LONG TERM ADAPTATION SCENARIOS

TOGETHER DEVELOPING ADAPTATION RESPONSES FOR FUTURE CLIMATES

BIODIVERSITY

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

giz

On behalf of
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

SANBI
Biodiversity for Life

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LONG-TERM ADAPTATION SCENARIOS
FLAGSHIP RESEARCH PROGRAMME (LTAS)

CLIMATE CHANGE IMPLICATIONS FOR THE BIODIVERSITY SECTOR IN SOUTH AFRICA

LTAS Phase 1, Technical Report (no. 6 of 6)

The project is part of the International Climate Initiative (ICI), which is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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LIST OF ABBREVIATIONS

CCAM	Cubic Conformal Atmospheric Modelling
CEPF	Critical Ecosystem Partnership Fund
CO_2	Carbon dioxide
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DGVM	Dynamic Global Vegetation Modelling
GIZ	Die Deutsche Gesellschaft für Internationale Zusammenarbeit
ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
MDGs	Millennium Development Goals
NMMU	Nelson Mandela Metropolitan University
NPAES	National Protected Areas Expansion Strategy
Rnd	Rainfall days
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
UNFCCC	United Nations Framework Convention on Climate Change

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THE LTAS PHASE 1

The Long-Term Adaptation Scenarios (LTAS) Flagship Research Programme (2012–2014) is a multi-sectoral research programme, mandated by the South African National Climate Change Response White Paper (NCCRP, para 8.8). The LTAS aims to develop national and sub-national adaptation scenarios for South Africa under plausible future climate conditions and development pathways. During its first Phase (completed in June 2013), fundamental climate modelling and related sector-based impacts and adaptation scoping were conducted and synthesised. This included an analysis of climate change trends and projections for South Africa that was compared with model projections for the same time period, and the development of a consensus view of scenarios for three time periods (short-, medium- and long-term). Scoping of impacts, adaptation options and future research needs, identified in the White Paper and guided by stakeholder engagement, was conducted for primary sectors namely water, agriculture and forestry, human health, marine fisheries, and **biodiversity**. This modelling and scoping will provide a basis for cross-sectoral and economic assessment work needed to develop plausible adaptation scenarios during Phase 2 (scheduled for completion in April 2014).

Six individual technical reports have been developed to summarise the findings from Phase 1, including one technical report on climate trends and scenarios for South Africa and five summarising the climate change implications for primary sectors, water, agriculture and forestry, human health, marine fisheries, and **biodiversity**. A description of the key messages emerging from the LTAS phase 1 has been developed into a summary for policy-makers; as well as into seven factsheets constituting the LTAS Climate and Impacts Factsheet Series.

REPORT OVERVIEW

This technical report presents the LTAS Phase I findings for the biodiversity sector. It references existing South African research combined with insights from global projections to develop a preliminary picture of the potential effects of climate change on South Africa's biodiversity using biome-based complemented by a species-based approach. Specifically, it summarises climate change impacts under an unconstrained global fossil fuel emissions scenario (IPCC A2 emissions scenario) as well as general adaptation response options and future research needs for the biodiversity sector, based on the results of relevant past and current research, including impact modelling for South African biomes and indicator species, as well as the National Biodiversity Framework, the National Protected Area Expansion Strategy and additional work under the Biome Adaptation Framework project, which is currently preparing to develop biome adaptation plans.

This report provides a significant update to previous understanding of the rate and extent of climate change impacts on biomes, ecosystems and biodiversity in South Africa. In particular, describes the potential vulnerability of South Africa's nine biomes (and their biodiversity) to projected climate change over the medium and long term (i.e. from 2020 – 2050). It updates previous vulnerability assessments that explored potential shifts in the 'bioclimatic envelope' of South Africa's biomes, a technique that provides a broad indication of areas that may suffer adverse impacts of climate change on biodiversity. The biome-based approach would benefit from assessments and projections at finer scales with potential to enhance monitoring and tracking of climate change impacts and the effectiveness of adaptation responses with greater precision. To this end, species-based results using indigenous birds are presented, including rates of species change in response to climate changes that have been determined by modelling the potential shifts in range of 623 of southern Africa's endemic bird species to complement the biome-based approaches. A brief description of each chapter of the technical report is provided below.

Chapter 1 (Introduction) describes the crucial links between biodiversity, ecosystem health, economic and livelihood activities and overall human well-being in South Africa, including the importance of well-functioning ecosystems in providing natural solutions for building resilience and helping society adapt to climate change impacts.

Chapter 2 (South Africa's Biomes) provides a description of South Africa's biomes, including a preliminary assessment of the ecosystem services they provide as well as their current protected area status.

Chapter 3 (Methodology) outlines the methodology used for the results presented in the report, building on previous assessments conducted in the late 1990s and early 2000s.

Chapter 4 (Climate change impacts on South Africa's biodiversity – a biome-based perspective) presents results of biome vulnerability separately for to land-use change and climate change under "low", "intermediate (median)" and "high" risk climate scenarios as well as results for overall biome vulnerability to combined the threats of land-use and climate change.

Chapter 5 (Climate change impacts on South Africa's biodiversity – a species-based approach) presents results for rates of species change in response to climate changes have been determined by modelling the potential shifts in range of 623 of southern Africa's endemic bird species.

Chapter 6 (Climate change adaptation response options) provides a broad overview of adaptation response options for South Africa highlighting the importance of mainstreaming the potential of biodiversity and ecological infrastructure to achieve sector-specific adaptation and development outcomes/benefits and indicating that the appropriate and specific types of local action required would need to be further define in biome specific adaptation plans.

Chapter 7 (Research requirements) briefly summarises research gaps related to climate change uncertainties as well as general considerations for research priorities for the sector.

Chapter 8 (Conclusion) concludes the report highlighting that the results in this report provide the basis for the developing specific biome adaptation plans under the Biome Adaptation Framework

EXECUTIVE SUMMARY

Biodiversity is crucial to ecosystem health, and healthy ecosystems are central to human well-being. Healthy ecosystems interlinked with working landscapes and other open spaces form the ecological infrastructure of the country and are the foundation for clean air and water, fertile soil and food. All South Africans depend on healthy ecosystems for economic and livelihood activities, including agriculture, tourism and a number of income generating and subsistence level activities. These natural ecosystems are under pressure from land use change and related processes causing degradation, as well as invasive alien species. Accelerated climate change (resulting in increasing temperature, rising atmospheric CO_2 and changing rainfall patterns) is exacerbating these existing pressures.

Based on a comparison of the threatened status and protection levels of each of South Africa's nine biomes, the following biomes are most vulnerable to land-use change:

- High priority: *Indian Ocean Coastal Belt* (critically endangered and with very low protected area representation)
- Second priority: *Grassland* (endangered and with low protected area representation)
- Third priority: *Fynbos* and *Forest* (endangered and with moderately well protected area representation).

Based on an assessment of the spatial shift of the optimum climatic conditions for South African biomes under "low", "intermediate (median)" and "high" risk climate scenarios, all representative of unconstrained emission scenarios, the following biomes are most vulnerable to climate change:

- Most threatened: *Grassland* – under all climate scenarios, with large portions of the biome prone to replacement by savannah and potentially forest vegetation.
- Second most threatened: *Nama-Karoo* – under all climate scenarios with savannah and desert vegetation projected to expand into large portions of the current biome.
- Third most threatened: *Indian Ocean Coastal Belt, Fynbos* and *Forest*:
  - Large portions of *Indian Ocean Coastal Belt* prone to replacement by *Savanna* under intermediate and high risk climate scenarios.
  - The north-eastern regions of *Fynbos* prone to replacement by *Succulent Karoo* or *Albany Thicket* under all climate scenarios.
  - *Forest* projected to retract significantly possibly as a result of increased fire and especially due to reduced rainfall under all climate scenarios.
- *Albany Thicket* is least threatened and projected to suffer losses in area only under the high risk climate scenario.
- *Desert* projected to expand at the expense of other biomes under all climate scenarios and in particular under the high risk climate scenario.
- The wettest and coolest "low" risk climate scenario projected to result in relatively minor impacts on almost all biomes.

The following species-level changes in response to climate changes have been determined by modelling the potential shifts in range of 623 of southern Africa's endemic bird species:

- High potential rates of loss in bird species richness are projected in the central interior, especially the Kgalagadi Transfrontier Conservation Area, an area at risk of potential aridification and Desert biome expansion.
- The north-eastern boundary of South Africa, from northern KwaZulu-Natal, along the border with Mozambique, and along the Limpopo basin is projected to face substantial risk for loss of bird species richness.

These results show that i) the rate and extend of biome "shift" for some biomes is less extreme than for projections made in early assessments such as South Africa's Initial National Communication to the UNFCCC, mainly because the projected rate of climate change is slower; ii) winter rainfall biomes could be more resilient to climate change impacts over the medium terms than previously estimated; iii) the Grassland Biome is projected to show the greatest reduction in spatial extent; and v) Savanna and Desert Biomes show the greatest potential expansion – which could change ecosystem structure and function across vast areas of the dry interior and moist coastal zone and highlands. Such geographic range changes in biomes would cause cascading effects through ecosystems, and substantially alter the benefits people derive from ecosystems, such as clean water, wood products and food. There remains substantial uncertainty in these projections due to poorly understood effects of seasonal changes in rainfall and the effects of rising atmospheric CO_2.

Biodiversity has been shown to have high value especially due to its role in maintaining healthy ecosystems, and its supporting role in livelihoods. Biodiversity and ecological infrastructure are national assets and powerful contributors to economic development, provision of recourses, ecological processes, and improvement of human wellbeing. Biodiversity is one of the pillars of sustainable development, without which we cannot achieve the Millennium Development Goals. Well-functioning ecosystems provide an immensely valuable current and future role in buffering human society from the worst effects of climate variability and climate change.

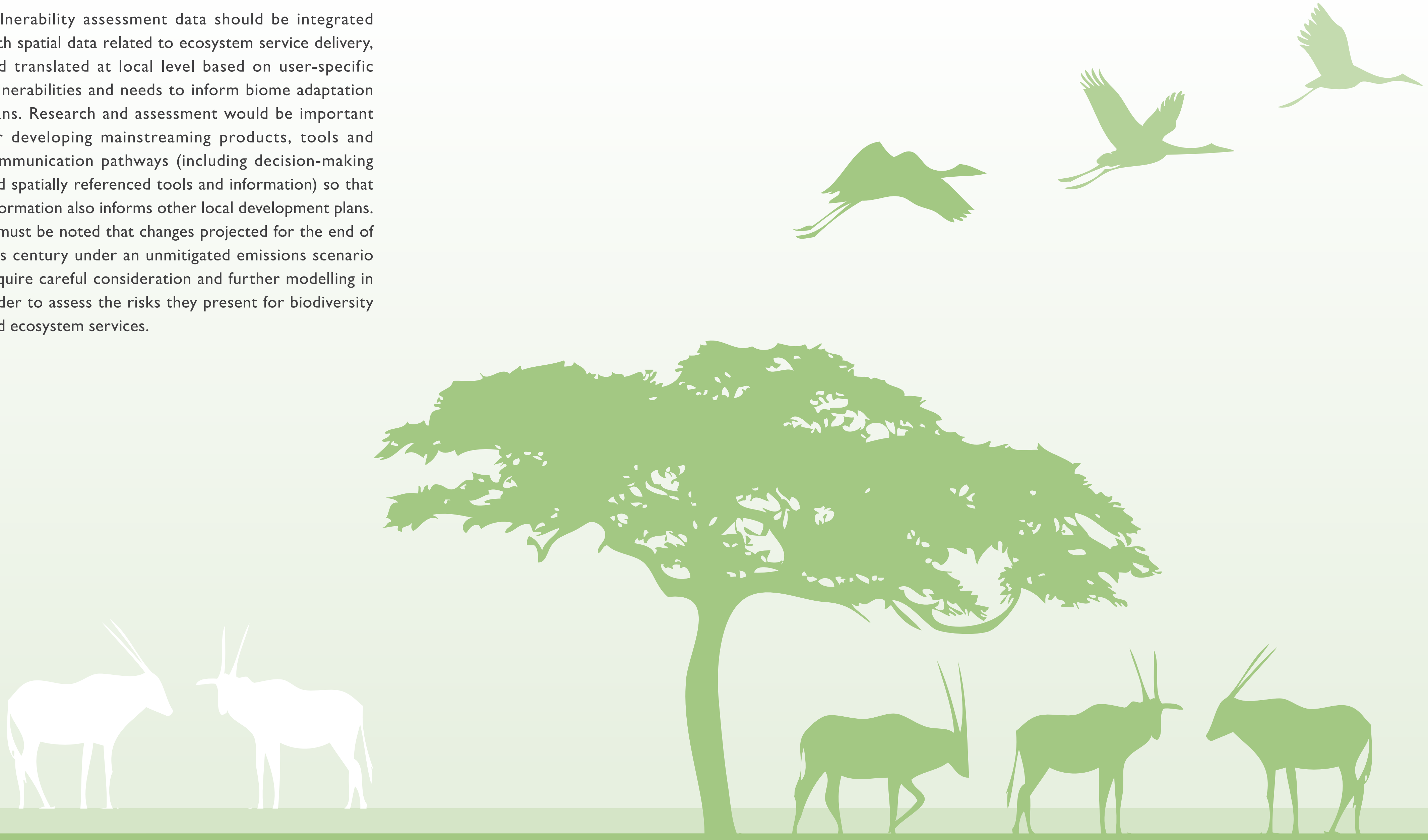
Well-functioning ecosystems provide natural solutions that build resilience and help society adapt to the adverse impacts of climate change. This includes, for example, buffering communities from extreme weather events such as floods and droughts, reducing erosion and trapping sediment, increasing natural resources for diversifying local livelihoods, providing food and fibre, and providing

habitats for animals and plants which provide safety nets for communities during times of hardship. Sustainably managed and/or restored ecosystems help in adapting to climate change at local or landscape level.

To increase the resilience of biodiversity and ecosystem service delivery under future climate conditions synergies could be developed during adaptation planning and implementation between biodiversity, poverty reduction and development objectives. Authorities should focus on mainstreaming the potential of biodiversity and ecological infrastructure for achieving adaptation and development benefits across sectors into policy planning and implementation. Ecosystem-based Adaptation and expansion of protected areas using climate-resilient approaches offer two adaptation response options for the biodiversity sector that are appropriate for achieving increases in the climate resilience of biodiversity and maintaining and/or enhancing ecosystem service delivery. These two approaches should be adapted as necessary to build the resilience of ecological infrastructure to support economic sectors and livelihood activities.

Appropriate and specific types of local action required would need to be further defined in biome specific adaptation plans. This would include stakeholder engagement and a focus on implementation at local level prioritising multi-benefit, low-cost approaches; integrating adaptation and mitigation responses; and making use of indigenous knowledge. Biome adaptation plans and their implementation, would contribute to building climate-resilience at the biome level, and provide support to adaptation in other sectors such as water, agriculture and forestry, and human health through ensuring continued supply of ecosystem services. These plans, however, need to be mainstreamed across sectors for adaptation benefits to be realised.

Vulnerability assessment data should be integrated with spatial data related to ecosystem service delivery, and translated at local level based on user-specific vulnerabilities and needs to inform biome adaptation plans. Research and assessment would be important for developing mainstreaming products, tools and communication pathways (including decision-making and spatially referenced tools and information) so that information also informs other local development plans. It must be noted that changes projected for the end of this century under an unmitigated emissions scenario require careful consideration and further modelling in order to assess the risks they present for biodiversity and ecosystem services.



1. INTRODUCTION

Economic activity, human security, health, well-being and quality of life depend on healthy functioning and biodiverse ecosystems. Ecosystems provide important services to society, such as the formation of soil; the provision of food, fresh water, wood, fibre and fuel; the regulation of climate, flood and disease; protection from storm surges and floods; and a range of cultural, spiritual, educational and recreational services. While biodiversity and healthy ecosystems provide wide-ranging benefits to society on the whole, many communities globally, and especially in Africa, depend directly on the products from local ecosystems for the majority of their food, energy, water and medicinal requirements (Murombedzi, 2008).

Climate change poses severe challenges for ecosystems, both as a direct threat and by heightening their existing stresses, which include degradation of habitat and landscapes through vegetation clearing, introduced pest animals and weeds, highly modified and overcommitted water resources, altered fire regimes, widespread use of fertiliser and other chemicals, urbanisation, mining and, for some species, over-harvesting. The degradation of ecosystems affects their ability to deliver ecosystem services, which in turn has a direct negative impact on human well-being as well as socio-economic conditions, especially for the poor. Climate change is likely to cause stress to ecosystems by altering their functioning and by compromising individual species (IPCC, 2007c).

Anthropogenic climate change was first recognised as a global threat in the late 1980's, prompting the development of the United Nations Framework Convention on Climate Change (UNFCCC). The Intergovernmental Panel on Climate Change (IPCC) was subsequently established to assess this risk. To date four assessment reports addressing impacts and adaptation have been published (IPCC, 1990; IPCC, 1996; IPCC, 2001; IPCC, 2007a,b,c). The IPCC's Fourth Assessment Report (IPCC, 2007a,b,c) drew the world's attention to the real and imminent effects of climate change, and especially those on ecosystems and biodiversity. It highlighted the potential impacts on biodiversity of rising global average temperature, changes in rainfall patterns, extreme weather events, and changes in sea levels. It further provided preliminary assessments of the consequences of these biodiversity impacts on the global economy and on rural livelihoods and development options. The report highlighted that climate change has the potential to undermine sustainable development, increase poverty, and delay or prevent the realisation of the Millennium Development Goals (MDGs). Significant adverse impacts for the African continent were also highlighted, including reduced water and food security (Madzwamuse, 2010).

The potentially adverse environmental and social impacts of these changes can be offset to some degree by applying principles that enhance the potential for ecosystems to adapt to a changing climate, which by extension includes maintaining the biodiversity within those ecosystems. This set of principles is termed 'ecosystem-based adaptation'.

In order for policymakers and practitioners involved in biodiversity and ecosystem management to design appropriate policy and management measures that support ecosystem-based adaptation, there is a critical need to assess the vulnerability of ecosystems and their component species to climate change and its associated impacts. 'Vulnerability' in this context can be defined as the degree to which an ecosystem is exposed and susceptible to the adverse effects of climate change, including climate variability and extremes, which is offset by its 'adaptive capacity', defined as the extent to which an ecosystem can reduce its exposure and/or its susceptibility to these adverse effects (Madzwamuse, 2010). Vulnerability assessments serve as a guide for spatially prioritising species conservation, ecosystem protection, and ecological restoration, and can facilitate the development of appropriate adaptation measures that can be integrated into existing sustainable development strategies.

2. SOUTH AFRICA's BIOMES

2.1 Introduction

The biome concept as developed for southern Africa groups ecosystems with broadly similar vegetation structure (*Rutherford et al, 2006a*). A significant advantage of this type of classification is that biomes also represent ecosystems with similar functions and processes, and which are subject to similar disturbance regimes, for example fire, browsing or grazing. The natural systems of South Africa consist of nine biomes (Mucina & Rutherford, 2006; Petersen & Holness, 2011; DEAT & SANBI, 2009), described in terms of their vegetation structure correlated with climatic variations (DEAT, 2005; Steenkamp et al, 2008). These are identified as follows: Albany thicket, desert, forest, fynbos, grassland, Nama-Karoo, Succulent Karoo, savanna and the Indian Ocean coastal belt (Figure 1). Although a particular biome usually predominates over large areas, component parts may sometimes be dispersed as sparse pockets within other biomes. For instance, the Maputaland-Pondoland-Albany region (Figure 2) is a regional biodiversity hotspot composed of forest, Albany thicket, savanna and grassland biomes (CEPF, 2010).

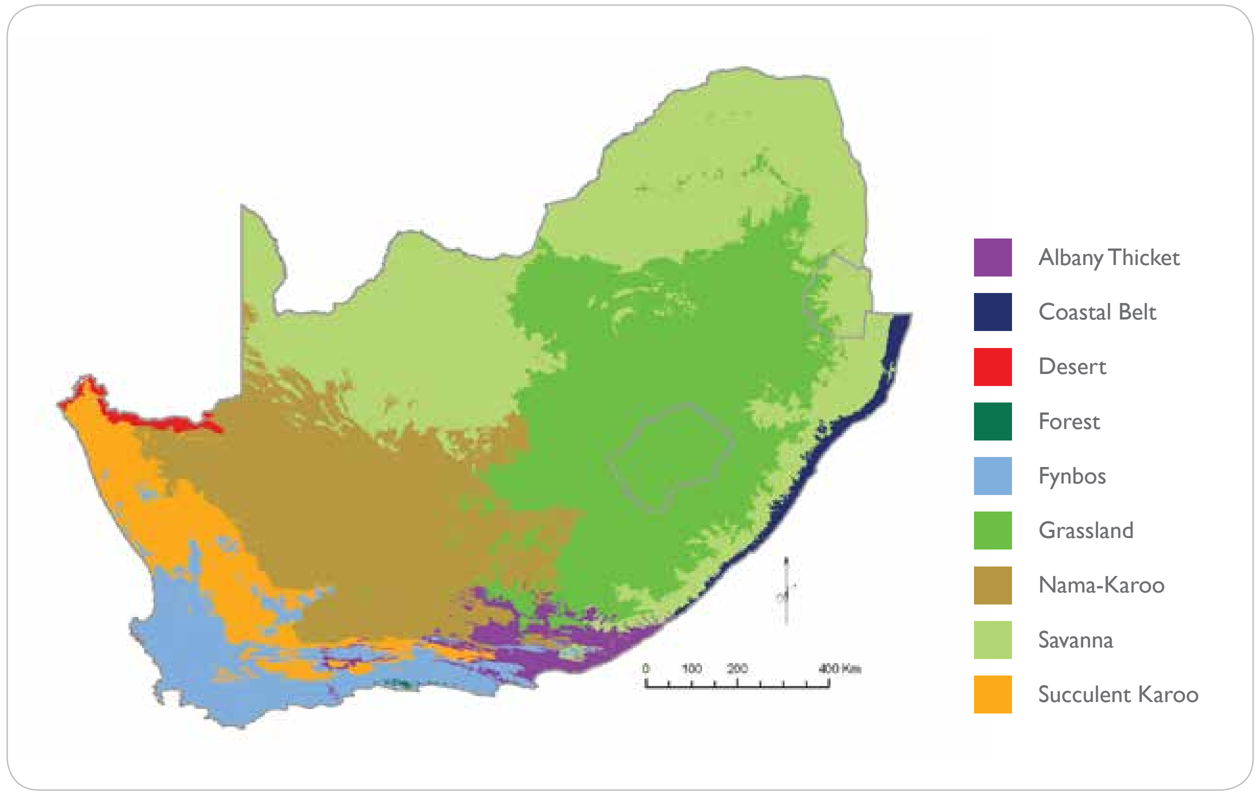


Figure 1: The biomes of South Africa (after Cadman et al. *2010).*

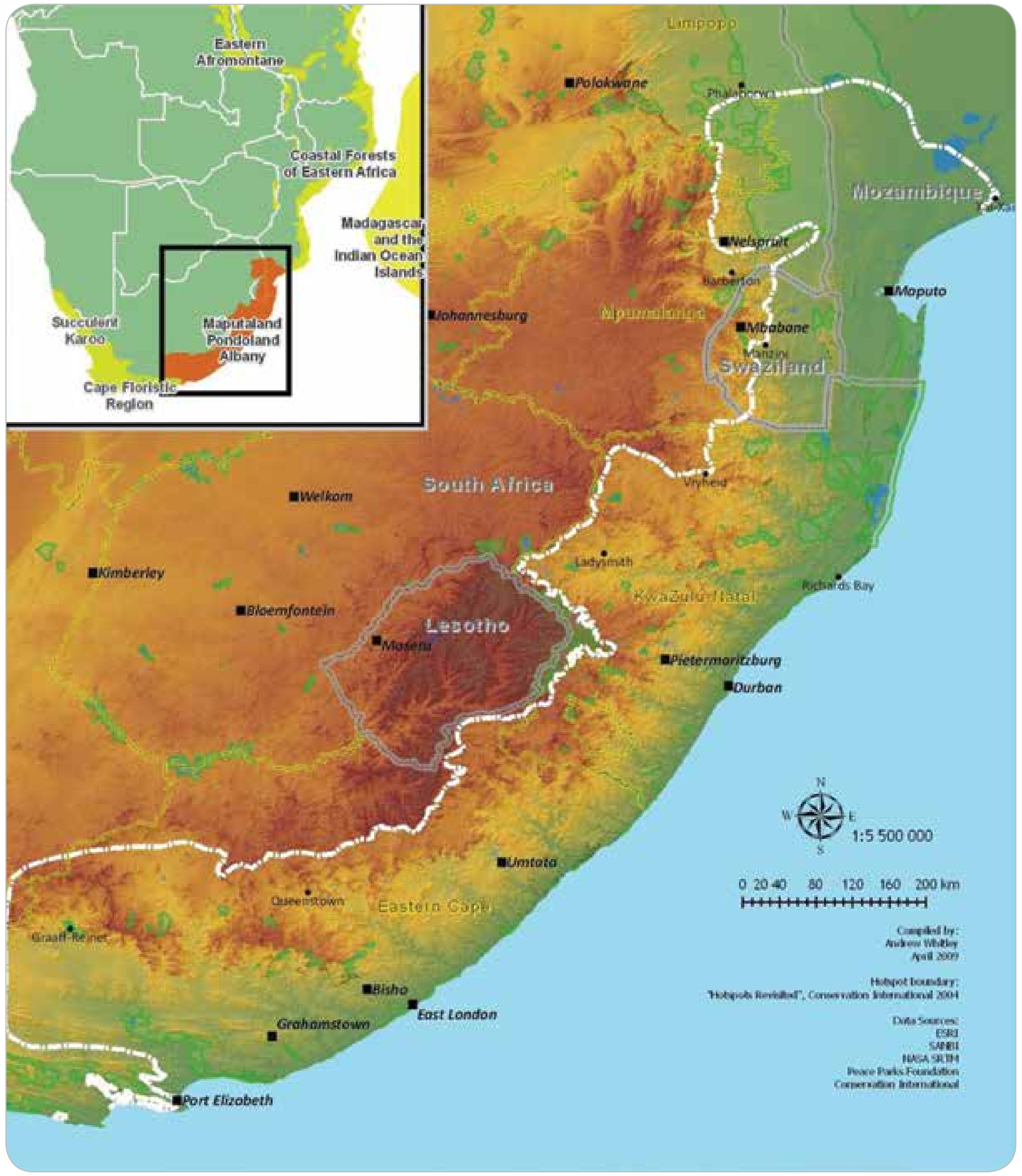


Figure 2: Map of the Maputaland-Pondoland-Albany region (CEPF, 2010).

Sections 2.1.1 to 2.1.9 below briefly describe each of the biomes and include a summary of some of the ecosystem services provided by each biome Azonal vegetation is not considered or described in this report, as its fragmented nature does not lend itself to assessment in the current framework. This is not to say that these critical elements of biodiversity do not deserve attention in a future climate change impact and vulnerability assessment. In addition to describing the overall picture for each of the biomes as depicted in Figure 3, Sections 2.1.1 to 2.1.9 also provide a summary of the current protected area status of each biome. The South African National Protected Areas Expansion Strategy (NPAES) (DEAT, 2008) set a 20-year protected area target for each biome, totalling to 12% of South Africa's land area. Figure 3 provides an overall picture of the protection status of the biomes at the time this strategy was released, showing the proportion of 20-year protected area targets not met per biome, versus biome size in hectares (ibid.). A full elaboration of these aspects is available in the recently completed National Biodiversity Assessment 2011 (Driver et al, 2012).

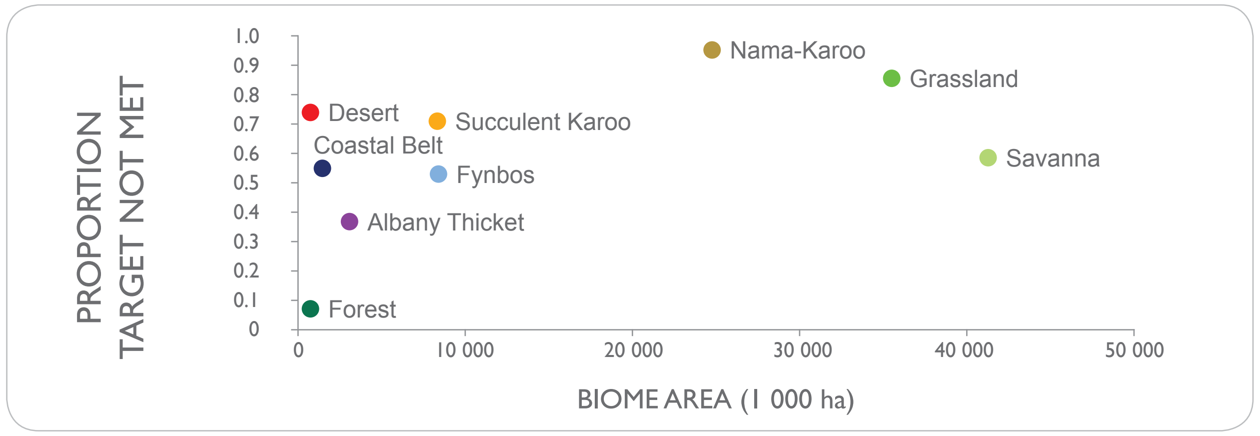


Figure 3: The proportion of 20-year protected area targets not met per biome, versus biome size (based in data from DEAT, 2008).

2.1.1 Albany Thicket

The Albany thicket is formed by a dense canopy of large evergreen shrubs and low trees (0.5 – 3.0 m) often straddled by woody lianas, and a sparse understorey of shade-tolerant herbs, mostly comprising geophytes and succulents. C_3 and C_4 grasses are poorly represented within thicket clumps, but may be common in the spaces between them. In general, large succulent shrubs such as *Portulacaria afra* and *Crassula ovata* dominate the canopy, while aloes and euphorbias frequently emerge from it (Noirtin, 2008). Portulacaria afra, commonly known as spekboom, is the signature shrub of this biome. It has adapted to high browsing pressure by elephants and other herbivores, and due to its high carbon sequestration capacity provides an opportunity for South Africa to capitalise on carbon markets (CEPF, 2010). The thicket biome is predominantly found where annual rainfall varies between 200 and 1,050 mm (Vlok et al, 2003), in deep and relatively fertile soils, and in sites that are protected from fire. The thicket biome is located in the southeastern region of South Africa, mainly in the Eastern Cape, where it is most extensive in the major river valleys such as the

Gouritz, Baviaanskloof-Gamtoos, Sundays, Great Fish and Kei (CEPF, 2010). The Albany Adder (*Bitis albanica*) is one of its flagship species.

Some of the ecosystem services found in this biome include the production of forage (Reyers et al, 2009), provision of soil services (Egoh et al, 2009), wood, fruits and medicines. As already mentioned, the thicket biome has a high carbon storage capacity and hence provides a carbon sequestration service. Other ecosystem services provided by the thicket biome (especially in the Baviaanskloof Nature Reserve) include the supply of water for domestic and irrigation uses, the maintenance of biodiversity through land cover and provision of eco-tourism services (Noirtin, 2008; Egoh et al, 2009).

Currently, Albany thicket is relatively well protected when compared with the other biomes, although almost 40% of its proportional protected area target as not yet been met (Figure 3).

2.1.2 Desert

The desert biome in South Africa occurs in a small area in the northwest of the country, mainly in the Springbokvlakte area of the Richtersveld in the lower Orange River valley (Rutherford, 1997). The climate is characterised by summer rainfall, but with high levels of summer aridity (ibid.). Mean annual rainfall ranges from approximately 10 mm in the west to 70 mm in its eastern inland margins (ibid.). The vegetation of the biome is dominated by annual plants (often annual grasses) and in some areas by drought resistant shrubs (ibid.).

The desert biome provides grazing resources to livestock, which are critical for pastoral communities in these regions (Desmet et al, 2006). Ecosystem goods and services include wild food sources, forage and rangeland grazing, fuel, building materials, and water for humans and livestock, for irrigation and for sanitation, and genetic resources, especially of arid-adapted species (Adeel et al. 2005; Hassan et al. 2005; IPCC 2007c). The desert is relatively poorly protected, with only just over 20% of its proportional protected area target having been met (Figure 3).

2.1.3 Forest

Indigenous forests are found on the southern coastal plain, in the area between George and Storms River, at high altitudes along the Drakensberg escarpment and the Hogsback area of the Eastern Cape, along the east coast of KwaZulu-Natal, and in fire-protected valleys in the southern and western Cape (DEAT, 2003). They are restricted to frost-free areas with mean annual rainfall of more than 525 mm in the winter rainfall region and more than 725 mm in the summer rainfall region (Bredenkamp et al, 1996; Midgley et al, 1997; Kraai, 2010). According to Midgley et al (2008), the forest biome is one of the smallest in the country: only 0.4% of South Africa is covered by this biome (DEA, 2010).

Ecosystem services available within the forest biome include carbon sequestration, provision of firewood, fencing material and medicinal plants (Egoh et al, 2009) as well as the provision of other non-market forest products (Le Maitre et al, 2007). Forests sequester the largest fraction of terrestrial ecosystem carbon stocks (Sabine et al. 2004; Fischlin et al. 2007). All forests are protected under the National Forests Act, (DWA 2005), having met more than 90% of its 20-year protected area target (Figure 3).

2.1.4 Fynbos

The fynbos biome is found in the western parts of South Africa. Average annual rainfall varies from about 210 mm in the inland valleys, to above 800 mm in the mountains (Cowling et al, 1997). Climatic factors, geology and soils distinguish fynbos from the Succulent Karoo (Milton et al, 1997). Fynbos is dominated by a wide variety of shrubs and grass-like restios, but lacks tree and grass cover, and thus does not support a significant large mammal fauna. Species richness of some animal groups is high, including birds, small mammals, frogs, reptiles and insects. It is understood that at least 5,600 of the 8,000 plant species found in the region are endemic to this area. Most fynbos plant endemics have specific adaptive characteristics that relate to disturbance by fire. Wildfire is therefore a key ecosystem process in fynbos, and an important management tool, because diversity and composition can be influenced by the season and frequency of burning (Mucina & Rutherford, 2006). Many fynbos species have highly localised distributions. This contributes to their vulnerability to various threats including alien plant invasion, and as a consequence roughly three-quarters of South African Red Data Book species occur in the fynbos biome (Mucina & Rutherford, 2006).

The fynbos biome provides significant amounts of water, and soil services (Egoh et al, 2009). This biome also provides ecosystem services in the form of products harvested from fynbos plant species as well rich genetic resources (Le Maitre et al, 2007). The fynbos biome also provides nutrient cycling and pollination services (ibid.).

While the fynbos biome appears relatively well protected (Figure 3), the reality is that mountain fynbos ecosystems are well protected, while the lowlands are severely under-protected, and are highly vulnerable to the compound future impacts of climate change and land use pressures (Driver et al, 2012).

2.1.5 Grassland

The grassland biome mostly occurs in the summer rainfall areas (Midgley et al, 2008), dominating much of the Highveld, where frost restricts the growth of trees. It spans an annual rainfall gradient of 400 to more than 1,200 mm and has a temperature gradient ranging from frost-free to snow-bound in winter (ibid.). The grassland biome adjoins all except the desert, fynbos and Succulent Karoo biomes (O'Connor & Bredenkamp, 1997).

In the grassland areas water flow regulation is one of the most important ecosystem services (CEPF, 2010). Grasslands also provide essential ecosystem services necessary for economic development (SANBI, 2005; DEAT & SANBI, 2009). Some grasslands contain thatching grass (mainly Hyparrhenia species) as well as craftwork materials (SANBI, 2005). The provision of medicinal plants is also mostly an attribute of grassland ecosystems (ibid.).

According to CEPF (2010), the grassland biome is one of the most threatened and least protected of all biomes types in southern Africa. It is understood that approximately 30% of South Africa's grasslands are irreversibly transformed and only 2% are formally conserved (Driver et al, 2012). Because of land use pressures, there are relatively few choices for meeting protected area targets in some grassland vegetation types. Furthermore, some grassland vegetation types are better protected than others. For example the moist Drakensberg grassland vegetation types are reasonably well protected, while the Highveld grassland types remain virtually unprotected (Driver et al, 2012).

2.1.6 Indian Ocean Coastal Belt

The Indian Ocean coastal belt contains a remarkable display of coastal dunes and coastal grassy plains (Kraai, 2010; Mucina et al, 2006a). This biome occurs in KwaZulu-Natal and the Eastern Cape, from sea level to an altitude of about 600 m (Kraai, 2010). Rain is experienced throughout the year, peaking in summer, with mean annual rainfall ranging from 819 to 1,272 mm (Kraai, 2010; Mucina et al, 2006a). The mean annual temperature ranges from 22°C in the north near the Mozambican border to 19.1°C near the Mbhashe River (Mucina et al, 2006a). Summers are hot to very hot, while winters are mild with negligible frost (Mucina et al, 2006a). The width of the belt ranges from about 35 km in the north, narrowing irregularly southwards to less than 20 km in parts of Pondoland, to less than 10 km in several parts of the Wild Coast (Mucina et al, 2006a).

According to Egoh et al (2009) and Mucina et al (2006a), water regulation and supply ecosystem services are provided by the Indian Ocean coastal belt. Provision of fodder for livestock grazing is also obtained in the grassy areas of this biome (Mucina et al, 2006a).

This biome is relatively well protected when compared with the other biomes having met approximately 45% of its 20-year protected area target (Figure 3).

2.1.7 *Nama-Karoo*

The Nama-Karoo, with its typical hardy bushes and grasses, covers much of the arid interior of the country (Midgley et al, 2008). This biome is flanked by six biomes: the Succulent Karoo to the south and west, desert to the northwest, the arid Kalahari form of the savanna biome to the north, grassland to the northeast, Albany thicket to the southeast and small parts of fynbos to the south (Mucina et al, 2006b). Annual rainfall varies from 60 to 400 mm decreasing from east to west (Palmer & Hoffman, 1997), is highly unpredictable (DEAT, 2003) and can experience periods of prolonged drought (Mucina et al, 2006b). The Nama-Karoo experiences high January mean maximum temperatures of more than 30°C and relatively low July mean minimum temperatures (below 0°C) (Palmer & Hoffman, 1997).

Water provision is a seasonal ecosystem service provided by the Nama-Karoo (Mucina et al, 2006b). This is due to the few non-perennial rivers, streams and shallow lakes that occur in the biome, such as the Bushman Vloere and the Great Fish River (Mucina et al, 2006b). The biome also provides fodder in the form of shrubs for livestock grazing (Mucina et al, 2006b).

The Nama-Karoo is virtually unprotected (Figure 3).

2.1.8 *Savanna*

The savanna is the country's largest biome, covering 399,600 km^2, or 32.8% of South Africa's surface area (Rutherford et al, 2006b). The term 'savanna' describes a wide range of vegetation types, from the arid camel-thorn vegetation of the Kalahari, to the bushveld and the coastal woodlands of KwaZulu-Natal. It occurs in the coastal and lowveld regions of the country where climate conditions are warm enough in winter to support vegetation (Midgley et al, 2008). The altitude of this biome ranges from sea level to 2,000 m above sea level. Mean annual rainfall ranges from less than 200 mm in the west in southern Gordonia Duneveld to about 1,350 mm in parts of the Swaziland Sour Bushveld in the east (Rutherford et al, 2006b). However, most of the savanna experiences an average of between 500 and 750 mm rainfall per year (ibid.).

Ecosystem services provided by savanna include carbon sequestration, provision of fodder for livestock grazing and soil retention (Rutherford et al, 2006b). Recreational services can be found in protected areas such as the Kruger National Park (Le Maitre et al, 2007). Savanna ecosystems possess significant wild faunal diversity that supports nature-based tourism revenue and subsistence livelihoods (food, medicinal plants and construction material) in addition to cultural regulating and supporting services (Fischlin et al. 2007). Water and grazing resources provision is a feature of Savanna ecosystems (van Wilgen et al. 2008). Woody Savanna ecosystems also provide regulation services in the form of climate regulation (Bond et al. 2003; Leadley et al. 2010).

While Figure 3 indicates that the savanna biome is reasonably well protected, this is only true for some of its vegetation types. Lowveld and arid savannas are well protected by the Kruger National Park and Kgalagadi Transfrontier Conservation Area respectively; however, the central bushveld savanna is very poorly protected (Driver et al, 2012).

2.1.9 *Succulent Karoo*

The Succulent Karoo biome is found on the western part of South Africa in areas that experience winter rainfall (Midgley et al, 2008). It stretches from southern Namibia into the Little Karoo (DEAT & SANBI, 2009). This biome comprises coastal plains and intermontane valleys along the western and southern edges of the Great Escarpment, predominantly above 100 m above sea level (Milton et al, 1997). The Succulent Karoo is characterised by low but fairly reliable annual rainfall ranging from 20 to 290 mm per year and relatively high summer aridity (Kraai, 2010). The average annual temperature for the biome is 16.8°C (Mucina et al, 2006c).

Ecosystem services provided by the Succulent Karoo include forage production (Reyers et al, 2009), soil nutrient recycling, soil water retention and pollination owing to large percentage of insects found in the area (Mucina et al, 2006c).

The Succulent Karoo is relatively poorly protected, with only about 30% of its proportional protected area target having been met (Figure 3).

3. METHODOLOGY

This vulnerability assessment makes use of climate scenarios (outlined in Section 3.1), to develop models of the effects of projected climate change on the spatial distribution of climatic conditions suitable for the biomes of South Africa (Section 3.2). In addition, it explores the risks of vegetation change driven not only by climate, but also by rising atmospheric CO_2, through the use of a Dynamic Global Vegetation Model (DGVM) which models ecosystem structure and function. In order to assess potential risks to individual species, models were also developed for the spatial distribution of the majority of birds endemic to South Africa (Section 3.3).

Both the climate and impact modelling research builds on and updates biome and species modelling work undertaken in the late 1990's and early 2000's (Kiker, 2000; Erasmus et al, 2002). This earlier research indicated that bioclimatic zones suitable for the country's biomes could be reduced to between 38 and 55% of their current coverage, resulting in an increased risk of range reduction or extinction for species with low reproductive capacity or smaller geographic ranges (Kiker, 2000).

Since this original South African biome and species modelling work was conducted, significant advances have been made in the development of climate modelling techniques, and the refinement of emissions scenarios and their related uncertainties. These developments have allowed global climate models to take account of a wider range of emissions uncertainty, and have also allowed their results to be applied at a regional and local level through a process termed 'downscaling'. Downscaling simply allows modelled outputs produced at very coarse spatial scales to be refined to account for local conditions, such as local geography (for example mountain ranges), which influence rainfall and air temperatures.

A key set of these new climate results has been processed for use in this project to allow the earlier vulnerability assessments to be updated as a key component of this initiative. In South Africa's Second National Communication to the UNFCCC (DEA, 2010), the severe climate change scenarios for the South and Western parts of South Africa projected by earlier studies (e.g. DEAT, 2000; Kiker, 2000) were revised, with some significant projected reductions in potential vulnerability of the biomes and species occupying these regions, at least by mid-century. This new information, together with updated biome- and species-based approaches, has been taken into account in the development of this vulnerability assessment.

3.1 Climate scenarios

In this vulnerability assessment, an effort was made to quantify the inherent uncertainty of climate change projections by modelling the potential impacts of a range of climate scenarios. This was done through defining a median projected climate change scenario, in addition to a high and low risk scenario.

The assessment was conducted with climate scenarios generated using the IPCC A2 emissions scenario, which is a relatively high-end emissions scenario, which is more or less consistent with current emissions trends (Nakicenovic et al, 2000). This emission scenario is less extreme than the 2% per annum emissions growth rate assumed in the IS92a emission trajectory in the IPCC's Second Assessment Report (IPCC, 1996) used in the climate scenario modelling for South Africa's First National Communication to the UNFCCC (2000). Climate modelling carried out since the Second and Third IPCC Assessment Reports (1996, 2001) has advanced in several respects, including aspects of ocean circulation that are now captured in a dynamic way. These advances are likely to produce more credible projections for southern Africa, a region that is under significant influence of ocean processes.

The modelling work used two sources of local climate scenarios developed from global model projections used in IPCC Fourth Assessment Reports (2007a,b,c). These two approaches represent distinct climate modelling methodologies, termed 'statistical downscaling' and 'mechanistic downscaling' respectively. Statistical downscaling uses established correlations between synoptic conditions and local weather patterns to derive projections of future climate (e.g. Hewitson & Crane, 2006). Mechanistic downscaling uses a physical dynamic model of the climate that is able to run at a fine spatial scale over the region of interest, thus avoiding a number of limitations of alternative methods (see Engelbrecht et al, 2009 for more information). Both approaches use the primary outputs of physical models of the climate run at a global scale as a basis for their downscaling.

Statistically downscaled scenarios were based on outputs from 15 global climate models, and were processed using a further statistical treatment, to derive three downscaled climate scenarios for South Africa, for approximately 2050 (mean monthly values for the time-slice 2041 – 2060), namely:

- Best-case 'low-risk' scenario: combining the 10th percentile smallest predicted increases in seasonal temperature and smallest reductions in seasonal rainfall.
- Intermediate scenario: middle of the range (median) predicted increases in temperature increases and changes in rainfall.
- Worst-case 'high-risk' scenario: 90th percentile greatest predicted increases in seasonal temperature and greatest reductions in seasonal rainfall.

The results generated represent a broad range of plausible climate futures. It is important to note that they combine climatic conditions for temperature and rainfall that may not naturally occur together, and may indeed not represent any one of the source models for the data. This point notwithstanding, the intention has been to conduct a traceable 'stress test' of the ecosystems under investigation, and to explore the possible future climate space with respect to the 'tails' of the frequency distribution as well as the median. Due to the significant uncertainties in modelling both climate and impacts, it is worthwhile for impacts and adaptation projections to model such a range of conditions. The range chosen for this study brackets the potential range of outcomes with an 80% confidence, given the current state of information available.

To provide an alternative approach that is traceable to individual climate models, six mechanistically downscaled climate scenarios were also considered to represent the current climatological understanding of possible climate futures. Three of these were used in this analysis, namely MIROC, ECHAM5 and CSIRO, representing the wettest, intermediate and driest members of a selection of six global climate models (Figure 4). Downscaling was conducted using Cubic Conformal Atmospheric Modelling (CCAM) technology and results were averaged for 2050 (mean monthly values for the time slice 2041 – 2060).

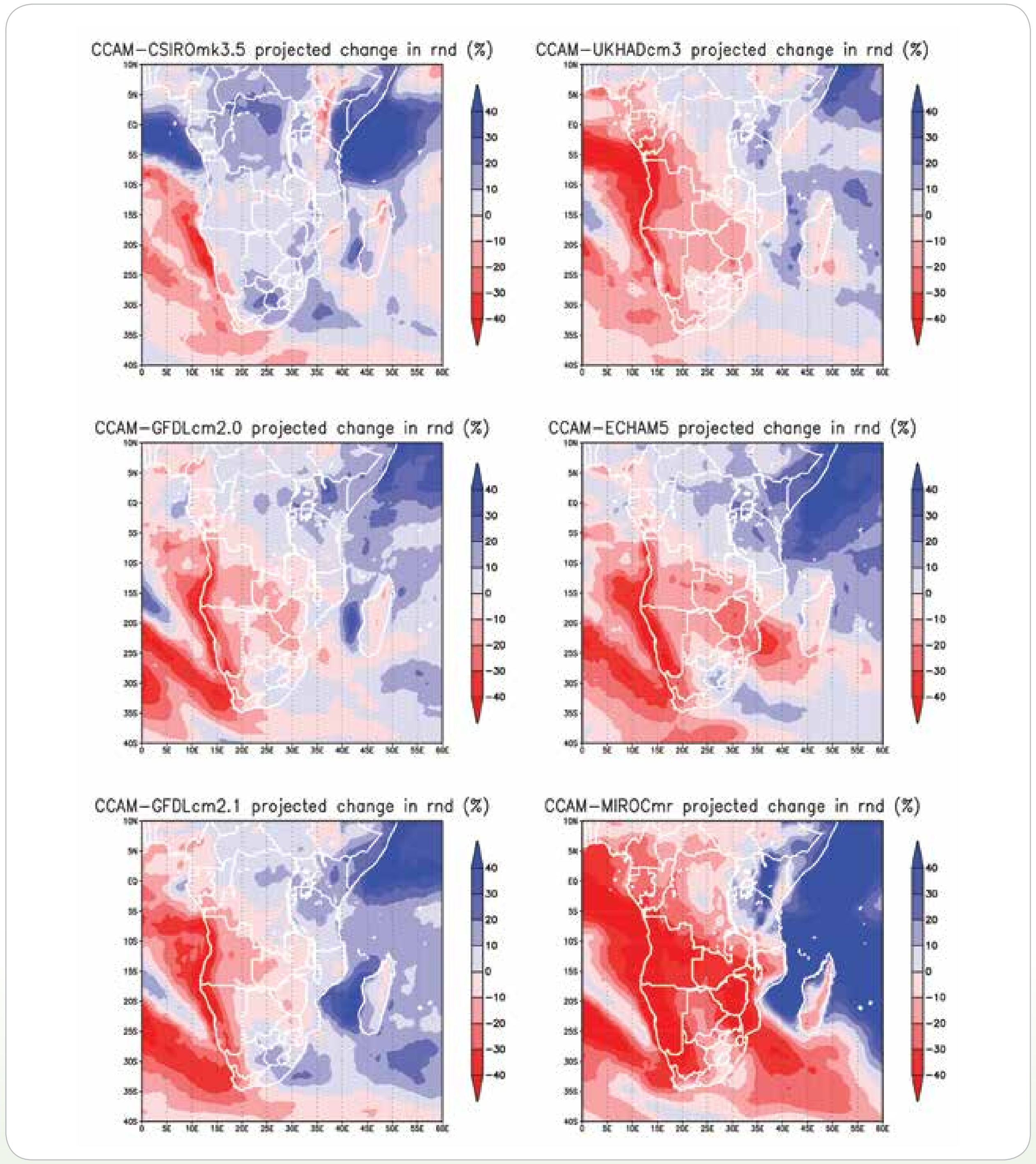


Figure 4: CCAM ensemble: projected change in annual rainfall (%) for 2071 – 2100 vs. 1961 – 1990, with the driest, intermediate and wettest members as selected for impacts modelling being CCAM-MIROCmr, CCAM-ECHAM5 and CCAM-CSIROmk3.5 respectively (after Engelbrecht et al. *2011).*

3.2 A biome based perspective

A biome distribution model based on climatic relationships alone was developed for each biome. This is an approach that determines the current optimum climatic conditions for a particular biome based on observed climate variables. This allows an impact assessment to be made by assessing the spatial shift in the optimum climatic conditions for each biome under different climate scenarios.

The ability of the model to predict future distributions of biomes was tested by using it to reproduce the current distribution of biomes. While the model was very accurate in reproducing the current distribution of biomes, this methodology clearly suffers from the limitation of correlation interpreted as causation, as the method does not capture mechanistic processes such as competitive interactions between plants, the effects of changing disturbance regimes and enhancement of plant growth by rising atmospheric CO_2 (referred to as 'CO$_2$ fertilisation'). Results must therefore be interpreted as changes in the bioclimatic conditions that most closely match the current optimal conditions for the modelled biomes, and cannot simply be interpreted as potential biome spatial shifts. Nonetheless, the areas identified as being outside the current bioclimatic envelope indicate areas that are most likely to experience adverse climatic impacts, and are important for planning possible interventions. Conversely, identifying areas that remain climatically within the current envelope indicate areas of relative climate stability, with a range of implications for conservation planning.

A DGVM approach was also employed to assess potential shifts in dominant vegetation structural types. In this approach, the response of dominant plant growth forms (e.g. trees and grasses) can be modelled using an understanding not only of climate impacts on plant growth, but also changes in disturbance regime, competitive interactions between growth forms, and rising atmospheric CO_2. This information provides a more complete understanding of the potential overall changes in ecosystem structure and biodiversity that can be expected. This modelling approach was discussed during a workshop to which members of an international DGVM team from University of Frankfurt were invited. The basic model is described by Scheiter and Higgins (2009), and is termed an adaptive DGVM (aDGVM). The model combines well-established routines for simulating photosynthesis, respiration and evapotranspiration with novel models for fire, phenology and allocation. It simulates grasses and trees as its two fundamental growth forms, and thus is well suited to the tropical and subtropical biomes of South Africa, namely the savanna, grasslands, the Indian Ocean coastal belt, and to a lesser extent to the Nama-Karoo. The model has been validated for its performance in tropical and subtropical Africa (Figure 5).

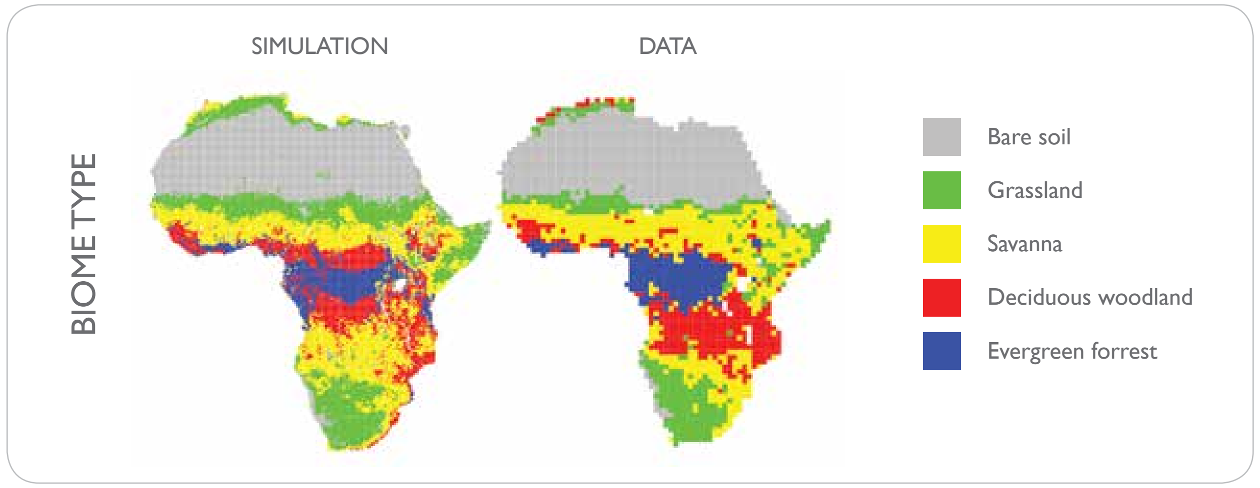


Figure 5: Validation of the aDGVM (based on Scheiter & Higgins, 2009) showing the performance of the model in simulating dominant plant growth forms across Africa.

3.3 A species based approach

The potential climate impacts of 623 of southern Africa's endemic bird species were modelled for this study, in order to gain a preliminary understanding of the potential range shifts of a taxon with highly mobile individuals. Bird species were chosen for a number of reasons. Firstly, they are potential indicators of climate responses. Secondly, they are the focus of a national monitoring effort that engages thousands of amateur and professional bird watchers and which has been used to build a significant database of changing bird distributions across South Africa. Thus, developing a predictive understanding of bird distributional shifts could provide an important basis for assessing observed bird range shifts and attributing these to climate change. Impact modelling of bird species used outputs from the ECHAM5 downscaled climate data sets (Figure 4), representing a median change in temperature and rainfall.

4. CLIMATE CHANGE IMPACTS ON BIODIVERSITY

4.1 Climate change impacts on biodiversity-a biome based perspective

Figures 6 and 7 provide projections of bioclimatic envelopes for South Africa's biomes under statistically and mechanistically downscaled climate scenarios respectively, looking ahead to approximately 2050. For both figures, each projection shows that the future climate envelope in an area that is likely to resemble the climate of a particular biome most closely is often different from the current biome in that area. This does not necessarily mean that the vegetation in the area will change to a different biome, but indicates that this is a region where endemic biota of that biome could experience significant climate-related stress. A complex set of factors will influence how ecosystems and species will actually respond over time, some of which are captured in the aDGVM results discussed alongside.

Based on the results in Figure 6, it is clear that the spatial pattern of change is consistent between all scenarios, but that there are significant differences in the extent of projected changes. These changes can be summarised as follows:

- Areas with an Albany thicket climate envelope persist under the low-risk and intermediate climate scenarios, but are replaced by Nama-Karoo and savanna conditions under the high-risk scenario.
- It is extremely difficult to predict the exact distributions of the climate envelope for the small forest biome, but it is likely that many forest areas, which are generally dependent on consistently available moisture and protection from fire, are likely to be under increasing pressure in the future.
- The desert climate envelope expands substantively under the high-risk scenario, encroaching on current areas of both the Succulent Karoo and Nama Karoo biomes, but shows no expansion in South Africa in the low-risk scenario.
- The eastern and northern sections of fynbos are likely to experience climate stress, with the climate envelopes in these areas becoming more like the Succulent Karoo or Albany thicket for all climate scenarios. The core southwestern portions of the fynbos (especially the mountainous areas) remain within the current biome envelope, but probably with significant up-slope movement of suitable climate envelopes for particular species and habit types.
- As concluded in earlier studies (e.g. Kiker, 2000), the grassland biome appears to be one of the biomes most at risk of significant change under all the scenarios. Areas with a climate envelope suitable for grassland are projected to be greatly reduced under all scenarios, and in the high-risk scenario to persist only in the highest altitude areas.
- The area with a climate envelope suitable for Indian Ocean coastal belt increases under the low-risk scenario, with the warm moist conditions that favour this biome expanding southwest along the coast and extending inland. However, under the intermediate and high-risk scenarios, where water becomes less available, the area with a climate suitable for Indian Ocean coastal belt shifts to a savanna climate envelope.
- The climate envelope found in large areas that are currently Nama-Karoo is likely to resemble an arid savanna under the low-risk and intermediate scenarios, and a desert climate envelope under the high-risk scenario.
- Although the climate envelope suitable for savanna is likely to expand significantly in the future, and specific savanna species are likely to benefit, this does not necessarily benefit existing habitats and species assemblages.
- Areas with a climate envelope characteristic of Succulent Karoo largely persist under all scenarios. This contrasts with earlier projections (DEAT, 2000; Kiker, 2000). Newer climate models indicate smaller impacts on winter rainfall than earlier models predicted.

The results for biome bioclimatic range shifts using mechanistically downscaled scenarios (Figure 7) are entirely consistent with the projections for the statistically downscaled scenarios (Figure 6), clustering around the intermediate risk scenario in Figure 6. This degree of consistency provides a level of confidence that the emerging outcomes for mid-century impacts based on these modelling methods are not likely to exceed the low- and high-risk extremes modelled using the statistically downscaled scenarios.

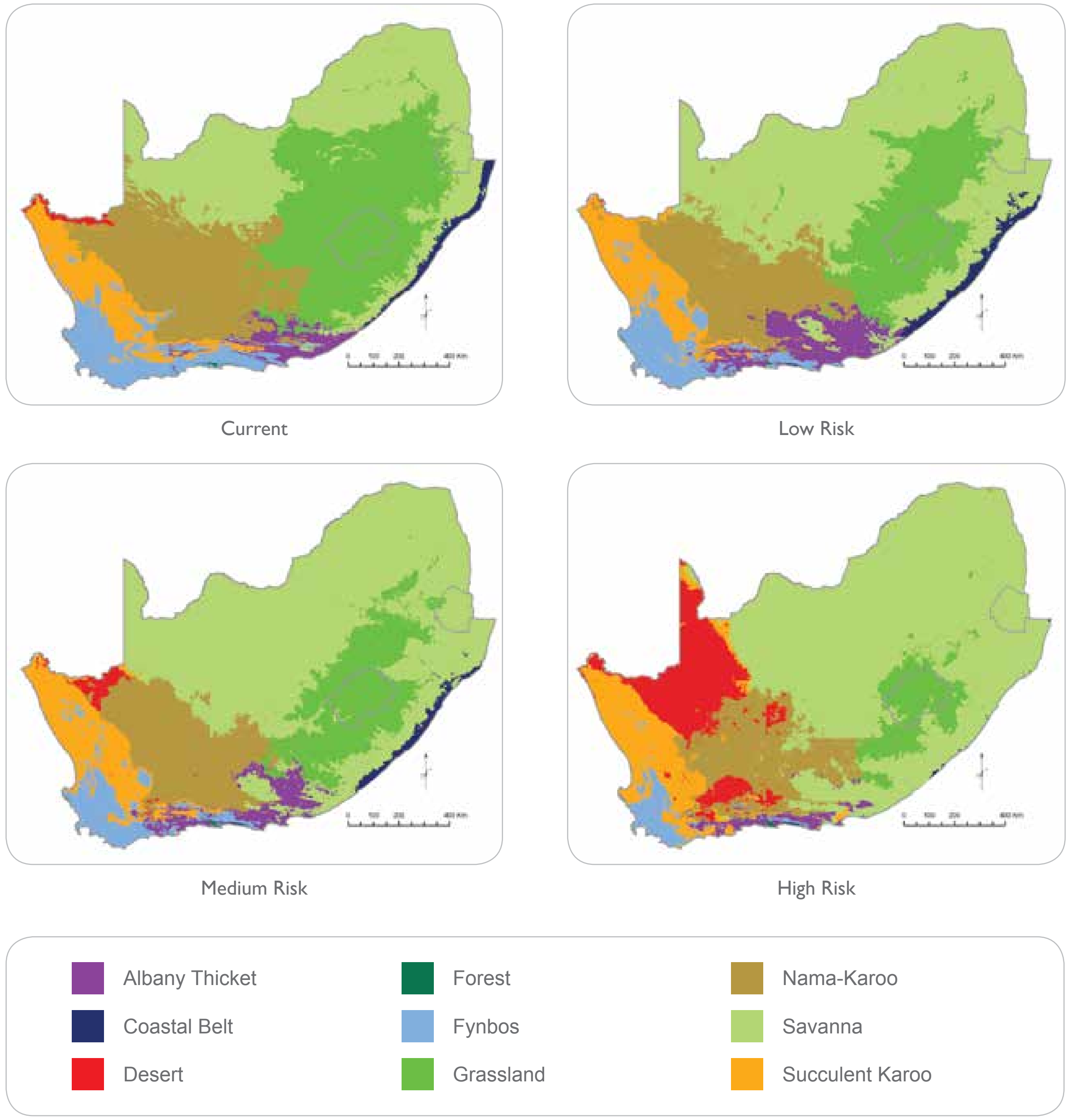
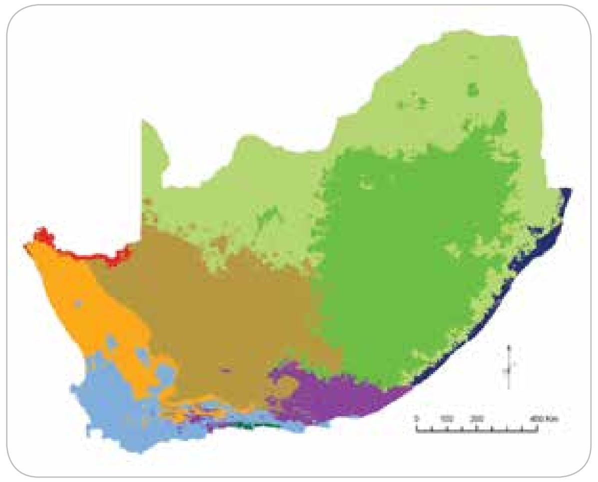
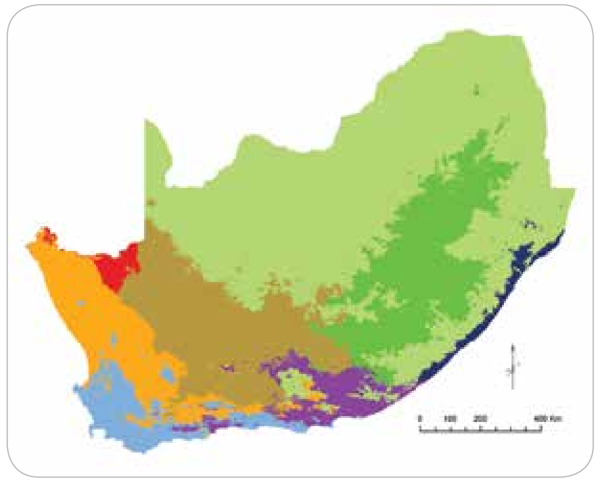


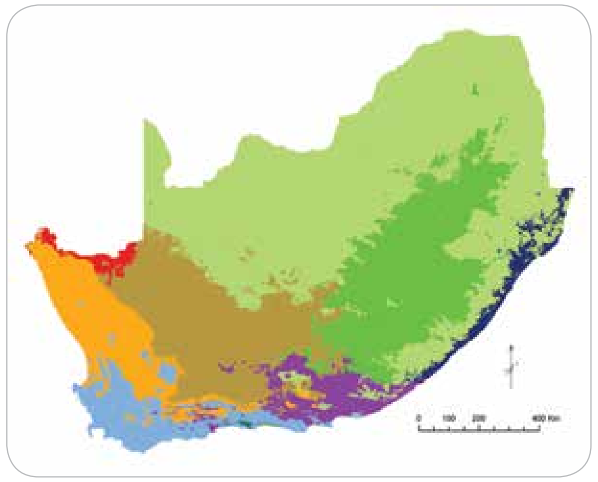
Figure 6: Projections of bioclimatic envelopes under statistically downscaled climate scenarios, looking ahead to approximately 2050. Low Risk map simulates impacts of wet/cool future climate projections, High Risk the impacts of dry/hot projections, Medium Risk the median temperature and rainfall projections (see Methodology on p.18).



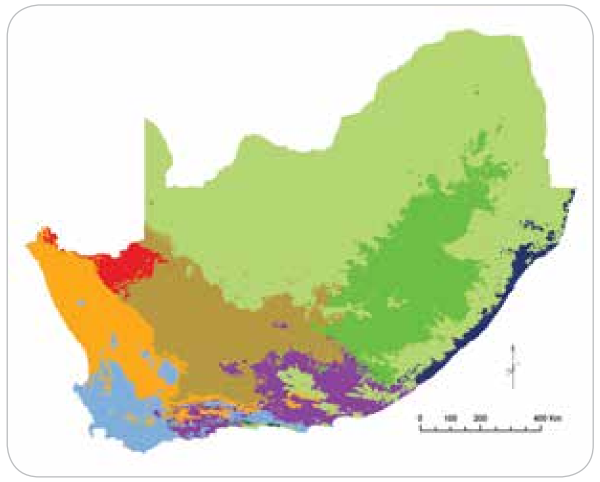
Predicted current biome climate envelope



Predicted biome climate envelope: CSIRO



Predicted biome climate envelope: CCAM ECHAM5



Predicted biome climate envelope: MIROC model

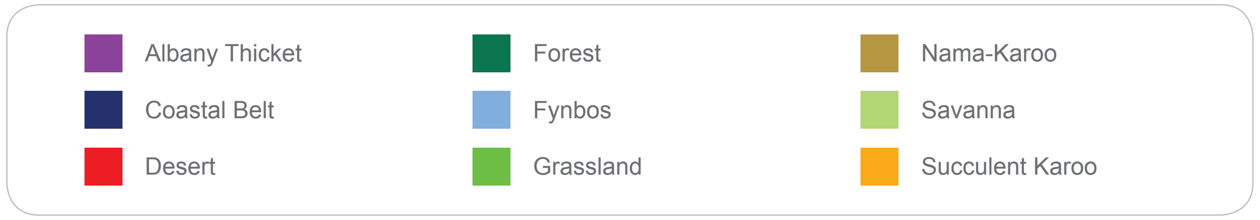


Figure 7: Projections of bioclimatic envelopes under mechanistically downscaled climate scenarios, looking ahead to approximately 2050. CSIRO represents a wetter future, MIROC a drier future, and ECHAM5 an intermediate rainfall future (see Figure 4 on p.19).

Turning to the results of the aDGVM, this approach reveals potentially significant shifts in dominant plant growth-form for southern Africa, driven by increases in atmospheric CO_2 and temperature change, (Higgins & Scheiter, 2012). It is now strongly suspected that rising CO_2 will fertilise the growth of trees and potentially allow them to establish dominance in areas that are currently grassland, where grass fires currently prevent tree saplings from establishing. It can be seen in Figure 8 that such a change could occur in the coastal and upland grassland regions of South Africa, and potentially also in the southern Cape. Tree dominance is projected decline in the arid central and western parts of South Africa, where biome modelling suggests an expansion of desert-type bioclimatic conditions. These results provide an important additional mechanism of dominant growth-form change suggested by bioclimatic niche modelling. However, it should be noted that while savanna and grassland biomes are well represented by this modelling approach, areas dominated by shrubs require further work in order for the DGVM to be able to provide more credible mechanistic simulations.

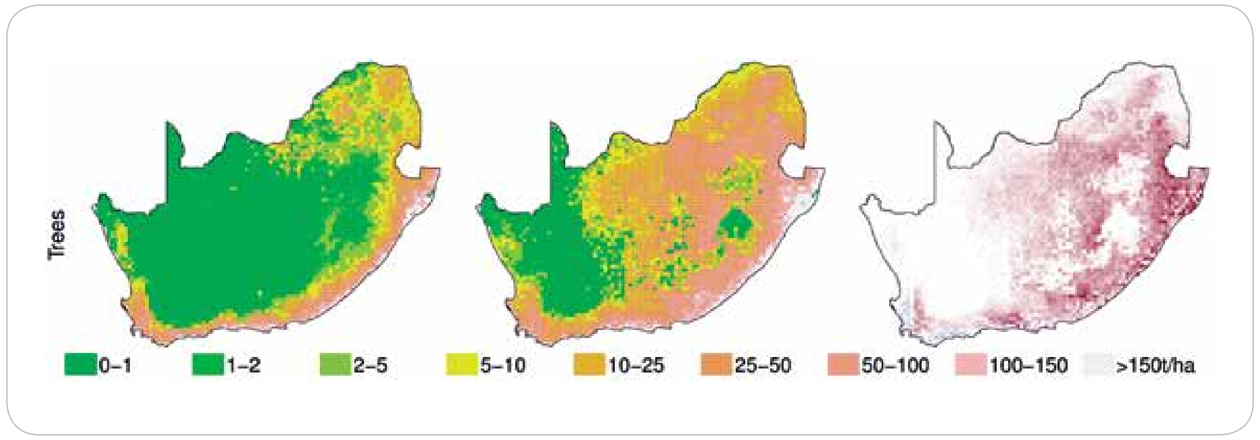


Figure 8: Maps of the response of tree biomass (tons per hectare above ground biomass) to the effect of rising atmospheric CO2 alone in South Africa, simulated by the Adaptive Dynamic Global Vegetation Model (Higgins et al. *2012) in ~2000 (centre panel), ~2100 (centre panel), and the indicative biomass difference (darker red indicates greater biomass gain; right hand panel).*

4.2 Climate change impacts on biodiversity – a species based approach

Figure 9 shows that modelled bird species richness under current climate conditions in southern Africa is highest in association with the high altitude regions of the Drakensberg and eastern coastal escarpment.

Projected species range change reflects a slightly greater concentration of species in the high altitude regions, and lower concentrations in more arid regions. Overall, the modelled loss of richness is lower than projected in earlier work on animal species (e.g. Erasmus et al, 2002).

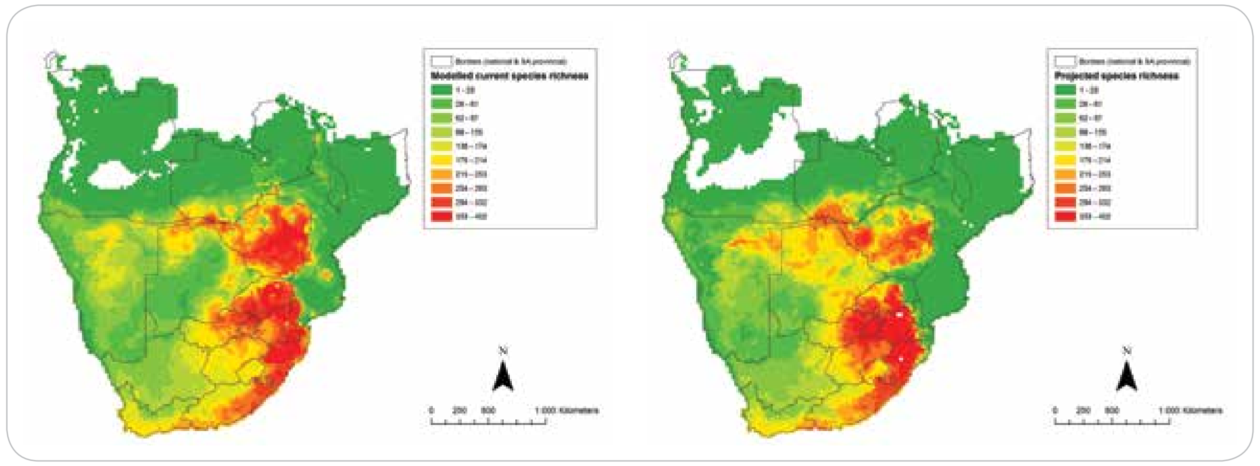


Figure 9: Current modelled species richness of 623 terrestrial bird species (left hand side) and projections of bird species richness change (right hand side) under mechanistically downscaled climate scenarios, looking ahead to approximately 2050.

Figure 10 A reveals that the median level of range change for all bird species for the region is about -10%. However, the spread is large, with several species showing range increases. Figure 10 B shows that the median proportion of future range occupied that represents a completely new range (i.e. a range shift) is about 10%.

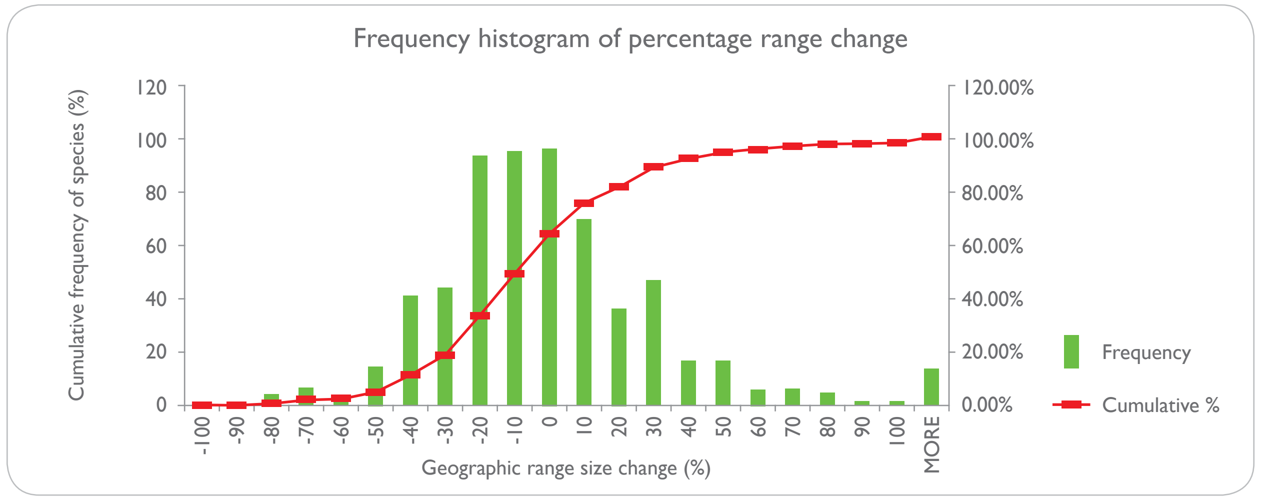


Figure 10 A

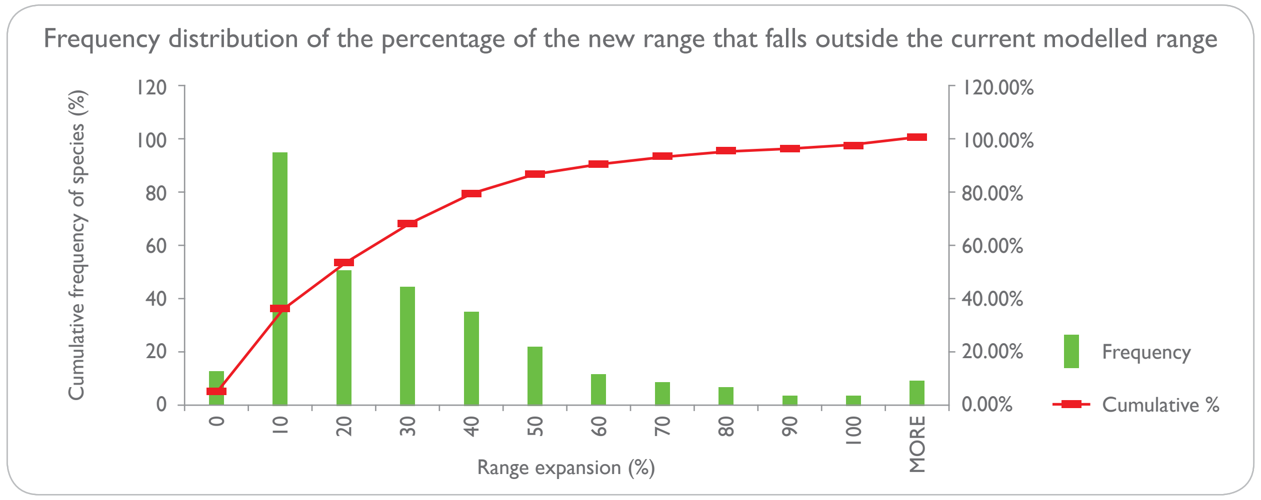


Figure 10 B: Projections of percentage species range change (loss and gain) in the southern African region for 623 terrestrial bird species under mechanistically downscaled climate scenarios (Figure 10 A), and the frequency distribution of the percentage of new geographic range that species are projected to occupy (Figure 10 B), looking ahead to approximately 2050.

Range shift projections for South Africa (Figure 11) indicate a low risk for significant bird range shifts that result in species losses as a result of climate change (temperature and rainfall) alone. However, in a few key areas this risk is high. High potential rates of species richness loss is projected in the central interior, especially the Kgalagadi Transfrontier Conservation Area, which is an area identified at risk of potential aridification and desert biome expansion in the statistically downscaled scenarios (See Figure 6). The northeastern boundary regions of South Africa, from northern KwaZulu-Natal, along the border with Mozambique, and along the Limpopo basin represent an even greater risk. This region has been previously identified as an area with a high risk of bird species extinction (Erasmus et al, 2002), to which these results add further weight.

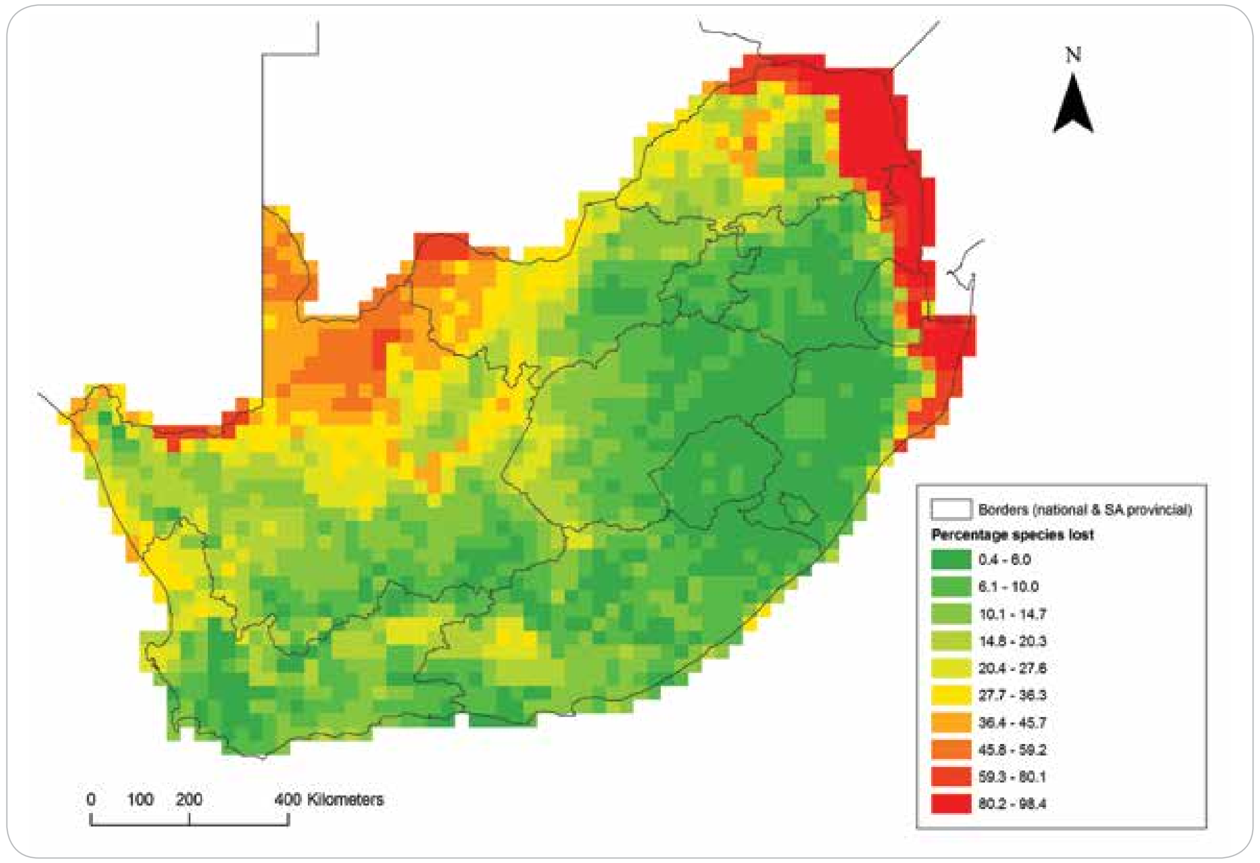


Figure 11: Projections of bird species richness loss for South Africa under mechanistically downscaled climate scenarios, looking ahead to approximately 2050. This is based on range modelling of 623 terrestrial bird species.

5. CLIMATE CHANGE ADAPTATION RESPONSE OPTIONS

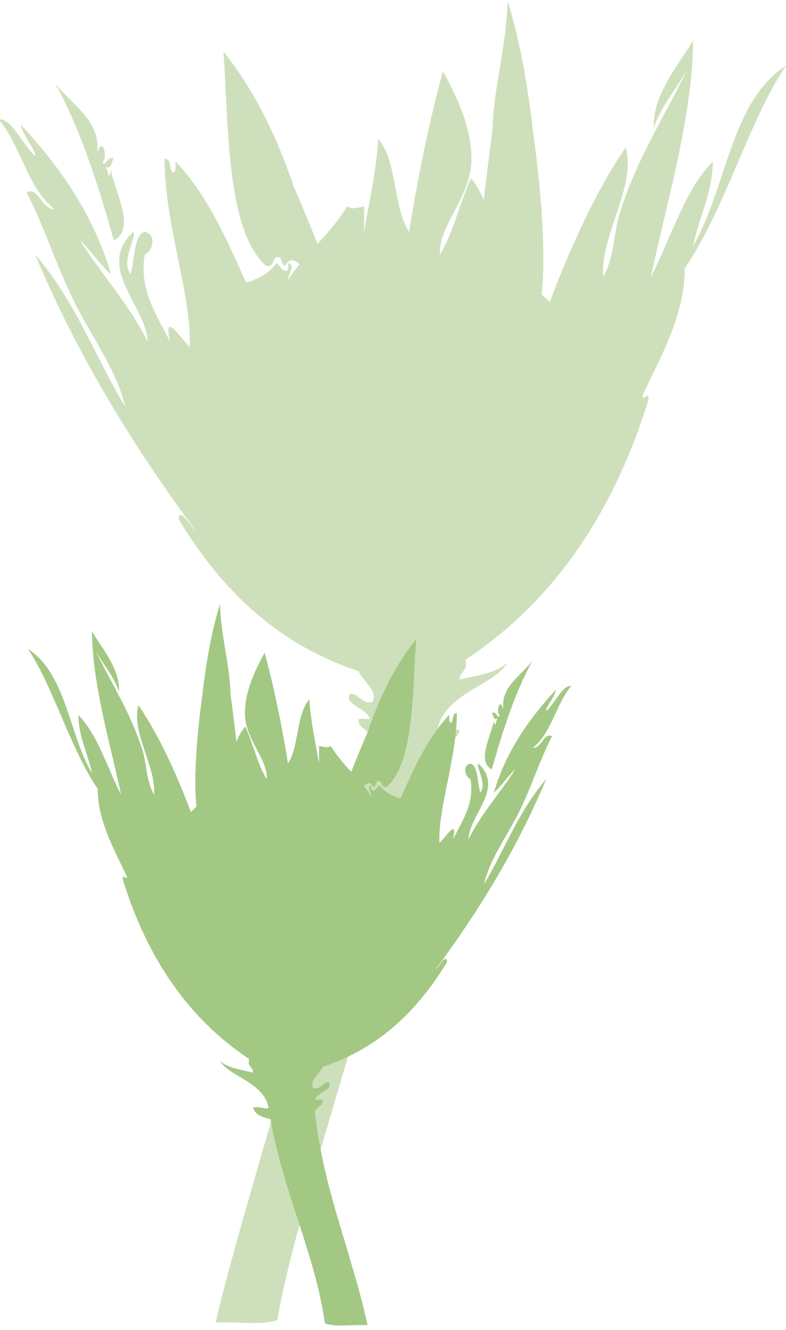
To increase the resilience of biodiversity and ecosystem service delivery under future climate conditions, synergies could be developed during adaptation planning and implementation between biodiversity, poverty reduction and development objectives. Specifically, the potential of biodiversity and ecological infrastructure to achieve sector-specific adaptation and development outcomes/ benefits would need to be mainstreamed into adaptation, development and poverty reduction processes and strategies at national and local level. Coordination across sectors (including the land use planning sectors) would be essential in this mainstreaming process.

The appropriate and specific types of local action required would need to be further defined in biome specific adaptation plans. Key elements of this would be to include strong stakeholder engagement and implementation focused at local level; prioritising low-cost approaches with multiple benefits; integrating adaptation and mitigation responses; and making use of indigenous knowledge. Ecosystem-based Adaptation and expansion of protected areas using climate-resilient approaches offer two adaptation response options for the biodiversity sector that are appropriate for achieving increases in the climate resilience of biodiversity and maintaining and/or enhancing ecosystem service delivery. However, these two approaches should be adapted as necessary to build the resilience of ecological infrastructure to support economic sectors and livelihood activities. For example:

- **Agriculture and forestry** hold great potential for gaining adaptation benefits while mitigating greenhouse gas emissions through reforestation and restoration, managing soil carbon and invasive species, implementing integrated crop and livestock management, and improving management of emissions from livestock and crop production. Specific related approaches include climate smart agriculture, conservation agriculture, agro-ecology and community-based adaptation.
- **Fisheries** that are successfully managed to achieve resource sustainability will be better positioned in the long term to adapt to the effects of climate change. An Ecosystem Approach to Fisheries can contribute to resource recovery through protection of spawning and nursery areas and the maintenance of other essential fish habitats which are in turn dependent on water flows that are mediated by land-based ecosystems.
- **Human health** and ecosystem impacts that are associated with increased rainfall intensities, flash floods and regional flooding include overflowing sewers and climate change impacts on water resources (quality and quantity). These can be addressed through collaboration between the health, water and biodiversity sectors on integrated water resource management, restoration of catchment areas and effective land-use planning.
- Developing a **climate-resilient network of protected areas** in South Africa with greater ecological connectivity, and designed specifically with future climate conditions in mind will work towards assisting with species migration and the maintenance and/or enhancement of ecosystem service delivery to support local communities and all sectors. Implementing efficient biodiversity stewardship programmes can assist in achieving connectivity between core biodiversity and ecosystem services areas.

6. FUTURE RESEARCH REQUIREMENTS

The potential of biodiversity adaptation strategies to provide co-benefits for other sectors could be mainstreamed and integrated across sectors if packaged and communicated appropriately. This would require both institutional and technical capacity building. Research and assessment would be important for developing products for mainstreaming, and tools and communication pathways (including decision-making and spatially referenced tools and information). Implementation of biome adaptation plans would contribute to building climate-resilience at biome level, and would provide support to adaptation in other sectors such as water, agriculture and forestry, and human health by ensuring continued supply of ecosystem services. Vulnerability assessment data should be integrated with spatial data related to ecosystem service delivery, and translated to the local level, based on user-specific vulnerabilities and needs, to inform biome adaptation plans. Priorities for future research include the development of a predictive understanding of the rates of spread of invasive plants (including the effects of rising atmospheric CO2) and changes to fire regimes under climate change conditions. Furthermore, there is a need to develop achievable goals for EBA and protected area expansion. This includes measurable criteria for assessing the success of restoration and protected area expansion in increasing the resilience of biodiversity, and maintaining ecosystem services under future climate conditions. A dedicated and focused monitoring programme across biomes would allow projected changes to be observed and quantified to improve modelling approaches.



7. CONCLUSIONS

Overall, the results presented above provide a significant update to the current understanding of the rate and extent of climate change impacts on biomes, ecosystems and biodiversity in South Africa. The results show both several similarities and some significant differences when compared with previous vulnerability assessments. The differences in the projections suggest some significant changes in potentially applicable adaptation approaches, with more options available at least up until mid-century, especially due to the projected reduced rate of change in response of biota to climate change impacts. The lower rate of change projected and the lower extent of change suggests that it will be possible to implement measured responses in several biomes, supported by a focused monitoring program to allow the projected changes to be observed and quantified in order to improve the modelling approaches used into the future. Exceptions to this are the high rate of tree cover increase in eastern and upland grasslands and savannas, and some indications of bird species richness reductions in the northeastern border regions of South Africa and the arid central interior.

For the winter rainfall biomes, a significantly revised adaptation approach is suggested, given a far lower level of exposure to imminent change in climate than previously projected. This will allow a focus by conservation bodies on building ecosystem resilience to climate change through conservation interventions, and a productive focus on ecosystem-based adaptation responses to benefit local communities. However, it must be noted that changes for the end of this century under an unmitigated emissions scenario require careful consideration and further modelling in order to assess the risks of such a scenario for these biodiversity hotspots.

For the grassland biome, there is a consistent message of potential significant change and loss of habitat due to climate change, likely related to the high altitude of the biome and its susceptibility to warming effects, and the possible increase in tree cover due to a lengthened growing season and CO_2 fertilisation. In addition, based on the bird species richness modelling, this region is likely to increase in importance as a habitat for animal diversity, and thus the conservation response in this region will be critical for preventing species richness reductions. Furthermore, the ingress of woody plants into the grassland biome has major implications for water delivery from highland catchments. Conversely, the savanna biome is projected to expand with its geographic range partly replacing grassland. There are likely to be related costs of increasing woody cover to a degree, which could shift the structure of some regions of this biome towards woodland and even forest. These include potential impacts on water delivery and grazing. Such shifts have extremely important implications for conservation and ecosystem service delivery, as well as ecosystem processes such as wildfire.

Authorities should focus on mainstreaming the potential of biodiversity and ecological infrastructure for achieving adaptation and development benefits across sectors, and for building the resilience of ecosystems and local communities to climate change through Ecosystem-based Adaptation, and climate resilient approaches in protected area expansion. Adaptation responses involving natural resources require a coherent framework that can be applied at national level, and then refined for sub-national purposes. South Africa has a good understanding – based on its vegetation biomes – of the functioning and structure of its ecological infrastructure that can provide a strong basis for such a framework. Phase 1 of the biodiversity work on the LTAS aimed to maximise the value of this background knowledge to develop a biome-based adaptation framework for the country that can serve this important purpose.

REFERENCES

Adeel, Z., Safriel, U., Niemeijer, D., White, R., de Kalbermatten, G., Glantz, M., Salem, B., Scholes, R., Niamir-Fuller, M., Ehui, S. and Yapi-Gnaore, V. Eds., (2005). *Ecosystems and Human Well-being: Desertification Synthesis.* Island Press, Washington, District of Columbia, 36 pp.

Bond, WJ., Midgley, GF. and Woodward, FI. (2003). The importance of low atmospheric CO_2 and fire in promoting the spread of grasslands and savannas. *Global Change Biology 9: 973-982.*

Bredenkamp, G., Granger, J.E. and van Rooyen, N. (1996). Forest Biome. In: Low, A.B. and Robelo, A.G. (eds). *Vegetation of South Africa, Lesotho and Swaziland*. Department of Environmental Affairs and Tourism, Pretoria.

Cadman, M., Petersen, C., Driver, A., Sekhran, N., Maze, K. and Munzhedzi, S. (2010). *Biodiversity for Development: South Africa's landscape approach to conserving biodiversity and promoting ecosystem resilience.* Pretoria: South African National Biodiversity Institute.

Cowling, R.M., Richardson, D.M. and Mustart, P.J. (1997). Fynbos. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds). *Vegetation of Southern Africa*. Cambridge University Press, United Kingdom.

Critical Ecosystem Partnership Fund (CEPF) (2010). *Ecosystem Profile: Maputaland-Pondoland-Albany Biodiversity Hotspot*. Conservation International Southern African Hotspots Programme and South African National Biodiversity Institute.

Department of Environmental Affairs (DEA) (2010). *South Africa's Second National Communication under the United Nations Framework Convention on Climate Change*. Department of Environmental Affairs. Republic of South Africa.

Department of Environmental Affairs and Tourism (DEAT) (2000). *South Africa's First National Communication to the United National Framework Convention on Climate Change*, Republic of South Africa, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) (2003). *People, Parks and Transformation in South Africa: A Century of Conservation, A Decade of Democracy*. Republic of South Africa, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) (2005). *South Africa's National Biodiversity Strategy and Action Plan*. Republic of South Africa, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) (2008). *National Protected Area Expansion Strategy for South Africa 2008: Priorities for expanding the protected area network for ecological sustainability and climate change adaptation.* Republic of South Africa, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) and the South African National Biodiversity Institute (SANBI) (2009). *South Africa's Fourth National Report to the Convention on Biological Diversity.* Republic of South Africa.

Department of Water Affairs. (1998) National Forests Act 84 of 1998. Republic of South Africa.

Desmet, P.G., Rutherford, M.C., Mucina, L. and Ward, R.A. (2006). Desert Biome. In: Mucina, L. and Rutherford, M.C. (eds). *The Vegetation of South Africa, Lesotho and Swaziland.* Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Driver A., Sink, K.J., Nel, J.N., Holness, S., Van Niekerk, L., Daniels, F., Jonas, Z., Majiedt, P.A., Harris, L. and Maze, K. (2012). *National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems*. Synthesis Report. South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria.

Egoh, B., Reyers, B., Rouget, M., Bode, M. and Richardson, D.M. (2009). Spatial congruence between biodiversity and ecosystem services in South Africa. *Biological Conservation*, 142: 553-562.

Engelbrecht, F.A., McGregor, J.L. and Engelbrecht, C.J. (2009). Dynamics of the conformal-cubic atmospheric model projected climate-change signal over southern Africa. *International Journal of Climatology*, 29:1013-1033.

Engelbrecht F.A., Landman W.A., Engelbrecht C.J., Stephanie S., Roux B., Bopape M.M., McGregor J.L. And Thatcher M. (2011). *Multi-scale climate modelling over southern Africa using a variable-resolution model.* Water SA 37 647-658

Erasmus, B.F.N., Van Jaarsveld, A.S., Chown, S.L., Kshatriya, M., and Wessels, K.J. (2002). Vulnerability of South African animal taxa to climate change. *Global Change Biology*, 8: 679-693.

Hassan, R., Scholes, R. and Ash, N. (Eds.). (2005). *Ecosystems and Human Wellbeing: Volume 1: Current State and Trends.* Island Press, Washington, District of Columbia, 917 pp.

Hewitson, B.C. and Crane, R.G. (2006). Consensus between GCM climate change projections with empirical downscaling: Precipitation downscaling over South Africa. *International Journal of Climatology*, 26: 1315-1337.

Higgins, S.I. and Scheiter, S. (2012). Atmospheric CO_2 forces abrupt vegetation shifts locally, but not globally. *Nature*, 488: 209-212.

International Panel on Climate Change (IPCC) (1990). IPCC *First Assessment Report: Scientific assessment of climate change*. Report prepared for IPCC by Working Group I. Cambridge University Press, Cambridge, United Kingdom.

International Panel on Climate Change (IPCC) (1995). *Second Assessment Report: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Report prepared for IPCC by Working Group II. Cambridge University Press, Cambridge, United Kingdom.

International Panel on Climate Change (IPCC) (1996). *Climate change 1995: The science of climate change*. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom.

International Panel on Climate Change (IPCC) (2001). *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom.

International Panel on Climate Change (IPCC) (2007a). Climate change 2007: *The Physical Science Basis*. In: Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

International Panel on Climate Change (IPCC) (2007b). *Climate Change 2007: Mitigation of Climate Change*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva.

International Panel on Climate Change (IPCC) (2007c). *Climate change 2007 - Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Assessment Report Four of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom.

Kiker, G.A. (2000). *South African Country Study on Climate Change: Synthesis Report for the Vulnerability and Adaptation Assessment Section (Draft).* School of Bioresources Engineering and Environmental Hydrology, University of Natal.

Kraai, M. (2010). *White rhinoceros populations in the Eastern Cape: distribution, performance and diet*. Thesis. Nelson Mandela Metropolitan University. Port Elizabeth.

Le Maitre, D.C., O'Farrel, P.J. and Reyers, B. (2007). Ecosystems services in South Africa: a research theme that can engage environmental, economic and social scientists in the development of sustainability science? *South African Journal of Science*, 103: 367-376.

Leadley, P., Pereira, H.M., Alkemade, R., Fernandez-Manjarres, J.F., Proenca, V., Scharlemann, J.P.W. and Walpole, M.J. (2010). *Biodiversity Scenarios: Projections of 21st century change in biodiversity and associated ecosystem services. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 50, 132 pages*. Leary, NA. Dokken, DJ. and White, KS. (Eds.), Cambridge University Press, Cambridge, 237-342.

Madzwamuse, M. (2010). *Climate Change Vulnerability and Adaptation Preparedness in South Africa*. Heinrich Böll Stiftung. Cape Town, South Africa.

Midgley, G.F., Rutherford, M.C., Bond, W.J. and Barnard, P. (2008). *The Heat is On: Impacts of climate change on plant diversity in South Africa*. South African National Biodiversity Institute, Cape Town.

Midgley, J.J., Cowling, R.M., Seydack, A.H.W. and van Wyk, G.F. (1997). Forest. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds). *Vegetation of Southern Africa*. Cambridge University Press, United Kingdom.

Milton, S.J., Yeaton, R.I., Dean, W.R.J. and Vlok, J.H.J. (1997). Succulent Karoo. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds). *Vegetation of Southern Africa*. Cambridge University Press, United Kingdom.

Murombedzi, J. (2008). *Climate Change, Natural Resources and Adaptation in Southern Africa*. Resource Africa-FFI Report. Resource Africa, Johannesburg, South Africa.

Mucina, L. and Rutherford, M.C. (eds). (2006). *The Vegetation of South Africa, Lesotho and Swaziland*. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Mucina, L., Jurgens, N., le Roux, A., Rutherford, M.C., Schmiedel, U., Esler, K.J., Powrie, L.W., Desmet, P.G. and Milton, S.J. (2006c). Succulent Karoo Biome. In: Mucina, L. and Rutherford, M.C. (eds). *The Vegetation of South Africa, Lesotho and Swaziland*. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Mucina, L., Rutherford, M.C., Palmer, A.R., Milton, L.S., Lloyd, J.W., van der Merwe, B., Hoare, D.B., Bezuidenhout, H., Vlok, J.H.J., Euston-Brown, D.I.W., Powrie, L.W. and Dold, A.P. (2006b). Nama-Karoo Biome. In: Mucina, L. and Rutherford, M.C. (eds). *The Vegetation of South Africa, Lesotho and Swaziland*. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Mucina, L., Scott-Shaw, C.R., Rutherford, M.C., Camp, K.G.T., Matthews, W.S., Powrie, L.W. and Hoare, D.B. (2006a). Indian Ocean Coastal Belt. In: Mucina, L. and Rutherford, M.C. (eds). *The Vegetation of South Africa, Lesotho and Swaziland*. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., Lebre la Rovere, E., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H.H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N. and Dadi, Z. (eds) (2000). *Emissions scenarios - a special report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press, Cambridge.

Noirtin, E. (2008). *Analysis of Stakeholder interactions and involvement in thicket restoration, Western Baviaanskloof, South Africa. Who is willing to restore and why?* Thesis Report, Subtropical Thicket Restoration Programme.

O'Connor, T.G. and Bredenkamp, G.J. (1997). Grassland. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds). *Vegetation of Southern Africa*. Cambridge University Press, United Kingdom.

Palmer, A.R. and Hoffman, M.T. (1997). Nama-Karoo. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds). *Vegetation of Southern Africa*. Cambridge University Press, United Kingdom.

Petersen, C. and Holness, S. (2011). *South Africa: Ecosystem-Based Planning for Climate Change*. World Resources Report, Washington DC.

Reyers, B., O'Farrell, P.J., Cowling, R.M., Egoh, B.N., Le Maitre, D.C. and Vlok, J.H.J. (2009). Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecology and Society*, 14(1): 38.

Rutherford, M.C. (1997). Categorization of biomes. In: Cowling R.M., Richardson D.M., Pierce S.M. (eds.) *Vegetation of Southern Africa*. Cambridge University Press, Cambridge: 91-98.

Rutherford, M.C., Mucina, L. and Powrie, L.W. (2006a). Biomes and bioregions of southern Africa. Pages 30-51 in Mucina, L. and Rutherford, M.C. (eds). *The Vegetation of South Africa, Lesotho and Swaziland*. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Rutherford, M.C., Mucina, L., Lotter, M.C., Bredekamp, G.J., Smit, J.H.L., Scott-Shaw, C.R., Hoare, D.B., Goodman, P.S., Bezuidenhout, H., Scott, L., Ellis, F., Powrie, L.W., Siebert, F., Mostert, T.H., Henning, B.J., Venter, C.E., Camp, K.G.T., Siebert, S.J., Matthews, W.S., Burrows, J.E., Dobson, L., van Rooyen, N., Schmidt, E., Winter, P.J.D., du Preez, P.J., Ward, R.A., Williamson, S. and Hurter, P.J.H. (2006b). Savanna Biome. In: Mucina, L. and Rutherford, M.C. (eds). *The Vegetation of South Africa, Lesotho and Swaziland*. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Sabine, C.L., Heimann, M., Artaxo, P., Bakker, D.C.E., Chen, C.T.A., Field, C.B., and Gruber, N. (2004). *Current status and past trends of the global carbon cycle. Global Carbon Cycle: Integrating Humans, Climate, and the Natural World*, In: Field, C.B. and Raupach, M.R. (Eds.), Island Press, Washington, District of Columbia, 17-44.

Scheiter, S. and Higgins, S.I. (2009). Impacts of climate change on the vegetation of South Africa: an adaptive dynamic vegetation modeling approach. *Global Change Biology*, 15: 2224-2246.

South African National Biodiversity Institute (SANBI) (2005). *National Grasslands Initiative: Identification of compatible land uses for maintaining biodiversity integrity*. Background Information Report No. 3. SANBI, Pretoria.

Steenkamp, K. Wessels, K., Archibald, S. and Von Maltitz, G. (2008). *Long Term Phenology and Variability of Southern Africa*. CSIR.

Van Wilgen, B.W., Forsyth, G.G., and Le Maitre, D.C. (2008). *The prioritization of species and primary catchments for the purposes of guiding invasive alien plant control operations in the terrestrial biomes of South Africa*. CSIR NRE Report number: CSIR/NRE/ECO/ER/2008/0070/C

Vlok, J.H.J., Euston-Brown, D.I.W. and Cowling, R.M. (2003). Acock's Valley Bushveld 50 years on: new perspectives on the delimitation, characterization and origin of thicket vegetation. *South African Journal of Botany*, 69: 27-51.

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