CHAPTER SIX

Summary and conclusion

Summary and conclusion

As the controversy on climate change rages, some fossil fuel companies and other interest groups mount active campaigns to raise doubts and create confusion about the spectre of climate change; including some scientists, the world and all its inhabitants stand defenceless against this imminent disaster, a disaster that is partly brought about by various kinds of human overexploitation of natural resources. Available observational evidence indicates that regional changes in climate, particularly increases in temperature, have already affected a diverse set of physical and biological systems in many parts of the world. Examples of observed changes include the shrinkage of glaciers, thawing of permafrost, later freezing and earlier break-up of ice on rivers and lakes, lengthening of mid- to high-latitude growing seasons, poleward and altitudinal shifts of plant and animal ranges, declines in some plant and animal populations, and earlier flowering of trees, emergence of insects, and egg-laying in birds (IPCC 2001). This means that climate change is not something likely to affect us "The *Day After Tomorrow*"! It is a present reality that global temperatures have increased by approximately 0. 6^0 C over the 20^{th} century and that additional warming of 0. 6 ^{o} C to 3.5 ^{0} C is expected over the present century (IPCC 2001).

In Africa, evidence of climate change includes a general decrease in diurnal temperature ranges, while deviations in precipitation are increasing. Increases in temperatures precipitating the melting of glaciers on Africa's major mountains are also evident. Observations have also shown that the frequency and intensity of El Niño and la Nina events has increased. Major coral bleaching events have occurred in recent times. More importantly, there are recorded direct and indirect impacts of climate change on diseases that are endemic to Africa. Following the 1997-1998 El Niño event for instance, malaria, Rift Valley fever, and cholera outbreaks were recorded in many countries in East Africa (UNEP Vital Climate Graphics Africa 2002). Furthermore, the meningitis belt in the drier parts of West and Central Africa is expanding into the eastern regions of the continent.

These climate change impacts, superimposed upon existing weak infrastructure, land-use change, and drug resistance against pathogens such as *Plasmodium falciparum, Vibrio cholerae*, *Theileria parva*, and others could impact heavily on the social, cultural and economic fabric of Africa if timely steps are not taken to reduce their consequences. Climate change is real, and it has great significance for sustainable development plans, life and livelihoods in Africa, even more so than on other continents. The diversity in climatic regimes across this vast continent from arid and seasonally arid tropical regimes to humid equatorial regimes, with differing degrees of temporal variability make discussions of climate change for Africa challenging (Desanker 2001). However, the uncertainties about climate change, the magnitude of the change to physical and biological systems should not shift attention from focusing on ways to reduce, combat and understand how ecosystems will react.

Natural systems are more vulnerable to climate change than societal systems because species and ecosystems have a more limited ability to adapt. Besides, ecosystems do not shift as a whole; instead individual species will migrate at different rates (IPCC 2001). New ecosystems will be formed and composed of different assemblage of species. Under climate change some species are unable to move in pace with shifting climatic zones because their paths of migration have been blocked by barriers resulting in extinctions (Thomas *et al.* 2004). "*Climate change is asking species to move when there is no place to move to*," Hannah 2004. This risk to natural habitats from climate change is far more serious because development has already put ecosystems under stress through habitat destruction, fragmentation and pollution. Preliminary studies in South Africa have shown that 25% of the species investigated are expected to require more than a 90% shift in their range (Erasmus *et al.* 2002). This general pattern of species showing limited overlap between their existing distributions and predicted future distributions is most marked for reptiles and invertebrates (van Jaarsveld *et al.* 2000). The implications of climate change on disease- vectors systems is an additional concern. Studies in Europe have so far shown that ticks and tick-borne disease systems will shift or be disrupted during climate change (Randolph & Rogers 2000 & Randolph 2001). This will lead to the introduction of disease and disease vectors in new areas and may prove catastrophic if prior warnings are not issued. Africa with its warm climate and diverse habitats renders it a haven for various species of vectors and an understanding of how their distributions will change under conditions of climate change is one of the most important and basic requirements for developing responses to future challenges.

Research looking at the impacts of climate change on vectors in Africa have mainly concentrated on vectors that affect human beings and there have hardly been any studies that have looked at the effect of climate change on vectors of livestock and wild animals. And yet these diseases place a considerable burden on the livelihoods of many African farmers. Also, altering landscapes can change the transmission dynamics and location of many serious diseases, not to mention the fact that parasitic life cycles existing in humans may include livestock and wild animals in cases of displacement and encroachment of areas not currently used by man. Therefore the goal of this study was not only to investigate the impacts of climate change on ticks and tick-borne diseases in sub-Saharan Africa but also to highlight the need for an ecosystem approach to the management of vectors and vector–borne diseases. The control of vector-borne zoonoses should not be considered in isolation from the control of vector-borne diseases in other animals. The relationships and interdepencies between all these systems must govern any vector borne diseases control approach. Here the tick-host- disease system in Africa is used as a model for exploring vector-borne diseases in Africa. This sub-Saharan tick study is concluded by focusing on the following issues: 1) the advantages of the climate data used here over other climate data used in previous studies 2) implications of the predicted range alterations 3) the advantages and shortcomings of the predictive modelling approach and 4) and finally some recommendations for future research and action.

As the urgency to assess the effects of climate change and other habitat changes on the distributions of species mounts, with the subsequent rise in new statistical approaches and the use of geographic information systems (GIS), more and more scientists are employing different models to predict the distributions of species. Consequently, the availability of suitable climate data becomes increasingly important. In general an evaluation of climate data sets is encouraged before use so that the best data are picked for a particular study. In this thesis, the predictions of the current distributions of ticks using climate data derived from DARLAM, a nested regional model, proved superior to the predictions derived from two other climate data sets (Olwoch *et al.* 2003 – Chapter two). The reasons for this are that DARLAM is able to capture climate at a sufficiently fine scales relative to the range sizes of species, is entirely based on a simulations of climate processes and does not use any observed meteorological data to generate climate surfaces (Engelbrecht *et al.* 2002). This is particularly useful in Africa where meteorological observation stations are inadequate.

The alternative climate datasets, e.g. CRES and CRU, although they have been resampled to increase the data resolutions, are still relatively smooth because they depend on the original low-resolution point observations. Differences observed in the predicted future distributions of ticks using future GCM and DARLAM further confirm the need to assess climate data before commencement of a study. Broader range sizes predicted by DARLAM are again a reflection of the existence of differences in climate model results and in this case the predicted GCM climate was much drier than that generated by DARLAM. Since DARLAM is a process driven model, it is able to capture today's conditions, it is sensitive to more local variations particularly in topography and more local interactions at a higher spatial resolution. GCMs on the other hand operate at a very low spatial resolution and have been criticized for their inability to capture the present day features of the global climate (Goodess & Palutikof 1993). Ticks are known to be habitat specialists, spend more that 90% of their lives on the ground and are more affected by local variations. In this regard, the use of climate simulations provided by a regional model such as DARLAM are more appropriate that broad scale GCM data in studies of this nature.

Range alterations, in the form of expansions, contractions and possible shifts in response to climate change are evident from this thesis. These results give support to the IPCC predictions that climate change may alter the distribution of vector species — increasing or decreasing the ranges, depending on whether conditions are favourable or unfavourable for the breeding places of vectors (e.g., vegetation, host, or water availability). Range expansions of ticks across sub-Saharan Africa, with its fragile economy and non-existent support systems in the livestock and health sectors may prove catastrophic if prior warnings are not provided and acted upon. Whether or not these tick ranges are correlated with increases in tick-borne diseases depends intimately on the availability of hosts that are involved in the transmission of vectors. Nevertheless, in an environment where the expansion of tick ranges is accompanied by predicted range contractions of the hosts, considerable uncertainty prevails. The tick mortality rates as a result of host finding behaviour might increase and may result in reduction in the number of ticks completing a life cycle. Though studies to date have emphasised that climate and not host influences the range of African ticks, in conditions of climate change as predicted in this thesis, the host are more probable to become limiting.

The main concern attributed to species range contraction is usually because of the negative relationship between range size and extinction probability (Gaston 1994). A reduction in the absolute range of a species will almost inevitably mean an increase in its risk of extinction. Extinction of parasite may in all cases be a welcome sign. However, since different tick species occupy different habitats and are influenced by different degrees of climate factors, contraction of one major tick species may give way to introduction of a lesser-known species. This displacement of populations in time has already reported in *Glossina* species in Cote d'Ivoire Gouteux & Jarry (1998) and also in *Boophilus* species in South Eastern Africa countries (Sutherst 2001).

The range shifts following climate change reported in this thesis are consistent with range shifts reported in other species in other parts of the world, in Europe (Randolph & Rogers 2000), in diseases (Harvell *et al.* 2002), in South African species (Erasmus *et al.* 2002), in plant and animals (Root *et al.* 2003 and globally (Parmesan & Yohe 2003). Range shifts reported here are likely to increase the vulnerability from tick-borne diseases in livestock populations in these new areas. In vector ecology, range shifts have an additional problem in that shifting in vectors is likely to introduce pathogen in a new area and these introduced pathogens are likely to be more virulent in the host populations. Increase in species richness in the drier western parts of the continent is consistent with the earlier assessment of how South African ticks will respond to climate change (Hulme1996) and this is obviously in response to the enhanced rainfall predicted for these areas.

Increased vulnerability of sub-Sahara Africa to tick-borne diseases revealed by this thesis through the predicted increase in ECF and increase in ranges of economically important ticks are again consistent with the IPCC predictions that climate change may favour the increase of vector-borne diseases. These predictions based solely on the current and future climatic suitability of *R. appendiculatus* and cattle should not be underestimated because the relative importance of other factors has not been thoroughly investigated. These factors including other competent hosts of *R. appendiculatus*, other reservoir hosts of the pathogen, tick-control policy, will increase or reduce ECF infection from the existing state of affairs determined by the two main factors; cattle and *R. appendiculatus* distribution. These results are an important measure of the expected vulnerability on which other broader studies could be done taking into account more factors. Since the occurrence of ticks is a potentially important variable in predicting the incidence of the pathogens that they transmit (Cumming 1999), these results are based on the available information and understanding and gives the most logical presentation of this complex system under climate change. Furthermore, cattle are neither the only hosts that support R. *appendiculatus* nor the only hosts that can carry the pathogen, *T. parva*, but despite the economic importance of ticks only a few countries have been thoroughly studied and the sampling regime under which tick collections have been made has been highly biased towards cattle ticks (Cumming 1999). Therefore, cattle provided the most reliable and consistent data than any other host.

The degree of range expansion, contraction and shifts and overall decrease in host diversity reported here might not be the same magnitude as the realized alterations because even without climate change, ticks and their hosts are already under stress from habitat-fragmentation, destruction and land use transformation. The combined effects of these factors and climate change on tick and tick-borne diseases distribution in sub-Saharan Africa may be different from the one presented in this thesis. Climate change and habitat fragmentation for instance are likely to be opposing shifting factors, with climate change forcing a distribution shift and habitat fragmentation preventing that shift through absence of suitable land (Warren *et al.* 2001). In this instance the net result is likely to be local extirpation of the population, rather than a shifted population (Erasmus 2003). In a tick-host diseases system this would disrupt the established relationships and likely result in a greater degree of change in species diversity than predicted in this thesis. This has a direct link with disease transmission rates. What I present in this thesis is therefore a foundation on which more elaborate studies could be done and wider conclusions made.

The predictive species model used in this thesis has been criticised as being unable to incorporate detail information regarding the factors that influence distribution of these species. In the first instance, such elaborate information regarding species does not exist. Furthermore even in field ecological study, it is impossible for a researcher to imply that all the factors affecting a species have been included because some factors are created by the mere presence of others. It has also been criticised as being simple and static. In most cases a mechanistic model would be the preferred choice. However, Robertson *et al.* (2003) have shown that an equilibrium type 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 to determine the bioclimatic envelop of the species; however, if the fundamental niche is not realised at the present, then it is unlikely to be realised in the future. Bioclimatic envelops based on observed distributions effectively capture the realised niches, and are likely to be more adept at predicting future distributions since some measure of factors determining the realised niche is implicitly included (Pearson & Dawson 2003).

Furthermore this model with its multivariate capabilities as opposed to provision of mere absent-present predictions gives a better estimate especially when dealing with poorly sampled species. Since this can operate effectively using only presence records and any number of climate variables available, it is one of the most practical models since most of the species in sub-Saharan Africa are poorly sampled. This approach neither disregards the need for a more detailed and comprehensive eco-physiological approach nor does it pretend to predict the future but it defines the role of climate as a factor in determining the potential for establishment when all other factors are not included (Sutherst 2003). Nevertheless, in spite of modelling efforts focused on single species or entire ecosystems, a few preliminary surveys of impact of climate change on different ecosystems and evidence of climate change-mediated shifts in several species, the likely effects of climate change on species' distributions remain little known, and fauna-wide or community-level effects are almost completely unexplored (Townsend *et al.* 2002). It is also one of the realisations of this thesis that more detailed and specific field studies are needed to allow the development of more comprehensive predictive models. Unfortunately, such detailed information is rarely available and managers have to make decisions based largely published information and local experience (Booth *et al.* 2002).

The rate at which African societies will be vulnerable, and whether or not they will effectively adapt to this change depends on numerous factors. Large-scale environmental changes such as, population movement, forest clearance and land-use patterns, human population density, and the population density of insectivorous predators all affect the vulnerability of a society to vector-borne infectious diseases. However an understanding of the vulnerability, which has been achieved by this thesis, is the first step towards adaptation. Adaptation measures can however benefit from easy access to information, including early warnings of extreme climate events and also constant dispensations of information on the relationship between local disease vector distribution and climate by the local control programs. Furthermore, improving the current level of public health infrastructure is the initial and most effective way of adapting to climate change induced effects. In very many countries in Africa, this infrastructure has declined in recent years. Many diseases and public health problems that otherwise may be exacerbated by climate change could be prevented substantially or completely with adequate financial and public health resources. These resources would encompass public health training programs, research to develop and implement more effective surveillance and emergency response systems, and sustainable prevention and control programs. As provided by this thesis, different countries will have different rates of vulnerability and adaptation will depend on several societal systems, including access to financial resources (for individuals and populations), technical knowledge, public health infrastructure, and the capacity of the health care system. Thus, individual, country community and geographical factors will also determine vulnerability.

The realised ecological consequences of climate change to ticks, hosts and tick-borne disease will however depend on many interacting variables and the results presented here may be different if all those other factors are included in the model. Despite this and other shortcomings of the model, this thesis has succeeded in identifying which tick species and vertebrate hosts are likely to show greater responses. Furthermore, this study has succeeded in identifying the importance of using a suitable climate data in predictive species modeling, has also provided an understanding of the magnitude of how regions and countries in sub-Saharan Africa are vulnerable to climate changes by using tick-host and tick-borne diseases system. Since an understanding of how a society is vulnerable to climate change is the first step towards identifying adaptation capacity, this thesis has been useful in that regard. This thesis, realizing the intricate relationships between different components in the ecosystem, has called for an ecological approach to vector-borne diseases management in sub-Saharan Africa. What this thesis has not made clear is the actual magnitude of the vulnerability and how the African people will adapt to this climate change impacts. The actual magnitude of future responses is not known but current vulnerability must be assessed through field studies. Further research is needed to identify actual vulnerabilities through field studies, adaptation needs, evaluate adaptation measures, assess their environmental and health implications, and set priorities for adaptation strategies ensuring active surveillance for important ticks and the diseases they transmit; and continuing research to further our understanding of associations between weather, extreme events, and tick-borne diseases. In addition, continuing research into ecological approaches to tick-borne and other vector-borne diseases control methods is one of the most important ways to understand this system and put into place measures based on practical scientific evidence. Understanding the impacts of climate change on ticks, hosts and tick-borne diseases in Africa is an important and necessary step towards future management of ticks and tick-borne diseases and reduction of their impacts to the health and veterinary industries, economy and welfare of African people.

REFERENCES

BOOTH, T. H., JOVANOVIC, T., OLD, K. M. & DUDZINSKI, M. J. (2000) Climatic mapping to identify high-risk areas for *Cylindrocladium quinqueseptatum* leaf blight on eucalypts in mainland South East Asia and around the world. *Environmental Pollution* 108, 365-372.

CUMMING, G.S. (1999) *The evolutionary ecology of African ticks*. Doctoral thesis, University of Oxford, Oxford, UK.

DESANKER, P.V. (2002) Desanker, P.V. (Guest Editor). Africa and Global Climate Change. *Climate Research* 17, 93-246.

ENGELBRECHT, F. A., RAUTENBACH, C. J. DE W., MCGREGOR, J. L. & KATZFEY, J. J. (2002) January and July climate simulations over the SADC region using the limited-area model DARLAM. *Water SA* 28, 361-373.

ERASMUS, B. F. N., VAN JAARSVELD, A. S., CHOWN S. L., KSHATRIYA, M. & WESSELS, K. J. (2002) Vulnerability of South African animal taxa to climate change. *Global Change Biology* 8, 679-693.

ERASMUS, B. F. N. (2002) Biodiversity and Climate Change: A South African Perspective. PhD Thesis, University of Pretoria, Pretoria, South Africa.

GASTON (1994) *Rarity*. Chapman & Hall, London.

GOODESS, C. M. & PALUTIKOF, J. P. (1992) The development of Regional Climate Scenarios and the Ecological Impact of Greenhouse Gas Warming. In *Global Climate Change: The Ecological consequences* edited by Woodward, F. I. London: Academic Press, pp 33.

REFERENCES

BOOTH, T. H., JOVANOVIC, T., OLD, K. M. & DUDZINSKI, M. J. (2002) Climatic mapping to identify high-risk areas for *Cylindrocladium quinqueseptatum* leaf blight on eucalypts in mainland South East Asia and around the world. *Environmental Pollution* 108, 365-372.

CUMMING, G.S. (1999) *The evolutionary ecology of African ticks*. Doctoral thesis, University of Oxford, Oxford, UK.

DESANKER, P.V. (2001) Desanker, P.V (Guest Editor). Africa and Global Climate Change *Special Issue, Climate Research* 17, 93-246.

ENGELBRECHT, F. A., RAUTENBACH, C. J. DE W., MCGREGOR, J. L. & KATZFEY, J. J. (2002) January and July climate simulations over the SADC region using the limited-area model DARLAM. *Water SA* 28, 361-373.

ERASMUS, B. F. N., VAN JAARSVELD, A. S., CHOWN S. L., KSHATRIYA, M & WESSELS, K. J. (2002) Vulnerability of South African animal taxa to climate change. *Global Change Biology 8*, 679-693.

ERASMUS, B. F. N (2003) Biodiversity and Climate Change: A South African Perspective, PhD Thesis, University of Pretoria, Pretoria, South Africa.

GASTON, (1994) *Rarity*. Chapman & Hall, London.

GOODESS, C. M. & PALUTIKOF, J. P. (1993) The development of Regional Climate Scenarios and the Ecological Impact of Greenhouse Gas Warming; In *Global Climate Change: The Ecological consequences* edited by Woodward, F. I. London, Academic Press, pp 337.

GOUTEUX, J. & JARRY, M. (1998) Tsetse flies, biodiversity and the control of sleeping sickness. Structure of a *Glossina* guild in southwest Cote d' Ivoire, Acta Oncol. 19, 453-471.

HANNAH, L. (2004) USA TODAY. Cost of Global warming: I million species. January 08 2004.

HARVELL, C. D., MITCHELL, C. E., WARD, J. R., ALTIZER, S. DOBSON, A. P., OSTFELD, R. S. & SAMUEL M. D. (2002) Climate warming and disease risk for terrestrial and marine biota. *Science* 296, 2158-2162.

HUTCHINSON, G. E. (1957) concluding remarks. Cold Spring Harbour Symposium on Quantitative Biology 22, 415-457.

HULME, M. (Ed.), (1996) Climate Change in Southern Africa: An Exploration of Some Potential Impacts and Implications in the SADC Region. Climatic Research Unit, University of East Anglia, Norwich, United Kingdom, 96 pp.

IPCC (2001c) Climate Change (2001) Impacts, Adaptation & Vulnerability (Eds) McCarthy, J. J., Canziani, O. F., Leary, N. A. & White, K. S. Cambridge University Press, UK, pp 1000.

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.

PARMESAN, C & YOHE, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421, 37-42.

PEARSON, R. Q. & 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.

RANDOLPH, S. E. & ROGERS (2000) Fragile transmission cycles of tick-borne encephalitis virus may be disrupted by predicted climate change. *Proceedings of the Royal Society of London B* 267, 1741-1744.

RANDOLPH, S. E. (2001) The shifting landscape of tick-borne zoonoses: tick-borne encephalitis and Lyme borreliosis in Europe. *Philosophical Transactions of the Royal Society, London* B 356, 1045-1056.

ROBERTSON, M. P., PETER, C. I., VILLET, M., & RIPLEY, B. C. (2003) Comparing models for predicting species potential distributions: a case study using correlative and mechanistic predictive modelling techniques. *Ecological Modelling* 164, 153-167.

ROOT, T., PRICE, J. T., HALL, K. R., SCHNEIDER, S. H., ROSENZWEIG, C. & POUNDS, J. A. (2003) Finger prints of global warming on wild animals and plants. *Nature* 421, 57-60.

SUTHERST, R. W. (2001) The vulnerability of animal and human health to parasites under global change. *International Journal for Parasitology* 31, 933-948.

SUTHERST, R. W. (2003) Prediction of species geographical ranges. *Journal of Biogeography* 30, 805-816.

THOMAS, C. D., CAMERON, A., GREEN, R.E., BAKKENES, M., BEAUMONT, L.J., COLLINGHAM, Y.C., ERASMUS, B.F.N., FERRIERRA DE SIQUEIRA, M., GRAINGER, A., HANNAH, L., HUGHES, L. HUNTLEY, B., VAN JAARSVELD, A.S., MIDGLEY, G.F., MILES, L., ORTEGA-HUERTA, M.A.,

PETERSON, A.T., PHILIPS, O. & WILLIAMS, S.E. (2004) Extinction risk from climate change. *Nature* 427, 145-148.

TOWNSEND PETERSON, MIGUEL A. ORTEGA-HUERTA, JEREMY BARTLEY, VICTOR SÁNCHEZ-CORDERO, JORGE SOBERÓN, ROBERT H. BUDDEMEIER, DAVID R. B. STOCKWELL (2002) Future projections of Mexican Faunas under climate change scenarios. *Nature* 416, 626 – 629.

UNEP Vital Climate Graphics Africa (2002) http://www.grida.no/climate/vitalafrica/english/index.htm

VAN JAARSVELD, A. S., CHOWN, S. L., ERASMUS, B. V. N., KSHATRIYA, M., & WESSELS, K. J. (2000) Vulnerability and adaptation assessment of South Africa animal Taxa to climate change. *Report to Department of Environmental Affairs & Tourism, Pretoria*. Pp. 64.

WARREN, M. S., HILL, J. K., THOMAS, J. A., ASHER, J., FOX, R., HUNTLEY, B., ROY, D. B., TELFER, M. G., JEFFCOATE, S., HARDING, P., JEFFCOATE, G., WILLIS, S. G., GREATOREX-DAVIES, J.N., MOSS, D. THOMAS, C. D. (2001) Rapid response of British butterflies to opposing forces of climate and habitat change. *Nature* 414, 65-69