survey sites. The highest insolation at a site (site no. 54: 19.32 MJ m^{-2} day^{-1}) was 4.7 times greater than the lowest insolation load (site no. 26: 4.08 MJ m^{-2} day^{-1}) and this resulted in a June temperature differential of 20.9°C. These two sites were situated on steep terrain, with slope angles of 29° (site no. 54) and 26° (site no. 26) (Appendix 1). They had a similar elevation (3 025 m & 3 000 m) but are were on opposite aspects, *viz.* 1° and 187°, respectively. It appears, therefore, that aspect has a large influence on insolation patterns during winter, especially on steep terrain.

Vegetation communities 3 and 5 were relatively similar in their seasonal insolation profiles compared to the other three communities (Figure 5.1a). The seasonal temperature and PE patterns for the five communities were more widely separated than their radiation profiles (Figures 5.1b & c). There appeared to be two distinct seasonal patterns within the five communities. In communities 3 and 5, insolation increased rapidly during the early spring months to reach a ceiling by September. This level was maintained through the summer months to decline again only in March (Figure 5.1a). Temperature and PE values in these two communities exhibited a similar summer plateau (Figures 5.1b & c). In contrast, the seasonal insolation, temperature and PE patterns of the other three communities (i.e VCs 1,2 & 4) reached a distinct mid-summer peak. The differences between the seasonal insolation profiles for the five communities are related to their contrasting topographic distributions. Communities 3 and 5 are confined to the northerly aspects in Study Area 1, whereas communities 1, 2 and 4 occur on southerly slopes (VCs 2 & 4) or at·high elevations on all aspects (VC1) (Figure 4.10).

The influence of aspect, altitude and slope on insolation, temperature and PE is indicated in Table 5.3. The correlation analysis was conducted for mid-summer (December) and mid-winter (June) values to account for the possible seasonal changes in the relative effect of different topographic variables on insolation, temperature and PE patterns (Schulze 1975).

Table 5.3   Correlations (during June and December) between insolation (RAD), temperature (TEMP), potential evaporation (PE), altitude (ALT), aspect (ASP) and slope (SLP) for the 88 sites in Study Area 1, eastern Lesotho.

June					
	RAD	TEMP	ALT	ASP	SLP
RAD	-	-	0.110ns	-0.920***	-0.134ns
TEMP	0.987***	-	-0.050ns	-0.912***	0.127ns
PE	0.991***	0.987***	0.058ns	-0.911***	-0.051ns
December					
	RAD	TEMP	ALT	ASP	SLP
RAD	-	-	0.013ns	0.181ns	-0.853***
TEMP	0.644***	-	-0.756***	0.186ns	-0.547***
PE	0.882***	0.919***	-0.445***	0.235*	-0.726***

ns   = non significant
*   = significant (P≤0.05)
**   = significant (P<0.01)
***   = significant (P<0.001)

As discussed earlier, insolation, temperature and PE were highly intercorrelated, especially during winter (Table 5.3). Aspect differences had an overriding influence on insolation, temperature and PE during winter (Table 5.3). South-facing aspects had low insolation receipts, resulting in cool temperatures and low PE values. Insolation levels during summer were determined solely by slope inclination, with the steeper slopes receiving less insolation than the flat areas (where the solar angle of incidence was close to 90°). Summer temperatures were largely determined by elevation rather than aspect. These results confirm observations by Schulze (1975) concerning the relative role of slope and aspect in influencing summer and winter insolation and temperature patterns.

Temperature influences the balance of temperate and subtropical grasses in the herbaceous layer as indicated by the significant (P<0.001) negative correlation between the temperatures simulated for each month at each site and the

proportion of C_3 grass species in the sward (Figure 5.2). Temperature, rather than insolation or PE, was used in the analysis as previous research in southern Africa has demonstrated the relationship between the distribution of C_3 grasses and temperature (Vogel *et al.* 1978). The correlation coefficient between temperature and C_3 grass proportion was lowest in December and highest in February and October (Figure 5.2). There was a decline in the magnitude of the correlation coefficient during the winter months.
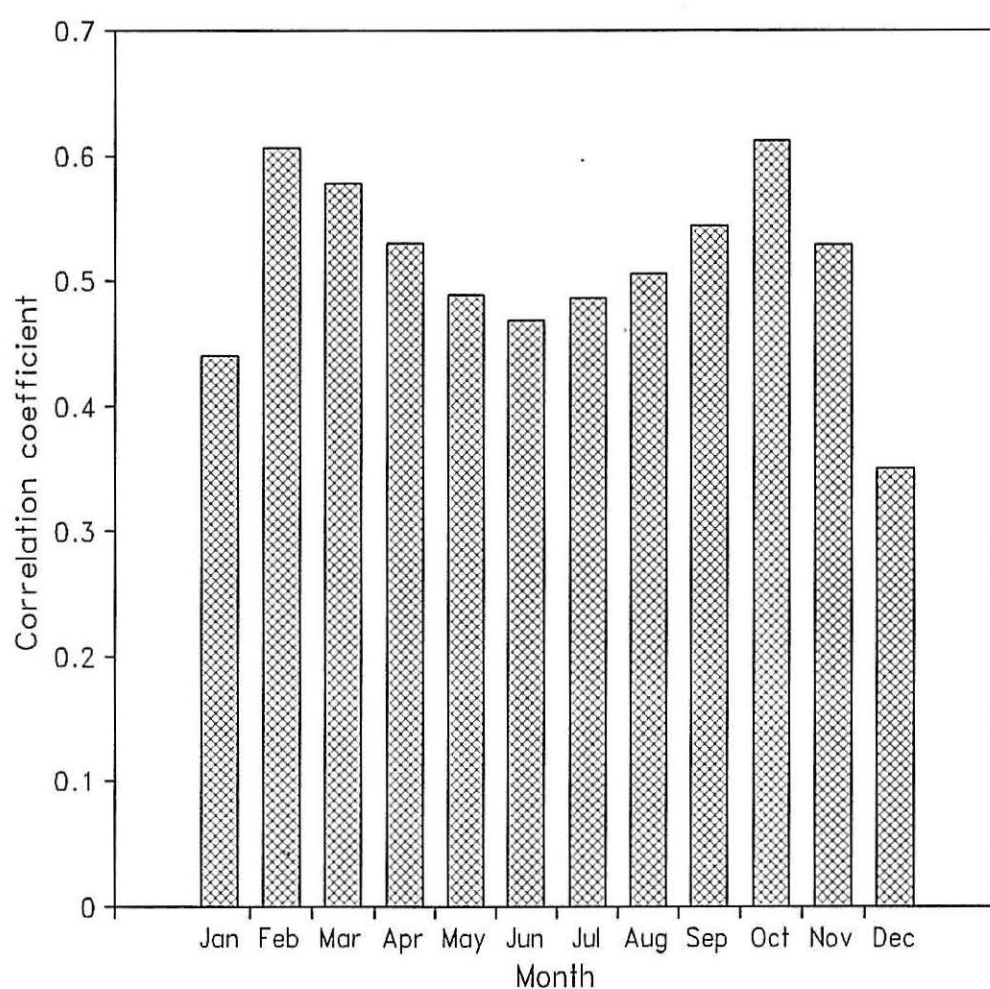
Figure 5.2 The correlation between monthly temperatures simulated by the RADSLOPE model and the proportion of C_3 grasses in the sward of 88 sites in Study Area 1, eastern Lesotho.

In the CCA ordination, axes 1 and 2 accounted for a large proportion (77%) of the variation in species composition that could be explained by the external variables used in the analysis (*viz.* topographic variables, the proportion of C_3 grasses and the mean October temperature (i.e. the month with maximum correlation with C_3 grasses)) (Table 5.4). Axis 1 represented a gradient from temperate to subtropical grasses, as indicated by the high negative correlation between C_3 grass proportion and axis 1 (Table 5.4). Variation along axes 2 was related strongly to an aspect gradient. October temperature was more closely correlated with CCA axis 1 than any of the topographic variables. This suggests that the dominant dimension of vegetation pattern in the study area is more closely related to temperature, which is a direct plant growth variable, than to the complex topographic gradients (*viz.* altitude, aspect and slope).

Table 5.4   The eigenvalues and the cumulative percentage variance of the species-environmental relationship (VAR) incorporated by the first four axes of a Canonical Correspondence Analysis (CCA) of species composition data from 88 sites in Study Area 1, eastern Lesotho. The correlations between the CCA axes and the topographic, climatic and floristic variables that were used in the analysis, are presented.

	CCA axis				
	1	2	3	4	Total inertia
Eigenvalue	0.464	0.117	0.087	0.058	3.830
VAR (%)	61.5	77.0	88.5	96.2	
Correlation					
Altitude	-0.613	0.377	-0.226	-0.621	
Aspect	-0.372	-0.896	-0.235	0.037	
Slope	0.081	-0.404	0.633	-0.399	
C_3 grass (%)	-0.989	0.013	0.135	0.047	
October temperature	0.671	0.497	0.128	0.236	

The distribution of the five vegetation communities in ordination space defined by CCA axes 1 and 2, reflects their distribution in the landscape (Figure 5.3). For example, the two high-elevation communities (VCs 1 & 3) were positioned towards the one end of the arrow representing the altitude gradient whereas communities 4 and 5, which occur at low elevations, were located towards the opposite end of the altitude gradient (Figure 5.3). The direction of the C_3 arrow was along CCA axis 1 and the communities with a temperate grass sward, i.e. VCs 1 and 2, were distributed towards the left of the ordination diagram, whereas the subtropical grasslands (VCs 4 & 5) were located on the right hand side of the ordination plot. These results corroborate those of the discriminant function analysis in Chapter 4.

The composition gradient along CCA axis 1 was correlated with altitude as well as with October temperature (Table 5.4). However, the influence of altitude on composition was independent of that of October temperature because their respective arrows in ordination space were at a wide angle to each other (Figure 5.3). The direction of influence of October temperature was close to that of aspect but in an opposite direction. These results suggest that altitude may be affecting floristic variation and the balance of temperate and subtropical grasses in the sward in a way that is independent of its effect on species composition via temperature.
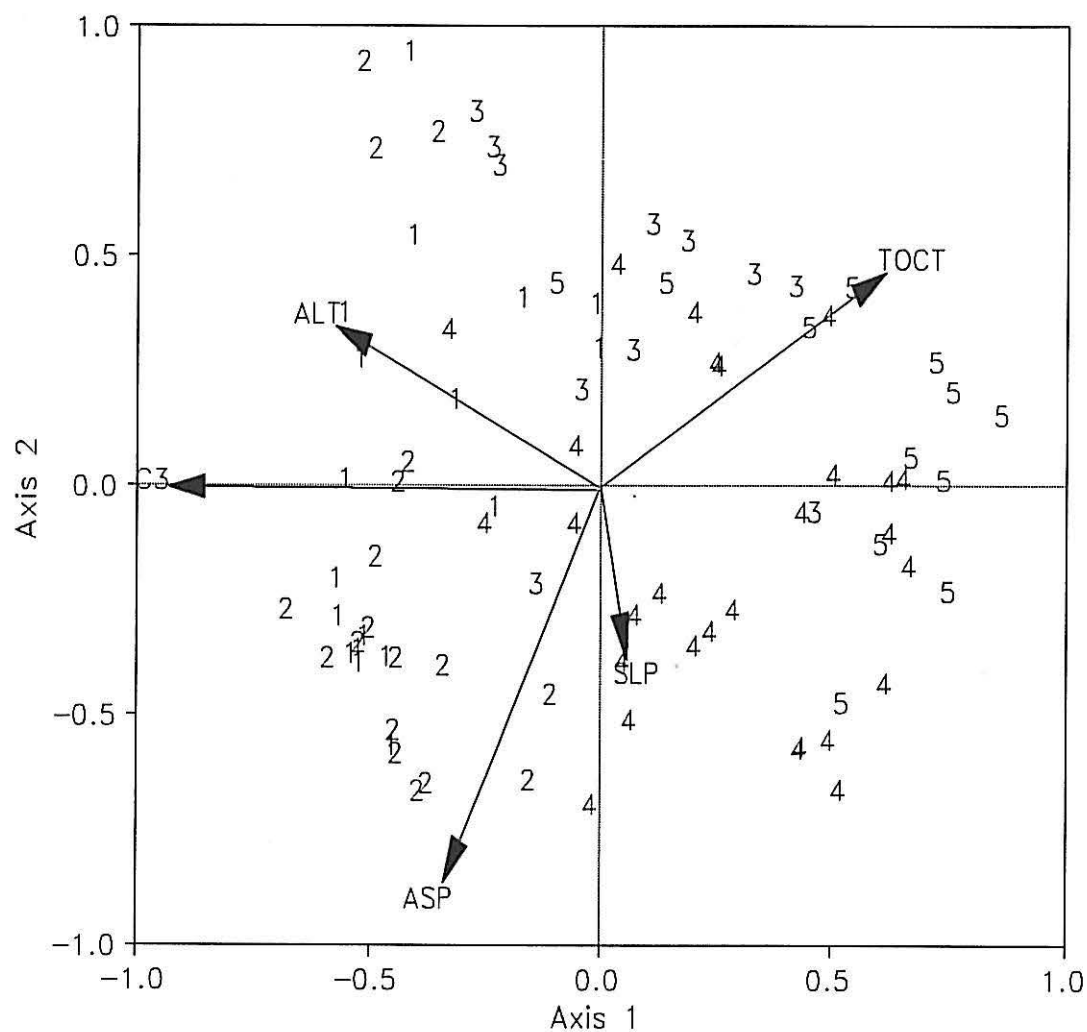
Figure 5.3   A Canonical Correspondence Analysis ordination plot of 88 sites belonging to the five vegetation communities (VCs) in Study Area 1, eastern Lesotho. The arrows indicate the direction of influence in the ordination plot of the variables: altitude (ALT); aspect (ASP); slope angle (SLP); the proportion of C_3 grasses in the sward (C3); and October temperature (TOCT).

5.4 Discussion

The results of the radiation simulation modelling indicate that insolation is an important determinant of vegetation pattern in Study Area 1. The deeply dissected terrain of the mountains serves to create a heterogenous mosaic of insolation, temperature and evaporative demand across the landscape. In particular, aspect has an important influence on insolation pattern. These aspect differences are accentuated in Study Area 1 because most of the valleys lie on an east-west orientation (Meiklejohn 1992). At certain times of the year, north-facing slopes receive direct sun all day whereas steep south-facing slopes may receive no direct sunlight at all.

The distribution of temperate and subtropical grasses in Study Area 1 was related to temperature patterns as determined by insolation. Terri (1988), in a review of studies from various areas in the world, noted that there was often a positive and near-linear correlation between growing season temperature and the percentage of C_4 grasses in the sward. In African mountains (Livingstone & Clayton 1980) and in Hawaii (Rundel 1980), the change from subtropical grasses at low elevations to temperate species at high altitudes has been attributed to a temperature gradient.

It has been suggested that the distribution of C_4 grasses in the upper Drakensberg and Maluti mountains is limited by low temperatures during the growing season, in particular summer nightly minima below 10°C (Vogel *et al.* 1978). Low temperatures reduce the quantum yield of C_4 photosynthesizing grasses (Ehleringer 1978) and extreme cold may result in structural and metabolic disorganization (Ode *et al.* 1980). With a decline in temperature, quantum yields of C_3 grasses become increasingly greater those of C_4 species (Ehleringer 1978; Ode *et al.* 1980). Therefore, C_3 grasses have the competitive advantage over C_4 species under low temperature regimes. Germination of grasses is also temperature dependent, with maximum germination in C_4 species occurring at temperatures >27°C, whereas the optimum germination temperature for C_3 species is between 5-7°C (Harper 1977).

The results of the correlation analysis indicate that temperatures during late summer (February & March) and spring (October) may be more important than mid-summer or mid-winter temperatures in determining the balance of temperate and subtropical grasses in the sward. Maximum temperature differences between vegetation communities occurred during winter. However, plants are dormant during this period and differential temperatures will have little effect on the relative fitness of species. In contrast, during the summer growing season, temperature differences between sites were small and the mean temperatures in vegetation communities dominated by temperate grass species (i.e. VCs 1 & 2), were no lower than those experienced by the subtropical grasslands (VCs 4 & 5). Spring and autumn may be the critical periods for determining the relative success of temperate and subtropical species in the mountains. On the cooler facets of the landscape, temperate species are able to initiate growth earlier in spring than subtropical species and they are also able to extend their growth period later into autumn (Ode *et al.* 1980).

It has been suggested that the upper altitudinal limit of cold-intolerant species, *viz.* C_4 grasses, may be directly determined by climatic factors, whereas the lower altitude boundary of cold-tolerant species (C_3 grasses) will be determined by competitive exclusion (Wardle 1964; Hamilton & Perrott 1981; Woodward 1988). However, the data used in this present study, which comprised the relative abundance of C_3 and C_4 grasses, cannot be used to test this hypothesis. This can be done using growth trials in the field, incorporating C_4 and C_3 grasses grown alone and together in pots, placed across the full temperature range in the mountains.

Another factor that has been suggested to influence the abundance of subtropical and temperate grass species is soil moisture availability (Kirkpatrick *et al.* 1988; Terri 1988). Granger and Schulze (1977) regarded the soil moisture regime in spring, as influenced by insolation, as being critical for the growth of shallow-rooted plants in the Natal Drakensberg. However, it was subsequently demonstrated that temperature, rather than soil moisture, limits grass regrowth in

spring in the Drakensberg (Everson & Everson 1987). Moisture will have its greatest influence on the relative performance of temperate and subtropical grass species under low rainfall conditions (Bouton *et al.* 1980; Kirkpatrick & Nunez 1980). In the mountains, where summer precipitation is high and spring moisture is often available from melting snow and ice, temperature is likely to be more important than soil moisture in determining the relative success of C_3 and C_4 species.

Cowling (1983) reported that the effects of insolation on the mountain vegetation of the south-eastern Cape overrode those of altitude. In those mountains, C_3 grasses are dominant on the southerly slopes at high altitudes, whereas the high elevation, north-facing slopes as well as the lower flats are dominated by C_4 grasses. This is different from the pattern occurring in the eastern mountains of Lesotho. In Study Area 1, insolation and temperature patterns on high altitude, northerly slopes (*viz.* VC3) were similar to those on similar aspects at lower elevations (*viz.* VC5) (Figure 5.1a & b). However, the proportion of temperate grasses was far higher in VC3 (54%) than in VC5 (10%). Further, the C_4 grass that does occur at high altitudes on northerly slopes, i.e. *Harpochloa falx*, has Afrotemperate/Afromontane geographical affinities rather than subtropical affinities like most of the other C_4 species encountered in the mountains (Cowling 1983). Therefore, it may be fairly cold-tolerant.

What is suggested from the above, is that growing conditions on the northerly aspects at high altitude are not as favourable as the simulated temperatures regimes would suggest (Figure 5.1b). It appears that species turnover along an altitude gradient on northerly aspects is not solely related to a temperature gradient but rather to some other factor associated with altitude. This is confirmed by the results of the Canonical Correspondence Analysis.

Exposure increases with altitude in mountainous terrain. The velocity and frequency of wind in mountainous areas is reported to increase with elevation (Barry & van Wie 1974; Yoshino 1975) and plants growing at high elevations,

particularly on the summits, are exposed to drying and chilling winds (Tyson 1968). In contrast, the lower valleys and footslopes are often surrounded closely by adjacent terrain which serves to shelter them from high velocity winds and to increase radiate energy loads through reflection of incoming shortwave radiation and absorption of outgoing longwave radiation. The exposure of plants growing at high elevations is exacerbated by intense ultra-violet radiation (Killick 1963; Barry & van Wie 1974).

In the present study, exposure was inadequately accounted for in the RADSLOPE simulations for two reasons. First, there are no data describing wind patterns and the relationship between elevation and wind in the mountains. Therefore, a default value for daily windrun (*viz.* 100 km day^{-1}) was used in RADSLOPE. Tyson (1968), in a study of wind patterns in a valley in the Natal Drakensberg, noted that wind patterns in mountainous areas are complex and are affected by, *inter alia*, regional wind patterns, pressure gradients between high-lying and lowland areas, local valley configurations and radiational heating. If reliable wind data are available for a particular area then these should be used in RADSLOPE to improve the prediction of exposure.

Second, radiation reflected from surrounding terrain is calculated in RADSLOPE for all sites on the assumption that the neighbouring terrain has a similar slope but an opposing aspect. These conditions may not apply to the high elevation slopes and summits which are often geographically isolated. Consequently, RADSLOPE may overestimate radiative energy loads on exposed sites. RADSLOPE needs to be modified to incorporate actual topographic information for each site, detailing the proximity, inclination and orientation of nearby terrain.

There are a number of implications concerning the influence of topography on insolation patterns and the resultant effects on the mountain vegetation. First, insolation and related climatic factors will influence not only the composition and spatial distribution of the mountain vegetation, but also the seasonal pattern of herbage production. Vegetation communities dominated by subtropical grasses

reach maximum productivity in mid-summer whereas those communities dominated by temperate species are relatively more productive during spring and autumn (Ode *et al.* 1980). Forage availability for livestock in the mountains will be influenced by this temporal displacement of production. The presence of temperate grass species serves to extend the grazing season into the cooler months of the year.

Another effect of topographically induced temperature variation in the mountains is manifest in the distribution of cattleposts in the summer grazing area. The majority of cattleposts in Study Area 1 are located on warm aspects at low elevations (Morris *et al.* 1989). Consequently, the extent of vegetation degradation and accelerated erosion is far greater on these slopes than in the higher and cooler areas (Klug *et al.* 1989; Morris *et al. 1989*). The effects of the uneven distribution of grazing pressure across the landscape on the vegetation/soil complex are considered in detail in the next chapter.

5.5 Conclusions

1. The spatial distribution of vegetation communities in the mountains is related to solar irradiance patterns, as influenced by topography.

2. Insolation-induced temperature patterns during spring and late summer, rather than in mid-summer, may be important in determining the balance of temperate and subtropical grass species in the herbaceous layer.

3. Exposure, which increases with altitude, is probably also an important determinant of species composition in mountainous terrain and needs to be adequately accounted for in ecological studies.

4. The use of a variable that has a direct physiological influence on plant growth, *viz.* temperature, rather than a complex topographic variable that has only an indirect effect on plants (e.g. altitude or aspect), will improve the prediction of vegetation distribution in the landscape.

5. Insolation patterns also affect the seasonal and spatial distribution of land-use patterns in the mountains which may result in preferential use of certain sectors of the landscape. This is likely to have important consequences for the long-term stability and productivity of the Alpine and Subalpine catchments.

CHAPTER 6

THE EFFECT OF LIVESTOCK ON VEGETATION COMPOSITION AND COVER

6.1 Introduction

Mountain rangelands in Lesotho have been grazed by domestic livestock since the late 19th century when increasing population pressure in the western Lowlands forced the Basotho to move into the mountains to seek grazing and cropland (Phororo 1979). By early this century, the hinterland of the country had been extensively settled and the higher mountain rangelands had been designated as summer grazing areas (Duncan 1960). Today, livestock from Mountain villages as well as from many areas in the Lowlands utilize the mountain pastures for summer grazing (Phororo 1979). The mountain grasslands are particularly suitable for sheep grazing and Staples and Hudson (1938) regarded these rangelands as the best in southern Africa for wool production. However, they warned of the loss of valuable grazing land through livestock-induced degradation.

In 1938 Staples and Hudson reported that settlement of the mountains had resulted in "regrettable" changes in the vegetation. They described how the composition of the indigenous pastures had been altered by overgrazing and how sheet erosion was prevalent on slopes which had lost the protection of a covering layer of vegetation through prolonged overuse. They predicted that these floristic and edaphic changes would have dire consequences in terms of animal production and catchment function.

Since the pioneering ecological survey of Staples and Hudson numerous reports have described the detrimental effects of grazing on the vegetation (Chapter 3). The cause of degradation has been attributed to continuous, 'close' grazing (Staples & Hudson 1938), selective grazing (LCRD 1986b; Limbach 1986) and incorrect seasonal 'timing' of grazing (Buzzard & Ntlale 1991). However, the link between range retrogression and grazing has not been clearly established through objective experimentation. Neither has the process of range degradation been

quantitatively described (Limbach 1986). Further, there is some ambiguity in the literature concerning the response of certain species to grazing. For example, *Festuca caprina* has been described by some as a valuable and palatable grass that declines in abundance with misuse (Rhodes University 1960), whereas others (LCRD 1986c) have grouped it together with those species that increase in abundance with overgrazing. Therefore, clarification is needed on the response of the species occurring in the mountains to grazing. Species that are responsive to the impact of livestock need to be identified so that they can be used as indicator species to monitor species composition changes in response to grazing management.

To study the impact of livestock on the vegetation of the Subalpine and Alpine Belts, use was made of gradients in grazing intensity that exist in the vicinity of cattleposts in the mountains. Cattleposts serve as centres of livestock management in the mountains during the grazing season (Dobb 1985b; Quinlan 1994) and are foci of animal concentration in the landscape. Largestock (cattle, horses and donkeys) are permitted to roam freely within the general surroundings of the cattlepost but smallstock (sheep and goats) are returned nightly to a kraal adjacent to the herders' hut for protection from the weather, predators and theft (Dobb 1985b). During the day, smallstock graze along familiar grazing routes within the confines of the local watershed (Quinlan & Matobo 1989). Because of the nightly kraaling of stock, the intensity of grazing and trampling is highest close to the cattlepost and declines with increasing distance from the cattlepost. Soil fertility, due to dunging, is also high in the immediate proximity of the cattlepost. These effects are similar to the 'piosphere' effect that exists around watering points, particularly in semi-arid regions (Lange 1969).

A 'piosphere' is the term used to describe vegetation and soil changes along gradients in grazing intensity that occur in the vicinity of watering points (van der Schijff 1957; Lange 1969). Such gradients have been used to study the response of plant species and vegetative cover to grazing intensity (Graetz & Ludwig 1978; Foran 1980; Bosch & Janse van Rensburg 1987; Friedel 1988a; Friedel &

Blackmore 1988; Thrash *et al.* 1993). Certain species proliferate in the highly fertile area in the immediate vicinity of the watering point. Further away, where fertility levels are not elevated but where grazing intensity is still high, other species are dominant. These species can either tolerate heavy grazing or are unpalatable and therefore avoid grazing. The more palatable species usually only occur at a distance from the watering point where the grazing pressure is lowest. These grazing gradients are useful for studying the effects of livestock on the vegetation/soil complex because rapid changes in species composition and vegetation cover can occur over short distances (Foran 1980; Thrash *et al.* 1993).

Variation in vegetative cover along gradients in grazing intensity in the vicinity of cattleposts was also quantified in the present study. Cover, which is generally considered the most important management variable influencing soil erosion and runoff in catchments (Coleman 1953), can be greatly modified by grazing (Lusby 1970; Rauzi *et al.* 1986) and trampling by livestock (Rhoades *et al.* 1964; Rauzi & Hanson 1966). Prolonged over-utilization leads to a reduction in vegetative cover and an increase in runoff, erosion and sedimentation (Smeins 1975; Kelly & Walker 1976; Venter *et al.* 1989). Steep slopes are particularly susceptible to erosion once cover has been denuded (Snyman & van Rensburg 1986).

When describing the influence of cover on hydrological processes, a distinction is usually made between cover provided by the aerial portions of the plant, i.e. crown or canopy cover, and that provided by the basal portions of the plant at ground level, i.e. basal cover (Greig-Smith 1983). Litter cover is usually also considered (Tiedeman & Wieland 1983). Canopy, basal and litter cover protect the soil from the impact of raindrops (Scott 1981) while basal cover also impedes overland flow, thereby increasing infiltration into the soil (Kelly & Walker 1976; Snyman & Fouche 1991). Although all components of cover are important in reducing erosion potential (Thurow *et al.* 1986), basal cover is the most useful fraction for quantifying and monitoring the long-term effects of livestock on vegetative cover and erosion (Tiedeman & Wieland 1983). Canopy and litter cover display considerable seasonal variation in response to climate (Tiedeman & Wieland 1983)

and canopy cover is directly affected in the short-term by grazing and fire. Therefore, an index of basal cover was used in the present study to examine the relationship between grazing intensity and vegetative cover.

6.1.1 Objectives

1. To examine the relative influence of grazing intensity and environment factors on vegetation composition and cover.

2. To identify species that are responsive to grazing for use as indicator species in a vegetation monitoring programme.

6.2 The grazing gradient approach to quantifying range degradation.

Various studies have aimed to quantify the response of species along a gradient of grazing intensity, either for the purpose of developing effective range condition assessment techniques or for monitoring purposes (reviewed in: Hurt 1989; Hurt & Bosch 1991; and Martens 1992). Martens (1992) noted that two approaches have been used to examine vegetation dynamics under grazing, namely the dynamic and the static approach.

6.2.1 The dynamic versus static approach

The dynamic approach involves measuring the response over time of species and other parameters of the vegetation to a number of grazing treatments (Hacker 1986). These studies are usually conducted over a number of years and preferably at a number of sites. In contrast, the static approach involves a single 'once-off' survey of a number of sites which are considered to represent the various stages of a grazing-induced successional sequence (Austin 1977; van der Maarel & Werger 1978). The study sites are then arranged, by various techniques, along what is perceived to be a grazing gradient and the changes in species abundance along the gradient are described (Martens 1992).

The main advantage of the static approach is that results can be obtained after only a single survey. Because the technique is relatively cost-effective a large

number of sites over a wide range of habitats can be surveyed and the effect of grazing on species composition in a number of different habitats can be examined (e.g. Janse van Rensburg & Bosch 1990; Martens 1992). In comparison, long-term grazing trials are usually limited to relatively few habitats because of the expense and logistics involved in conducting such trials (Austin 1977; Martens *et al.* 1990). The primary disadvantage of the static approach, however, is that it assumes that spatial and temporal variation are equivalent (Pickett 1989). Further, it assumes a deterministic model of succession (*sensu* Clements 1916), in that stages in the successional pathway have an obligative order and sites within an area all share the same climax or end-point (Teuller & Blackburn 1974; Pickett 1989). However, it is argued that space cannot always be substituted for time (Gleason 1927; Walker 1970) and that the past condition of a site as well as the nature of the surrounding vegetation will affect the dynamics of vegetation under a disturbance like grazing (Pickett 1989). Notwithstanding these objections, the static approach has been widely used in ecological studies. It provides a general or qualitative description of the 'average' successional pathway in a particular habitat rather than a comprehensive and precise model of vegetation dynamics (Pickett 1989).

Because long-term data were not available for an examination of species dynamics under grazing in the Alpine and Subalpine Belts of Lesotho, the static approach to the description and analysis of grazing gradients was employed.

6.2.2 Definition and interpretation of the grazing gradient

6.2.2.1 Range condition scoring

Once survey data have been collected for the static approach, the sites have to be arranged in an order that reflects a gradient in grazing intensity. The simplest way to do this is to compare each site with a reference or 'benchmark' site, i.e. the site which is perceived to represent the 'best' vegetation for the area (Foran 1976). In areas where the climatic climax is a grassland, the climax vegetation is considered to be the benchmark (Dyksterhuis 1949), e.g. Dry *Cymbopogon-Themeda* Veld (Acocks 1975), whereas in areas where grassland is only

maintained through regular burning or grazing, the fire-grazing climax vegetation is the benchmark (Foran *et al.* 1978), e.g. Highland Sourveld (Acocks 1975). The condition of a particular site relative to the benchmark - and hence is position along the grazing gradient - is judged by ascertaining the proportion of the benchmark vegetation that is present at the site (Dyksterhuis 1949). This can be done by allocating the species encountered at a particular site into functional groups based on their response to grazing and then weighting the proportional representation of the groups in that site by various means (e.g. Foran 1976; Cooper 1977; Tainton *et al.* 1980; Vorster 1982; Page 1986). The underlying principles of these techniques are those of Dyksterhuis' (1949 & 1952) 'Quantitative Climax Method'.

In the Quantitative Climax Method species are allocated into one of three groups:

Decreasers - species that are abundant in the benchmark and which decline in abundance with increased grazing pressure;

Increasers - species that are not abundant in the benchmark but which increase in abundance with heavy grazing. They often show an initial increase in abundance with increased grazing intensity up to a maximum at intermediate grazing intensities, followed by a decline in abundance under severe grazing pressure; and

Invaders - species not commonly found in the benchmark but which invade the sward after a disturbance like prolonged, intense grazing.

Various workers in southern Africa have refined this classification further to reflect local vegetation dynamics (e.g. Foran *et al.* 1978; Vorster 1982; Heard *et al.* 1986; Bosch *et al.* 1989; Hurt 1989; Hurt *et al.* 1993). For example, in the humid grasslands of South Africa (e.g. Highland Sourveld of Natal), a category has been defined for species that increase in abundance when the range is under-utilized (*viz.* Increaser I; Foran *et al.* 1978; Tainton *et* al. 1980) and for those that proliferate under selective grazing (*viz.* Increaser III; Tainton *et al.* 1980).

In Lesotho, Decreaser species are termed 'Desirables', Increasers are known as 'Intermediates' and Invaders are classed as 'Undesirables' (LCRD 1986a). This classification is meant to reflect the relative usefulness of the species groups for grazing as well as the ecological status or condition of the range. Domination by Invader species indicates a history of mis-management with little potential for primary or secondary production without extensive remedial action (Limbach 1986). In contrast, a grassland with a high proportion of Desirable species should be able to sustain animal production without deterioration of the soil resource under 'correct' grazing management (Limbach 1986). Most of the grass species encountered on the range in Lesotho have been classified into one of the above three groups (LCRD 1986c). This classification was largely based on the results of research conducted in South Africa as well as the knowledge and experience of local range researchers (Limbach 1986). A fair amount of guesswork was also involved (Limbach 1986).

Range condition scoring techniques have been criticised for two reasons. First, allocation of species into functional groups has usually been based on a subjective notion of how a particular species responds to grazing and not on objective experimental evidence (Mentis 1983; Martens 1992; Hurt *et al.* 1993). Second, the condition gradient, as reflected by site condition scores, may be confounded with local environmental gradients that affect the abundance of particular species (Hacker 1986; Martens 1992). Further, the response of a particular species to grazing may differ between habitats (Janse van Rensburg & Bosch 1990; Martens 1992). Multivariate methods have been proposed as a means of overcoming some of these problems (Mentis 1983; Hacker 1986; Martens 1992).

6.2.2.2   Multivariate methods: direct and indirect gradient analysis

The data collected in a vegetation survey are suited to multivariate analysis because they usually comprise three dimensions, *viz.* sites, species and environmental variables. Multivariate techniques, like ordination, help to reduce the complexity of the multivariate data set in order to identify pattern in the data (Gauch 1982). Ordination provides a means of objectively defining gradients

(dimensions of variability) in species composition. These gradients can then be interpreted in the light of what is known about the grazing history or the condition of the sites in order to ascertain whether the composition gradient/s represent a sequence along a gradient in grazing pressure (Austin 1977; Hacker 1983; Foran *et al*. 1986; Heard *et al*. 1986; Stuart-Hill *et al*. 1986; Bosch *et al*. 1987; Archer *et al*. 1988; Martens 1992).

In the ordination solution, gradients in species composition that are related to environmental gradients are often represented by ordination axes orthogonal to that of the grazing gradient, thereby allowing the partitioning of grazing and environmental effects (Hacker 1986; Bosch *et al*. 1987; Janse van Rensburg & Bosch 1990; Martens 1992). For example, in a Principal Components Analysis (PCA) of species composition data in the arid regions of Australia, Foran *et al*. (1986) found that PCA axis 1 reflected compositional differences due to grazing intensity, whereas higher ordination axes were related to edaphic variation and the seasonal growth response of species.

In most studies where ordination techniques were used to study the effects of grazing on species composition the inference was made that the grazing gradient was represented by one of the main ordination axes. This was usually concluded after an examination of the order of sites and/or species positions (eigen scores) along the axes in the light of what was known about the grazing history of the sites and the response of the species to grazing. If species that were known to have a very different response to grazing were positioned at opposite ends of the ordination axis then that axis was described as reflecting a grazing gradient (Hacker 1983). This has also been done more formally by correlating the range condition scores of the sites with the eigen scores of the ordination axes (Foran *et al*. 1986). Other methods that have been used to interpret the ordination axes include: (1) relating the past stocking history of sites to site ordination scores (Hardy & Hurt 1989; Hurt *et al*. 1993); (2) inspection of the ordination position of paired sites placed on opposite sides of fences where two obviously different (visually assessed) range conditions prevailed (Hacker 1983; Martens 1992); and (3) the

use of sites placed at varying distance from watering points (Hacker 1983; Bosch
et al. 1987; Friedel & Blackmore 1988; Janse van Rensburg & Bosch 1990; Thrash
et al. 1993).

In many studies which have employed ordination techniques to define a grazing
gradient, the past grazing history was not available for all the sites in the survey.
In such cases, the location in ordination space of 'marker sites', whose relative
position along the grazing gradient was known or could be deduced from available
information, was used to interpret the ordination axes (e.g. Hacker 1983; Bosch
& Janse van Rensburg 1987; Hurt 1989; Martens 1992; Hurt *et al*. 1993). Where
data are available for all sites in the sample then correlation or regression methods
can be applied to formally interpret ordination axes. For example, Thrash *et al*.
(1993), who examined the influence of watering points on the vegetation in the
Kruger National Park, South Africa, used a logistic regression model to describe the
relationship between distance from a watering point and eigen scores along axis
1 of a Detrended Correspondence Analysis (DCA) of the species composition data.

The ordination techniques mentioned above all involve indirect gradient analysis
(IGA) procedures (Chapter 4). Interpretation of the species composition gradients
(i.e. ordination axes) in the light of the grazing and environmental data is done
subsequent to the ordination analysis (Gauch 1982). In contrast, in direct gradient
analysis (DGA), the relationship between the variables of interest (i.e. grazing and
the environment) and the vegetation is examined directly by plotting the response
of the species along the known environment or grazing gradients. The advantage
of DGA is that the relationship between species and environmental variables can
be explicitly described by graphical techniques (e.g. Whittaker 1956) or by
regression models (ter Braak & Looman 1987). Generalized Linear Modelling
(McCullagh & Nelder 1983) has been proposed as a means of describing the
response of individual species to a combination of environmental variables (Austin
et al. 1984).

The main disadvantage of classical DGA techniques is that the response of each

species has to be examined separately, unlike IGA where all species are included simultaneously in the analysis (Chapter 4). However, in the last decade, multivariate DGA procedures have been developed which combine regression and ordination into a single analysis in order to provide a synchronous description of the response of all species along the measured environmental gradients (ter Braak 1987a). In these techniques, ordination axes are constrained to be weighted linear functions of the environmental variables by regressing species composition axes onto the environmental variables during the mathematical derivation of the ordination axes (Chapter 5) (ter Braak 1986). This type of analysis is known as canonical ordination and includes Redundancy analysis (RDA; Israëls 1984), Canonical Correspondence analysis (CCA; ter Braak 1986) and Detrended Canonical Correspondence analysis (DCCA; ter Braak 1986).

Canonical ordination is superior to indirect ordination for describing the relationship between species and the environment because it provides a direct environmental interpretation of the variation in species composition rather than an inferred one. Canonical Correspondence analysis has been used to examine the relative influence of grazing and environmental factors on seed bank composition (O'Connor & Pickett 1992), leaf miner assemblies (Sterling *et al*. 1992) and vegetation succession (Gibson & Brown 1992).

Canonical ordination can be extended further to enable the effects of a particular variable on composition (e.g. grazing) to be separated from those of other variables (e.g environmental factors) by employing partial canonical ordination (ter Braak 1987c). In partial canonical ordination the influence on composition of a variable or a combination of variables can be removed or 'partialed out' by deriving a canonical axis that is a function of these variables and then examining the variation in composition that is residual to this axis (ter Braak 1987c). The variable/s whose effect on species composition are to be removed are known as 'covariables'. The variables of interest in the analysis are also replaced by the residuals of a regression of each of these variables onto the covariables in order to examine variation that is independent of the covariables. Partial canonical

ordination allows the influence on composition of a particular variable to be highlighted. For example, variation in composition that is attributable to soil and topographic factors can be partialed out before deriving a gradient in composition that is related to grazing. Thereafter, the response of species along this grazing gradient can be described by plotting the distribution of species along the ordination axis.

6.2.2.3   Describing the response of species to grazing

The final step when using IGA or DGA ordination procedures to define a grazing gradient is to examine the response of species along the particular ordination axis which is inferred to represent a grazing gradient. Various methods have been used to examine and describe the response of species along ordination axes.

Scatterplots of the abundance of species in sites along the ordination axis indicate whether a particular species is confined to a sector of the axis or whether it is has a wide tolerance along the gradient (ter Braak 1987a). It should be noted, however, that species which are located towards the middle of an ordination axis do not necessarily have their optima in that region of the gradient. They might have a bimodal distribution, with two optima, or be unrelated to the particular gradient (ter Braak 1987a). Inspection of a scatterplot of a species' distribution along the gradient will indicate the nature of the response curve.

Freehand curves (envelopes) encompassing the limits of a species' distribution can be drawn to describe the distribution (Curtis 1959; Austin & Cunningham 1981). Alternatively, a moving mean of species abundances along the gradient can be used if the data are not highly skewed by numerous zero values (Austin & Cunningham 1981). A plot of the abundance of species in sites along the gradient provides an indication of the confidence that can be attached to the shape of response curves (Austin & Cunningham 1981). Martens (1992) and Hurt *et al.* (1993) plotted a moving mean of the abundance of species along the DCA axis that represented a grazing gradient in order to ascertain whether a species demonstrated a definite response along the gradient. This concept was extended

further by Bosch *et al.* (1987) and Janse van Rensburg & Bosch (1990) who fitted polynomial response curves by least-squares regression to species abundances along DCA axis 1 (the inferred grazing gradient). The multiple correlation coefficient (r^2) was then used to asses the sensitivity of a species' response to grazing. However, the validity of this approach has been questioned because the data are inappropriate to a parametric least-squares analysis as species abundance data are usually highly skewed and the data are truncated at zero (Austin & Cunningham 1981; Martens 1992). Simple correlation analysis has also been used to identify responsive species. For example, Stuart-Hill *et al.* (1986) correlated the species' abundances with the position of sites along a PCA ordination axis that was perceived to represent a gradient in 'bush condition' in the Valley Bushveld of the eastern Cape, in order to identify species with a significant positive or negative response along the gradient.

In most of the studies mentioned above, species that were found to be responsive along the gradient were subsequently grouped into grazing categories (*sensu* Dyksterhuis 1949) according to the nature of their response (e.g. Bosch *et al.* 1989; Hurt 1989; Martens 1992; Hurt *et al.* 1993). Non-responsive species were usually not considered further, whereas responsive species were termed 'key' species (Heard *et al.* 1986; Hurt & Hardy 1989). It has been demonstrated that changes in the abundance of one or two of the more common key species in the sward indicates a change in the overall composition, and hence ecological status of the sward (Foran *et al.* 1978; Heard *et al.* 1986; Willis & Trollope 1987; Anon. 1993). Key species are ideally those that are sensitive to grazing and are abundant at least along one portion of the grazing gradient (Hurt & Hardy 1989).

The optimum position of a species along a gradient is indicated by its centroid of abundance along that gradient (ter Braak 1987a). In an ordination axis this position is approximated by the weighted average (i.e. eigen score) of the particular species along the axis (ter Braak 1986). It follows then, that if weights are derived for each key species based on the relativized eigen scores of the key species and if these weights are then used to calculate a weighted sum for a site, the weighted

sum will be an index of the position of that site along the gradient. Hurt & Hardy (1989) found that a weighted sum, based on DCA eigen scores for key species that were relativized on a scale from 1-10, was highly correlated ($r = 0.86$) with the site positions along DCA axis 1. Martens (1992) reported similar results for weighted key species indices in six vegetation types in the eastern Cape. However, he suggested that species that displayed a unimodal response along the gradient should be excluded in the calculation of a weighted index as they could have the same abundance at two different places along the grazing gradient.

6.2.3 Conclusion

The grazing gradient approach to investigating the effect of grazing on species composition has proved useful, especially when multivariate techniques were used to obtain an objective definition of the grazing gradient and to separate the effects of spatial and environmental factors from those of grazing. Ordination procedures based on direct gradient analysis appear to hold promise for the definition and description of grazing gradients. Information should be collected concerning the grazing history of as many sites in the sample as possible in order to aid the derivation and interpretation of the grazing gradient.

It should be noted, however, that the underlying theoretical model of grazing gradient analysis is problematic in that it assumes a deterministic and reversible response to grazing pressure. This may not always be the case (Friedel 1988b; Mentis *et al.* 1989) and a state-and-transition model may be more appropriate for describing vegetation dynamics under grazing (Westoby *et al.* 1989; Laycock 1991; Morris *et al.* 1992). However, data from long-term grazing trials are required to construct state-and-transition models and the analysis of grazing gradients will provide a useful first-step towards an understanding of the impact of grazing on the range. Hypotheses generated by the grazing gradient approach can be tested using long-term trials if finances allow.

6.3 Methods

6.3.1 Data collection

Study Area 1, rather than Study Area 2, was used for the examination of grazing gradients because the distribution and density of cattleposts in Study Area 1 was such as to allow for gradients of sufficient length (i.e. distance) to be examined. In contrast, the few cattleposts that occurred in the summer grazing area of Study Area 2 were mostly clustered and gradients between cattleposts were short.

A total of 23 cattleposts were used in the study. A stratified random procedure (Smartt & Grainger 1974) was used to select a sample of cattleposts. The area was stratified according to vegetation belt, i.e. the Alpine and Subalpine Belts (Chapter 4), and aspect, with all aspects sampled where possible. This was done to ensure that the influence of livestock on the vegetation would be examined in as wide a range of habitats as possible.

The following sampling procedure was followed at each cattlepost.

1.   Plots (30 x 30 m) were placed at a distance of 0, 60, 120, 180 and 500 m away from the cattlepost, along the contour, on one side of the cattlepost. As far as possible, plots were placed on similar aspects and slope inclinations along the contour. The first plot was located immediately adjacent to the cattlepost but just outside the area of bare soil and high fertility that surrounds most cattleposts. The last plot (500 m) was used to record the composition and cover of the vegetation in a lightly stocked zone. It was not always possible to place a site at this distance from the cattlepost as nearby cattleposts as well as abrupt changes in aspect or moisture (i.e drainage lines) were occasionally encountered, thereby introducing floristic changes that could not be attributable to grazing alone.

2.   A total of 47 sites from 11 cattleposts were surveyed in the Alpine Belt and 46 sites from 12 cattleposts in the Subalpine Belt. The environmental

information recorded at each site (*viz.* slope, aspect, altitude and distance from cattlepost) is presented in Appendix 4.

3. The nearest-plant method was used to record species composition within each plot (Chapter 4; Foran *et al.* 1978). A metal spike was used to systematically locate 200 sampling points at 1 m intervals within each plot. At each point the nearest rooted plant was identified to species level, where possible. Species which were indistinguishable vegetatively were identified at the genus level (e.g. *Senecio* spp.). Nomenclature was according to Gibbs-Russell *et al.* (1985) and Gibbs-Russell *et al.* (1990).

4. The distance from the point to the base of the nearest live plant was measured to the nearest centimetre in order to provide an index of basal cover (Hardy & Tainton 1993). A 'bare area index' (BAI) was calculated for each plot (Chapter 4; Appendix 4).

6.3.2 Data analysis

Canonical Correspondence Analysis (CCA; ter Braak 1986) and Partial Canonical Correspondence analysis (PCCA; ter Braak 1987c) were used to examine variation in species composition along: (1) environmental gradients; (2) a gradient of decreasing grazing intensity represented by increasing distances from cattleposts (DIST); and (3) a gradient of decreasing basal cover represented by increasing BAI. The computer program CANOCO was used to perform the analyses (ter Braak 1985). The following procedure was adopted.

1. Sites from cattleposts within a vegetation belt were analysed together in order to minimise the variation in composition due to environmental factors.

2. In all analyses, species that were found in only a single site or whose mean abundance within a vegetation belt was less than 1% were removed. The abundance data for the rarer species is insufficient to enable a precise description of their response to grazing.

3.   Site no. 6 in the Alpine Belt was removed from the analyses because its BAI value was considered to be an extreme outlier (*viz.* 1.759; Appendix 4).

4.   Distance from cattlepost (DIST) was used as an index of grazing intensity. It is recognised, however, that cattleposts differed in their age as well as in their past stocking history.   Therefore, distances were not directly comparable between cattleposts in terms of their position along a gradient in grazing intensity. However, for the purposes of the study it was assumed that distance gradients in all the cattleposts represented gradients from 'heavy' to 'light' grazing in order to seek general trends in composition and cover in response to grazing.

5.   Detrending was not employed in CCA (ter Braak 1987b). Detrending is a mathematical rescaling of ordination axes in order to remove the 'arch' effect that often occurs in correspondence analysis (Chapter 4; Hill & Gauch 1980). The arch effect is unlikely to occur in CCA when the number of environmental variables is small, as in the present study (ter Braak 1987a).

6.   Subsequent to CCA, Partial Canonical Correspondence Analysis (PCCA) (ter Braak 1987c) was used to derive gradients in composition that were related to grazing and cover once the effects of environmental variables (slope, altitude & aspect) within a vegetation belt had been accounted for.

7.   The position of species centroids along the grazing and cover gradients was obtained by perpendicular projection of the species points in two-dimensional ordination space onto the arrows representing the cover and grazing gradients (ter Braak 1987b). The positions of the species along these gradients were then rescaled to a scale ranging from 0-10 (rounded to the nearest whole number) in order to provide an approximation of the relative position of the species optima along the gradients (Hurt *et al.* 1993).

8.   In order to examine the response of species along the grazing gradient, the

relative position of the sites along the grazing gradient was obtained by projection of the site positions in ordination space onto the arrow representing the grazing gradient, as above. Thereafter, a ten-point moving mean of the species abundance along the grazing gradient was plotted. Envelopes encompassing the upper limits of the species' distributions along the grazing gradient were also drawn.

6.4 Results and discussion

In the CCA analyses the canonical axes, i.e. the variation in composition that can be directly associated with the environmental data, accounted for 36.4% of the total inertia (variance) in the Alpine Belt and 29.5% of the total inertia in the Subalpine Belt. Although these proportions were low, indicating that variation in species composition may have been associated with unmeasured factors, or may have simply been noise, this did not negate the usefulness of the ordination solution for describing the observed patterns (ter Braak 1987a).

In both vegetation belts most of the variation in composition that was attributable to the measured variables was incorporated into CCA axes 1 and 2 (Tables 6.1 & 6.2). Therefore, a biplot of the species positions in ordination space defined by these two axes, along with indications of the directions and magnitudes of influence of the environmental variables in ordination space, will adequately describe the species-environment relationships in the data (Figures 6.1 & 6.2).

Table 6.1   The eigenvalues and the cumulative percentage variance (VAR) of the species-environmental relationship incorporated by the first four axes of a Canonical Correspondence Analysis (CCA) of species composition data from the Alpine Belt in Study Area 1, eastern Lesotho. The correlations between the CCA axes and the measured variables are presented.

	CCA axis				
	1	2	3	4	Total inertia
Eigenvalue	0.316	0.142	0.055	0.045	1.558
VAR (%)	55.7	80.7	90.4	98.3	
Correlation					
Altitude	0.107	0.033	0.007	0.957	
Aspect	-0.833	0.125	0.136	-0.517	
Slope	0.022	0.795	-0.485	-0.296	
DIST[1]	-0.087	-0.066	-0.548	-0.128	
BAI[2]	0.683	0.439	0.483	0.175	

[1]Distance from cattlepost.
[2]'Bare area index' (see text for details).

Table 6.2   The eigenvalues and the cumulative percentage variance (VAR) of the species-environmental relationship incorporated by the first four axes of a Canonical Correspondence Analysis (CCA) of species composition data from the Subalpine Belt in Study Area 1, eastern Lesotho. The correlations between the CCA axes and the measured variables are presented.

	CCA axis				
	1	2	3	4	Total inertia
Eigenvalue	0.436	0.154	0.086	0.061	2.653
VAR (%)	55.7	75.5	86.5	94.3	
Correlation					
Altitude	-0.468	-0.024	0.247	-0.749	
Aspect	-0.517	-0.415	-0.684	0.249	
Slope	0.487	0.547	-0.470	-0.489	
DIST[1]	-0.325	0.817	-0.142	0.400	
BAI[2]	0.742	-0.065	-0.234	-0.193	

[1] Distance from cattlepost.
[2]'Bare area index' (see text for details).
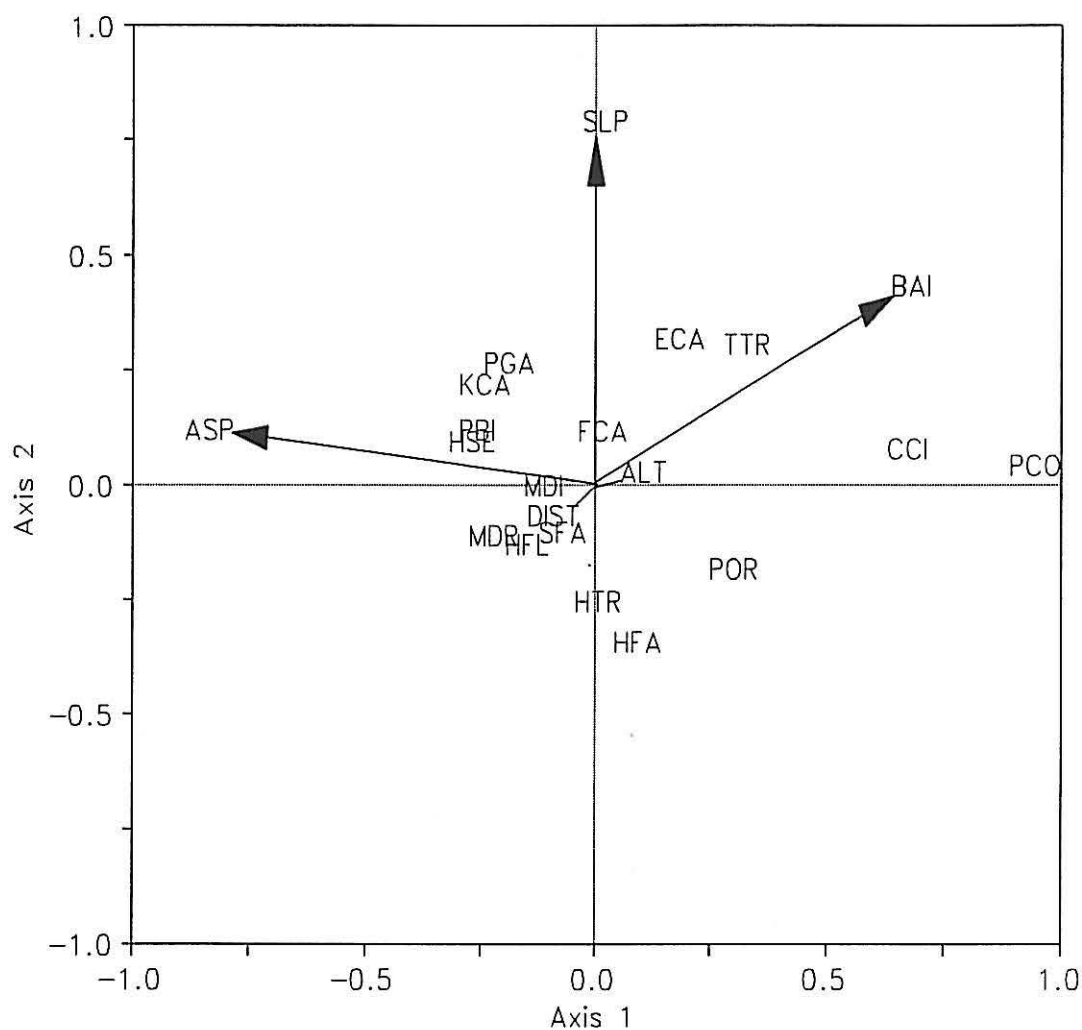
Figure 6.1   A Canonical Correspondence Analysis ordination plot of species in the Alpine Belt of Study Area 1, eastern Lesotho. The arrows indicate the direction of influence in the ordination plot of the variables: altitude (ALT); aspect (ASP); slope angle (SLP); bare area index (BAI); and distance from cattlepost (DIST). Species acronyms are: CCI = *Chrysocoma ciliata*; ECA = *Eragrostis caesia*; FCA = *Festuca caprina*; HFA = *Harpochloa falx*; HFL = *Helichrysum flanaganii*; HSE = *H. sessilioides*; HTR = *H. trilineatum*; KCA = *Koeleria capensis*; MDI = *Merxmuellera disticha*; MDR = *M. drakensbergensis*; PBI = *Poa binata*; PCO = *Pentzia cooperi*; PGA = *Pentaschistis galpinii*; POR = *P. oreodoxa*; SFA = *Scirpus falsus*; and TTR = *Themeda triandra*.

Figure 6.2   A Canonical Correspondence Analysis ordination plot of species in the
Subalpine Belt of Study Area 1, eastern Lesotho. The arrows indicate
the direction of influence in the ordination plot of the variables:
altitude (ALT); aspect (ASP); slope angle (SLP); bare area index (BAI);
and distance from cattlepost (DIST).   Species acronyms are:
AJU = *Aristida junciformis* subsp. *galpinii*;   BCA = *Bromus catharticus*;
CCI = *Chrysocoma ciliata*; CGR = *Catalepis gracilis*; CHI = *Cynodon hirsutus*;
ECA = *Eragrostis caesia*; ECU = *Eragrostis curvula*; FCA = *Festuca caprina*;
GBI = *Gymnopentzia bifurcata*;   HFA = *Harpochloa falx*; HFL = *Helichrysum
flanaganii*; HSE = *H. sessilioides*; HTR = *H. trilineatum*; MDI = *Merxmuellera
disticha*;   PCO = *Pentzia cooperi*;   POR = *Pentaschistis oreodoxa*;
PSP = *Pennisetum sphacelatum*; SFA = *Scirpus falsus*; SSP = *Senecio* spp.;
TBU = *Trifolium burchellianum*; and TTR = *Themeda triandra*.

In the Alpine Belt the major direction of species composition variation (CCA Axis 1) was associated with aspect and cover (BAI) (Table 6.1 & Figure 6.1). Temperate grass species (e.g. *Poa binata, Koeleria capensis* & *Merxmuellera drakensbergensis*) were more abundant on the cooler aspects, where cover was generally high, whereas dwarf karroid shrubs (*Pentzia cooperi* & *Chrysocoma ciliata*) were abundant on the warmer slopes in poorly vegetated sites (Figure 6.1). Certain species, e.g. *Harpochloa falx*, exhibited a preference for the flatter slopes in the Alpine Belt. Distance from a cattlepost (DIST) and altitude had little influence on composition within the Alpine Belt.

In the Subalpine Belt, CCA axis 1 was closely associated with a gradient in cover (Table 6.2 & Figure 6.2). Topographic variables also influenced composition within the Subalpine Belt (Chapter 4; Table 6.2). There was evidence that a gradient in composition, associated with a gradient in grazing intensity, existed around cattleposts in the Subalpine Belt, as indicated by the high correlation (r = 0.817) between CCA axis 2 scores and DIST (Table 6.2).

Although BAI was related to gradients in species composition in both the Subalpine and Alpine belts, the distribution of BAI values differed between vegetation belts. BAI was low in the most of the Alpine sites and only 20% of the sites had a BAI value of greater than 0.4 (i.e. corresponding to a point to plant distance of 1.49 cm). The cover gradient in the Alpine Belt was defined largely by the few sites that had poor cover. Poorly vegetated sites were more common in the Subalpine Belt, with 38% of the BAI values larger than 0.4. There was no significant correlation between DIST and BAI in both vegetation belts. However, the probability of encountering a high BAI value declined with an increase in DIST (Figure 6.3).
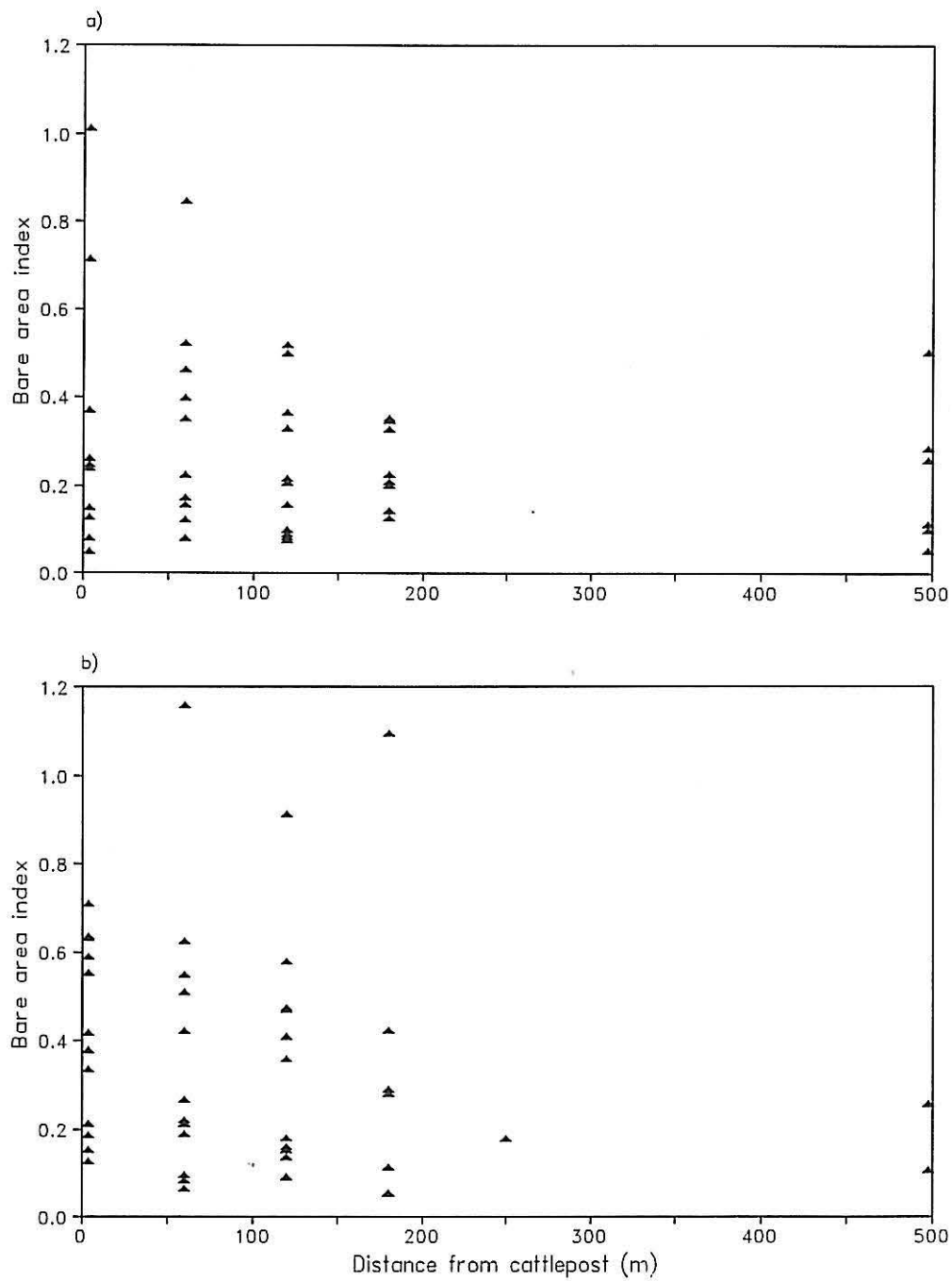
Figure 6.3   The relationship between distance from cattlepost and 'bare area index' in the Alpine (a) and Subalpine (b) Belts of Study Area 1, eastern Lesotho.

The first two Partial Canonical Correspondence Axes in both vegetation belts encapsulated a low proportion of the total variation in composition but they represented all the variation that could be associated with cover and grazing gradients (Table 6.3). Little confidence could be attached to the interpretation of the second PCCA axes as their eigenvalues were a lot smaller than those of the first partial canonical axes.

Table 6.3   The eigenvalues and the cumulative percentage variance of the species-environmental relationship (VAR) incorporated by the first four axes of a Partial Canonical Correspondence Analysis (PCCA) of species composition data from the Alpine and Subalpine Belts in Study Area 1, eastern Lesotho. The correlations between the PCCA axes and distance from cattlepost (DIST) and cover (BAI) are presented.

| | PCCA axis | | | | |
	1	2	3	4	Total inertia
Alpine Belt					
Eigenvalue	0.096	0.027	0.231	0.163	1.558
VAR (%)	78.0	100.0	-	-	
Correlation					
DIST	-0.273	0.962			
BAI[1]	0.990	0.140			
Subalpine Belt					
Eigenvalue	0.230	0.053	0.372	0.278	2.653
VAR (%)	81.3	100.0			
Correlation					
DIST	0.879	-0.477			
BAI[1]	-0.750	-0.662			

[1]'Bare area index' (see text for details).

In the Alpine Belt, the first PCCA axis represented a gradient in cover, from sites at the one end of the gradient with good cover that were dominated by *H. falx*, *Pentaschistis oreodoxa* and *Scirpus falsus*, through to sites at the opposite end of the axis that had many open patches in the sward and where *C. ciliata* and *P. cooperi* were abundant (Table 6.3 & Figure 6.4).

In the Subalpine Belt, species which commonly occurred close to cattleposts and in poorly vegetated sites were positioned towards the negative end of PCCA axis 1 (e.g. *Bromus catharticus* & *Catalepis gracilis*), whereas those species that were more abundant at a distance from cattleposts, and in swards where cover conditions were good, had high positive eigen scores along the PCCA axis 1 (e.g. *Themeda triandra*, *Festuca caprina* & *H. falx*) (Figure 6.5). Both DIST and BAI were highly correlated with PCCA axis 1 (Table 6.3).

An examination of the species positions along the cover gradient in the Alpine Belt, indicated that the majority of the species were positioned towards the low BAI (good cover) end of the gradient whereas two species, namely *C. ciliata* and *P. cooperi*, were located at the end of the gradient which represented poor cover (high BAI) (Table 6.4). As expected, *H. falx* had the highest score along the cover gradient. In the Subalpine Belt, *H. falx* and *T. triandra* had the highest scores on the cover gradient, whereas *Senecio* spp., *B. catharticus* and *C. gracilis* had low scores along the gradient (Table 6.5).
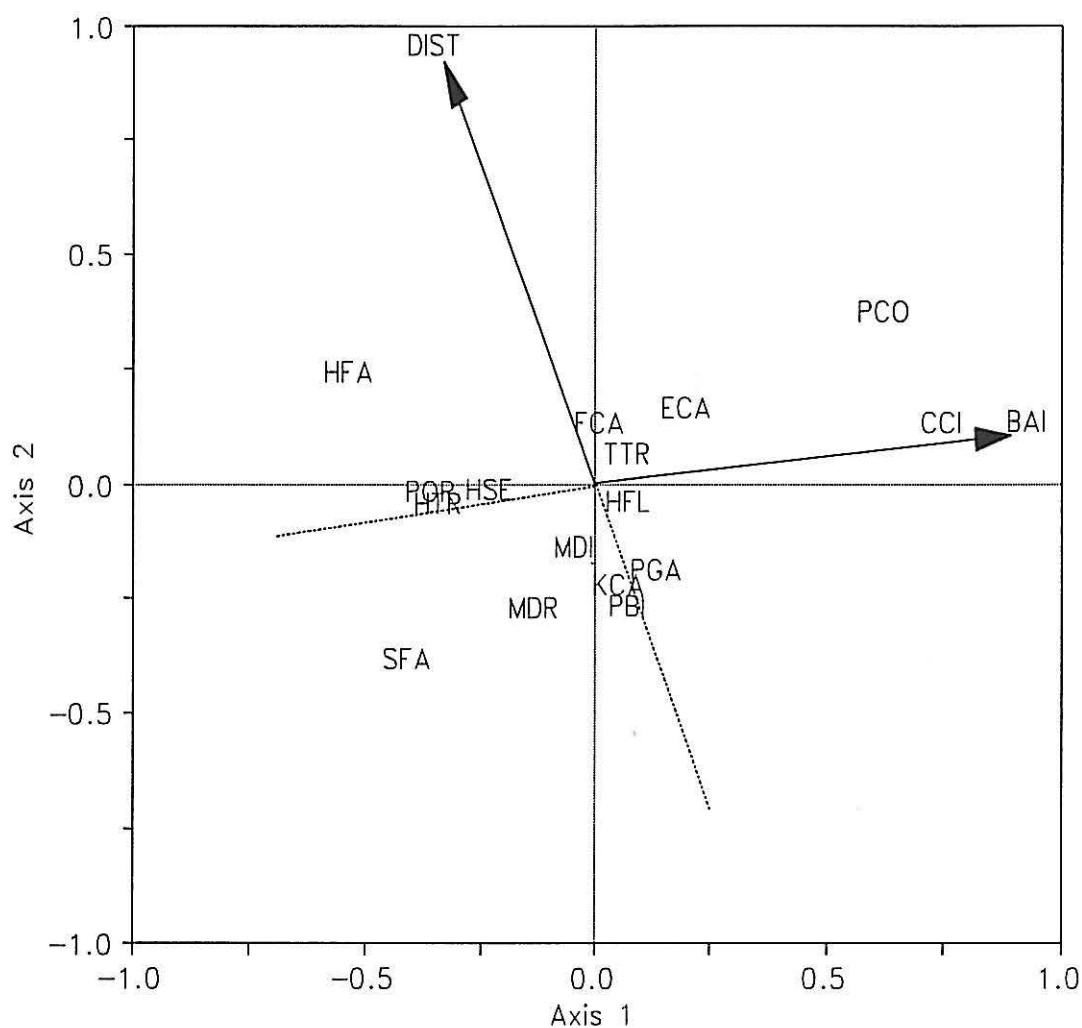
Figure 6.4   A plot of the positions of species along gradients of grazing intensity (distance from cattlepost (DIST)) and cover (bare area index (BAI)) as defined by a Partial Canonical Correspondence Analysis of species composition data in the Alpine Belt of Study Area 1. Species acronyms are: CCI = *Chrysocoma ciliata*; ECA = *Eragrostis caesia*; FCA = *Festuca caprina*; HFA = *Harpochloa falx*; HFL = *Helichrysum flanaganii*; HSE = *H. sessilioides*; HTR = *H. trilineatum*; KCA = *Koeleria capensis*; MDI = *Merxmuellera disticha*; MDR = *M. drakensbergensis*; PBI = *Poa binata*; PCO = *Pentzia cooperi*; PGA = *Pentaschistis galpinii*; POR = *P. oreodoxa*; SFA = *Scirpus falsus*; and TTR = *Themeda triandra*.
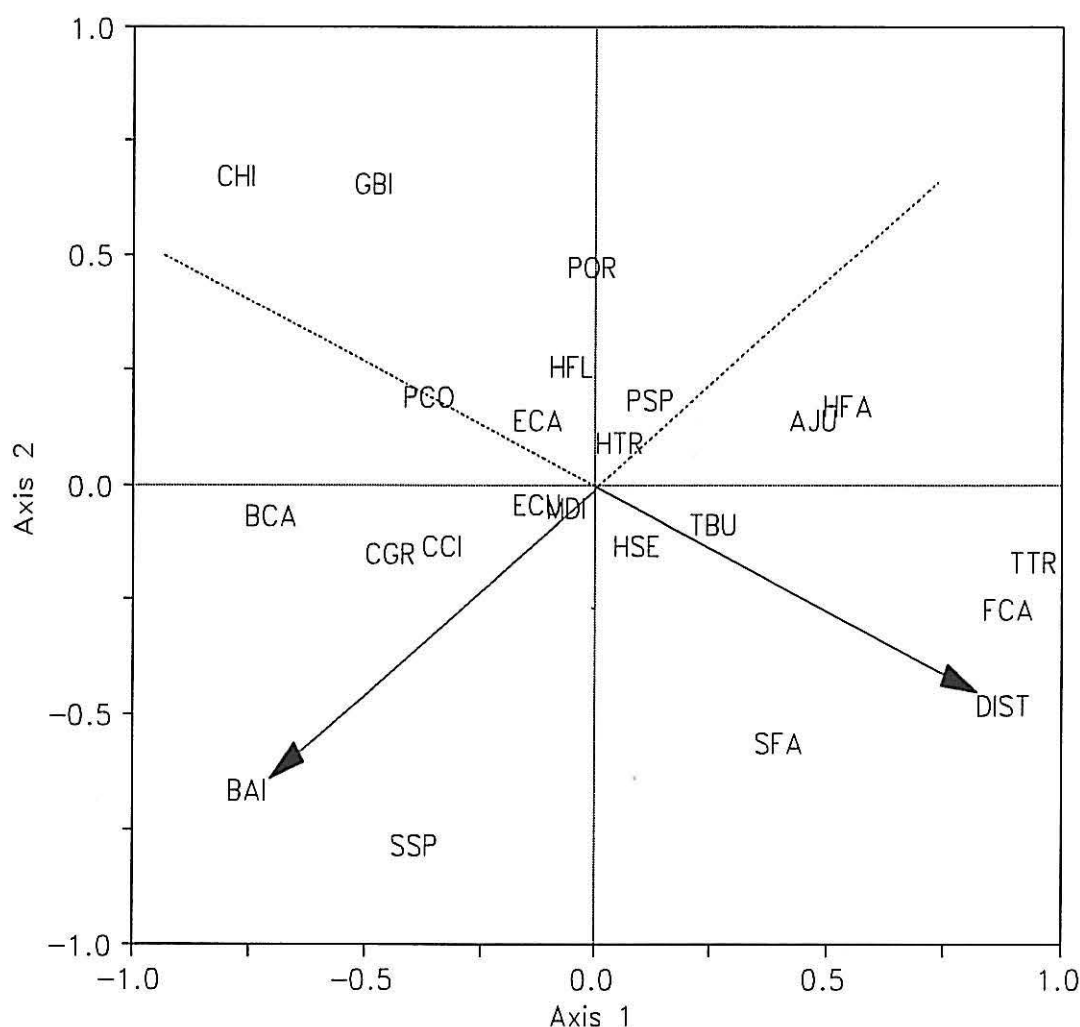
Figure 6.5   A plot of the positions of species along gradients of grazing intensity (distance from cattlepost (DIST)) and cover (bare area index (BAI)) as defined by a Partial Canonical Correspondence Analysis of species composition data in the Subalpine Belt of Study Area 1.   Species acronyms are: AJU = *Aristida junciformis* subsp. *galpinii*; BCA = *Bromus catharticus*;   CCI = *Chrysocoma   ciliata*;   CGR = *Catalepis   gracilis*; CHI = *Cynodon hirsutus*; ECA = *Eragrostis caesia*; ECU = *Eragrostis curvula*; FCA = *Festuca caprina*; GBI = *Gymnopentzia bifurcata*;   HFA = *Harpochloa falx*;   HFL = *Helichrysum   flanaganii*;   HSE = *H.   sessilioides*;   HTR = *H. trilineatum*;   MDI = *Merxmuellera   disticha*;   PCO = *Pentzia   cooperi*; POR = *Pentaschistis oreodoxa*; PSP = *Pennisetum sphacelatum*; SFA = *Scirpus falsus*;   SSP = *Senecio   spp.*;   TBU = *Trifolium   burchellianum*;   and TTR = *Themeda triandra*.

Table 6.4   The relative positions of the abundant species along a gradient in cover (BAI) in the Alpine Belt in Study Area 1, eastern Lesotho.

Species	Relative position along BAI[1] gradient (0-100)	Cover score (0-10)
Chrysocoma ciliata	0.0 'high BAI - poor cover'	0
Pentzia cooperi	8.7	1
Eragrostis caesia	42.5	4
Pentaschistis galpinii	47.2	5
Helichrysum flanaganii	52.8	5
Themeda triandra	52.8	5
Koeleria capensis	53.5	5
Poa binata	53.5	5
Festuca caprina	56.7	6
Merxmuellera disticha	62.2	6
M. drakensbergensis	68.5	7
Helichrysum sessilioides	76.4	8
Helichrysum trilineatum	85.0	9
Pentaschistis oreodoxa	85.8	9
Scirpus falsus	89.8	9
Harpochloa falx	100.0 'low BAI - good cover'	10

[1]'Bare area index' (see text for details).

Table 6.5   The relative positions of the abundant species along a gradient in cover (BAI) in the Subalpine Belt in Study Area 1, eastern Lesotho.

Species	Relative position along BAI[1] gradient (0-100)	Cover score (0-10)
Senecio spp.	0.0 'high BAI - poor cover'	0
Bromus catharticus	22.2	2
Catalepis gracilis	30.9	3
Chrysocoma ciliata	37.0	4
Eragrostis curvula	51.9	5
Scirpus falsus	51.9	5
Pentzia cooperi	53.1	5
Merxmuellera disticha	54.3	5
Cynodon hirsutus	58.0	6
Helichrysum sessilioides	58.0	6
Eragrostis caesia	61.7	6
Helichrysum trilineatum	69.1	7
Trifolium burchellianum	69.1	7
Gymnopentzia bifurcata	70.4	7
Helichrysum flanaganii	71.6	7
Pennisetum sphacelatum	76.5	8
Pentaschistis oreodoxa	86.4	9
Festuca caprina	90.1	9
Aristida junciformis[2]	91.4	9
Harpochloa falx	97.5	10
Themeda triandra	100.0 'low BAI - good cover'	10

[1]'Bare area index' (see text for details).
[2]*Aristida junciformis* subsp. *galpinii*.

The grazing gradient in the Alpine Belt was not examined further because it was poorly defined in the PCCA ordination (Table 6.3; Figure 6.4). In contrast, the Subalpine grazing gradient was adequately described by the PCCA ordination (Table 6.3). The positions and the scores of the species along the grazing gradient in the Subalpine Belt are presented in Table 6.6.

Table 6.6   The relative positions of the abundant species along a grazing gradient (distance from cattlepost (cpst.)) in the Subalpine Belt in Study Area 1, eastern Lesotho.

Species	Relative position along grazing gradient[1] (0-100)	Grazing score (0-10)
Cynodon hirsutus	0.0 'close to cpst. -	0
Gymnopentzia bifurcata	12.7 heavy grazing'	1
Bromus catharticus	25.5	3
Pentzia cooperi	32.7	3
Pentaschistis oreodoxa	38.2	4
Catalepis gracilis	40.0	4
Helichrysum flanaganii	43.6	4
Eragrostis caesia	43.6	4
Chrysocoma ciliata	43.6	4
Eragrostis curvula	50.0	5
Merxmuellera disticha	52.7	5
Pennisetum sphacelatum	53.6	5
Helichrysum trilineatum	53.6	5
Senecio spp.	60.9	6
Helichrysum sessilioides	61.8	6
Trifolium burchellianum	67.3	7
Aristida junciformis[2]	70.0	7
Harpochloa falx	71.8	7
Scirpus falsus	88.2	9
Themeda triandra	99.1 'far from cpst. -	10
Festuca caprina	100.0 light grazing'	10

[1]Based on distance from cattlepost (see text for details).
[2]Aristida junciformis subsp. galpinii.

Species that had a score of five along the grazing gradient (*Helichrysum trilineatum, Pennisetum sphacelatum, Merxmuellera disticha* & *Eragrostis curvula*) were located at or near the origin of the PCCA ordination plot (Figure 6.5 & Table 6.6). This indicates that their weighted average along the grazing gradient was

close to the mean weighted average of all the species in the analysis (ter Braak 1987a). Species that had a score along the grazing gradient of greater than five were those species whose projected position along the grazing gradient lay between the origin of the ordination plot and the head of the DIST arrow (Figure 6.5 & Table 6.6). These species had higher than average scores along the gradient, whereas species that were ranked low along the grazing gradient had below average scores along the gradient (Table 6.6). *Cynodon hirsutus* and *Gymnopentzia bifurcata* had particularly low scores along the grazing gradient. These two species, as well as *B. catharticus*, were usually abundant only in the proximity of cattleposts or other disturbed areas.

It is interesting to note that *Aristida junciformis* subsp. *galpinii* had a score of 7 along the gradient which was equal to that of *H. falx* (Table 6.6). In parts of Natal and the Transkei, *A. junciformis* subsp. *junciformis* invades mismanaged grassland and is largely unacceptable to livestock due to it tough, fibrous leaves (Morris & Tainton 1993). In contrast, *A. junciformis* subsp. *galpinii* appears to be grazed fairly readily in the Subalpine Belt and is not abundant in the highly stocked zone close to cattleposts.

In general, the response curves of the species along the Subalpine grazing gradient were either unimodal (i.e. with a single optimum), monotonic within the range of the data, or ill-defined (Figure 6.6 (a-u)). None of the species exhibited a clear bimodal response. Certain species had a narrow ecological tolerance along the grazing gradient and their optima were well defined by a peak in their response curve (e.g. *C. hirsutus* & *B. catharticus*). Other species did not exhibit a preference for a particular sector of the gradient (e.g. *Senecio* spp.). In certain cases (e.g. *H. sessilioides* & *S. falsus*) the data were too sparse to adequately describe the response curves. Those species that decreased in abundance from the 'heavy' towards the 'light' end of the grazing gradient included *P. cooperi*, *C. gracilis* and *C. ciliata*. *Harpochloa falx*, *T. triandra* and *F. caprina* showed the opposite response and were most abundant at a distance from a cattlepost. These are classical Decreaser species in terms of the classification of Dyksterhuis (1949).

a) Aristida junciformis

b) Bromus catharticus

c) Catalepis gracilis

d) Chrysocoma ciliata

e) Cynodon hirsutus

f) Eragrostis caesia

g) Eragrostis curvula

h) Festuca caprina

Relative abundance (%)

"heavy"   "light"   "heavy"   "light"
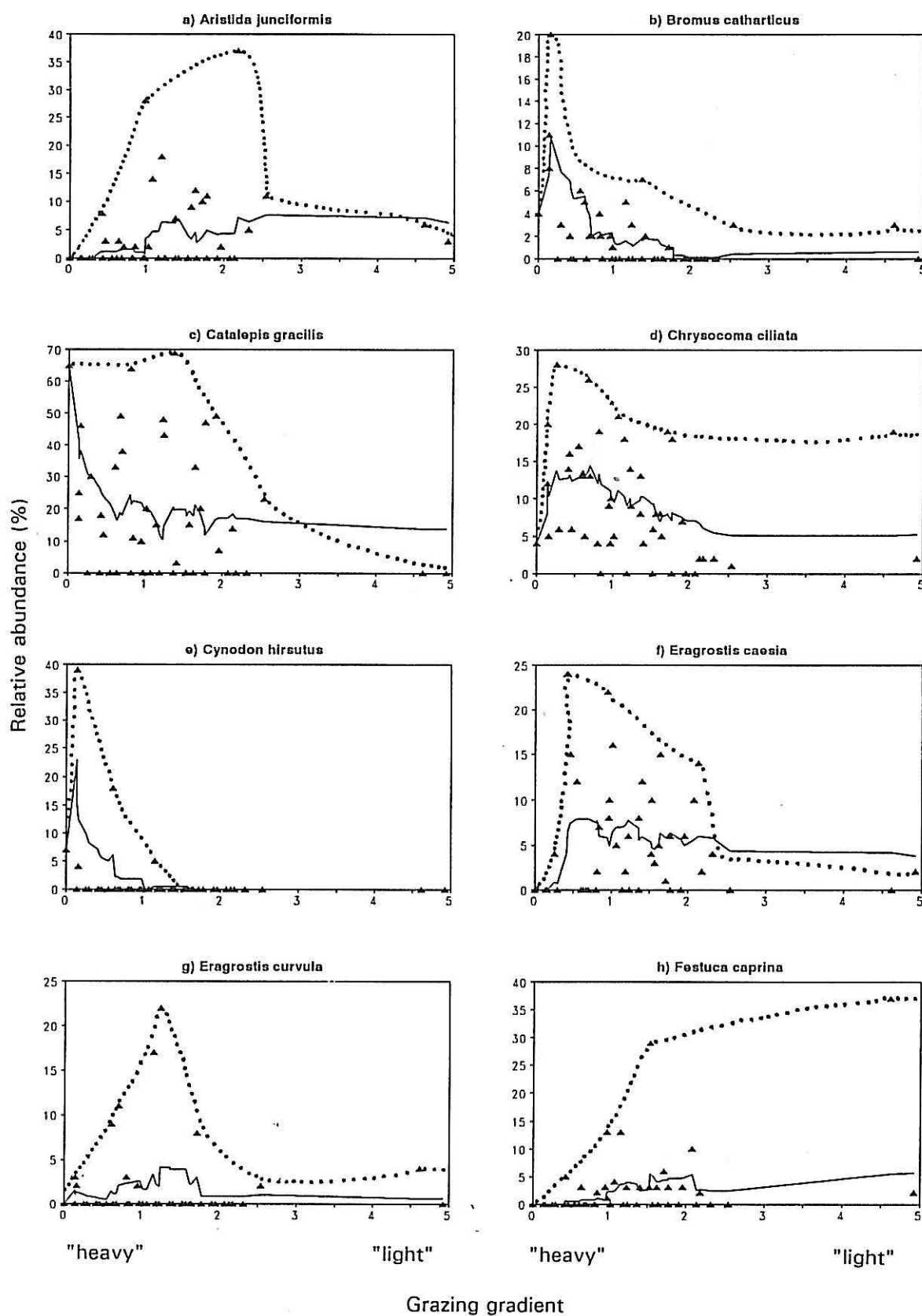
Grazing gradient

Figure 6.6   A plot of the response of 21 abundant species (a-u) along a grazing gradient in the Subalpine Belt of Study Area 1, eastern Lesotho. The boundary encompassing the upper limit of abundance for each species is displayed (···) along with a ten-point moving mean of species abundance (—) along the grazing gradient.

i) Gymnopentzia birfurcata

j) Harpochloa falx

k) Helichrysum flanaganii

l) Helichrysum sessilioides

m) Helichrysum trilineatum

n) Merxmuellera disticha

o) Pennisetum sphacelatum

p) Pentaschistis oreodoxa

"heavy"   "light"

Relative abundance (%)

Grazing gradient

Figure 6.6 continued.

q) Pentzia cooperi

r) Scirpus falsus

s) Senecio spp.

t) Themeda triandra

u) Trifolium burchellianum

Relative abundance (%)

"heavy"   "light"

Grazing gradient

"heavy"   "light"

Grazing gradient

Figure 6.6 continued.

Classification of species into categories that reflect their response to grazing involves a subjective decision as to whether a particular species has a clear and unambiguous response along the grazing gradient. A classification of the 21 abundant species in the Subalpine Belt according to the criteria of Dyksterhuis (1949) and Hurt (1989) was attempted and is presented in Table 6.7. Species that

displayed no response along the grazing gradient or whose response was not clear were not classified. Classification of the species by workers in Lesotho, where available, is also presented in Table 6.7. A definition of the species categories used is as follows.

1.   **Invaders**: species which usually occur only in areas disturbed by intense, prolonged grazing and trampling.

2.   **Strong Increasers**: species which increase in abundance in response to an increase in grazing intensity. They are most abundant towards the 'heavy' end of the grazing gradient.

3.   **Weak Increasers**: species which show an initial increase in abundance with an increase in grazing intensity followed by a decline in abundance at high grazing intensities. They are most abundant towards the middle of the grazing gradient.

4.   **Decreasers**: species which decline in abundance in response to an increase in grazing intensity. They are most abundant at the 'light' end of the grazing gradient.

Categorization of Increaser species into numerically defined categories reflecting their relative response to grazing, e.g. Increaser 1, 2, 3 & 4 (Bosch & Gauch 1991) or Increaser IIa, IIb, IIc etc (Martens 1992), was not attempted as this involves a number of subjective decisions as to the boundaries between classes. Further, the meaning of the numerical terminology used in such classifications is not immediately apparent to the user.

Most species in the Subalpine Belt were classified either as Weak Increasers or Strong Increasers (Table 6.7). Strong Increaser species had scores of less than five along the grazing gradient whereas Weak Increasers had scores of five or more along the gradient. However, the distinction between these two categories, based on the shape of the response curve, was not always clear. Only two species in the Subalpine Belt were classified as Invaders (Table 6.7). These were the stoloniferous grass *C. hirsutus* and *G. bifurcata*, a low-growing shrub. *Themeda*

triandra and *F. caprina* were identified as being Decreasers.

Table 6.7   The classification of the abundant Subalpine species in Study Area 1, eastern Lesotho, according to their response to grazing. Classification of the species by previous workers are given.

Species	Grazing score[1]	Grazing category	Previous classification	
			LCRD[3]	Limbach[4]
Cynodon hirsutus	0	Invader	I	INV, I
Gymnopentzia bifurcata	1	Invader		
Bromus catharticus	3	Strong Increaser	D	INV, I
Pentzia cooperi	3	Strong Increaser		
Pentaschistis oreodoxa	4	Strong Increaser	I	INC, I
Catalepis gracilis	4	Strong Increaser		DEC, D
Helichrysum flanaganii	4	Strong Increaser		
Eragrostis caesia	4	Strong Increaser	I	INC, I
Chrysocoma ciliata	4	Strong Increaser	U	INV, U
Eragrostis curvula	5	Weak Increaser	I	INC, I
Merxmuellera disticha	5	Weak Increaser		INC, D
Pennisetum sphacelatum	5	Weak Increaser	I	INC, I
Helichrysum trilineatum	5	Weak Increaser	U	
Senecio spp.	6	No response	U	U
Helichrysum sessilioides	6	Uncertain		
Trifolium burchellianum	7	Weak Increaser	U	
Aristida junciformis[2]	7	Weak Increaser		
Harpochloa falx	7	Weak Increaser/ Decreaser	D	DEC, D
Scirpus falsus	9	Uncertain		
Themeda triandra	10	Decreaser	D	DEC, D
Festuca caprina	10	Decreaser	I	INC, D

[1]From Table 6.6.
[2]*Aristida junciformis* subsp. *galpinii*.
[3]LCRD 1986c.   'Desirability factor': D = Desirable; I = Intermediate; and U = Undesirable.
[4]Limbach 1986.   Quantitative Ecological Method (Dyksterhuis 1949): DEC = Decreaser; INC = Increaser; and INV = Invader. 'Desirability factor': D = Desirable; I = Intermediate; and U = Undesirable.

There are discrepancies between previous classifications and the classification presented in Table 6.7. For example, *C. gracilis*, which in the present study has been classified as a Strong Increaser, has been classified as a Decreaser and a

Desirable species by Limbach (1986). *Festuca caprina* has previously been described as a species of intermediate value (LCRD 1986c) that increases in abundance with overgrazing (Limbach 1986; Morris *et al.* 1989). However, its distribution pattern along the grazing gradient is consistent with that of a Decreaser and not an Increaser species (Figure 6.6). *Themeda triandra* has been consistently recognised as a Decreaser species, both in Lesotho and in South Africa (Janse van Rensburg & Bosch 1990; Hurt *et al.* 1993). The exception is Cooper (1977), who reported that *T. triandra* acted as a Decreaser on thin-soiled and rocky habitats in the 400 to 600 mm rainfall zone in Lesotho and as an Increaser on sites with deeper soils in the same rainfall zone. The karroid shrubs, *C. ciliata* and *P. cooperi*, have generally been recognised as indicators of overgrazed range (Staples & Hudson 1938; Limbach 1986; Morris *et al.* 1989). This is confirmed by the results of the present study (Table 6.7).

A large part of the discrepancy between classifications in Lesotho is due to the subjectivity involved in classifying species into grazing categories. Because of the lack of experimental data in Lesotho, classifications were based on local knowledge and the results of research conducted in South Africa (Limbach 1986). However, it was noted that these classifications were preliminary and that they should be subject to continuous revision in the light of new information (Cooper 1977; LCRD 1986c; Limbach 1986). The terminology used to describe species categories in Lesotho has also been inconsistently applied in the past. Limbach (1986) and LCRD (1986c) did not always concur in how they equated 'desirability' with ecological status (Table 6.7).

Although multivariate techniques provide a means of objectively defining the grazing gradient, subjectivity is still involved when allocating species into grazing categories (e.g. Morris *et al.* 1989; Martens 1992). For example, it was not completely clear from the data whether *H. falx* should be classified as a Decreaser or a Weak Increaser species (Table 6.7). Although *H. falx* does decrease in abundance towards the 'heavy' end of the grazing gradient, it reaches maximum abundance towards the middle of the grazing gradient (Figure 6.6). In previous

classifications, *H. falx* has been classified both as a Decreaser (Cooper 1977; Limbach 1986; Hardy & Hurt 1989) and as an Increaser (Morris *et al.* 1989; Hurt *et al.* 1993).

Although it may be desirable for communication purposes to provide an unambiguous classification of at least the more common species in an area, this may not always be possible from data collected in a once-off survey. The alternative is to avoid attempting to categorize the species into discrete classes and to report only the ranking and the relative positions (i.e the scores) of the species along the grazing gradient. This would provide an indication of the relative response of the more common species to grazing and it would indicate, in an approximate way, the sequence of species replacement in the grazing-induced degradation pathway. It should be noted, however, that the successional pathway of recovery of an overgrazed area may be different to that of the degradation sequence and that species that are eliminated from the sward through grazing may not reestablish if the area is rested (Morris *et al.* 1992).

The scores of the species along the grazing gradient could be used in a weighted composition scoring procedure to provide an indication of the past grazing history of a site (Hurt & Hardy 1989). Weighted composition scores have been proposed as a means of assessing ecological status (*viz.* range condition) and detecting temporal changes in composition (Heard *et al.* 1986; Hurt & Bosch 1991; Martens 1992). In the procedure (Hurt & Hardy 1989), a weighted sum (S) for a site is calculated as follows:

$$S = \sum_{i=1}^{n} (A_i \times W_i)$$

where:

S is the score for the site;

A is the relative abundance of key species i; and

W is the score along the grazing gradient of species i.

Although site scores could potentially range from 0 to 1 000, in practice the extremes would not occur because sites are never completely dominated by one or only a few species. Sites with a high score would be dominated by species that are located towards the 'light' end of the grazing gradient (*viz.* Decreasers) whereas a low score would indicate a high proportion of Increaser or Invader species. Therefore, the weighted score could be termed a 'grazing score'. In Table 6.8 four examples are given of grazing scores for sites with different compositions.

Table 6.8   An example of the weighted key species scoring procedure applied to four sites in the Subalpine Belt in eastern Lesotho in order to provide an index of the position of sites along a gradient in grazing intensity (*viz.* distance from cattlepost (cpst.)).

Site no.	Distance from cpst. (m)	Relative abundance of the most abundant key species[2] (%)		Weighted score
9	0	*Catalepis gracilis* *Eragrostis caesia*	76.5 8.2	356.5
41	180	*Harpochloa falx* *Catalepis gracilis* *Eragrostis caesia*	41.0 16.7 16.7	512.0
32	60	*Aristida junciformis*[3] *Harpochloa falx*	40.0 24.3	604.3
46	500	*Themeda triandra* *Harpochloa falx*	44.1 35.5	806.5

[1]'Bare area index' (see text for details).
[2]Abundance relative to other key species.
[3]*Aristida junciformis* subsp. *galpinii.*

There was a significant (P<0.001) exponential relationship between the grazing scores calculated for the 46 sites in the Subalpine Belt and the cover of the sites (as indexed by BAI). High grazing scores (>700) were associated with good cover (low BAI) and BAI increased exponentially with a decrease in grazing score (Figure 6.8). There was considerable variation about this trend ($r^2 = 0.457$), however, and some sites with intermediate and low grazing scores (i.e <500) had low BAI values. This variation may be partly due to the difference between cattleposts in

their past stocking regimes but it also results from an increase in the abundance, with overgrazing, of stoloniferous species which contribute to a low BAI value (e.g. *C. hirsutus*). Further, intense grazing does not always result in a deterioration in cover because grazing may encourage prostrate, rather than upright, growth in certain species (e.g. *H. falx*), thereby increasing the protective cover provided by the vegetation (Cooper 1977; Tiedeman 1983b).

The equation shown on the figure:

$$y = e^{0.51 - 0.0035X}$$

$$r^2 = 0.457$$
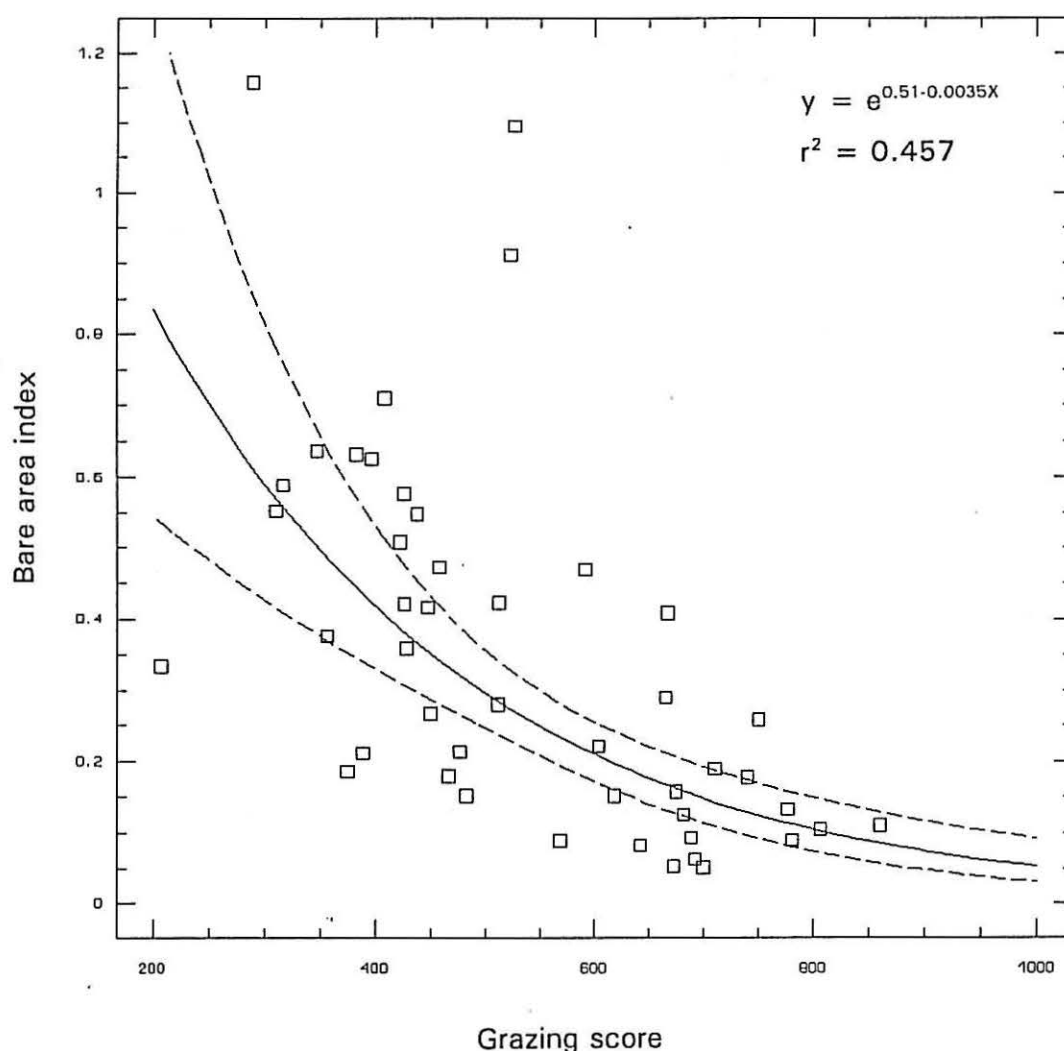
Figure 6.8   The exponential relationship between grazing score and cover (bare area index) for sites in the Subalpine Belt of Study Area 1, eastern Lesotho. The 95% confidence limits are indicated (···).

The range condition scoring technique that is presently used in Lesotho (Page 1986) is essentially also a weighted composition approach. The score that is calculated for a site is a weighted sum of the relative abundances of all the species recorded at the site with the species weights as follows: Decreasers x 2; Increasers x 0; and Invaders x -1. However, such a score will not provide a sensitive measure for monitoring range condition because the weights that have been assigned to species categories are arbitrary and all species encountered in the sward are classified and included in the score irrespective of whether they are responsive to the impact of grazing or not. The accuracy and the sensitivity of the procedure can be improved by using only those species that are known to be sensitive to the grazing impact (*viz.* key species; Hurt *et al.* 1993) and using more objectively derived species weights such as those given in Table 6.6.

The grazing score for a site could be used in a monitoring programme simply as a means to detect temporal species turnover (Hurt *et al.* 1993) or it could be used to evaluate the status of the sward in terms of a particular user-defined objective (Tiedeman & Wieland 1983; Stuart-Hill & Hobson 1991). By itself, the grazing score provides only an index of the ecological status of the sward in terms of its grazing history. However, ecological status is usually synonymous with forage production potential in that swards that have been overgrazed in the past usually contain few palatable and productive grass species, whereas those swards that have been moderately to leniently grazed are usually dominated by grasses with a high forage production potential (Dyksterhuis 1949; Cooper 1977; Foran *et al.* 1978). Therefore, the grazing score will reflect the condition of a site in terms of its production potential (Heard *et al.* 1986; Martens 1992).

If the objective function for the area is profitable animal production then high grazing scores are desirable. However, in a traditional pastoral system, such as Lesotho, where graziers may seek to maximise animal numbers rather than cash-flow through animal products (Chapter 3; Klosterman 1983), sward resilience rather than sward productivity is important (Walker 1980; Mentis 1984a). It is argued that vegetation communities that result from overgrazing (i.e. with low

grazing scores) may be more resilient to the impacts of livestock and other environmental factors than communities which have not experienced prolonged, intense grazing and which have a high proportion of palatable grasses (Walker 1980; Mckenzie 1982). However, the ability of such 'degraded' communities to protect the soil mantle from accelerated erosion is questionable (Anon. 1993) because they are usually (although not always) associated with poor vegetative cover (Figure 6.8). In contrast, sites with high grazing scores invariably have low BAI values (Figure 6.8). Therefore, high grazing scores would be desired by managers seeking to maximise the production of clean water from the mountain catchments (Morris *et al.* 1989).

It should be noted that a high grazing score may not always be commensurate with other user values (Tiedeman & Wieland 1983). For example, a *C. ciliata* dominated shrubland which would be regarded as being in poor condition for grazing, provides a valuable habitat for certain bird and insects species (Anon. 1993). 'Degraded' grassland, however, provides inadequate protective cover for Greywing Francolin (a potential commercial hunting species) and little food for large mammals, such as rhebuck (Anon. 1993). Multiple-user values are best accommodated via sets of species weights or scores that are specific for each use. Thus, a weighted composition score will reflect the relative value of sites for a particular objective function. These weights need not necessarily be derived from rigorous analytical procedures but could simply be user-perceived rankings of species in terms of their suitability for a particular use.

Independent data are needed to evaluate the accuracy of the weighted scoring technique in Lesotho (Hurt & Hardy 1989; Martens 1992). These data should collected from as wide an area as possible to ensure that the technique has general applicability throughout the Subalpine Belt in Lesotho. The weighted scoring technique should also be continuously refined when new data become available. In this respect, data from long-term grazing impact studies will be invaluable and may lead to some adjustment of the species weights proposed in this study and the inclusion or exclusion of certain species from the list of key species (e.g. Hurt

et al. 1993). Other shrub species, apart from those listed in Table 6.7, which were not abundant in Study Area 1 but which occur in the Subalpine and Montane Belts elsewhere in Lesotho, could also be useful indicators of overgrazing and should be considered for inclusion in the list of key species. These species are *Artemisia afra*, *Felicia filifolia*, *F. muricata* subsp. *muricata* and *Selago* spp. (Chapter 4; Jacot-Guillarmod 1971; Schmitz 1982; Limbach 1986).

Lastly, it is recommended that BAI be included as a routine measure in all vegetation surveys in the mountains. Not only does it provide an indication of the vegetative cover for evaluating the condition of a site but it also is a sensitive indicator of change (Anon. 1993). It is quick and easy to measure, requiring little expertise.

6.5 Conclusions

1. The analysis of grazing gradients associated with livestock gradients at cattleposts provided a means of assessing the effect of grazing intensity on species composition and cover in the mountains.

2. The effect of livestock on the vegetation of the Alpine Belt was not clear. There was little evidence of a shift in species composition and cover under grazing. Habitat factors, rather than grazing, appeared to be more influential in determining vegetation pattern in the Alpine Belt.

3. There was an identifiable relationship between vegetation composition and grazing pressure in the Subalpine Belt. With prolonged heavy grazing, short dense grasslands dominated by palatable grass species degrade to a dwarf karroid shrubland with sparse herbaceous cover.

4. In the Subalpine Belt, certain species showed a clear response to a gradient in grazing intensity. The relative positions, or scores, of these species along

the grazing gradient can be used in a weighted scoring procedure to provide an indication of the past grazing history of a site and to monitor changes in composition in response to grazing. However, the accuracy of the technique as well as its relevance for evaluating grassland for uses other than grazing still has to be established.

CHAPTER 7

DISCUSSION AND CONCLUSION

7.1 The implications of livestock grazing in the mountain catchments

Vegetation pattern and land-use in the mountains of Lesotho is dictated largely by the environment (Chapter 4). The climate of the mountains is harsh and low temperatures limit the distribution of many plant species to warm, sheltered positions in the landscape (Chapter 5). Temperature also affects transhumance and livestock management practices in the mountains. Consequently, there is an interaction between the environment and the impact of livestock grazing on the mountain vegetation. The impact of grazing is unevenly distributed in the mountains, both spatially and temporally, and certain areas have experienced a greater degree of grazing pressure than others.

7.1.1 Spatial distribution of grazing

It appears that grazing has affected the vegetation of the subtropical Subalpine Belt more than the temperate Alpine vegetation (Chapter 6). In 1938 Staples and Hudson noted that streams flowing from the temperate (*letsiri*) grasslands ran clear after high-intensity summer storms and that there was little sign of degradation and accelerated soil erosion in the high-elevation grasslands. This was in contrast to the extensive soil loss observed from areas where dense stands of *sehalahala* (*Chrysocoma ciliata*) had replaced the subtropical Subalpine grasslands (*seboku*) as a result of overgrazing (Staples & Hudson 1938). Recent reports (Anon. 1989.; Klug *et al.* 1989; Showers 1989) and the results presented in this thesis (Chapter 6) indicate that this is still the case, and that the Alpine grasslands in Lesotho are in good condition compared to the Subalpine grasslands.

It cannot be concluded, however, that livestock have had no impact on the Alpine Belt. Vegetation cover has been denuded around certain cattleposts in the Alpine Belt and karroid shrubs have invaded the warmer of these sites. Numerous stock trails serve to initiate erosion, especially at the head of valleys where they

converge (Staples & Hudson 1938; Weaver 1987; Anon. 1989). Many Alpine wetlands have been adversely impacted by livestock and some of these have been severely damaged by trampling and overgrazing (Backeus 1988; Schwabe *et al.* 1989; Anon. 1993).

One of the factors that has limited the impact of livestock on the Alpine vegetation is the low density of cattleposts in the Alpine Belt. Less than 28% of the cattleposts in the eastern mountain catchments occur above 2 975 m a.s.l. (Morris *et al.* 1989). The warmer slopes and valley bottoms in the Subalpine Belt are the preferred locations for cattleposts. Cattleposts at high elevations are usually occupied for a shorter period during the year than those at lower altitudes because of the high risk of stock loss through unseasonal cold weather and snow at high altitudes (Quinlan & Matobo 1989; Buzzard & Ntlale 1991). Further, the amount of useable forage in the Alpine Belt, especially for cattle, is less than that produced by the Subalpine vegetation (Tiedeman 1983a; Limbach 1986; Morris *et al.* 1989). Together, all these factors result in a lower stocking rate in the Alpine Belt than in the Subalpine Belt.

Because cattleposts are foci of livestock concentration in the mountains their distribution over the landscape will affect the spatial pattern of grassland degradation. Warm positions in the landscape are favoured locations for cattleposts. Only 17% of the cattleposts in the eastern catchments are located on cool aspects (Morris *et al.* 1989). Consequently, soil erosion in the form of sheet erosion and gully formation is more prevalent on warm slopes than on the cooler aspects (Klug *et al.* 1989). Basalt benches, where soils are particularly thin, are also erosion sensitive areas (Klug *et al.* 1989) and cattleposts are often built on these scarps (Morris *et al.* 1989). Valley bottom positions adjacent to streams are also favoured locations for cattleposts (Dobb 1985b). However, soils there are generally deeper than on the adjacent slopes and the potential for accelerated erosion is low (Schmitz & Rooyani 1987).

The density of cattleposts in a particular area will largely determine the stocking

rate in that area (Morris *et al.* 1989). Livestock, especially sheep and goats, are usually confined to graze within a local watershed in order to prevent mixing with stock from cattleposts in adjacent watersheds (Dobb 1985b; Shoup 1987). Consequently, the potential for grassland degradation is highest in valleys that have a high cattlepost density (Buzzard & Ntlale 1991).

Cattlepost densities in the mountain catchments are increasing (Quinlan 1994). Morris *et al.* (1989) reported an exponential increase in cattlepost numbers in the eastern mountains from 1930 to 1988. Data are not available to ascertain whether this trend has continued over the last five years and whether a similar increase in cattleposts numbers has occurred in the central and western mountains. Presumably there will be a limit to the number of cattleposts in an area which will be determined by the availability of suitable locations for new cattleposts and the availability of grazing in the area. District Chiefs have the authority to determine the number and location of cattleposts in the summer cattlepost area under their jurisdiction and they are responsible for issuing permits for grazing in the cattlepost areas (Phororo 1979). However, many District Chiefs do not consider the condition of the range when authorizing the construction of cattleposts in a particular area or when issuing grazing permits (Maclaurin 1992; Tshabalala 1994). Also, stock numbers cannot be controlled by restricting cattlepost construction because livestock owners will simply share cattleposts with those of kinsman or friends (Dobb 1985a; Quinlan 1994).

7.1.2 Seasonal distribution of grazing

The seasonal distribution of grazing pressure in the mountains is determined by transhumance patterns (Chapter 3). Traditionally, grasslands in the summer cattlepost areas are rested during winter when stock are in the village areas. Recently, however, livestock (both largestock and smallstock) are increasingly being kept in the summer cattlepost areas throughout the year (Lawry 1988; Quinlan & Matobo 1989; Quinlan 1994). This is even occurring at high elevations in the Alpine Belt (S Grab pers. comm., Dept. Geography, University of Natal, Pietermaritzburg). Dobb (1985b) estimated that up to one third of the summer

cattleposts in the Molumong area were occupied during winter. It is mostly stockowners with large flocks that are willing to risk overwintering their stock in the summer cattlepost areas (Lawry 1988; Quinlan & Morris in prep).

A possible reason for the change in transhumance patterns is a decline in the amount of forage available for overwintering stock in the village grazing areas as a result of the general escalation in stock numbers. This shortfall is further exacerbated by livestock that are kept in the village throughout the year because the owners, who have small stock holdings (1 or 2 animals), cannot afford to hire herders to accompany their stock to the summer cattlepost areas or want to minimize the risk of stock death by not sending their stock to the cattleposts areas (Quinlan & Morris in prep). Winter cattleposts, which are situated in the lower Subalpine Belt between the villages and the summer cattlepost areas, are increasingly being used as an alternative to the village areas for overwintering stock (Chapter 3; Quinlan & Morris in prep; Quinlan 1994). These winter cattlepost areas are particularly prone to degradation and erosion as they are situated in the warmer, drier regions of the mountains. Winter cattleposts are used to some extent for up to eight months of the year and intensively, at a high stocking density, for several months during winter (Quinlan & Morris in prep). It has been recommended that these changes in the socio-ecology of the mountains should not be ignored in the development of a conservation policy and of grazing management plans as they may have important long-term consequences for the stability and productivity of the mountain rangelands (Quinlan & Morris in prep; Quinlan 1994).

7.2 Grazing management options

Changes to certain aspects of the prevailing livestock system in the mountains are needed in order to prevent further resource degradation at the expense of both livestock production and water yield (Anon. 1990c). The need for planned management of the mountain rangelands was recognised as early as the 1930's when stock numbers in Lesotho reached a historical maximum and severe range degradation, which was attributed to overgrazing, became apparent (Pimm

Commission 1935; Staples & Hudson 1938). Since then there have been various attempts by government and non-government agents to institute livestock improvement schemes and grazing management programmes (Phororo 1979; Darkoh 1984; Dobb 1985b; Motsamai 1991). These programmes have generally been more successful in their attempts to improve animal productivity through improvements in animal health, breeding and fibre marketing, than in their efforts to manage livestock to reduce range degradation and enhance animal nutrition. The Government of Lesotho has recently outlined a plan to address the problems of declining animal and range productivity (Anon. 1990c). In that plan, a number of livestock management strategies are outlined.

In the National Livestock Policy Implementation Plan (Anon. 1990c) priority is to be given to the following areas of management: (1) a reduction in stocking rates on the mountain rangelands; (2) termination of seasonal transhumance from the Lowlands to the Mountains; (3) adjudication of grazing rights; and (4) extension of the Range Management Area (RMA) programme to other areas in Lesotho.

7.2.1 Reduction of stock numbers

The reduction of stock numbers in order to alleviate overgrazing of the range in Lesotho has been repeatedly called for (Chapter 3). However, efforts to persuade stockowners to voluntary reduce their stock holdings to boost individual animal performance have not succeeded in Lesotho and in traditional livestock systems elsewhere in the world (Phororo 1979; Sandford 1983; Erskine 1993). This failure has been partly attributed to the common-property nature of land tenure in the mountains which is proposed to act as a disincentive for individual stockowners to reduce animal numbers and to upgrade range and herd quality (Hardin 1968; Tiedeman 1983a; Brokken et al. 1986; Lyne & Nieuwoudt 1990).

Aspect of common-property use affecting range management will not be addressed in detail here (see Runge 1981; Dobb 1985b; Lawry 1988; Artz 1991; Mpofu 1991). What needs to be noted, however, is that Hardin's (1968) model of the 'tragedy of the commons', which predicts the inevitable destruction of natural

resources utilized communally because the costs of resource degradation do not accrue to the individual but are borne by the community as a whole, has been questioned as to its general applicability to all communal grazing systems (Runge 1981; Vink & Kassier 1987; Mpofu 1991). Hardin's model had been criticised for it's oversimplification of the complexities of common-property resource ownership. It is argued, that in many communal grazing systems, institutions and regulations do exist within the community using the land which serve to control the rights and practices of users. Therefore, the system is not completely 'free' and 'open'. In Lesotho, chieftainship control of grazing and other natural resources through the practice of *leboella* (Chapter 3; Quinlan 1994) is a case in point. It has also been suggested that common-use range systems, if regulated in some way, may even be superior to private tenure for equitable and sustained multiple resource use (Artz 1991). However, the extent to which this is so would depend largely on the effectiveness of the chiefs who control the use of the range, and this may vary widely (Shoup 1987).

A second reason why stockowners have not voluntary reduced stock holdings in Lesotho is that livestock contribute significantly to the household economy through 'flow' products (i.e. draft, fibre and dung) and a reduction in numbers will adversely affect the smaller stockowners who rely on livestock largely for subsistence (Tshabalala 1994). Livestock also contribute significantly to the cash economy of households (Chapter 3) and commercial stock farmers may destock only if alternative, cash-generating forms of land-use are encouraged (Anon. 1993). Initiatives to develop multiple resource use should be focused on the tourist industry because the potential for tourism in the mountains is high due to improved accessibility to the area as a result of the construction of all-weather roads in many parts of the mountains (Bainbridge *et al.* 1991; Anon. 1993). Examples of such tourist related commercial activities include conducting mountain trails on horseback or on foot with overnight accommodation provided by local residents, marketing of traditional crafts, gamebird shooting, fishing etc (Anon. 1993).

The Government of Lesotho plans to encourage destocking through the

introduction of a grazing fee for each animal using the range (Anon. 1990c). The objective of the grazing fee is to ensure that the individual stockowners bear the cost of utilizing the range in order to encourage economic rationalization of livestock production. It is hoped that stockowners will voluntary sell off 'non-productive' livestock to pay grazing fees (Motsamai 1991). Grazing fees will be collected by Village Development Councils (VDCs) and be used for livestock and range development projects or other community development programmes. In order to institute grazing fees, a national livestock inventory needs to be conducted, a grazing fee accounting system needs to be developed and stockowners need to issued with livestock registration booklets in which they will be required to detail all livestock holdings. Although the grazing fee programme is to be introduced in a phased manner, area-by-area, staffing and logistic problems will be immense. It remains to be seen whether the programme will meet with resistance from stockowners who previously have not had to pay for use of the grazing resource (Brokken et al. 1986; Phororo 1994).

A second initiative planned by the Lesotho Government to reduce stock numbers is the National Livestock Culling Programme (Anon. 1990c). Agricultural officers will inspect livestock to identify off-colour sheep and goats which will be marked as cull animals. A later phase of the programme will include all 'low productivity' stock. Cull animals will be marketed through the Livestock Products Marketing Service (LPMS), the National Feedlot and the National Abattoir. Smallstock that are designated as culls can also be exchanged for quality breeding stock (two high quality Angora goats or Merino sheep for every three cull animals), under the current National Smallstock Exchange Programme (Anon. 1990c). It is hoped that an increase in the quality of livestock will compensate stockowners for the forced reduction in animal numbers (Motsamai 1991). Although a culling and exchange programme will reduce animal numbers in the short term, a reduction in stock numbers would most likely lead to improved nutrition for remaining animals, resulting in enhanced fertility and reduced mortality which in the long term could offset the effects of the culling programme (Brokken et al. 1986). It is also likely that enforced culling will be resisted by certain stockowners (Darkoh 1984).

7.2.2 Termination of transhumance from the Lowlands to the Mountains

It is the intention of the Government of Lesotho to phase out seasonal transhumance between the summer cattlepost areas in the Mountains and lower-lying areas in Lesotho in order to reduce soil erosion due to seasonal trailing of stock and to reduce grazing pressure on the 'fragile' mountain ecosystem (Anon. 1990c). Intensive livestock production systems based on cultivated forages and on village-based rotational grazing systems will be encouraged in the Lowlands (Shoup 1987; Motsamai 1991). However, it has been recommended that research be conducted to assess the impacts of increased animal numbers in the Lowlands as well as possible sociological impacts before a blanket policy prohibiting all seasonal transhumance is adopted (Dobb 1988; Anon. 1990c).

7.2.3 Adjudication of grazing rights

The need has been recognised for a reallocation of cattlepost ownership rights in order to ensure that groups of villages can be allocated a summer cattlepost area in closest possible proximity to them (Anon. 1990c). This will aid the delineation of areas that can be managed as a single RMA. Presently, cattlepost ownership is not always organised on a village basis. Dobb (1985a) has shown that although residents of the same village use the same winter grazing area, stockowners from the same village do not necessarily use the same summer cattlepost grazing area. A particular cattlepost area may be shared by stockowners from various villages and even from different wards and districts.

A national cattlepost inventory is presently being conducted by the Division of Range Management to document cattlepost and livestock ownership profiles throughout the Mountains. This information will be used, in consultation with local authorities, to assist with the reallocation of cattlepost rights. However, any reallocation programme is advised to carefully consider existing social arrangements between stockowners, such as cattlepost sharing and *mafisa* arrangements (Chapter 3) (Shoup 1987; Dobb 1988; Quinlan 1994).

7.2.4 Extension of the Range Management Area Programme

The National Range Management Programme, under the direction of the Range Management Division with assistance from USAID, was initiated in 1982 (Weaver 1991). By 1992 four RMAs had been established (Sehlabathebe, Ha Moshebi/Ha Ramatseliso, Pelaneng/Bokong and Mokhotlong/Sanquebethu) encompassing a total area of *c.* 130 000 ha (Artz 1993). The Government of Lesotho has planned to establish an additional five RMAs in the next five to 10 years (Anon. 1990c). The Managed Resource Area (MRA), which has been proclaimed in the eastern mountains with the aim of providing a framework for conservation of the mountain catchments under sustainable resource utilization (Chapter 1), will operate through the establishment of a number of RMAs within the MRA (Bainbridge *et al.* 1991).

An RMA is an area that has been set aside for the exclusive use of stockowners resident within the area in order to improve range and livestock production through the application of 'advanced' management procedures (Weaver 1991). Stockowners form a grazing association (GA) which has responsibility for the cooperative management of RMA rangelands and the development of livestock improvement programmes. The GA is directed by a management committee comprised of the chief/headman and two elected members from each village within the RMA. Technical assistance to the GA is provided by an RMA advisor from the Range Management Division. The underlying concept of an RMA is that management of natural resources, e.g. rangelands, is vested with a community who have exclusive use of their resources, *viz.* 'controlled communal use' (Weaver 1987). It would then be in the best interests of the community to ensure sustained use of the resources (Weaver 1991). It has been generally recognised that cooperative management of common-property is the best option for the management of rangelands in Lesotho and elsewhere in Africa (World Bank 1980; Dobb 1985b; Lawry 1986a; Artz 1991; Erskine 1993).

Programmes designed to improve livestock productivity and the quality of livestock products in the RMA include: (1) improved animal health services (dipping, dosing and vaccination); (2) breed improvement through culling, castration and the

purchase of improved breeding stock; and (3) improvement of marketing facilities. Grazing management is achieved through a mandatory, deferred rotation grazing management scheme (Chapter 3).

It was reported that the RMA programme at Sehlabathebe and Ha Moshebi/Ha Ramatseliso - the first two RMAs to be established - had resulted a noticeable improvement in animal weights and condition since the management program was instituted in 1983 (Weaver 1991). On average, cattle from within the RMAs were 50 kgs heavier than cattle from outside the RMAs and this resulted in higher sale prices being achieved for RMA cattle compared to non-RMA cattle (Weaver & Sekoto 1991). This improvement in animal productivity was attributed to an improvement in range condition resulting from the implementation of a grazing management plan (Anon. 1991; Weaver & Sekoto 1991). At Sehlabathebe RMA, comparison of vegetation data collected from permanent transects at the initiation of the grazing management plan in 1983 with data collected seven years later indicated a increased representation of 'Desirable' and 'Intermediate' grasses and a decline in 'Undesirable' species in the sward (Weaver & Sekoto 1991). This change was accompanied by an increase in vegetative cover and species diversity. It was noted, however, that the observed improvement in condition of the range could not be ascribed solely to an improvement in grazing management but also to the effects of a reduction in stocking rate when livestock of non-resident stockowners were excluded from the area when the RMA was proclaimed (Weaver & Sekoto 1991).

The aim of the National RMA programme is to ensure that RMAs are eventually self-sustaining, independent of outside organisation, and self-financing through RMA membership fees and other revenue-generating programmes (e.g. livestock breeding fees, fodder and veterinary sales etc) (Buzzard 1994). However, their sustainability without outside support has been questioned (Hunter & Weaver 1991; Artz 1993; Buzzard 1994). Although surveys have indicated that the RMA programs at Sehlabathebe and Ha Moshebi/Ha Ramatseliso have generally been well received by RMA residents and that there was adequate participation in

mandated GA activities (e.g. rotational grazing scheme), active participation in other facets of the programme (e.g breed improvement and livestock marketing) was low and commitment to the programme was not always forthcoming in the form of membership fees (Artz 1993). Buzzard (1994) reported that there was some confusion amongst participants in the other three RMAs as to who was responsible for the development and implementation of the RMA grazing management plan and that the general perception was that they (the community) had little input into the development of the plan. Buzzard (1994) concluded that control over grazing practices had not yet been achieved in these RMAs and the rangelands were not been managed in an 'ecologically sound' way. Therefore, it was recommended that there should be a gradual, phased turnover of management of the RMAs to the community and that greater community participation, especially by chiefs, should be sought (Artz 1993; Buzzard 1994).

Part of the problems that are been experienced in RMAs arise out of conflict of authority between traditional structures and new institutions of authority. Chiefs have traditionally been involved in regulating grazing practices and the use of other natural resources (Chapter 3). However, the authority of chieftainship has declined over time (Dobb 1985b; Hunter 1987) and their effectiveness and ability to promote the conservation of resources has been questioned by the Government of Lesotho (Motsamai 1991; Tshabalala 1994). Part of this decline in authority is due to intervention by government into resource management in the mountains by according increased authority to government appointed officials (e.g. Range Management Officers) and elected bodies (e.g. VDCs) (Shoup 1987; Tshabalala 1994). However, at the same time, chiefs have been incorporated into RMA authority structures and their support is seen by government agents as being vital for the success of grazing associations (Weaver 1991; Buzzard 1994). The chieftainship continues to have legitimacy amongst rural Basotho and chiefs are still intimately involved in the day-to-day management of resources (Shoup 1987; Tshabalala 1994). This dualism in authority, where both government officials and traditional authorities are involved in decisions concerning range management, has the potential to create a certain amount of confusion and tension within the

community which may lead to conflict (Shoup 1987; Quinlan 1994).

What arises out of the above discussion is that intervention into community processes and affairs in order to develop more effective livestock management systems is not simple. Intervention by outsiders certainly has the ability to alter the *status quo*, both positively (Weaver 1991) and negatively (Ferguson 1990). A clear understanding of the existing social organisation and structures of authority is needed in order to implement effective and acceptable resource management policy (Phororo 1994). Ongoing and comprehensive monitoring of development intervention is also required to determine its' impact on the socio-economy of the rural community and to ascertain the extent to which development is altering the underlying framework of values and institutions in the community.

7.3   Monitoring

Monitoring needs to be an integral part of the management of the mountain catchments. Monitoring involves the repeated measurement of various parameters to detect change over time. Factors that are expected to impact on the system may also be measured concurrently in a monitoring programme in order to aid in the interpretation of change (Mentis 1989). Human impact on the vegetation of the Lesotho mountains has increased steadily over time (Chapter 3 & 6) and is expected to increase dramatically with the construction of the Lesotho Highlands Water Project (LHWP).

The impact of livestock on the vegetation of Phase IA area of the LHWP (Study Area 2) is likely to be modified upon inundation of the Katse reservoir in 1995. Altogether 790 ha of cultivated land and 2 791 ha of rangeland will be flooded (Chapter 4). This will result in a 6% decrease in the carrying capacity of the local catchment (Anon. 1993). More importantly, however, it will be largely winter forage (both from the range and crop stover) that will be lost, thereby increasing the pressure on the winter and summer cattlepost areas. This will most likely accelerate the loss of soil from the range, resulting in increased sedimentation loads in rivers (Anon. 1989).

Transhumance patterns in the Katse area will most likely also be affected by the Katse dam. Movement of livestock across the Bokong and Malibamatso rivers will be severely impeded and many livestock owners who live on the eastern bank of the Malibamatso river will loose access to their summer cattleposts in the upper Bokong area, to the west of the Malibamatso river (Buzzard & Ntlale 1991). This will result in an increase in the grazing pressure in the cattlepost areas on the eastern bank of the Malibamatso.

Without outside intervention, the equilibrium between livestock and the range (i.e. at ecological carrying capacity) will most likely eventually be restored through feedback mechanisms affecting livestock mortality and recruitment (Chapter 3). Under these conditions, range condition is unlikely to change substantially. However, if forage is imported into the area to reduce the winter 'bottleneck' then livestock populations will be artificially maintained above the ecological carrying capacity, which may result in accelerated range degradation and soil erosion (Anon. 1993).

Transport of livestock into and out of the Katse area has been made easier by the upgrading of the access road from the Lowlands and this, together with increased financial liquidity of local residents, could affect livestock purchases and sales in the area (Anon. 1993). However, the socio-economy of the area is complex (Tshabalala & Turner 1989) and it is difficult to precisely predict the effects of the LHWP on the livestock economy. Therefore, monitoring of the dynamics of the livestock system is necessary in order to evaluate and fully understand the impact of the LHWP.

Livestock and cattlepost numbers as well as seasonal transhumance patterns need to be monitored regularly. This should be done in conjunction with a vegetation monitoring programme designed to detect temporal changes in species composition and cover. Factors that could possibly impact the vegetation, in addition to grazing (e.g. fire and rainfall patterns), should also be monitored. A concurrent programme to describe changes in key socio-economic factors that may influence the livestock

economy, such as the income and spending patterns and time budgets of rural households (Tshabalala & Turner 1989), will aid interpretation of data from vegetation and livestock monitoring programmes.

There are a number of components of the mountain ecosystem that may change in response to the impact of the LHWP and other development projects and it will not be feasible to monitor every variable. Further, the influence of the LHWP on the biota will be indirect, via a myriad of interacting factors whose individual effect will not easily be isolated. Therefore, it will be necessary to identify a number of key variables or components of the system that are sensitive to the expected impacts and which will provide an indication of a general change in the system and the possible cause/s of change.

With respect to the vegetation, the value of using key species and an index of cover (bare area index (BAI)) to measure the impact of livestock in the mountains has already been noted (Chapter 6). Changes in the general dynamics of the livestock system may be indicated by factors such as: (1) an increase in the number of cattleposts built in unfavourable locations in the landscape (such as at high altitudes and cool aspects within the Alpine Belt) - this may indicate an increasing scarcity of grazing; (2) changes to seasonal patterns of transhumance (e.g. the construction of winter cattleposts and overwintering of stock in the summer cattlepost areas); and (3) increased use of alternative sources of forage for winter (e.g. 'landsgrasses', cultivated fodder crops and imported fodder).

It will not be possible to· monitor all areas that are to be affected by the LHWP even if only key variables are measured. Therefore, monitoring efforts should be concentrated in a few areas, selected so as to cover the full spectrum of land-use patterns (both village and cattlepost areas) and habitats in the region. It has been recommended that local catchments ('micro-catchments') form the basic sampling unit for the monitoring of soil loss in the Katse Area (Anon. 1989). Vegetation transects should be located in the same micro-catchments that are to be used in the soil-loss monitoring programs. Land-use practices (livestock and cropping) in

these valleys should be documented and monitored regularly as discussed above. It has been suggested that the monitoring programme should also include valleys adjacent to the catchment of the Phase IA (Katse) area as a control to provide a means of assessing the effects of the LHWP and any 'improved' farming practices which are to be implemented in the Katse catchment (Anon. 1989; Anon. 1990a). However, it cannot be assumed that these catchments will be outside the area of influence of the LHWP because the effects of the project will most likely not be confined to the immediate catchments of the LHWP.

Vegetation monitoring programmes have already been instituted in various areas in the mountains. In Study Area 2, baseline floristic data have been collected from 87 permanently marked transects (Anon. 1993). These data include species composition of the herbaceous layer, measured in fifty of the transects (Chapter 4), and the relative abundance of a selected set of key indicator shrubs (8 species) as well as a measure of cover (BAI), recorded in all 87 transects. The indicator shrub species were selected so as to obtain a rapid, repeatable and sensitive measure for detecting vegetation change. The intention is to monitor shrub composition and BAI every three years and herbaceous composition every six years (Anon. 1993).

A further 12 permanent vegetation transects in Study Area 2, all located within the Pelaneng/Bokong RMA on the western bank of the Malibamatso river, have been surveyed by the Range Management Division (Buzzard 1991a). Species composition and various soil surface parameters have been recorded in each transect. Baseline floristic data for monitoring vegetation have also been collected in the other four RMAs (Anon. 1991; Buzzard & Ntlale 1991; Weaver & Sekoto 1991). These vegetation monitoring programmes provide a means of assessing the effectiveness of grazing management in the RMAs (e.g. Weaver & Sekoto 1991).

7.4 Conclusion

The mountain ecosystem in Lesotho comprises a complex of interacting components that act in concert to determine vegetation and land-use patterns. Although the concept of 'holism' (Smuts 1987) has become somewhat of a popularism which is seen by some as the only means of analyzing and describing complex systems (Savory 1988; Buzzard 1991b), the concept is particularly relevant to the analysis of vegetation and livestock dynamics in the mountains of Lesotho. Patterns of land-use which influence the biota (the vegetation/soil complex) cannot be examined without reference to the local and wider socio-economy. In addition, the system is not static and relations within the system are constantly been altered by environmental fluctuations and intervention by outside factors.

The solution to the problem of resource degradation in the mountains of Lesotho is not simple, or even obvious, and there is no single strategy or plan that will 'solve' the problems. Comprehensive research is required to develop an understanding of the dynamics of the socio-ecology in the mountains and to understand how development interventions affect various components of the system. **This research should not be multi-disciplinary but rather inter-disciplinary** in its approach because multi-disciplinary research programmes (e.g. the D/MCCP and the baseline biological survey of Phase IA) have failed to provide an integrated, broad perspective on the complexities of the vegetation/livestock system. The reason for this is that the various specialised studies in the multi-disciplinary programmes were usually conducted separately, without collaboration and consultation in the field. Monitoring programmes in the mountains should also be integrated between disciplines, where possible, in order to provide a comprehensive analysis of the process and causes of change.

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Appendix 1 The environmental variables recorded at each site in Study Area 1 in eastern Lesotho.

Site number	Altitude (m a.s.l.)	Slope (degrees)	Aspect (degrees - true north)	Aspect (degrees - linear scale[1])
1	3 175	26	343	17
2	3 175	32	231	129
3	3 100	9	31	129
4	3 125	12	31	31
5	3 100	23	27	27
6	2 975	5	27	27
7	2 975	10	201	159
8	3 075	21	56	56
9	3 075	23	356	4
10	3 000	9	71	71
11	3 175	18	281	79
12	3 125	6	271	89
13	3 050	12	271	89
14	3 025	7	241	119
15	3 000	14	9	9
16	2 950	9	221	139
17	2 925	9	11	11
18	2 900	9	247	113
19	2 900	3	0	0
20	2 950	20	189	171
21	3 150	10	31	31
22	3 150	11	181	179
23	3 325	20	191	169
24	3 050	3	21	21
25	2 750	19	251	109
26	3 000	26	187	173
27	2 750	26	161	161
28	2 750	22	171	171
29	2 750	15	251	109
30	2 700	6	206	154
31	2 925	26	231	129
32	2 925	26	306	54
33	2 800	15	351	9
34	2 825	22	353	7
35	2 875	25	221	139
36	2 950	26	271	89
37	2 650	17	321	39
38	2 700	8	88	88
39	2 875	19	125	125
40	2 725	12	61	61
41	2 975	25	51	51
42	2 975	15	157	157
43	2 775	13	293	67
44	2 825	26	295	65
45	2 900	24	295	65

Appendix 1 continued.

Site number	Altitude (m a.s.l.)	Slope (degrees)	Aspect (degrees - true north)	Aspect (degrees - linear scale[1])
46	2 750	22	135	135
47	2 825	22	123	123
48	2 900	21	147	147
49	2 975	34	269	91
50	2 775	23	227	133
51	2 700	9	229	131
52	2 700	14	21	21
53	2 825	23	15	15
54	3 025	29	1	1
55	3 125	17	157	157
56	3 025	15	165	165
57	3 000	12	32	32
58	3 075	15	311	49
59	2 975	22	285	75
60	2 975	25	71	71
61	3 025	11	167	167
62	3 125	19	165	165
63	2 950	10	33	33
64	2 875	25	193	167
65	2 800	19	175	175
66	2 725	6	235	125
67	3 025	0	0	0
68	3 000	5	281	79
69	2 800	22	281	79
70	2 625	14	209	151
71	2 975	25	349	11
72	2 950	10	61	61
73	2 950	12	55	55
74	2 950	10	3	3
75	2 650	10	265	95
76	2 950	10	61	61
77	3 025	20	206	154
78	3 000	25	116	116
79	3 000	23	266	94
80	2 825	19	351	9
81	3 150	10	51	51
82	2 675	19	19	19
83	2 700	21	221	139
84	3 075	17	321	39
85	2 875	15	181	179
86	3 050	19	161	161
87	2 675	24	231	129
88	2 750	11	291	69

[1]Aspect converted to linear scale as follows: aspect = aspect, for aspect ≤ 180°; aspect = 360-aspect, for aspect > 180°.

Appendix 2 The environmental variables recorded at each transect in Study Area 2 in western Lesotho.

Transect number	No. of points	No. of segments	Lower altitude (m a.s.l.)	Upper altitude (m a.s.l.)	Aspect (degrees - true north)	Aspect (degrees - linear scale[1])	Slope (degrees)
1	473	17	2 350	2 890	161	161	30
2	634	24	2 375	2 925	331	29	23
3	262	9	2 675	3 070	145	145	37
4	424	15	2 650	2 975	8	8	21
5	348	12	2 650	3 025	81	81	28
6	418	15	2 250	2 575	8	8	21
7	435	16	2 250	2 600	155	155	22
8	179	6	2 675	2 850	313	47	26
9	253	9	2 725	2 925	125	125	22
10	162	5	2 850	2 950	82	82	17
11	155	5	3 000	3 075	110	110	14
12	276	9	3 000	3 125	290	70	13
13	296	10	2 850	3 050	229	131	19
14	318	11	2 750	3 000	283	77	21
15	289	10	2 825	3 025	331	29	19
16	175	5	2 650	2 800	1	1	23
17	193	6	2 725	2 875	189	171	21
18	129	4	2 725	2 850	331	29	26
19	261	9	2 600	2 750	319	41	16
20	188	6	2 600	2 800	91	91	28
21	271	9	2 600	2 825	33	33	23
22	254	9	2 575	2 775	223	137	22
23	190	6	2 450	2 625	171	171	25
24	151	4	2 600	2 800	276	84	33
25	96	2	2 375	2 450	61	61	21
26	177	6	2 600	2 775	256	104	26
27	159	5	2 250	2 425	173	173	29
28	124	3	2 550	2 625	233	127	17
29	148	4	2 200	2 400	157	157	34
30	141	4	2 525	2 625	26	26	20
31	108	3	2 075	2 150	21	21	19
32	119	3	2 075	2 200	251	109	28
33	174	5	2 275	2 400	351	9	20
34	187	6.	2 225	2 375	40	40	22
35	131	4	2 450	2 450	0	0	0
36	148	4	2 250	2 400	223	137	27
37	162	5	2 250	2 400	286	74	25
38	265	9	2 250	2 425	77	77	18
39	205	7	2 400	2 550	49	49	20
40	170	5	2 450	2 450	0	0	0
41	180	6	2 500	2 675	41	41	25
42	300	10	2 500	2 775	181	179	25
43	284	10	2 600	2 850	190	170	24
44	239	8	2 625	2 800	51	51	20

Appendix 2 continued.

Transect number	No. of points	No. of segments	Lower altitude (m a.s.l.)	Upper altitude (m a.s.l.)	Aspect (degrees - true north)	Aspect (degrees - linear scale[1])	Slope (degrees)
45	92	2	2 325	2 425	177	177	29
46	200	6	2 500	2 725	123	123	29
47	189	6	2 450	2 650	181	179	28
48	93	2	2 225	2 325	123	123	28
49	100	2	2 325	2 425	325	35	27
50	134	4	2 250	2 400	161	161	29

[1]Aspect converted to linear scale as follows: aspect=aspect, for aspect≤180°; aspect=360-aspect, for aspect>180°.

Appendix 3 A list of species acronyms and the corresponding full species names for species that were encountered in Study Area 1 and Study Area 2 in Lesotho.

AREA	ACRONYM	SPECIES NAME
2	AGROBARB	*Agrostis barbuligera* Stapf var. *barbuligera*
2	AGROLACH	*Agrostis lachnantha* Nees var. *lachnantha*
2	ALEPSPEC	*Alepidea pusilla* Weim.
		Alepidea thodei Duemmer
2	ALLOSEMI	*Alloteropsis semialata* (R. Br.) Hitchc. subsp. *eckloniana* (Nees) Gibbs Russel
2	ANDRAMET	*Andropogon amethystinus* Steud.
2	ANDRAPPE	*Andropogon appendiculatus* Nees
2	ANTHECKL	*Anthoxanthum ecklonii* (Nees ex Trin.) Stapf
1,2	ANTHMONT	*Anthospermum monticola* Puff
2	ANTHSPEC	*Anthospermum* sp.
2	ARCTMICR	*Arctotis microcephala* (DC.) Beauv.
2	ARGYPUMI	*Argyrolobium pumilum* Eckl. & Zeyh.
1	ARISJUNC	*Aristida junciformis* Trin. & Rupr. subsp. *galpinii* (Stapf) De Winter
2	ARISSPEC	*Aristida adscensionis* L.
		Aristida congesta Roem. & Schult. subsp. *congesta*
		Aristida diffusa Trin. subsp. *burkei* (Stapf) Meld.
		Aristida junciformis Trin. & Rupr. subsp. *galpinii* (Stapf) De Winter
2	ARTEAFRA	*Artemisia afra* Jacq.
1	ASCLSPEC	*Asclepias* sp.
2	ASTEBAKE	*Aster bakeranus* Burtt Davy ex C.A. Sm.
2	ASTEERUC	*Aster erucifolius* (Thell.) Lippert
1,2	ATHRSPEC	*Athrixia angustissima* DC.
		Athrixia fontana Macowan
2	BARBVERN	*Barbarea verna* (Mill.) Aschers.
1	BASUPROP	*Basutica propiniqua* Hilliard
1,2	BERKCIRS	*Berkheya cirsiifolia* (DC.) Roessl.
2	BIDEPILO	*Bidens pilosa* L.
1,2	BRACBOLU	*Brachypodium bolusii* Stapf
2	BRACERUC	*Brachiaria eruciformis* (J.E. Sm.) Griseb.
2	BRACSERR	*Brachiaria serrata* (Thunb.) Stapf
1,2	BROMCATH	*Bromus catharticus* Vahl
1,2	BULBHUMI	*Bulbostylis humilis* (Kunth) C.B. Cl.
1	CAREGLOM	*Carex glomerabilis* Krecz.
1,2	CATAGRAC	*Catalepis gracilis* Stapf & Stent
1,2	CERASPEC	*Cerastium arabidis* E. Mey. ex Fenzl
		Cerastium capense Sond.
1	CHENSPEC	*Chenopodium* sp.
1,2	CHRYCILI	*Chrysocoma ciliata* L.
1	CLUTNANA	*Clutia nana* Prain
2	CONVTHUN	*Convolvulus thunbergii* Roem. & Schult.
1,2	COTUHISP	*Cotula hispida* (DC.) Harv.
1,2	COTURADI	*Cotula radicalis* (Killick & Claassen) Hilliard & Burtt
2	COTYORBI	*Cotyledon orbiculata* L. var. *oblonga* (Haw.) DC.
1	CRASNATA	*Crassula natalensis* Schonl.
1	CRASSETU	*Crassula setulosa* Harv. var. *longiciliata* Toelken
		Crassula setulosa Harv. var. *setulosa*
2	CRASSPEC	*Crassula natalensis* Schonl.
		Crassula peploides Harv.
		Crassula setulosa Harv. var. *longiciliata* Toelken
		Crassula setulosa Harv. var. *setulosa*
1	CRASSPP1	*Crassula* sp.
1,2	CRATCONG	*Craterocapsa congesta* Hilliard & Burtt
2	CYMBPLUR	*Cymbopogon plurinodis* (Stapf) Stapf ex Burtt Davy
1,2	CYNOHIRS	*Cynodon hirsutus* Stent

Appendix 3 continued

AREA	ACRONYM	SPECIES NAME
1,2	DELOSPEC	*Delosperma clavipes* Lavis
		Delosperma concavum L. Bol.
		Delosperma monanthemum Lavis
		Delosperma sp.
1	DESCCESP	*Deschampsia cespitosa* (L.) Beauv.
1,2	DIANBASU	*Dianthus basuticus* Burtt Davy subsp. *basuticus* Var. *Basuticus*
2	DIERROBU	*Dierama robustum* N.E. Br.
2	DIGIERIA	*Digitaria eriantha* Steud.
2	DIGITERN	*Digitaria ternata* (A. Rich.) Stapf
1	EHRHLONG	*Ehrharta longigluma* C.E. Hubb.
2	ELIOMUTI	*Elionurus muticus* (Spreng.) Kunth
1,2	ERAGCAES	*Eragrostis caesia* Stapf
2	ERAGCAPE	*Eragrostis capensis* (Thunb.) Trin.
1,2	ERAGCURV	*Eragrostis curvula* (Schrad.) Nees
2	ERAGRACE	*Eragrostis racemosa* (Thunb.) Steud.
1	ERAGSPEC	*Eragrostis* sp.
1	ERICALGI	*Erica algida* H. Bolus
1	ERICALOP	*Erica alopecurus* Harv.
1,2	ERICDOMI	*Erica dominans* Killick
1,2	ERICFRIG	*Erica frigida* H. Bol.
1	ERICGLAP	*Erica glaphyra* Killick
1	EUMOSERI	*Eumorphia sericea* Wood & Evens subsp. *sericea*
2	EUPHCLAV	*Euphorbia clavarioides* Boiss.
2	EUPHERIC	*Euphorbia ericoides* Lam.
1,2	FELIFILI	*Felicia filifolia* (Vent.) Burtt Davy subsp. *filifolia*
2	FELIMURI	*Felicia muricata* (Thunb.) Nees subsp. *muricata*
1,2	FESTCAPR	*Festuca caprina* Nees
1,2	FESTSCAB	*Festuca scabra* Vahl
1,2	FINGSESL	*Fingerhuthia sesleriiformis* Nees
2	FORBSPEC	Unidentified forb
1	FORBSPP1	Unidentified forb
1	FORBSPP2	Unidentified forb
1	FORBSPP3	Unidentified forb
1	FORBSPP4	Unidentified forb
1	FORBSPP5	Unidentified forb
2	GALICAPE	*Galium capense* Thunb. subsp. *garipense* (Sond.) Puff
1,2	GAZASPEC	*Gazania krebsiana* Lees. subsp. *krebsiana*
		Gazania krebsiana Lees. subsp. *serrulata* (DC.) Roessl.
1,2	GERASPEC	*Geranium magniflorum* Knuth
		Geranium multisectum N.E. Br.
1,2	GEUMCAPE	*Geum capense* Thunb.
2	GUNNPERP	*Gunnera perpensa* Linn
1,2	GYMNBIFU	*Gymnopentzia bifurcata* Benth.
1,2	HARPFALX	*Harpochloa falx* (L. f.) Kuntze
2	HEBECOMO	*Hebenstretia comosa* Hochst.
1	HELIAURE	*Helichrysum aureum* (Houtt.) Merr. var. *monocephalum* (DC.) Hilliard
1	HELIBASA	*Helichrysum basalticum* Hilliard
1,2	HELIFLAN	*Helichrysum flanaganii* H. Bol.
2	HELILONG	*Helictotrichon longifolium* (Nees) Schweick.
1,2	HELIMARG	*Helichrysum marginatum* DC.
2	HELIODOR	*Helichrysum odoratissimum* (L.) Sweet
1,2	HELISESS	*Helichrysum sessilioides* Hilliard
2	HELISPEC	*Helichrysum adenocarpum* DC. subsp. *adenocarpum*
		Helichrysum albo-brunneum S. Moore
		Helichrysum aureum (Houtt.) Merr. var. *monocephalum* (DC.) Hilliard
		Helichrysum basalticum Hilliard
		Helichrysum bellidiastrum Moeser
		Helichrysum bellum Hilliard
		Helichrysum caespititium (DC.) Harv.
		Helichrysum montanum DC.
		Helichrysum nudifolium (L.) Less.
		Helichrysum palustre Hilliard
		Helichrysum pilosellum (L. f.) Less.
		Helichrysum praecurrens Hilliard

Appendix 3 continued

AREA	ACRONYM	SPECIES NAME
2	HELISPEC	*Helichrysum rugulosum* Less.
		Helichrysum splendidum (Thunb.) Less.
		Helichrysum sutherlandii Harv.
1,2	HELISUBG	*Helichrysum subglomeratum* Less.
1,2	HELITRIL	*Helichrysum trilineatum* DC.
1,2	HELITURG	*Helictotrichon turgidulum* (Stapf) Schweick.
1	HELIWITB	*Helichrysum witbergense* H. Bol.
2	HETECONT	*Heteropogon contortus* (L.) Roem. & Schult.
2	HYPAHIRT	*Hyparrhenia hirta* (L.) Stapf
2	HYPOSPEC	*Hypoxis* sp.
2	INULTHOD	*Inulanthera thodei* (H. Bol.) Kallersjo
2	JUNCDREG	*Juncus dregeanus* Kunth
1,2	KAROPURP	*Karoochloa purpurea* (L. f.) Conert & Tuerpe
2	KNIPCAUL	*Kniphofia caulescens* Bak.
1,2	KOELCAPE	*Koeleria capensis* (Steud.) Nees
2	LEDECOOP	*Ledebouria cooperi* (Hook. f.) Jessop
1,2	LEGUSPEC	*Lotononis* sp.
		Melolobium obcordatum Harv.
1	LESSSPEC	*Lessertia* sp.
2	LOTOSERI	*Lotononis sericophylla* Benth.
1,2	LUZUAFRI	*Luzula africana* Drege ex Steud.
1,2	MELIDECU	*Melica decumbens* Thunb.
1	MENTSPEC	*Mentha* sp.
1,2	MERXDIST	*Merxmuellera disticha* (Nees) Conert
1,2	MERXDRAK	*Merxmuellera drakensbergensis* (Schweick.) Conert
2	MERXGUIL	*Merxmuellera guillarmodiae* Conert
1,2	MERXMACO	*Merxmuellera macowanii* (Stapf) Conert
1	MERXSTER	*Merxmuellera stereophylla* (J.G. Anders.) Conert
2	MICRCAFF	*Microchloa caffra* Nees
2	MOHRCAFF	*Mohria caffrorum* (L.) Desv. var. *caffrorum*
2	MONSBREV	*Monsonia brevirostrata* Knuth
1	MORAALTI	*Moraea alticola* Goldblatt
1,2	MORASPEC	*Moraea modesta* Killick
		Moraea spathulata (L. f.) Klatt
2	OSTEJUCU	*Osteospermum jucundum* (E.P. Phill.) T. Norl.
1,2	OXALOBLI	*Oxalis obliquifolia* Steud. ex Rich.
2	PANISHIN	*Panicum schinzii* Hack.
2	PELASPEC	*Pelargonium alchemilloides* (L.) L'Herit
		Pelargonium grossularioides (L.) L'Herit.
		Pelargonium sidoides DC.
1,2	PENNSPHA	*Pennisetum sphacelatum* (Nees) Dur. & Schinz
1,2	PENTCOOP	*Pentzia cooperi* Harv.
1,2	PENTGALP	*Pentaschistis galpinii* (Stapf) McClean
1	PENTOREO	*Pentaschistis oreodoxa* Schweick.
2	PENTSETI	*Pentaschistis setifolia* (Thunb.) McClean
1	PENTSPEC	*Pentaschistis* sp.
1	POAAANNU	*Poa annua* L.
1,2	POAABINA	*Poa binata* Nees
2	POLERIGI	*Polevansia rigida* De Winter
1,2	POLYHISP	*Polygala hispida* Burch.
1,2	PSAMMUCR	*Psammotropha mucronata* (Thunb.) Fenzl var. *mucronata*
2	RANUMULT	*Ranunculus multifidus* Forssk.
1	RHODSPEC	*Rhodohypoxis* sp.
2	RHUSPYRO	*Rhus pyroides* Burch. var. *gracilis* (Engl.) Burtt Davy
1,2	SCABCOLU	*Scabiosa columbaria* L.
1,2	SCIRFALS	*Scirpus falsus* C.B. Cl.
2	SCIRFICI	*Scirpus ficinioides* Kunth
1,2	SEBANATA	*Sebaea natalensis* Schinz
2	SEDGSPEC	*Carex glomerabilis* Krecz.
		Cyperus semitrifidus Schrad. var. *semitrifidus*
		Cyperus usitatus Burch. var. *usitatus*
		Mariscus congestus (Vahl) C.B. Cl.
		Schoenoxiphium distinctum Kukkonen
		Schoenoxiphium rufum Nees
		Schoenoxiphium sp.

Appendix 3 continued

AREA	ACRONYM	SPECIES NAME
1,2	SELASPEC	*Selago galpinii* Schltr.
		Selago schlechteri Rolfe
		Selago speciosa Rolfe
2	SENEMACR	*Senecio macrocephalus* DC.
1	SENEPARA	*Senecio parascitus* Hilliard
1,2	SENESEMI	*Senecio seminiveus* Wood & Evans
1,2	SENESPEC	*Senecio harveianus* Macowan
		Senecio macrospermus DC.
		Senecio othonniflorus DC.
		Senecio tugelensis Wood & Evans
1	SENESPP1	*Senecio* sp.
1	SENESPP2	*Senecio* sp.
2	SILESPEC	*Silene* sp.
2	STACRUGO	*Stachys rugosa* Ait.
2	STACTYSO	*Stachys tysonii* Skan
1,2	SUTEPRIS	*Sutera pristisepala* Hiern
2	TAGEMINU	*Tagetes minuta* L.
1,2	TARASPEC	*Taraxacum brachyglossum* (Dahlst.) Dahlst.
		Taraxacum officinale Weber (sens. Lat.)
2	TETRDREG	*Tetrachne dregei* Nees
1,2	THEMTRIA	*Themeda triandra* Forssk.
2	THESDURU	*Thesium durum* Hilliard & Burtt
2	TRACSPIC	*Trachypogon spicatus* (L. f.) Kuntze
2	TRAGRACE	*Tragus racemosus* (L.) All.
2	TRICGRAN	*Trichoneura grandiglumis* (Nees) Ekman
1,2	TRIFBURC	*Trifolium burchellianum* Ser. subsp. *burchellianum*
1,2	URSIMONT	*Ursinia montana* DC. subsp. *montana*
2	WAHLUNDU	*Wahlenbergia undulata* (L. f.) A. DC.
1,2	ZALUSPEC	*Zaluzianskya glareosa* Hilliard & Burtt
		Zaluzianskya oreophila Hilliard & Burtt
		Zaluzianskya ovata (Benth.) Walp.
		Zaluzianskya rubrostellata Hilliard & Burtt

Appendix 4 The environmental variables recorded at each cattlepost (cpst.) in Study Area 1, eastern Lesotho.

Alpine Belt						
Site no.	Cpst. no.	Distance from cpst. (m)	Altitude (m a.s.l.)	Aspect (degrees[1])	Slope (degrees)	BAI[2]
1	1	0	3 025	129	24	0.369
2	1	60	3 025	129	24	0.172
3	1	120	3 025	99	22	0.216
4	1	180	3 025	99	22	0.142
5	1	500	3 025	154	20	0.111
6	2	0	3 025	81	23	1.759
7	2	60	3 025	81	23	0.350
8	2	120	3 025	111	23	0.206
9	2	180	3 025	111	23	0.208
10	2	500	3 000	116	25	0.501
11	3	0	3 000	39	18	0.261
12	3	60	3 000	39	18	0.522
13	3	120	3 000	114	20	0.365
14	3	180	3 000	114	20	0.353
15	3	500	3 000	94	23	0.259
16	4	0	3 175	51	10	1.013
17	4	60	3 175	51	10	0.461
18	4	120	3 175	51	10	0.498
19	4	180	3 175	51	10	0.227
20	4	500	3 150	51	10	0.285
21	5	0	3 075	26	20	0.248
22	5	60	3 075	26	20	0.224
23	5	120	3 075	26	20	0.518
24	6	0	3 175	111	12	0.128
25	6	60	3 175	111	12	0.156
26	6	120	3 175	111	12	0.088
27	6	180	3 175	76	12	0.201
28	7	0	3 075	21	17	0.149
29	7	60	3 075	21	17	0.397
30	7	120	3 075	21	17	0.157
31	7	180	3 075	21	17	0.346
32	7	500	3 075	39	17	0.052
33	8	0	2 875	149	15	0.079
34	8	60	2 875	149	15	0.122
35	8	120	2 875	161	15	0.074
36	8	180	2 875	136	15	0.126
37	8	500	2 875	179	15	0.099
38	9	0	2 825	161	22	0.239
39	9	60	2 825	161	22	0.156
40	9	120	2 825	161	22	0.098
41	10	0	2 825	119	13	0.049
42	10	60	2 825	119	13	0.079
43	10	120	2 825	119	13	0.083
44	11	0	2 975	11	19	0.713
45	11	60	2 975	11	19	0.845
46	11	120	2 975	11	19	0.329
47	11	180	2 975	11	19	0.327

Appendix 4 continued.

Subalpine Belt						
Site no.	Cpst. no.	Distance from cpst. (m)	Altitude (m a.s.l.)	Aspect (degrees[1])	Slope (degrees)	BAI[2]
1	1	0	2 650	95	10	0.636
2	1	60	2 650	95	10	0.508
3	1	120	2 650	95	10	0.577
4	1	180	2 650	95	10	0.423
5	1	250	2 650	95	10	0.178
6	2	0	2 950	1	8	0.710
7	2	60	2 950	1	8	0.548
8	2	120	2 950	1	8	0.473
9	3	0	2 750	9	19	0.377
10	3	60	2 750	9	19	1.158
11	3	120	2 750	9	19	0.912
12	3	180	2 750	9	19	1.095
13	3	500	2 750	9	19	0.258
14	4	0	2 700	11	14	0.334
15	4	60	2 700	11	14	0.421
16	4	120	2 700	11	14	0.180
17	5	0	2 725	26	15	0.589
18	5	60	2 725	26	8	0.212
19	5	120	2 725	26	5	0.359
20	6	0	2 875	91	16	0.553
21	6	60	2 875	91	16	0.625
22	6	120	2 875	91	16	0.469
23	7	0	2 750	139	8	0.417
24	7	60	2 750	139	8	0.190
25	7	120	2 750	139	8	0.158
26	7	180	2 750	139	8	0.051
27	8	0	2 950	61	8	0.126
28	8	60	2 950	61	8	0.063
29	8	120	2 950	16	8	0.408
30	8	180	2 950	14	8	0.290
31	9	0	2 750	69	8	0.153
32	9	60	2 750	69	8	0.221
33	9	120	2 750	69	8	0.134
34	10	0	2 950	71	11	0.632
35	10	60	2 950	71	11	0.094
36	10	120	2 950	71	11	0.090
37	10	180	2 950	71	11	0.111
38	11	0	2 675	27	5	0.213
39	11	60	2 675	54	5	0.267
40	11	120	2 675	54	5	0.153
41	11	180	2 675	54	5	0.280
42	12	0	2 750	59	11	0.186
43	12	60	2 750	79	11	0.083
44	12	120	2 750	79	11	0.089
45	12	180	2 750	79	11	0.053
46	12	500	2 750	69	11	0.105

[1]Aspect converted to linear scale as follows: aspect = aspect, for aspect $\leq 180°$; aspect = 360-aspect, for aspect $> 180°$.
[2]'Bare area index' (see Chapter 4 for details).