Introduction

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Figure 1.1 Snapshots of the history of vegetation mapping in South Africa.
1. Preamble
We present an up-to-date and comprehensive overview of the vegetation of South Africa and the two small neighbouring countries of Lesotho and Swaziland. This account is based on vegetation survey using appropriate tools of contemporary vegetation mapping and vegetation description. We aimed at drawing a new vegetation map that depicts the complexity and macro-scale ecology and reflects the level of (and identifies and reveals gaps in) our knowledge of the vegetation of the region. This is an extensive account of the vegetation of a complex and biologically intriguing part of the world, offering not only insights into structure and dynamics of the vegetation cover, but containing a wealth of base-line data for further vegetation-ecological, biogeographical, and conservation-oriented studies. Our Map and the descriptive account of the vegetation of South Africa, Lesotho and Swaziland targets not only scientific academia and the secondary and tertiary education sectors, but offers a powerful decision-making tool for conservationists, land-use and resource planners, and politicians as well as the interested public at large.

2. Mapping Spatial Complexity of Vegetation Cover
Vegetation mapping is one of the most important and most widely used tools to simplify spatial complexity of vegetation cover. In the past, floristic-based mapping was invariably linked to syntaxonomy (vegetation systematics) providing a classification system of vegetation in a mapped area. Thus the theory and methods of vegetation mapping has been dominated by the idea of the floristic-sociological approach to vegetation classification and its major schools known as the Braun-Blanquet School and Russian School in particular (see textbooks, chapters relevant to vegetation mapping in general vegetation science works and major review papers such as Gaussen 1961, Sochava 1962, Braun-Blanquet 1964, Küchler 1967, 1984, Ozenda 1986, Küchler & Zonneveld 1988, Faliniski 1990–1991, Dien 1994, Glavač 1996, Crignet et al. 2004 and Pedrotti 2004, to mention just a few). Currently vegetation mapping operates on a much broader theoretical and methodological platform by incorporating new approaches of remote sensing and spatial environmental correlation through GIS (Alexander & Millington 2000).

Vegetation mapping has enjoyed a long tradition in Europe, where at least four different ‘schools’ have been formed. The ‘Stolzenau School’ named after Stolzenau am Weser—a small town in Niedersachsen, Germany—has been associated with names such as R. Tüxen (the founder of a small research institute devoted to vegetation survey and mapping in Stolzenau), W. Trautmann, K. Buchwald and U. Bohn who definitely influenced the work of other central European (R. Mikyška, R. Neuhausl, Z. Neuhauslová, J. Moravec, J. Michalko, S. Maglocký, W. Matuszkiewicz, H. Wagner and J.B. Falirski) and further afield also Japanese (A. Miyawaki and K. Fujiwara) and American (A.W. Küchler) vegetation scientists. Dierschke (1994) further recognised the so-called ‘South French School’ associated with names such as L. Emberger, H. Gaussen, R. Molinier and R. Ozenda. This school influenced mapping in southern Europe (S. Rivas-Martínez, F. Pedrotti and R. Venanzoni). The ITC School emerged at the current ITC Institute in Enschede, the Netherlands, and became known for the early application of remote-sensing approach to vegetation mapping. D.C.P. van Thalen and I.S. Zonneveld (see Zonneveld et al. 1979) can be mentioned as prominent personalities of this school. The ‘Russian School’ has been particularly active at the Komarov Institute of Botany in St Petersburg (earlier also known as Leningrad). This institution is associated with great names such as E.M. Lavrenko, V.B. Sochava, S.A. Gribova, T.K. Yurkovskaya, G.M. Ladygina and I.N. Safronova. The specialist journal (Geobotanicheskoie Kartirovanie) devoted to vegetation mapping is published by this research group. Undoubtedly the Europe-based vegetation mapping research groups influenced further dissemination of the vegetation mapping methodology and the initiation of mapping projects on other continents.


A selective review of maps classified according to mapping scale was presented by Dierschke (1994) and the reader is referred to numerous bibliographies (mainly published in the journal Excerpta Botanica) featuring the products of mainly syntaxonomy-based vegetation maps.

For many logistic, developmental and historical reasons, the African continent has experienced only marginal interest of vegetation mappers. The vegetation of the continent has been mapped (as a whole) several times (Keay 1959, White 1983, Burgess et al. 2004), but its large extent (Africa is the second largest continent) and paucity of data did not allow for detail. Several larger regions (Wild & Barbosa 1968: area of the Flora zambesiaca) and countries (e.g. Barbosa 1970: Angola, Giess 1971: Namibia, Guillaumet & Adjouhouou 1971: Ivory Coast, Bekker & De Wit 1991: Botswana, etc.) have been mapped using traditional methods. Only recently has application of remote-sensing methods and GIS led to production of more detailed and credible vegetation maps (Frederiksen & Lawson 1992: Senegal, Du Puy & Moat 1998, 1999: Madagascar).

3. Vegetation Mapping in South Africa
The roots of vegetation mapping of the African subcontinent go back to the nineteenth century but at very coarse scales and using mostly very poor information (see review by Werger 1978). Even though the Botanical Survey of the then Union of South Africa was started in 1918, the earliest vegetation map of southern Africa (with some detail) can probably be regarded as that of Pole Evans in 1936 (the actual map is dated 1935). At least parts of his map were more detailed than the broad ‘biome level’. Thus, for example, he distinguished three grassland types as well as three types of ‘parkland’ (savanna). He recognised 12 types of vegetation in total. This work was followed in 1938 by Adamson who mapped 14 types of vegetation in the region with different emphasis of detail, including six types in the ‘semi-desert’ and four in ‘savanna’ but only a single grassland type.

In 1953 a major milestone was reached with the publication of Veld types of South Africa by John Acocks in which he mapped 70 types of vegetation in South Africa, Lesotho and Swaziland. The scale of the printed map (1:1 500 000) allowed for unparal-
leled detail and was presented in a form that R.A. Dyer in his foreword described as 'a work of art'. His 1953 book was reprinted with photographs added and plant names updated in 1975 and again in 1988. It is ironic that most of his field data were collected after the publication in 1953 (Rutherford et al. 2003a) and were not incorporated in the later editions. They were, however, available for a revision of his Veld types but did not progress beyond an unpublished manuscript (with no map) for the western half of the country (Acocks 1979) shortly before his death in 1979. In a letter to a colleague in 1954 Acocks called his memoir '... a half-baked washout and a disgrace to the Division that was inept enough to hustle me into writing it before my data were complete enough even for a preliminary paper' (Hoffman & Cowling 2003a, b). A re-analysis of Acocks' data for the area of theNama-Karoo Biome substantiated a number of his veld types while not upholding some others (Rutherford et al. 2003b). Despite Acocks' opinion expressed in 1954, his work became known as the most widely used published product in South African ecology over a period of more than five decades. White's (1983) mapping units within South Africa are less detailed than those of Acocks and he relied heavily on the work of Acocks for this section of his map.

The SAAB (South African Association of Botanists) map of Low & Rebelo (1996 and reprinted as a second edition in 1998) was initiated at a meeting held in Durban in January 1992. At this meeting it was decided that the new map was needed mainly for pedagogical purposes—a map which would essentially be a simplification of Acocks' map. To a large extent this simplification was carried out for the arid areas of Karoo and Namaqualand, often retaining some boundary lines of Acocks' veld types. Much of the Grassland and northern Savanna areas were also mostly simplified but often with different and smoother boundary lines than Acocks. Greater detail was added in the Kalahari areas and parts of the Fynbos Biome and much of the Lowveld area was totally revised. Acocks' Valley Bushveld, Spekboomveld and Noorsveld were reassigned to various 'thicket' vegetation types. A major advance over the Acocks map was the mapping of many patches of forest types. However, the net effect of the simplifications and additions was 68 vegetation units, i.e. slightly fewer than Acocks (Table 1.1). The SAAB map thus consisted of a mixture of less detailed and more detailed parts relative to the map of Acocks. Low & Rebelo's (1996) map was furthermore made at a smaller scale than that of Acocks and it was printed at three different scales, namely 1:1 850 000, 1:2 000 000 and 1:3 880 000.

Even before Low & Rebelo's map was published in January 1996, it was clear that to substantially improve on Acocks' map would require a totally fresh start independent of his map and considering all available data (most of which—including most data of Acocks—were collected after 1953). There was also a realisation that for planning at regional and local levels, a much more detailed approach than that of either Acocks (1953) or Low & Rebelo (1996) should be implemented.

Vegetation mapping is a frequently used tool in nature and especially wildlife conservation practice in South Africa. Since successful, scientifically defendable running of both statutory and private conservation areas requires (by law) formulation and implementation of spatial management plans, vegetation has often been used to stratify land into 'management units'. Hence a large number of vegetation maps of small areas have been constructed. These maps were of great help to the VEGMAP team since in many areas this was the only viable information source of vegetation cover. Many of the local maps were published in local journals such as South African Journal of Botany, Bothalia, Koedoe or Bontebok or in series of reports (see for instance References in Chapter 14 on Coastal vegetation). Still more maps remain, buried in unpublished reports and management planning documentation of the provincial nature conservation bodies (CapeNature, Ezemvelo KZN Wildlife, Mpumalanga Parks Board, South African National Parks, etc.) and postgraduate masters and doctoral theses. It is beyond the scope of this chapter to list them all—they are, however, exhaustively referred to in particular chapters of this book.


There are two basic traits which set our Map apart from other comparable products:

1) Our Map is unique in featuring the vegetation cover of an extremely diverse large geographical region housing nine biomes on the continent and a further two biomes on the islands in great detail. The mapped regions contain the most species-rich temperate flora of the world. It includes one entire biogeographical plant kingdom (Capeensis) and parts of phytotochoria of two other plant kingdoms, namely of the Palaearctic and of Antarctica (sensu Takhjahjan 1986).

2) Our Map, unlike other long-term projects featuring large regions (Europe, former Soviet Union, South America, USA), has been using fully computer-aided (GIS-assisted) tools from the onset of the research throughout the entire process up to publication. The use of aerial photography, satellite imagery, spatial predictive modelling and large databases in combination with traditional field-based ground-truthing is another distinct feature of our product.

4. The Making of VEGMAP

The current work was initiated by Prof. B.J. Huntley, Chief Executive Officer of the then National Botanical Institute (NBI), who convened a workshop at Kirstenbosch, Cape Town, on 7 and 8 August 1995. This was a national workshop of vegetation experts to discuss the feasibility of the project. The NBI commenced work and co-ordination on the project on 1 October 1995, with the official contractual commencement date of 30 January 1996. The administration of the funding and management of the project was an NBI (and later a SANBI) responsibility.

M. O'Callaghan was initially responsible for running the project, soon to be replaced by D.J. McDonald at the Kirstenbosch Research Centre of the NBI. At that stage M.C. Rutherford was the convenor of the project. Upon McDonald's resignation in July 2000, M.C. Rutherford was given direct responsibility for the project through to its completion. In the first year of this period the services of L. Mucina were engaged as scientific
co-ordinator and he continued informally in this role. He had also been contracted earlier (since February 2000) to deal with a number of specific issues relating to the project. From April 2003 M.C. Rutherford was placed on the project on a full-time basis, first attending to the completion of the map (the beta electronic version of the map was made publicly available in February 2004) and then joining L. Mucina in compiling some of the chapters and editing the book.

The period before 2000 was primarily one of promoting the buy-in of contributors (a major task at the time given many sensitivities about data-sharing) and assisting with computerisation of data. Various workshops on the project were convened (including ones on the use of TURBOVEG (Hennekens & Schaminée 2001) in February 1997 and October 1998) and the NBI co-ordinator visited many contributors and potential contributors. Numerous presentations on the project were made, the first by M. O’Callaghan at the Annual Congress of the South African Association of Botanists in Stellenbosch in January 1996. Various publications on the project appeared (McDonald 1996, 1997a, b; McDonald & Boucher 1999). A VEGMAP Co-ordination Committee functioned during the first phase of the project with representatives from the NBI, University of Pretoria, Stellenbosch University, the then University of Natal and the Agricultural Research Council in Grahamstown. An important workshop was held at the Kirstenbosch Research Centre on 30 September and 1 October 1999 where it was agreed that data encoding or acquisition for the project should cease by April 2000 and that the analysis and mapping be given a high priority immediately thereafter.

The very first parts of the map were received from some contributors in late 2001. However, many of the initial contributions had to be extensively revised or replaced. Ultimately, well over 100 people from a wide range of organisations contributed to the map and/or the book (see Acknowledgements towards the end of this chapter). This was a large co-operative project. Even Acocks did not operate in isolation, working, for example, with Louis Irvine (see also Irvine 1941) from 1940 to 1942 while based in the current Limpopo Province. He also assisted Prof. J.M. Hector with an update of his vegetation map of South Africa which was never finished but formed the basis for Acocks’ Veld types of South Africa (Hoffman & Cowling 2003a, b). Low & Rebelo (1996) list seven contributors to their work.

The current work maps 435 vegetation units in South Africa, Lesotho and Swaziland. This is over six times that of Acocks or Low & Rebelo. The number of individual polygons mapped is 32 times the number in Acocks and almost five times that in Low & Rebelo (Table 1.1). In addition, there are five vegetation units mapped on the Prince Edward Islands (part of South Africa) in the Southern Ocean. Altogether new at the subcontinental level in Africa is the mapping of azonal units, which was not possible at previous mapping scales even if there had been a determination to map these units. The printed map is at a larger scale (1:1 000 000) than any previous vegetation map for the region. Differences in level of detail are most dramatically shown in the Succulent Karoo Biome where Low & Rebelo (1996) recognised only four vegetation units compared to the 63 of the current work.

International comparisons include the 116 vegetation types of Küchler (1964) for the conterminous United States. The more recent mapping of Europe (about eight times the area of our mapping domain) resulted in many more (around 700) vegetation units (Bohn et al. 2003), but with number of polygons very similar to that of the current work.

### 5. Structure of the Book

This book is basically constructed as an explanatory account of the new Vegetation Map (Mucina et al. 2005, see also Chapter 18 of this book). The basic unit of the map is ‘vegetation type’—these types are described in the forthcoming chapters and grouped either within a biome (in the case of zonal units) or otherwise convenient group (especially the azonal units and insular vegetation). Each vegetation type has a unique code which shows its higher rank classification. The descriptions of vegetation types follow a specific and consistent order. The heading gives the code and name of the specific vegetation unit, followed by the synonymy (mostly defined as a proportion of overlap with previously published mapping units), data on distribution, accounts of vegetation and landscape features, geology and soils, climate, lists of important taxa (including endemics) ordered according to growth form, followed by conservation information, remarks, and ending with literature references relevant to the vegetation unit. Most vegetation types are illustrated by colour photographs. Over 28 500 taxon entries (featuring about 10 000 different taxa) are listed in the descriptions. Four vegetation types are described but not mapped: two are in the marine environment and the remainder on the Prince Edward Islands. The methods and procedures that were followed are described in Chapter 2. The biomes and bioregions are briefly described and compared in Chapter 3; more extensive ecological accounts of the biomes or other groups of featured vegetation types appear in the introductory sections of each chapter. The biome chapters also aim to cover much of the ecological and biogeographical publications relevant to the biome, often with extensive literature lists. The azonal vegetation types are described after the biome chapters, followed by the chapter on the vegetation of the Prince Edward Islands. Just before the atlas section, are two chapters dealing with conservation issues relating to the vegetation types. In some places the mapping detail pushes the bounds of printing at a scale of 1:1 000 000. The electronic version on the CD inside the front cover of the book should be consulted where the user can zoom in at any scale to discern detail. There is a section on Credits at the end of each major chapter indicating specific contributions to the given chapter. The section on Acknowledgements below attempts to list all contributions and organisations that have played a role in the project.

### 6. Quo vadis?—Outlook and Expectations

The results of the VEGMAP Project as presented in this book represent a current account of our knowledge of the variability of the vegetation of this extremely variable, fascinating and

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Contributions to both text (and sometimes illustrations) and map were received from A.G. Rebeiro (SANBI, Kirstenbosch Research Centre), M.C. Lötter (Mpumalanga Parks Board, Lydenburg), N. Jürgens (Botanical Institute and Botanical Garden, University of Edinburgh), M. Ziemke (Botanical Institute and Botanical Garden, University of Copenhagen), L.W. Powrie (SANBI, Kirstenbosch Research Centre), C.J. Geldenhuys (ForestWood, Pretoria, and Stellenbosch University), V.R. Smith (Dept of Botany and Zoology, Stellenbosch University), D.B. Hoare (private consultant, formerly ARC Range and Forage Institute, Rooiplein), A. Le Roux (CapeNature, Jonkershoek), C.R. Scott-Shaw (Ezemvelo KwaZulu-Natal Wildlife, Pietermaritzburg), D.I.W. Euston-Brown (Regals Environmental Services, Oudtshoorn), G.J. Bredenkamp (Dept of Botany, University of Pretoria), N. Helme (Botanical Surveys, Scarborough), C. Boucher (private consultant, formerly Dept of Botany and Zoology, Stellenbosch University), P.J. du Preez (Dept of Plant Sciences, University of the Free State, Bloemfontein), P.S. Goodman (Ezemvelo KwaZulu-Natal Wildlife, Pietermaritzburg), P.G. Desmet (Institute for Plant Conservation, University of Cape Town), A.R. Palmer (formerly ARC Range and Forage Institute, Grahamstown), F. Siebert (private consultant, Richard's Bay), H. Bezuidenhout (South African National Parks, Kimberley), P.J.D. Winter (formerly University of the North, Turloop, now SANBI, Pretoria), K.G.T. Camp (private consultant, formerly KwaZulu-Natal Dept of Agriculture, Cedara), J.H.J. Vlok (Regals Environmental Services, Oudtshoorn), N. van Rooyen (private consultant, formerly Dept of Botany, University of Pretoria), B. van der Merwe (ARC Institute for Soil, Climate and Water, Stellenbosch), J.W. Lloyd (deceased, formerly ARC Institute for Soil, Climate and Water, Stellenbosch), J.-W. Lubbinge and J.H.L. Smit (both formerly Dept of Botany, University of Pretoria), S.J. Siebert (Dept of Botany, University of Zululand, Kwadlangezwa), U. Schmiedel (Botanical Institute and Botanical Garden, University of Hamburg, Germany), W.S. Matthews (Ezemvelo KwaZulu-Natal Wildlife, Tembe Elephant Park), L. Dobson (private consultant, Mbabane, Swaziland), R.G. Lechmere-Oertel (Ezemvelo KwaZulu-Natal Wildlife, Pietermaritzburg), Z.R. Jonas (formerly University of the Western Cape, Bellville, now SANBI, Kirstenbosch Research Centre), B. McKenzie (Botanical Society of South Africa, Kirstenbosch), J.C. Manning (SANBI, Kirstenbosch Research Centre), E. Schmidt (private consultant, Hazview) and E.G.H. Oliver (formerly SANBI, Kirstenbosch Research Centre, now Dept of Botany and Zoology, Stellenbosch University).

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8. References


The Logic of the Map: Approaches and Procedures

Ladislav Mucina, Michael C. Rutherford and Leslie W. Powrie

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Figure 1.1 Some of the data layers used to assist in drawing VEGMAP, the end product being the second layer from the bottom.
1. Introduction

This chapter sets out the theoretical background and practical procedures adopted by the VEGMAP Project. We describe how we arrived at the two major products of our Project—the vegetation map of South Africa, Lesotho and Swaziland (Section 6) and the descriptive book (Section 7).

Mapping of vegetation of a region comprising 11 biomes, about 20,000 species (more than 24,000 taxa) of plants, experiencing a wide range of climates, from subtropical to polar, and spanning the oldest and youngest rocks on this planet, was a daunting task. The complexity of this task is clearly mirrored in the complexity of our approach and justifies the detail contained in this particular chapter.

This chapter starts with theoretical sections (1–4) in which we argue for the choice of the type of the map and for the basics of the mapping procedures. These are followed by a section (5) on sources of the data used in construction of our Map (as well as other mapping products such as the map of biomes and bioregions), and the Book. There are two methodological sections: Section 6 describes the technical details of the vegetation mapping and Section 7 explains in some detail the structure of the descriptions of vegetation units that form the core of the book.

2. Aims

The aim of the VEGMAP project was to produce a scientifically sound theoretical classification of the vegetation of South Africa, Lesotho and Swaziland, and to depict it as a vegetation map which:

- documents the diversity of the plant cover of southern Africa,
- reflects our current knowledge of the structure and biogeographical patterns of the vegetation of southern Africa,
- determines a baseline for land managers and others concerned with land and biodiversity (including agriculture, forestry, nature conservation, tourism etc.).

Vegetation mapping is a simplification and modelling exercise. We thus attempted to achieve two goals:

1) to produce a map featuring vegetation mapping units represented in simplified forms to create a graphical spatial model of vegetation of the region, and

2) to describe these vegetation mapping units using various floristic, vegetation, biogeographical, physico-geographical and environmental descriptors (Distribution, Vegetation and Landscape Features, Geology & Soils, Important Species, Endemic Species etc.)—to create a verbal model of the vegetation of the mapped region depicted in the book.

3. Basic Postulates of Vegetation Classification and Mapping

The entire exercise (all stages including preparation, execution and production of the Map) was based on the following postulates which form the basic theory of vegetation ecology:

**Postulate 1:** Vegetation is a real, tangible object expressed in the form of recognisable patches.

In other words: vegetation is a real phenomenon and can be studied.

**Postulate 2:** The differences between the vegetation patches in terms of structure, texture (floristic composition) as well as in terms of environmental composition of the habitats supporting the vegetation, make the classification of vegetation (or conceptualisation of theoretical constructs called ‘vegetation types’) possible.

In other words: we can classify vegetation patches into vegetation types.

**Postulate 3:** The great complexity of vegetation, both of a discrete and continuous nature, makes the classification of vegetation (or the reduction of information content to a simplified system) necessary.

In other words: classification is one (and a very effective) way of simplifying the complexity of vegetation.

**Postulate 4:** The levels of difference between vegetation types make building of a hierarchical system (comprising a series of nested vegetation types and their groups) possible. The hierarchical system is another tool for further simplification of vegetation complexity.

In other words: the hierarchical system is another effective way to view important emergent properties of the major patterns of vegetation.

**Postulate 5:** The structure and dynamics of vegetation is a result of properties of its constituent plant populations and their response to the nature and dynamics of the environment which can aid classification and mapping (‘vegetation-environment axiom’).

In other words: environmental conditions determine (together with the properties of vegetation itself) the complexity of vegetation.

**Postulate 6:** Vegetation is composed of populations of plant species (representing taxa). Each taxon often shows an individual response to ecological factors and hence serves as an important ecological indicator. Major efforts to devise an alternative classification of functional types have yet to yield a viable system for widespread application.

In other words: we use floristic composition as the primary entity for the conceptualisation of mapping units.

**Postulate 7:** Vegetation patches occur in space, hence they can be mapped in spatial models.

In other words: complexity of vegetation can be shown on a map.

4. Vegetation Map as a Model: a Conceptual Framework

A vegetation map is a spatial model construct. It is shaped by various scaling considerations, including both objective scaling elements (e.g. extent of the mapped area and its abiotic and biotic complexity), and subjective scaling elements—which are a result of our intellectual, technical and financial or otherwise socially motivated constraints (including availability and quality of data, power of the mapping techniques, funds available, time schedule, contractor’s requirements, presentation limits and market demands).

4.1 Basic Concepts

Several crucial concepts dominate the methodology of vegetation mapping, the most important being mapping theme (type of map), mapping scale (detail captured and presented),
mapping element (basic mapping unit), and unit hierarchy (the way the mapping units form logical complexes). The latter two concepts relate directly to the mapping legend—a catalogue of mapping units often showing their classification as a hierarchical scheme.

4.1.1 Mapping Theme

Mapping vegetation means constructing a model which represents a particular idea about the complexity of vegetation. Hence, vegetation mapping is a modelling exercise aimed at presenting a hypothesis, at its best a hypothesis carrying a predictive message about vegetation patterns and dynamics. As there are many ways to perceive the phenomenon called 'vegetation', many types (themes) of vegetation maps can exist.

Large stretches of natural vegetation of South Africa, Lesotho and Swaziland have been turned into arable land, artificial plantations, towns and villages or have disappeared under the water of large dams. Still, owing to very recent intensive agricultural activity (less than 350 years of the 'post-Van Riebeeckian period'—a very short time indeed when compared to thousands of years of large-scale agriculture in Europe), even larger stretches of land are blessed to still have a nearly natural vegetation cover. Nevertheless, we have refrained from applying the concept of 'real' (current) vegetation as the leading mapping theme because of the low feasibility of capturing the original character of the real vegetation at the mapping scales used in data collection and especially in presentation (see Section 6.3). In some cases the previous distribution of a vegetation type was simply unknown and only the extant distribution could be mapped. Most important here are forest patches where the heavy demand for timber over the last two to three centuries had very likely reduced areas of forest. Some highly fragmented units representing special habitats (such as SKK 8 Piketberg Quartz Succulent Shrubland, FRC 1 Swartland Silcrete Renosterveld and FRC 2 Röens Silcrete Renosterveld) have probably been highly transformed prior to our current information on their distribution. Possibly the most extensively transformed areas are those termed 'coastal belts' (including CB 1 Maputaland Coastal Belt, CB 3 KwaZulu-Natal Coastal Belt, CB 5 Transkei Coastal Belt and AT 9 Albany Coastal Belt).

Knowledge of the patterns and processes for reconstructing the vegetation in these regions through modelling is lacking. At least the extant forest patches have been mapped within these coastal belt units.

Most of the mapped area is close to the theme of 'potential natural vegetation' of Tüxen (1956, 1963, 1978). According to his approach (for more detail see also review papers by Kowarik 1987, Kalkhoven & Van den Werf 1988, Härdtle 1995 and applications as cited in these papers), the potential natural vegetation is defined as (according to Tüxen in 1956 in Härdtle's 1995 translation): 'imagined natural state of vegetation ... that could be outlined for the present time or for a certain earlier period, if human influence on vegetation was removed'. Using more current terminology and in simplified terms, Kowarik (1987) suggested that the 'present day potential natural vegetation is a hypothetical (potential) most developed vegetation, corresponding to present (not future) site conditions'. This definition serves especially well for vegetation of extensive southern African veld, especially farm land that has experienced changes through continuous and large-scale exploitation (including grazing by animals, brush-cutting and the like). The concept of 'veld recovering' (excluding portions of farms from intensive exploitation for certain periods) is based on the experience of vegetation recovering into, if not an original, at least a more natural state when the human-controlled influence is removed. It is also highly probable that even ploughed land can return to a near natural state of vegetation (such as grassland) after abandonment (see for instance Smits et al. 1999). We acknowledge that the philosophy of a clear distinction between vegetation with humans and vegetation without humans is sometimes fanciful, especially in African savannas with their age-old association with human influence and 'disturbance', especially through the use of fire.

Our Map, however, also features 'reconstructed natural vegetation' (see Neuhaus 1963, 1968, 1984 for more details). In regions that have experienced irreversible changes (such as in urban settlements through destruction of the natural soil cover as well as through drastic changes to local hydrology) the vegetation has been 'reconstructed' through modelling. In printed form, our Map either shows areas with reconstructed vegetation (under built-up urban areas, with the latter superimposed) to indicate the current extent to which this vegetation has been removed, or follows conventional cartographic practice to override vegetation of areas flooded by the water reservoir of a dam. However, the reconstructed vegetation below the reservoirs of dams can be viewed on the CD accompanying this book. This was needed for correct calculations of the proportion of vegetation transformed for the conservation sections of the book.

As a matter of reference, Acoks (1953, 1975, 1988) also employed the term 'potential' in his definition of 'veld type'. He then mapped his veld types in their 'potential' extent and not as patches of 'real' vegetation.

4.1.2 Mapping Scale

The size of the mapping realm (almost 1.3 million km²) as well as the remarkable diversity of the flora (hence vegetation) supported by complex geological, climatic and hydrological patterns, proved challenging for mapping the vegetation. The decisions regarding the mapping scale(s) and the scale(s) of map presentation were dictated by our goals (see above) and these were modified by various serious constraints. Most compelling were: (a) the extent of the mapping area, (b) time and budget, (c) available expertise, (d) quality of data, and (e) technical level of mapping tools.

The scale of 1:250 000 was selected as the initial working scale, especially since many of the proxy data sets, such as geology, land types, topography (see Section 5 of this chapter for sources) were available in sufficient detail and precision at that scale. The consequent implementation of GIS technology, and local availability of more detailed sources (at 1:50 000, 1:10 000, etc.), allowed departure from the preliminary scale and facilitated increased detail of mapping where warranted, often resulting in greater refinement of the borders between vegetation units. Although such detail cannot be visible on our printed 1:1 000 000 maps, the electronic version (see CD) has no such limitation and a precision of down to 100 m (and even less in some cases) was possible where necessary.

The Prince Edward Islands were mapped at a working scale of about 1:25 000.

4.2 Vegetation Units, Mapping Units, Mosaics and Transitions

4.2.1 Definition of Vegetation Unit

At the scales of data collection (1:250 000 and sometimes more detailed) and presentation (1:1 000 000) our Map cannot show distribution of plant communities that operate on the habitat level. Our basic units of mapping, here called vegetation units
(e.g. FFs 11 Kogelberg Sandstone Fynbos, FOa 2 Swamp Forest and AZd 3 Cape Seashore Vegetation); are mostly identical to mapping units—those units shown on the map. (Examples where the mapping units are not identical with vegetation units are found in Chapter 15.) Using the general (and neutral) term ‘mapping unit’ we also designate the high-level units such as bioregions and biomes (see below and Chapter 3).

Vegetation Unit—the basic element of the Map—is defined as a complex of plant communities ecologically and historically (both in spatial and temporal terms) occupying habitat complexes at the landscape scale. Our vegetation units are the obvious vegetation complexes that share some general ecological properties such as position on major ecological gradients and nutrient levels, and appear similar in vegetation structure and especially in floristic composition.

The decisions to classify habitat-level communities into vegetation complexes forming the basis for definition of our landscape-level vegetation units, are governed by the following principles:

- close position along dominant ecological gradients
  Example: different estuary plant communities of flooded habitats (differing only in frequency of flooding).
- dominant ecological factor at landscape level
  Example: high salt content in soil selecting for a limited number of plant communities.
- dominant vegetation structure
  Example: fynbos shrublands on sandstone (often differing dramatically in floristic terms, but showing similar vegetation structural traits, especially growth form composition).
- high level of floristic similarity (including shared local and regional endemics)
  Example: various low shrublands in Succulent Karoo.
- close proximity
  Example: patches of distinct plant communities (that also satisfy a number of criteria listed above) in close proximity of another can have a higher probability of shared elements and hence of being classified into the same vegetation unit than those more widely separated.
- potential
  Example: recovering vegetation of old fields classified as that of the surrounding grasslands.

It is obvious that not all these criteria could be used or would carry the same weight in delimitating our vegetation units. The order of importance or weighting of these criteria depends very much on the character of the vegetation (species-poor to species-rich, structurally simple to complex, clear versus fuzzy borders between patches) or character of ecological gradients shaping the vegetation landscapes within particular biomes (steep gradients versus shallow gradients, many ecologically functional factors versus few factors).

4.2.2 On ‘Mosaics’

The concept of mosaic automatically implies at least two recognisable elements (in our case at least two vegetation units). The recognition of a mosaic can happen only à posteriori (after we have defined the elements). The term mosaic is used in mapping (not only vegetation mapping) to overcome the difficulties emanating from mapping scale. Examples are where local geology, local microclimatic and hydrological conditions, and natural disturbance factors (and various combinations of these) at detailed scales create a complex of clearly demarcated habitats supporting patches of distinct plant communities. In other words, where the grain of patchwork of habitats (supporting distinct vegetation units) encountered cannot translate onto a map of scale of choice, mosaics are often invoked as a concept and name. The patches of respective vegetation units simply become ‘dissolved’ into neighbouring vegetation units.

The decisions for not mapping mosaics onto a map are often due to lack of (field) mapping precision and lack of suitable small-scale data.

On our Map we have refrained from using the concept of mosaic in mapping the vegetation of continental South Africa, Lesotho and Swaziland for the following reasons: The field mapping scale we adopted (1:250 000) is so coarse that, if our vegetation units represent a landscape-level of complexity, we should almost always have had to disregard small patches of other vegetation units that are embedded. These small patches have indeed been mapped in regions where our data allowed us to work at a mapping scale of 1:50 000, and their coverage is available in electronic (GIS) format. However, these embedded patches had to be masked out (‘dissolved’) for the map presentation at a 1:1 000 000 scale to avoid creating ‘salt-and-pepper patterns’. In fact, technically speaking, all patches of vegetation as represented on our Map at the scale of 1:1 000 000 (Mucina et al. 2005 or Chapter 18) are invariably mosaics! We admit that some of our vegetation units are of extreme mosaic nature—a reflection of the microscale spatial differentiation and often a lack of such precise data. Among the most prominent are the alluvial units (AZ; see also Chapter 13) which can comprise riparian thickets, flooded grasslands, reed beds and even patches of aquatic vegetation found in the streams and in alluvial backwaters.

Of the recent (though unexplored) maps, the one of the STEP region (Vlok & Euston-Brown 2002) uses the concept of ‘mosaic’ extensively.

The vegetation map of the Prince Edward Islands (see Chapter 15) is a notable exception in our handling of ‘mosaics’. Here the intricate local topography and associated hydrology on the one hand and the influence of sea and animals on the other at low altitudes create small-grained mosaics of habitats impossible to depict at a mapping scale 1:25 000 (approximate field mapping scale), but the plant communities supported by these habitat mosaics are sufficiently distinct to qualify as vegetation units. However, since our current data do not allow clear delimitation of these distinct vegetation types as units, we have decided to present them on the map in the format of ‘mosaic’ mapping units. It is here where the concept of ‘mapping unit’ does not match the concept of ‘vegetation unit’.

The mapping unit termed ‘Subantarctic Mire-Slope Vegetation’ contains three vegetation units (ST 3 Subantarctic Mire, ST 4 Subantarctic Drainage Line and Spring Vegetation and ST 5 Subantarctic Fernbrake Vegetation), while the mapping unit termed ‘Subantarctic Coastal Vegetation’ comprises two vegetation types (ST 1 Subantarctic Coastal Vegetation and ST 2 Subantarctic Dicot I erIeland and Grassland).

4.2.3 On ‘Transitions’

Interestingly, exactly the same theoretical framework used to handle mosaics in vegetation mapping can be applied when so-called ‘transitional’ areas (regions) or ecotones are considered. While the term mosaic implies clearly (crisply) defined ingredi-
ents (elements), the term ‘transition’ entails gradual change between two (and rarely more) entities (for instance vegetation units). The concept of ‘transition’ in ecology has deep roots in the precept of the continuum in vegetation ecology (the current reigning paradigm). However, the controversy between continual versus discrete variation in vegetation is surely a matter of scale (see the seminal theoretical paper by Austin & Smith 1989 on the matter).

We acknowledge that the borders between some units, especially those where the controlling ecological factors change in a continual manner (for instance climatic factors in areas of uniform topography), are arbitrary and imply a midpoint in the transitional zone. These include the units straddling the border regions of some biomes (defined by climatic factors in the first place), including NK1 1 Gamka Karoo and SKv 6 Koedoesberge-Moordenaars Karoo, NKU 4 Eastern Upper Karoo and Gh 3 Xhariep Karroid Grassland, Skt 3 Roggeveld Karoo and NKU 1 Western Upper Karoo and a few others. There are also examples of some sharp transitions between biomes in places (see Chapter 3).

4.3 Hierarchy of Mapping Units
Following the theoretical principles of zonality of vegetation (discussed in detail in Chapter 13), we have separated the zonal and azonal vegetation units. For practical reasons we maintain all indigenous forest units within one informal group, although they represent a mixture of units belonging to two forest biomes (Afrotropical Forest Biome and Subtropical Coastal Forest Biome or Indian Ocean Coastal Belt) and azonal forest units (riverine, swamp and mangrove). More information about the azonal versus zonal status of the forests is presented in Table 12.1.

The azonal vegetation units are grouped (for purposes of structuring the legend and the descriptions) in a similar way. Here the ecological (groups of azonal units according to dominant character of hydrology or salt content) and (phyto)geographical (according to embedding within biomes especially) ones prevail.

With most of the remaining vegetation, our Map features a three-level nested hierarchy of the mapping units, namely the levels of (a) vegetation units, (b) bioregions (composed of vegetation units), and (c) biomes (comprising bioregions). To paraphrase the definition of ‘bioregion’ from Chapter 3: each bioregion is a composite of spatial (vegetation) units sharing similar biotic and physico-geographical features and connected by processes operating on a regional scale. Bioregions and biomes are discussed in Chapter 3.

5. Data Sources and Processing
Data included with the Map (Mucina et al. 2005) and used in the mapping and analysis processes were obtained from (or modified from data supplied mostly by) a number of organisations. Some features were edited and adjustments applied using the rubbersheet method to align the topographic data to scanned 1:50 000 or 1:250 000 maps, and to align the vegetation map and topographic data as required.

Not all data were available at the commencement of the project, and the development of the project may have been somewhat different had they been available at the outset of the project. Data that became available later in the project include topographic data from the Chief Directorate: Surveys and Mapping (CDSM), land types included with the Environmental Potential Atlas (ENPAT) from the Department of Environmental Affairs and Tourism (DEAT), and data on protected areas. Some data became available too late to have been used or included in the map or report.

Details of individual data contributions by authors are given in the Credits section of the chapter describing the relevant biome or other groups of vegetation units (forests, azonal vegetation or vegetation of the subantarctic islands).

5.1 Topography
The 100 m and 20 m contours and the scanned topographic maps were obtained from CDSM. The 200 m Digital Elevation Model (DEM) (Schulze 1997) was used to model some slopes in the process of mapping some vegetation types associated with slopes. Terrain morphology was consulted for describing some vegetation types (Schulze 1997). Some contour heights had to be corrected. Altitude profiles of vegetation types were derived as follows: The DEM was classified into 20 m classes and the class grid converted to polygons. These polygons were then combined with the vegetation map to obtain the intersection of vegetation types with altitude classes. The area of each polygon was then calculated and a single table created with vegetation type, altitude class, and sum of area. Frequencies of altitude classes in each vegetation type were then prepared as histograms which were used for describing the altitude profiles.

Other topographic data were obtained from the Chief Directorate: Surveys and Mapping (national Department of Land Affairs, Mowbray, Cape Town (w3sli.wcape.gov.za), reproduced under Government Printer's Copyright Authority No. 11243 dated 4 January 2005.

5.2 Geology, Soils and Land Types
Digital geological data obtained from the Council for Geoscience included the 1:1 000 000 map, 1:250 000 geology map for selected map sheets limited to the Fynbos Biome area, and the volcanology of Marion and Prince Edward Islands. Soils (Land Types) were obtained from ENPAT. Landsat (contrast-adjusted colour composite of TM bands 7,4,2 as R,G,B) satellite imagery was obtained from NASA. Predicted Soil Loss (erosion) data were supplied by the national Department of Agriculture (NDA).

5.3 Climate
Climate data were obtained from the South African Atlas of Agrohydrology and Climatology (see Schulze 1997). Selected temperature maxima and minima were extracted from data for climate stations of the South African Weather Service (SAWeather).

The climate diagrams (Figure 2.2) were prepared by summarising vegetation type zones (using ArcView 3) using the vegetation polygon theme and climate grids. For these diagrams, mean values were taken for each month for the Median Monthly Rainfall, Maximum Temperature and Minimum Temperature. Mean values for Mean Annual Precipitation (MAP), Annual Precipitation Co-efficient of Variation, Mean Annual Temperature, Mean Frost Days (days when screen temperature was below 0°C), Mean Annual Potential Evaporation and Mean Annual Soil Moisture Stress Days (percentage of days when evaporative demand was more than double the soil moisture supply) were taken to give figures for the parameters to the right of each graph.

Vegetation types with small portions in a given grid cell would not be represented in that cell in this summarising process. This resulted in statistics being biased towards parts with larger
extents of each vegetation type. This has particular relevance for shale bands, koppie units, etc. For example, it is likely that shale bands cross many grid cells but will have no data for many of those grid cells because they are not the majority of the total vegetation in those cells. Thus, for example, the shale bands might have skewed seasonality or other mean climate data over their ranges. Where there is no value for a type in any particular grid cell, each climate grid will have no data for that vegetation type in that grid cell, so in the same cell the data would be absent for each parameter. In some instances, i.e. SVcb 22 VhaVenda Mombo, AZf 2 Cape Vernal Pools and Dn 2 Namib Lichen Fields, each polygon was a minority in its respective grid cell and points were used instead of polygons to derive climate diagrams for these small units. Climate diagrams were not created for the Desert Biome and the Succulent Karoo units of the Richtersveld due to a lack of confidence in the modelled data in that area. In some of these cases, data for weather stations situated in the respective vegetation type were used to create modified climate diagrams.

Crosswalks were used for preparing some descriptions of vegetation types in Sections 7.2, 7.5, 7.6, 7.8. These crosswalks were derived by converting the climate grids to polygons and then overlaying the polygons and getting actual areas of overlap (in ha) of vegetation and each value for the climate. The crosswalks were done with classes of cell values (e.g. 1–10 mm of rainfall).

5.4 Sources of Plant Distribution Data

The main source of plant distribution data was PRECIS (National Herbarium [PRE] Computerized Information System)—a database managed from the Pretoria centre of the South African National Biodiversity Institute (Magill et al. 1983, Germishuizen & Meyer 2003). The spatial resolution of specimens in Specimen-PRECIS (about 800 000 records) is generally 1:50 000 map sheets, the so-called 'quarter degree squares' (QDS) (approximately 30 x 30 km). Because of this very coarse scale, the data were considered to be potentially useful only where a QDS was at least 90% within a vegetation type. An intersection of QDS with vegetation types enabled the calculation of the percentage representation of a grid cell in a vegetation type. Azonal types and sea within a QDS were taken into account, reducing the total area of the grid cell to be apportioned to the vegetation type. By referring to the individual collectors' label data, the accuracy could sometimes be greatly improved from incorrect or even missing geographical co-ordinates in PRECIS. In cases of outliers where the geographical co-ordinates and the locality description recorded by the collector on the label disagreed, we used the label data and not the geographical co-ordinates.

Place names mentioned on specimens were checked against PRECIS Gazetteer, CDSM Gazetteer, ENPAT2001 (DEAT) cadastral data (farm names), and names of places and parent farms from SAEExplorer (MDB). Data were generally used with greater confidence if the point was located within the vegetation type where the collecting locality was recorded by the collector with a precision of less than 2 km, as is the case with some older specimens, and increasingly so for newer specimens where GPS is used.

The ACKDAT database (O'Callaghan 2000) is curated at the Kirstenbosch centre of the South African National Biodiversity Institute and contains about 300 000 records of data on species presence and abundance and sometimes habitat. It was created by the computerisation of J.P.H. Acoccks's field notes (Rutherford et al. 2003) recorded during some 44 years of field work throughout South Africa and parts of Swaziland. Geographical co-ordinates generally have a precision of about 1.5 km. We
used ACKDAT data for sites specifically selected as being representative of the vegetation type in which each occurred. For example, if sites were close to the edge of a type or if Acoccks's description of the site indicated that it was not typical of the vegetation type, the data were generally not used for that type if better alternatives were available. Acoccks sometimes specified the habitat of a site as forest or pan, making it unrepresentative of the surrounding type being described. Because of the progress South African taxonomy has made over the past 50 years, many of Acoccks's records considered as useful were checked against other sources for identification certainty. In the process, for instance, all records for vygies (Aizoaceae) were disregarded. The Nama-Karoo sites of Acoccks served as a basis in preliminary steps towards mapping of the biome (see Section 6.2.2 further on).

The third important source of distribution data was the database of the Protea Atlas Project (Rebelo 1991). It currently contains about 265 000 high-precision records of all Proteaceae occurring in southern Africa, collected by professionals and trained amateurs. Data usually include an estimate of abundance and sometimes habitat. The database is curated at the Kirstenbosch centre of the South African National Biodiversity Institute and served as a major source of data, especially for the descriptions of the vegetation units of the Fynbos Biome.

National Vegetation Database (Mucina et al. 2000) served as a source of vegetation data in some preliminary classification studies in several fynbos regions as well as for classification of the forest data (Von Maltitz et al. 2003, Mucina & Geldenhuys 2002, Geldenhuys & Mucina 2006), the results of which led to the definition of the forest vegetation units in our Map. The vegetation data are stored in the form of relevés (list of taxa per plot) and are managed by the TURBOVEG 2.0 software (Hennekens & Schaminée 2001). This database was used as a source of plant species distributions in relatively few cases because of the frequent lack of geo-referencing of sampling plots.

Gertenbach's (1983) species lists for landscape types in the Kruger National Park were a useful source of species data which helped to shape the species lists of all vegetation units of the Park.

The distribution of alien plant species were sourced from the National Invasive Alien Plant Database (CSIR) (McKelly et al. 2000).

The species lists of the descriptions of vegetation units extracted from the databases listed above were further supplemented by:

- distribution data from all major taxonomic revisions and monographs of southern African genera,
- all major flora field guides featuring various segments of the flora of the region,
- unpublished (and not yet digitised) voucher collections from major herbaria in the region,
- unpublished records collected by many field botanists, both professionals and amateurs (see the sections on Credits in particular chapters as well as general Acknowledgements in Chapter 1).

5.5 Conservation Data

Protected areas network data were compiled in April 2005 for purposes of the National Spatial Biodiversity Assessment (Driver et al. 2005). They are included with the digital data of the Map and were also used for describing the proportion of most vegetation types statutorily conserved. These included national parks from the SANParks, and other data collected for the National Spatial Biodiversity Assessment. SANParks supplied some recent changes and missing data, such as those on the proposed Garden Route National Park. Some conservation areas were digitised from sources at SANBI and SANParks, e.g. Tsehlanyane National Park in Lesotho. See above for the source of the alien plant coverage.

Census data (from SAIMplorer from the Municipal Demarcation Board) were consulted in some cases to help locate areas of major human pressures in some vegetation types.

See also Section 5.7 for man-made impacts.

5.6 Other Vegetation Maps as Sources

Vegetation maps used as sources are referred to at their application in Sections 6 and 7. Gertenbach (1983) boundaries were used for our vegetation boundaries within the Kruger National Park.

5.7 Man-made Geographical Features

The basic cartographic data on political boundaries, settlements, roads and dams were conventionally applied, but with numerous necessary modifications to source data.

National and international boundaries were obtained from ENPAT, and borders with countries neighbouring the mapped area were corrected using 1:50 000 map images from CDSM.

Settlements (ranging from selected small groups of huts to cities) data from GlobalMap (supplied by CDSM) were used. Place names were updated according to gazetted names listed on the website of the South African Geographical Names Council on 1 January 2005. Names of some additional built-up areas were taken from data provided by CDSM.

Roads data were obtained from the Council for GeoScience. Some new roads were added, e.g. the stretch of N1 between Polokwane and Mokopane, the road north of Upington to Askam, some roads in the Richtersveld, Namakwaland, Maputaland and in Limpopo Province. The mapping of the road networks in Lesotho and Swaziland was improved. Railway data from GlobalMap were used, with some editing in Swaziland. Data on rivers were obtained from the Council for GeoScience. River courses were reconciled with the position of riverine vegetation and dams. They were checked against CDSM-scanned maps in certain instances.

A coverage representing radically altered landscapes was prepared using the classes 'Forest Plantations', 'Cultivated Lands', 'Urban/Built-up Lands' and 'Mines and Quarries' from the National Land Cover database (Fairbanks et al. 2000). CDSM 1:500 000 roads (excluding footpaths) were buffered (30 m for major roads, 20 m and up to 10 m for lesser roads) using GIS and added to the radically altered layer. Areas transformed by water impoundment were obtained from CDSM. Data on dams were derived mostly from 1:500 000 digital map data and some from 1:50 000 digital data, or by checking against 1:250 000 scanned maps, and some digitised using Landsat 5 images. Dams smaller than 100 ha (making up 3.6% of the total dam area) were omitted to avoid the many farm dams. Vegetation on islands of smaller than 20 ha in dams was not mapped. Dam names were checked against the dams shapefile from DWAF, scanned 1:50 000 and 1:250 000 maps, and independent sources. Certain dams that had not been in the dataset, were digitised, e.g. the Mohale and Marico Dams, and the coverage of some had to be corrected (e.g. Straassfontein Dam, Free State).
6. Vegetation Map as a Graphical Spatial Model

6.1 Mapping Procedures: Basic Features

In this section we shall address only the theory of the mapping procedures. The technical details of the mapping are presented in Section 6.2.

The mapping procedures adopted in the VEGMAP project include the following five basic features:

1. Zonality concept as a major classification criterion.
2. Recognition of controlling factors at the scale of mapping.
3. Adoption of proxy data as major source.
4. Application of a top-down approach in conceptualising mapping units.
5. Bottom-up approach in building a hierarchy of mapping units.

Zonality. The enormous extent of the mapping realm (almost 1.3 million km²) corresponds to the scale of the macroclimate which probably plays a major role in differentiating vegetation complexes at the subcontinental scale. The concept of zonality (Walter 1964) has been used as an a priori criterion in recognising azonal vegetation types under strong control of factors other than climate. The concept of zonality and related terminology is discussed at length in Chapter 13. Application of this prime criterion in our Map is unique in the history of South African vegetation mapping.

Controlling Factors. Vegetation patterns are a result of a complex of environmental factors co-acting both spatially and temporally. Various ecological factors determine the patterning and dynamics of vegetation and it is therefore essential to identify those most important to understand the distribution of vegetation types in space and time. Application of zonality (identifying those controlling climatic factors in zonal vegetation) was one of these essential steps. We consider those factors that control, for example, the diversity of the azonal (water dynamics, salinity) or zonal vegetation (soil patterns, geology).

Proxy Data. Because of the lack of primary vegetation data (including vegetation samples, interpretable remote-sensing coverage etc.) in many areas, vegetation mapping is forced to use proxy data—soil maps, geological maps, modelled climatic surfaces etc. The proxy data were extensively used in our mapping studies to create physico-geographical units to serve as a basis for recognition of vegetation units.

Top-down Approach. We used this approach in spatial delimitation and conceptualisation of the mapping units. Starting from broad mapping realms representing biomes (or other groups of plant communities) and applying the knowledge of the controlling factors, and aided by proxy data, we proceeded in subdividing the mapping realm into smaller homogeneous (physico-geographical) units. These units were then re-evaluated in terms of vegetation concepts, in other words the physico-geographical unit was characterised in terms of its vegetation cover and composition. Three basic steps constitute the process from the recognition of mapping units to their actual spatial mapping. These are: (1) spatial delimitation of units, followed by (2) conceptualisation (including calibration and verification) of the units, and finally (3) description by which the properties of the established mapping units are expressed in a comprehensive yet condensed text form to accompany the map and aid its interpretation. The last step is handled in more detail in Section 7 of this chapter.

Bottom-up Approach. Using the similarity in terms of vegetation structure and floristic composition as well as several other mainly ecological or physico-geographical traits, the distinguished vegetation (mapping) types were grouped into a nested hierarchy. In our terminology, the vegetation units (basic level) group into bioregions and these group into biomes (see also Section 4.3 in this chapter).

6.2 Mapping Procedures: Practical Approach

6.2.1 General Mapping Procedures

Commencing with the top-down approach, we handled the mapping of the target region (South Africa, Lesotho and Swaziland) in stages.

Stage 1: Initially we divided the target region into areas to be covered by particular mapping teams using the methodology as indicated in Sections 4.1 and 6.1 and adapted to local conditions (complexity of vegetation, extent of the area, availability of proxy and field data etc.). These areas were (1) Grassland and Savanna Biomes (excluding the Eastern Cape and KwaZulu-Natal), (2) so-called arid biomes, including Nama-Karoo, Succulent Karoo and Desert, (3) Fynbos Biome, (4) Eastern Cape and (5) KwaZulu-Natal. The Eastern Cape team mapped, among other vegetation types, also the southermost extensions of Grassland and Savanna. Each of these teams (with exception of the arid biomes team) produced a map of the respective areas. The Grassland/Savanna team did not only create a new product for most of the area but relied heavily on existing (although not comprehensively published) maps covering the Kalahari region. The arid biomes were mapped, at this stage, in a different manner: the Nama-Karoo region (with broad buffer zone encroaching into neighbouring biomes such as Savanna/Kalahari, parts of Succulent Karoo and Fynbos and especially summer-rainfall parts of the Desert Biome) was mapped as an entity. The Richtersveld was covered by very detailed, unpublished survey data and the Namaqualand region (excluding the Richtersveld) was initially mapped using satellite imagery (see below for the details of the mapping procedures). The remainder of the target area (the Succulent Karoo area outside the above-mentioned areas) was mapped de novo.

The various contributors had been asked to map data and to digitise these and supply ArcView shapefiles in Decimil Degrees, WGS84 spheroid and Hartebeesthoek datum. Those mapping coverages supplied in Cape Datum, Clarke 1884 spheroid, or in mixed datum were reprojected. In cases where the supplied data were more inaccurate than could be attributed to the datum point (1.6 km northeast in the Molopo River area), the spatial adjust method of ArcGIS 8 using a rubbersheet of all features was used to adjust such portions of the map to align them to 1:50 000 data supplied by the CDSM.

Stage 2: This stage proved to be the most complex part of the whole process. After initial screening of the supplied products, we attempted the first stitching of the partial products to identify gaps and incompatibility of units along 'stitched' borders. During this period, new mapping sources, especially valuable unpublished maps, became available. Involvement of new collaborators who were asked to deal with local/regional mapping issues, led to a considerable revision of large portions of the initial mapping products supplied, especially in the Grassland, Savanna and Fynbos Biomes as well as in the Eastern Cape Province, Lesotho and Swaziland. A fresh attempt was made to map the vegetation of Lesotho and an unpublished map of Swaziland was supplied to the VEGMAP team at that stage. Both maps replaced existing initial mapping coverages of the
Grassland and Savanna Biomes within the borders of these two countries. A large part of the Fynbos Biome was mapped in a second attempt assisted by better digital (more detailed geological map) and floristic (improved access to extensive databases) data. The western portion of the initial Eastern Cape mapping coverage was replaced by the very detailed STEP map, which had to be simplified for the purpose of our Map and the limitations imposed by the mapping scales. The original KwaZulu-Natal map also underwent simplification and adjustments resulting from input from experts of Ezemvelo KZN Wildlife (especially in Maputaland, northern KwaZulu-Natal and in the Midlands). At this stage the very detailed Richtersveld map had also been adapted to our aims (simplified and improved in some boundary detail) in the first place and collated to fit the concepts of the neighbouring regions, especially the Namaqualand and northern Bushmanland coverage (originally part of the initial Nama-Karoo map). In summary, this stage saw (1) much improvement in providing more soundly based types and more accurately mapped units in local and regional coverages (through improved access to unpublished mapping sources and powerful proxy data as well as floristic databases), and (2) the 'stitching' process—a phase of reconciliation of different sources in spatial (boundaries) and conceptual terms involving unification of concepts of units subject to stitching.

In practice this meant many iterations operating at very different cycle lengths which, together with the number of vegetation polygons ultimately exceeding 17 000, required close and careful management. Numerous field checks and consultations were undertaken by the VEGMAP management team to improve the quality of the map.

Stage 3: Although less complicated than the previous one, this was a stage of small-scale improvement, including incorporation of comments of consulted experts, refinement of borders (increasing detail of boundaries at more detailed scale), handling of very small polygons for cartographic reasons and, finally, cleaning of the coverage.

Editing was done using ArcView 3.2. Occasional cleaning was done by converting the shapefile to an ArcInfo coverage using the ArcCatalog process to export the shapefile to coverage to generate topology for overlaps and gaps in the combined source data. Slivers resulting from overlaps between various coverages were identified and removed. Almost all polygons smaller than 5 ha were merged to the appropriate adjacent type to avoid a salt-and-pepper effect in the graphical presentation (too fragmented coverage consisting of many spatially separated polygons obstructing the general pattern).

6.2.2 Specific Mapping Examples

Grassland and Savanna

Most of the borders between the Grassland units of the Highveld north and west of Lesotho and much of the eastern Highveld and the Eastern Cape are frequently very similar to land type boundaries. Certain localised units west of Lesotho were mapped independently of land types, e.g. Gh 7 Winburg Grassy Shrubland, Gh 8 Bloemfontein Karroid Shrubland and Gh 7 Northern Free State Shrubland. Vegetation in KwaZulu-Natal has a somewhat lesser correlation with land type boundaries. Northern summit and eastern escarpment units of Grassland (e.g. Gm 20, 23, 27 and 29) as well as Lesotho and Swaziland do not follow land types.

Few vegetation units of the Savanna Biome follow land type boundaries. Those that do are mainly the Savanna Thornveld types of the Central Bushveld (units SVcb 1, 3, 6, 14 and 15) and the separation of SVmp 1 Musina Mapane Bushveld and SVmp 2 Limpopo Ridge Bushveld. Elsewhere there are some units that partially coincide with land type boundaries, such as the northeastern parts of SVi 3 Granite Lowveld, the western edge of SVi 1 Makuleke Sandy Bushveld, part of the eastern side of SVcb 21 Soutpansberg Mountain Bushveld, the southern edge of SVkd 1 Gordonia Duneveld and the northern parts of SVk 4 Kimberley Thornveld.

We also made use of boundaries of previously mapped vegetation types in the delimitation of some Grassland and Savanna units, for instance the landscape types of the Kruger National Park (Gertenbach 1983), units mapped in the Blouberg (Scholes 1979) and those of the Kalahari duneveld (Lubinge 1998) etc.

While the Sub-Escarpment Grassland and Savanna units in the Eastern Cape (central to eastern regions of the province; D.B. Hoare & A.R. Palmer, unpublished data) were mapped using satellite imagery, the Sub-Escarpment units of KwaZulu-Natal in principle followed the borders of Broad Resources Groups (BRG) and Bioresource Units (BRU) as defined by Camp (2001 and the preceding series of reports). A BRG is defined as 'a specific vegetation type controlled by an interplay of biotic factors such as soil and altitude'. It is formed by one or more Bioresource Units, each of the same vegetation type, and related to one another in terms of climate and broad soil association patterns (Camp 2001). In the same work Camp defined a BRU as ‘… an area within which the environmental factors such as climate (rainfall, temperature and evaporation), soil type, vegetation and terrain type, have a degree of homogeneity such that land use practices, farming enterprises, production and production techniques, can be clearly defined for practical planning purposes’. Details on the mapping procedures leading to the BRG/BRU classification of KwaZulu-Natal are also given in Camp (2001).

Geology was used as a guide for boundaries of some Grassland and Savanna types, including units such as Gh 7 and 8, Gh 11 and 15, Gm 10, 22, 23 and 26, Gs 2, SVi 5, 6 and 13, SVcb 2, 7, 11, 13, 25, SVmp 4 and 8.

Altitudinal limits were used to approximate boundaries of, for example, Gm 20 Leolo Summit Sourveld, Gm 29 Waterberg-Magaliesberg Summit Sourveld, Gd 10 Drakensberg Afroalpine Heathland and SVi 17 Lebombo Summit Sourveld. Digital Elevation Model (DEM) data were used to calculate minimum slopes to identify some units associated with koppies, for example, Gm 5 Basotho Montane Shrubland and Gd 4 Besemkaree Koppies Shrubland. Topographic maps were used to identify units such as SVi 7 Gravelotte Rocky Bushveld, eastern outliers of SVi 9 Legogote Sour Bushveld and SVi 12 Kaalrug Mountain Bushveld. Gm 2 Senqu Montane Shrubland was mapped on the basis of steep slopes up to a maximum altitude approximating the upper limits of the sandstone. Much of the extent of the units where we applied DEM data extensively were later verified by ground truthing.

The approximate 600 mm isoline for MAP was used as an upper limit for Gh 2 Aliwal North Dry Grassland and for separating Gh 4 Besemkaree Koppies Shrubland on the dry side from Gm 5 Basotho Montane Shrubland.

Albany Thicket

The core (solid) thicket vegetation types of the Subtropical Thicket Ecosystem Planning (STEP) Project were closely followed for our Albany Thicket vegetation types. The mosaic thicket units of STEP were assigned as follows: The Fynbos units identified by the Fynbos mapping team took preference, and the remainder of the mosaics were then individually evaluated against avail-
Arid Biomes

A multivariate data analysis of the link between the vegetation and climate data (e.g., precipitation, temperature, and soil properties) using GIS and statistical software allowed for the identification of distinct vegetation types across the study area. The analysis revealed that the vegetation patterns were strongly influenced by the climatic gradients, with distinct vegetation types occurring along a moisture gradient. The vegetation types were classified using a supervised classification approach based on remote sensing data. The resultant vegetation map was validated using field data collected from various locations across the study area.

Forests

The mapping of forest patches was based on the analysis of aerial photography and satellite imagery. The forest types were identified using spectral signatures derived from high-resolution satellite images. The forest cover was estimated using a combination of Landsat Thematic Mapper data and aerial photographs. The forest types were categorized based on their dominant tree species and canopy structure. The extent of the forest patches was determined by overlaying the forest type map with the land use map.
Biome Project Map or simply ‘DWAF Map’ was available in a GIS format as well. It served as the mapping substrate for the National Forest Classification (Von Maltitz et al. 2003), which yielded 24 Forest Types of floristic-biogeographical character, of which four azonal types were considered stand-alone and the rest were summarised into seven Forest Groups. This classification was based in principle on floristic data such as plots, with (semi)quantitative data on (mainly) woody species. Details of the data collection, collation, elaboration and interpretation leading to the classification scheme were summarised by Mucina & Geldenhuys (2002). Because of unduly great detail for our mapping purposes, the original forest classification (Von Maltitz et al. 2003) was simplified by recognising these seven Forest Groups as well as the original four azonal Forest Types as vegetation units. Furthermore, we have added and mapped one vegetation type that was not part of the National Forest Classification—the Ironwood Dry Forest. The original azonal forest type called ‘Licuati Sand Forest’ was lumped with Nwambiya Sand Forest (also not part of the National Forest Classification) into a vegetation unit called ‘Sand Forest’. Details of the crosswalk between the National Forest Classification of 2003 and the current composition of the vegetation unit on our Map are presented in Table 12.1 in Chapter 12.

The obvious errors of the so-called DWAF Map, especially in the Western Cape, KwaZulu-Natal, Swaziland and northern provinces of South Africa, were corrected using other mapping sources. The forests of KwaZulu-Natal have been re-mapped by FOR-SEA project (Adie & Goodman 2000) and the forests of Mpumalanga by Lötter et al. (2002). The Sand Forest of Maputaland was mapped using coverage based on satellite imagery by Smith (2001). The new data for both provinces available in a GIS format then replaced the original coverage depicted by the DWAF Map (Anonymous 1987). The forest patches of Swaziland were provided by L. Dobson as part of the Swaziland vegetation map (see also Löffler & Löffler 2003). The coverage of the milkwood forests of the Overberg (Western Cape) was provided by D.I.W. Euston-Brown (unpublished data) and that of the Still Bay region (Western Cape) was digitised from a map published by Rebelo et al. (1991). The forest patches on Table Mountain were mapped from a map published by McKenzie et al. (1977). As source of the coverage of the Ironwood Dry Forest (Androstachys johnsonii), the Nwambiya Sand Forest as well as some riparian forests along the Limpopo River and its tributaries in the northern Kruger National Park, we used the map by Van Rooyen et al. (1981), digitised by A. Grobler (then Department of Botany, University of Pretoria). The extent of the mangrove forests in the Kosi Bay area was adjusted by digitising the map published by Ward et al. (1986). Additional patches of forest (not depicted by the DWAF Map) were digitised from topographic maps on the basis of information provided by G.P. von Maltitz (Magaliesberg area), L. Mucina (eastern Free State, tallus forests of the Hottentot Holland Mountains and Limpitberg), M.C. Lötter (eastern and southern Mpumalanga) and B. McKenzie (Langeberg, Riviersonder and Outeiniqa Mountains).

For the final cartographic presentation on the Wall Map (Mucina et al. 2005) as well as in the Vegetation Atlas (Chapter 18) and correspondingly on the electronic form on CD, the forest patches smaller that 5 ha have been disregarded.

**Indian Ocean Coastal Belt**

The extent of the IOCB was defined within the borders of the KwaZulu-Natal Province by the extent of the BRG 1 Coastal Belt as mapped by Camp (1999a) for purposes of planning agricultural activities in the province. He distinguished five units within his BRG 1, which we found too detailed to be interpreted unambiguously in terms of our vegetation units. We used floristic data and climate (mainly precipitation and mean annual temperature) to distinguish Maputaland from the rest of the KwaZulu-Natal coast (defined as a composite of the other four Camp subunits within his BRG 1). The borders of the Maputaland Coastal Belt were subject to adjustment based on occurrence of tropical floristic element sand vegetation complexes along the Mzumzini-Mandini coastal segment (as far south as Zinkwazi River mouth) by C.R. Scott-Shaw (unpublished data). The final appearance of the latter unit was further modified by extraction of the azonal units. Embedded within the Maputaland Coastal Belt, the Maputaland Wooded Grassland has been defined on the basis of an unpublished mapping source derived from satellite imagery by Smith (2001). Where the latter source mapped timber plantations, the extent of the former (destroyed) wooded grasslands was reconstructed by C.R. Scott-Shaw using topographic data.

The sandstone-dominated coastal regions of the Ugu District in KwaZulu-Natal and the Pondoland Wild Coast with its sandstone-dominated coastal souwelds form a natural landscape and vegetation unit, which was already distinguished, also in extent, by Acocks (1953). This vegetation unit strictly follows the extent of the sandstone geology except for the forest and valley bushveld patches mapped as different vegetation units.

The extension of the IOCB along the Transkei coast follows D.B. Hoare & A.R. Palmer (unpublished data), whose approach encompassed multivariate analysis of the vegetation-environment relationships to create a system of land classes to be reclassified later using satellite imagery accompanied by subsequent ground-truthing.

The final appearance of all IOCB vegetation units on the Map (see Mucina et al. 2005) was also influenced by definition of the extent coastal forest patches as well as coastal and inland azonal vegetation units.

**Azonal Vegetation**

Scanned 1:50 000 maps were used extensively for mapping AZI 5 Bushmanland Viero, AZI 4 Southern Kalahari Salt Pans and some other pans, wetlands and alluvia. Wetlands mapped for the National Land Cover were used selectively and their extent was also improved through consulting topographic maps. Some alluvia were modified from those mapped for land types (the width of many being reduced, for example, in AZI 5 Highveld Alluvial Vegetation). Some alluvia, estuaries and beaches (seashore vegetation units) were mapped by referring to Landsat 5 images.

A minimum size of 5 ha was generally used for inclusion in the final map, with a general minimum size of 10 ha for selection of many pans. Certain patches smaller than 5 ha such as AZI 2 Cape Vernal Pools were specifically included because they are particularly unique in terms of species.

6.3 Construction of Bioregion and Biome Maps

In preparing the biome and bioregion maps, the bioregions were dissolved to join adjacent polygons in the same bioregion, excluding forest, azonal and infrastructure units. The holes left by excluding forests etc. in the biome and bioregion coverages were filled using the value assigned based on Euclidean Distance in a 200 m grid. Biome polygons smaller than 2 000 ha and bioregion polygons smaller than 600 ha were excluded from the resulting coverage, except for selected smaller polygons such as coastal strips and islands that could not confidently be assigned to another biome. Forests larger than 2 000 ha

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were then added to the resulting biome map. The process is described in Figure 2.3.

6.4 Final Production of the Vegetation Maps

Final colours for each vegetation unit were selected attempting to maintain a suite of similar colours within each biome, while trying to ensure good visual distinction between adjacent polygons of different vegetation types at the same time. Colour distinction sometimes required using a very different colour. Additional difficulty arises from the difference between the colour seen on the computer screen and the colour on the printed map, requiring manual adjustment of hue, saturation and value to arrive at suitable printed colours when using the CMYK standard colour model used in offset printing.

The vegetation under the reservoir of dams was reconstructed from evidence of surrounding vegetation and, in certain cases, the topography below the water (by reference to maps that predated the construction of the dam). This coverage can only be viewed on the accompanying CD.

The legend was prepared in a novel way by creating a shapefile with blocks in rows and columns. This enabled colour precision for the legend boxes as well as spacing of headings and subheadings in the legend. Each vegetation type was assigned a column and row value. A table with box identification, row, column and names for biome, group and vegetation type was linked to the polygon (legend box) shapefile. Labels were positioned using these boxes. As the Wall Map was printed in projected units at a scale of 1:1 000 000, the box sizes and spacing were easily calculated based on map units.

The Wall Map was printed by USS Graphics, Cape Town, South Africa, on SAPP 170 g Magna Gloss paper using 600 dpi PDF files, transferred to offset lithographic plates using computer-to-plate technology. The colour sequence for printing was red (magenta), yellow, black, blue (cyan) and not the normal sequence of black, blue, red, yellow. Colours were converted in ArcGIS to CMYK before PDF files were created. The initial RGB colours did not translate well to CMYK at the printing office, and therefore CMYK colours had to be manually defined in ArcMap. The Wall Map formed the basis for printing the atlas in the current work.

7. Vegetation as a Verbal Model

The verbal model, consisting of descriptive text, is not limited by the constraints of scale inherent in the printed spatial model of the Map. The description has a scale-independent flexibility that can easily allow for inclusion of information on fine-scaled mosaics and can potentially include any nuances that would be impossible to depict on the Map.

Our descriptions of vegetation units are sometimes flanked with short descriptions of groups to which they belong (see for instance Chapter 3 on Fynbos). Each biome is always preceded by an introductory text featuring important physico-geographical, ecological, biogeographical, evolutionary, socio-economical etc. background information on the vegetation units being described (see Chapter 1).

The description of a vegetation unit consists of the following elements:

7.1 Name of Vegetation Unit

Each vegetation unit carries a unique informative name, consisting of four (or three) elements indicating (1) its code, (2) geographic address, (3) major habitat (often geological) characteristic, and (4) vegetation-structural character. The code provides the context of the unit and is useful for identification of the unit on the Map (see Mucina et al. 2005). Take, for example, FRs 9 Swartland Shale Renosterveld. This code consists of four parts, indicating the classification of the vegetation
unit into a biome (F: Fynbos Biome), bioregion or major group of units (R: renosterveld), and minor group units (s: shale), followed by the numerical code linked to the minor group. In the case of forest, for instance, we recognise two groups (zonal and azonal), hence a code for the scarps forests would read: FOz S Scarp Forest (FO: Forest Biome, z: zonal group, S: unit no. 5 within the zonal group).

Most of the names of our vegetation units consist of three elements, but some are composed of only two words. These are either well-established geographical (and/or ecological) concepts such as 'Ngongoni Veld' and 'Tanqua Karoo', or shorter two-word names that can reflect all information elements necessary. For example, the name 'Lesotho Mires' clearly indicates the geographic address, while the term 'mire' implies major ecological and vegetation-structural characteristics of the unit.

The way of naming the vegetation units was largely motivated by the paper by Cowling & Heijnis (2001), where they used it for naming their Broad Habitat Units (to a large extent spatially and partly also conceptually similar to our vegetation units). It seems, however, that this terminology has a precursor in the work of Campbell (1985) where it was applied in naming Fynbos structural units. We have especially borrowed the novel term 'vygieveld' from Cowling & Heijnis (2001), while the term 'gwariweld' comes from Vlok et al. (2003).

We have refrained from using the South African-developed vegetation-structural terminology by Edwards (1983) because it is more suited for vegetation units at the habitat scale.

7.2 Spatial Co-incidence with Other Vegetation Maps

The aim of the paragraph on 'synonymy' is to assist the reader in matching the new concepts of vegetation units presented in this work with the older, previously widely used mapped or unmapped vegetation-classification concepts. It simply indicates the level of spatial correspondence with our vegetation units. Acocks (1953, 1988) and Low & Rebelo (1996) cover the same area as our Map and therefore are automatically referred to within this category of spatial overlap. Here we list those Acoks 'veld types' or Low & Rebelo 'vegetation types' that make up an overlap of at least 50%. We used the same spatial-overlap principle to list the units of Moll & Bossi (1984), Cowling et al. (1999) and Cowling & Heijnis (2001) for the Fynbos Biome (and partly also Succulent Karoo), of Vlok & Euston-Brown (2002) and Vlok et al. (2003) for the Albany Thicket Biome (and some units of the surrounding biomes), and finally the zonal units of Edwards (1967) and Camp (1999a, b) encountered in KwaZulu-Natal.

Especially the synonymy of forest, azonal and subazonal units also contains entries of communities at the habitat level derived by various approaches, including the floristic-sociological, numerical, etc. (see for example the synonymy of AZd 3 Cape Seashore Vegetation).

7.3 Distribution

The section on Distribution gives the major distribution of the vegetation unit. It is introduced by the name of the province (in most cases), followed by a reasonably accurate description of locality or localities (but not an account of every polygon in highly fragmented vegetation types) sufficient for the geographically informed reader to get a good idea of just where the type occurs. We used the names and spelling of towns in South Africa as approved by the South African Geographical Names Council (SAGNC) as gazetted before 1 January 2005.

As a rule the indication of the altitudinal range of most of the area occupied by the unit concludes this particular section.

7.4 Vegetation and Landscape Features

This includes the appearance of the landscapes (including terrain type) and the main structural features (dominant growth forms, layering, canopy openness, patchiness, vegetation mosaics etc.) of major plant communities dominant in these landscapes. Particular attention is paid to these features in the case of units with a distinct mosaic of habitats (such as coastal units, alluvial units etc.).

7.5 Geology and Soils (Geology, Soils and Hydrology)

The geological and pedological section contains information on major rocks, both petrographically (rock types) and stratigraphically (age of geologic substrate). Information from GIS overlays between our vegetation coverage and geology was used and interpreted with care (especially with regard to the different scales of sources). Soils are very broadly described (usually using textural characteristics), but where we have sufficient knowledge (based on local pedological studies), we also list major soil types. Information on land types is given for most vegetation types. In many azonal units we use a slightly different heading (Geology, Soils and Hydrology) and we include a description of hydrology (permanent or intermittent flow of streams/riders, tidal dynamics) and some other factors underlying the azonality of the unit (e.g. salt content). We use the terminology of the South African Committee for Stratigraphy (1980) for geology, the Soil Classification Working Group (1991) for soils and ENPAT for land types.

7.6 Climate

We provide a brief overview statement of the main features of the relevant climate diagram (see Figure 2.2), often including important geographical ranges of parameters (especially MAP and frost). In some cases, one or two actual climate stations in the unit are used to provide mean monthly maximum and minimum temperatures. Any special climatic factors that are not reflected in the climate diagram, for example extreme temperatures, wind or fog, are given.

7.7 Structure of the Species Lists

The species lists are one of the core elements of the description of a vegetation unit. They are primarily aimed at providing information on floristic composition of the plant communities forming the vegetation unit. The categorisation of the species into Important, Biogeographically Important and Endemic adds value to the species lists in terms of biogeography and conservation.

7.7.1 Taxonomic Nomenclature

The names of taxa occurring in southern Africa cited in the descriptions, and throughout the book for that matter, basically follow the recent checklist of the flora (Germishuizen & Meyer 2003) and the PRECIS system. We also use those species names that have been published after appearance of the checklist cited above as well as some other taxonomic concepts that have not yet found acceptance in PRECIS. A number of
## Table 2.1 System of growth forms used in the descriptions of the vegetation units.

<table>
<thead>
<tr>
<th>Category/ Subcategory</th>
<th>Main Traits</th>
<th>Example</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree</td>
<td>secondary (woody) thickening of tissues; single-stemmed</td>
<td>Acazia karoo</td>
<td>excluding Succulent Trees</td>
</tr>
<tr>
<td>Small Tree</td>
<td>lower than 15 m in forests; lower than 10 m in savanna</td>
<td>Ekebergia capensis</td>
<td>excluding Succulent Trees</td>
</tr>
<tr>
<td>Tall Tree</td>
<td>taller than 15 m in forests; lower than 10 m in savanna</td>
<td>Afrocarpus falcatus</td>
<td>excluding Succulent Trees, only in tall-grown forests</td>
</tr>
<tr>
<td>Emergent Tree</td>
<td>taller than 25 m (overlapping canopy)</td>
<td>Euphorbia triangulina</td>
<td></td>
</tr>
<tr>
<td>Succulent Tree</td>
<td>succulent stems and branches; taller than 6 m of tree stature, always less than 5 m tall</td>
<td>Cyathes capensis</td>
<td>special category of Small Tree</td>
</tr>
<tr>
<td>Shrub</td>
<td>secondary (woody) thickening of tissues (at least at base); multi-stemmed as a rule, when single-stemmed, then branching from base</td>
<td>excluding all epiphytic forms</td>
<td></td>
</tr>
<tr>
<td>Low Shrub</td>
<td>lower than 2 m; no parasitic or semi-parasitic feeding, non-succulent</td>
<td>Pentzia incana</td>
<td>excluding Soft Shrubs, succulent and (semi)parasitic shrubs</td>
</tr>
<tr>
<td>Tall Shrub</td>
<td>taller than 2 m; no parasitic or semi-parasitic feeding; non-succulent</td>
<td>Gymnospora bixifolia</td>
<td>excluding Soft Shrubs, succulent and (semi)parasitic shrubs</td>
</tr>
<tr>
<td>Soft Shrub</td>
<td>secondary (woody) thickening of tissues along main stem; herbaceous tips of branches</td>
<td>Pleuranthus fruticosus</td>
<td>a transition category between Herbs and Shrubs, typical of some warm-temperate and sub-tropical forests</td>
</tr>
<tr>
<td>Geocarpy Suddnuten</td>
<td>large underground woody &quot;rhizome&quot;; usually imitating Low Shrub form above ground</td>
<td>Dichapetalum cyphum</td>
<td>excluding Shrubs with smaller lignotubers</td>
</tr>
<tr>
<td>Succulent Shrub</td>
<td>succulent leaves and/or stems; any height</td>
<td>Ruschia caroli</td>
<td>very common among Asocaceae, including Stem- succulent Shrub, Stem- &amp; Leaf-succulent Shrub and Leaf-succulent Shrubs (recognised only in Chapter 8)</td>
</tr>
<tr>
<td>Semiparastatic Shrub</td>
<td>green, but parasitising on xylem of other plants; any height</td>
<td>Theca hybrida</td>
<td>growth form limited to few families (mainly Santalaceae)</td>
</tr>
<tr>
<td>Climber</td>
<td>feeding on animal waste resembling carrion (usually other plants as support for climbing or scrambling)</td>
<td>Roridula gorgons</td>
<td>only 2 species of genus Roridula</td>
</tr>
<tr>
<td>Woody Climber</td>
<td>secondary (woody) thickening of tissues (at least at base)</td>
<td>Dalbergia armata</td>
<td>also including scrambler and strangler forms; excluding all epiphytic forms</td>
</tr>
<tr>
<td>Woody Succulent Climber</td>
<td>secondary (woody) thickening of tissues (at least at base); succulent leaves and/or stems</td>
<td>Sarcostemma vininale</td>
<td>excluding Succulent Climbers</td>
</tr>
<tr>
<td>Herb</td>
<td>no secondary (woody) thickening of tissues; usually primary/ root system</td>
<td>Cerberis nana</td>
<td>rare growth form</td>
</tr>
<tr>
<td>Grannoidoid Herb</td>
<td>no secondary (woody) thickening of tissues; usually primary/ root system</td>
<td>Cerepagia</td>
<td>excluding trailing (creeping) or prostrate herbs</td>
</tr>
<tr>
<td>Herb</td>
<td>no secondary (woody) thickening of tissues; usually primary/ root system</td>
<td>Protophytla preiheraufalis</td>
<td>very rare growth form</td>
</tr>
<tr>
<td>Megaherb</td>
<td>herbas taller than 3 m</td>
<td>Strelitzia nicolai</td>
<td>including annual, paucioennial or perennial herbs</td>
</tr>
<tr>
<td>Herb</td>
<td>including annual, paucioennial or perennial herbs</td>
<td>'bananoid' herbs; tall and with megaphylls</td>
<td></td>
</tr>
<tr>
<td>Geophytcn Herb</td>
<td>presence of herbaceous underground storage organs such as rhizomes, cores, tubers and bulbs</td>
<td>Lachenalia camos</td>
<td>excluding all those showing typical aquatic adaptations, geophytes, succulent, parasitic and carnivorous forms as well as annual plants</td>
</tr>
<tr>
<td>Sensculent Herb</td>
<td>succulent leaves and/or stems</td>
<td>Calepseum papulosus</td>
<td>excluding all aquatic, succulent, parasitic and carnivorous forms</td>
</tr>
<tr>
<td>Parasitic Herb</td>
<td>lack of assimilation apparatus; fully parasitic feeding</td>
<td>Hybanthe sanguinea</td>
<td></td>
</tr>
<tr>
<td>Carnivorous Herb</td>
<td>using additional animal (insect) source for some nutrients</td>
<td>Drosera capensis</td>
<td>including geophytic forms</td>
</tr>
<tr>
<td>Aquatic Herb</td>
<td>morphological adaptations to spend at least part of life cycle in under-water environment (saturated tissues, reduction of roots etc.)</td>
<td>Lemma minor</td>
<td>including all aquatic forms (Utriculana)</td>
</tr>
<tr>
<td>Gramnoidoid</td>
<td>'grassly' appearance (long, narrow, mostly tufted leaves); secondary root system</td>
<td>using water column or water surface as floating medium; including geophytic forms, including some aquatic mosses</td>
<td></td>
</tr>
<tr>
<td>Gramnoidoid Herb</td>
<td>lower than 2 m</td>
<td>Aristida concomata</td>
<td>including all Peaeeae, Cvaeraceae, Restionaceae, Xyridaceae; excluding Juncaginaceae, Thurnaiaceae and Enoeaeaceae</td>
</tr>
<tr>
<td>Mega-granmoid Herb</td>
<td>taller than 2 m; secondary (woody) thickening of tissues (at least at base)</td>
<td>Phragmites australis</td>
<td>excluding climbing forms</td>
</tr>
<tr>
<td>Bamboo</td>
<td>tall reeds; also including geophytic forms (Prionium)</td>
<td>Thamnocalamus tessellatus</td>
<td></td>
</tr>
<tr>
<td>Epiphyte</td>
<td>both woody and non-woody; using other plants as substrate, but necessarily as source of nutrients; not rooting in soil</td>
<td>Mysystodium</td>
<td></td>
</tr>
<tr>
<td>Epiphytic Herb</td>
<td>no secondary (woody) thickening of tissues; succulent leaves and/or stems</td>
<td>Dermatobrya saundersi</td>
<td>excluding all succulent and (semi)parasitic forms usually epiphytic orchids; including geophytic forms</td>
</tr>
<tr>
<td>Epiphytic Succulent Herb</td>
<td>no secondary (woody) thickening of tissues; succulent leaves and/or stems</td>
<td>Cassythe ciliata</td>
<td>excluding all succulent and (semi)parasitic forms, very rare category</td>
</tr>
<tr>
<td>Epiphytic Shrub</td>
<td>no secondary (woody) thickening of tissues (at least at base)</td>
<td>Viscum capense</td>
<td>mistletoes</td>
</tr>
</tbody>
</table>
| Epiphytic Parasitic Herb | no secondary (woody) thickening of tissues (at least at base) | }

## Other
- Moss
- Liverwort
- Lichen
- Macroalgae

<table>
<thead>
<tr>
<th>Other Category</th>
<th>taxonomic category (Bryophyta)</th>
<th>taxonomic category (Marchantopsida and Anthocerotopsida)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moss</td>
<td>taxonomic category including lichenised fungi</td>
<td>Cladonia pyxidata</td>
</tr>
<tr>
<td>Liverwort</td>
<td>taxonomic category including lichenised fungi</td>
<td>Eclonia maxima</td>
</tr>
<tr>
<td>Lichen</td>
<td>taxonomic category including lichenised fungi</td>
<td>Phaeophyta and Charophyta</td>
</tr>
<tr>
<td>Macroalgae</td>
<td>taxonomic category (some representatives of</td>
<td></td>
</tr>
</tbody>
</table>
new taxa pending descriptions, but often already in informal use by the botanical community, have also been listed, usually accompanied by the citation of a voucher specimen.

7.7.2 Growth Forms

All species in the lists are classified into growth forms using a system (Table 2.1) developed within the Ecological Flora of Southern Africa Database (L. Mucina, unpublished data). This system is a pragmatic tool based on several major features of the structural and functional life history of plants such as longevity, architecture, height, woodiness, succulence, parasitism, carnivory, epiphytism and the like.

In some chapters similar basic growth forms have been lumped (e.g. 'Small Trees & Tall Shrubs' in the vegetation units of the Indian Ocean Coastal Belt) or split (e.g. 'Stem-succulent Shrubs' and Leaf-succulent Shrubs' in the Desert chapter). This was done because distinction of the growth forms concerned might not always be clear-cut or both growth forms could be equally important in determining the structure of the vegetation.

7.7.3 Important Taxa

The category of Important Taxa includes those species (and lower taxa) that have a high abundance, a frequent occurrence (not being particularly abundant) or are prominent in the landscape of the unit.

The taxa are arranged according to growth forms, the order depending on the overall character of the vegetation concerned: in forests this sequence starts with Tall Trees and ends with growth forms in the undergrowth (Herbs, Graminoids); in succulent shrubland its starts with Succulent Shrubs etc. Mosses and Lichens are always placed at the end. Dominant taxa are given first in the particular lists within each growth form category—these are the species that are dominant (biomass) in the local communities or that are prominent, e.g. conspicuous quiver trees (Aloe dichotoma) scattered in a Succulent Karoo shrubland.

This list forms a basic floristic profile of the vegetation unit.

7.7.4 Endemic Taxa

The concept of endemism is determined by the extent of the vegetation unit. This means that a plant taxon is listed as endemic in the description when it occurs exclusively within the unit concerned. We have relaxed the strict interpretation of the 'unit-based endemism' in the Fynbos Biome, where an endemic plant species may have less than 10% of localities outside the vegetation unit in question. In some other biomes we accepted a relatively narrow interpretation of the notion of 'near-endemic' where the clear concentration of the given taxon is within the vegetation unit and a few outliers occur nearby in one or more adjacent units. We are well aware of the fact that the current endemic status of many plants would change in future as our knowledge about distribution of the species becomes more detailed and the extent of our vegetation units becomes more precisely defined. As our vegetation units are naturally defined entities, we consider the use of the term 'endemism' in this sense more appropriate than using this term in a political context (defined by the boundaries of countries or tourist regions).

7.7.5 Biogeographically Important Taxa

Biogeographically Important Taxa (BIT) are those that do not qualify as endemic (see Section 7.7.4), and may qualify as

Important Taxa (as defined in Section 7.7.3), but carry an additional important biogeographical message: they are limited to a small group of vegetation units (hence qualify as regionally endemic), they have been listed as regionally endemic in an established Centre of Endemism, they occur at the limits of their (large) distribution area and they show a very disjunct distribution pattern. We decided to single out these taxa to sometimes strengthen the case for delimitation of vegetation units and to indicate their value in raising interesting academic questions and conservation concerns.

Within the Fynbos Biome, with one of the highest concentrations of regional and local endemics, we have refrained from using the category BIT in most of the vegetation units except for those that fall within the CEs with their core in neighbouring biomes (for instance Nieuwoudtville-Roggeveld Dolerite Renosterveld is considered a part of the Roggeveld-Hantam CE,Namaqualand Sand Fynbos is part of the Namaqualand CE). We also use the BIT category for the strandveld units, and here we recognise two (new) putative CEs, namely the West Coast CE and South Coast CE.

Many of the BIT were recruited from the endemics of the putative phytocoria defined as Centres of Endemism (CE) by Van Wyk & Smith (2001). The spatial delimitation of their CEs is largely defined in approximate terms—the boundaries have been painted with a very thick brush (with a notable exception of the Pondoland CE). The (relatively) crisp spatial definition of our vegetation units, however, allows for re-definition of the boundaries of most of the Van Wyk & Smith's (2001) CEs. This revision is in progress (L. Mucina et al., in preparation) and here, when referring to Van Wyk & Smith's concept, we use them already in revised form. We also added some new concepts resulting from our preliminary studies of local endemism based on the list of endemics of our vegetation units.

Some regions of southern Africa house a number of CEs of Van Wyk & Smith (2001). For example, the northern provinces of South Africa (including Gauteng, Limpopo and Mpumalanga, as well as neighbouring Swaziland and parts of Mozambique, and northern KwaZulu-Natal) house five of these CEs—nos. 3.1, 6, 7, 8 and 9. We have observed that some species occur in a number of these CEs and are invariably linked to vegetation units that can be summarised under the informal category called 'sourveld' (some of them straddling the borders of the Savanna and Grassland Biomes). This observation led to the definition of a putative endemic category 'Northern Sourveld Endemic'. Examples are Encephalartos eugene-maraisii and Faurea galpinii; see also a long list of BIT in unit GM 18 Lydenburg Montane Grassland, etc. We have also been able to identify (see Van Rooyen et al. 2001) a group of endemics for the Kalahari. These taxa are limited to deep sands of the Kalahari Basin and reach South African territory in vegetation units of the groups SVK and SVKd exclusively.

Further we have introduced a number of other informal entities, based on groups of vegetation units as delimited in this book, namely:

(a) Central Bushveld endemics (shared by a number of SVcb units), e.g. Mosdenia leptostachys.

(b) Kalahari endemics (shared by a number of SVk and SVkd units), e.g. Panicum kalaharense, Neuradopsis behuenaensis.

(c) Camdebo endemics, e.g. Duvalia modesta.

(d) Capensis elements (species of typical Cape clades; Linder (2003), occurring in other than Fynbos units), e.g. Muraltia, Raspalia, Watsonia and many others in Pondoland.
Northern KwaZulu-Natal endemics (sharing several Gs or SVs units of this region), e.g. *Cissus cussonioides*.

Important long-distance biogeographical links such as a link to mountains of Zimbabwe (e.g. *Eriosema buchananii, Nemesia zimbabwensis*) were useful in classifying some species as carrying an important biogeographical message.

Widely distributed species occurring at the limits of their distribution, such as those reaching southern Africa from the northern hemisphere (*Lycium shawii*), were also noted in BiT category in places.

### 7.8 Conservation

This section collates important information available on the conservation status related to the vegetation unit. Here we mention the conservation status (using the scale of categories of Critically endangered, Endangered, Vulnerable, Least threatened after Golding 2002), conservation target and percentage of the surface of the unit currently under protection (listing also the main statutory and private conservation areas). Threats to the unit such as the occurrence of major (mostly woody) alien species and the erosion status (from the Predicted Soil Loss data of the national Department of Agriculture) are also given. The five categories of levels of erosion (soil loss) are as follows: very high (> 60 t/ha/a — tons per hectare per annum), high (26–60 t/ha/a), moderate (13–25 t/ha/a), low (6–12 t/ha/a) and very low (0–5 t/ha/a).

### 7.9 Remarks

The sections on Remarks are devoted to (1) discussion of any important issue mentioned in the description in more detail, (2) interesting biogeographical phenomena and oddities, (3) problems of delimitation, (4) level of our knowledge about the unit, and any other aspect of particular interest pertaining to the unit.

### 7.10 References

This section lists (in alphabetical and then chronological order) all references that feature vegetation patterns pertinent to the vegetation unit concerned. We also added some references otherwise useful to elucidate ecology and distribution of the unit or some of its important species. We also attempted to list many 'grey-literature' sources, such as major unpublished reports, university theses and projects. Where no published information was available, we cited the source(s) of unpublished data.

### 8. Concluding Remarks

Although vegetation surveys and mapping are not the most fashionable topics of contemporary plant ecology (especially outside Europe), their potential in providing quick and reliable simplified models of vegetation patterns that assist in important decisions on nature management and on other land uses, is indispensable. The need for understanding (using, protecting, managing) vegetation patterns encourages and will continue to fuel the development of new tools and procedures of vegetation survey. Progress in vegetation mapping will continue to focus more closely on the acquisition and interpretation of remote-sensed data and stocking and utilisation of databases to assist in the spatial data analysis. We hope that extensive use of our Map (and the accompanying Book) will further enhance especially detailed vegetation surveys—an invaluable source of data for any mapping project, especially when planned and co-ordinated for incorporation in a national scale network. We believe, as we have already alluded to in the Introduction chapter, the VEGMAP is a process; we shall be closely monitoring new methodological developments in vegetation survey and mapping for new editions of both our Map and the Book.

### 9. Credits

The ideas presented in this chapter are a result of co-operation between members of the core VEGMAP team (M.C. Rutherford, L. Mucina, L.W. Powrie) and by the regional mapping teams and other contributors at large. L. Mucina wrote Sections 1, 2, 3, 4, 7, 8 and 9 and compiled the list of References (Section 10). All these sections were edited (both conceptually and technically) by M.C. Rutherford and L.W. Powrie, whose contribution was vital both to the contents and presentation of all these sections. M.C. Rutherford and L.W. Powrie (assisted by L. Mucina) compiled the text of the Sections 5 and 6. The complex subsection 6.2.2 (featuring the specific examples of mapping various biomes) was written by M.C. Rutherford (assisted by L.W. Powrie) for Albany Thicket, Grassland and Savanna, Azonal vegetation, Fynbos, and most of the arid biomes. In this subsection, L. Mucina contributed text on Forests, Indian Ocean Coastal Belt and Nama-Karoo (part of the arid biomes) as well as on Azonal vegetation.

### 10. References


Biomes and Bioregions of Southern Africa

Michael C. Rutherford, Ladislav Mucina and Leslie W. Powrie

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Figure 3.1 Visual collage of biome diversity.
1. Biomes

1.1 The Biome Concept

The terms biome, ecoregion and bioregion of academic ecology are becoming increasingly used by those concerned with management and conservation of natural resources. These terms have broad-scale applicability to those who have to develop conservation and management strategies over large areas. This chapter attempts to re-define the biome classification of the region encompassing South Africa, Lesotho and Swaziland in the context of the new vegetation map in the atlas section of Chapter 18. We also introduce the first consistent classification of "bioregions"—subordinate units to a biome.

The key to understanding the concept ‘biome’ is rooted in the issue of scale and in the concept ‘biotic community’. The concept ‘community’ (‘biotic community’) itself is marred by a history of inconsistent use and interpretation to such an extent that some view it as a nonconcept (Peters 1991). If we define ‘community’ very broadly as an assemblage of living organisms sharing the same portion of space during a certain period of time, then this all-encompassing definition applies to biome as well. The real difference is in scale. Biome is viewed as a high-level hierarchical (hence simplified) unit having a similar vegetation structure exposed to similar macroclimatic patterns, often linked to characteristic levels of disturbance such as grazing and fire. The biome can be considered a kind of ‘subcontinental biotic supercommunity’. Cox & Moore (2000) call it a ‘large-scale ecosystem’. As a high-level hierarchy unit, biomes are not characterised by individual species (which appropriately characterise units at the more detailed lower hierarchical levels) but mainly by the emergent properties of vegetation structure and associated climate or any other applicable broad-scale environmental factors (O’Neill et al. 1986). Hierarchy theory also suggests that higher-level spatial hierarchy scales (such as biomes) are associated with longer-term time scales although there is a complex interplay between evolutionary (long-term) and ecological (short-term) time scales. Rutherford & Westfall (1986, 1994) provided (at that stage) an exhaustive review of the complexity in defining biomes, also referring to five criteria (maximum global limits, mapping scale limits, primary and secondary bases for classification, and excluded areas) described further below. The main proponents in biome (or an equivalent) definition were either those emphasising the overriding role of climate acting at broad scales (Schipper 1898, 1903, Rubel 1930, Schipper & Von Faber 1935, Weaver & Clements 1938, Holdridge 1947, 1967, Walter 1973, 1976, Whittaker 1975, Walter & Breckle 1991, Rivas-Martinez 1995, Polis 1999, Krebs 2001) or those using a combination of life forms matching (not always perfectly) the major climatic patterns (Box 1981, 2002, Rutherford & Westfall 1986, 1994, Cox & Moore 2000, Mucina 2000).

The quantitative link between climate and life form combinations serves as basis for construction of biome models making use of key ecophysiological principles (see below). Bond et al. (2003, 2005), Woodward et al. (2004), Bond (2005) and Bond & Keeley (2005) found that the extent of the modern biomes (especially in C₃-dominated grasslands, savanna as well as in fynbos—all ‘fire-driven ecosystems’ (FDE sensu Bond et al. 2003) is at variance with classical climate potential models of biomes. These findings strongly suggest that the biome concept has to be revised to recognise the role of large-scale disturbance as an important factor shaping the zonal vegetation.

Strictly speaking the term biome includes both plant and animal communities, as its original American roots (Clements & Shelford 1939) suggest. Because of the dominant nature of vegetation cover in (nearly) all terrestrial ecosystems, biomes have been based only on vegetation characteristics.

In vegetation ecology, the concept of a plant community on a (sub)continental scale was called a ‘formation’ (Grisebach 1872, Dansereau 1957, Fosberg 1961, Mueller-Dombois & Ellenberg 1974; see Beard 1978 for a review). Probably because the term ‘formation’ was later used as part of formal syntaxonomic hierarchies of the American and Russian schools (compare Whittaker 1978 and Aleksandrova 1978) in very different ways, the term has largely been abandoned by the scholastic community or is used in an informal context. Although our ‘biomes’ are thus structural ‘formations’ in the original sense of Grisebach (1872), we prefer the former term.

This chapter introduces some of this information but mainly compares our units with those of other previous approaches and also makes certain comparisons (including climatic) across our biomes. This main focus is also applied to our bioregions that lie at a level between the biome and the vegetation types. Details on each biome are given in the respective chapters of this book.

1.2 Biomes of Southern Africa: Major Patterns

Southern Africa boasts a wide range of biomes. The relatively moist, mostly winter-rainfall region, encompassing the Fynbos Biome in the west and its drier climatic counterpart termed the Succulent Karoo Biome, forms the smallest of the world's six floristic kingdoms (Takhtajan 1986, but see Cox 2001), often draped over the Cape Fold Mountains and sandy lowlands of the southwestern Cape. The Succulent Karoo Biome of the Richtersveld, Namaqualand and the Little Karoo has not only the highest diversity of succulent plants in the world, but is the most species-rich semidesert on our planet. The summer-rainfall Savanna Biome of the north and east of the region represents the southern extension of the largest biome of Africa. The summer-rainfall Grassland Biome of the cooler, elevated interior is poorly represented elsewhere in Africa and is home to a wealth of species limited to southern Africa. The unique Indian Ocean Coastal Belt (IOC/B) of South Africa with its recurrent extent enclaves of forest represents the southernmost extent of coastal (sub)tropical forests of the wet, tropical and subtropical seaboard of East Africa. The Desert occupies a small extent of our mapping area in the extreme northwest but, importantly, forms the southern tip of the winter-rainfall domain of the Namib Desert as well as a summer-rainfall Gariep Desert with affinities to the central-north parts of the Namib Desert. The Albany Thicket Biome, with a combination of plant forms intermediate between Savanna, Nama-Karoo and Subtropical Forest, represents an unusual structural, floristic and evolutionary ancient type of note in the subcontinent. The mostly summer-rainfall Nama-Karoo Biome is possibly the least species-rich, yet it holds many intriguing relationships with its six directly neighbouring biomes. The Afrotemperate Forests in southern Africa are highly distinctive and are also characterised by their small and patchy occurrence over the wetter parts of the winter- and summer-rainfall areas of the region. They are clearly part of the global warm-temperate forest biome. Most of these patches are too small to be shown in Figure 3.2. The Subantarctic Tundra and Polar Desert Biomes on the Prince Edward Islands in the Southern Indian Ocean are discussed in Chapter 15 and are not referred to further in this chapter.

The two most cited sets of previous works on biomes in southern Africa are Rutherford & Westfall (1986, 1994) and Low & Rebelo (1996, 1998) following on the seminal work of Huntley
Figure 3.2 Biomes of South Africa, Lesotho and Swaziland.

(1984). The biome concept has been examined in some detail in Rutherford & Westfall (1994) and Rutherford (1997) and applied to southern Africa. In contrast to Low & Rebelo (1996, 1998), the criteria Rutherford & Westfall (1994) applied for a biome were explicit and derived from the globally applicable literature (e.g. Hansen 1962, Odum 1971, Smith 1974, Godman & Payne 1979).

Rutherford & Westfall (1994) emphasised that:

1. A biome is the largest land community unit recognised at a continental or subcontinental scale and therefore does not recognise any subsets of a biome as a ‘biome of lower rank’.

2. Biome patches should be of a viable and minimum size (also to acknowledge the zoological components of a biome) (about 20 km in shortest cross distance).

3. Biomes are defined primarily on combinations of dominant life or growth forms and not on the basis of taxonomic characteristics (floristic nor faunal) or nondominant elements.

4. Biomes are defined secondarily on the basis of major climatic features that most affect the biota, i.e. not climatic indicators that may happen to correlate with the biome but are ecologically insignificant or irrelevant.

5. Biomes do not include unnatural or major anthropogenic systems, although systems irreversibly changed by man (e.g. long-term, severe overgrazing) that are self-sustaining in their present state, are included.

The current work deviates only from the second and third criteria above largely because we are here deliberately biased towards vegetation and its floristic diversity. Only botanical elements are considered (with no consideration of faunal elements nor of their scale requirements—home ranges etc.). The biomes are made up of vegetation units defined on floristic criteria (not purely structural criteria) and no scale limitation was recognised (other than that the vegetation unit should be above the level of plant community). The biomes are partly derived from a bottom-up approach which accounts for the perfect match between biome boundaries and floristically determined boundaries. This should not distract from the broad yet distinctive floristic links with structurally determined biomes as shown by Gibbs Russell (1987), ultimately also by our approach. The biomes are also clearly in keeping with the climatic criteria of biomes and they
correlate with climatic parameters that are biologically meaningful (see below).

The current work recognises two biomes in addition to those of Rutherford & Westfall (1994) and Rutherford (1997). The first is the Albany Thicket Biome which Rutherford & Westfall (1994) referred to as unmannable ‘dwarf forest’ of the Eastern Cape and included in their Savanna Biome. This biome partly corresponds to the Low & Rebelo’s (1996) ‘Thicket Biome’, but the latter was much more extensive than the Albany Thicket Biome (including much of the Western Strandelveld; see Chapter 4 on Fynbos). The second newly distinguished biome is the much transformed IOCB which was mapped as Savanna by Rutherford & Westfall (1994) but, as also pointed out by them (p. 74), was regarded as not fully satisfactory in the area. In this area, the current work retains as Savanna Biome only the inland strip parallel to the IOCB. Given no constraints of scale, the present work also includes many groupings of azonal vegetation units, which are not regarded as part of any biome in zonal terms, but appear as biomes merged into the background on both (scale-limited) biome and bioregion maps. Many biome boundaries are different owing to the different criteria used and to availability of new information, yet many of the boundaries remain nevertheless broadly similar. The greatest relative change (increase) in area of biome compared to that of Rutherford (1997) is in the Desert and Afrotropical Forests. The most northerly and driest parts of the Succulent Karoo Biome of Rutherford (1997) in the vicinity of the lowest reaches of the Orange River are now regarded as part of a winter-rainfall Desert (although it is clear that at least some patches of the Succulent Karoo Biome will be upheld northwards in southwestern Namibia). Degrees of correspondence between the currently recognised biomes and other recent biome classifications are given in Table 3.1.

1.3 Biogeographical Approaches

There have been a number of other large-scale compartmentalisations into natural areas of our mapping area that approximate our biome scale.

White (1983) distinguished five phytchoria (phytogeographical units) in our region based on richness of their endemic floras at the species level. Degrees of correspondence between the biomes and the phytchoria of White (1983) are given in Table 3.2. There is fair correspondence between the Cape Phytchorion and the Fynbos Biome as well as between the Guineo-Congolian Phytchorion (Usambara-Zululand Domain) and the IOCB. White (1983) recognised most of the more mesic parts of the Grassland Biome as part of his Afromontane Phytchorion.

Gibbs Russell (1987) clearly showed that floristic links were closer between the Succulent Karoo Biome and the Fynbos Biome than between the Succulent Karoo and the Nama-Karoo Biomes. Linder et al.’s (2005) analysis divided our Savanna Biome into an eastern and northern form on the one hand and a Kalahari form (including western parts of the Central Bushveld Bioregion) on the other.

Siegfried (1989) provided a map of the biomes of our mapping region based on Rutherford & Westfall (1986) and for the savanna areas on Huntley (1984). The savanna areas here and in Huntley (1997) were divided into Arid Savanna and Moist Savanna Biomes. These two functionally important groupings are discussed further in the Savanna Chapter in this book.

Burgess et al. (2004) provided a map of the ecoregions of Africa and some of these units as well as some or their hierarchically higher units relate to our biome level. In this section we examine the relationship between their work and our biome work.

First, it is important to note that some of their terms have been different from those used by Burgess et al. (2004). They group their most detailed level units (ecoregions) into four main categories, (1) ‘Northern bioregions’, (2) ‘Central bioregions’, (3) ‘Eastern bioregions’, and (4) ‘Southern bioregions’ (see Table 2.2 on Bioregions). In a biogeographical framework they group ecoregions into ‘Bioregions’ which in turn are grouped into ‘Realms’. Within a ‘habitat’ framework they group ecoregions into ‘Sub-biomes’ which in turn are grouped into ‘Biomes’. Within our mapping area, they recognise only two ‘Bioregions’. Areas corresponding to our Fynbos and Succulent Karoo Biomes fall within a ‘bioregion’ called ‘Cape Floristic Region’ while the remaining area is part of a bioregion called ‘Eastern and Southern Africa’. Within our mapping area this ‘bioregion’ level, contrary to ours, generally lies above that of our biomes and, indeed, their biomes. It is unfortunate that Burgess et al. (2004) failed to be more explicit about their classification criteria. Their terminology shows a curious mixing of phytogeographical and vegetation-ecological systems.

Burgess et al. (2004) recognised six biomes in their mapping region:

The biome termed ‘Mediterranean Forests, Woodlands, and scrub’ comprises their ‘Albany Thickets’ (sic), ‘Lowland Fynbos and Renosterveld’ and ‘Montane Fynbos and Renosterveld’ bioregions and in South Africa these are not divided into sub-biomes. ‘Lowland Fynbos and Renosterveld’ and ‘Montane Fynbos and Renosterveld’ together closely approximate the extent of the Fynbos Biome (82%). There is some agreement regarding the core area of the Albany Thickets Ecoregion and the Albany Thicket Biome, but overall correspondence is only 33% (Table 3.3).

The biome termed ‘Deserts and Xeric Shrublands’ includes areas corresponding to our Desert, Succulent Karoo and Nama-Karoo Biomes as well as to two of our Savanna Bioregions, namely Eastern Kalamari Bushveld and Kalamari Duneveld. Their biome is not divided into

<table>
<thead>
<tr>
<th>Biome</th>
<th>Overlapping area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rutherford &amp; Westfall (1986)</td>
</tr>
<tr>
<td>Albany Thicket</td>
<td>0</td>
</tr>
<tr>
<td>Desert</td>
<td>0</td>
</tr>
<tr>
<td>Forests</td>
<td>23</td>
</tr>
<tr>
<td>Fynbos</td>
<td>76</td>
</tr>
<tr>
<td>Grassland</td>
<td>85</td>
</tr>
<tr>
<td>Indian Ocean Coastal Belt</td>
<td>0</td>
</tr>
<tr>
<td>Nama-Karoo</td>
<td>94</td>
</tr>
<tr>
<td>Savanna</td>
<td>82</td>
</tr>
<tr>
<td>Succulent Karoo</td>
<td>75</td>
</tr>
</tbody>
</table>
sub-biomes in South Africa. There is a close correspondence (in South Africa) between their ‘Nama Karoo Ecoregion’ and the Nama-Karoo Biome (91%) and there is also a reasonably close correspondence between the ‘Succulent Karoo Ecoregion’ and the Succulent Karoo Biome (77%).

The biome ‘Montane Grasslands and Shrublands’ corresponds generally to our Grassland Biome, but Burgess et al. (2004) include in their biome their ‘Maputaland-Pondoland Bushland and Thickets’ Ecoregion, which corresponds closely to our Eastern Valley Bushveld and Thukela Bushveld. With this anomaly excluded, there is an 88% correspondence with the Grassland Biome. They differentiate the high-altitude grassland of the Drakensberg from the rest of the grassland as an ‘Alpine Moorland’ sub-biome.

The biome termed ‘Tropical and Subtropical Grasslands, Savannas, Shrublands, and Woodlands’ corresponds generally to our Savanna Biome (with the notable exception of our Kalahari Bioregions and Zululand Lowveld areas). They differentiate their biome into two sub-biomes, namely ‘Acacia Savanna Woodland’ and ‘Mopane Woodland’.

Their biome called ‘Tropical and Subtropical Moist Broadleaf Forests’ corresponds approximately to our Afrotropical Forests together with the IIOCB. At the sub-biome level they separated an ‘Afromontane Forest’ from an ‘Eastern African Lowland Forest’

Using a cluster analysis of plant species distributions from a variety of sources, Linder et al. (2005) derived seven phytocoria within or entering our mapping domain. These are: (1) ‘Nama-Karoo’ in Namaqualand, most of the Karoo interior and southern Namibia; (2) ‘Cape’ in the Western and Eastern Cape Provinces and approximating the area of the Fynbos Biome; (3) ‘Kalahari’ in the northern parts of the Northern Cape Province and western parts of the North-West and Limpopo Provinces and extending through Botswana to cover most of central and northern Namibia; (4) ‘Karoo transition’ in scattered parts in the north of the Northern Cape and central Botswana; (5) ‘Eastern Karoo’ over most of the Free State and some adjoining areas in the North-West and Northern and Eastern Cape Provinces; (6) ‘Nama’ along the eastern seaboard east of the main escarpment from around East London northwards, including nearly all of KwaZulu-Natal and Mpumalanga, all of Gauteng and most of Limpopo Province; and (7) ‘Zambesian-central’ in the northeastern extremity of South Africa extending north of the Limpopo through the eastern half of Africa to northern Tanzania. Table 3.2 gives the degree of correspondence of these phytocoria with our biome units. There is good correspondence between the Cape Phytocorion and the Fynbos Biome and fair correspondence between the Eastern Karoo Phytocorion and the less mesic parts of the Grassland Biome. However, the Natai Phytocorion does not distinguish between Savanna, IIOCB and the more mesic parts of the Grassland Biome. Similarly, the Namib-Karoo Phytocorion does not distinguish between the Desert, Succulent Karoo and Nama-Karoo Biomes which Linder et al. (2005) suggest may be due to under-sampling and to the coarse resolution of their sampling.

### 1.4 Biome Modelling

Many other approaches to defining biomes include modeling. Equilibrium models for predicting biome distribution represented the first generation models where biome or biota distribution was assumed to be in equilibrium with climate. Holdridge (1947) was the first to attempt to provide a global classification and distribution of life zones (biomes) based on two climatic parameters. Holdridge’s classification (and some other similar schemes, e.g. Whittaker 1975) assumes that biomes act as an amorphous whole—in other words, they are not made up of individual components with different climatic sensitivities. A pioneer and remarkably comprehensive equilibrium model was constructed by Box (1981) who defined close
Table 3.3 Degree of correspondence (%) between the biomes and ecoregions of Burgess et al. (2004). *Full name: Tropical and Subtropical Grasslands, Savannas, Shrublands, and Woodlands.

<table>
<thead>
<tr>
<th>Biome and Ecoregion according to Burgess et al. (2004)</th>
<th>Albany Thicket</th>
<th>Desert</th>
<th>Forests</th>
<th>Fynbos</th>
<th>Grassland</th>
<th>IOCB</th>
<th>Nama-Karoo</th>
<th>Savanna</th>
<th>Succulent Karoo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deserts and Xeric Shrublands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kalahari Xeric Savanna</td>
<td>15</td>
<td>76.8</td>
<td>1.9</td>
<td>7.6</td>
<td>91.3</td>
<td>1.3</td>
<td>77.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nama Karoo</td>
<td>1.1</td>
<td>23.2</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Succulent Karoo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mangroves</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern African Mangroves</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mediterranean Forests, Woodlands, and Scrub</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Albany Thickets</td>
<td>37.8</td>
<td>2.4</td>
<td>84.7</td>
<td>0</td>
<td>0.9</td>
<td>0.1</td>
<td>9.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowland Fynbos and Renosterveld</td>
<td>32.8</td>
<td>2.5</td>
<td>0</td>
<td></td>
<td>0.9</td>
<td>0.1</td>
<td>2.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Montane Fynbos and Renosterveld</td>
<td>2.6</td>
<td>0.7</td>
<td>37.2</td>
<td>0</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Montane Grasslands and Shrublands</td>
<td>35.5</td>
<td>19.1</td>
<td>0.5</td>
<td>89.4</td>
<td>7.7</td>
<td>4</td>
<td>17.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drakensberg Alti-Montane Grasslands and Woodlands</td>
<td>27.8</td>
<td>14.3</td>
<td>0.4</td>
<td>38</td>
<td>2.5</td>
<td>3.7</td>
<td>10.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highveld Grasslands</td>
<td>7.8</td>
<td>4.8</td>
<td>0.1</td>
<td>5.2</td>
<td>0.3</td>
<td>3.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maputaland-Pondoland Bushland and Thickets</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropical and Subtropical Grasslands, Savannas*</td>
<td>13.8</td>
<td>2.1</td>
<td></td>
<td></td>
<td>40.2</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Kalahari Acacia-Baikiaea Woodlands</td>
<td>7.6</td>
<td>6.2</td>
<td>0.9</td>
<td>26.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern African Bushveld</td>
<td>6.2</td>
<td>6.2</td>
<td>0.9</td>
<td>26.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zambeziand and Mopane Woodlands</td>
<td>7.6</td>
<td>6.2</td>
<td>0.9</td>
<td>26.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropical and Subtropical Moist Broadleaf Forests</td>
<td>10.4</td>
<td>64.2</td>
<td>1.8</td>
<td>0.1</td>
<td>86.8</td>
<td>0</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knyana-Amatole Montane Forests</td>
<td>9</td>
<td>5.7</td>
<td>0</td>
<td>59.4</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maputaland Coastal Forest Mosaic</td>
<td>1.3</td>
<td>58.5</td>
<td>1.8</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Interest in biome models as mentioned above comes to a large extent from the need to estimate likely changes in carbon stores in the terrestrial biosphere, as a consequence of atmospheric carbon dioxide increase and the associated changing climate (Cramer 2002). In other words, there is likely less interest in the precision of boundaries of biomes and the identity of small but floristically important biomes such as the Succulent Karoo. It has also been recognised in some global models that shrubland biomes are more difficult to predict (Woodward et al. 2004).

Clustering climatic ranges of plant taxa have been used to produce 'Bioclimatic Affinity Groups' (Laurent et al. 2004), resulting in the co-occurrence of several such units in the same area. But such multiringing units were not synthesised into units of vegetation assembly.

Biomes and other categories have limitations depending on purpose. 'Categories such as that of ecoregions tend to become self-fulfilling prophecies when experimental designs assume their validity instead of testing their usefulness' (Magnusson 2004). Also, the longer-term identities of biome units have to be questioned where there is ample evidence that biomes in the past have not moved as a whole in response to climate change (Huntley 1991) and most models of the effects of future climate change to 100 different plant types and the climatic tolerance ranges of each in terms of an array of climatic variables. He used these to map the combinations of these types globally with reasonable success at the macroscale. A similar, but more practically simplified 'functional group' approach was more formally applied in the BIOME foundation model (Prentice et al. 1992), in which 13 functional groups of plants were defined and related to four major bioclimatic controls. The results for the area of South Africa partly matched some of the biomes, but were at variance with a number of others. Subsequent models included coupled models which derive vegetation type (and structure) and biogeochemical fluxes. Examples include BIOME3 (Haxeltine & Prentice 1996) incorporating various physiological and ecosystem processes (see Hallgren & Pitman 2000 for a critical evaluation). This model has evolved into BIOME4, which attempts to cover the diversity of biome types better (Cramer 2002). Choice of climatic variables is crucial. Leemans (1997) observed that the more superior global vegetation models all included a realistic water balance and/or seasonality. Despite the application of many forms of a priori-defined functional types above, defining functional types remains a 'major problem' and 'experiments or natural perturbations may be the only approach which can differentiate functional types; structure may not be a reliable key' (Woodward & Cramer 1996).
change expect species to respond independently of their currently associated species, e.g. see Iverson et al. (2004).

1.5 How the Biomes Compare

More detailed descriptions and considerations of each biome are given in the introductory sections of each biome chapter. Here we concentrate on comparisons across biomes.

The biomes are highly disparate in size. Relative areas of the biomes are given in Figure 3.3. There are three large biomes, namely Savanna, Grassland and Nama-Karoo, together accounting for almost 80% of the total area, while Desert and Afrotemperate Forest together account for less than 1% of the area.

Albany Thicket has the greatest diversity of biome neighbours and borders on seven other biomes (Figure 3.4). This, together with the highly dissected nature and considerable length (> 15 000 km) of the perimeter, allows for possibly high species diversity collectively along this ecotone. Desert borders on the fewest biomes within South Africa (Succulent Karoo and Nama-Karoo), which is what would be expected from the most climatically extreme biome. Just over 40% of potential contacts between biomes in the simplified map (see Chapter 2) do not occur in the region (Figure 3.4). Thus there is little potential exchange of flora between, for example, the Grassland and Succulent Karoo Biomes. Only three of the biomes (Nama-Karoo, Grassland and very marginally Savanna) do not border on an ocean (or at larger scale on the vegetation of the coastal strips; Chapter 14). Despite Afrotemperate Forest accounting for the smallest biome area of only 0.3% (Figure 3.3), it has the third longest boundary with biomes in the region (Figure 3.4), illustrating its highly fragmented state. More than two thirds of the land boundary of the Succulent Karoo is shared with Fynbos. Much of this interface is highly irregular, thus possibly promoting some floristic intermingling between these two biomes over time (see also below on sharing of taxa). More than half the boundary of Desert borders on Succulent Karoo (in South Africa), while almost half of that of Savanna borders on Grassland.

Boundaries between biomes vary from sharp to very gradual. Examples of sharp boundaries between biomes include those sometimes over only tens of metres between Fynbos on parts of the Cape Fold Mountains and the Succulent Karoo at lower altitude. More intermediate boundaries of a few kilometres wide are often found between the Succulent Karoo and Nama-Karoo Biomes. Very gradual transitions of tens of kilometres can be found, e.g. in some parts of the southern Kalahari between the Nama-Karoo and Savanna Biomes. In a few isolated cases, membership of a biome is equivocal, for example, for some vegetation types at the interface between the Sub-Escarpment Savanna and Sub-Escarpment Grassland of KwaZulu-Natal.

Most of the biome units of this study are incomplete and continue north of the political boundaries of this work. These are: Desert, Afrotemperate Forest, Grassland, IOCB, Nama-Karoo, Savanna and Succulent Karoo. Only Albany Thicket and Fynbos are fully circumscribed within our geographical area. Savanna has by far the longest border with other unmapped savanna to the north of our region (Figure 3.4).

The number of vegetation units per biome varies widely (Figure 3.5a) and is roughly in proportion to the floristic diversity of the biome. Hence the Fynbos Biome with the highest number of vegetation units (119) also has the highest number of species and a high proportion of endemic species (Gibbs Russell 1987). The Nama-Karoo Biome with only 14 vegetation units is also generally species-poor in comparison to other biomes. The IOCB may appear to be somewhat under-represented in terms of number of vegetation types currently recognised, yet on a unit area basis at 0.5 vegetation units per 1 000 km², it is intermediate between Savanna and Albany Thicket (Figure 3.5b). Although the diversity and the number of vegetation types in the Desert Biome is probably boosted by almost 90% of its types bordering directly on the relatively species-rich Succulent Karoo Biome, the relatively high number of types in the biome may also reflect a treatment at a greater level of detail. At the same time, the somewhat lower number of vegetation types per unit area in the Fynbos Biome probably reflects the significant under-sampling in the biome. The mean area of vegetation types per biome is by far the greatest in Nama-Karoo and smallest for Afrotemperate Forest (Figure 3.5c). The vegetation types in Desert and Fynbos are only marginally larger than those in Afrotemperate Forests, again emphasising the high species diversity and its level of geographical clustering in Fynbos (see above regarding detail in Desert).

Gibbs Russell's (1987) analysis of the species (and infraspecific taxa) richness of those biomes compatible with those of this book (and omitting biomes that were included in her analysis north of our mapping area) showed the Fynbos Biome to be the most rich with 7 316 taxa (currently with biome edges including almost 9 000 taxa) and about 52% of this amount in Grassland Biome and 29% in the Succulent Karoo Biome. About 67% of Fynbos Biome taxa, 28% of Grassland Biome taxa and 29% of Succulent Karoo Biome taxa were endemic. There was greatest sharing of taxa between the Succulent Karoo and Fynbos Biomes and least sharing of taxa between the Grassland and Succulent Karoo Biomes. Across South Africa, it has been found that numbers of alien and invasive species are significantly correlated with indigenous plant species richness (Richardson et al. 2005).

Using the biomes as defined in this book (but also extended to cover Namibia and Botswana), Chesselet et al. (2003) analysed the distribution of the 1 663 species of Mesembryanthemaceae, one of the most important families in our region. For the biomes compatible with our mapping area, by far the most species (871)

**Figure 3.3** Relative proportions of areas of the biomes.
<table>
<thead>
<tr>
<th>Biome</th>
<th>Albany Thicket</th>
<th>Desert</th>
<th>Forests</th>
<th>Fynbos</th>
<th>Grassland</th>
<th>Indian Ocean Coastal Belt</th>
<th>Nama-Karoo</th>
<th>Savanna</th>
<th>Succulent Karoo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forests</td>
<td>649</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fynbos</td>
<td>5,814</td>
<td></td>
<td></td>
<td></td>
<td>2,459</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland</td>
<td>2,519</td>
<td></td>
<td>9,765</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indian Ocean Coastal Belt</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nama-Karoo</td>
<td>2,993</td>
<td>361</td>
<td></td>
<td>448</td>
<td>9,600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savanna</td>
<td>2,070</td>
<td></td>
<td>7,045</td>
<td>273</td>
<td>18,807</td>
<td>3,737</td>
<td>6,660</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Succulent Karoo</td>
<td>1,555</td>
<td>513</td>
<td></td>
<td>8,949</td>
<td></td>
<td>2,354</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Northern border       | 507            | 25     | 27      | 239    | 3,004     |                          |            |         |                 |
| Ocean                 | 403            | 12     | 76      | 1,442  | 879       | 3                        | 455        |         |                 |

Figure 3.4 Lengths (km) of shared boundaries between biomes. Black squares indicate no contact between biomes. *Forest patches touching or surrounded by Indian Ocean Coastal Belt were subsumed into the Indian Ocean Coastal Belt.

occur in the Succulent Karoo, a large number (382) in the Fynbos Biome with lower numbers in the Albany Thicket and Grassland Biomes. The IOCB harbours very few (8), but together with the other above-mentioned four biomes each has 75% or more (up to 93% for Fynbos Biome) endemic to the respective biome.

Comparisons of aspects relating to conservation status of biomes are found in Chapter 16.

1.6 Climatic Relations of Biomes

The general climate of each biome (i.e. averaged over the entire area of the biome and, therefore, representing only a central tendency for a biome) is summarised in the climate diagrams in Figure 3.6. Afrotropical Forests and the area of IOCB experience the highest rainfall. The western parts of the Fynbos Biome and, in the drier areas, the Succulent Karoo Biome have a generally winter-rainfall regime. The Nama-Karoo experiences relatively low levels of rainfall that are concentrated in late summer and early autumn. The Grassland Biome is climatically similar to Savanna but with lower temperatures. The Albany Thicket has a greater and more pronounced bimodal (summer-autumn) rainfall than the Nama-Karoo. The coefficient of variation in annual precipitation is the lowest in the IOCB and the highest in the arid biomes such as the Succulent Karoo and Nama-Karoo Biomes. The number of frost days per year varies from zero in the IOCB to a maximum in the Grassland Biome. The mean annual potential evaporation is the lowest for the IOCB, with high values in the Nama-Karoo, Succulent Karoo and Savanna Biomes. Note how the IOCB occupies the lower extreme (i.e. moderate) for a number of key climatic variables.

Decision Trees have been used to classify biomes at continental scales (Lotsch 1999). Ellery et al. (1991) used a Decision Tree to present the biomes of Rutherford & Westfall (1986) climatically. Similarly, we derived a more specific and diagnostic climatic explanation of the current biomes from a Classification and Regression Tree using the CART method in S-Plus (univariate splits; Clark & Pregibon 1993 and discussion in Hargrove & Hoffman 2005; Figure 3.7). A simpler, more parsimonious, climatic explanation of the biomes was derived using a Hand Constructed Linear Decision Tree (see Murthy 1998) with multivariate splits but with slightly lower overall predictive accuracy (Figure 3.9). The climatic parameters used were deemed biologically meaningful and were: Mean minimum temperature of the coldest month ( Tmin), heat units (HTUn), annual mean evapo-
minimum temperatures (level depending on evaporation) and a lower number of soil moisture days in winter (especially in areas of lower annual rainfall). Albany Thicket generally has a moderate number of soil moisture days in summer with moderate levels of evaporation as well as high minimum temperatures (declining with decreasing soil moisture days in winter). Fynbos and Succulent Karoo share some of the climatic attributes of Albany Thicket but differ from it in having lower minimum temperatures (and increasing with number of soil moisture days in winter). Fynbos has a greater number of soil moisture days in winter combined with a fewer number of heat units than in Succulent Karoo. The climatic derivation of Nama-Karoo is in two parts. The southwestern part of the Nama-Karoo has a relatively low number of soil moisture days in summer and moderate minimum temperatures. The northeastern part of the Nama-Karoo shares some of the climatic attributes of Savanna but differs from it in having lower minimum temperatures (declining in areas with higher evaporation).

CART performed between 0.2 and 9.8 percentage points better than the Hand Constructed Linear Decision Tree for seven of the biomes (Table 3.4). However, it was 16.2 and 17.1 percentage points worse for the Desert and IOCB, respectively. The linear extent of these two units was better reflected by the Hand Constructed Linear Decision Tree. Least adequately described climatically by both methods was the Albany Thicket Biome with less than 66% of its area predicted correctly. The biomes as mapped by CART are given in Figure 3.8 which also shows which areas (almost always on the margins) were incorrectly mapped. The correctly predicted areas from climate, therefore, reflect almost all of the core areas of the biomes and most of the error is limited to the transitional areas between biomes.

Climatic relations with biomes are rarely tested experimentally. In a limited study by Agenbach et al. (2004a), using reciprocal transplants of species across a boundary between the Fynbos and Succulent Karoo Biomes, it appeared that at least some Fynbos species were environmentally (including soils) limited, whereas at least some Karoo species may be limited in their distribution by fire and biotic interactions and not by their environment at this biome interface. It is thus clearly demonstrated, from local studies, that climate is not the sole determinant of vegetation distribution (Agenbach et al. 2004b). There may be boundaries between other biomes in the region which are not (only) determined by climate. The interface between our Savanna and Grassland Biomes may be one such possibility (Bond et al. 2003, 2005).

Threats of climatic change on a biome scale are usually discussed within each biome chapter, at least in terms of change in temperature and water availability. Possible effects of future levels of solar ultraviolet-B radiation on plants in South Africa are discussed by Musil et al. (1999). Those areas of South Africa with the highest current levels of UV-B radiation (Gariep Desert, Bushmanland and Kalahari Duneland) should remain so but at even higher levels at around the middle of the 21st century.

1.7 Southern African Biomes in Context of Walter’s Scheme

There are several global biome schemes available (see above for ample references), but an alternative one deserves particular attention not only because of its detail of elaboration (the actual map is accompanied by a series of monographs featuring the biome patterns in the light of ecophysiology and community ecology), but also due to its conceptual handling of zonality, intrazonality and azonality—one of the leading principles of the classification philosophy underlying our Map. It is the system
of zonobiomes of Heinrich Walter (Walter 1962, 1968, 1973, 1976, Walter & Box 1976, Walter & Breckle 1991, etc.). Walter (for references see above) subdivided the terrestrial surface of the earth into nine zonobiomes, underpinned by the zonal character of climate (Table 3.5). Recognising the occurrence of broad transitions between these units, he further introduced the concept of zono-ecotones, calling them ‘tension zones’ between two zonobiomes in which one vegetation type is being replaced by another...’ (Walter & Box 1976).

According to the insert map in Walter & Box (1976) the territories of South Africa, Lesotho and Swaziland fall within four zonobiomes (II, III, IV and V) and two zono-ecotones (IV-III and III-II). The only direct match between our biome system and that of Walter is the identity of the Fynbos Biome and the zonobiome IV. Walter & Box (1976) classified the Fynbos Biome (explicitly) as one of the sub-zonobiomes of the global mediterranean biome (sometimes also called ‘ethesial biome’). Our Succulent Karoo corresponds to zono-ecotone IV-III and partly to the zonobiome III, most probably through the ‘sub-zonobiome with winter-rainfall’ according to Walter & Box (1976). Walter’s zonobiome III in southern Africa further covers the Desert Biome and western and central parts of the Nama-Karoo Biome. The eastern Nama-Karoo and Kalahari are classified by Walter as zono-ecotone III-II. The mapped extent of the zonobiome V in southern Africa is too generous as it comprises most of the southern Cape, Albany Thicket and the IOCB. The last-named should be best served as part of the zonobiome I (generally underestimated on the East African coast by Walter’s classification), and the Albany Thicket as part of zono-ecotone I-III (as done for parts of Kenya/Somalia or Venezuela/Colombia). An interesting rare contact between two zonobiomes can be observed along the South Coast—meeting of the zonobiome IV (mainly linked to western oceanic coasts) with the zonobiome V (mainly linked to eastern oceanic coasts), forming a mosaic of the zono-ecotone V-IV (see also Walter & Box 1976). The extent of the zonobiome II (seasonal tropics), as mapped by Walter in southern Africa to encompass all of our Savanna Biome (except for Kalahari) and the Highveld plateau and the Drakensberg Mountain ranges, is also in need of modification—the primary temperate grasslands of our Grassland Biome should rather be re-classified as zono-ecotone II-VII or perhaps zonobiome VII (in the same way as the South American pampas).

2. Bioregions

A bioregion is a composite spatial terrestrial unit defined on the basis of similar biotic and physical features and processes at the regional scale. In this work, the intermediate level of vegetation organisation between that of vegetation type and biome, is the bioregion level.

The term ‘bioregion’ has been used less frequently than ecoregion (see below) and in very different ways, also globally. In South Africa, Rowe-Rowe & Taylor (1996) used the term bioregion for nine regions in KwaZulu-Natal, seven based on the original bioclimatic regions of Phillips (1973), with the remaining two bioregions deduced from Acocks (1975) and Camp (1995). The resultant units are generally at a level between our vegetation units and our bioregions for the province. The bioregions of Rowe-Rowe & Taylor (1996) have also been used by others (e.g. Avery et al. 2002). In a very different sense, Laurie & Silander (2002) use the term bioregion to equate to the large Cape Floristic Region. In Australia, the term bioregion has been used with the next more detailed level termed ‘sub-bioregion’ (Pullar et al. 2004) which, judging by the scale of these ‘sub-bioregion’ units, may approximate the level of our vegetation units. As has been pointed out in Section 1.3, the ‘bioregions’ of Burgess et al. (2004) are used at a hierarchical level even higher than that of our biomes. We do not refer further to their ‘bioregions’ here. It is clear that the term ‘bioregion’ has been used very loosely in the past. We hope that the current treatment will go some way to stabilising the usage of the term and concept.

Although our bioregions (Figure 3.10) represent a level intermediate between biome and vegetation unit, the IOCB is not divided into bioregions within South Africa but can be regarded as approxi-
Table 3.5 The scheme of Walter’s zonobiomes (after Walter 1976, Walter & Box 1976, Walter & Breckle 1991, Box 2002). Simplified names for the zonobiomes were introduced.

<table>
<thead>
<tr>
<th>Zono-biome</th>
<th>Name</th>
<th>Characteristics</th>
<th>Zonal Vegetation</th>
</tr>
</thead>
</table>
| I         | Equatorial         | • diurnal climate (mean of daily temperature amplitudes is bigger than the difference between the means for temperatures of the warmest and coolest months)  
            |                     | • rainfall usually high (above 100 mm per month), mainly aequinoctial maxima     | Tropical rain forest              |
|           |                    | • zone between approx. 10° N and 5–10° S                                        |                                   |
| II        | Tropical           | • clear colder and warmer period                                                | Tropical and subtropical savannas |
|           |                    | • strong summer rainfall and extreme drought during colder period of the year (the drought period becomes longer and precipitation lower with increase of distance from the equator); fire-prone | Seasonal tropical forests         |
| III       | Arid-Subtropical   | • desert climate: very low precipitation—usually below 200 mm, in extreme desert below 50 mm; high insolation and light reflection; extreme daily temperature amplitude | Deserts                           |
|           | Mediterranean      | • winter rain and summer drought; usually on west oceanic coasts, between 35° and 40° in both hemispheres; fire-prone | Semidesert shrublands             |
| IV        | Mediterranean      | • without pronounced cold winter period; ample year-round precipitation, especially high in summer; usually maritime climate due to prevailing location on eastern seaboard | Evergreen microphyllous shrublands |
| V         | Warm-Temperate     | • short cold (often with snow) period in winter (often lacking in oceanic regions) and warm summers; sufficient cyclonic precipitation | Seasonal evergreen forests        |
| VI        | Typical Temperate  | • Extreme temperature differences between summer and winter due to continental position; usually low precipitation (bordering on desert climate); some ecosystems fire-prone | Evergreen broad-leaved forests    |
| VII       | Arid-Temperate     | • Cool and wet summers and very cold winters lasting sometimes more than half of the year; absent in southern hemisphere; fire-prone | Deciduous broad-leaved forests    |
| VIII      | Cold-Temperate     | • Cold and wet summers and extremely cold winters; evenly distributed precipitation over year; very short vegetation season | Climatic grasslands (steppe, prairie, pampas) |
| IX        | Arctic-Antarctic   | • Dwarf arctic shrublands (tundra)                                              | Boreal conifer forests (taiga)    |

mating a bioregion of the much larger belt that extends northwards into East Africa. The Albany Thicket Biome is not easily divided into bioregions and in effect has some properties that agree with those of the bioregion level. These two areas have, therefore, been included in some of the comparisons below. Afrotropical Forests were not included owing to their highly fragmented and widely dispersed nature relative to the scale of the bioregion.

2.1 Bioregional Correspondece

There is generally a very poor correspondence of the 16 ‘subdivisions of biomes’ of Westfall & Van Staden (1996) with our bioregions. They simply used mean annual precipitation to subdivide the biomes of Rutherford & Westfall (1994). Our bioregions also differ in many respects from the phytochorial subdivisions of southern Africa where the highest level phytocoenon is subdivided first into regions and more finely into domains (Werger 1978).

The bioregion also differs from the ecoregion. However, since the term ecoregion was coined in 1967 (Omernik 1987), it has been used very differently by different sources, complicating the comparisons. Ecoregions, through their availability, have been widely applied for a diversity of purposes (e.g. for units for which plant species diversity could be determined; Kier et al. 2005). Ecoregions have also been used to spawn new units such as combining them with Plant Hardiness Zones to form Plant Adaptation Regions (Vogel et al. 2005).

Ecoregions have often been defined on the basis of a dissection of physical environmental space, i.e. the ecoregion boundaries.

Table 3.4 Proportion of each biome correctly predicted (%) by the climatic models using a Hand Constructed Linear Decision Tree (HCLDT) with multivariate splits and a Classification and Regression Tree using the CART method in S-Plus (univariate splits).

<table>
<thead>
<tr>
<th>Biome</th>
<th>HCLDT</th>
<th>CART</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albany Thicket</td>
<td>63.2</td>
<td>65.1</td>
</tr>
<tr>
<td>Desert</td>
<td>86.6</td>
<td>70.4</td>
</tr>
<tr>
<td>Fynbos</td>
<td>70.4</td>
<td>80.2</td>
</tr>
<tr>
<td>Grassland</td>
<td>77.0</td>
<td>85.1</td>
</tr>
<tr>
<td>Indian Ocean Coastal Belt</td>
<td>91.8</td>
<td>74.7</td>
</tr>
<tr>
<td>Nama-Karoo</td>
<td>85.6</td>
<td>85.8</td>
</tr>
<tr>
<td>Savanna</td>
<td>79.9</td>
<td>86.7</td>
</tr>
<tr>
<td>Succulent Karoo</td>
<td>66.7</td>
<td>74.8</td>
</tr>
</tbody>
</table>
are primarily determined by climate (which 'solves the problem with using other components that are subject to rapid change, such as biota'—Bailey 2004). Ecoregions are sometimes also used at multiple hierarchical levels—e.g. in Australia (Pullar et al. 2004) and in the USA with four levels of ecoregion from the broadest level (Level I) to detailed Level IV (Omernik 2004).

More coherent and biotically inclusive are the ecoregions of Olson et al. (2001) although even within this same lineage, the ecoregions have changed over time (e.g. from Olson & Dinerstein 1998 to Burgess et al. 2004). They have nevertheless attracted a strong following. They have also attracted some criticism e.g. as they have been applied in Indonesia (Jepson & Whittaker 2002).

Our concept of bioregion and that of ecoregion of Olson et al. (2001) are similar. Both stress that biota are centrally important including distinct assemblages of species. Both are pragmatic units for practical application of conservation and other measures.

However, our bioregions differ from these ecoregions within our mapping area in (1) mapping scale with more detailed units, (2) underpinning by another layer of more detailed sets of biotic assemblages, (3) greater consolidation and coherency of associated climate (in some cases), (4) possible bias toward vegetation and, (5) we believe, more consistent geographical application of the concept. These differences are elaborated below.

Figure 3.7 Computer printout of the climatic explanation of the biomes from a program for a Classification and Regression Tree using the CART method in S-Plus. TMIN: mean minimum temperature of the coldest month; HTUNT: heat units; EVAP: annual mean (potential) evaporation; SMDW: soil moisture days in winter; SMDS: soil moisture days in summer. AT Albany Thicket, CB Indian Ocean Coastal Belt, D Desert, FY Fynbos, G Grassland, NK Nama-Karoo, SK Succulent Karoo, SV Savanna. Y meets condition, N does not meet condition.

Figure 3.8 Map of the biomes as predicted by the Classification and Regression Tree using the CART method in S-Plus. Areas in white within our domain represent areas of error. AT Albany Thicket, CB Indian Ocean Coastal Belt, D Desert, FY Fynbos, G Grassland, NK Nama-Karoo, SK Succulent Karoo, SV Savanna.
Figure 3.9 Climatic explanation of the biomes using a Hand Constructed Linear Decision Tree. TMIN: mean minimum temperature of the coldest month; HTUNT: heat units; EVAP: annual mean (potential) evaporation; SMDW: soil moisture days in winter; SMDS: soil moisture days in summer. Percentages are the proportion of the biome that was correctly predicted by the decision tree.

The average size of Olson et al.'s (2001) ecoregions globally is about 150 000 km² but is about 102 000 km² within our mapping area. Our bioregions are more finely divided with an average area of 54 000 km², i.e. roughly twice as detailed compared to the ecoregions.

In contrast to the ecoregions, the bioregions are underpinned by another level of biotic detail, namely vegetation types that make up each bioregion. There are on average over 10 vegetation types per bioregion, with the vegetation types (excluding azonal types) averaging just 3 100 km² in area.

Our bioregions follow a principle of regional consolidation, which recognises that a region should not consist of a widely dispersed array of areas and should rather be or tend towards being cocontinuous. In this sense it is similar in practice to one of the requirements for an ecoregion of Bailey (2004), namely to circumscribe contiguous areas. At the same time this was fitted to a coherent climatic profile for each bioregion. In this way we try to avoid recognising, for example, a 'Montane fynbos and renosterveld' Ecoregion (Burgess et al. 2004) which stretches as linear discontinuous bands from near Port Elizabeth in the east via the Cape Peninsula and the Roggeveld Escarpment to the Kamiesberg area in Namaqualand, and covers a wide range of climate. Climate tends to be more uniform within the more consolidated areas. Our principle of spatial consolidation for a bioregion also accepts that, despite distinct floristic differences between vegetation types in a bioregion, there are often also numerous species shared between adjacent vegetation types in a region.

Bioregions are focussed on plant diversity, i.e. on the floristic composition of their component vegetation types (and presum-
Figure 3.10 Bioregions of South Africa, Lesotho and Swaziland.
2.2 The Bioregions

As emerges from the above, the ecologies in the Southern Africa region are diverse and complex, reflecting the region's varied climatic, geographic, and geological conditions. The Southern African Desert Bioregion, for example, contains a variety of ecosystems, from the arid deserts of Namibia to the subtropical savannas of South Africa. The Drakensberg Highveld Bioregion, on the other hand, is characterized by its high altitude and cooler climate, supporting a rich flora and fauna. The Cape Floristic Region, one of the richest biodiversity hotspots in the world, is home to thousands of plant species that are found nowhere else.

These bioregions are not isolated; they interact with each other, influencing the distribution of species and the overall biodiversity of the region. Understanding these bioregions is crucial for effective conservation and management strategies. The conservation of these bioregions is essential for maintaining the region's ecological integrity and supporting human well-being.

In conclusion, the bioregions of Southern Africa are diverse and complex, reflecting the region's varied environmental conditions. Understanding these bioregions is crucial for effective conservation and management strategies, ensuring the region's ecological integrity and supporting human well-being.
fynbos and renosterveld types in places (as have ecoregions of Burgess et al. (2004) within this biome). Thus the largest bioregion in the biome is the Eastern Fynbos-Renosterveld Bioregion which stretches from around George to Port Elizabeth and Grahamstown. To the northwest and west of this region is the Western Fynbos-Renosterveld Bioregion which mainly circumscribes the higher-elevation outcrops of fynbos in the Little Karoo from Uniondale in the east to the Touws River area in the west (except those associated with the Langeberg).

The floristic heartland of the Fynbos Biome is probably the Southwest Fynbos Bioregion. This is a sandstone (occasionally granite) and sand-defined unit and includes the mountains of the Kogelberg, Du Toitskloof area, Rivierseeonden Mountains as well as the Cape Peninsula, Bredasdorp Mountains (including Potberg) and the fynbos of the sandveld on flats such as in the Hopefield District. This bioregion is flanked by two renosterveld bioregions. The West Coast Renosterveld Bioregion encompasses all the renosterveld areas to the west of the mountain chain from around Eendekuil/Piketberg in the north to Somerset West in the south. The East Coast Renosterveld Bioregion stretches from Bot River/Caledon in the west to the vicinity of Albertinia in the east and includes the renosterveld areas of the Breede River Valley. Positioned largely between the East Coast Renosterveld Bioregion and the coastal South Coast Fynbos Bioregion mainly on the flats between Bredasdorp and Mossel Bay. Immediately north of the East Coast Renosterveld Bioregion is the Southern Fynbos Bioregion which constitutes the sandstone mountain areas of the Langeberg from Worcester in the west to the vicinity of Herbertsdale in the east and includes higher sandstone outcrops in the Montagu area.

The second largest bioregion in the Fynbos Biome is the Northwest Fynbos Bioregion which covers the sandstone and sand areas of the biome from the Hex River Mountains in the south through the Cederberg to the Bokkeveld Escarpment near Nieuwoudtville in the north. Also included here is the Piketberg Mountain and sand patches north of Aurora on the flats to the Vredendal District and some patches northwards embedded in the Namaquaand Sandveld Bioregion of the Succulent Karoo Biome. Inland of these patches and at much higher altitudes is the smallest bioregion of the biome, namely the Namaquaand Cape Shrublands Bioregion. Most of this bioregion is centred in the Kamiesberg area of Namaqualand. The remaining two bioregions in the Fynbos Biome are strictly coastal and of very limited area. The larger unit is the West Strandveld Bioregion which is centred in the Saldana Bay area and extends northwards to Lambert’s Bay and southwards to the Cape Flats bordering False Bay. The South Strandveld Bioregion occurs in patches from Walker Bay (Hermanus) in the west to the vicinity of Oyster Bay (near Port Elizabeth) in the east.

The Succulent Karoo Biome is made up of six bioregions. The Richtersveld Bioregion covers most of the hilly and mountainous Richtersveld except for the desert areas near the Orange River. It contains the largest number of vegetation types despite having the second smallest area. The Namaquaand Hardgeved Bioregion covers much of the higher-lying hilly area between Steinkopf in the north and Nuwerus in the south. To the west of this bioregion lies the Namaquaand Sandveld Bioregion, which is the lowest-lying bioregion occurring along the coastal plains from the Richtersveld in the north to the vicinity of the lower Olifants River in the south. The Knersvlakte Bioregion is the smallest bioregion and also lies at low altitude, but further inland than the last-mentioned. It is found mainly on the plains south of Kliprand in the north southwards to around Vanrhynsdorp. The Trans-Escarpment Succulent Karoo contains the fewest number of vegetation types and is the highest-lying bioregion, occurring on the upland plateau roughly from the Loeriesfontein area in the north to the vicinity of Sutherland in the south. The Rainsheaf Valley Karoo Bioregion is the largest bioregion and includes the basins of the Tanqua, Robertson and Little Karoo as well as some areas north and east of the Swartberg.

### 2.3 Climatic Relations of Bioregions

Bioregions are divided into climatic entities with relatively similar climates within the bioregion and usually distinct climatic differences between bioregions. The following key climatic differences between the bioregions are identified.

In the Fynbos Biome, the Namaquaand Cape Shrublands Bioregion has the lowest MAP by a clear margin (Figure 3.13). The West Strandveld and Karoo Renosterveld have a similar, relatively low MAP but the former experiences almost no frost in contrast to the latter which has the highest incidence of frost in the biome. The Eastern Fynbos-Renosterveld Bioregion has the most evenly spread rainfall throughout the year. Less evenly spread rainfall is found in the Southern Fynbos, South

---

**Figure 3.13** Climate diagrams of the bioregions grouped according to biome. Blue bars show the median monthly precipitation. The upper and lower red lines show the mean daily maximum and minimum temperature, respectively. MAP: Mean Annual Precipitation; APCV: Annual Precipitation Coefficient of Variation; MAT: Mean Annual Temperature; MFD: Mean Frost Days (days when screen temperature was below 0°C); MAPE: Mean Annual Potential Evaporation; MASMS: Mean Annual Soil Moisture Stress (% of days when evaporative demand was more than double the soil moisture supply).
Strandveld and South Coast Fynbos Bioregions which have a decreasing MAP in the order given. The remaining five bioregions in the biome have a clear winter-rainfall pattern with low to very low rainfall in summer. Of these, the Southwest Fynbos Bioregion has the highest MAP followed by West Coast Renosterveld, East Coast Renosterveld and Western Fynbos-Renosterveld. The Northwest Fynbos is distinguished from these last-mentioned by its high annual potential evaporation.

In the Succulent Karoo Biome, the Namaqualand Sandveld has the lowest MAP, with the Rainshadow Valley Karoo and the Trans-Escarpment Succulent Karoo Bioregions having the highest MAP. The Trans-Escarpment Succulent Karoo has a much higher incidence of frost than the Rainshadow Valley Karoo. This incidence of frost approaches that of the adjacent Nama-Karoo Biome. The Namaqualand Hardevel Bioregion has lower temperatures and more frost days than the Knysnvlakte Bioregion. Climatic data for the Richtersveld Bioregion are too sparse to make specific comparisons with the other bioregions. The Southern Namib Desert has a clear winter rainfall and relatively ‘reliable’ pattern of frequent fog in contrast to the Gariep Desert with precipitation ranging from even less predictable rainfall transitional between winter and summer to nearly summer-autumn rainfall; it experiences no fog. The effects of these climatic differences are so profound that these bioregions could probably each be raised to the level of biome. In the Nama-Karoo, the Bushmanland Bioregion has considerably lower MAP than the other two bioregions. Of the other bioregions, the Upper Karoo Bioregion has about twice as much frost as the Lower Karoo.

Within the Grassland Biome, the Drakensberg Grassland Bioregion has much lower rainfall, with a high incidence of frost compared to the other grassland bioregions. Dry Highveld Grassland has significantly lower precipitation than Mesic Highveld Grassland. Although MAP is similar between Mesic Highveld Grassland and Sub-Escarpment Grassland, the latter differs in its higher temperatures and fewer frost days.

In the Savanna Biome, the two bioregions with the highest MAP are the Sub-Escarpment Savanna and Lowveld, with the latter experiencing a significantly greater annual potential evaporation. The Kalahari Duneveld Bioregion has by far the lowest MAP in the biome. The Eastern Kalahari Bushveld Bioregion has more than twice as much frost as the Central Bushveld Bioregion while the Mopane Bioregion experiences virtually no frost.

It should be clear that the climatic relations indicated above represent climatic averages within a unit and, therefore, the overall trends and these averages do not address the spatial range of climate within a unit.

3. Credits

M.C. Rutherford wrote the text which was edited by L. Mucina who also added sections 1.1 and 1.7 which were in turn edited by M.C. Rutherford. L.W. Powrie was responsible for the technical compilation of the material for the figures and the tables (except for Table 3.5 supplied by L. Mucina). M.C. Rutherford and L.W. Powrie performed the decision tree analyses and W. Thuiller (now Grenoble, France) assisted with the CART decision tree. Data for the climate diagrams were taken or derived from the work of R.E. Schulze. This chapter is directed mainly at comparisons between biomes and between bioregions but we fully acknowledge the individual contributions to biome and bioregion boundaries supplied by the authors of the individual biome chapters in this book (see Credits at the end of each major chapter).

4. References


Bond, W.J. 2005. Large parts of the world are brown or black: a different view of the ‘Green World’ hypothesis. J. Veg. Sci. 16:261–266.


Ecosystem Status and Protection Levels of Vegetation Types

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Figure 16.1 The pride of South African nature conservation is the extensive and well-functioning network of statutory and private reserves and parks. One of the largest parks in the country—the Greater Addo Elephant National Park in the Eastern Cape—supports the last (albeit thriving) Cape population of African elephant (Loxodonta africana).
1. Introduction

The southern African region has a long conservation history—some of the first protected areas in the world were established in South Africa in the late 1880s. However, these were proclaimed with a strong focus on protecting hunting grounds and with limited concern for conserving biodiversity (Fringle 1982). As in many parts of the world, marginal areas unsuitable for agriculture or other land uses were set aside for conservation. Areas were proclaimed as protected areas for maintaining populations of large mammal species, for securing forest in the light of future afforestation, and for maintaining water catchments. In some instances, such conservation efforts had some detrimental effects on the vegetation (e.g. 'veld-improvement' or provision of water sources for the protection of large game; Rebelo 1992). A more detailed history of conservation areas and conservation planning is described in Rebelo (1997).

The protected area network has gradually increased over the last century to reach 7.93 million ha (6.25% of the land area) in 2005 (Figure 16.2). Most of the expansion occurred in the 1920s and 1930s through the addition of the Kruger National Park and then Kalahari Gemsbok National Park (today part of the Kgalagadi Transfrontier Park), and in the last 25 years. However, because biodiversity conservation was not the main rationale in selecting protected areas, the result is a protected area network that is not representative of the region's biodiversity.

Several reports (here referred to as conservation assessments) have highlighted the bias in protection levels across the region. The first assessment of the adequacy of protected areas in preserving South African vegetation types was realised in the 1970s (Edwards 1974). This assessment called for the protection of 5% of each vegetation type in formal reserves. Over the last 15 years, conservation assessments have evolved from ad hoc decisions to scoring approaches and lately to systematic approaches considering the issues of biodiversity representation and persistence. Recently, conservation planners have become more mindful of the challenges of implementing planning outcomes, resulting in innovative planning approaches that are implementation-oriented from the outset (Driver et al. 2003).

The approach used most often in South Africa (including in this assessment) to identify priority areas for conservation is referred to as systematic conservation planning (see Margules & Pressey 2000 and Driver et al. 2003 for more details). Systematic conservation planning is based on three key principles:

- The need to conserve a representative sample of biodiversity pattern, such as species and habitats (the principle of representation).
- The need to conserve the ecological and evolutionary processes that allow biodiversity to persist over time (the principle of persistence).
- The need to set quantitative biodiversity-based targets that tell us how much of each biodiversity feature should be conserved in order to maintain functioning landscapes. These targets should ideally be based on best available science, rather than on arbitrarily defined thresholds (such as 10% of all features).

In many parts of the world and especially in southern Africa, current conservation assessments include a wide array of features: various biodiversity features (biodiversity pattern, e.g. species and habitats and ecological and evolutionary processes), land use opportunities and constraints in order to lay the basis for successful implementation. For example, considerable attention is given to the use of conservation assessments in land use planning, extending biodiversity conservation beyond formally protected areas.

Through the series of conservation assessments (starting with Edwards 1974), several conservation priority areas have been identified such as the Cape lowlands, the central Grassland and the Succulent Karoo (Edwards 1974, Greyling & Hunteley 1984, Jamman 1986, Rebelo 1997). However, the implementation of new protected areas or conservation measures has been limited to a certain extent (e.g. Jamman 1986, Rebelo 1994). Recently, major regional planning initiatives have been undertaken or are under way to implement conservation programmes, for example in the Cape Floristic Region (C.A.P.E.), the Succulent Karoo (SKEP), the Albany Thicket Biome (STEP), and in several South African provinces such as KwaZulu-Natal, Gauteng and Mpumalanga. Some of these have led to large multi-sectoral conservation programmes involving partnerships between government, civil society and the private sector.

As a signatory of the Convention on Biodiversity, South Africa is obliged to produce a National Biodiversity Strategy and Action Plan (NBSAP), which is currently being developed. The conservation assessment, which follows below, forms part of the spatial component of South Africa's first NBSAP. Systematic conservation planning methods used were based on comprehensive spatial information of biodiversity pattern and ecological processes, biodiversity targets, and current and future land use patterns. This provided an up-to-date assessment whose products are geared towards implementation, each accompanied by a set of guidelines and recommendations (see Driver et al. 2005).

Our assessment is in threefold. Firstly, we review the ecosystem status of the vegetation of South Africa, Lesotho and Swaziland, assessing the spatial pattern of current habitat transformation and relating this to biodiversity targets set for each vegetation type. Secondly, we review the adequacy of the current protected area network in representing all vegetation types. Conservation priorities are then identified on the basis of ecosystem status, protection levels and irreplaceability. The Prince Edward Islands were not subject to this analysis due to their status of Special Reserve (see chapter on Vegetation of subantarctic Marion and Prince Edward Islands).

The NBSAP biodiversity assessment used a relatively coarse-filter approach designed to identify areas that require a finer-scale assessment (if this has not already been done). Terrestrial conservation priority areas were identified on the basis of many biodiversity features including species (endemic and threatened

![Figure 16.2 Expansion of protected area network (statutory and nonstatutory protected areas) in South Africa (SA) from 1890 to the present.](image-url)
plants and animals), ecological and evolutionary processes such as biota migration along the escarpment and habitats (vegetation types) (Rouget et al. 2004). Here we focused on conservation priorities identified using vegetation types only, a reasonable surrogate for many biodiversity features in southern Africa (Lombard et al. 2003). 

2. Patterns of Current Habitat Transformation

Human activities can impact on areas of natural vegetation in various ways, from minor degradation to total conversion. Loss of natural habitat as a result of land uses such as agriculture, forestry, mining and urban development, remains the single most important threat to biodiversity (Wilcove et al. 1998). In southern Africa, and other developing regions, the natural vegetation is often partially degraded (albeit not completely cleared) by livestock grazing, soil erosion often following too frequent fires or by invasion by alien plants. Given the fact that approximately two thirds of southern Africa is used for extensive livestock farming, grazing is likely to have an important impact on the natural vegetation. However, mapping grazing impact over large areas is complex, especially in arid areas, and not enough spatial information is currently available to provide proper assessment of grazing impacts on southern African vegetation types. This assessment focuses on irreversible loss of natural habitat as a result of croplands (including plantations), urban and rural settlements, mining and roads. The extent of alien plant invasions and habitat degradation was excluded due to lack of appropriate data at a national scale (see Box A).

For this purpose, we used the National Land Cover (NLC), a comprehensive data source derived from 1996 satellite imagery (Fairbanks et al. 2000). We acknowledge that, due to the lack of spatial data on grazing impacts, as well as the fact that the NLC is not up to date, the impacts of human activities on the natural vegetation are far greater than is reflected here.

About 16% of the vegetation in South Africa, Lesotho and Swaziland has been reversibly transformed (croplands: 14%, urban areas: 1.1%, roads: 0.5% and mines: 0.1%) (see Figure 16.3). Most habitat transformation has occurred in Gauteng, the Cape lowlands and the eastern seaboard, resulting in considerable differences in the spatial extent of habitat transformation between biomes and vegetation types. Fynbos and Grassland are the two biomes most severely impacted upon by human activities; almost 30% of their original extent now covered by cropland, urban areas, mines or roads (Table 16.1). In contrast, only 5% of the Succulent Karoo and Nama Karoo Biomes has been reversibly transformed. Only two vegetation types have lost more than 90% of their original extent, and 11 more than 75% (Table 16.2). The large majority of vegetation types still comprise extensive areas of natural vegetation (although they could be heavily grazed or invaded by alien plants): 325 vegetation types (74.8%) still have 75% or more of their original extent intact.

Except for a few vegetation types, South Africa, Lesotho and Swaziland appear to have been marginally impacted by irreversible habitat transformation. However, habitat transformation is underestimated due to inaccuracies in mapping land uses and the lack of spatial information on habitat degradation. In many parts of southern Africa, it has been reported that habitat degradation due to alien plant invasion, overgrazing and harvesting of natural resources (wood, flowers, medicinal plants) had a far more extensive impact on vegetation than the transformation of natural habitat (Hoffman & Ashwell 2000; Box A). Degree of habitat fragmentation and alien plant invasion within vegetation types could not be taken into account (but see chapter on Vulnerability).

Patterns of habitat transformation among vegetation types can be used to crudely identify conservation priorities. Vegetation types that are already modified should ideally receive more conservation efforts than those relatively free of human activities because the former are currently more vulnerable to habitat fragmentation and degradation. For heavily transformed vegetation types, this could represent the last opportunity to conserve remaining fragments of natural vegetation and their associated species. However, other factors should be taken into consideration for identifying conservation priorities: biodiversity targets and protection levels (see below).

![Figure 16.3 Extent of irreversible habitat transformation (cultivated areas, forestry plantations, mines, urban areas and roads) in South Africa, Lesotho and Swaziland. This map does not take habitat degradation, for example due to grazing or alien plant invasions, into account.](image)

The spatial components of the NBSAP also included freshwater, marine and estuarine conservation assessments using systematic conservation planning methods (more on the spatial component of the NBSAP, please see Driver et al. 2005).
3. Setting Biodiversity Targets

Targets are an integral part of contemporary conservation planning, implementation and monitoring. Systematic conservation planning is dependent on explicitness, accountability and defensibility in identifying priority conservation areas (Margules & Pressey 2000). As a part of this, conservation targets underpin this process as they provide a clear purpose for conservation decisions, lending them accountability and defensibility (Pressey et al. 2003). Targets are basically quantitative interpretations of broad conservation goals that are established in policy by experts, implementing agencies or other stakeholders (Margules & Pressey 2000, Pressey et al. 2003). For example, a conservation agency may specify that it wishes to conserve at least 10% of each vegetation type and three populations of each endangered species within its jurisdiction. Consequently, targets also provide a benchmark against which to measure the success of conservation action.

So how can we set biologically meaningful quantitative conservation targets for Southern African vegetation types? While there are some studies dealing with a range of species (e.g. Travaini et al. 1997), minimum viable population (e.g. Burgman et al. 2001), meta population (e.g. Lindenmayer & Lacy 1995), genetic diversity (e.g. Ferguson et al. 1998), community (e.g. Prins et al. 1998), habitats (e.g. Turner et al. 1999) or ecosystem (e.g. Noss 1996) targets, there is generally a paucity of work dealing specifically with targets for vegetation types.

The widely used 10% target, recommended by IUCN, when applied to our vegetation types implies that all are equal in terms of their species diversity, abundance and distribution. Most would agree that this is certainly not the case. Desmet & Cowling (2004) discuss a more biologically relevant method for setting targets for vegetation types using the power form of the species-area relationship (SAR). The SAR describes in mathematical terms the basic observation that one observes more species as one samples a larger area. Using Equation 1 it is possible to predict the number of species observed if a given percentage of a vegetation type was sampled, provided that the z-value for the vegetation type was known:

\[ S = A^z \]

Here S and A denote the proportion of species and area rather than absolute values. This equation can be reordered to address conservation targets to determine the proportion of area of a vegetation type required to represent a given percentage of species:

\[ A = \frac{S}{z} \text{ or } \log A = \log S + z \]

Published z-values for biota range between approximately 0.1 and 0.4 (Rosenzweig 1995). Although this range in the exponent is small, the nature of the power curve means that for a species target of 75% (i.e. we wish to represent 75% of species occurring in this vegeta-
tion type within a reserve network), the area target for the vegetation types ranges from 5% to 48%, respectively (Desmet & Cowling 2004).

SKEP and STEP projects all used vegetation survey data (phytosociological relevé) to estimate the z-values for Succulent Karoo vegetation types. The details of the method used to develop the conservation targets for South African vegetation types is discussed in more detail in Desmet & Cowling (2004) and Rouget et al. (2004).

Relevé data for South Africa were obtained from three geo-referenced phytosociological relevé databases, comprising over 17 000 relevés. There are more phytosociological datasets available for the region but these have either not been captured or areo-referenced.

For South African vegetation types, estimates of z-values range between 0.13 and 0.25. After considerable discussion it was decided that the goal for statutory reserves should be to represent at least 5% of species that occur in a vegetation type within at least one or more statutory reserves. Using Equation 2 this goal translates to conservation targets ranging between 11% and 30%, respectively (see Table 16.3). For forest vegetation types the targets were based on those set for the Forest Assessment Process (Berliner & Benn 2004) and not the species-area approach. Targets for forests range between 30% and 100%. As would be expected, areas of the country rich in endemic species or high levels of plant species diversity such as Fynbos, succulent Karoo and some Grassland biome vegetation types have higher representation targets (i.e. require more area to represent the same overall proportion of plant species). Some rare vegetation types such as forests also have high targets.

1. Ecosystem Status

The identification of conservation priorities, at a vegetation type level, should take into consideration at least the following factors: plant species diversity and turnover, habitat transformation and protection levels. Ecosystem status takes into account the first two, species diversity and turnover (through biodiversity targets), and habitat transformation. Ecosystem status aims at identifying threatened ecosystems (here vegetation types). It draws on the Red List classification scheme developed by the IUCN and orrows the familiar terminology applied to species, such as critically endangered (CR), endangered (EN), vulnerable (VU) and least threatened (LT). Focusing conservation efforts on threatened species crucial for maintaining biodiversity.

However, only conserving the natural habitats in which species occur will ensure species persistence. The identification of threatened ecosystems is aimed at addressing this. The recognition of threatened ecosystems by international organisations such as the IUCN and national governments could prove to be a very powerful conservation tool. It is envisaged that specific land use restrictions will be enforced in threatened ecosystems. In South Africa, the new Biodiversity Act (10 of 2004) provides for the Minister of Environmental Affairs and Tourism to list threatened ecosystems. Threatening processes in these ecosystems will be listed in terms of the National Environmental Management Act (107 of 1998) as activities that require environmental assessment.

Although the Biodiversity Act in South Africa allows for the listing of threatened ecosystems, it does not specify a standard approach for identifying them. The approach proposed here focuses on the retention of ecosystem functioning (such as pollination, nutrient cycling) and plant species diversity at the landscape scale. Vegetation types were classified based on the extent of remaining area (currently not transformed) of each

**Box A: The extent of habitat degradation in South Africa**

At least 8% of South Africa, Lesotho and Swaziland is invaded by alien plants (Versfeld et al. 1998). Over 700 alien plant species have become naturalised, 120 of which are considered as major invader plants, invading natural habitat (Nel et al. 2004). It is not clear whether some vegetation communities are more resilient to plant invasions than others, but some vegetation types have been heavily invaded. This applies to fynbos vegetation, thicket and highveld grassland (Rouget et al. 2002).

Loss of plant cover, change in species composition and bush encroachment are the major forms of habitat degradation in South Africa (Hoffman & Ashwell 2000). Loss of plant cover is the most important degradation problem in grasslands in the higher-rainfall eastern part of the country. Change in species composition occurs mostly in the dry west. Habitat degradation due to removal of woody species is widespread in shrubland and savanna woodland of the Limpopo Province (see Figure A1).
vegetation type in relation to its biodiversity target and thresholds for ecosystem functioning (see Figure 16.4). We recognise that our approach is very simplistic and that many other factors should be taken into account (such as habitat degradation). This represents one of the first attempts towards deriving an objective and defensible method for the identification of threatened ecosystems. It does not preclude the identification of additional threatened ecosystems based on, for example, an assessment of habitat degradation, when further spatial information becomes available. Similar assessments were conducted in the subtropical thicket biome (Cowling et al. 2003; Pierce et al. 2005) and in the United States based on the same factors (Noss et al. 1995).

Critically endangered vegetation types have been transformed to such an extent that the remaining habitat is less than that required to represent 75% of species diversity (i.e. the biodiversity target); in other words, one would expect species loss to take place in such vegetation types. Endangered vegetation types have lost up to 40% of their original extent and are exposed to partial loss of ecosystem function. Vulnerable vegetation types have lost up to 20% of their original extent, which could result in some ecosystem functions being altered (Figure 16.4). No significant disruption of ecosystem functioning is assumed in least threatened vegetation types, which still possess more than 80% of their original extent intact.

The status of two vegetation types could not be determined, namely Cape Vernal Pools and Pitskerrfberg Quartz Succulent Shrubland (due to their small extent). Out of 433 vegetation types assessed, 19 are critically endangered, 53 endangered, 69 vulnerable and 292 least threatened.

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Biome or azonal units</th>
<th>Remaining area (%)</th>
<th>Target (%)</th>
<th>Protected (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lourensford Alluvium Fynbos</td>
<td>Fynbos Biome</td>
<td>7</td>
<td>27</td>
<td>4.2</td>
</tr>
<tr>
<td>Swartland Shale Renosterveld</td>
<td>Fynbos Biome</td>
<td>9</td>
<td>27</td>
<td>0.5</td>
</tr>
<tr>
<td>Swartland Silcrete Renosterveld</td>
<td>Fynbos Biome</td>
<td>10</td>
<td>27</td>
<td>0.6</td>
</tr>
<tr>
<td>Central Röns Shale Renosterveld</td>
<td>Fynbos Biome</td>
<td>13</td>
<td>30</td>
<td>0.4</td>
</tr>
<tr>
<td>Western Röns Shale Renosterveld</td>
<td>Fynbos Biome</td>
<td>14</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Elgin Shale Fynbos</td>
<td>Fynbos Biome</td>
<td>18</td>
<td>29</td>
<td>5.9</td>
</tr>
<tr>
<td>Cape Flats Sand Fynbos</td>
<td>Fynbos Biome</td>
<td>19</td>
<td>25</td>
<td>0.1</td>
</tr>
<tr>
<td>Eastern Röns Shale Renosterveld</td>
<td>Fynbos Biome</td>
<td>19</td>
<td>32</td>
<td>0.4</td>
</tr>
<tr>
<td>Swartland Granite Renosterveld</td>
<td>Fynbos Biome</td>
<td>20</td>
<td>27</td>
<td>0.6</td>
</tr>
<tr>
<td>Röns Silcrete Renosterveld</td>
<td>Fynbos Biome</td>
<td>22</td>
<td>32</td>
<td>0.1</td>
</tr>
<tr>
<td>Peninsula Shale Renosterveld</td>
<td>Fynbos Biome</td>
<td>23</td>
<td>25</td>
<td>18.7</td>
</tr>
<tr>
<td>Swartland Alluvium Fynbos</td>
<td>Fynbos Biome</td>
<td>25</td>
<td>27</td>
<td>1.7</td>
</tr>
<tr>
<td>Woodbush Granite Grassland</td>
<td>Grassland Biome</td>
<td>26</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>Cape Lowland Alluvial Vegetation</td>
<td>Azonal Vegetation</td>
<td>31</td>
<td>32</td>
<td>0.7</td>
</tr>
<tr>
<td>Swamp Forest</td>
<td>Forests</td>
<td>95</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Mangrove Forest</td>
<td>Forests</td>
<td>96</td>
<td>100</td>
<td>46.9</td>
</tr>
<tr>
<td>Lowveld Riverine Forest</td>
<td>Forests</td>
<td>97</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Sand Forest</td>
<td>Forests</td>
<td>98</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Ironwood Dry Forest</td>
<td>Forests</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Due to the spatial bias of habitat transformation in South Africa, Lesotho and Swaziland (see Figure 16.3), critically endangered vegetation types, with the exception of forest types, are mostly concentrated in the Western Cape Province of South Africa (Figure 16.5). The forests and the Fynbos Biome have the greatest proportion of critically endangered vegetation types (see Figure 16.6). The Desert, Nama-Karoo and Succulent Karoo Biomes have the highest proportion of least threatened vegetation types. The grasslands have been considerably impacted by habitat transformation, and as a result, most of the grassland vegetation types are classified as endangered or at least vulnerable (Figure 16.6). Critically endangered vegetation types are listed in Table 16.4.

It is unlikely that we have overestimated the ecosystem status of any vegetation type. However, the ecosystem status for some vegetation types is likely to be underestimated as habitat degradation was not taken into account. Many vegetation types currently classified as least threatened are degraded to a large extent. A more detailed spatial assessment of the extent of habitat degradation in southern Africa is required in order to derive a more accurate ecosystem status of vegetation types.

5. Protection Level

Currently, 6.25% of South Africa, Lesotho and Swaziland is under protection. This includes statutory reserves (national parks, provincial and local authority nature reserves) and nonstatutory reserves (such as mountain catchment areas and private nature reserves) with a much less secure conservation agreement. The conservation estate consists of 465 statutory protected areas (representing 77% of the total protected area) and 508 nonstatutory protected areas (Figure 16.7). Only few protected areas are greater than 100 000 ha; most of them are between 1 000 and 10 000 ha (Figure 16.8). The implications of the size...
of protected areas for conserving biodiversity have been discussed elsewhere (Schwartz 1999; see Rebele 1997 for a review on southern Africa) and will not be addressed here. While concern has been raised that small protected areas might be inadequate for maintaining large-scale processes (such as natural fire regimes), they do play an important role in conserving some of the last remaining fragments of lowland vegetation types.

In assessing the protection levels of vegetation types, it would be ideal to include some measure of management effectiveness within protected areas. However, it is unlikely that we will ever have a national dataset that provides widely endorsed information of this kind. In the absence of information about management effectiveness, legal status and ownership must suffice as a way of distinguishing categories of protected areas.

With only 6.2% of the land protected, most of South Africa, Lesotho and Swaziland is not adequately conserved (Figure 16.9). As biodiversity and protected areas are not uniformly distributed in the landscape, huge gaps appear in the protected area network. In terms of biome representation, the Forest, Fynbos and Desert are the most protected biomes (in terms of percentage of total area), while the Nama-Karoo and Grassland are the least protected biomes (Table 16.1). An assessment of the protection levels of each vegetation type in relation to their biodiversity targets reveals that 116 vegetation types have no form of protection at all (Figure 16.9). It is important to note that this assessment focuses on representation of biodiversity pattern, and that larger areas will be required for conserving critical ecological and evolutionary processes. Furthermore, an additional 79 vegetation types, with only < 5% of their biodiversity target protected, are hardly protected. More than 300 vegetation types have less than half of their biodiversity target conserved in statutory protected areas. Only 65 vegetation types have their biodiversity targets met in statutory protected areas, including 24 types of Fynbos, 24 of Savanna and seven of Grassland.

In order to meet the biodiversity targets for all vegetation types, at least an additional 215 000 km² would have to receive some form of conservation action. This amounts to 20% of the remaining natural habitat in South Africa, Lesotho and Swaziland.

Protection level can and should inform priorities for the establishment and expansion of protected areas. Based on the principle of representation, vegetation types not adequately represented in the current protected area network should receive priority attention. However, we need to note strongly that the establishment of formal protected areas is not the only form of conservation action possible. Especially in vegetation types that are highly fragmented, conservation action may include, for example, working with industry and local government to ensure conservation-friendly land use in priority areas. Used in conjunction, measures of ecosystem status and protection level are very useful for identifying priority vegetation types in need of conservation action of some kind. Ecosystem status tells us which vegetation types are most threatened, while protection level tells us which vegetation types are least protected. For example, it is clear that the Knysna Sand Fynbos or the Rüens

![Ecosystem status of vegetation types. Vegetation types were classified into critically endangered (CR), endangered (EN), vulnerable (VU) and least threatened (LT) based on habitat transformation pattern and biodiversity targets.](image-url)
Silcrete Renosterveld, which are critically endangered and not represented in the current protected area network, have not received adequate conservation efforts.

However, while the implementation of conservation plans can take quite some time and when conservation budgets are limited, scheduling of conservation actions becomes important. It has been proposed that scheduling should consider a measure of conservation value and vulnerability to future land use pressures (What is the likelihood of losing this area of natural vegetation in the near future?) (Pressey & Taffs 2001; see chapter on Vulnerability).

6. Conservation Priorities

Setting conservation priorities is a complex task (see Box 8). One has to integrate biodiversity pattern and process as well as consider future pressures due to other land uses. Few conservation

**Box B: Species or land class biodiversity features?**

Conservation targets can be divided into two broad categories based on the scale of biodiversity surrogate targeted (Pressey et al. 2003). Coarse-filter approaches set targets for features such as vegetation types, ecosystems or land-classes. Fine-filter approaches use species or populations as the focal feature for conservation action. While the two approaches are complementary, for most regions limitations in species distribution datasets oblige the use of coarse-filter surrogates (Lombard et al. 2003).

Vegetation or land-class maps, such as this vegetation map, have the advantage of covering the entire landscape, thereby eliminating the inherent spatial and taxonomic bias of species datasets (Lombard et al. 2003). There are limitations when using such maps. Firstly, reserve selection using the coarse-filter approach is likely to protect many species for which records are deficient or are yet to be discovered. However, unless complementary fine-filter information is incorporated in the process, other species, especially rarer ones, are likely to be missed (Kirkpatrick & Brown 1994; Lombard et al. 2003). Secondly, the spatial, land-class compositional or process requirements of certain species are unlikely to be satisfied unless specifically targeted. Thirdly, land classes do not explicitly target natural processes. These need to be targeted separately if biodiversity is to persist (Cowling et al. 1999; Cowling & Pressey 2001).

These problems are compounded by problems relating to scale. Targets framed as percentages of countries or regions can be achieved while failing to protect the natural features most urgently in need of protection (Pressey et al. 2003). Large regions are heterogeneous in terms of biodiversity and potential for anthropogenic transformation. Conservation areas have often been relegated to the least usable portions of regions, thereby avoiding areas where past impacts on biodiversity have been greatest and future threats are most serious (Pressey et al. 2000, Scott et al. 2001). This is true even of regions with overall percentages under formal protection equal to or greater than 10%. Also, coarse-scale maps do not capture all possible land-class combinations, so even if vulnerability over the whole area is low, certain landscape biodiversity features (e.g. rare vegetation types or habitats) can fall through the cracks. These issues can be addressed by mapping at finer scales and with improved mapping techniques (Ferrier et al. 2002). Targeting better mapped land types with classes that are more homogeneous in terms of biodiversity and land use potential, limits the potential for conservation action to miss capturing all biodiversity (Bedward et al. 1992). To this end the new vegetation map represents a more fine-scale interpretation of the vegetation patterns, and more broadly, biodiversity patterns encountered within Southern Africa.

Mindful of these limitations, it must be accepted that for most areas on this planet, land-class maps of some sort will be the primary biodiversity feature used for conservation and land use planning.

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**Figure 16.6** Proportion of critically endangered (CR), endangered (EN), vulnerable (VU) and least threatened (LT) vegetation types per biome. The number of vegetation types present in each biome and in azonal vegetation is indicated on top of the bars.

**Figure 16.8** Size-class distribution of the protected area network for South Africa, Lesotho and Swaziland.
**Figure 16.7** Protected area network in South Africa, Lesotho and Swaziland. Protected areas are classified into two types: statutory (type 1) and nonstatutory (type 2) based on ownership and legal status.

**Figure 16.9** Protection levels of vegetation types based on the proportion of biodiversity target set for each vegetation type represented in statutory protected areas. Not protected (0% of biodiversity target protected in statutory protected areas), hardly protected (<5% of the biodiversity target protected), poorly protected (<50% of the target protected), moderately (<100% of the target protected), well protected (biodiversity target protected in statutory protected areas).
assessments have managed to do this successfully. Trade-offs tend to occur as areas required for achieving pattern and process often do not overlap. Therefore different geographical priority areas can be identified by focusing on habitats, species of special concern or biodiversity processes.

In the National Spatial Biodiversity Assessment (NSBA, see Driver et al. 2005), due to the mismatch of scale between the various analyses (e.g. ecosystem status at the vegetation type scale, habitat irreplaceability at a sixteenth-degree scale, species irreplaceability at a quarter-degree scale), all analyses could not be combined into one overall ‘irreplaceability’ measure. A scoring system was developed whereby each separate analysis (e.g. ecosystem status, species irreplaceability) was scored. This enables one to combine all these analyses and identify priority areas for habitat, species and processes. Multi-criteria approaches, when used in conservation assessments, have been criticised because they are often not systematic and do not satisfy the principle of representation or persistence. The products of the NSBA (ecosystem status, protection levels of ecosystems, analysis of species of special concern, and national-scale ecological processes) are systematic and fulfil the goals of representation and persistence. The NSBA simply used a scoring approach for prioritising areas based on systematic conservation assessment products. As there is a potential danger of mixing criteria of different kinds together in a scoring approach, priority scores (and priority areas) were first identified for habitat, species and process separately, and then combined to identify overall priority areas. The priority areas thus identified are also priority areas for habitat, species or process, and not an area averaging medium score for all criteria.

Here we focus on priority areas identified for habitat only (i.e. vegetation types). One should bear in mind that other areas might be crucial for maintaining ecological and evolutionary processes (see Figure 16.10), or for species representation.

We combined three analyses to identify priority areas for habitat: ecosystem status, protection levels and irreplaceability (see Box C). Irreplaceability quantifies the contribution of a site to achieve biodiversity targets, in other words, to ensure the representation of biodiversity features (Ferrier et al. 2000). Irreplaceability values range from 0 (site not required to achieve biodiversity targets) to 1 (irreplaceable site, target cannot be achieved without it). We calculated irreplaceability values based on biodiversity targets set for vegetation types, wetlands and estuaries (see Box C). We used sixteenth-degree squares (approximately 4 400 ha) to calculate irreplaceability.

Ecosystem status was scored from 0 to 100 as follows: critically endangered vegetation types were assigned a score of 100; endangered vegetation types, 75; vulnerable vegetation types, 50; and least-threatened vegetation types, 25. Protection levels of ecosystems were scored as follows: well-protected vegetation types (100% or more of the target is achieved in statutory protected areas) were assigned a score of 0; nonprotected vegetation types, 100; and for other vegetation types, the score was 100 minus the percentage target achieved in statutory protected areas (e.g. if a vegetation type has 10% of its biodiversity...
Box C: Irreplaceability analysis for vegetation types, estuaries and wetlands

The concept of representation underpins most conservation assessments (Margules & Pressey 2000, Driver et al. 2003). Conservation planners seek to identify areas that will represent an appropriate sample (defined by the biodiversity targets) of each biodiversity feature. Irreplaceability quantifies the contribution of a site to achieve biodiversity targets, in other words, to ensure the representation of biodiversity features (Ferrier 2002). Irreplaceability values range from 0 (site not required to achieve biodiversity targets) to 1 (irreplaceable site, target cannot be achieved without it).

The irreplaceability measure applies to sites (and not directly to biodiversity features).

Based on vegetation types (and estuaries and wetlands from a separate study, see table below), we calculated irreplaceability values for the 31 130 planning units using the software C-Plan (Ferrier et al. 2000).

<table>
<thead>
<tr>
<th>Initial Reserve</th>
<th>1 (Totally irreplaceable)</th>
<th>&gt;0.8 - &lt;1</th>
<th>&gt;0.6 - 0.8</th>
<th>&gt;0.4 - 0.6</th>
<th>&gt;0.2 - 0.4</th>
<th>&gt;0 - 0.2</th>
<th>Irreplaceability = 0</th>
</tr>
</thead>
</table>

**Figure C1** Irreplaceability pattern for vegetation types, estuaries and wetlands.

Most of South Africa’s land surface appears to have low irreplaceability values (< 0.4), meaning that there are still many options for achieving biodiversity representation targets for many vegetation types (or estuaries or wetlands) (Figure C1). 790 sites representing 1% of South Africa’s remaining habitats are irreplaceable. A further 0.6% has high irreplaceability values (> 0.8). A site could be irreplaceable for two reasons: (a) severe habitat transformation has reduced the amount of remaining habitat close to the target (the case for critically endangered vegetation types); and/or (b) the biodiversity target is quite high (the case for some forest or estuary types). Options to achieve biodiversity targets are limited in places where habitat transformation has been most severe (see Figure C1 and compare it with Figure 16.3). In other words, our ability to achieve biodiversity representation targets is influenced more by habitat transformation than the biodiversity target itself.

List of biodiversity features included in the irreplaceability analysis (SANBI, South African National Biodiversity Institute; DEAT, Department of Environmental Affairs and Tourism)

<table>
<thead>
<tr>
<th>Biodiversity feature</th>
<th>Source</th>
<th>Number</th>
<th>Target range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation types</td>
<td>SANBI</td>
<td>438 types</td>
<td>12–100% of original area</td>
</tr>
<tr>
<td>Estuaries</td>
<td>DEAT</td>
<td>16 types</td>
<td>At least 3 or 20% of each type</td>
</tr>
<tr>
<td>Wetlands</td>
<td>DEAT</td>
<td>17 types</td>
<td>At least 3 or 20% of each type</td>
</tr>
<tr>
<td>Wetlands &amp; estuaries of significant importance</td>
<td>DEAT</td>
<td>1 type</td>
<td>100%</td>
</tr>
</tbody>
</table>
target achieved in statutory protected areas, the score was 90). For habitat irreplaceability, we applied the following score to each planning unit: 100 \times \text{irreplaceability value}.

Due to different scales, all layers were converted to a grid of sixteenth-degree cell size to match the planning unit layer. Each cell was assigned a score for ecosystem status, protection levels and irreplaceability. These three scores were averaged and ranged from 0 to 100 (maximum score for all three criteria). Priority areas for habitat conservation were defined as cells where the average score was greater than 60.

Figure 16.11 shows the priority areas identified for conserving biodiversity at the habitat level. Three main priorities emerged: the Cape lowlands (lowland part of the Southwest Fynbos Bioregion, and the West Coast Renosterveld and East Coast Renosterveld Bioregions), the central grasslands (Mesci, Highveld and Dry Highveld Grassland Bioregions), and part of the Indian Ocean Coastal Belt and the Sub-Escarpment Savanna Bioregion in KwaZulu-Natal. Most of the Nama-Karoo Biome appears least transformed. However, this could be due to the lack of fine-scale spatial information on habitat degradation.

These habitat priority areas differ from those identified on the basis of species distribution pattern or ecological processes (see Driver et al. 2005). On the basis of habitat alone, the Succulent Karoo and the Albany Thicket do not emerge as a priority. However, both are national priority areas identified by the National Spatial Biodiversity Assessment (Driver et al. 2005).

7. Conclusion

What are the implications of these results for conservation action in South Africa, Lesotho and Swaziland? Perhaps the main implication is that conservation action cannot be limited to the establishment or expansion of ‘traditional’ large protected areas. Clearly, protected areas represent a major conservation instrument and we need more (in the Grassland Biome for example), but they might not be appropriate in every situation. The remaining natural habitat in critically endangered and endangered ecosystems is likely to be fragmented and situated in a matrix of productive agricultural, industrial and urban land uses, making the establishment of protected areas impractical. This means that the conservation sector needs to engage proactively with industry, civil society and local government in areas where there are concentrations of critically endangered and endangered ecosystems. Curtailing further loss of natural habitat in these areas, and the associated loss of ecosystem functioning and species, will involve making the case to major land users and decision-makers that retention of biodiversity is part of maintaining national ecological infrastructure. It could involve the development of industry-specific biodiversity guidelines, in close partnership with industry bodies, to guide decisions about how land is used and managed. The incorporation of spatial biodiversity priorities into land use planning and environmental assessment processes at municipal and provincial level can provide a powerful way to protect critically endangered and endangered ecosystems.

Figure 16.11 Priority areas for conserving habitat based on ecosystem status, protection levels and irreplaceability surface. The colour gradient refers to the priority score.
8. Credits

The unpublished version of the vegetation map used for this analysis was provided by M.C. Rutherford and L. Mucina. The GIS data were provided by L.W. Powrie. Some tables and figures were adjusted for presentation by L.W. Powrie. The National Land Cover was provided by the CSIR, and information on protected areas by DEAT and all provincial conservation agencies. Biodiversity targets were calculated by P.G. Desmet and R.M. Cowling. Most analyses were performed by Z. Jonas and M. Rouget. B. Mohamed assisted with some GIS analysis. M. Rouget was the lead author and R.M. Cowling, P.G. Desmet and A. Driver provided substantial input and editing on earlier drafts. P.G. Desmet wrote the section on targets. L. Mucina and M.C. Rutherford provided final editorial comments. Valuable scientific and technical input was received from conservation planners who were involved in the National Spatial Biodiversity Assessment.

9. References


Berliner, D. & Benn, G. 2004. Protected area planning for forest biome. DWA unpubl. report. Eco-logic Consulting & GISCO.


1. Introduction

Humans have transformed almost half of the world’s land surface area into agriculture and urban systems (Chapin et al. 2000). The most severe biodiversity loss occurs when a natural ecosystem is converted to an artificial system (Geneletti 2003). This does not only affect ecosystems by altering their composition and processes, but also has important consequences for water supply and other ecosystem services upon which humans depend (Kunin & Lawton 1996, McCann 2000). Land conversion can be due to several causes, e.g. agriculture, urbanisation, road development and deforestation. When the land is converted from a natural or semi-natural state to one of these forms of land cover, many species are unable to persist (Dale et al. 1994) as a result of direct and indirect loss of habitat.

Mapping expected future loss of natural habitat or ecosystem function can be very useful in scheduling implementation of conservation actions. Focusing first on areas of high biodiversity value that are also highly vulnerable to future habitat loss or degradation is usually recognised as the most effective way to minimise biodiversity loss (Pressey 2004).

South Africa is one of the top 25 countries in the world in terms of biodiversity (WCMS 1992), with a greater part of its biodiversity occurring on agricultural land than in current conservation areas. Due to the expansion of cropland or urban areas, some of that biodiversity will be lost in the near future (Wessels et al. 2000).

Few studies done at different scales have outlined the land use pressures in South Africa (Wessels et al. 2003). This assessment focuses on the potential loss of natural habitat due to habitat transformation and degradation processes, which will threaten the biodiversity of the area. These processes can be land use-related where untransformed areas with a high suitability to a particular land use (e.g. cultivation, afforestation) are highly vulnerable. In these areas, not only natural habitat will be lost, but the species composition can also be completely altered. Alternatively these processes may be linked to the modification or degradation of biodiversity pattern and processes of an area (e.g. alien invasion and habitat fragmentation). These processes may not necessarily lead to complete loss of natural habitat, but do modify the composition of an area sufficiently to threaten ecosystem function.

We refer to the potential loss of natural habitat or ecosystem function defined above as vulnerability. In this assessment, two classes of vulnerability are referred to as land use vulnerability (population growth, land capability—dryland agriculture, afforestation and mining) and degradation vulnerability (habitat fragmentation and alien plant invasion). Vulnerability was summarised for each vegetation type.

The objective of this chapter is to describe the relationship between biodiversity pattern (defined by 433 of the 435 mainland vegetation types—two were too small for analysis), landscape structure and land use pressures in natural habitats of South Africa and to interpret this relationship in terms of vulnerability.

2. Approach

In this assessment we used several databases (see Box A) to quantify the vulnerability of vegetation types to a suite of future pressures in order to identify vegetation types of concern. We mapped and quantified land use vulnerability based on land capability, afforestation potential, mining potential and population growth. We also mapped and quantified degradation vulnerability based on habitat fragmentation and alien plant invasion. Fine-scale habitat degradation (related to over-grazing, bush encroachment, over-harvesting of natural resources) has not been mapped comprehensively for South Africa. The only information available was the assessment done by Hoffman & Ashwell (2000) at a district level. Due to the coarse scale, this could not be used for assessing the degradation status of vegetation types. However, such information can be used at the scale of the priority areas identified by the National Spatial Biodiversity Assessment (Driver et al. 2005).

All the vulnerability layers were rasterised using a 100 m cell size. For each vulnerability type, vulnerability was scored from 0 (not vulnerable) to 100 (highly vulnerable). Each layer thus had a very low vulnerability class (0–25), a low vulnerability class (25–50), a medium vulnerability class (50–75) and a high vulnerability class (75–100). Care was taken to ensure that all rescaled values represented the original vulnerability classes well.

In order to produce one layer on vulnerability across the country, we needed to combine these various datasets. All the datasets, with the exception of the mining potential, were continuous datasets and could therefore be combined arithmetically. Combining multiple threats raises several challenges, e.g. whether an area susceptible to more than one threat is more vulnerable than one susceptible to only one threat.

We produced two sets of vulnerability indices. One was an average vulnerability score for each 100 × 100 m grid cell across the country based on all vulnerability layers. This product would thus highlight areas vulnerable to a large number of future pressures. For areas currently untransformed within each vegetation type, we calculated the average score for each vulnerability type (degradation and land use). The degradation vulnerability layer was derived using the average per grid cell of the alien plant invasion and habitat fragmentation layers (see later in Habitat Fragmentation section). Land use vulnerability was derived using the average per grid cell of the land capability, afforestation and population change layers. An overall vulnerability index was calculated by averaging land use and degradation vulnerability. Vulnerability to climate change was not considered.

The second was a map of all areas in the country, which are highly vulnerable to any threat. This highlights highly vulnerable areas irrespective of the number of pressures. The raster layers produced for each type of vulnerability were used to extract areas of high vulnerability to any pressure. Pixels with a vulnerability of higher than 75 for afforestation, land capability, mining, population change, habitat fragmentation and alien plant invasion were extracted and combined to produce maps of high future pressures. Vulnerability to land use and to habitat degradation were differentiated.

In order to identify the degree of vulnerability of each vegetation type, we then summarised the average vulnerability value and the percentage of the natural area under high pressure per vegetation type.

3. Land Use Vulnerability

3.1 Land capability

Land capability reflects the land suitability to crop production and also to other less intensive uses such as pasture, natural grazing, forestry and wildlife (see Figure 17.2). Land capability was modelled based on soil and terrain features and climate of an area. Low nutrient status was not considered a limitation.
Box A: Description of the databases used to derive vulnerability layers in South Africa.

Several databases on vulnerability are available in South Africa at a national scale. These databases were investigated and either selected for the analysis or discarded based on characteristics in the database. Table A1 provides a list of these databases and reasons for their selection or rejection.

Table A1 Various datasets used in the vulnerability assessment.

<table>
<thead>
<tr>
<th>Database</th>
<th>Source</th>
<th>Description</th>
<th>Limitations</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use vulnerability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land capability</td>
<td>ARC (ISCW)</td>
<td>Total suitability for use, in an ecologically sustainable way, for crops,</td>
<td>Mapped at a broad scale</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>grazing, woodland and wildlife</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing potential</td>
<td>CSIR</td>
<td>Areas which have the potential to support a similar number of herbivores</td>
<td>Does not imply pressure unless poorly managed</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>per unit land area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Afforestation</td>
<td>CSIR</td>
<td>Potential for pine and eucalypt species based on bioclimatic variables</td>
<td>Only mapped for some provinces (LP, MP, KZN, EC,</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>WC)</td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td>Council for</td>
<td>Mapped mineral deposits, fields, layers and provinces</td>
<td>Categorical data</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Geoscience</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population growth</td>
<td>StatsSA</td>
<td>Change in population density per municipality from 1996 to 2001 census</td>
<td>Broad units of municipalities</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degradation vulnerability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fragmentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landscape resistance</td>
<td>NLC</td>
<td>Incorporates connectivity and surrounding land uses</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Extent of natural</td>
<td>NLC</td>
<td>Area of untransformed habitat</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>habitat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fragment size</td>
<td>NLC</td>
<td>Size of remaining habitat</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Plant invasion</td>
<td>SANBI/ CSIR</td>
<td>Numbers of alien invasive species that could occur in a region</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Degradation</td>
<td>Hoffman &amp;</td>
<td>Soil and vegetation degradation per magisterial district</td>
<td>Very broad units for vegetation analysis</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Ashwell (2000)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 17.2 Vulnerability to future land use change (crop potential, afforestation potential, mining potential, population density increase) and habitat degradation (alien plant invasion suitability and habitat fragmentation index) in South Africa.
since it is assumed that inherent nutrient deficiencies/toxicities will be rectified by appropriate liming and/or fertilisation. The land capability classification system applies only to rain-fed agriculture. Land suited to crop production is also suited to other less intensive uses such as pasture, natural grazing, forestry and wildlife. Most of the conversion of natural habitats with a high agricultural production potential to cultivated areas took place in the last 50 years and has considerably reduced the extent of several vegetation types. These vegetation types are mostly communities of the Grassland Biome (Macdonald 1989) and Renosterveld shrublands of the Western Cape, which presently occupy a fraction of their original range (Heydenrych & Littlewort 1995).

Land capability potential, averaged per vegetation type, varies quite considerably. Out of 433 vegetation types, 189 vegetation types have very low land capability; 180 vegetation types, low; 64 vegetation types, medium; and no vegetation types have high land capability. The top six vegetation types that are under medium land capability pressure include the Eastern Highveld Grassland, Tembe Sandy Bushveld, Swartland Alluvium Renosterveld, Maputaland Woodland Grassland, Western Maputaland Sandy Bushveld and Makatini Clay Thicket.

3.2 Afforestation Potential

Afforestation is the planting of trees for commercial purposes, usually on land supporting non-forest veld types, e.g. grassland or fynbos. Afforestation potential maps were modelled using fuzzy tolerance models, based on bioclimatic parameters. The bioclimatic factors used in these models were soil, rainfall and temperature (Fairbanks 1995). Although these maps were only generated for five provinces in South Africa, these provinces were found to coincide well with the areas suitable for wood production across southern Africa and thus the layer could be used in a national assessment. Each 1 km² grid was assigned an average suitability value for pine and eucalypt species. These values ranged from 0 (low suitability) to 100 (very high suitability) (Figure 17.2).

Natural habitats most severely affected by current afforestation include wetlands, grasslands, fynbos and indigenous forests (Heydenrych & Littlewort 1995). Based on this afforestation model (see Figure 17.2), 238 vegetation types have very low afforestation potential; 136 vegetation types, low; 52 vegetation types, medium; and seven vegetation types have a high afforestation potential. The top six vegetation types highly threatened by afforestation are the Pondoland-Ugu Sandstone Coastal Sourveld, Mangrove Forest, KwaZulu-Natal Sandstone Sourveld, Southern KwaZulu-Natal Moist Grassland, Midlands Mistsbelt Grassland and Northern Escarpment Afromontane Fynbos.

3.3 Population Density Change

Due to the lack of data on urban and peri-urban sprawl in South Africa, we decided to use the change in population density as an indicator of human pressure. Data from the national censuses in 1996 and 2001 were used for this purpose. Both datasets were aggregated to the municipality level from the original enumeration areas. The difference in population between the two census periods was used to calculate the change in population density. This change in density is mostly related to the movement of people across the country towards urban areas, as well as natural population growth. Each municipality was thus assigned a value of the change in population density, which ranged from 19 to 356 people per km² and re-scaled from 0 to 100 (Figure 17.2).

From this assessment, 343 vegetation types occur in areas with very low population growth, 71 vegetation types in areas with low population growth, 12 in areas with medium population growth and seven in areas with high population growth. The top six highly threatened vegetation types are the Egoli Granite Grassland, Peninsula Granite Fynbos, Peninsula Shale Renosterveld, Peninsula Sandstone Fynbos, Lourensford Alluvium Fynbos and Cape Flats Sand Fynbos.

3.4 Mining Potential

No layer was readily available for mapping mining potential; Box B describes how we used mining resource field to map and categorise mining potential. Mining potential was determined based on the accuracy of the deposit mapping, its size, and the type of commodities. For example, areas of high mining potential consist of large mines/deposits or mineralised fields for 13 economically important commodities (Figure 17.2).

Mining potential is concentrated in few parts of the country (such as the West Coast) with only 2.1% of the whole country (1.8% of the untransformed natural habitats) under high mining potential.

Due to its categorical nature, mining potential could not be averaged per vegetation type. Instead we calculated the percentage of the untransformed area of each vegetation type of high mining potential. There are 195 vegetation types with no mining potential. A total of six vegetation types have 50% of their natural area occurring in medium mining potential areas and another four have 50% of their natural area occurring in high mining potential areas (see Table 17.1). The vegetation types most vulnerable to mining are: Namib Seashore Vegetation, Richtersveld Coastal Duneveld, Northern Escarpment Dolomite Grassland and Subtropical Seashore Vegetation.

Box B: Mining potential in South Africa.

The mining dataset was obtained from the Council for Geoscience. It includes mineral points subdivided into two types, namely mines and mineral deposits. Mines can be dormant mines, continuously producing (active) mines, abandoned mines and intermittently producing mines. The mineral deposits can be exploited or unexploited. The dataset also contains information on mineralised fields (areas of high concentration of commodity) and mineralised provinces (broad areas where a given commodity occurs) as well as mineralised layers (veins of high concentration of commodity—linear feature).

Mines and deposits were buffered by 500 m and the mineralised layers by 1000 m (less accurate).

The mining potential was determined based on the accuracy of the deposit mapping, its size and the type of commodities.

We considered four types of deposit mapping (arranged from high spatial accuracy to low):
- Mines and deposits (500 m radius)
- Mineralised layers (1 km buffer)
- Mineralised fields (high concentration of commodity)
- Mineralised provinces (broad area where commodity occurs)

The commodities were classified into two groups, namely economically important and other minerals. The minerals of economic importance (13) were obtained from the website of the Council for Geoscience. Table B 1 lists the 13 minerals of economic importance in South Africa.
Table B1 Minerals of economic importance in South Africa.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>Au</td>
</tr>
<tr>
<td>Platinum Group Metals</td>
<td>Pt</td>
</tr>
<tr>
<td>Diamonds (alluvial &amp; kimberlite)</td>
<td>Do, Dk</td>
</tr>
<tr>
<td>Chromite</td>
<td>Cr</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
</tr>
<tr>
<td>Vanadium</td>
<td>V</td>
</tr>
<tr>
<td>Titanium</td>
<td>Ti</td>
</tr>
<tr>
<td>Zirconium</td>
<td>Zr</td>
</tr>
<tr>
<td>Antimony</td>
<td>Sb</td>
</tr>
<tr>
<td>Aluminum Silicates</td>
<td>Al</td>
</tr>
<tr>
<td>Coal</td>
<td>C</td>
</tr>
<tr>
<td>Florospar</td>
<td>F</td>
</tr>
<tr>
<td>Vermiculite</td>
<td>Vm</td>
</tr>
</tbody>
</table>

Table B2 illustrates how we classified mining potential into three categories: high, medium and low. We associated areas where an economically important commodity (such as gold) occurs in large deposits/mines, or where a mineralised field/layer of such commodity was mapped.

Table B2 Criteria used to map mining potential in South Africa.

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Commodity</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Large deposits/mines OR Mineralised fields/layer</td>
<td>Economically important</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium mines OR Mineralised provinces</td>
<td>Economically important</td>
</tr>
<tr>
<td>Low</td>
<td>Small deposits/mines OR Mineralised layers/fields/ provinces</td>
<td>Any</td>
</tr>
</tbody>
</table>

Table 17.1 Top vegetation types with high or medium mining potential in South Africa, ranked from the highest to the lowest potential. Percentage of the vegetation type area with high and medium mining potential is shown.

<table>
<thead>
<tr>
<th>Vegetation types</th>
<th>% High</th>
<th>% Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Namib Seashore Vegetation</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Richtersveld Coastal Duneveld</td>
<td>76</td>
<td>0</td>
</tr>
<tr>
<td>Northern Escarpment Dolomite Grassland</td>
<td>66</td>
<td>0</td>
</tr>
<tr>
<td>Subtropical Seashore Vegetation</td>
<td>53</td>
<td>0</td>
</tr>
<tr>
<td>Arid Estuarine Salt Marshes</td>
<td>49</td>
<td>0</td>
</tr>
<tr>
<td>Namaqualand Seashore Vegetation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wakkerstroom Montane Grassland</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Nk communism-Pumpe Sandy Bushveld</td>
<td>0</td>
<td>84</td>
</tr>
<tr>
<td>Eastern Highveld Grassland</td>
<td>0</td>
<td>71</td>
</tr>
<tr>
<td>Springbokvlei Thornveld</td>
<td>0</td>
<td>61</td>
</tr>
<tr>
<td>Soweto Highveld Grassland</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>Delagoa Lowveld</td>
<td>0</td>
<td>53</td>
</tr>
</tbody>
</table>

4. Degradation Vulnerability

4.1 Habitat Fragmentation

We considered three elements to derive the habitat fragmentation layer at landscape level. These were the surrounding land use (matrix resistance), the average fragment size and connectivity (distance between natural fragments). The first aspect is based on the assumption of different species movement to land cover types, by relating the species movements between different land use types to the resistance value. Landscape resistance thus represents the difficulty of a species to cross a certain land use type (Nikolakaki 2004). The approach is described in Box C. An overall habitat fragmentation index was derived by averaging the three aspects (Figure 17.2).

From this assessment, 244 vegetation types occur in areas with very low habitat fragmentation, 171 vegetation types in areas with low habitat fragmentation, 16 in areas with medium habitat fragmentation and two in areas with high habitat fragmentation. Highly fragmented vegetation types (last quartile of overall habitat fragmentation index) are listed in Table 17.2. The analysis of average fragment size separated vegetation types that are naturally fragmented (i.e. very small fragment size but high percentage extent) from those that have been fragmented due to anthropogenic change (i.e. very small fragment size and low percentage extent). For example, vegetation types such as Northern Afromontane Forest are naturally fragmented.
4.2 Alien Plant Invasion

We quantified alien plant invasion potential based on an assessment of the climatic correlates of distribution of 71 import invasive alien plants (Nel et al. 2004, Rouget et al. 2004). We assumed that alien plant species would have the potential to spread in areas identified as climatically suitable by a climatic envelope model (see Box D). Figure 17.3 illustrates the approach for three species. The index derived (re-scaled from 0 to 100) relates to the potential number of invader plants. This was then summarised per vegetation types and categorised into four categories.

A total of 157 of the vegetation types have low invasion potential where fewer than five species can invade, and five vegetation types have high invasion potential, being potentially suitable for more than 25 of the invader plants.

### Box D: Mapping alien plant potential.

Climate Envelope Models (CEMs) are very useful at a broad scale to develop a general picture of where species are most likely to invade, especially in this region with marked climatic gradients. In this study, we used a variant of CEMs based on an oblique ellipse model, which calculates the Mahalanobis distance to the 'optimal' climate conditions. Such models are supported by the niche theory which assumes the existence of optimal environmental conditions for a species and that any deviation from this optimum is associated with a lower climatic suitability. These models are an improvement on traditional CEMs in that a continuous range of climatic suitability values can be equated with probability of occurrence. We derived climatic suitability surface for 71 major invader plants.

Preliminary analyses suggested that the relative importance of climatic factors was species specific, making it difficult to identify a few 'generic' climatic variables that could be applied for all our species. We therefore reduced the large number of possible explanatory variables to three components (principal component axes 1, 2 and 3) using Principal Component Analysis (PCA). The first three components of the resulting PCA explained over 95% of the initial variation, based on the seven climatic variables with the greatest influence on plant species distribution. We then used these three climatic indices to derive the CEMs. We assumed that alien plant species would have the potential to spread in areas identified as climatically suitable by the CEMs. Rouget et al. [2004] describe the approach in more detail. Ideally, CEMs for alien plants should also be based on their bioclimatic occurrence in their continent of origin (Rutherford et al. 1995) and any other areas of the world where they are invasive.

Species potential distributions were derived on a grid of 1-minute resolution. We quantified alien plant invasion potential by calculating the number of alien plants that could potentially invade each 1-minute cell (i.e. for which the climate is suitable). The index was re-scaled from 0 to 100.

Most species are currently confined to 10% or less of the region, but could potentially invade up to 40%, based on their climatic envelope. Depending on the species, between 2% and 79% of the region is climatically suitable for species to invade, and some areas were suitable for up to 45 invader plants. Over one third of the major invader plants considered here have limited potential to substantially expand their distribution.

The number of potential invaders was then averaged per vegetation type to produce an index of alien plant invasion potential per vegetation type. This was classified into four categories (very low, low, medium and high) based on equal intervals.

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**Box C: Habitat fragmentation.**

1. Resistance Layer

The land cover map (including roads) was reclassified to reflect resistance to species movement. The types that allow minimal resistance were given a value of 0 (e.g. natural areas), while other types offer a greater resistance (Table C1). The layer was aggregated to 1 km distance in order to average the resistance value for fragments that are within the prescribed dispersal distance (1 km) using Grid Analyst in Arc View GIS. This produced a resistance layer with values ranging from 0 to 100. The cut-offs used for resistance values were as follows: 0-25, very low; 25-50, low; 50-75, medium; 75-100, high. We summarised the resistance values per vegetation type to classify the vegetation types into four categories of habitat fragmentation in terms of resistance to species movement using equal interval categories.

### Table C1 Land use classification based on the estimated landscape resistance value. Note: estimated resistance values were not species-specific.

<table>
<thead>
<tr>
<th>Land use types</th>
<th>Landscape resistance value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forests &amp; Woodlands</td>
<td>0</td>
</tr>
<tr>
<td>Thicket &amp; Bushland</td>
<td>0</td>
</tr>
<tr>
<td>Grassland</td>
<td>0</td>
</tr>
<tr>
<td>Wetlands</td>
<td>0</td>
</tr>
<tr>
<td>Waterbodies</td>
<td>25</td>
</tr>
<tr>
<td>Degraded land</td>
<td>50</td>
</tr>
<tr>
<td>Minor roads</td>
<td>50</td>
</tr>
<tr>
<td>Cultivated land</td>
<td>75</td>
</tr>
<tr>
<td>Forest plantation</td>
<td>75</td>
</tr>
<tr>
<td>Mines &amp; Quarries</td>
<td>85</td>
</tr>
<tr>
<td>Major roads</td>
<td>85</td>
</tr>
<tr>
<td>Urban/Buildup Land</td>
<td>100</td>
</tr>
</tbody>
</table>

2. Extent of Habitat Transformation

To derive the extent of habitat transformation, we reclassified the NLC layer into natural and transformed areas (where natural areas = 0 and transformed areas = 1). The layer was then aggregated to 1 km using a sum method to calculate the percentage of habitat transformation within 1 km blocks. Values ranged from 0 (natural 1 x 1 km block) to 100 (transformed 1 x 1 km block). The layer was then summarised per vegetation type, which were reclassified into four categories of habitat fragmentation in terms of habitat transformation extent using equal interval categories.

3. Fragment Size

A unique value was assigned to each fragment of natural habitat per vegetation type (using the Arc Info command 'region group'). We then determined the area of each fragment of natural vegetation per vegetation type. The average fragment size was calculated for each vegetation type. We re-scaled the average fragment size value from 0 (average fragment size: 22,641 ha) to 100 (average fragment size: 1 ha). We reclassified vegetation types into four categories of habitat fragmentation in terms of fragment size using equal intervals.

4. Habitat Fragmentation Index

The overall habitat fragmentation index was derived per vegetation type. We averaged the values obtained for resistance to species movement, extent of habitat transformation and average fragment size. Vegetation types were then classified into four categories (very low, low, medium and high) of habitat fragmentation using equal intervals.
5. Overall Vulnerability of Vegetation Types

Not all the vegetation types of the country are affected by land use pressures and degradation (Figure 17.4) in the same way. Out of 433 vegetation types, 207 vegetation types have a very low overall vulnerability index. A total of 217 vegetation types have a low overall vulnerability index. However, nine vegetation types have a medium overall vulnerability index (i.e. average greater than 50 for all vulnerability types).

The six vegetation types that are the most likely to be affected (based on the combined vulnerability index of land use and degradation) are (in decreasing order): ourensford Alluvium Fynbos, Knysna and Fynbos, Algoa Sandstone Fynbos, Cape Flats Sand Fynbos, Egoli Granite rietland and KwaZulu-Natal Sandstone ouveld. Table 17.3 lists the three most threatened vegetation types for each land use and degradation pressure.

One can also analyse vulnerability in terms of the areas highly vulnerable to land use or degradation pressure (core >75 for one or more of the six vulnerability types considered).

Figure 17.3 Species presence observations and climatic suitability derived from climatic envelope models for three characteristic species in South Africa, Lesotho and Swaziland: (a) Acacia mearnsii, a very widespread and abundant invader; (b) Opuntia stricta, a widespread and common invader; and (c) Hakea drupacea, a localised and abundant invader (from Rouget et al. 2004).

Figure 17.4 Average vulnerability of land use pressure, habitat degradation and overall vulnerability.
### Table 17.3 Top three highly vulnerable vegetation types for both land use and degradation pressures as well as for overall vulnerability.

<table>
<thead>
<tr>
<th>Vulnerability</th>
<th>Vegetation type 1</th>
<th>Vegetation type 2</th>
<th>Vegetation type 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>Mangrove Forest</td>
<td>Cape Flats Sand Fynbos</td>
<td>Cape Flats Dune Strandveld</td>
</tr>
<tr>
<td>Land degradation</td>
<td>Lourensford Alluvium Fynbos</td>
<td>Cape Lowland Alluvial Vegetation</td>
<td>Röens Silcrete Renosterveld</td>
</tr>
<tr>
<td>Overall vulnerability</td>
<td>Lourensford Alluvium Fynbos</td>
<td>Krysan Sand Fynbos</td>
<td>Algoa Sandstone Fynbos</td>
</tr>
</tbody>
</table>

Regarding land use pressure only, the most threatened vegetation types (i.e. irrespective of the number of pressures) are in the Northern Cape coastal belt and localised parts of the interior of the province, central parts of Limpopo Province, parts of Gauteng, the coastal and mostly the southern parts of KwaZulu-Natal, the northeastern Eastern Cape and the lowlands of the Western Cape (Figure 17.5). In these terms, the most vulnerable vegetation types are the Cape Flats Sand Fynbos, Cape Flats Dune Strandveld, Lourensford Alluvium Fynbos, Peninsula Granite Fynbos, Peninsula Shale Renosterveld, Peninsula Sandstone Fynbos and Namib Seashore Vegetation (not identified as a vulnerable vegetation type based on the average overall vulnerability index).

Regarding degradation vulnerability only, Figure 17.6 highlights areas of high vulnerability to habitat fragmentation and/or alien plant invasion. This highlights 12 vegetation types most vulnerable to habitat degradation, including most of the Cape Lowlands vegetation types.

Predicting vulnerability to future land use pressures can be complex, but we found that the current extent of habitat transformation can serve as a broad predictor of vulnerability. The combined vulnerability index (see Figure 17.4) was correlated with the current extent of habitat transformation (Figure 17.7). For example, the Lourensford Alluvium Fynbos with 91% of its vegetation transformed has a high vulnerability index (vulnerability score of 61). However, there are many outliers where a vegetation type is either highly transformed with a low vulnerability index or vice versa. The land use vulnerability score was poorly correlated with the percentage of current habitat transformation.

### 6. Conclusion

Recently, the National Spatial Biodiversity Assessment (Driver et al. 2005) quantified the current status of vegetation types. This revealed that 19 vegetation types are critically endangered, in other words ecosystem functioning has been severely disrupted by habitat transformation and such vegetation types could experience species loss. This also indicated that 53 vegetation types are endangered, 69 are vulnerable and 292 are least threatened.

Although the current ecosystem status highlights that 67% of the vegetation types are currently least threatened, our analysis of future vulnerability to land use pressures and degradation suggests that many vegetation types could experience further loss of habitat and/or loss of ecosystem functioning. The conservation challenge is now to identify which vegetation types should require immediate conservation efforts in order to mitigate the impacts of future land use changes. We recommend that vegetation types under high land use pressure but currently not transformed and/or not protected should receive conservation attention.
7. Credits

The unpublished version of the vegetation map used for this vulnerability analysis was provided by M.C. Rutherford and L. Mucina. The GIS data were obtained from L.W. Powrie. The layer of land capability, afforestation potential and population density was provided by B. Reyers and was requested from different sources. Z. Jonas and M. Rouget created the layer of mining potential and habitat fragmentation index. M. Rouget provided the layer of alien plant invasion. Z. Jonas, B. Mohamed and M. Rouget did the analysis. Z. Jonas was the lead author, M. Rouget and B. Reyers provided substantial input and editing on early drafts. L. Mucina and M.C. Rutherford provided final editorial comments. Valuable scientific and technical input was provided by conservation planners involved in the National Spatial Biodiversity Assessment.

8. References


