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Implications of global change for Important Bird Areas in South Africa

by

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Implications of global change for Important Bird Areas in South Africa

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Abstract

The Important Bird Areas (IBAs) network of BirdLife International aims to identify sites that are essential for the long-term conservation of the world's avifauna. A number of global change events have the potential to negatively affect, either directly or indirectly, most bird species, biodiversity in general and associated ecological processes in these areas identified as IBAs. To assist conservation decisions, I assessed a suite of ten landscape scale anthropogenic pressures to 115 Important Bird Areas (IBAs) in South Africa, both those currently placing pressures on IBAs and those that constitute likely future vulnerability to transformation. These threats are combined with irreplaceability, a frequently used measure of conservation importance, to identify the suite of IBAs which are high priority sites for conservation interventions: those with high irreplaceability and are highly vulnerable to anthropogenic threats. A total of 22 (19%) of the South African IBAs are highly irreplaceable and are highly vulnerable to at least some of the pressures assessed. Afforestation, current and potential future patterns of alien plant invasions affect the largest number of highly irreplaceable IBAs. Only 9% of the area of highly irreplaceable IBAs is formally protected. A total of 81 IBAs (71%) are less than 5% degraded or transformed. This result, together with seven highly irreplaceable IBAs found outside of formally protected areas with lower human densities than expected by chance provides an ideal opportunity for conservation interventions. However, all the pressures assessed vary geographically, with no discernible systematic pattern that might assist conservation managers to design effective regional interventions. Furthermore, I used the newly emerging technique of ensemble forecasting to assess the impact of climate change on endemic birds in relation to the IBAs network. I used 50 endemic species, eight bioclimatic envelope models, four climate change models and two methods of transformation to presence or absence, which essentially creates 2400 projections for the years 2070-2100. The consensual projection shows that climate change impacts are very likely to be severe. The majority of species (62%) lose climatically suitable space and 99% of grid cells show species turnover. Five species lose at least 85% of climatically suitable space. The current locations of the South African Important Bird Areas network is very likely ineffective to conserve endemic birds under climate change along a "business a usual" emissions scenario. Many IBAs show species loss (41%; 47 IBAs) and species turnover (77%; 95 IBAs). However, an irreplaceability analysis identified mountainous regions in South Africa as irreplaceable refugia for endemic species, and some of these regions are existing IBAs. These IBAs should receive renewed conservation attention, as they have the potential to substantially contribute to a flexible conservation network under realistic scenarios of climate change. Considering all the global change threats assessed in this study, the Amersfoort-Bethal-Carolina District and the Grassland Biosphere Reserve (IBA codes: SA018; SA020) are the key IBAs in South Africa for conservation prioritisation.

Key words: afforestation, alien invasive plants, bioclimatic niche modelling, BIOMOD, climate change, conservation planning, conservation prioritisation, ensemble modelling, human population density, irreplaceability, transformation vulnerability.

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As always, “Never give in…”
– W. L. S. C. –

Disclaimer

Chapters 2 and 3 in this thesis have been prepared for submission to different scientific journals. As a result styles and formats may vary between all chapters in the thesis and overlap in content may occur throughout the thesis to secure publishable entities. For ease of reading, tables and figures have been placed on separate pages.

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Preface

"...we do not know how many species inhabit the earth or even a small part of it – even to the nearest order of magnitude. We know even less about how and where most species on Earth originate, live and die. Many of my colleagues in other fields are surprised to learn that the study of biodiversity is still largely in the Linnaean phase of discovering and naming new species. Although our tools are more advanced, in many ways the science of biodiversity is not much farther along then medicine in the Middle Ages. We are still at the stage, as it were, of cutting open bodies to find out what organs are inside. The low investment and slow pace of biodiversity research might be tolerable were it not for the overwhelming and rapid destruction of the natural world. Without hyperbole we can truthfully say that we are almost out of time to save much of the diversity of life on Earth."

Stephen P. Hubbell 2001
The Unified Neutral Theory of Biodiversity and Biogeography
Princeton University Press, USA

Our changing climate, hunger for resources, incessant pollution, growing population together with the ever increasing destruction of the natural world and our homogenisation of the earths species is driving biodiversity into oblivion. Ultimately, we know that the fates of biodiversity and humans are inextricably linked.[1] This fact transcends boundaries, religions and races. I implore the human species to heed it.

I hope that this manuscript in some way contributes to our understanding of biodiversity loss, its prevention and to the ultimate goal of conservation biology: biodiversity preservation.

Bernard W.T. Coetzee
Pretoria, South Africa, December 2007

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[1] Millennium Ecosystem Assessment (www.MAweb.org)

Chapter 1

Introduction

Running title: 1. Introduction

Introduction

Global change

Global change refers to changes that are altering our world at a global scale. There are two categories. Firstly, changes are occurring in the fluid envelopes of the earth, the atmosphere and the oceans (Vitousek, 1992). Drivers of these changes include climate change, acidification of the ocean, decreased stratospheric ozone concentrations and fluctuations in ultraviolet input. Secondly, changes occur at discrete sites but are so widespread globally, and if observed over long enough time scales, constitute a global change. Drivers of this form of global change include land use change, biological invasions, ecosystem nitrification, and the loss of biodiversity (Vitousek, 1992, 1994; Vitousek et al., 1997).

Drivers of global change have altered the way scientists view the world, as these are sources of concern for biodiversity loss and for human well-being (Millennium Ecosystem Assessment, 2005). This has also come with the realization that these often dissimilar processes across the planet are integrated at multiple temporal and spatial scales, and are interrelated through complex feedback mechanisms (e.g. Pimm and Sugden, 1994; Falkowski et al., 2000). The ultimate cause of the unprecedented rates of global biodiversity loss that the earth is currently experiencing is due to both the individualistic and the synergistic effects of global change.

Important Bird Areas

Given that global change is taking place, there is a need to streamline global conservation efforts and financial investment in conservation. One such approach is the use of global prioritization systems to identify areas that are most in need of conservation action. Nine major institutional prioritization frameworks have been published over the past decade (for a review see Brooks et al., 2006). One of these is the Important Bird Areas (IBAs) network of BirdLife International. It is a worldwide initiative aimed at identifying, documenting, and protecting a network of sites critical for the long-term viability of naturally occurring bird populations across their geographical range (Fishpool and Evans, 2001). To qualify as an IBA and using birds as the only criterion, a site must fulfill at least one of four criteria. It should hold (1) significant numbers of one or more species of global conservation concern, (2) significant populations of one or more restricted-range species (those with global distributions of < 50,000 km^2), (3) a significant component of a group of species whose distributions are largely or wholly confined to one biome, or (4) significant numbers of one or more congregatory species. The IBAs program guidelines emphasize that IBAs should complement each other and build on existing protected-area networks (Barnes, 1998; Fishpool and Evans, 2001). IBAs have been shown to be a reasonable surrogate for identifying areas important for conservation of other components of biodiversity. Programs to identify IBAs, involving BirdLife and its national partner organizations, have already been implemented in Europe, the Middle East, Asia, and Africa. A major strength of the IBA system is that its pragmatic and especially appropriate for data poor regions. Of all the global biodiversity conservation prioritisation schemes (Brooks et al., 2006), the IBA system has most developed site based, and fine grained implementation of conservation actions (Tushabe et al., 2006). As such, they form an excellent first approximation for areas in need of conservation (Tushabe et al., 2006). Their wide use and implementation is a conservation success story.

In South Africa, 122 IBAs have been nominated by BirdLife International, which is the highest of any country in the entire African continent. Of these, 42 are formally protected in nature reserves or national parks, 33 are partially protected (only a portion of the IBAs fall inside a formally protected area) and the remaining 26 are unprotected (some of which occur in Natural Heritage Sites, conservancies or privately owned nature reserves). The IBA network is spread out over all the nine provinces within South Africa and occurs within all biomes (Figure 2.1; p.24).

Rationale

The degree of transformation and the nature and intensity of threats to IBAs are not explicitly defined or assessed in selecting IBAs across a region. A number of current and future anthropogenic global change activities have the potential to negatively affect, either directly or indirectly, most bird species, biodiversity in general and associated ecological processes in these areas identified as IBAs. Threats to IBAs include human population expansion, general land transformation (e.g., agriculture, afforestation, mining), increased urbanization and infrastructure (like roads and railways) and the ever increasing introduction and spread of invasive alien species (Vitousek et al., 1997; Neke and du Plessis, 2004; Driver et al., 2005). In South Africa, human population density and avian species richness are positively related, and there are more IBAs in high human population density areas than expected by chance (van Rensburg et al., 2004). This means there is substantial scope for conflict between human development needs and conservation requirements. Also, there is now a scientific consensus that observed climate change is very likely caused by human activities (IPCC, 2007). Climate change is already affecting birds across the world. Changes in phenology, distributions and the arrival of migrants have all been documented (e.g. Crick and Sparks, 1999; Chambers et al., 2005; Jonzén et al., 2006). Severe impacts on biodiversity in general and large changes in bird distributions in particular are expected in South Africa (van Jaarsveld and Chown, 2001; Simmons et al., 2004). Conservation planners are in dire need of robust estimates of climate change impacts on species and this needs to be incorporated into conservation planning strategies, since it is likely that species will be driven out of the current locations of reserve networks (Hannah et al., 2002a,b; Araújo et al., 2004).

As a result, there is a great need to assess the vulnerability of the South African IBA network to these drivers of global change. Assessing the current status of the habitat and the ability to predict which areas, that have high conservation value, are most susceptible to transformation and threat is an important component of effective and realistic conservation planning (Neke and du Plessis, 2004; Driver et al., 2005). Furthermore, conservation action is often implemented largely at the regional scale (e.g. at the provincial level in South Africa or the state level in the United States) as apposed to the national scale. Thus an important question for managers is to what extent the same conservation challenges are applicable across regions that make up a country. That is, should the same anthropogenic pressures (and levels of anthropogenic pressures) be applicable across most IBAs within a country, or in specific regions, then it would simplify management planning and interventions considerably.

BirdLife South Africa is currently coordinating a conservation programme of action, advocacy and monitoring for South Africa's IBAs. Due to the large number of South African IBAs and limited resources, it is necessary to prioritize conservation activities for the IBAs (Evans, 2001). Further, given that biodiversity conservation initiatives have limited resources it is vital to know where to invest these limited resources (Tushabe et al., 2006). All IBAs are arguably important for avian conservation across the globe, but by quantifying the anthropogenic pressures to them we can also inform conservation urgency, i.e., which IBAs are most likely to be transformed the soonest (Reyers, 2004).

Aims

The specific aims of this thesis are:

(i) To assess the vulnerability of the terrestrial South African IBA network to current anthropogenic pressures and future likelihood of transformation, and by considering IBA irreplaceability, to identify IBAs with a high conservation priority,

(ii) To determine how these anthropogenic pressures are distributed spatially across the region,

(iii) A general description of possible range changes in South African endemic birds due to climate change.

(iv) To investigate projected range changes in endemic bird species due to climate change in terms of the locations of the IBAs network.

Data

Assessments of vulnerability to transformation critically depend on the type of data available (Wilson et al., 2005). To enable assessments collectively across a region, it is important that data have a spatial component. The advent of Geographic Information Systems (GIS) has enabled vast amounts of data to be captured and more importantly, expressed spatially. Data used here represents readily obtainable and spatially referenced data, but adequate data is not always available (Wilson et al., 2005). For example, it is vitally important to incorporate economics into conservation planning and assessments, but data of this nature is rarely spatially referenced (Naidoo et al., 2006). Nonetheless, South Africa is in a rare position on the African continent in that it has an abundance of appropriate and high quality data at a fine spatial resolution. It is an opportune moment then to apply these datasets in context of global change threats to IBAs.

Current anthropogenic pressures

Current land cover and land transformation data which represent current anthropogenic pressures to terrestrial IBAs were obtained from a variety of sources. I used the newly released South African National Land cover database of 2000 (NLC2000). I also incorporated information on the road network within a region, which is rarely done in conservation assessments, although the affects of roads on ecosystems can be large (Strasburg, 2006). Furthermore, I included data on current patterns of human population density and also the location of alien invasive plants, both are considered to be large threats to biodiversity (Vitousek et al., 1997). I also considered IBAs outside of the formal protected areas network as being threatened, since no formal mechanism is in place to conserve them. A detailed description of these five datasets is given in Chapter two.

Future vulnerability

The National Spatial Biodiversity Assessment (Driver et al., 2005) identified areas in South Africa that are considered to be susceptible to future anthropogenic land transformation using a number of datasets. I used data on afforestation potential, mining potential, human population expansion, suitability to alien plant invasions and suitability for agriculture. A detailed description of all five datasets used in this study is given in Chapter two, and the limitations to these datasets are discussed in Driver et al. (2005).

Species data

Complete avian species inventories do not yet exist for all IBAs in South Africa, or for most protected areas, although this is being addressed (e.g. Birds In Reserves Project, 2007; Southern African Bird Atlas Project 2, 2007). However, the Southern African Bird Atlas Project (SABAP; Harrison et al., 1997) database provides atlas data at a relatively fine resolution of high quality (Harrison et al., 2007). Consequently, it has been used in over 50 research publications and is suitable here to address a conservation assessment for South African IBAs (Harrison et al., 2007). Also, it arguable provides the best dataset available in South Africa for the BIOMOD modelling approach used here (Thuiller, 2003). The technique is dependent on presence and absence records of species, of which the SABAP data makes a good approximation.

Climate Change data

The Climate Research Unit (CRU) provides monthly means climate data for the period 1961-1990 over the most of the terrestrial surface of the planet (New et al., 2002). Southern Africa is especially vulnerable to climate change, but few Regional Climate Modelling climate change studies have been undertaken in this region (Tadross et al., 2005). Here I used four climate change models, all along the “business as usual” or so called “worst case” A2 SRES scenario (Nakicenovic & Swart, 2000). This scenario is considered relatively plausible in future (Broennimann et al., 2006). As far as I am aware, these models represent the most recent and readily available climate change data for Southern Africa at an appropriate spatial resolution. This analysis essentially compares four equally justifiable climate change models for the region, thus taking cognisance of the fact that there is uncertainty in climate change models and downscaling techniques themselves (Beaumont et al., 2007).

Thesis outline

This thesis is comprised of four chapters, the first being a general introduction to global change in the context of the South African IBA network. In Chapter two, I assess the current status and quantify possible future anthropogenic threats to South African IBAs in a spatially explicit manner using various input layers in GIS (Geographic Information Systems) software (aims (i) and (ii) above). Chapter three addresses the issue of climate change. I use the newly emerging technique of ensemble bioclimatic envelope modelling (Araújo and New, 2006) to make distributional range change predictions for endemic birds in South Africa (aims (iii) and (iv) above). Chapter four addresses the limitations of the study, discusses possibilities for improvements and possible directions for future research.

References

Araújo, M.B., Cabeza, M., Thuiller, W., Hannah, L., Williams, P.H. 2004. Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. Global Change Biology 10, 1618–1626.

Araújo, M.B., New, M. 2006. Ensemble forecasting of species distributions. Trends in Ecology and Evolution 22, 42–47.

Barnes, K.N. 1998. The Important Bird Areas of Southern Africa. Birdlife South Africa, Johannesburg, South Africa.

Beaumont, L.J., Pitman, A.J., Poulsen, M., Hughes, L. 2007. Where will species go? Incorporating new advances in climate modelling into projections of species distributions. Global Change Biology 13, 1368–1385.

Birds in Reserves Project 2007 (BIRP 2007) [Online] (14 May 2007) (http://www.birds.sanbi.org/birp/birp_frameset_parent.htm).
Broennimann, O., Thuiller, W., Hughes, G., Midgley, G.F., Alkemade, J.M.R., Guisan, A. 2006. Do geographic distribution, niche property and life form explain plants' vulnerability to global change? Global Change Biology 12, 1079–1093.

Brooks, T.M., Mittermeier, R.A., da Fonseca, G.A.B., Gerlach, J., Hoffmann, M. Lamoreux, J. F., Mittermeier, C.G., Pilgrim, J.D., Rodrigues, A.S.L. 2006. Global biodiversity conservation priorities. Science 313, 58–61.

Chambers, L.E., Hughes, L., Weston, M.A. 2005. Climate change and its impact on Australia's avifauna. Emu 105, 1–20.

Crick, H.Q.P., Sparks, T.H. 1999. Climate changes related to egg-laying trends. Nature 399, 423−424.

Driver, A., Maze, K., Rouget, M., Lombard, A.T., Nel, J., Turpie, J.K., Cowling, R.M., Desmet, P., Goodman, P., Harris, J., Jonas, Z., Reyers, B., Sink, K., Strauss, T. 2005. National Spatial Biodiversity Assessment 2004: Priorities for Biodiversity Conservation in South Africa. Strelitzia 17. South African National Biodiversity Institute, Pretoria, South Africa.

Evans, S.W. 2000. Prioritising of South Africas Important Bird Areas for Conservation Action. BirdLife South Africa, Johannesburg, South Africa.

Falkowski, P., Scholes, R.J., Boyle, E., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Högberg, P., Linder, S., Mackenzie, F.T., Moore III, B., Pedersen, T., Rosenthal, Y., Seitzinger, S., Smetacek, V., Steffen, W. 2000. The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System. Science 290, 291–296.

Fishpool, L.D.C., Evans, M.I. 2001. Important Bird Areas in Africa and associated islands: Priority sites for conservation. Newbury and Cambridge, UK: Pisces Publication and BirdLife International (BirdLife Conservation Series No. 11).

Hannah, L., Midgely, G.F., Lovejoy, T., Bond, W.J., Bush, M., Lovett, J.C., Scott, D., Woodward, F.I. 2002a. Conservation of biodiversity in a changing climate. Conservation Biology 16, 264–268.

Hannah, L., Midgley, G.F., Millar, D. 2002b. Climate change-integrated conservation strategies. Global Ecology and Biogeography 11, 485–495.

Harrison, J.A., Allan, D.G., Underhill, L.G., Herremans, M., Tree, A.J., Parker, V., Brown, C.J. 1997. The atlas of Southern African birds. Birdlife South Africa, Johannesburg, South Africa.

Harrison, J.A., Underhill, L.G., Barnard, P. 2007. The seminal legacy of the Southern African Bird Atlas Project. South African Journal of Science, In Press.
IPCC 2007. Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Science Basis, AR4 Synthesis Report, [Online] (On 3 Dec 2007) (www.ipcc.ch).

Jonzén, N., Lindén, A., Ergon, T., Knudsen, E., Vik, J.O., Rubolini, D., Piacentini, D., Brinch, C., Spina, F., Karlsson, L., Stervander, M., Andersson, A., Waldenström, J., Lehikoinen, A., Edvardsen, E., Solvang, R., Stenseth, N.C. 2006. Rapid advance of spring arrival dates in long-distance migratory birds. Science 312, 1959–1961.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

Naidoo, R., Balmford, A., Ferraro, P.J., Polasky, S., Ricketts, T.H., Rouget, M. 2006. Integrating economic costs into conservation planning. Trends in Ecology and Evolution 21, 681–687.

Nakicenovic, N., Swart, R. 2000. Emissions Scenarios. Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Neke, K.S., Du Plessis, M.A. 2004. The threat of transformation: Quantifying the vulnerability of Grasslands in South Africa. Conservation Biology 18, 466–477.

New, D., Lister, D., Hulme, M., Makin, I. 2002. A high-resolution data set of surface climate over global land areas. Climate Research 21, 1–25.

Pimm, S.L., Sugden, A.M. 1994. Tropical Diversity and Global Change. Science 263, 933–934.

Reyers, B. 2004. Incorporating anthropogenic threats into evaluations of regional biodiversity and prioritisation of conservation areas in the Limpopo Province, South Africa. Biological Conservation 118, 521–531.

South African Bird Atlas Project 2 (SABAP2). [Online] (26 October 2007) (http://sabap2.adu.org.za).

Simmons, R.E., Barnard, P., Dean, W.R.J. Midgley, G.F., Thuiller, W., Hughes, G. 2004. Climate change and birds: perspectives and prospects from southern Africa. Ostrich 75, 295–308.

Strasburg, J.L. 2006. Roads and genetic connectivity. Nature 440, 875–876.

Tadross, M., Jack, C., Hewitson, B. 2005. On RCM-based projections of change in southern African summer climate. Geophysical Research Letters 32, (doi:10.1029/2005GL024460).
Thuiller, W. 2003. BIOMOD – optimizing predictions of species distributions and projecting potential future shifts under global change. Global Change Biology 9, 1353–1362.

Tushabe, H., Kalema, J., Aruhanga, A., Asasira, J., Ssegawa, P., Balmford, A., Davenport, T., Fjeldså, J., Friis, I., Pain, D., Pomeroy, D., Williams, P., Williams, C. 2006. A Nationwide Assessment of the Biodiversity Value of Uganda's Important Bird Areas Network. Conservation Biology 20, 85–99.

van Jaarsveld, A.S., Chown, S.L. 2001. Climate change and its impacts in South Africa. Trends in Ecology and Evolution 16, 13–14.

van Rensburg, B.J., Erasmus, B.F.N., van Jaarsveld, A.S., Gaston, K.J., Chown, S.L. 2004. Conservation during times of change: correlations between birds, climate and people in South Africa. South African Journal of Science 100, 266–272.

Vitousek, P.M. 1992. Global Environmental Change: An Introduction. Annual Review of Ecology and Systematics 23, 1–14.

Vitousek, P.M. 1994. Beyond global warming: Ecology and global change. Ecology 75, 1861–1876.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M. 1997. Human domination of earth's ecosystems. Science 277, 494–499.

Wilson, K., Pressey, R.L., Newton, A., Burgman, M., Possingham, H., Weston, C. 2005. Measuring and Incorporating Vulnerability into Conservation Planning. Environmental Management 35, 527–543.

Chapter 2

Prioritising conservation action in South African Important Bird Areas: an assessment of irreplaceability and transformation vulnerability

Running title: 2. IBAs and transformation

Prioritising conservation action in South African Important Bird Areas: an assessment of irreplaceability and transformation vulnerability

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Abstract

To assist conservation decisions, we assessed a suite of ten landscape-scale anthropogenic pressures to 115 Important Bird Areas (IBAs) in South Africa, both those currently placing pressures on IBAs and those that constitute likely future vulnerability to transformation. These threats are combined with irreplaceability to identify the suite of IBAs which are high priority sites for conservation interventions: those with high irreplaceability and facing high vulnerability. A total of 22 (19%) of IBAs are highly irreplaceable and highly vulnerable to at least some of the pressures assessed. Afforestation, current and potential future patterns of alien plant invasions affect the largest number of highly irreplaceable IBAs. Only 10 (9%) of highly irreplaceable IBAs are formally protected. A total of 81 IBAs (71%) are less than 5% degraded or transformed. This result, together with seven highly irreplaceable IBAs found outside of formally protected areas with lower human densities than expected by chance provides an ideal opportunity for conservation interventions. However, all the pressures assessed vary geographically, with no discernible systematic pattern that might assist conservation managers to design effective regional interventions.

Key words: conservation planning, conservation prioritisation, bird conservation, afforestation, alien invasive plants, human population density.

Introduction

The world is facing unprecedented rates of global biodiversity loss mainly due to anthropogenic habitat transformation (Vitousek et al., 1997). Furthermore, conservation resources are limited and most conservation initiatives are under-funded (James et al., 1999; Balmford and Whitten, 2003; Balmford et al., 2003). There is thus a need to streamline global conservation efforts and financial investment in conservation. One such an approach is the use of global prioritization systems to identify areas that are most in need of conservation action and nine major institutional prioritization frameworks have been published over the past decade (for a review see Brooks et al., 2006). One of these is the Important Bird Areas (IBAs) network of BirdLife International which aims to identify sites that are essential for the long-term conservation of the world's avifauna. IBAs are designated using criteria based on the presence of globally threatened, restricted-range, or biome restricted bird species, or the presence of substantial congregations of individuals. IBAs are designed so that they overlap as far as possible with the existing reserve network of the particular region in question, although this is not always the case. In Africa for example, 51% of IBAs fall outside of conservation areas (Fishpool and Evans, 2001).

The IBAs system is different to that of systematic conservation planning approaches in that it is expert driven and does not use algorithms to identify priority areas. Herein lies some of the criticism levelled at IBAs. While it may be a pragmatic system, it is a qualitative process with low repeatability and does not assess the effectiveness of conservation decisions (O'Dea et al., 2006). Furthermore it does not assess the irreplaceability (the likelihood that a given site will need to be protected to ensure certain conservation targets are met; Margules and Pressey, 2000) or relative vulnerability of sites, here considered an estimate of the likelihood or imminence of habitat loss or degradation (Pressey and Taffs, 2001). These two concepts are the cornerstones of systematic conservation planning approaches (Margules and Pressey, 2000; van Rensburg et al., 2004; Brooks et al., 2006).

A number of current and future anthropogenic activities have the potential to negatively affect, either directly or indirectly, most bird species, biodiversity in general and associated ecological processes in these areas identified as IBAs. Also, all IBAs are arguably important for avian conservation across the globe, but by quantifying the anthropogenic pressures to them we can also inform conservation urgency, i.e., which IBAs are most likely to be transformed the soonest (Reyers et al., 2004). Furthermore, conservation action is often being implemented largely at the regional scale (e.g. at the provincial level in South Africa or the state level in the United States) as apposed to the national scale. Thus an important question for managers is to what extent the same conservation challenges are applicable in regions across the national scale. That is, should the same anthropogenic pressures (and levels of anthropogenic pressures) be applicable across most IBAs within a country, or in specific regions, it would simplify management planning and interventions considerably.

Owing to its phenomenal habitat diversity, South Africa contains *ca*. 800 described bird species amounting to ~7% of the world’s avifauna (Fishpool and Evans, 2001). BirdLife International has designated 122 IBAs in South Africa, which is the highest of any country on the African continent. At least 52% of these IBAs fall outside of formally protected areas; this is approximately 73 000 km^2 outside of protected areas designated by BirdLife as essential for avian conservation in South Africa. Conserving these IBAs is therefore challenging especially with most of them being located in areas of greater human population density than expected by chance (van Rensburg et al., 2004). This means there is substantial scope for conflict between human development needs and conservation requirements.

The aims of this study were (1) to assess the vulnerability of the South African IBA network to current anthropogenic pressures and future likelihood of transformation, and by considering IBA irreplaceability, to identify IBAs with high conservation priority, and (2) to determine how these anthropogenic pressures are distributed spatially across the region. It was not our intention to assess whether the South African IBA network captures other components of biodiversity (Tsuhabe et al., 2006) or how the IBA system compares to other systematic conservation approaches (O'Dea et al., 2006). Rather, this study complements and advances existing knowledge on how best to conserve South Africa's avifauna, in keeping with its obligations as a signatory to the Convention on Biological Diversity (Balmford et al., 2005). Also, the literature is replete with calls to move global scale conservation prioritization analysis to more regional scales where conservation implementation is more likely to take place (e.g. da Fonseca, 2000; Mace, 2000; Brooks et al., 2006).

Materials and Methods

2.1. Site selection

We used a relatively simple and rapid approach consistent with current thinking in systematic conservation planning by combining irreplaceability and vulnerability (Margules and Pressey, 2000; Pressey and Taffs, 2001; Lawler et al., 2003; Reyers, 2004). Irreplaceability is a widely used measure to achieve representativeness, meaning that all designated biological features are represented (Margules and Pressey, 2000). With the emphasis on land transformation and future vulnerability to likely transformation, the focus of our study was on the terrestrial IBAs of South Africa (n = 115) and therefore excluded a total of nine IBAs representing mainly offshore islands. We also excluded one very small site, Boulders Bay (IBA117), as it was incompatible with the large spatial resolution of some of the transformation layers. South African IBAs were digitized in ArcGIS v. 9.1 (ESRI; Figure 2.1) using data from Barnes (1998). Various GIS (Geographic Information Systems) layers were used to locate conspicuous geographic features mentioned in the location descriptions of each IBA, including geographic coordinates, major roads, rivers, towns, wetlands and farms.

2.2. Current anthropogenic pressures

Current land cover and land transformation data which represent current anthropogenic pressures to terrestrial IBAs were obtained from a variety of sources (Table 2.1).

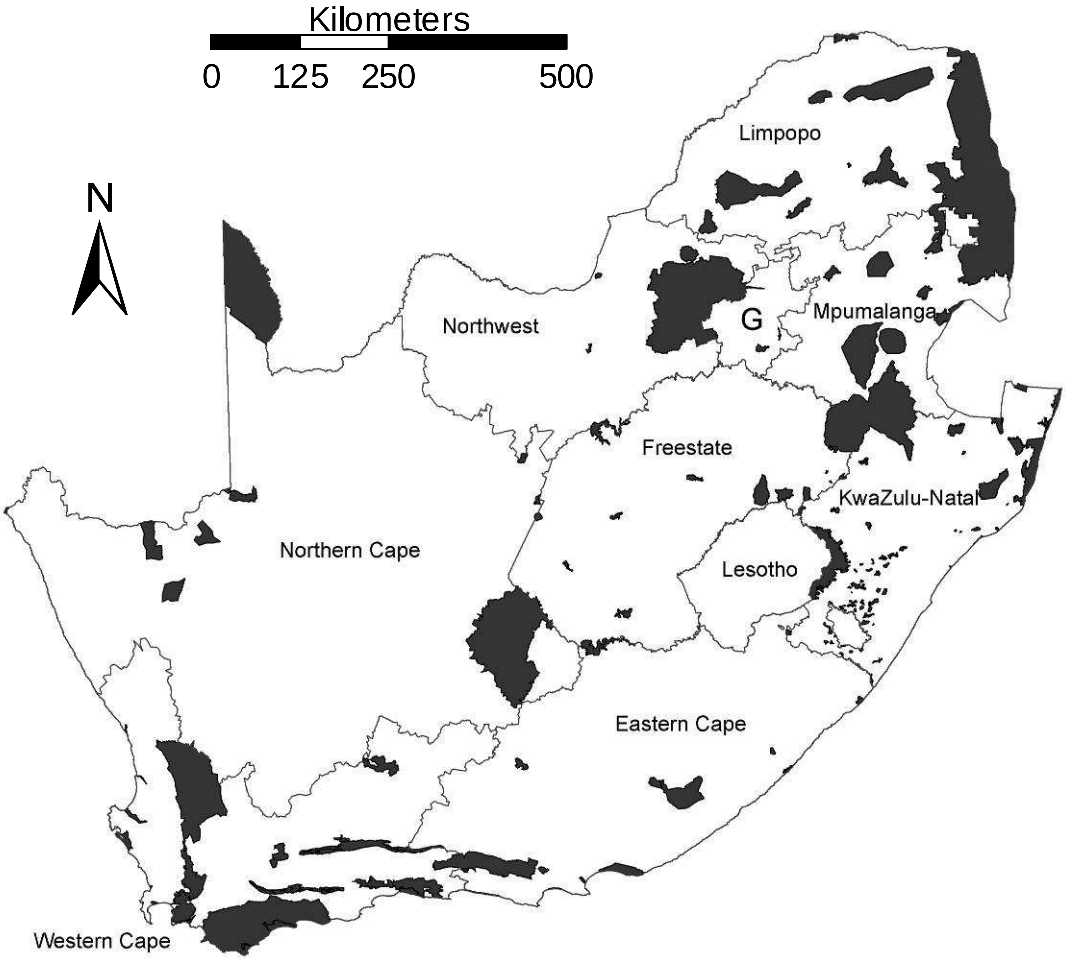

Figure 2.1. Important Bird Areas across South Africa. Provincial names and boundaries and the country of Lesotho are indicated. G = Gauteng Province.

Table 2.1. Input data and sources used to assess current anthropogenic pressures, future vulnerability to transformation and biological importance of Important Bird Areas in South Africa. Detailed methods in text. N = number of species used in each index. spp. = species

Current anthropogenic pressures

Input layer	Description	Data Source
Land transformation	2000 Land cover database with land classes reclassified to natural, transformed and degraded areas	1
Road infrastructure	Buffered road network	2, 3
Human population density	Based on the 2001 census	4
Alien invasive plant species	Distribution of major invasive Aliens (71 spp.)	5, 6
Percentage formally conserved	Percentage area of each IBA captured in the reserve network	7

Future vulnerability to transformation

Input layer	Description	Data Source
Afforestation potential	Potential for *Pinus* & *Eucalyptus* based on bioclimatic parameters	7
Mining potential	Mapped mining suitability	7
Human population expansion	Change in population density from 1996-2001 censuses	7
Suitability to alien plants	Number of major alien invasives that may invade in an area based on bioclimatic parameters (71 spp.)	7
Land capability map	Suitability for use of crops, grazing, wildlife (thus broadly cultivation)	7

Biological importance

Index	N	Description	Data Source
Species richness	655	Across all IBAs	8
Endemic species richness	34	South Africa Endemics in each IBA	8
Range restricted species	24	Range restricted spp.	9
Biome restricted species	71	Biome restricted spp.	9
Congregatory species	52	Congregatory spp.	9
Threatened species	115	IUCN and Regional Red data spp.	10, 11
Range size rarity index	655	Continuous variable of all spp.	8

Data Sources: (1) CSIR and ARC, 2005 (2) Municipal Demarcation Board South Africa, 2005 (3) Reyers et al., 2001 (4) Anon., 2001 (5) Henderson, 1998 (6) Nel et al., 2004 (7) Driver et al., 2005 (8) Harrison et al., 1997 (9) Barnes, 1998 (10) IUCN (11) Barnes, 2004.

2.2.1. Land transformation

The South African National Land cover database of 2000 (NLC2000) was produced from ortho-rectified Landsat ETM satellite imagery. Two seasonally standardised datesets were used (primarily early and late growth season dates). The minimum mapping unit was 1ha and a combination of digital image classification (pixel and object based) and on-screen digitising was used (CSIR and ARC, 2005). The 49 land-cover classes were grouped into three categories of natural, degraded and transformed land-cover following Reyers et al. (2001). Natural land-cover included all untransformed vegetation (e.g. forest and grassland), but unlike Reyers et al. (2001), water bodies were classified as natural because several of these IBAs are essential for waterbird conservation. The degraded class included all areas with very low vegetation cover in comparison with the surrounding natural vegetation cover and erosion scars. These are areas associated with subsistence farming and rural population centres where wood harvesting and overgrazing have augmented soil erosion. The transformed category included all cultivated, urban/built-up classes, forestry plantations (of mainly *Pinus* and *Eucalyptus* species) as well as mines and quarries. Following Wessels et al. (2000) we determined the proportion of transformed and degraded cover classes in all IBAs as a percentage.

2.2.2. Road infrastructure

Road networks have been shown to have large negative effects on biodiversity, ranging from road kills to large scale habitat degradation (see Trombulak and Frissell, 2000; Strasburg, 2006). Following Reyers et al. (2001), the South African road network, obtained from the Municipal Demarcation Board South Africa (2005) was buffered according to the relative impact of the road type on the ecosystem. The effect of road networks, for example, construction, maintenance or road use extends beyond the road into the so called “road effect zone” and the buffer accounts for this. In contrast to Reyers et al. (2001) we included roads in protected areas as some IBAs are in protected areas while others are not. National roads and freeways were buffered by a distance 1000m, arterial and main roads were buffered 500m and secondary and rural roads were buffered 100m. We then calculated the percentage area of each IBA impacted upon by the road effect zone.

2.2.3. Human Population Density

We obtained human population data from the 2001 South African census based on *c.* 21 000 recorded "sub-place" sites (Anonymous, 2001). Sub-places represent geographically unique entities nested within municipalities. This represents the finest scale human population data readily obtainable for South Africa. We calculated the human population density per sup-place (humans/km^2), the area each sub-place overlaps with each IBA and these values are summed to obtain human population density per IBA (humans/km^2).

2.2.4. Alien Invasive Plants

The Southern African Plant Invaders Atlas (SAPIA; Henderson, 1998, 1999, 2001) is the best source of data on the distribution of invasive alien plants in South Africa. The SAPIA database contains records for over 500 species with data on their distribution, abundance, habitat preferences, and time of introduction across South Africa, Lesotho and Swaziland. Records are georeferenced at the quarter-degree grid cell (15' x 15' ~ 676 km^2; hereafter grid cells) resolution. Using the same criteria as Rouget et al. (2004) and Nel et al. (2004) we identified 71 major alien plant invaders that represent alien plant species that are widespread, locally abundant and largely invade natural landscapes as opposed to human dominated landscapes only (Nel et al., 2004; Rouget et al., 2004). We determined the presence or absence of these species in each IBA by intersecting the SAPIA distribution records with each IBA.

2.2.5. Percentage formally protected

We calculated the percentage of each IBA that is formally conserved using the South African National Spatial Biodiversity Assessment (Driver et al., 2005) classification of protected areas. The values were rescaled so that an IBA with 100% of its area occurring inside a protected area was assigned a value of zero and an IBA with no formal protection was assigned a value of one.

2.3. Future vulnerability

Vulnerability refers to an estimate of the likelihood of habitat loss through land transformation or degradation in a particular site (Pressey and Taffs, 2001). Vulnerability is measured as the extent to which a given land area is suitable for utilisation by some form of commercial land use (Wessels et al., 2003). The National Spatial Biodiversity Assessment (Driver et al., 2005) identified areas that are considered to be susceptible to future anthropogenic land transformation using a number of datasets (Table 2.1). A detailed description of all these datasets and the data limitations is provided by Driver et al. (2005).

2.3.1. Afforestation potential

Afforestation potential was modelled using fuzzy tolerance models, based on bioclimatic parameters like soil, rainfall and temperature (Driver et al., 2005; Fairbanks, 1995). Although these maps were only generated for five out of the nine provinces of the country, these provinces were found to coincide well with the areas suitable to wood production across southern Africa (Scholes and Biggs, 2004). At a 1km^2 resolution each grid cell was assigned an average suitability value for *Pinus* and *Eucalyptus* species, the major forestry species in South Africa. These values ranged from 0 (low suitability) to 100 (very high suitability).

2.3.2. Mining Potential

Mining potential indicated the locations of 13 minerals of economic importance. The dataset from the Council of Geoscience contains information on mineralised fields (areas of high concentration of a commodity) and mineralised provinces (broad areas where a given commodity occurs) as well as mineralised layers (veins of high concentration of a commodity – mapped as a linear feature; Driver et al., 2005). It also contains information on the location of mines and mineralised layers, which were buffered by 500m and 1000m, respectively. Mining potential suitability is scored into four categories: high, medium, low and no potential. We reclassified these four categories into two classes: suitable for mining and unsuitable for mining. Mining suitability was calculated as the area of each IBA that is suitable for mining.

2.3.3. Human population expansion

Data for human population expansion is not available in South Africa. However, Driver et al. (2005) used an index based on the difference between the 1996 and 2001 human population censuses for South Africa (Anonymous, 1996, 2001) as a proxy for urban sprawl and related to the movement of people across the country from rural to urban areas. The change between 1996 and 2001 censuses is taken as being indicative of the broad trend over the next ten years. These values ranged from 0 (low population expansion) to 100 (very high population expansion).

2.3.4. Susceptibility to alien plant invasions

The invasion potential of 71 important alien invasive plants, as identified by Nel et al. (2004) and mapped by SAPIA (Henderson, 1998, 1999, 2001) at the grid quarter-degree grid cell (15’ x 15’ ~ 676 km^2) resolution, have been modelled using a variant of climatic envelope models (CEMs) based on the Mahalanobis distance (Farber and Kadmon, 2003) to derive climatic suitability surfaces for each species (Rouget et al., 2004). CEMs were developed using the first three principal components derived from an analysis of seven climatic variables. At a one minute resolution, potential distributions for all species are derived based on climate suitability and the index is rescaled from 0-100, where 100 indicates that the climate is suitable for all 71 species. We used this probability map (from Rouget et al., 2004) to identify IBAs that are highly suitable for invasion by these 71 alien invasive plants.

2.3.5. Agricultural suitability

The land capability map identifies areas in South Africa that are suitable for agriculture (Smith, 1998). It was produced using soil, terrain features and climate of an area and identifies areas suitable for rain fed agricultural crops. It excludes low nutrient status as this can easily be remedied by the use of fertilizers. Each land type has a land capability index which ranges from I (good) to VIII (poor) which we scored on an equal interval scale from 0 to 100 following Driver et al. (2005).

2.4. Biological indicators

Irreplaceability is not the only way to express the biological importance of a particular area or site, and may not be appropriate for all studies and all research areas (Pressey and Taffs, 2001). To investigate the relationship between irreplaceability and other measures of conservation importance, we calculated additional indices. In addition to examining the irreplaceability scores of each IBA, we identified seven biological indicators using avian species distribution data obtained from the Southern African Bird Atlas Project (SABAP; Harrison et al., 1997). SABAP data were collected mainly between 1987 and 1992 by observers visiting each grid cell. A total of 655 species were analysed for this study after excluding vagrant and introduced species. Seabirds breeding within South Africa were included as several of the terrestrial IBAs included here are important for the conservation of the selected seabirds. Using SABAP we calculated (i) *total species richness*, (ii) *endemic species richness* i.e. bird species restricted to South Africa (Hockey et al., 2005), (iii) *number of range restricted species*, and (iv) *number of biome restricted species* (Barnes, 1998) per IBA.

In semiarid areas such as South Africa most wetlands are ephemeral, leading to large fluctuations in wetland bird numbers. As a result, important breeding populations of wetland birds often consist of fewer individuals than the ≥ 1% criterion used internationally by BirdLife. As a result, BirdLife South Africa used a lower threshold of ≥ 0.5% of the population of a congregatory species to indicate important sites for those species (Barnes, 1998). Species in IBAs containing ≥ 1% of the population of a congregatory species scored 1, whereas species in IBAs containing ≥ 0.5% of the population of a congregatory species scored 0.5. Species in IBAs that are labelled as “other important populations” of a congregatory species where scored 0.25 (Barnes, 1998). Using the species inventory lists for each IBA, these scores where summed for each IBA to represent a *congregatory indicator* (criterion v).

To estimate the contribution of threatened species to the importance of IBAs, a *threatened species indicator* was calculated (criterion vi) using a combination of IUCN Red lists (IUCN, 2006) and Regional Red Data lists (Barnes, 2004). As some species may be highly threatened regionally, but not necessarily globally threatened, species that are regionally threatened often fall into categories representing higher threat than used in global criteria. Consequently, for each species we selected the highest threat category for each species from either the sub-regional or global assessment list. Scoring of the vulnerability categories followed Keith et al. (2005), where 1.0 = Critically Endangered (CR); 0.80 = Endangered (EN); 0.70 = Vulnerable (VU); 0.56 = Near Threatened (NT); 0.42 = Data Deficient (DD); 0.00 = Least Concern (LC) or Not evaluated (NE) or not listed. Vulnerability scores for each of the threatened species were summed for each IBA, and then divided by the number of threatened species in that IBA to arrive at a threatened species indicator. This approach accounts for differences in species richness among IBAs.

Range restricted bird species are those, as classified by BirdLife International, with a distribution of less than 50 000km^2 (Fishpool and Evans, 2001). The common criticism of this approach is that it excludes species with ranges sizes only slightly above this arbitrary threshold (Brooks et al., 2005). To address this problem we used “range size rarity” as a continuous variable by summing the reciprocals of the range sizes of all species in each cell; in that way each species makes some contribution to the score. Thus, we calculated a *range size rarity indicator* (criterion vii) for each IBA by summing the inverse of the range sizes of the species occurring in a given IBA, and dividing by the species richness in that IBA. Range size was calculated by counting the number of grid cells in which the species was recorded in the entire SABAP database.

Species lists per IBA were obtained by intersecting the SABAP species distribution records with the IBA locations. We considered a species to be present in a particular IBA if the quarter-degree grid cell in which the species was recorded intersected with an IBA boundary, but we acknowledge the effect of using an arbitrary threshold to decide when a protected area is present in a particular grid cell (see Araújo, 2004). Our approach is liberal, as followed by others, (e.g. Kiester et al., 1996) and will tend to overestimate species presences in IBAs. Complete avian species inventories do not yet exist for all IBAs in South Africa, or for most protected reserves, although this is being addressed (e.g. Birds In Reserves Project, 2007; South African Bird Atlas Project 2, 2007). This approach therefore allows rapid calculation of probable species inventories for IBAs although we concede that we may inflate false positives. While a considerable problem in its own right (e.g. Araújo, 2004), in this study we consider false positives to be preferable to false negatives.

2.5. Data analysis

Where applicable, data extraction for data layers was done with ArcGIS using the Zonal Statistics module. This calculates the median value of all the grid cells of the variable of interest that occurs in each IBA. All data for each of the biological importance indices, current anthropogenic pressures and future vulnerability indices were standardised from 0-1 by dividing all index values by the highest value observed for that index (Appendix S1). Thus, index values are on a continuous scale from zero to one, where one equals the highest value obtained for that particular index.

Irreplaceability is defined as the likelihood that a given site will need to be protected to achieve a specified set of conservation targets (Ferrier et al., 2000; Margules and Pressey, 2000). Its value ranges from zero to one, where a value of one indicates an entirely biologically distinct and totally irreplaceable site, thus containing species that only occur in that site. We calculated irreplaceability based on the derived species inventories for each IBA using C-Plan conservation planning software (C-Plan, 2007; Version 3.11). We set targets at one, so that each species would be represented in at least one IBA.

Following similar arguments and approaches to those used in previous studies (Margules and Pressey, 2000; Pressey and Taffs, 2001; Lawler et al., 2003; Reyers, 2004) we identified sites with both high vulnerability and high irreplaceability which are the highest priority sites for conservation action. The results obtained from the irreplaceability analysis and both current anthropogenic pressure and future vulnerability analyses are used to produce two-dimensional plots of all IBAs to identify those sites of highest conservation concern. Plots were categorised into two equal sized classes of high

(H) or low (L) value; each IBA therefore has one of four potential irreplaceability and vulnerability combinations (HH, HL, LH, or LL) denoting its priority (Figure 2.2).

Using Principal Components Analysis (PCA), we investigated whether certain IBAs showed similar patterns or trends in anthropogenic pressures and whether there was spatial clustering of these anthropogenic pressures. PCAs are ideal for data reduction and hypothesis generation. PCAs were performed separately on the current anthropogenic pressure and future vulnerability datasets using the raw (unstandardised) data to calculate the correlation matrices upon which each PCA was based (StatsSoft, 2004). To investigate the spatial relationship between the resultant clusters, sites where grouped according to provincial boundaries, irreplaceability scores, and the seven South African biomes as defined by Low and Rebelo (1996). While spatial similarity with biomes may be biologically more meaningful, the implementation of conservation action takes place at the provincial level in South Africa, so this investigation may provide novel management answers if anthropogenic pressure variables are spatially congruent at this resolution. To investigate the relationship between irreplaceability and all the biological indicators for all IBAs we subjected the raw data (before standardisation) for all indices to a PCA and identified the highly irreplaceable (>0.5) IBAs among these.

Results

As an example, Figure 2.2 indicates how IBAs which are highly irreplaceable and under high pressure can be identified for both current anthropogenic pressures and future vulnerability. In this case (Figure 2.2), irreplaceability has been plotted against current species richness of invasive alien plant species. Those IBAs with high irreplaceability (> 0.5; 27 IBAs; 23%) but under high anthropogenic pressure (> 0.5; 22 IBAs; 19%) are listed in Appendix 2.1 and thus represent a total of 22 (19%) IBAs.

When IBAs with high irreplaceability values are compared against high current anthropogenic pressure variables (thus only HH), only alien plant invasions and protected area status showed high anthropogenic pressure values (Table 2.2). Of these, 10 IBAs (9%) are heavily invaded by alien plant species and these only have 50% area under

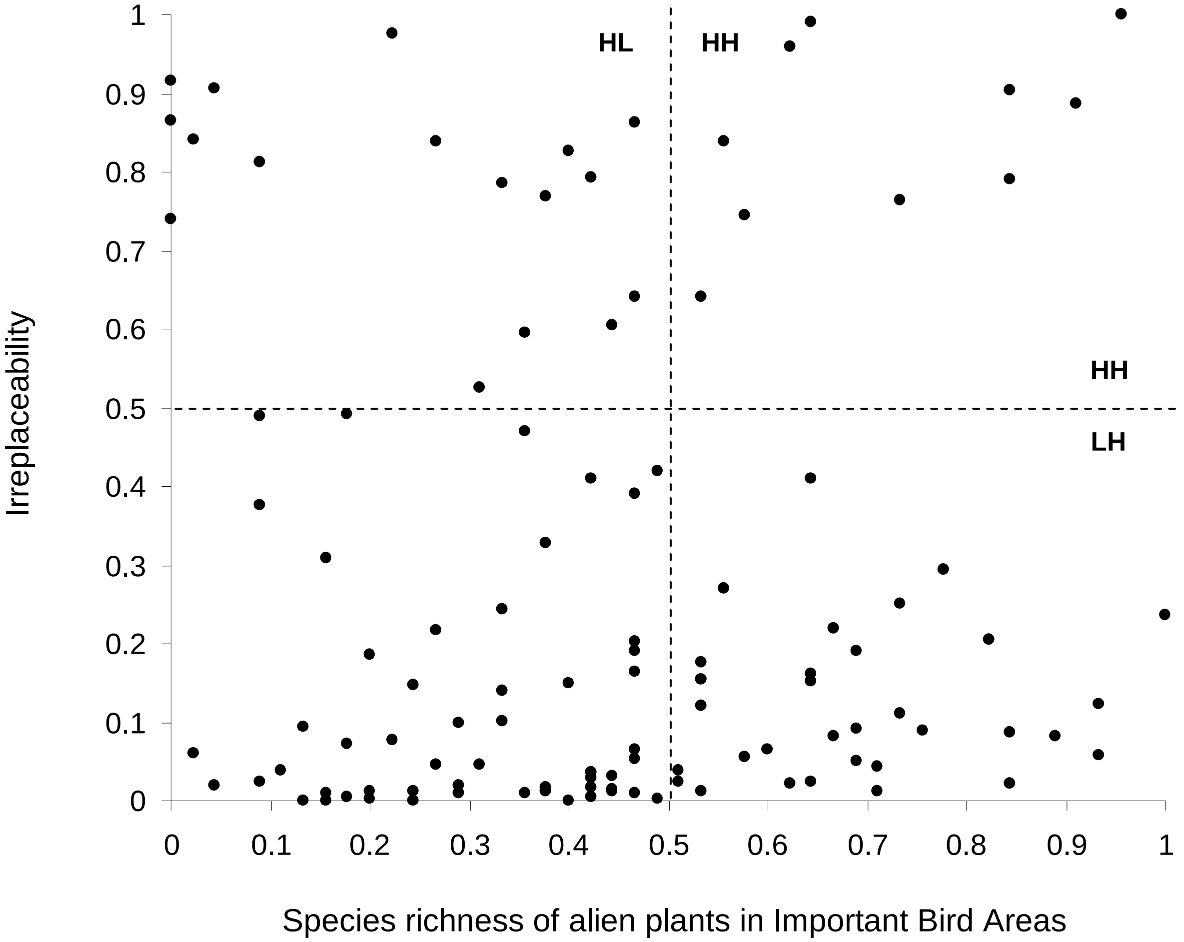

Figure 2.2. Hypothetical example of conservation areas plotted on two axes, here irreplaceability against current patterns of invasive alien plant species is shown. Irreplaceability is the likelihood that a given site will need to be protected to achieve a specified set of conservation targets. Sites with higher irreplaceability values can be viewed as having higher conservation value. The horizontal axis depicts the degree to which the conservation targets at a site are vulnerable to any of a number of potential threats, in our case a suite of ten landscape scale threats. Priority sites in terms of these threats are those with high irreplaceability and under high threat (HH).

Table 2.2. The number of IBAs, expressed as a percentage value compared to all 115 IBAs examined, identified with low or high avian species irreplaceability values, respectively, while scoring a high threat value (>0.5). The percentage of area for all the IBAs identified within each threat category within formally protected areas is shown. Values in brackets are the number of IBAs affected.

	Low irreplaceability (<0.5); High threat (>0.5)		**High irreplaceability(>0.5); High threat (>0.5)**	
Threat indices	**Percentage of IBAs affected**	**Percentage area of IBAs protected**	**Percentage of IBAs affected**	**Percentage area of IBAs protected**
Current pressures				
Aliens	27% (31)	59%	8% (9)	50%
Human population density	2% (2)	17%	-	-
Protected area status	8% (9)	9%	8% (9)	9%
Land Cover	3% (3)	8%	-	-
Roads	7% (8)	43%	-	-
Future vulnerability				
Afforestation suitability	40% (46)	57%	7% (8)	59%
Aliens invasion suitability	40% (46)	54%	9% (10)	41%
Cultivation suitability	6% (7)	58%	3% (3)	100%
Human population growth	10% (12)	42%	2% (2)	100%
Mining suitability	16% (18)	40%	3% (3)	45%

protection. Also, 10 highly irreplaceable IBAs (9%) are not formally protected; indeed these only have 9% area under protection. When compared against all potential future vulnerability variables, potential alien plant invasion affected the largest number of these IBAs (9%) and only 41% of the surface area of these IBAs are within protected areas (Table 2.2).

This was followed by afforestation, affecting 7% of the IBAs with high irreplaceability values although quite a large percentage (59%) of the surface area of these IBAs are within protected areas. The remaining variables, i.e. cultivation suitability, human population growth and mining suitability, showed relatively low numbers (2 to 3%) of highly irreplaceable IBAs being affected (Table 2.2).

Similar to the patterns described above, when IBAs with low irreplaceability values are compared against current anthropogenic pressure variables, alien plant invasions (27%) followed by protected area status (meaning the area of IBA not formally protected; nine IBAs, 8%) affected most of the IBAs examined (Table 2.2). Overall, 7% of low irreplaceability IBAs examined are under high pressure from the current road network and 43% area of these IBAs are within the protected areas network. Those IBAs affected by aliens showed the highest overlap with protected areas (59%). In the case of potential future vulnerability variables, the pattern of those IBAs with low, compared to those with high, irreplaceability values were again very similar. That is, afforestation and aliens affecting most of the IBAs (40% in both cases) with those affected by afforestation having a slightly larger proportion (57%) in protected areas than alien invasion suitability (54%; Table 2.2). The remainder of the vulnerability variables affecting IBAs varied between 6% and 16% with those areas affected by mining showing the lowest spatial overlap with protected areas (40%).

The spatial clustering of threats was weak when examining anthropogenic pressures to IBAs at the provincial level (Figure 2.3). The KwaZulu-Natal province showed some spatial similarity in anthropogenic pressures, meaning IBAs in this region are pressured

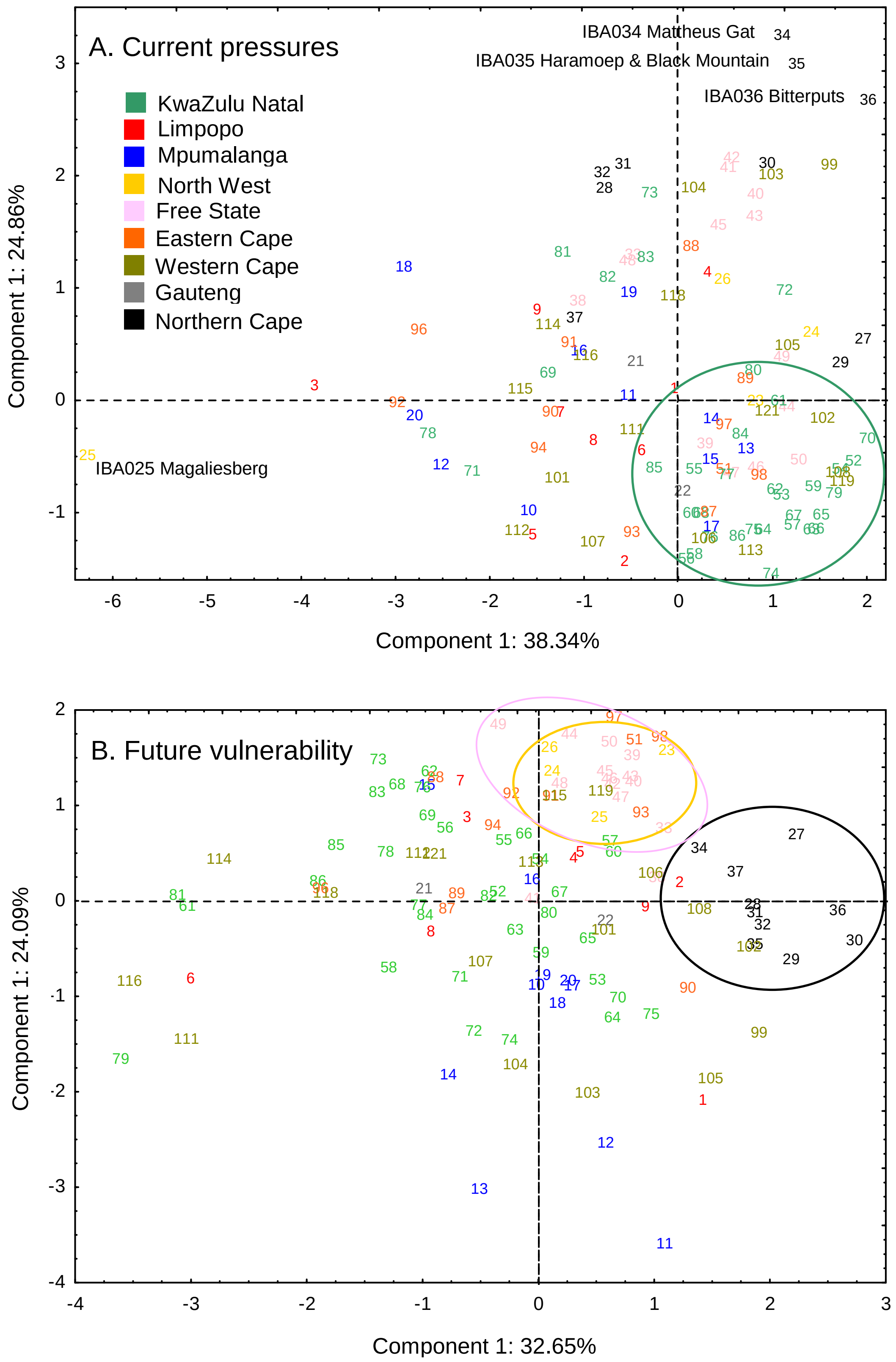
A. Current pressures
🟩 KwaZulu Natal
🟥 Limpopo
🟦 Mpumalanga
🟨 North West
Free State
🟧 Eastern Cape
Western Cape
Gauteng
⬛ Northern Cape
IBA034 Mattheus Gat 34
IBA035 Haramoep & Black Mountain 35
IBA036 Bitterputs 36
IBA025 Magaliesberg
Component 1: 24.86%
Component 1: 38.34%
-6
-5
-4
-3
-2
-1
0
1
2
3
B. Future vulnerability
Component 1: 24.09%
Component 1: 32.65%
-4

Figure 2.3. Plots of Principal Component Scores of all IBAs for current pressures and future vulnerability to transformation. IBAs are differentiated by province using colour. Evident clusters in (A) are within the KwaZulu-Natal province, and within (B) for the Free State, Northern Cape and North West Provinces. Numbers refer to IBA codes in Barnes (1998) contained in Appendix S1. IBA025, IBA034; IBA035; IBA036 discussed in results.

Table 2.3. Eigenvectors for the first three components of PCAs of all current pressure variables, future vulnerability to transformation variables and biological importance indicators. Highest loading components are in bold.

Current pressure	Human Population density	Land Cover	Road effect Zone	Alien invasive plants	Area formally protected
Component 1	**-0.55**	-0.48	-0.46	-0.4	0.30
Component 2	-0.07	-0.15	0.31	-0.6	**-0.72**
Component 3	-0.05	**-0.68**	0.65	0.28	0.17

Future vulnerability	Human population expansion	Agricultural suitability	Afforestation suitability	Alien invasive suitability	Mining suitability
Component 1	**-0.61**	-0.53	-0.43	-0.32	0.26
Component 2	-0.07	-0.24	-0.43	**0.64**	-0.59
Component 3	0.13	0.39	-0.56	0.36	**0.62**

Biological importance	Biome restrictedness	Range restrictedness	Threatened species	Species richness	Endemic richness	Range size rarity	Congregatory
Component 1	**-0.51**	-0.49	-0.43	-0.39	-0.37	-0.16	0.08
Component 2	0.14	0.30	-0.44	-0.51	**0.54**	-0.32	-0.21
Component 3	-0.07	0.03	0.20	0.05	0.18	-0.56	**0.78**

by the same anthropogenic variables namely, human population density and land transformation patterns (PC1), and protected area status and current patterns of alien invasive species (PC2; Figure 2.3). For current anthropogenic pressures, the first three principal components explained 78.31% of the total variation (PC1 = 38.3%; PC2 = 24.81%; PC3 = 15.1%). Human population density and land transformation patterns accounted for the greatest variation in the first component (Table 2.3) although IBA025, the Magaliesberg, showed some clear divergence when compared against all sites (Figure 2.3a).

Protected area status and current patterns of alien invasive species explained most of the variation of the second component (Table 2.3). IBAs 34, 35 and 36 (Mattheus Gat, Haramoep & Black Mountain and Bitterputs conservation areas) show some divergence from other IBAs, along the second component axis. These IBAs are unprotected and in the arid northwestern region of the country, which has been less affected by alien invasions than other more mesic regions.

In the case of future vulnerability, some clustering is evident when examining pressures to IBAs at the provincial level (Figure 2.3b). The Free State, Northern Cape and North West provinces showed some spatial similarity in anthropogenic pressures, meaning IBAs experience similar anthropogenic pressures, including human population expansion, future vulnerability to invasion by aliens and mining suitability. The first three principal components explained 74.2% of the total variation (PC1 = 32.7%; PC2 = 24.1%; PC3 = 17.5%). Change in human population density and potential invasion by invasive alien plants explained most of the variation of component 1 (Figure 2.3b). Future vulnerability to invasion by aliens and mining suitability explained the greatest variation in the second component (Table 2.3). Little clustering in geographic space was evident when we performed a similar analysis on IBAs by biome or by irreplaceability and we do not report these patterns further.

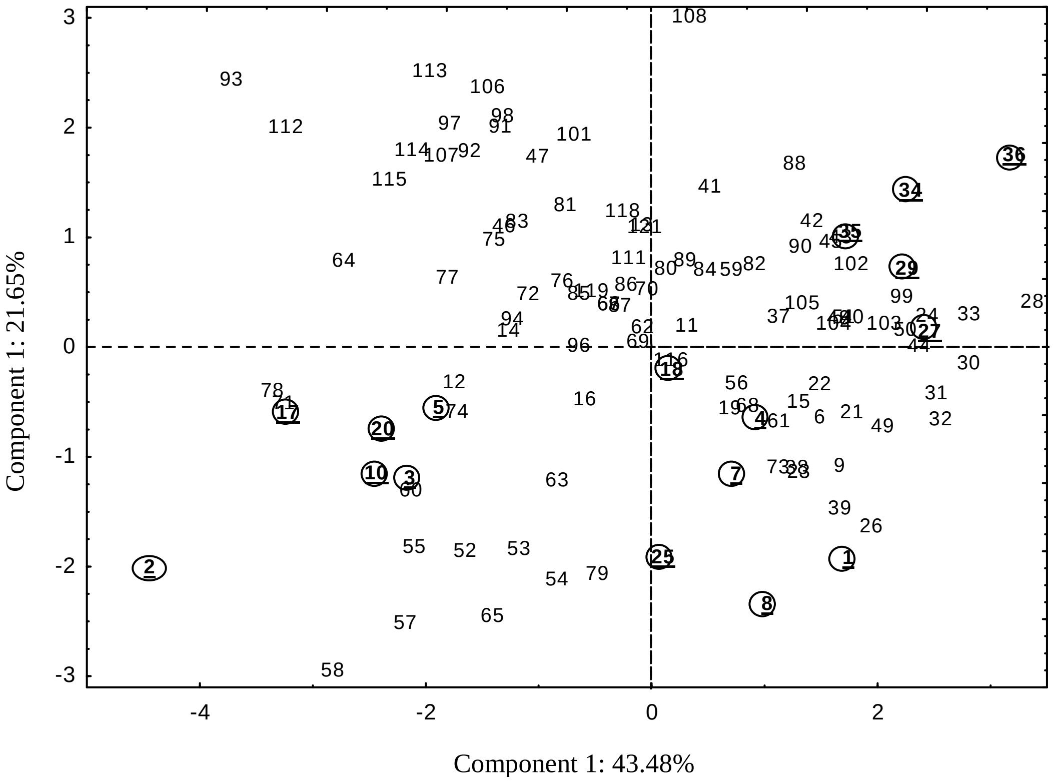

Figure 2.4. Plots of Principal Component Scores of all IBAs for biological indicators. Highly irreplaceable IBAs are circled. Numbers refer to IBA codes in Barnes (1998) contained in Appendix S1.

The relationship between irreplaceability and all the biological indicators for all IBAs show little congruence and no spatial clustering (Figure 2.4). The first three principal components explained 80.67% of total variation in the biological importance PCA (PC1 = 43.5%; PC2 = 21.7%; PC3 = 15.5%). Biome-restrictedness and range-restrictedness accounted for most variation in component 1. Endemic species richness and species richness accounted for the greatest variation in component 2 (Table 2.2).

Discussion

Current anthropogenic pressures

IBAs with high irreplaceability and high vulnerability represent the highest conservation urgency. These IBAs should form a core part of a prioritization strategy for conservation interventions (see IBAs in Appendix 2.1). However, all the pressures assessed vary geographically, with no discernible systematic pattern that might assist conservation managers to design effective regional interventions (Figure 2.3). Current patterns of alien invasive plant invasion represent major anthropogenic pressures to South African IBAs. In South Africa, most information on the impact of invasions (mainly alien plants) is site specific and confined to the Fynbos biome in the Western Cape Province (Richardson and van Wilgen, 2004). As is the case with most other countries, little information is available on how alien plants affect, or potentially could affect, the structure of bird communities in South Africa (Dean et al., 2002). It has however been shown that in some areas in South Africa, certain bird species have benefited from alien plant invasions (see Dean et al., 2002), while others can be both negatively and positively influenced (Hockey et al., 2005). A staggering 97% of all IBAs are invaded by at least some of these species. We regard them as having an impact on IBAs themselves as they alter ecological functioning, and may have a direct impact on the bird assemblages within them. Invasive plant management, prevention and monitoring should be considered a priority in IBAs, especially for those highly irreplaceable IBAs that are under high pressure from invasion (Appendix 2.1).

Highly irreplaceable IBAs are not massively impacted by current transformation patterns, human population density, or road networks (Table 2.2) though these pressures explain most of the variation in all anthropogenic pressures measured (Table 2.3). A total of 81 IBAs (71%) are less than 5% degraded or transformed (Appendix S1). This provides an ideal opportunity for effective conservation interventions, as these regions are in relatively pristine condition, under low extractive use with low human impacts. Of primary concern is that many highly irreplaceable IBAs are outside of conservation areas and only 9% of the surface area of these IBAs are formally protected.

Human population density and avian species richness is positively correlated across South Africa (Chown et al., 2003) and for many taxa across Africa (Balmford et al., 2001). IBAs too, are located in grid cells with higher human population than expected by chance (van Rensburg et al., 2004). These relationships are often cited as causing conflicts between human development needs and biodiversity. Despite these patterns, if the irreplaceability of IBAs are taken into account, there seems to be little conflict between highly irreplaceable sites and human population.

Taking cognisance of this observation and to further aid conservation decisions, we performed a subsequent analysis to that of van Rensburg et al. (2004). They identified the maximum number of grid cells containing IBAs that are not in protected areas which have lower human population density than expected by chance. However, based on a more comprehensive map of IBAs and more recent human population density data, we complemented those grid cells identified by van Rensburg et al. (2004) for a total of 177 cells that matched the criteria. For each of these grid cells, we calculated irreplaceability values using the entire quarter-degree grid cell map (15’ x 15’) across South Africa, to estimate the most irreplaceable among them using our database of bird species across South Africa (C-Plan, 2007; V. 3.11). A total of seven grid cells have irreplaceability values > 0.5, varying between 0.56 and 0.93 (Figure 2.5; Appendix 2.2). Balmford et al. (2001) suggest that at the one degree resolution across Africa, the conflicts between conservation and human development needs are not easily avoided, as many high human density cells contain high species richness for various taxa. Our results suggest that, at least for birds and at a finer resolution, there are opportunities for conservation in IBAs with relatively low human population density, outside of protected areas, where highly

Figure 2.5. Important Bird Areas of South Africa. Priority grid cells with high opportunities for conservation interventions are indicated. These contain IBAs which are outside of protected areas with lower human population densities than expected by chance. Irreplaceability values for grid cells of >0.5 are indicated in black. Irreplaceable grid cell codes in Appendix 2.2.

irreplaceable species assemblages are contained. Few studies have explored the relationship between human population density, species richness and complementarity (irreplaceability is essentially complementarity operationalised; Graham et al., 2005). We show that these patterns are complex and in need of further investigation, as others have recently pointed out (Araújo and Rahbek, 2007).

Future vulnerability to transformation

Highly irreplaceable IBAs seem particularly susceptible to invasion by alien plant species and suitable for afforestation. IBAs are more suitable for invasion by alien species than their current levels of invasion, and as we showed earlier, invasive plants can pose a major threat to IBAs. Cultivation has shown a modest increase in South Africa of 7.5%; although 12.2% of the entire surface is cultivated lands (Fairbanks, 2000). Few highly irreplaceable IBAs are highly pressured by cultivation and those that are have 100% formal protection. Although mining accounts for much variation in the principal component 1 (Figure 2.3) and is a wholly destructive process, only 19% of IBAs are potentially suitable for mining, 3% of which are highly irreplaceable and of those 45% are protected. A national analysis indicates that only 1.8% of untransformed natural habitats are highly suitable for mining and that these areas are clustered to the west coast of the country (Driver et al., 2005). Consequently we do not consider mining and agricultural suitability to be dominant anthropogenic pressures to highly irreplaceable South African IBAs.

Afforestation has been identified as a major anthropogenic pressure to birds which can alter species assemblages (Allan et al., 1997; Dĭaz et al., 1998; Barnes, 2004; Naddra and Nyberg, 2001; Matthews et al., 2002; Brennan and Kuvlesky, 2005). Indeed, afforestation is estimated to be the greatest anthropogenic pressure to South Africa’s endemic and threatened birds specifically and biodiversity in general (Barnes, 2004). It is probably the most critical anthropogenic pressure to the grassland biome (Barnes, 2004), proportionally South Africa’s least protected and a critically endangered biome (Olsen and Dinerstein, 1998; Driver et al., 2005). It has a negative impact on South African grassland bird diversity even when only a small area is under plantation (Allan et al., 1997). Our analysis found that IBAs located in the grassland score disproportionately high in threatened species (Appendix S1) and a continental scale conservation assessment for Africa found a similar pattern (Brooks et al., 2005). Also, afforestation has been identified as a major sector that provides employment and financial resources in South Africa (Allan et al., 1997). The fact that afforestation has increased 50.5% nationally since the mid-1980's (Fairbanks et al., 2000) is indicative of its potential to increase rapidly in the near future, with concomitant negative impacts on IBAs. Although no reason for complacency, as of 2002, afforestation expansion in South Africa has been temporally paused by government.

Caveats

Vulnerability consists of three components; exposure, intensity and impact, defined mainly by the type of data used within the analysis. Exposure refers to the probability of a threatening process affecting an area; intensity ultimately refers to measures of magnitude, frequency and duration while impact refers to the effects of a threatening process on features within areas (Wilson et al., 2005). Even standardised and equivalent values for different vulnerability indices indicate different levels of transformation. For example, similar values for population expansion and mining mean very different things, as these indices have different temporal exposures, intensities and impacts on biodiversity. Our data here is limited to exploring exposure and intensity in a more simplistic way (for a review see Wilson et al., 2005). We also do not for example assess the timing until exposure or intensity of our pressures or weight its predicted impact on biodiversity.

There have been attempts to incorporate this uncertainty into assessments of vulnerability. For example, Neke and du Plessis (2004) weighted the predicted exposure of grassland to forestry, agriculture, grazing, mining, and urban development according to their expected relative impacts on grassland biodiversity. The overall vulnerability to transformation of each area was then determined by the maximum score across all potential anthropogenic pressures. These weights are arbitrary and difficult to justify. Lawler et al. (2003) simply summed different anthropogenic pressures to estimate overall vulnerability to transformation. We suggest extreme caution in summing different biological indices or summing different vulnerability indices, or weighting the impact they may have on biodiversity, as others have done (Lawler et al., 2003; Neke and du Plessis, 2004). Even on a continuous scale, the widths of various anthropogenic pressure categories are variable and their impact on biodiversity is poorly understood. Summing indices therefore comes with undefined errors (Pressey and Taffs, 2001).

Similarly, it is also tempting to create a composite index from all the individual biological importance indices that we calculated. However, there is lack of congruence between irreplaceable IBAs and IBAs important for other biological indices (Figure 2.4). This emphasises that these indices are essentially dissimilar measures and also come with undefined errors. It could be argued that by maximizing species representation through using irreplaceability, we underestimate the importance of IBAs for congregatory and migratory species, especially in areas where for example migration bottlenecks occur. Irreplaceability is dependent on how species are distributed throughout the landscape, and where more species are contained that are not represented in other areas, the irreplaceability of that area increases. Irreplaceability captures components of species richness, endemicity patterns and/or range restrictedness of species; indeed, these factors explained most of the variation in Figure 2.4. As our focus here is only on reporting on the broad trends across South Africa irreplaceability is the most appropriate. We suggest that irreplaceability, as operationalised here, is potentially very useful in a prioritisation framework. It functions to singularly compare all sites with each other, especially assessing patterns of complementarity and is widely recognised (Margules and Pressey, 2000). We calculated other biologically important indices for each IBA and we suggest that these values can be substituted for irreplaceability against the whole suite of current anthropogenic pressures or future vulnerability values (Appendix S1). Indeed, sites can be identified across any relevant axis deemed important and these decisions should be tailored to specific management questions. For example, this enables the identification of that particular suite of IBAs that are vitally important for endemics and highly pressured by afforestation (Barnes, 2004).

It is important to see our study as a “conservation assessment” and not as a “conservation planning” study (Driver et al., 2003). We have identified the broad-scale major anthropogenic pressures to IBAs and where conservation attention should be focused. BirdLife International specifically recommends that planning and implementation of adequate management action for all IBAs, and interventions for those IBAs that face most anthropogenic pressures, is a vital step to ensure their conservation (Fishpool and Evans, 2001). However, conservation planning is the finer scale assessment of particular parcels of land including the conservation action plan for the area with collaboration from local stakeholders and ultimately implementation (Margules and Pressey, 2000; Driver et al., 2003). Our analysis provides a useful first assessment at the national scale of where finer scale assessments could be focused to further avian conservation efforts while following current paradigms in conservation planning (Margules and Pressey, 2000). We reaffirm the important contribution of areas outside of the formal protected areas network in South Africa in contributing to conservation. Many of these are IBAs and add valuable flexibility to conservation management in an otherwise highly restricted conservation network (Chown et al., 2003, Van Rensburg et al., 2004; Scholes and Biggs, 2005; Evans et al., 2006).

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References

Allan, D.G., Harrison, J.A., Navarro, R.A., van Wilgen, B.W., Thompson, M.W. 1997. The impact of commercial afforestation on bird populations in Mpumulanga province, South Africa- insights from Bird-atlas data. Biological Conservation 79, 173-185.

Anonymous, 1996. Population census 1996. Statistics South Africa, Pretoria.

Anonymous, 2001. Census 2001: key results. Statistics South Africa, Pretoria.

Araújo, M.B. 2004. Matching species with reserves - uncertainties from using data at different resolutions. Biological Conservation 118, 533–538.

Araújo, M.B., Rahbek, C. 2007. Conserving biodiversity in a world of conflicts. Journal of Biogeography 34, 199–200.

Balmford, A., Moore, J.L., Brooks, T., Burgess, N., Hansen, L.A., Williams, P., Rahbek, C. 2001. Conservation conflicts across Africa. Science 291, 2616–2619.

Balmford, A., Whitten, T. 2003. Who should pay for tropical conservation, and how could the costs be met? Oryx 37, 238–250.

Balmford, A., Gaston, K.J., Blyth, S. James, A., Kapos, V. 2003. Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. Proceeding of the National Academy of Sciences 100, 1046–1050.

Balmford, A., Bennun, L., ten Brink, B., Cooper, D., Côté, I.M., Crane, P., Dobson, A., Dudley, N., Dutton, I., Green, R.E., Gregory, R.D., Harrison, J., Kennedy, E.T., Kremen, C., Leader-Williams, N., Lovejoy, T.E., Mace, G., May, R., Mayaux, P., Morling, P., Phillips, J., Redford, K., Ricketts, T.H., Rodríguez, J.P., Sanjayan, M., Schei, P.J., van Jaarsveld, A.S., Walther, B.A. 2005. The Convention on Biological Diversity’s 2010 Target. Science 307, 212–213.

Barnes, K.N. 1998. The Important Bird Areas of Southern Africa. Birdlife South Africa, Johannesburg, South Africa.

Barnes, K.N. 2004. The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland. Birdlife South Africa, Johannesburg, South Africa.

Brennan, L.A., Kuvlesky, W.P. 2005. North American grassland birds: an unfolding conservation crisis? Journal of Wildlife Management 69, 1–13.

Brooks, T. Balmford, A., Burgess, N., Fjeldså, Hansen, L.A., Moore, J., Rahbek, C., Williams, P. 2005. Towards a blueprint for conservation in Africa. BioScience 51, 613–624.

Brooks, T.M., Mittermeier, R.A., da Fonseca, G.A.B., Gerlach, J., Hoffmann, M. Lamoreux, J.F., Mittermeier, C.G., Pilgrim, J.D., Rodrigues, A.S.L. 2006. Global Biodiversity Conservation Priorities. Science 313, 58–61.

Birds in Reserves Project 2007 (BIRP, 2007) [Online] (14 May 2007) (http://www.birds.sanbi.org/birp/birp_frameset_parent.htm).

Chown, S.L., van Rensburg B.J., Gaston K.J., Rodrigues A.S.L., van Jaarsveld, A.S. 2003. Species richness, human population size and energy: conservation implications at a national scale. Ecological Applications 13, 1233–1241.

C-Plan, 2007. The C-Plan Conservation Planning System. [Online] (On 3 Dec 2007) (http://www.uq.edu.au/~uqmwatts/cplan.html).

CSIR and ARC (2005). National Land-Cover Database 2000. Council for Scientific and Industrial Research and the Agricultural Research Council. Pretoria, South Africa.

da Fonseca, G.A.B., Balmford, A., Bibby, C., Boitoni, L., Corsi, F., Brooks, T., Gascon, C., Olivieri, S., Mittermeier, R.A., Burgess, N., Dinerstein, E., Olson, D., Hannah, L., Lovett, J., Moyer, D., Rahbek, C., Stuart, S., Williams, P. 2000. Following Africa’s lead in setting priorities. Nature 405, 394.

Dean, W.R.J., Anderson, M.D., Milton S.J., Anderson, T.A. 2002. Avian assemblages in native *Acacia* and alien *Prosopis* drainage line woodland in the Kalahari, South Africa. Journal of Arid Environments 51, 1–19.

Dĭaz, M., Carbonell, R., Santos, T., Tellerĭa, J.L. 1998. Breeding bird communities in pine plantations of the Spanish plateaux: biogeography, landscape and vegetation effects. Journal of Applied Ecology 35, 562–574.

Driver, A. Cowling, R.M., Maze, K. 2003. Planning for living landscapes: Perspectives and lessons from South Africa. Washington DC; Center for Applied Biodiversity Science at Conservation International, Cape Town; Botantical Society of South Africa, Fire Escape Design and Publishing, Cape Town, South Africa.

Driver, A., Maze, K., Rouget, M., Lombard, A.T., Nel, J., Turpie, J.K., Cowling, R.M., Desmet, P., Goodman, P., Harris, J., Jonas, Z., Reyers, B., Sink, K., Strauss, T. 2005. National Spatial Biodiversity Assessment 2004: Priorities for Biodiversity Conservation in South Africa. Strelitzia 17. South African National Biodiversity Institute, Pretoria, South Africa.

Evans, K.L., Rodrigues, A.S.L., Chown, S.L., Gaston, K.J. 2006. Protected areas and regional avian species richness in South Africa. Biology Letters 2, 184–188.

Fairbanks, D.H.K. 1995. An Afforestation-Potential Land Evaluation for the Eastern Transvaal, KwaZulu-Natal, and Eastern Cape Provinces. Forestek, CSIR, Pretoria, Report: FOR-DEA 873.

Fairbanks, D.H.K., Thompson, M.W., Vink, D.E., Newby, T.S., van den Berg, H.M., Everard, D.A. 2000. The South African land-cover characteristics database: a synopsis of the landscape. South African Journal of Science 96, 69–82.

Farber, O., Kadmon, R. 2003. Assessment of alternative approaches for bioclimatic modelling with special emphasis on the Mahalanobis distance. Ecological Modelling 160, 115–130.

Ferrier, S., Pressey, R.L., Barrett, T.W., 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its application in real-world planning, and a research agenda for further refinement. Biological Conservation 93, 303–325.

Fishpool, L.D.C., Evans, M.I. 2001. Important Bird Areas in Africa and associated islands: Priorit sites for conservation. Newbury and Cambridge, UK: Pisces Publication and BirdLife International (BirdLife Conservation Series No. 11).

Graham, C.H., Smith, T.B., Languy, M. 2005. Current and historical factors influencing patterns of species richness and turnover of birds in the Gulf of Guinea highlands. Journal of Biogeography 32, 1371–1384.

Harrison, J.A., Allan, D.G., Underhill, L.G., Herremans, M., Tree, A.J., Parker, V., Brown, C.J. 1997. The atlas of Southern African birds. Birdlife South Africa, Johannesburg, South Africa.

Henderson, L. 1998. Southern African Plant Invaders Atlas (SAPIA). Applied Plant Science 12, 31–32.

Henderson, L. 1999. The Southern African Plant Invaders Atlas (SAPIA) and its contribution to biological weed control. African Entomology 1, 159–163.

Henderson, L. 2001. Alien weeds and invasive plants: a complete guide to declared weeds and invaders in South Africa. ARCPPRI, PPRI Handbook no. 12, Pretoria, South Africa.

Hockey, P.A.R., Dean, W.R.J., Ryan, P.G. 2005. Roberts – Birds of Southern Africa, VIIth ed. The trustees of the John Voelcker Bird Book Fund, Cape Town, South Africa.

IUCN 2006. IUCN Red List of Threatened Species, IUCN-SSC [Online] (15 May 2007) (http://www.iucnredlist.org).

James, A.N., Gaston, K.J., Balmford, A. 1999. Balancing the Earth’s accounts. Nature 401, 323-324.

Kiester, A.R., Scott, J.M., Csuti, B., Noss, R.F., Butterfield, B., Sahr, K., White, D. 1996. Conservation prioritization using GAP data. Conservation Biology 10, 1332–1342.

Lawler, J.J., White, D., Masters, L.L. 2003. Integrating representation and vulnerability: two approaches for prioritizing areas for conservation. Ecological Applications 13, 1762–1772.

Low, A.B. & Rebelo, A.G. 1996. Vegetation map of South Africa, Lesotho and Swaziland. Department of Environmental Affairs, Pretoria, South Africa.

Mace, G.M., Balmford, A., Boitania, L., Cowlishaw, G., Dobson, A.P., Faith, D.P., Gaston, K.J., Humpries, C.J., Vane-Wright, R.I., William, P.H., Lawton, J.H., Margules, C.R., May, R.M., Nicholls, A.O., Possingham, H.P., Rahbek, C., van Jaarsveld, A.S. 2000. It's time to work together and stop duplicating conservation efforts. Nature 405, 393.

Margules, C.R., Pressey, R.L., 2000. Review article: Systematic conservation planning. Nature 405, 243–253.

Matthews, S., O'Connor, R., Plantinga, A.J. 2002. Quantifying the impacts on biodiversity of policies for carbon sequestration in forests. Ecological Economics 40, 71–87.

Municipal Demarcation Board South Africa. 2005. [Online] (20 November 2007) (http://www.demarcation.org.za/).

Naddra, R. Nyberg, D. 2001. Effects of Afforestation of Pastures on Bird Abundance. Transactions of the Illinois State Academy of Science 94, 243–250.

Neke, K.S., Du Plessis, M.A. 2004. The threat of transformation: Quantifying the vulnerability of Grasslands in South Africa. Conservation Biology 18, 466–477.

Nel, J.L., Richardson, D.M., Rouget, M., Mgidi, T., Mdzeke, N., Le Maitre, D.C., van Wilgen, B.W., Schonegevel, L., Henderson, L., Neser, S. 2004. A proposed classification of invasive plant species in South Africa: towards prioritizing species and areas for management action. South African Journal of Science 100, 53–64.

Pressey, R.L., Taffs, K.H., 2001. Scheduling conservation action in production landscapes: priority areas in western New South Wales defined by irreplaceability and vulnerability to vegetation loss. Biological Conservation 100, 355–376.

O'Dea, N., Araújo, M.B., Whittaker, R.J. 2006. How well do Important Bird Areas represent species and minimize conservation conflict in the tropical Andes? Diversity and Distributions 12, 205–214.

Olsen, D.M., Dinerstein, E. 1998. The global 200: A representation approach to conserving the earth most biologically valuable ecoregions. Conservation Biology 12, 502–512.

Reyers, B., Fairbanks, D.H.K., Wessels, K.J., Van Jaarsveld, A.S. 2001. Priority areas for the conservation of South African vegetation: a coarse filter approach. Diversity and Distributions 7, 77–96.

Reyers, B. 2004. Incorporating anthropogenic threats into evaluations of regional biodiversity and prioritisation of conservation areas in the Limpopo Province, South Africa. Biological Conservation 118, 521–531.

Richardson, M.D., Van Wilgen, B. 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts. South African Journal of Science 100, 45–52.

Rouget, M., Richardson, D.M., Nel, J.A., Le Maitre, D.C., Egoh, B., Mgidi, T. 2004. Mapping the potential ranges of major plant invaders in South Africa, Lesotho and Swaziland using climatic suitability. Diversity and Distributions 10, 475–484.

South African Bird Atlas Project 2 (SABAP2). [Online] (On 26 October 2007) (http://sabap2.adu.org.za).

Scholes, R.J., Biggs, R. 2004. Ecosystem services in southern Africa: a regional assessment. Council for Scientific and Industrial Research, Pretoria, South Africa.

Scholes, R.J., Biggs, R. 2005. A biodiversity intactness index. Nature 434, 45–49.

Smith, H.J. 1998. Definition and demarcation of high potential land for rain-fed annual crop production. Unpublished M Inst. Agrar. dissertation. University of Pretoria, Pretoria, South Africa.

StatSoft, Inc. 2004. STATISTICA (data analysis software system), Version 7. [Online] (On 4 June 2007) (www.statsoft.com).

Strasburg, J.L. 2006. Roads and genetic connectivity. Nature 440, 875–876.

Trombulak, S.C., Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14, 18–30.

Tushabe, H., Kalema, J. Aruhanga, A., Asasira, J., Ssegawa, P., Balmford, A., Davenport, T., Fjeldså, J., Friis, I., Pain, D., Pomeroy, D., Williams, P., Williams, C. 2006. A Nationwide Assessment of the Biodiversity Value of Uganda's Important Bird Areas Network. Conservation Biology 20, 85–99.

van Rensburg, B.J., Erasmus, B.F.N., van Jaarsveld, A.S., Gaston, K.J., Chown, S.L. 2004. Conservation during times of change: correlations between birds, climate and people in South Africa. South African Journal of Science 100, 266–272.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M. 1997. Human domination of earth's ecosystems. Science 277, 494–499.

Wessels, K.J., Reyers, B., Van Jaarsveld, A.S. 2000. Incorporating land cover information into regional biodiversity assessments in South Africa. Animal Conservation 3, 67–79.

Wessels, K.J., Reyers, B., van Jaarsveld, A.S., Rutherford, M.C. 2003. Identification of potential conflict areas between land transformation and biodiversity conservation in north-eastern South Africa. Agriculture, Ecosystems and Environment 95, 157–178.

Wilson, K., Pressey, R.L., Newton, A., Burgman, M., Possingham, H., Weston, C. 2005. Measuring and Incorporating Vulnerability into Conservation Planning. Environmental Management 35, 527–543.

Chapter 3

The impact of climate change on the South African Important Bird Areas network

Running title: 3. IBAs and climate change

The impact of climate change on the South African Important Bird Areas network

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Abstract

Aim: To examine climate change impacts on endemic birds. We specifically assess projected range changes in terms of the Important Bird Areas (IBAs) network and assess the possible consequences for conservation.

Location: South Africa, Lesotho and Swaziland.

Methods: An ensemble modelling approach is used with 50 species, four climate change models for the period 2070-2100 and eight bioclimatic envelope models in the statistical package BIOMOD. Model evaluation is done using Receiver Operating Characteristic and the newly introduced True Skill Statistic. Future projections are made considering two extreme assumptions: species have full dispersal ability and species have no dispersal ability. A consensus forecast is identified using a Principal Components Analysis. This forecast is interpreted in terms of the IBAs network. An irreplaceability analysis is used to highlight priority IBAs for conservation in terms of climate change. Modelling results are also compared to a previous study which identified priority IBAs in terms of ten landscape scale anthropogenic pressures.

Results: The majority of species (62%) lose climatically suitable space. Five species lose at least 85% of their climatically suitable space. Many IBAs lose species (41%; 47 IBAs) and show high rates of species turnover (77%; 95 IBAs). Mountainous regions, some of which are IBAs, are predicted to be highly irreplaceable in future.

Main conclusions: The South African Important Bird Areas network is likely ineffective for conserving endemic birds under climate change. Two IBAs in particular (Grassland Biosphere Reserve and Amersfoort District) currently have high irreplaceability values and are very vulnerable to transformation and climate change. These, and IBAs along key altitudinal gradients, are the highest priority sites for conservation action.

Key words: BIOMOD, bird conservation, bioclimatic niche modelling, conservation planning, conservation prioritisation, endemic birds, ensemble modelling, True Skill Statistic (TSS).

Introduction

Many studies have focused on birds to assess climate change impacts because they are a relatively well known and charismatic taxon. Empirical evidence suggests that climate change is already having an impact on birds as changes in phenology, distributions and the arrival of migrants have already been documented (e.g. Crick et al., 1997; Crick and Sparks, 1999; Thomas and Lennon, 1999; Crick, 2004; Chambers et al., 2005; Jonzén et al., 2006). Several studies have predicted large changes in bird distributions which in many cases may result in extinction for those species that are unable to track their suitable environment (e.g. Peterson et al., 2001; Thomas et al., 2004; Simmons et al., 2004). Climate change impacts are of course not unique to birds, indeed, documented impacts of climate change on other species range from changes in distributions and phenology to changes in physiology and evolutionary rates (Parmesan, 1999; Hughes, 2000; Mcarty, 2001; Walther et al., 2002; Parmesan and Yohe, 2003; Root et al., 2003; Root et al., 2005; Bradshaw and Holzapfel, 2006; Thomas et al., 2006; Lovejoy and Hannah, 2006; Foden et al., 2007).

The idea that we can conserve species as they currently exist is unrealistic as they will probably track their bioclimatically suitable space (Hannah et al., 2002a). Conservation planners are in dire need of robust estimates of climate change impacts on species that can be incorporated into conservation planning strategies, since it is likely that species will be driven out of the current locations of reserve networks (Hannah et al., 2002a,b; Araújo et al., 2004; Araújo et al., 2006).

One example of such a network of sites important for conservation is the Important Bird Areas (IBAs). IBAs are a global network of sites designated by BirdLife International as being important for the conservation of the world's avifauna (Fishpool and Evans, 2001). IBAs are designated using criteria based on the presence of globally threatened, restricted-range, or biome-restricted bird species, or the presence of substantial congregations of bird species. IBAs are designed so that they overlap as far as possible with the existing reserve network of the particular region in question. In Africa, a total of 1228 IBAs covering 7% of the region have been identified across 58 countries (Fishpool and Evans, 2001). However, compared to other continents, Africa is a region particularly vulnerable to climate change and large impacts on its people and biodiversity are predicted (IPCC, 2007). As a result, many African IBAs there are predicted to experience a major loss of species as bird distributions change in response to changing climate (unpublished data- David Hole).

Climate change impacts in South Africa are predicted to be severe, especially to biodiversity (van Jaarsveld and Chown, 2001; Erasmus et al., 2002; Ogutu and Owen-Smith, 2003; Midgley et al., 2003; Bomhard et al., 2005; Thuiller et al., 2006). For example, the Fynbos biome, a biodiversity hotspot, has a projected loss of climatically suitable area between 51% and 65% by 2050 (Midgley et al., 2002). Foden et al. (2007) recently documented the poleward range shift in a long-lived Namib Desert tree (*Aloe dichotoma*) in this area, and provided strong empirical evidence that the range shift in this species is a “fingerprint” of anthropogenic climate change. For birds, Simmons et al. (2004) predicted a mean loss of climatically suitable area of 40% for six bird species in southern Africa by 2050.

Bioclimatic envelope models are widely used to estimate the potential impacts of climate change (e.g. Pearson and Dawson, 2003; Guisan and Thuiller, 2005; Thuiller, 2007). However, substantial challenges remain in their use and application (Pearson and Dawson, 2003; Thuiller, 2004; Guisan and Thuiller, 2005; Araújo and Guisan, 2006; Pearson et al., 2006; Austin, 2007). A suite of methodologically equally justifiable modelling approaches exists. While these models excel at predicting the current distributions of species, it is unclear which models perform the best at predicting future distributions under a changing climate as modelling projections can vary widely (Thuiller, 2004; Araújo and Rahbek, 2006; Pearson et al., 2006). A recently emerging alternative method to reduce uncertainty among models is the use of ensemble forecasting, meaning, averaging multiple bioclimatic niche models (Thuiller, 2004; Araújo et al., 2005; Araújo et al., 2006; Araújo and New, 2006). By using a suite of models and many climate change scenarios, combined by ensemble techniques, more robust forecasts can be made if interpreted appropriately (Araújo and New, 2006). In a seminal paper, Araújo et al. (2005) tested the predictive accuracy of bioclimatic models using observed bird species range shifts under climate change in two periods of the recent past. The study verifies the use of ensemble forecasting approaches in climate change modelling research and demonstrated how uncertainty in predictions can be reduced by selecting the most consensual projections.

Here, we use an ensemble modelling approach to examine climate change impacts on South African endemic birds and investigate possible consequences for conservation. We specifically investigate (i) the likely climate change impacts on the distribution ranges of endemic birds in South Africa and (ii) assess projected range changes in terms of the current locations of the Important Bird Areas network.

Data and Methods

Species and climate data

Species locality data were obtained from the Southern African Bird Atlas Project database (SABAP; Harrison et al., 1997). SABAP data were collected mainly between 1987 and 1992 by observers visiting quarter-degree grid cells (0.25° x 0.25° ~ 676 km^2; hereafter grid cells). We assumed that when no records were available for a particular species in a grid cell that the species was absent, as done by van Rensburg et al. (2004) and Chown et al. (2003). We selected 50 species that are endemics with >90% of their distributions within South Africa, occupying >20 grid cells and excluding those where taxonomic uncertainties exist (Hockey et al., 2005; Appendix 3.1). In total we used 18 658 records in 2000 grid cells.

Endemics are irreplaceable in terms of conservation; extinction in their resident country means global extinction. They form a core part of all of the family of nine global conservation prioritization systems (for a review see Brooks et al., 2006). Importantly, they are particularly suitable for bioclimatic envelope models since these are more accurate if they capture the entire distributional range of a species in question, as it prevents the risk of fitting truncated response curves of species to environmental variables (Thuiller, 2004; Guisan and Thuiller, 2005; Broennimann et al., 2006). Also, model performance varies depending on the geographical and environmental distribution of the species (McPherson et al., 2004; McPherson and Jetz, 2007). In general, errors are greater with species with larger areas of occupancy and great extents of occurrence. This is probably due to variation in the models' ability to fit response curves to species with different distributions and which are affected by environmental factors with different strengths and lengths of gradients affecting them throughout their ranges (Segurado and Araújo, 2004). Being endemics, species used here generally have relatively smaller extents of occurrence. Furthermore, a key assumption of bioclimatic envelope models is that species distributions are at equilibrium with the environment, which is not always the case (Pearson and Dawson, 2003). However, owing to their dispersal characteristics, it is believed that birds in general are at equilibrium more often than other taxa so in theory at least very suitable for bioclimatic modelling approaches (Araújo and Pearson, 2005).

Mean values of six climatic predictor variables were derived from the Climate Research Unit (CRU) monthly mean climate data (New et al., 2002) for the period 1961-1990. The climate variables included: annual temperature (°C), temperature of the coldest month (°C), temperature of the warmest month (°C), annual precipitation (mm), precipitation in the warmest month (mm) and precipitation in the coldest month (mm). The choice of variables reflects energy and water (which are primary qualities of climate) and the availability of suitable variables obtained from the various climate change models. Variables impose known constraints on upon species distributions as a result of widely shared physiological limitations (e.g. Lennon et al., 2000; Chown et al., 2003; Crick, 2004; Araújo et al., 2005).

Southern Africa is especially vulnerable to climate change, but few Regional Climate Models (RCMs) have been applied to the region (Tadross et al., 2005). We used four climate change models (MM5; PRECIS; HadCM3; CCAM – details follow). As far as we are aware, these models represent the most recent available climate change data for southern Africa at an appropriate spatial resolution. While a variety of emissions scenarios reflect different assumptions about anthropogenic emissions rates, all our climate change models follow the "business as usual" or so called "worst case" A2 SRES scenario, meaning it assumes global carbon emissions continue unhindered (Nakicenovic and Swart, 2000). Our analysis essentially compares four equally justifiable climate change models for the region, thus taking cognisance of the fact that there is substantial uncertainty in climate change models themselves.

MM5 is a mesoscale model (fifth generation) developed by the Pennsylvania State University's National Center for Atmospheric Research (Tadross et al., 2005). PRECIS (Providing REgional Climates for Impacts Studies) is based on the HadRM3P climate model, a regional model based on the United Kingdoms Meteorological Office's HadCM3 (Hadley Centre Third generation General Circulation model). Both MM5 and PRECIS have been produced at the 50 km x 50 km spatial resolution and are nested within 10 years of control and future integrations of HadAM3H (Jones et al., 2004). The current climate calibration for PRECIS spans the period 1970–1979 whereas the current climate calibration of MM5 is 1975–1984. Future climate projections are for 2070-2080 and 2090-2100 for MM5 and PRECIS, respectively. The performance of MM5 and PRECIS have been assessed over the southern African domain shown to be relatively credible (Hudson and Jones, 2002; Tadross et al., 2005). HadCM3 is a coupled ocean-atmosphere General Circulation Model developed by the Hadley Centre for Climate Prediction (Gordon et al., 2000), and statistically downscaled to a regional resolution by Hewitson (2003). The current climate calibration for HadCM3 spans the period 1970-1999 and the future climate projection is for 2071-2100. The Conformal-Cubic Atmospheric Model (CCAM) is a variable resolution model (but here used at the 50 km x 50 km spatial resolution) originally developed by the Atmospheric Research section of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia and applied to sub-Saharan Africa by Engelbrecht (2005). Climate forcing was obtained from the CSIRO Mk3 OAGCM (Ocean Atmosphere General Circulation Model), which was integrated for the period 1961-2100. CCAMs predecessor, DARLAM, has also been used in bioclimatic envelope modelling, and under current climate conditions provides equal or even better species distribution modelling performance (Olwoch et al., 2003; Olwoch et al., 2007). Thus, MM5, PRECIS and CCAM are Regional Circulation Models at their native resolution, while HadCM3 is a statistically downscaled Global Circulation

Model. For temperature, anomaly values for each climate change model are added to its calibration baseline, whereas for rainfall we calculated a ratio adjustment and added it to the climate change models baseline following methods and arguments by Tadross et al. (2005).

Modelling methods

Bird distributions where modelled using eight models in the bioclimatic envelope modelling package known as BIOMOD (Thuiller, 2003), within the R environment (R Development Core Team, 2006). BIOMOD enables many bioclimatic models to be run simultaneously on a large suite of species with data for up to five climate change models. Models included: (1) generalized linear models (GLM), (2) generalized additive models (GAM), (3) classification tree analysis (CTA), and (4) feed-forward artificial neural networks (ANN) (5) Generalised Boosting Models (GBM; also known as boosting regression trees; BRT), (6) Random Forests (RF), (7) Mixture Discriminant Analysis (MDA) and (8) Multivariate Additive Regression Spline (MARS). GLM, GAM, CTA and ANN are described and discussed in Thuiller (2003). In a recent test of 16 niche models (Elith et al., 2006), including GBM, MARS, GLM, GAM and CTA, the GBM models performed best. MDA (Hastie and Tibshirani, 1996) and RF (Breiman, 2001) were also added as promising newer modelling techniques which are gaining acceptance in the literature (e.g. Broennimann et al., 2007).

Models were calibrated using a 70% random sample of the observed data and model performance was assessed using the remaining 30% of the data. We evaluated model projections between observed species presences and absences and projected distributions by calculating the area under curve (AUC) of the receiver operating characteristic (ROC) curve (see Thuiller, 2003). We calculated AUC using the nonparametric method based on the derivation of the Wilcoxon statistic (Fielding and Bell, 1997). Predictions are considered random when they do not differ from 0.5, poor when they are in the range 0.5–0.7, and useful in the range 0.7–0.9. Predictions greater than 0.9 are considered good to be excellent (Swets, 1988).

Although the Kappa statistic has been widely used for model evaluation (Monserud and Leemans, 1992; Thuiller, 2003; Araújo et al., 2005; Pearson et al., 2006), it has recently been shown to be particularly sensitive to prevalence (Allouche et al., 2006). Using a very similar dataset to that used here, McPherson et al. (2004) showed that species distribution characteristics, such as range size and prevalence, have a large affect on the performance of distribution models and their evaluation. Based on the recommendations of these studies, we used the True Skill Statistic (TSS) as it is considered to be a better alternative to Kappa (Allouche et al., 2006). The TSS is more often used to assess the accuracy of weather forecasts and compares the number of correct forecasts minus those attributable to random guessing to that of a hypothetical perfect forecast. In more conventional species modelling terms, it uses a confusion matrix (Fielding and Bell, 1997), to calculate sensitivity plus specificity minus one. As it is not affected by prevalence, the TSS compensates for the shortcomings of the Kappa statistics while keeping all of its advantages (Allouche et al., 2006). Effects of prevalence on TSS can be interpreted as real ecological phenomena rather than statistical artifacts which can be caused by using the Kappa statistic (see McPherson et al., 2004; Allouche et al., 2006). The following ranges were used to interpret TSS statistics: values from 0.2 to 0.4 were poor, values from 0.6 to 0.8 were useful, and values larger than 0.8 were good to excellent. Binary transformations to presence and absence where obtained in BIOMOD by estimating an optimum threshold maximising the percentage of presence and absence correctly predicted for ROC curves and by calculating the best probability threshold by maximising the TSS statistic for the evaluation data.

Overall we obtained 64 projections for each of the 50 species modelled, thus 2400 projections in total (eight models by four climate change models by two methods of transformation to presence/absence for 50 species).

Ensemble models

A consensus principal components analysis (PCA), which identifies orthogonal groups of linearly covarying projections (e.g. Thuiller, 2004), was run in R (R Development Core Team, 2006). Input data was the species richness per grid cell obtained from the presence absence transformation methods, for each model combination (64 combinations in total – eight models by four climate change models by two methods of transformation). PCA has been used successfully in ensemble forecasting (Thuiller, 2004; Thuiller et al., 2005; Araújo et al., 2005). The first principal component (PC1) is equal to a line that goes through the central tendency of all sets of model projections and minimizes the square of the eigen distance of each set of projections to that line. PC1 is as close to all of the data as possible and thus the consensus axis (Araújo et al., 2005). Component loadings in PCA (the weights given to individual model projections within each component) represent the relative contribution of each projection within components. We selected individual models which have the highest loading, from the first principal component which best summarises the overall pattern of variation in climate change projections. These highest loading models are averaged to create the consensus forecast, following Araújo et al. (2005). In our case we selected nine modelling combinations, which were averaged to create our single consensus forecast representing the median projected range shift across models (hereafter the *consensus forecast*).

Data analysis

To account for differences in species dispersal and establishment abilities, we considered two scenarios of range change. Species can either fully establish in all new suitable areas (full dispersal) or they are unable to disperse and establish in all new suitable areas (no dispersal). This is a broad assumption, but used commonly, and represents two opposing extremes of how climate change may affect species ranges, based on the dispersal abilities of species (Thomas et al., 2004; Thuiller et al., 2005, 2006). The realised patterns will necessarily fall somewhere between these two extremes. We calculated either of these two scenarios for all species within the consensus forecast, and thus have a consensus forecast under no dispersal and a consensus forecast under full dispersal.

To estimate the climatically suitable space gained or lost per species under the consensus forecast, we calculated the percentage of grid cells gained or lost and the percentage of range change under no dispersal and full dispersal assumptions. For each grid cell, under a full dispersal assumptions, we calculated species turnover using $T = 100 \times (L + G)/ (SR$

+ G); where T = turnover; L = number of grid cells lost; G = number of grid cells gained; SR = current species richness of that grid cell. A turnover value of 0 indicates that the assemblage of species is predicted to remain the same in the future (i.e. no loss or gain of species) and a value of 100 indicates that the assemblage of species in that grid cell is completely different (i.e. the species loss equals the initial species richness).

In Chapter two, we digitized the terrestrial IBAs within South Africa, following Barnes (1998), and we included IBAs in Lesotho and Swaziland. In total we used 122 IBAs across southern Africa. Species lists per IBA were obtained by intersecting the SABAP species distribution records within the IBA locations, both current distribution records and from our consensus forecasts. This approach is liberal, as followed by others, (e.g. Kiester et al., 1996) and will tend to overestimate species presences in IBAs (see Araújo, 2004). This approach allows rapid calculation of probable species inventories for IBAs although we concede that we may inflate false positives under current distribution patterns. We consider this acceptable given the relatively coarse scale (0.25° x 0.25°) of our analysis and its aim of identifying broad trends. For each species we calculated the number if IBAs gained or lost. For each IBA we calculated the number of species gained or lost.

Irreplaceability is defined as the likelihood that a given site will need to be protected to achieve a specified set of conservation targets (Ferrier et al., 2000; Margules and Pressey, 2000). Its value ranges from zero to one, where a value of one indicates an entirely biologically distinct and totally irreplaceable site, thus containing species that only occur in that site. We calculated irreplaceability using the consensus forecast with C-Plan conservation planning software (C-Plan, 2007; Version 3.11). We set targets at one, so that each species would be represented in at least one 0.25° x 0.25° grid cell and investigated the overlap of this pattern with the IBA network.

Following similar arguments and approaches to those used in previous studies (Margules and Pressey, 2000; Pressey and Taffs, 2001; Lawler et al., 2003; Reyers, 2004; Chapter two) we consider sites with both high vulnerability and high irreplaceability as the highest priority sites for conservation action in terms of climate change. Species loss per data per IBA where standardised from 0-1, and plotted against the irreplaceability values for each IBA, ranging from 0-1, calculated previously by for 655 species across South Africa in Chapter two. This two-dimensional plot of all IBAs is used to identify those sites that are likely to be most affected by the threats of climate change. Plots were categorised into two equal sized classes of high (H) or low (L) value; each IBA therefore has one of four potential irreplaceability and climate change vulnerability combinations (HH, HL, LH, or LL) denoting its priority. These conservation priority sites are then compared to those identified in a similar manner as Chapter two, which assessed a suite of ten landscape scale anthropogenic pressures to 115 Important Bird Areas (IBAs) in South Africa, both those currently placing pressures on IBAs and those that constitute likely future vulnerability to transformation. Together, this suite of IBAs better informs on where conservation action could be focused in terms of global change threats to IBAs.

Results

In general models had good agreement between observed data and current modeled predictions (Table 3.1). Values above 0.7 for TSS are considered to indicate good agreement, while values above 0.9 indicate good agreement for the AUC statistic. Random Forest (RF) models seemed however to greatly overfit the data, which results in a poor agreement in evaluation data using either TSS or AUC statistics. GBMs also seemed to overfit the data when TSS are considered. However, GBM models appeared overall to be the best performing bioclimatic model.

The first principal component (PC1 or consensus axis) explained 46.8% of model variation. The nine consensus models were selected from the first axis of the PCA and included outputs from MM5, PRECIS, CCAM climate change models, GBM and CTA bioclimatic niche models and both ROC and TSS binary transformation outputs (Appendix 3.3). Interestingly, irrespective of the vastly dissimilar climate change models used, patterns in species range changes where broadly similar across the Regional Circulation Models, and seem highly correlated as the similar component loadings show (Appendix 3.3).

Table 3.1. Mean and standard deviation of Area Under Curve (AUC) and True Skill Statistics (TSS) for the 50 species for each model, according to the data used (min = minimum, me = mean and max = maximum values of AUC or TSS statistics). Calibration refers to the 70% dataset used to fit the models, Evaluation is the 30% dataset used to evaluate the fitted models, and Original essentially means (Calibration + Evaluation) data.

AUC	Calibration			Evaluation			Original		
	Me	Min	Max	Me	Min	Max	Me	Min	Max
GLM	0.94	0.77	0.99	0.93	0.75	1.00	0.94	0.76	0.99
GAM	0.95	0.80	0.99	0.94	0.77	1.00	0.95	0.80	0.99
CTA	0.92	0.75	0.98	0.87	0.71	0.96	0.91	0.75	0.96
ANN	0.95	0.85	1.00	0.93	0.82	0.99	0.95	0.84	0.99
GBM	0.98	0.90	1.00	0.94	0.80	1.00	0.97	0.87	1.00
RF	1.00	1.00	1.00	0.94	0.79	1.00	0.99	0.96	1.00
MDA	0.93	0.79	0.99	0.91	0.75	0.99	0.93	0.78	0.98
MARS	0.95	0.83	0.99	0.93	0.77	1.00	0.94	0.82	0.99

TSS	Calibration			Evaluation			Original		
GLM	0.78	0.43	0.94	0.78	0.43	0.98	0.77	0.43	0.93
GAM	0.80	0.50	0.95	0.79	0.43	0.99	0.79	0.47	0.95
CTA	0.77	0.50	0.94	0.68	0.38	0.87	0.74	0.46	0.88
ANN	0.81	0.54	0.96	0.77	0.47	0.97	0.79	0.52	0.95
GBM	0.87	0.65	0.99	0.77	0.45	0.99	0.83	0.59	0.98
RF	1.00	1.00	1.00	0.78	0.43	0.99	0.92	0.83	0.99
MDA	0.74	0.47	0.91	0.71	0.36	0.93	0.73	0.43	0.90
MARS	0.79	0.53	0.95	0.76	0.42	0.99	0.78	0.49	0.94

Mainly GBM and to a lesser extent CTA models best summarise the overall patterns in range change for all models used.

The majority of species (31 species; 62%) lose climatically suitable space. Using the consensus forecast, the 50 endemic species modelled show a median loss of climatically suitable space of 12% under full dispersal and 26% under no dispersal (standard deviations of 208.7% and 72.5% respectively). Irrespective of the dispersal scenario analysed, five species (Cape Clapper Lark, Pied Starling, African Rock Pipit, Southern Black Korhaan and Sicklewinged Chat) are predicted to lose at least 85% of their climatically suitable ranges (Appendix 3.1). Sixteen species (32%) lose more than 50% of their climatically suitable ranges under full dispersal assumptions. Nineteen species (38%) show a gain in climatically suitable space (Appendix 3.1).

Climate change is predicted to have large impacts on species richness patterns, with substantial changes in species distributions being predicted (Figure 3.1a-c). The north western and central region of South Africa is predicted to lose all climatically suitable space for all species modelled. Under a no-dispersal assumption, these patterns remain similar, although species loss is more acute especially in the north eastern region of the country where the Savannah Biome is located. Much of South Africa is predicted to experience high rates of species turnover, meaning the grid cells undergo a high degree of turnover of species (Figure 3.1d). A large number of IBAs also show high rates of species turnover (77%; 95 IBAs). Regions that undergo little turnover of species (meaning more climatically stable regions) are in the west and northern Cape, and along the escarpment of the eastern central South Africa, but excluding the escarpment at the southern Cape Fold Mountains (red line; Figure 3.1d; also see Figure 3.2).

In general, IBAs show a loss of their respective species as climate becomes unsuitable, irrespective of species dispersal ability (Figure 3.2). The predictions suggest that most species (29; 58%) will no longer occur in the IBAs they currently find suitable. In total, 47 (41%) of IBAs lose some species, while 37 (29%) show no change and 39 (30%) gain some species. IBAs in central South Africa and the southern Cape Fold Mountains lose

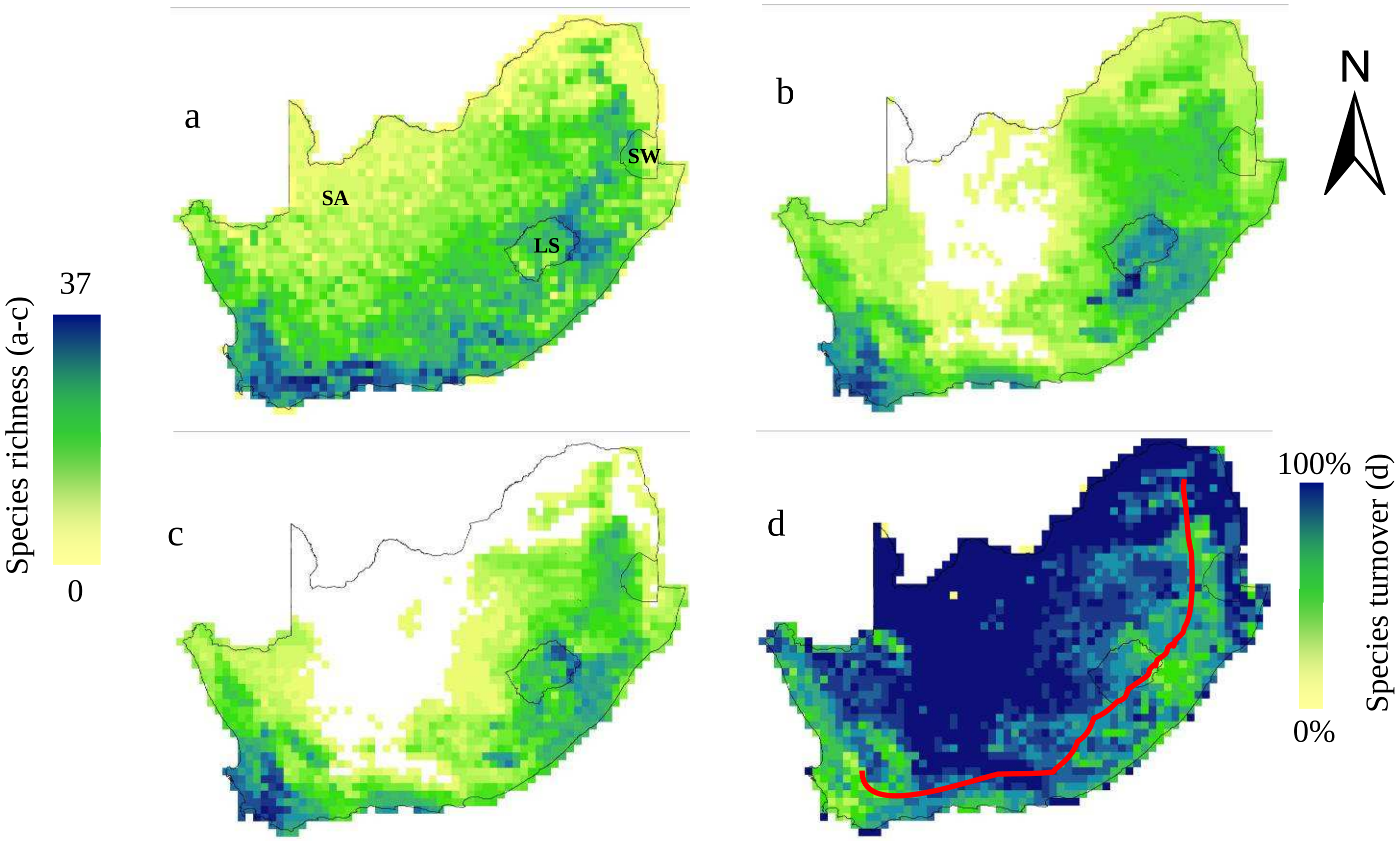

Figure 3.1. Current and modelled future species richness of grid cells assessed, country boundaries are indicated, SA = South Africa; LS = Lesotho; SW = Swaziland. (a) Current species richness of the 50 endemics modeled. (b) Future species richness based on a consensus forecast from 16 models and 4 climate change models for the period 2070-2100 under a full dispersal assumption. (c) Future species richness based on an identical consensus forecast constrained by a no dispersal assumption, meaning that species will only occupy areas that are currently suitable. (d) Species turnover per grid cell. The red line indicates the relative position of the mountainous regions within South Africa.

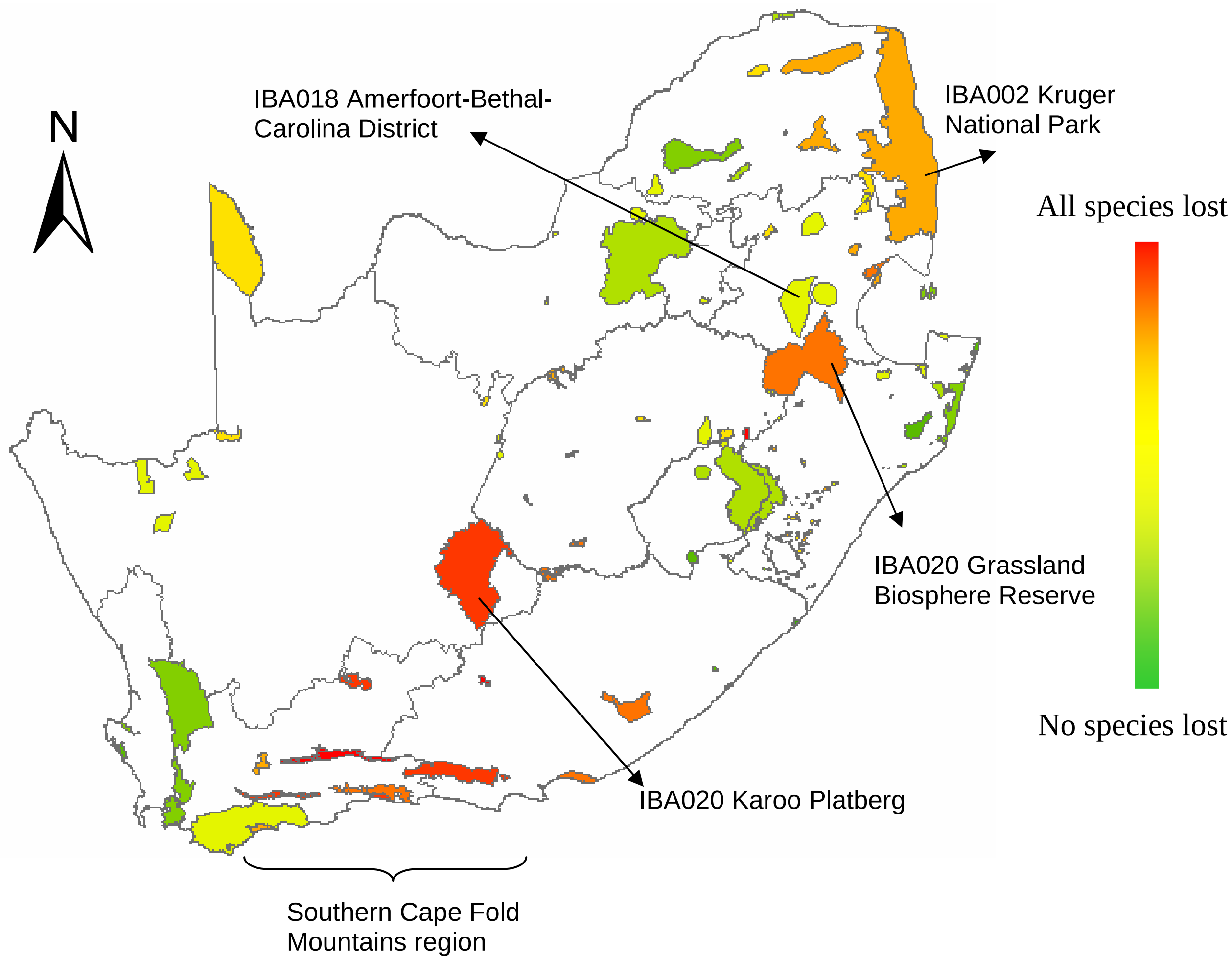

Figure 3.2. Important Birds Areas (IBAs) with provincial boundaries of South Africa. Endemic Bird Species lost per IBA under a consensus forecast of 16 models and 4 climate change models for the period 2070-2100 under a full dispersal assumption.

almost all of their endemic species. The Swartberg Mountain (IBA106) is predicted to be unsuitable for 17 of its current 37 endemic species. Kruger National Park (IBA002) is predicted to be unsuitable for five species, and the Grassland Biosphere Reserve (IBA020), an endemic species hotspot, is projected to lose eight species. IBAs in the Nama Karoo and Forest biomes in particular show a loss of species. IBAs in the Fynbos biome on average show a loss of species, although overall this seems to be offset by species gained from other regions (Figure 3.3).

Two highly irreplaceable regions are identified for endemic birds under the consensus forecast (Figure 3.4). Firstly, most of Lesotho is highly irreplaceable and seven grid cells have irreplaceability values of one. These grid cells are in the Upper Senqu, Sehonghong and Natal Drakensberg Park IBAs (IBA codes: L002/4 and SA064). To the south of this region, in the highlands of the Eastern Cape Province, a small cluster of highly irreplaceable cells occur which fall outside of the current IBA network. Secondly highly irreplaceable cells occur in the Western Cape Province, and approximately 30% of the area of those cells occur in the Eastern False Bay Mountains and Cederberg Mountains IBAs (IBA codes: SA107; SA101).

Highly irreplaceable IBAs which are highly threatened by climate change (Figure 3.5) are identified in Appendix 3.2. In terms of climate change, these are the IBAs that need renewed attention in a conservation prioritization system. Appendix 2.1, is the list of highly irreplaceable IBAs that are under high threat from anthropogenic transformation. Only two IBAs are added to this list if one includes climate change as a threat to that framework, these are the Kalahari Gemsbok National Park and the Augrabies Falls National Park (IBA codes: IBA027; IBA029). The Grassland Biosphere Reserve and the Amersfoort-Bethal-Carolina District (IBA codes: SA020; SA018; SA058; Figure 3.2) overall are the most threatened by climate change and at least four of the suite of threats identified in Chapter 2. Note that many IBAs are not highly irreplaceable, but are highly threatened by climate change (the LH quadrant; see Figure 3.5; Appendix 3.2).

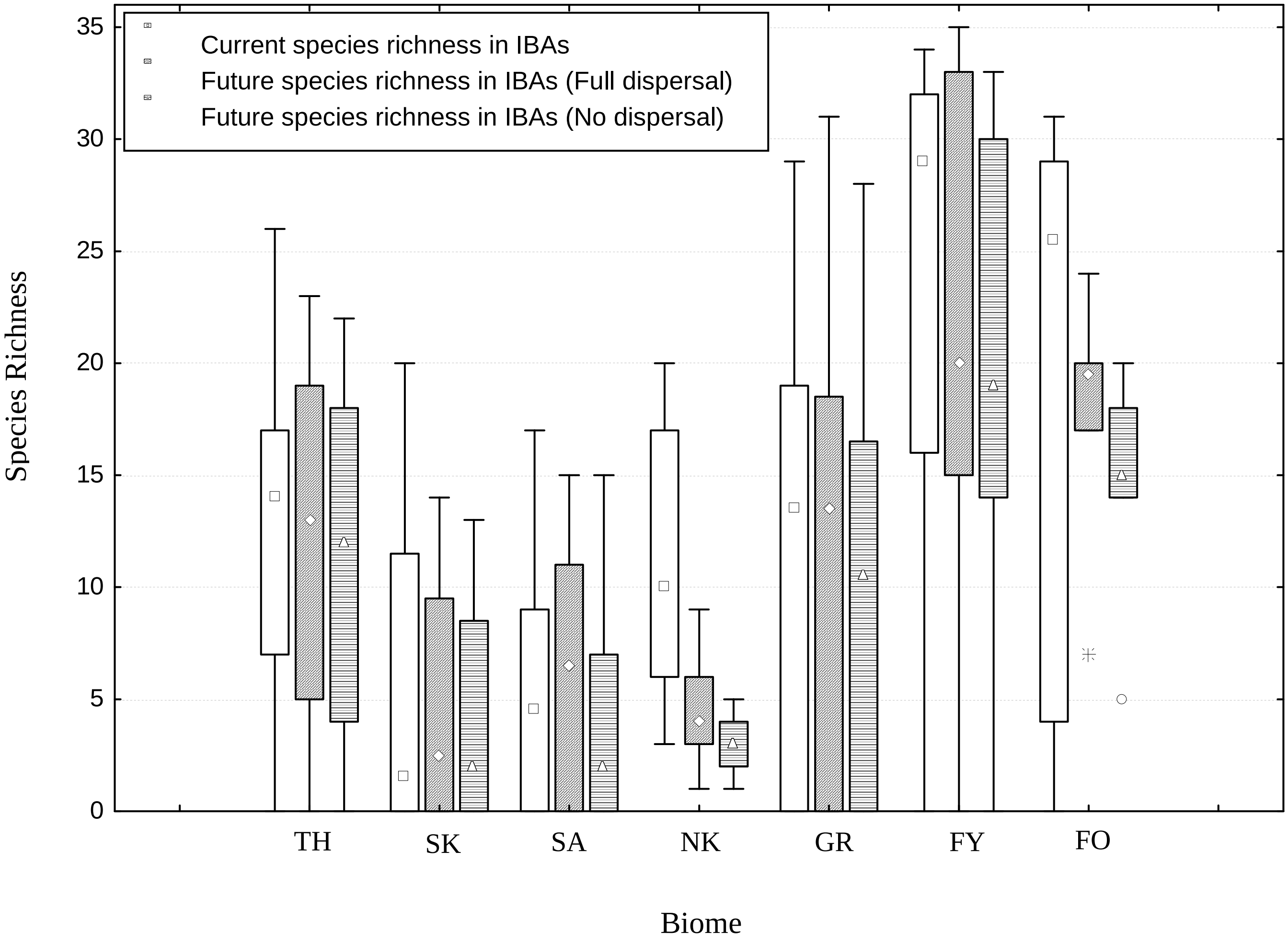

Figure 3.3. Boxplots of species loss in Important Bird Areas grouped by biome, under both full and no dispersal assumptions. The shaded bars represent the interquartile range and the median is marked within this; the line extensions from each box are the largest and smallest values, excluding outliers. TH – Thicket; SK – Succulent Karoo; SA – Savanna; NK – Nama Karoo; GR – Grassland; FY – Fynbos; FO – Forrest.

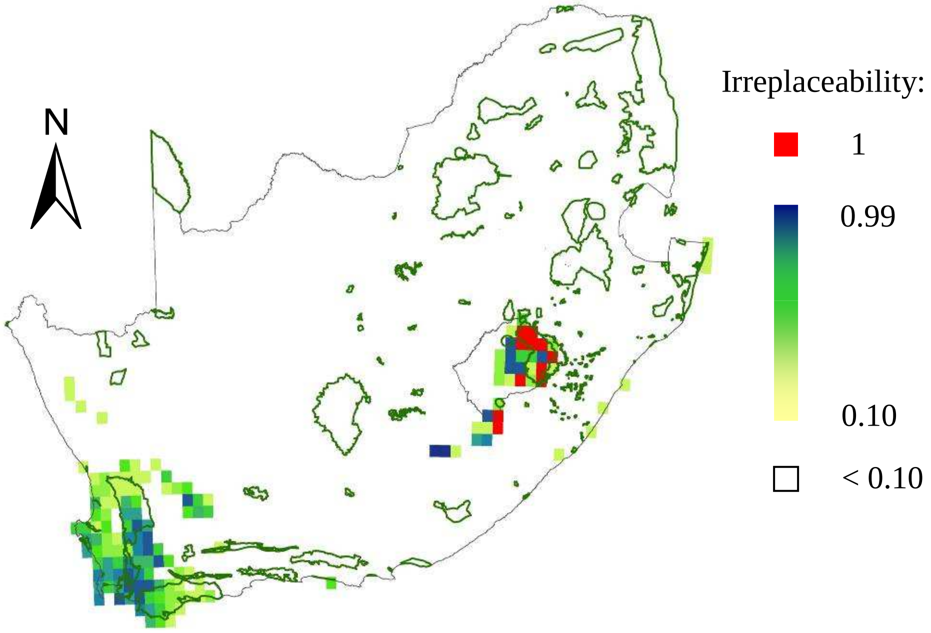

Figure 3.4. Irreplaceability patterns for 50 endemic species based on a consensus forecast from 16 models and 4 climate change models for the period 2070-2100 under a full dispersal assumption. Red grid cells have an irreplaceability of 1.

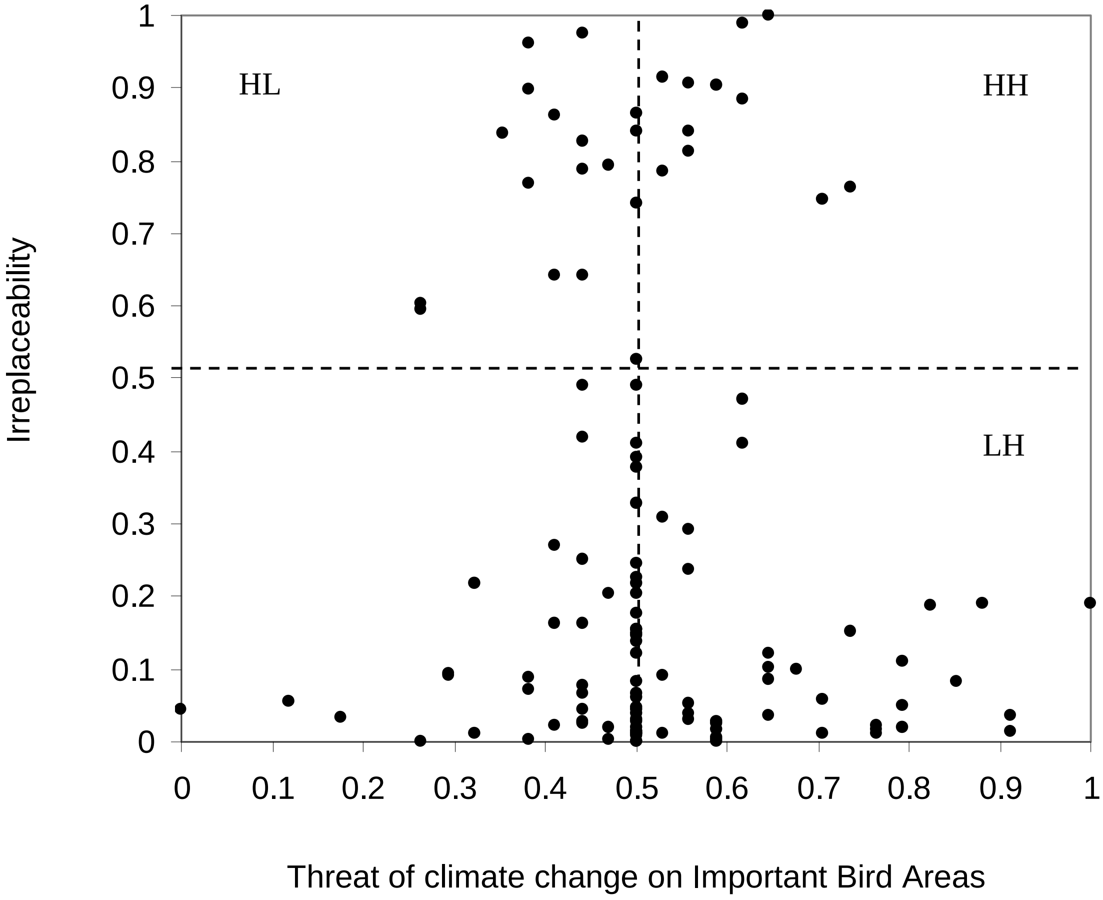

Figure 3.5. IBAs irreplaceability values and climate change plotted on two axes. Sites with higher irreplaceability values can be viewed as having higher conservation value. The horizontal axis depicts the degree to which the conservation targets at a site are vulnerable to species loss caused by climate change. Priority sites in terms of climate change are those with high irreplaceability and under high threat (HH). These 11 IBAs are in identified in Appendix 3.2. Note that many IBAs are not highly irreplaceable, but are highly threatened by climate change (the LH quadrant).

Discussion

Climate change impacts are likely to be severe as endemic species richness patterns are predicted to undergo large shifts by 2070-2100 (Figure 3.1). All of the five species that are predicted to undergo a loss of more than 85% of their climatically suitable spaces (irrespective of dispersal ability) are currently listed as "not threatened" using IUCN criteria (Appendix 3.1; IUCN, 2006; Barnes, 2004). This emphasises the need for threatened species lists to incorporate vulnerability to climate change (Bomhard et al., 2005; IUCN, 2006). Our predictions indicate that bird ranges will likely shift eastward, southward and toward the escarpment regions in the interior of the country. Regions in the arid north west of the country show particularly high rates of species range change, consistent with other studies for the region on a range of taxa (plants, reptiles, invertebrates, mammals; Rutherford et al., 1999; Erasmus et al., 2002; Broennimann et al., 2006; Foden et al., 2007). This region is predicted to have a climate unlike anything experienced presently in South Africa and none of the birds modelled are likely to find it suitable. There is a pronounced east-west aridity gradient in South Africa with a decline in bird species richness in that direction (Schulze et al., 1997). This is largely in response to primary productivity, in turn determined by energy and water availability (Chown et al., 2003). Consensus climate change models predict this arid north west region of South Africa to undergo a decline in precipitation (IPCC, 2007) so it seems likely then that predicted bird responses are a realistic reflection of climate change impacts.

We report broad patterns but species responses are likely to be idiosyncratic (Lovejoy, 2005). It is important to assess species predictions in terms of their individual ecological requirements, something that is rarely done in ensemble modelling studies (Peterson et al., 2001; Araújo et al., 2005; Thuiller et al., 2005). For example, the highly range-restricted Cape Parrot (*Poicephalus robustus*) is projected to gain almost 533% of climatically suitable areas assuming full dispersal. This species is an Afromontane Forest specialist and is restricted to this patchy and uncommon habitat type. A gain in climate space will not necessarily translate into a larger range size. In contrast, the Southern Bald Ibis' (*Geronticus calvus*) distribution is in part driven by climatic variables especially rainfall (Hockey et al., 2006), which remains stable or increases in the current area of its range and our predictions reflect this. Climate change is unlikely to have a big impact on this species, and proximate threats like habitat destruction will be more important to the short term conservation of this species. Conversely, a widely distributed and common species like the Pied Starling (*Spreo bicolor*) loses much climatically suitable space (>85% irrespective of its dispersal ability) and climate change is likely to affect this common species severely.

In the long term, the current locations of the South African Important Bird Areas network are likely to be ineffective for conserving endemic birds under climate change. Large impacts are to be expected in IBAs in the Nama Karoo, the South Coast Belt Mountains and the small and highly fragmented Forest biome. Current large protected areas like Kruger National Park, and proposed conservation areas like the Grassland Biosphere Reserve (both of which are IBAs) are likely to be greatly impacted by climate change (Figure 3.2). However, the irreplaceability analysis identifies mountainous regions in South Africa as irreplaceable refugia for endemic species, and some of these regions contain existing IBAs. There is also less species turnover in these regions compared with the rest of South Africa (Figure 3.1d). Species have been observed to expand their distributions to higher elevations (see Thomas et al., 2006). The modelled prediction then emphasises the crucial role of altitudinal gradients and mountainous regions as buffers against climate change.

There are 11 highly irreplaceable IBAs particularly vulnerable to climate change (Appendix 3.2). Interestingly, these sites are similar to those identified as priority sites in terms of landscape scale anthropogenic pressures (Chapter 2; Appendix 2.1). This means that the core sites where conservation efforts should be focused essentially remains identical even with the inclusion of such diverse threats such as human population density and climate change. Nonetheless, the impact of climate change is likely to be large across the network as many IBAs are not highly irreplaceable, but are highly threatened by climate change (Figure 3.5). Two IBAs deserve special mention. These are the Grassland Biosphere Reserve and the Amersfoort-Bethal-Carolina District (IBA codes: SA020; SA018). These IBAs are highly threatened by a variety of transformation pressures and are particularly vulnerable to climate change (Appendix 2.1; Appendix 3.2). Similarly, a continental-scale conservation assessment for Africa also found that this area to be characterised by high threat and high endemism (Brooks et al., 2005). Considering all the threats assessed in this study, these two sites, which have little of their area under formal protection, form the key IBAs in South Africa for conservation prioritisation (Figure 3.2).

A major strength of the IBAs system is that planning for climate change can relatively easily be incorporated into the systems design and planning. IBAs outside of protected areas are not static, and despite the initial investment in IBAs, the greatest strength of the system may be that it is flexible, pragmatic and "human" driven (as opposed to driven by algorithms – but see O'dea et al., 2006). Unlike the protected areas network then, the delineation of IBAs outside of protected areas can shift and expand as is necessary to include climate change vulnerability. This paper has made some key recommendations, and continued refinement of the approaches used here can add valuable flexibility to an otherwise restricted conservation network in South Africa (van Rensburg et al., 2004).

Irreplaceability is not the only way to express the biological importance of a particular area or site, and may not be appropriate for all studies and all research areas (Pressey and Taffs, 2001). As far we are aware, it has also not been used in a conjunction with climate change to identify priorities for conservation. Irreplaceability is dependent on how species are distributed throughout the landscape, and where more species are contained that are not represented in other areas, the irreplaceability of that area increases. Therefore, as used in this study it may be particularly sensitive to modelling outputs, since relatively small changes in the predicted species distributions will have a concomitant large affect on the irreplaceability value. I also made modelling predictions over a relatively long time scale (2070-2100), which has an affect on the accuracy of the predicted species distributions. Climate change is likely to increase the frequency of extreme events, which this study can not account for. Results then should be seen as indicative of broad trends, without focus on particular irreplaceability values. However, if interpreted in this manner, I suggest that irreplaceability is potentially very useful in identifying key areas vulnerable to climate change and those sites that form refugia in future.

While an ensemble of models is rapid and useful to investigate broad patterns of climate change impacts, using this approach is no substitute for creating “better” models. Much of our approach still suffers from the same methodological problems as dealt with comprehensively elsewhere (e.g. Pearson and Dawson, 2003; Guisan and Thuiller, 2005; Araújo and Guisan, 2006; Araújo and New, 2006; Broennimann et al., 2006; Araújo and Rahbek, 2006; Austin, 2007; Thuiller, 2007). Notably we don’t include land use change, which will most likely have profound impacts on the short term conservation of endemic birds. Given the temporal and spatial scale of the analysis however, the influence of land cover is likely to be overridden, but effects of habitat fragmentation are very likely to be exacerbated by climate change (Opdam and Wascher, 2004). The use of ensemble modelling methods in this study provides an improvement over earlier modelling techniques in reducing uncertainty and increasing accuracy through selection of the most consensual projections (Araújo et al., 2005). Since this technique has also been empirically validated, it provides a robust and defensible approach to the projections of species ranges under climate change and to aid conservation planning (Araújo et al., 2004; Araújo et al., 2005; Thuiller et al., 2005, 2006).

There is additional uncertainty introduced through the climate change models used. It has been shown recently that internal climate model variability can be larger than variability between climate models and this represents a source of added uncertainty (Beaumont et al., 2007), which this study does not account for. Nonetheless, here pattern generation remains similar across models, although one climate change model (HadCM3) was discarded in creating the consensus forecast. It reaffirms that, despite the uncertainty introduced by climate change models, the consensus forecast represents an adequate representation of the likely impacts of climate change.

In using the A2, or “worst case” emissions scenario, this analysis is an extreme prediction of climate change impacts and the observed reality may not be as severe. However, given the currently observed rates of global CO_2 emissions (Raupach et al., 2007), on which the "business as usual" A2 SRES scenario is based, our analysis is by no means an overestimate as this scenario is considered reasonably credible in future (Broennimann et al., 2006). Despite some shortcomings, models remain a vital tool in our understanding of climate change impacts (Thuiller, 2007). The message from our analysis is clear. We have identified key IBAs that are particularly vulnerable to climate change and reiterate that climate change will have large impacts on endemic birds in South Africa. Consequently, it is essential to explore and refine methods for incorporation climate change impacts into conservation planning.

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References

Allouche, O., Tsoar, A., Kadmon, R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of Applied Ecology 43, 1223–1232.

Araújo, M.B. 2004. Matching species with reserves - uncertainties from using data at different resolutions. Biological Conservation 118, 533–538.

Araújo, M.B., Pearson, R.G. 2005. Equilibrium of species distributions with climate. Ecography 28, 693–695.

Araújo, M.B., Cabeza, M., Thuiller, W., Hannah, L., Williams, P.H. 2004. Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. Global Change Biology 10, 1618–1626.

Araújo, M.B., Whittaker, R.J., Ladle, R.J., Erhard, M. 2005. Reducing uncertainty in projections of extinction risk from climate change. Global Ecology and Biogeography 14, 529–538.

Araújo, M.B., Thuiller, W., Pearson, R.G. 2006. Climate warming and the decline of amphibians and reptiles in Europe. Journal of Biogeography 33, 1712-1728.

Araújo, M.B., Rahbek, C. 2006. How does climate change affect biodiversity? Science 313, 1396–1397.

Araújo, M.B., New, M. 2006. Ensemble forecasting of species distributions. Trends in Ecology and Evolution 22, 42–47.

Araújo, M.B., Thuiller, W., Pearson, R.G. 2006. Climate warming and the decline of amphibians and reptiles in Europe. Journal of Biogeography 33, 1712–1728.

Araújo, M.B., Guisan, A. 2006. Five (or so) challenges for species distribution modelling. Journal of Biogeography 33, 1677–1688.

Austin, M. 2007. Species distribution models and ecological theory: A critical assessment and some possible new approaches. Ecological Modelling 200, 1–19.

Barnes, K.N. 1998. The Important Bird Areas of Southern Africa. Birdlife South Africa, Johannesburg, South Africa.

Barnes, K.N. 2004. The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland. Birdlife South Africa, Johannesburg, South Africa.

Beaumont, L.J., Pitman, A.J., Poulsen, M., Hughes, L. 2007. Where will species go? Incorporating new advances in climate modelling into projections of species distributions. Global Change Biology 13, 1368–1385.

Bomhard, B., Richardson, D.M., Donaldson, J.S., Hughes, G.O., Midgley, G.F., Raimondo, D.C., Rebelo, A.G., Rouget, M., Thuiller, W. 2005. Potential impacts of future land use and climate change on the Red List status of the Proteaceae in the Cape Floristic Region, South Africa. Global Change Biology 11, 1452–1468.

Bradshaw, W.E., Holzapfel, C.M. 2006. Evolutionary Response to Rapid Climate Change. Science 312, 1477–1478.

Breiman, L. 2001. Random forests. Machine Learning 45, 5–32.

Broennimann, O., Thuiller, W., Hughes, G., Midgley, G.F., Alkemade, J.M.R., Guisan, A. 2006. Do geographic distribution, niche property and life form explain plants' vulnerability to global change? Global Change Biology 12, 1079–1093.

Broennimann, O., Treier, U.A., Müller-Schärer, H., Thuiller, W., Peterson, A.T., Guisan, A. 2007. Evidence of climatic niche shift during biological invasion. Ecology Letters 10, 701–709.

Brooks, T. Balmford, A., Burgess, N., Fjeldså, Hansen, L.A., Moore, J., Rahbek, C., Williams, P. 2005. Towards a blueprint for conservation in Africa. BioScience 51, 613–624.

Brooks, T.M., Mittermeier, R.A., da Fonseca, G.A.B., Gerlach, J., Hoffmann, M. Lamoreux, J. F., Mittermeier, C.G., Pilgrim, J.D., Rodrigues, A.S.L. 2006. Global biodiversity conservation priorities. Science 313, 58–61.

Chambers, L.E., Hughes, L., Weston M.A. 2005. Climate change and its impact on Australia's avifauna. Emu 105, 1–20.

Chown, S.L., van Rensburg B.J., Gaston K.J., Rodrigues A.S.L., van Jaarsveld, A.S. 2003. Species richness, human population size and energy: conservation implications at a national scale. Ecological Applications 13, 1233–1241.

C-Plan, 2007. The C-Plan Conservation Planning System. [Online] (On 3 Dec 2007) (http://www.uq.edu.au/~uqmwatts/cplan.html).

Crick, H.Q.P., Dudley, C., Glue, D.E., Thomson, D. L. 1997. UK birds are laying eggs earlier. Nature 388, 526.

Crick, H.Q.P., Sparks, T.H. 1999. Climate changes related to egg-laying trends. Nature 399, 423–424.

Crick, H.Q.P. 2004. The impact of climate change on birds. Ibis 146, 48–56.

Engelbrecht, F. 2005. Simulations of Climate and Climate Change over Southern and Tropical Africa with the Conformal-Cubic Atmospheric Model. In: Schulze, R.E. (Ed) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05. Chapter 4, 57–74.

Erasmus, B.F.N., van Jaarsveld, A.S., Chown, S.L., Kshatriya, M., Wessels, K. 2002. Vulnerability of South African taxa to climate change. Global Change Biology 8, 679–693.

Ferrier, S., Pressey, R.L., Barrett, T.W., 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its application in real-world planning, and a research agenda for further refinement. Biological Conservation 93, 303–325.

Fielding, A.H., Bell, J.F. 1997. A review of methods for the assessment of prediction errors in conservation presence/ absence models. Environmental Conservation 24, 38–49.

Fishpool, L.D.C., Evans, M.I. 2001. Important Bird Areas in Africa and associated islands: Priorit sites for conservation. Newbury and Cambridge, UK: Pisces Publication and BirdLife International (BirdLife Conservation Series No. 11).

Foden, W., Midgley, G.F., Hughes, G., Bond, W.J., Thuiller, W., Hoffman, M.T., Kaleme, P., Underhill, L.G., Rebelo, A., Hannah, L. 2007. A changing climate is eroding the geographical range of the Namib Desert tree *Aloe* through population declines and dispersal lags. Diversity and Distributions 13, 645–653.

Gordon, C., Cooper, C., Seniot, C.A., Banks, H., Gregory, J.M., Johns, T.C., Mitchell, J.F.B., Wood., R.A. 2000. The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. Climate Dynamics 16, 147–168.

Guisan, A., Thuiller, W. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters 8, 993–1009.

Hannah, L., Midgley, G.F., Lovejoy, T., Bond, W.J., Bush, M., Lovett, J.C., Scott, D., Woodward, F.I. 2002a. Conservation of Biodiversity in a Changing Climate. Conservation Biology 16, 264–268.

Hannah, L., Midgley, G.F., Millar, D. 2002b. Climate change-integrated conservation strategies. Global Ecology and Biogeography 11, 485–495.

Harrison, J.A., Allan, D.G., Underhill, L.G., Herremans, M., Tree, A.J., Parker, V., Brown, C.J. 1997. The atlas of southern African birds. Birdlife South Africa, Johannesburg, South Africa.

Hastie, T.J., Tibshirani, R. 1996. Generalised Additive Models. Chapman Hall, London.

Hewitson, B. 2003. Developing Perturbations for Climate Change Impact Assessments. Transactions of the American Geophysical Union 84, 337–341.

Hockey, P.A.R., Dean, W.R.J., Ryan, P.G. 2005. Roberts – Birds of Southern Africa, VIIth ed. The trustees of the John Voelcker Bird Book Fund, Cape Town, South Africa.

Hudson, D.A., Jones, R.G. 2002. Regional climate model simulations of present-day and future climates of southern Africa, Hadley Centre Technical Note 39, 42 pp., Meteorological Office Hadley Centre, Exeter, U. K.

Hughes, L. 2000. Biological consequences of global warming: is the signal already apparent? Trends in Ecology Evolution 15, 56–61.

IPCC 2007. Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Science Basis, AR4 Synthesis Report. [Online] (On 3 Dec 2007) (www.ipcc.ch).

IUCN, 2006. IUCN Red List of Threatened Species, IUCN-SSC [Online] (15 May 2007) (http://www.iucnredlist.org).

Jones, R.G., Noguer, M., Hassell, D.C., Hudson, D., Wilson, S.S., Jenkins, G.J., Mitchell J.F.B. 2004. Generating high resolution climate change scenarios using PRECIS, report, 40 pp., Met Office Hadley Centre, Exeter, U.K.

Jonzén, N., Lindén, A., Ergon, T., Knudsen, E., Vik, J.O., Rubolini, D., Piacentini, D., Brinch, C., Spina, F., Karlsson, L., Stervander, M., Andersson, A., Waldenström, J., Lehikoinen, A., Edvardsen, E., Solvang, R., Stenseth, N.C. 2006. Rapid advance of spring arrival dates in long-distance migratory birds. Science 312, 1959–1961.
Kiester, A.R., Scott, J.M., Csuti, B., Noss, R.F., Butterfield, B., Sahr, K., White, D. 1996. Conservation prioritization using GAP data. Conservation Biology 10, 1332–1342.

Lawler, J.J., White, D., Masters, L.L. 2003. Integrating representation and vulnerability: two approaches for prioritizing areas for conservation. Ecological Applications 13, 1762–1772.

Lennon, J.J., Greenwood, J.J.D., Turner, J.R.G. 2000. Bird diversity and environmental gradients in Britain: a test of the species-energy hypothesis. Journal of Animal Ecology 69, 581–598.

Lovejoy, T.E. 2005. Conservation with a changing climate. Chapter 19: 325–328. In: Climate change and Biodiversity, Eds: Lovejoy, T.E., Hannah, L. Yale University Press, New Haven, U.S.A.

Lovejoy, T.E., Hannah, L. 2005. Climate change and Biodiversity. Yale University Press, New Haven, U.S.A.

Margules, C.R., Pressey, R.L., 2000. Review article: Systematic conservation planning. Nature 405, 243–253.

McCarty, J.P. 2001. Ecological Consequences of Recent Climate Change. Conservation Biology 15, 320–335.

McPherson, J.M., Jetz, W. 2007. Effects of species ecology on the accuracy of distribution models. Ecography 30, 135–151.

McPherson, J.M., Jetz, W., Rogers, D.J. 2004. The effects of species’ range sizes on the accuracy of distribution models: ecological phenomenon or statistical artefact? Journal of Applied Ecology 41, 811–823.

Midgley, G.F., Hannah, L., Millar, D., Rutherford, M.C., Powrie, L.W. 2002. Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. Global Ecology and Biogeography 11, 445–451.

Midgley, G.F., Hannah, L., Millar, D., Thuiller, W., Booth, A. 2003. Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. Biological Conservation 112, 87–93.

Monserud, R.A., Leemans, R. 1992. Comparing global vegetation maps with the Kappa statistic. Ecological Modelling 62, 275–293.

Nakicenovic, N., Swart, R. 2000. Emissions Scenarios. Special Report of the Intergovernmental Panel on Climate Change. Cambridge, University Press, Cambridge.

New, D., Lister, D., Hulme, M., Makin, I. 2002. A high-resolution data set of surface climate over global land areas. Climate Research 21, 1–25.

O'Dea, N., Araújo, M.B., Whittaker, R.J. 2006. How well do Important Bird Areas represent species and minimize conservation conflict in the tropical Andes? Diversity and Distributions 12, 205–214.

Ogutu, J.O., Owen-Smith, N. 2003. ENSO, rainfall and temperature influences on extreme population declines among African savanna ungulates. Ecology Letters 6, 412-419.

Olwoch, J.M., Rautenbach, C.J. de W., Erasmus, B.F.N., Engelbrecht, F.A., van Jaarsveld, A.S. 2003. Simulating tick distributions over sub-Saharan Africa: the use of observed and simulated climate surfaces. Journal of Biogeography 30, 1221–1232.

Olwoch, J.M., Reyers, B., Engelbrecht, F.A., Erasmus, B.F.N. 2007. Climate change and the tick-borne disease, *Theileriosis* (East Coast fever) in sub-Saharan Africa. Journal of Arid Environments, In Press (doi:10.1016/j.jaridenv.2007.04.003).

Opdam, P., Wascher, D. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117, 285–297.

Parmesan, C., Ryrholm, N., Stefanescu, C., J.K. Hillk, Thomas, C.D., Descimon, H., Huntley, B., Kaila, L., Kullberg, J., Tammaru, T., Tennent, W.J., Thomas, J.A., Warren, M. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399, 579–583.

Parmesan, C., Yohe, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421, 27–42.

Pearson, R.G., Dawson, T.P. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography 12, 361–371.

Pearson, R.G., Thuiller, W, Araújo, M.B., Martinez-Meyer, E., Brotons, L., McClean, C., Miles, L., Segurado, P., Dawson, T.P., Lees, D.C. 2006. Model-based uncertainty in species range prediction. Journal of Biogeography 33, 1704–1711.

Peterson, A.T., Sáchez-Cordero, V., Soberón, J., Bartley, J., Buddemeier, R.W., Navarro-Sigüenza, A.G. 2001. Effects of global climate change on geographic distributions of Mexican Cracidae. Ecological Modelling 144, 21–30.

Pressey, R.L., Taffs, K.H., 2001. Scheduling conservation action in production landscapes: priority areas in western New South Wales defined by irreplaceability and vulnerability to vegetation loss. Biological Conservation 100, 355–376.

R Development Core Team. 2006. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0 [Online] (On 6 November 2007)(http://www.R-project.org).

Raupach, M.R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J.P., Klepper, G., Field, C.B. 2007. Global and regional drivers of accelerating CO_2 emissions. Proceeding of the National Academy of Science, In Press (doi:10.1073/pnas.0700609104).

Reyers, B. 2004. Incorporating anthropogenic threats into evaluations of regional biodiversity and prioritisation of conservation areas in the Limpopo Province, South Africa. Biological Conservation 118, 521–531.

Root, T.L., Price, J.T., Hall, K.R., Schneider, S.H., Rosenzweig, C., Pounds, J.A. 2003. Fingerprints of global warming on wild animals and plants. Nature 421, 57–60.

Root, T.L., MacMynowski, D.P., Mastrandrea, M.D., Schneider, S.H. 2005. Human-modified temperatures induce species changes: Joint attribution. Proceeding of the National Academy of Science 102, 7465–7469.

Rutherford, M.C., Powrie, L.W., Schulze, R.E. 1999. Climate change in conservation areas of South Africa and its potential impact on floristic composition: a first assessment. Diversity and Distributions 5, 253–262.

Schulze et al. 1997. South African atlas of Agrohydrology and Climatology. CSIR, Pretoria, 276 pp.

Segurado, P., Araújo, M.B. 2004. An evaluation of methods for modelling species distributions. Journal of Biogeography 31, 1555–1568.

Simmons, R.E., Barnard, P., Dean, W.R.J. Midgley, G.F., Thuiller, W., Hughes, G. 2004. Climate change and birds: perspectives and prospects from southern Africa. Ostrich 75, 295–308.

Swets, K.A. 1988. Measuring the accuracy of diagnostic systems. Science 240, 1285–1293.

Tadross, M., Jack, C., Hewitson, B. 2005. On RCM-based projections of change in southern African summer climate. Geophysical Research Letters 32, (doi:10.1029/2005GL024460).

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., de Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Peterson, A.T., Phillips, O.L., Williams, S.E. 2004. Extinction risk from climate change. Nature 427, 145–148.

Thomas, C.D., Franco, A.M.A., Hill, J.K. 2006. Range retractions and extinction in the face of climate warming. Trends in Ecology and Evolution 21, 415–416.

Thomas, C.D., Lennon, J.J. 1999. Birds extend their ranges northwards. Nature 399, 213.

Thuiller, W. 2003. BIOMOD – optimizing predictions of species distributions and projecting potential future shifts under global change. Global Change Biology 9, 1353–1362.

Thuiller, W. 2004. Patterns and uncertainties of species' range shifts under climate change. Global Change Biology 10, 2020–2027.

Thuiller, W., Lavorel, S., Araujo, M.B., Sykes, M.T., Prentice, I.C. 2005. Climate change threats to plant diversity in Europe. Proceedings of the National Academy of Sciences 102, 8245–8250.

Thuiller, W. Lavorel, S., Sykes, M.T., Araújo, M.B. 2006. Using niche-based modelling to assess the impact of climate change on tree functional diversity in Europe. Diversity and Distributions 12, 49–60.

Thuiller, W. 2007. Climate change and the ecologist. Nature 448, 550–552.

van Jaarsveld, A.S., Chown, S.L. 2001. Climate change and its impacts in South Africa Trends in Ecology and Evolution 16, 13–14.

van Rensburg, B.J., Erasmus, B.F.N., van Jaarsveld, A.S., Gaston, K.J., Chown, S.L. 2004. Conservation during times of change: correlations between birds, climate and people in South Africa. South African Journal of Science 100, 266–272.

Walther, G., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J., Hoegh-Guldberg, O., Bairlein, F. 2002. Ecological responses to recent climate change. Nature 416, 389–395.

Chapter 4

Summary and Conclusions

Running title: 4. Conclusions

Summary and Conclusions

Main findings

The declaration of an Important Bird Area (IBA) does not ensure its conservation. While declaration is a vital step toward that goal, it is only through planning and implementation of adequate management actions for all IBAs that long-term conservation is achieved (Fishpool and Evans, 2001). I have identified the broad-scale major anthropogenic pressures to IBAs and by combining these data with irreplaceability values have indicated where conservation attention should be focused. In addition to irreplaceability, I also provide other biologically important indices for each IBA and suggest that these values can be substituted for irreplaceability as a means of quantifying the importance of the IBA. The data on current anthropogenic pressures or future vulnerability values that have been calculated for each IBA can be used to address specific management questions (Appendix S1).

Optimistically, there are major opportunities for conservation in irreplaceable IBAs outside of the current protected areas network. Overall, a total of 81 IBAs (71%) are less than 5% degraded or transformed. Disconcertingly however, only 9% of the area of the 9 IBAs that are highly irreplaceable fall within the formal protected area network. Important threats to highly irreplaceable IBAs are alien invasive species and afforestation. A major finding is that there are highly irreplaceable grid cells (0.25° x 0.25°) representing IBAs that fall outside of protected areas and have a lower human population density than expected by chance. These grid cells provide an ideal opportunity for conservation interventions and could act as a starting point for further and finer scale analysis (Appendix 2.2).

Climate change is a major concern for the long-term conservation of IBAs. Climate change is *already* affecting birds around the world, and changes in phenology, distributions and the arrival timing of migrants have been documented (e.g. Crick et al., 1997; Crick and Sparks, 1999; Crick, 2004; Chambers et al., 2005; Jonzén et al., 2006). In general, impacts of climate change are very likely to be severe as endemic species richness patterns are predicted to undergo large shifts by 2070-2100. This study shows that the current locations of IBAs in the South African IBA network are very likely to be ineffective for conserving endemic birds under climate change. The results of the climate change predictions suggest that endemic species will undergo large rates of species turnover, meaning that species assemblages per grid will be very different in future. However, mountainous regions like Lesotho and parts of the Western Cape Province, which contain at least some IBAs that I have identified (Chapter three; Appendix 3.2), will provide important refugia for species and should be a priority for further conservation interventions.

Two IBAs deserve special mention. These are the Grassland Biosphere Reserve and the Amersfoort-Bethal-Carolina District (IBA codes: SA020; SA018). These IBAs are highly threatened by a variety of transformation pressures and particularly vulnerable to climate change. Considering all the threats assessed in this study, without hyperbole I can state that these two sites, which have little of their area under formal protection, form the key IBAs in South Africa for conservation prioritisation (Figure 3.2; p.71).

Limitations

Chapter 2 addressed some conceptual limitations of incorporating vulnerability into an assessment such as this one. Ultimately, many shortfalls of this study are the result of data limitations. In South Africa, there is currently insufficient appropriate datasets to determine the time until exposure of a pressure or the affect that a pressure will have on biodiversity. This shortfall is receiving much attention in the conservation planning literature (Wilson et al., 2005; Wilson et al., 2007). Ideally, this study should be used as an addition to a long term conservation plan. This would take cognisance of imminent threats to IBAs (for instance, pollution in a wetland) while formulating a strategy to address broad and cross-cutting threats as identified here, like the management of alien invasive species, afforestation and addressing climate change, with a focus on the regions I have identified.

Although the modelling analysis highlighted Lesotho as being particularly important for conservation under climate change (Chapter three), none of the IBAs in Lesotho were included in the anthropogenic pressures analysis due to data shortages (Chapter two). It is thus unclear to what degree the IBAs in this region face anthropogenic pressures, but, in terms of climate change considerations they should be considered as priorities for conservation action.

The climate change analysis only considers a “business as usual” carbon emissions scenario, meaning it assumes carbon emissions globally continue unhindered. This is of uncertain as it depends on how the global community intervenes with current CO_2 emissions to address climate change. This analysis then is an extreme scenario of climate change and the observed reality may not be as severe. However, given the currently increasing observed rates of global CO_2 emissions (Raupach et al., 2007), on which the “business as usual” A2 SRES scenario is based, this analysis is by no means an overestimate as this scenario is considered reasonably credible in future (Broennimann et al., 2006). Nonetheless, there remains uncertainty as to which scenario is more likely in future. The advantage however is that I combined outputs from four different climate change models. The analysis essentially compares four equally justifiable climate change models for the region, thus taking cognisance of the fact that there is substantial uncertainty in climate change models themselves. Also, climate change is likely to increase the frequency of extreme events, which this study can not account for, so results then should be seen as indicative of broad trends over long time scale.

In the present form of this analysis I combined the vulnerability to anthropogenic threats with those introduced by climate change in a simple and robust manner. However, it is important to acknowledge the added level of uncertainty. There are two major criticisms. Firstly, there is a very large temporal disjunction between the effects of climate change and the other drivers of global change investigated here (Walther, 2007). While the threat from climate change is large, it operates over a much longer time scale, and affects populations over much larger spatial extents (Thuiller, 2007) than the other anthropogenic pressures I investigated. Secondly, few studies have explored the synergistic effects between climate change and other drivers of global change. For example, it is unclear how invasive species will interact with climate change (Thuiller et al., 2007). It is also highly likely that areas suitable for agriculture will change under climate change, thus changing the pressures from agriculture in a particular location. The impact of habitat fragmentation is also likely to be exacerbated by climate change (Opdam and Wascher, 2004). Conceptually then, either part of the study should be viewed as essentially separate but complementary chapters. However, much progress is being made into combining global change threats such as land use with climate change predictions (see Bomhard et al., 2005; Broennimann et al., 2006).

Future directions

1. Quite simply, better data will provide better answers, and more robust conservation plans. Thus there is a need to continue to refine and expand the spatial datasets as used here, primarily by incorporating a temporal scale. Land cover databases should be updated and repeated at more regular time steps, and using identical methodologies, which is currently not done in South Africa. An empirically validated estimate of the effect of land use pressures on biodiversity is also needed, especially to feed into ongoing efforts to monitor the state of biodiversity (Scholes and Biggs, 2005). There is a massive scope for finding better ways of incorporating vulnerability to transformation into conservation planning (Wilson et al., 2005; Wilson et al., 2007). The process is essentially heuristic, meaning approaches need to be tested, validated and improved continually. As such I strongly support ongoing initiatives such as the National Spatial Biodiversity Assessments (Reyers et al., 2007). Also, future conservation plans need to incorporate economics, as conservation decisions that ignore economics will invariably fail. Analyses that incorporate the spatial distributions of biological benefits and economic costs into conservation planning show that limited budgets can achieve substantially larger biological gains than when planning ignores costs (Naidoo et al., 2006; Wilson et al., 2007). Since conservation has limited resources, rational decision making and the judicial allocation of scare resources are key to the advancement of the field.

2. Conservation planners are in dire need of robust estimates of climate change impacts on species and these need to be incorporated into conservation planning strategies (Hannah et al. 2002a,b; Lovett et al., 2005; Araújo et al., 2004; Araújo et al., 2006; McClean et al.,

2006). While conservation planning is a well established field (e.g. Margules and Pressey, 2000), few studies have explored the methodological considerations necessary for incorporating climate change into conservation planning. The literature however, is replete with calls for robust strategies to do this. The fields of conservation planning and climate change biology need to converge.

3. The use of ensemble modelling methods in this study provides an improvement over earlier modelling techniques in reducing uncertainty and increasing accuracy through selection of the most consensual projections (Araújo et al., 2005). However, challenges remain in the use and application of bioclimatic niche models and current modelling capabilities are not perfect (Thuiller, 2007). It falls outside of the scope of this thesis to discuss specific improvements to niche models as this is dealt with comprehensively elsewhere (e.g. Guisan and Thuiller, 2005; Araújo and Guisan, 2006; Araújo and New, 2006; Broennimann et al., 2006; Araújo and Rahbek, 2006; Austin, 2007; Thuiller, 2007). Despite their limitations however, they are a vital tool in understanding and anticipating the effects of climate change (Pearson and Dawson, 2003; Thuiller, 2007). We will never be able to predict the future with accuracy, but bioclimatic niche models improve our understanding of the likely effects of future climate on biodiversity (Araújo and Rahbek, 2006).

4. Few studies have explored the relationship between human population density, species richness and species complementarity patterns. Complementarity is the extent to which an area, or set of areas, contributes unrepresented features to an existing area or set of areas (Margules and Pressey 2000). Irreplaceability is defined as the likelihood that a given site will need to be protected to achieve a specified set of conservation targets (Margules and Pressey 2000). Irreplaceability is a widely used measure to achieve representativeness, meaning that all designated biological features are represented and is essentially complementarity functionally operationalized (Margules and Pressey 2000; Graham et al. 2005). Although I did not directly test for complementarity, an emerging pattern from this study is that high human population density areas and highly irreplaceable regions do not necessarily coincide. This pattern is in contrast to most other studies (Fjeldså and Rahbek,

1998; Balmford et al., 2001; Araújo et al., 2002; Luck et al., 2004; O'Dea et al., 2006) but the results of this study are supported by Diniz-Filho et al. (2006). Evidence to support a widespread coincidence between complementarity and human population density is still incomplete and the mechanism to explain this pattern remains elusive (Araújo and Rahbek, 2007). Evidently, these patterns are interesting and complex and should form the basis for future research, as others have also pointed out (Araújo and Rahbek, 2007).

5. Being a well known and charismatic taxon, with a substantial public interest, I cannot emphasise strongly enough the role birds can play in understanding, planning for and detecting signs of climate change. Importantly, the possibility exists that long-term datasets are already in existence which can inform on changes already taking place due to climate change, and these essentially "dormant" sources provide a lucrative avenue for future research (for a review see Chambers et al., 2005). As a consequence, I strongly support long term ecological monitoring, data capture and storage projects like the South African Ecological Observations Network (van Jaarsveld et al., 2007).

6. This study reaffirms the important contribution of atlas data of species distributions to conservation planning and addressing other especially biogeographical hypotheses (Harrison et al., 2007). In climate change research especially, adequate species distribution data is vital, as the Protea Atlas Project database also reiterates (Protea Atlas Project, 2007; Bomhard et al., 2005; Williams et al., 2005). Consequently, I strongly support species distribution atlas initiatives such as the South African Bird Atlas Project 2 (SABAP2; Harrison et al., 2007).

7. Ultimately, only unprecedented cuts in global carbon emissions will have any real chance at reducing the impacts of climate change. We need to change in dramatic and prolonged ways, in order to offer a future to subsequent generations and the diverse life on earth. The time for change is today. We can only achieve a real impact if we move in a quick and decisive manner, with a maturity that we have rarely shown as a society or a species (McKibben, 2007).

Closing remarks

Assessments such as this one, which aim for the conservation of biodiversity and the identification of priority conservation areas, often have little impact in reaching these aims (Cabeza and Moilane, 2001). Conservation planners are confronted by an "implementation crisis" where our understanding of conservation planning techniques far exceeds our ability to apply them to real world conservation problems (Knight et al., 2006). It is only by putting conservation science, assessments and plans into practice, among a host of other challenges, that one achieves conservation (Balmford and Cowling, 2006). Ultimately, the answer lies in politics. The political arena is the real world conduit for implementing effective conservation interventions. The knowledge gained on how to save life on earth will be for nothing if we lack the political know-how to apply it (Johns, 2007).

References

Araújo, M.B., Williams, P.H., Turner, A. 2002. A sequential approach to minimise threats within selected conservation areas. Biodiversity and Conservation 11, 1011–1024.

Araújo, M.B., Cabeza, M., Thuiller, W., Hannah, L., Williams, P.H. 2004. Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. Global Change Biology 10, 1618–1626.

Araújo, M.B., Whittaker, R.J., Ladle, R.J., Erhard, M. 2005. Reducing uncertainty in projections of extinction risk from climate change. Global Ecology and Biogeography 14, 529–538.

Araújo, M.B., Guisan, A. 2006. Five (or so) challenges for species distribution modelling. Journal of Biogeography 33, 1677–1688.

Araújo, M.B., Rahbek, C. 2006. How does climate change affect biodiversity? Science 313, 1396–1397.

Araújo, M.B., New, M. 2006. Ensemble forecasting of species distributions. Trends in Ecology and Evolution 22, 42–47.

Araújo, M.B., Rahbek, C. 2007. Conserving biodiversity in a world of conflicts. Journal of Biogeography 34, 199–200.

Araújo, M.B., Thuiller, W., Pearson, R.G. 2006. Climate warming and the decline of amphibians and reptiles in Europe. Journal of Biogeography 33, 1712–1728.

Austin, M. 2007. Species distribution models and ecological theory: A critical assessment and some possible new approaches. Ecological Modelling 200, 1–19

Balmford, A., Moore, J.L., Brooks, T., Burgess, N., Hansen, L.A., Williams, P., Rahbek, C. 2001. Conservation conflicts across Africa. Science 291, 2616–2619.

Balmford, A., Cowling, R.M. 2006. Fusion or Failure? The Future of Conservation Biology. Conservation Biology 20, 692–695.

Bomhard, B., Richardson, D.M., Donaldson, J.S., Hughes, G.O., Midgley, G.F., Raimondo, D.C., Rebelo, A.G., Rouget, M., Thuiller, W. 2005. Potential impacts of future land use and climate change on the Red List status of the Proteaceae in the Cape Floristic Region, South Africa. Global Change Biology 11, 1452–1468.

Broennimann, O., Thuiller, W., Hughes, G., Midgley, G.F., Alkemade, J.M.R., Guisan, A. 2006. Do geographic distribution, niche property and life form explain plants' vulnerability to global change? Global Change Biology 12, 1079–1093.

Cabeza, M., Moilanen, A. 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology and Evolution 16, 242–248.

Chambers, L.E., Hughes, L., Weston, M.A. 2005. Climate change and its impact on Australia's avifauna. Emu 105, 1–20.

Crick, H.Q.P., Dudley, C., Glue, D.E., Thomson, D.L. 1997. UK birds are laying eggs earlier. Nature 388, 526.

Crick, H.Q.P., Sparks, T. H. 1999. Climate changes related to egg-laying trends. Nature 399, 423–424.

Crick, H.Q.P. 2004. The impact of climate change on birds. Ibis 146: 48–56.

Diniz-Filho, J.A.F., Bini, L.M., Pinto, M.P., Rangel, T.F.L.V.B., Carvalho, P., Bastos, R.P. 2006. Anuran species richness, complementarity and conservation conflicts in Brazilian Cerrado. Acta Oecologica 29, 9–15.

Fishpool, L.D.C., Evans, M.I., 2001. Important Bird Areas in Africa and associated islands: Priority sites for conservation. Newbury and Cambridge, UK: Pisces Publication and BirdLife International (BirdLife Conservation Series No. 11).

Fjeldså, J., Rahbek, C. 1998. Continent wide conservation priorities and diversification process. In: Conservation in a changing world (ed. by G.M. Mace, A. Balmford and J. Ginsberg), pp. 139–160. Cambridge, University Press, Cambridge.

Graham, C.H., Smith, T.B., Languy, M. 2005. Current and historical factors influencing patterns of species richness and turnover of birds in the Gulf of Guinea highlands. Journal of Biogeography 32, 1371–1384.

Guisan, A., Thuiller, W. 2005 Predicting species distribution: offering more than simple habitat models. Ecology Letters 8, 993–1009.

Hannah, L., Midgely, G.F., Lovejoy, T., Bond, W.J., Bush, M., Lovett, J.C., Scott, D., Woodward, F.I. 2002a. Conservation of biodiversity in a changing climate. Conservation Biology 16, 264–268.

Hannah, L., Midgley, G.F., Millar, D. 2002b. Climate change-integrated conservation strategies. Global Ecology and Biogeography 11, 485–495.

Harrison, J.A., Underhill, L.G., Barnard, P. 2007. The seminal legacy of the Southern African Bird Atlas Project. South African Journal of Science, In Press.

Johns, D. 2007. Like it or not, politics is the solution. Conservation Biology 21, 287–288.

Jonzén, N., Lindén, A., Ergon, T., Knudsen, E., Vik, J.O., Rubolini, D., Piacentini, D., Brinch, C., Spina, F., Karlsson, L., Stervander, M., Andersson, A., Waldenström, J., Lehikoinen, A., Edvardsen, E., Solvang, R., Stenseth, N.C. 2006. Rapid advance of spring arrival dates in long-distance migratory birds. Science 312, 1959–1961.

Knight A. T., Cowling, R.M., Campbell, B. M. 2006. Planning for implementation: an operational model for implementing conservation action. Conservation Biology 20, 549–561.

Lovett, J.C., Midgley, G.F., Barnard, P. 2005. Climate change and ecology in Africa. African Journal of Ecology 43, 167–169.

Luck, G.W., Ricketts, T.H., Daily, G.C., Imhoff, M. 2004. Alleviating spatial conflicts between people and biodiversity. Proceedings of the National Academy of Sciences 101, 182–186.

Margules, C.R., Pressey, R.L., 2000. Review article: Systematic conservation planning. Nature 405, 243–253.

McClean, C.J., Doswald, N., Küper, W., Sommer, J.H., Barnard, P., Lovett, J.C. 2006. Potential impacts of climate change on Sub-Saharan African plant priority area selection. Diversity and Distributions 12, 645–655.

McKibben, B. 2007. Carbon’s new Math. National Geographic 212 (4), 33–37.

Naidoo, R., Balmford, A., Ferraro, P.J., Polasky, S., Ricketts, T.H., Rouget, M. 2006. Integrating economic costs into conservation planning. Trends in Ecology and Evolution 21, 681–687.

O'Dea, N., Araújo, M.B., Whittaker, R.J. 2006. How well do Important Bird Areas represent species and minimize conservation conflict in the tropical Andes? Diversity and Distributions 12, 205–214.

Opdam, P., Wascher, D. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117, 285–297.

Pearson, R.G., Dawson, T.P. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography 12, 361–371.

Protea Atlas Project. 2007. [Online] (On 3 Dec 2007) (http://protea.worldonline.co.za/default.htm).

Raupach, M.R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J.P., Klepper, G., Field, C.B. 2007. Global and regional drivers of accelerating CO2 emissions. Proceeding of the National Academy of Sciences (doi:10.1073/pnas.0700609104).

Reyers, B., Rouget, M., Jonas, Z., Cowling, R.M., Driver, A., Maze, K., Desmet, P. 2007. Developing products for conservation decision-making: lessons from a spatial biodiversity assessment for South Africa. Diversity and Distributions 13, 608–619.

Scholes, R.J., Biggs, R. 2005. A biodiversity intactness index. Nature 434, 45–49.

van Jaarsveld, A.S., Pauw, J.C., Mundree, S., Mecenero, S., Coetzee, B.W.T., Alard, G.F. 2007. South African Environmental Observation Network: vision, design and status. South African Journal of Science 103, 289–294.

Walther, R. 2007. Tackling Ecological Complexity in Climate Impact Research. Science 315, 606–607.

Williams, P., Hannah, L., Andelman, S., Midgley, G., Araújo, M.B., Hughes, M., Manne, L., Martinez-Meyer, E., Pearson, R. 2005. Planning for Climate Change: Identifying Minimum-Dispersal Corridors for the Cape Proteaceae. Conservation Biology 19, 1063–1074.

Wilson, K., Pressey, R.L., Newton, A., Burgman, M., Possingham, H., Weston, C. 2005. Measuring and Incorporating Vulnerability into Conservation Planning. Environmental Management 35, 527–543.

Wilson, K., Underwood, E.C., Morrison, S.A., Klausmeyer, K.R., Murdoch, W.W., Reyers, B., Wardell-Johnson, G., Marquet, P.A., Rundell, P.W., McBride, M.F., Pressey, R.L., Bode, M., Hoekstra, J.M., Looker, M., Rondinini, C., Karieva, P., Shaw, M.R., Possingham, H.P. 2007. Conserving Biodiversity Efficiently: What to Do, Where, and When. Public Library of Science: Biology 5, 1850–1861.

Thuiller, W., Richardson, D.M., Midgley, G.F. 2007. Will climate change promote alien plant invasions? In: Nentwig, N. (ed.) Biological Invasions. Springer Press, The Netherlands.

Thuiller, W. 2007. Climate change and the ecologist. Nature 448, 550–552.

Appendices

Supplementary Appendix S1. All irreplaceability, current anthropogenic pressures, future vulnerability and biological indicators data, normalised for each of 115 Important Bird Areas in South Africa. For an electronic copy of this supplementary appendix, contact the author: Bernard Coetzee, Centre for Invasion Biology and Department of Zoology & Entomology; University of Pretoria; Pretoria; 0002; South Africa; Telephone: +27 12 420 4614; Email: bwtcoetzee@zoology.up.ac.za.

Appendix 2.1. All Important Bird Areas identified across South Africa with high irreplaceability (> 0.5) and high threat scores (> 0.5) based on current pressure and future vulnerability to threats. These sites are flagged for the urgent scheduling of conservation action and in terms of species irreplaceability patterns, are primary areas for conservation measures and/or protected area expansion. There are no sites with both high irreplaceability and high current pressures of road networks, human population density and land transformation. The IBA codes following Barnes (1998) are given in parentheses. N.R. = Nature Reserve; N.P. = National Park; G.R= Game Reserve.

(Appendix 2.1 overleaf)

Appendix 2.1.

Current pressures		Future vulnerability				
Protected area status (i.e. unprotected)	**Invaded by alien invasive plants**	**Afforestation suitability**	**Mining suitability**	**Human Population Expansion**	**Aliens suitability**	**Cultivation suitability**
Soutpansberg (3)	Kruger National N.P. & Adjacent areas (2)	Richards Bay G.R. (79)	Amerfoort- Bethal- Carolina (18)	Richards Bay G.R. (79)	Soutpansberg (3)	Richards Bay G.R. (79)
Magalies & Witwatersberg (25)	Magalies & Witwatersberg (25)	Amerfoort- Bethal- Carolina (18)	Vhembe Nature Reserve (1)	Ndumo G. R. (52)	Lake St. Lucia & Mkuze Swamps (58)	Lake St. Lucia & Mkuze Swamps (58)
Amerfoort- Bethal- Carolina (18)	Wolkberg Forrest (5)	Grassland Biosphere R. (20)	Grassland Biosphere Reserve (20)		Grassland Biosphere Reserve (20)	Umlalazi N.R. (63)
Haramoep & Black M. Mine N.R. (35)	Soutpansberg (3)	Ngoye Forest Reserve (65)	Nylriver floodplain (8)		Wolkberg Forest Belt (5)	
Mattheus-gat Conservation Area (34)	Blyde River Canyon (10)	1Blyde River Canyon (10)			Blouberg Vulture colonies (4)	
Bitterputs Conservation (36)	Grassland Biosphere Reserve (20)	Songimvelo G.R. (17)			Waterberg System (7)	
Blouberg Vulture Colonies (4)	Songimvelo G.R. (17)	Lake St. Lucia & Mkuze Swamps (58)			Nylriver floodplain (8)	
Grassland Biosphere Reserve (20)	Waterberg System (7)	Wolkberg Forest Belt (5)			Magalies & Witwatersberg (25)	
Waterberg System (7)	Lake St. Lucia & Mkuze Swamps (58)	Kosi Bay System (53)			Amerfoort- Bethal- Carolina (18)	
	Umlalazi N.R. (63)				Hluhluwe Umfolozi P. (60)	

Appendix 2.2. Grid cell codes (QDS) for South African Important Bird Areas (IBAs) which are outside of protected areas, have a relatively low human population density (calculated with a iterative algorithm), and contain highly irreplaceable (>0.5) species assemblages based on a database of 655 species. These sites represent an immediate opportunity for conservation interventions.

QDS	Irreplaceability	IBA Number	IBA Name
2230BD	0.93212	SA002	Kruger National Park and Adjacent areas
2931AD	0.90768	SA073	Umvoti Estuary
3326DA	0.85713	SA094	Alexandria Coastal belt
2229DD	0.79780	SA003	Soutpansberg
2630CC	0.68055	SA020	Grassland Biosphere Reserve
3218CC	0.58309	SA104	Lower-Bergriver wetlands
2731CD	0.56288	SA071	KwaZulu Natal Mistbelt Forests

Appendix 3.1. Endemic species modeled in present study (n = 50). Shown is the current number of 0.25° x 0.25° grid cells occupied by each species (Grid cells); climatically suitable space gained or lost under both full dispersal (FD) and no dispersal (ND) assumptions; number of IBAs currently occupied and number of IBAs occupied under a consensus climate change projection under full dispersal. Species in bold lose at least 85% of climatic suitable space irrespective of their dispersal abilities. Roberts's number refers to species codes used in Hockey et al. (2005) which contain species names.

Roberts No.	Common name	Current Grid cells occupied	% change Full Dispersal	% change No Dispersal	# IBAs currently occupied	# IBAs occupied under FD
92	Southern Bald Ibis	256	106.64	31.64	28	49
150	Forest Buzzard	149	168.46	69.13	26	50
190	Greywinged Francolin	492	-75.20	-75.20	39	11
195	Cape Spurfowl	225	-8.89	-27.56	17	12
208	Blue Crane	723	-78.15	-84.79	55	17
234	Blue Korhaan	365	-74.25	-80.55	21	7
239	**Southern Black Korhaan**	**1069**	**-85.31**	**-90.27**	**40**	**9**
362	Cape Parrot	72	533.33	38.89	10	38
370	Knysna Turaco	220	123.64	16.82	32	49
480	Ground Woodpecker	494	-81.17	-81.17	38	10
484	Knysna Woodpecker	107	-12.15	-46.73	13	11
492	Melodious Lark	159	-61.01	-76.10	8	4
495	Cape Clapper Lark	882	-86.85	-89.12	37	10
502	Karoo Lark	256	-44.53	-45.31	10	6
504	Red Lark	45	173.33	53.33	2	3
512	Large-billed Lark	691	-83.50	-83.50	24	7
551	Grey Tit	463	-58.53	-60.04	16	10
565	Bush Blackcap	84	117.86	44.05	14	25
566	Cape Bulbul	262	-46.18	-52.29	18	12
581	Cape Rock Thrush	586	40.27	9.22	57	63
582	Sentinel Rock Thrush	282	-3.55	-13.83	34	29
588	Buffstreaked Chat	227	155.95	53.30	31	52
591	**Sicklewinged Chat**	**555**	**-84.50**	**-85.41**	**19**	**4**
598	Chorister Robin-chat	214	162.62	24.30	33	60
611	Cape Rockjumper	51	101.96	66.67	9	10
612	**Drakensberg Rockjumper**	**80**	**-80.00**	**-80.00**	**12**	**2**

616	Brown Scrub-Robin	101	735.64	124.75	17	68
639	Barratt's Warbler	134	61.94	30.60	22	31
640	Knysna Warbler	36	77.78	11.11	5	10
641	Victorin's Warbler	64	-26.56	-51.56	9	4
660	Cinnamonbreasted Warbler	70	278.57	195.71	5	9
661	Cape Grassbird	520	22.31	0.00	54	58
686	Karoo Prinia	989	-64.21	-64.21	57	31
687	Namaqua Warbler	359	-30.92	-51.25	12	9
706	Fairy Flycatcher	902	-80.27	-84.26	42	15
721	**African Rock Pipit**	**266**	**-85.71**	**-87.22**	**15**	**2**
725	Yellowbreasted Pipit	44	1036.36	256.82	5	41
742	Southern Tchagra	301	29.90	-18.27	28	36
759	**Pied Starling**	**1165**	**-85.75**	**-85.92**	**58**	**17**
773	Cape Sugarbird	150	-10.67	-25.33	15	11
777	Orangebreasted Sunbird	138	-31.88	-40.58	14	7
783	Southern Doublecollared Sunbird	674	-23.44	-36.65	50	26
785	Greater Doublecollared Sunbird	487	64.27	-2.05	51	63
796	Cape White-eye	1457	-20.73	-29.51	90	80
813	Cape Weaver	921	-11.29	-18.57	67	65
850	Swee Waxbill	379	87.60	22.69	49	67
873	Forest Canary	214	7.01	-20.56	32	34
874	Cape Siskin	128	-11.72	-17.19	13	10
875	Drakensberg Siskin	49	-79.59	-79.59	5	2
880	Protea Seedeater	74	66.22	39.19	8	11

Appendix 3.2. Impact of climate change on Important Bird Areas (IBAs) as assessed in the present study, using distributional range shifts of 50 endemic birds. Shown is current endemic species richness in IBAs; richness under a consensus forecast from 16 models and 4 climate change models for the period 2070-2100 under a full dispersal assumption, species lost or gained, irreplaceability, and climate change impact in terms of species lost (normalised from 0-1). IBAs in bold have both a irreplaceability value (>0.5) and are highly threatened by climate change (normalised value of >0.5). N.R. = Nature Reserve; N.P. = National Park; G.R. = Game Reserve; M = Mountain; N.H.S. = Natural Heritage Site; SW = Swaziland; L = Lesotho.

IBA Nr.	IBA name	Current Richness	Consensus Climate change richness (FD)	Species Lost/Gained	Irreplaceability	CC Impact
1	Vhembe N.R.	0	2	2	0.98	0.44
2	**Kruger N.P. & adjacent areas**	**17**	**12**	**-5**	**1.00**	**0.65**
3	**Soutpansberg**	**14**	**10**	**-4**	**0.99**	**0.62**
4	**Blouberg vulture colonies**	**5**	**3**	**-2**	**0.84**	**0.56**
5	**Wolkberg forest belt**	**17**	**13**	**-4**	**0.89**	**0.62**
6	Pietersburg N.R.	0	0	0	0.33	0.50
7	Waterberg system	8	13	5	0.84	0.35
8	Nylriver floodplain	5	7	2	0.83	0.44
9	Norhern turf thornveld	3	3	0	0.41	0.50
10	**Blyderiver canyon**	**16**	**13**	**-3**	**0.90**	**0.59**
11	Graskop Grasslands	0	0	0	0.08	0.50
12	Mac-Mac escarpment & forests	17	15	-2	0.29	0.56
13	Misty M. N.H.S.	0	0	0	0.01	0.50
14	Blue Swallow N.H.S.	16	12	-4	0.41	0.62
15	Loskopdam N.R.	12	10	-2	0.05	0.56
16	Steenkampsberg	13	13	0	0.20	0.50
17	**Songimvelo G.R.**	**22**	**15**	**-7**	**0.75**	**0.71**
18	**Amerfoort-Bethal-Carolina district**	**15**	**14**	**-1**	**0.79**	**0.53**
19	Chrissie pans	15	15	0	0.39	0.50
20	**Grassland Biosphere R.**	**27**	**19**	**-8**	**0.76**	**0.74**
21	Blesbokspruit	10	13	3	0.27	0.41
22	Suikerbosrand N.R.	15	14	-1	0.09	0.53
23	Pilansberg N.P.	7	7	0	0.49	0.50
24	Botsalano N.R.	2	2	0	0.38	0.50
25	Magalies & Witwatersberg	13	15	2	0.79	0.44
26	Barberspan & Leeupan	4	3	-1	0.31	0.53
27	**Kalahari-Gemsbok N.P.**	**2**	**0**	**-2**	**0.91**	**0.56**
28	Spitskop dam	3	0	-3	0.02	0.59
29	**Augrabies Falls N.P.**	**6**	**4**	**-2**	**0.81**	**0.56**
30	Orangeriver mouth wetlands	3	5	2	0.49	0.44

31	Dronfield farm	0	0	0	0.15	0.50
32	Kamfersdam	0	0	0	0.24	0.50
33	Benfontein gamefarm	0	0	0	0.05	0.50
34	Mattheus-Gat	4	4	0	0.87	0.50
35	**Haramoep & Black M. N.R**	**7**	**6**	**-1**	**0.91**	**0.53**
36	Bitterputs	3	3	0	0.74	0.50
37	Platberg-Karoo conservancy	20	7	-13	0.19	0.88
38	Middle Vaalriver	11	13	2	0.16	0.44
39	Sandveld & Bloemhof N.R.	6	2	-4	0.47	0.62
40	Sterkfontein-Merinodal	0	0	0	0.01	0.50
41	Voordeel conservancy	0	0	0	0.00	0.50
42	Alexpan	0	0	0	0.00	0.50
43	Bedford-Chatsworth	9	10	1	0.00	0.47
44	Willem Pretorius G.R.	7	4	-3	0.01	0.59
45	Murphys Rust	0	0	0	0.02	0.50
46	Sterkfonteindam N.R.	27	13	-14	0.04	0.91
47	Golden Gate & QwaQwa N.P.	21	18	-3	0.03	0.59
48	Fouriesburg-Bethlehem-Clarens	17	17	0	0.01	0.50
49	Soetdoring N.R.	12	2	-10	0.02	0.79
50	Kalkfonteindam N.R.	10	1	-9	0.01	0.76
51	Gariep/Oviston/Tussen-d-Rivieree	18	9	-9	0.02	0.76
52	Ndumo G.R.	4	4	0	0.84	0.50
53	Kosibay system	3	11	8	0.60	0.26
54	L. Sibaya	0	0	0	0.53	0.50
55	Pongolapoort N.R.	4	5	1	0.79	0.47
56	Itala G.R.	9	10	1	0.02	0.47
57	Mkuzi G.R.	5	8	3	0.86	0.41
58	L. St. Lucia & Mkuze swamps	7	11	4	0.96	0.38
59	Chelmsford Nature Reserve	15	12	-3	0.00	0.59
60	Hluhluw-Umfolozi P.	5	13	8	0.60	0.26
61	L. Eteza N.R.	0	0	0	0.22	0.50
62	Spionkop N.R.	15	10	-5	0.04	0.65
63	Umlalazi N.R.	6	8	2	0.64	0.44
64	Natal Drakensberg P.	29	31	2	0.06	0.44
65	Ngoye forest R.	4	7	3	0.64	0.41
66	Entumeni N.R.	0	0	0	0.16	0.50
67	Dhlinza forest N.R.	0	0	0	0.16	0.50
68	Weenen G.R.	12	9	-3	0.00	0.59
69	Mvoti vlei	0	0	0	0.01	0.50
70	Blinkwater N.R.	0	0	0	0.01	0.50
71	KwaZulu Natal Mistbelt forests	26	21	-5	0.12	0.65
72	Hlatikulu N.R.	0	0	0	0.05	0.50
73	Umvoti estuary	0	0	0	0.14	0.50
74	Karkloof N.R.	0	17	17	0.04	0.00
75	Umgeni vlei N.R.	22	19	-3	0.02	0.59
76	Midmar N.R.	17	20	3	0.02	0.41
77	Impendle N.R.	22	20	-2	0.03	0.56
78	KwaZulu Natal Mistbelt grasslands	24	22	-2	0.24	0.56
79	Richards Bay G.R.	3	7	4	0.77	0.38
80	Ingangwana river (Coleford N.R.)	0	0	0	0.01	0.50

81	Franklin Vlei	14	20	6	0.01	0.32
82	Matatiele commonage	0	0	0	0.15	0.50
83	Penny Park	22	21	-1	0.01	0.53
84	M. Currie N.R.	13	17	4	0.00	0.38
85	Oribi gorge N.R.	13	15	2	0.42	0.44
86	Umtumvuna N.R.	14	16	2	0.02	0.44
87	Mkambati N.R.	4	17	13	0.06	0.12
88	Collywobbles vulture colony	7	15	8	0.00	0.26
89	Dwesa & Cwebe N.R.	11	13	2	0.08	0.44
90	Karoo N.R. Incl Graaf-Reinet	19	5	-14	0.01	0.91
91	Katberg-Readsdale forest	26	19	-7	0.01	0.71
92	Amatole forest complex	29	20	-9	0.02	0.76
93	Kouga-Baviaanskloof complex	34	22	-12	0.08	0.85
94	Alexandria coastal belt	17	9	-8	0.15	0.74
96	Swartkops estuary & Chatty pans	0	0	0	0.18	0.50
97	Maitland-Gamtoos coast	0	0	0	0.12	0.50
98	Tsitsikamma N.P.	22	20	-2	0.04	0.56
99	Olifantsriver estuary	0	0	0	0.06	0.50
101	Cederberg-Kouebokkeveld	29	35	6	0.22	0.32
102	Karoo N.P.	17	6	-11	0.19	0.82
103	Verlorenvlei	0	0	0	0.04	0.50
104	Lower Bergriver wetlands	14	18	4	0.07	0.38
105	Westcoast N.P & Saldanhabay	16	23	7	0.09	0.29
106	Swartberg M.	32	15	-17	0.19	1.00
107	Eastern Falsebay M.	31	35	4	0.09	0.38
108	Anysberg N.P.	20	14	-6	0.10	0.68
111	Rietvlei wetland R.	16	23	7	0.09	0.29
112	Outeniqua M.	31	24	-7	0.06	0.71
113	Southern Langberg M.	34	24	-10	0.11	0.79
114	Wilderness-Sedgefield L.	29	19	-10	0.05	0.79
115	Overberg wheatbelt	32	33	1	0.20	0.47
116	False Bay P.	16	18	2	0.25	0.44
118	Botriviervlei & Kleinmond estuary	0	0	0	0.07	0.50
119	De Hoop N.R.	25	20	-5	0.10	0.65
121	Heuningsnes river & estuary	17	20	3	0.16	0.41
SW001	Malolotja N.R.	16	11	-5	0.09	0.65
SW002	Hlane & Mwawula N.R.	2	6	4	0.90	0.38
L001	Liqobong	0	0	0	0.03	0.50
L002/004	Upper Senqu/ Sehonghong	29	31	2	0.05	0.44
L003	Mafika Lisiu	16	18	2	0.03	0.44
L005	Sehlabathe N.P.	0	0	0	0.03	0.50
L006	Upper Quthing Valley	8	19	11	0.03	0.18

Appendix 3.3. Component loadings of the principal components analysis (PCA) of the 64 model combinations from the consensus forecast for 50 endemic bird species from 16 models and 4 climate change models. Only first nine highest loading models are shown. Model names follow the convention: climate change model, niche model and evaluation method e.g. CCAM.GBM.Roc refers to the CCAM Climate Change model, the GBM niche model and the Roc transformation method. See text for detail on model abbreviations.

Model	PC1	PC2	PC3	PC4	PC5
Cumulative variance explained (%)	46.78	52.93	56.74	58.86	60.25
CCAM.GBM.Roc	-0.138	0.077	-0.073	0.042	-0.005
MM5.GBM.Roc	-0.138	0.077	-0.073	0.042	-0.005
PRECIS.GBM.Roc	-0.138	0.077	-0.073	0.042	-0.005
CCAM.GBM.TSS	-0.138	0.084	-0.068	0.038	-0.020
MM5.GBM.TSS	-0.138	0.084	-0.068	0.038	-0.020
PRECIS.GBM.TSS	-0.138	0.084	-0.068	0.038	-0.020
CCAM.CTA.TSS	-0.137	0.066	-0.007	0.041	-0.008
MM5.CTA.TSS	-0.137	0.066	-0.007	0.041	-0.008
PRECIS.CTA.TSS	-0.137	0.066	-0.007	0.041	-0.008