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CHAPTER 8

Summary and conclusion

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The case studies presented have a common thread – all evidence, modeled solutions as well as observed shifts in the literature, points to the fact that species distributions are expected to show substantial changes in response to a changing climate. These changes, whether they are range shifts, range contractions or complete range dislocations, are expected to be severe enough that long term land-use planning can no longer afford not to incorporate a climate change contingency plan (Hannah et al. 2002)

Conservation, where conservation goals are often measured by the presence of vulnerable species or communities, faces a particular challenge. Not only will the reserve network need considerable redundancy in the off-reserve matrix for anticipated range shifts, but it will also have to deal with range contraction, and associated potential local population declines (Gaston et al. 1996, Gaston 1998). Range contraction is a common predicted outcome (Erasmus et al. 2002). Even without any climate change, species with contracted ranges would already be at greater risk through simple area-abundance relationships (Gaston et al. 1996). However, given the degree of stress that most populations are already subjected to in their present ranges due to unsustainable land-use practices (Lande 1998), the additional stress of climate change may make local extinctions a more likely outcome. This finding from this South African assessment concurs with sentiments expressed by the IPCC Regional Assessment (IPCC 1997) on the vulnerability of African ecosystems to climate change due to unsustainable land-uses. It is a significant step forward to be able to confirm findings from broad regional assessments at a national scale where conservation planning decisions are taken (Erasmus et al. 1999).

Eastward range shifts are another typical feature of predicted future species distributions in South Africa. This predicted shift tracks the predicted decrease in precipitation across the east-west aridity gradient in South Africa. This predicted shift confirms the IPCC report (IPCC 1997) that deserts in Africa are particularly at risk; the arid western parts of South Africa are expected to lose species as arid regions become too arid for even arid-adapted species which might be close to physiological tolerance limits. This report (IPCC 1997) also identifies the grasslands of southern and eastern Africa as biomes vulnerable to climate change. Erasmus et al. (2002) show that the predicted eastward shifts will result in new species entering this biome, with novel species interactions as a result. The outcomes of

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these novel interactions are difficult to predict, but it is likely that some species will be out-competed (Lande 1998). Microcosm experiments with novel communities might provide insight into potential outcomes of species interactions.

The likelihood of successful range shifts will be decreased by habitat fragmentation, the presence or absence of suitable habitat in intermediate areas and the degree of land transformation encountered. Climate change and habitat fragmentation are likely to be opposing shifting forces, with climate change forcing a distribution a shift and habitat fragmentation preventing that shift through absence of suitable habitat (Warren et al. 2001). In South Africa, conflict is expected as areas of significant land transformation straddle potential range displacement routes (Erasmus et al. 2002). A distribution shift consists of one edge of the distribution experiencing a net mortality, and the other edge a net colonization. Honnay et al. (2002) have shown that habitat fragmentation inhibits net colonization at the edge of a shifting distribution, resulting in a severely reduced ability to shift. Apart form the caveats associated with the availability of suitable habitat for a successful shift, the required rate of shift is a further complicating factor. In his review, Huntley (1998) shows that the time frame within which climate change is expected to induce shifts, may be too short; and that few species have the ability to shift at the required rates. Once again, the net result is likely to be local extirpation of the population, rather than a shifted population.

The pattern of range contraction and range shift predicted for South Africa confirms assessments at broader scales. Vulnerable areas (e.g. arid areas and grasslands) identified at a continental scale (IPCC 1997) were confirmed, and quantified, by a more detailed fine scale analysis (Erasmus et al. 2002). At the outset of this study a main aim was to fulfill the need identified by the IPCC for more detailed level studies. This has been done, and in doing so, confirmed that the broader scale assessments of the IPCC (IPCC 1997, 2002) are generally applicable to South Africa.

Range shifts and the resulting novel species interactions also have indirect implications for conservation, agriculture and forestry through a change in risk profile to potential pathogens. This change in risk profile will happen through shifting distributions of pathogens (Van Staden et al in press) as well as through pathogens encountering novel hosts. The same principles governing the outcome of novel species assemblages will determine the survival of the pathogen in the presence of a new host. In South Africa susceptible eucalypt plantations

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are currently planted in areas to which a pathogen is expected to shift. This result is consistent with changes in disease risk due to climate change reported elsewhere (Daszak et al. 2000, Rogers & Randolph 2000, Harvell et al. 2002).

The other main focus of this thesis was a methodological one, and some valuable insights were gained. Climate envelope modelling is by definition a static equilibrium approach (Guisan & Zimmerman 2000) that relies on a snapshot of climate and distribution data to make predictions. This approach has three main shortcomings:

1. The nature of the climate data is such that there is limited scope to incorporate an explicit temporal component into a single variable. Long-term mean monthly values can be used to describe the "normal" onset of a particular season in a particular month. However, inter-annual variation in the onset of such a "normal" season is easily lost with long term mean data and processes dependent on particular climate cycles, i.e. seasonal reproductive events, of which the timing can be critical for population persistence, cannot easily be described. Climates of the future are expected to exhibit increased levels of inter-annual variability (Easterling et al. 2000, also see Schulze et al. 2001 for a South African perspective). Climate fluctuations have well-documented effects on ecosystems (Stenseth et al. 2002). These effects might be amplified in future climates that are more variable. Currently, effects of such changes in variability, i.e. more flash floods, can be estimated but the events themselves cannot be predicted. Even if climate science progresses to the point where such events can be predicted, an equilibrium model will still struggle to incorporate this dynamic-orientated data. A solution at this stage is to use derived variables such as precipitation seasonality (see Erasmus et al. 2000) that describe intra-annual variability.
2. The equilibrium nature of the model also pertains to population processes; dynamic interactions between populations as well as sub-populations of a metapopulation cannot be captured with this approach.
3. Analogous to the climate envelope model's inability to capture interactions between populations, it cannot capture interactions between species either. Such interactions have been shown to enforce range limitations (Hochberg & Ives 1999; Samways 2003).

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In spite of these seemingly gross oversimplifications, the climate envelope model implemented throughout this study performed well using a standard model evaluation technique. Further support for the climate envelope model came from its agreement with other more complex models that were specifically developed for distribution prediction. Not only is there agreement in the mean outputs of these models, but there is also agreement about the areas in which the models perform poorly. Robertson et al. (2003) have shown that an equilibrium type envelope model can perform at least as well, if not better, than a mechanistic model that is based on explicit and known ecophysiological constraints. Such a mechanistic model effectively uses the fundamental niche (Hutchinson 1957) to determine the bioclimatic envelope of a species; however, if the fundamental niche is not realized at present then it is unlikely to be realized in future. Bioclimatic envelopes based on observed distributions effectively capture the realized niche, and are likely to be more adept at predicting future distributions (Pearson & Dawson 2003), since some measure of the factors determining the realized niche is implicitly included. It seems as if all the models tested here have at least some useful ability to extract a climate-related distribution dependency from the climate data. Although this finding needs to be tested with a wider selection of models, it may be that predictor variable selection are more important than model selection to improve predictive model outputs.

Although we identified the inability of a climate envelope model to incorporate detail information on species- and population interactions as a weakness, there are in fact very few communities, or even populations, for which this sort of detailed information exists. Typically, detail data on species' habitat preferences at the individual scale lends itself to a different modelling approach (e.g. Gurnell et al. 2002), but these more detailed approaches, very seldom lend themselves to extrapolating to scales at which integrated conservation planning is conducted.

Therefore, although the broad scale climate envelope approach does have its limitations, at present it is one of the only techniques with which a quick and useful assessment of potential climate change vulnerabilities can be made. The technique can be applied in such a way as to limit the effects of its shortcomings. For example, although it is tempting to interpret predicted distributions as actual ranges, in fact, they only represent potential climatic areas of occupancy. The re-sampling technique developed by Smit et al. (in prep) provides an additional tool with which to interpret the reliability of the envelope model output.

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Identifying and partitioning sources of variation in the data (including spatial variation) *a priori*, and treating these data explicitly to ensure geographically homogenous model performance (Erasmus et al. in prep), will improve the quality of envelope model output.

In spite of all the caveats of the envelope modelling approach, I hold that the results from such modeling exercises are useful for showing potential effects of climate change and the magnitudes of these effects. Despite criticism (Davis et al. 1998, Samways 2003) of the envelope approach, it has been shown that some species have moved (Parmesan 1996, Parmesan & Yohe 2003, Root et al. 2003) and ecosystem changes have occurred in response to climate. The often-cited critique of climate envelope models being "invalidated" by species interactions (Davis et al.1998) was only performed at fine scale in a laboratory. This is not the scale at which bioclimatic envelopes have proven their usefulness as a tool for conservation practitioners. In a recent review, Pearson & Dawson (2003) concluded that the usefulness of bioclimatic envelope modelling is dependent on the scale at which it is applied. They argue that at broad scales climate is the most important factor that shapes distribution patterns and therefore this is a sensible scale at which to apply this technique. At increasing finer scales, other limiting factors such as land use, soil type, and biotic interactions become more important, and results from bioclimatic envelope modelling at these finer scales should be interpreted with informed caution (Pearson & Dawson 2003). The studies presented in this thesis was conducted at the interface of what Pearson & Dawson (2003) calls regional and landscape scales, where climate and topography are important factors, and these (or their covariates) are the variables which were used.

Therefore, the notion that all climate envelope approaches are irrelevant is not true. Species interactions may be important but so is climate, and if a model using the latter gives useful answers, then conservation practitioners cannot afford to discard any of these approaches at present. Conservation has become a time-critical discipline and we cannot afford to wait until ideal data and methods are developed before taking mitigating action (Van Jaarsveld et al 1998).

Consequently, by exploring a series of case studies about the application of climate change modeling on biodiversity features I identify a number of procedures that need to be incorporated into a national level study on the biodiversity consequences of climate change:

1. The study should have a long-term view to collect time series data.

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2. This longer-term study should include different taxa at different scales.
3. The study should incorporate an effort to improve information on animal diversity and distribution in South Africa. Current databases present a historic snapshot, and are becoming increasingly irrelevant as land-uses change.
4. There should be an effort to identify systems especially vulnerable to climate change, and conduct detailed investigations, but not exclusively so. Fynbos, succulent karoo, isolated pockets of afromontane forest, highveld grassland and extreme arid areas have been identified by the IPCC as vulnerable (IPCC 2002). This procedure should include the identification of potential climate change indicator species *a priori*.
5. Methodologies should be standardized to facilitate between-site comparisons, but also follow IPCC guidelines for climate change assessment (Benioff et al. 1996, IPCC 1994). Following these guidelines would ensure comparability with studies elsewhere and as such make a contribution to climate change impact studies at a global level. Modelling procedures should be well established in the scientific literature.
6. The study should be designed with a view to inform non-scientific decision makers and politicians. A shortcoming of the latest IPCC report (IPCC 2001a,b,c,d) is that it is based on studies that were not intended to inform policy makers as an end-result (Viner 2003).
7. The study should have a dual approach by modelling broad scale patterns and at the same time, conduct detail investigations into the causal links between climate and animal distributions. The latter takes place at the level of individual species, and it is envisaged that as the nature of climate dependence becomes known for a larger number of species and systems, this information will be used to feed back into the broader scale models, and thus improve their predictions.
8. As an outcome, the study should have a mechanism to feed recommendations into an integrated land-use planning exercise. Part of this integrated planning should be a representative conservation area network for South Africa that incorporates considerable redundancy in order to buffer effects of climate change.

Mitigation of the impacts of climate change is ultimately a function of political will to confront difficult issues such as climate change-integrated land-use planning. Climate change presents a significant threat to the South African national biodiversity estate, and our ability to manage it, and should be considered as of the utmost importance. Implementing the

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steps outlined above would go a long way towards improving our ability to meet this challenge successfully.

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