Title: The spatial variation of environmental factors on the Illawarra escarpment and their influence on vegetation patterns

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Year: 2009

Repository DOI:

2009

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The spatial variation of environmental factors on the Illawarra Escarpment and their influence on vegetation patterns

A thesis submitted in fulfilment of the requirements for the award of the degree of

Doctorate of Philosophy

From the School of Earth and Environmental Sciences, University of Wollongong

By   Michael B. Ashcroft, BMath/BE (Elec), MEnvSci, October 2009

'Please see print copy for image'

The escarpment between Mt Keira and the City of Wollongong.
Photo: Imke Büsing © 2005

The relatively undisturbed vegetation on the Woronora Plateau.
Photo: Bernard Ashcroft © 2005

Thesis certification

I, Michael Bernard Ashcroft, declare that this thesis, submitted in fulfilment for the requirements for the award of Doctor of Philosophy in the School of Earth and Environmental Sciences, University of Wollongong, is wholly my own work unless otherwise acknowledged. The document has not been submitted for qualifications at any other academic institution.

The chapters in this thesis that have been published with co-authors are approximately 80% my own work. I developed the initial ideas, aims and methods for each chapter, conducted the analyses, and prepared the first drafts of the articles. These drafts were then subject to change following reviews from my supervisors, journal reviewers and editors, and other people that are included in the acknowledgements. In general, these changes improved the presentation and interpretation of results, but did not change the original aims or methods. For consistency, 'I' is used throughout this thesis, although 'we' is used in the corresponding journal articles that have been prepared with co-authors.

Mick Ashcroft Laurie Chisholm Kristine French October 2009

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Abstract

Mapping and explaining the distribution of vegetation helps land managers to make systematic conservation planning decisions. This is typically achieved using models that correlate the distribution of species with environmental factors, and can predict the vegetation at unsurveyed locations. These Species Distribution Models (SDMs) have numerous unresolved issues, but serve as a useful first-pass approximation for planning purposes.

This thesis investigates some of the uncertainties of SDMs, including the impact of data accuracy, the incorporation of spatial processes, the evaluation of alternative models, and the benefits and challenges of producing models at the landscape scale. The research was conducted on the Illawarra Escarpment, 80 km south of Sydney, Australia (34.4 ^{o}S, 150.9 ^{o}E). The escarpment contains a north-south trend in eucalypts (*Eucalyptus spp*.) that cannot be explained in terms of elevation or geology. It also exhibits a patchy distribution of rainforest communities, some unique to the Illawarra. It is not known which environmental factors determine the distribution of either the eucalypts or rainforest species, or how they may respond to a changing climate.

Species distributions are sensitive to the accuracy of data used, and yet many models only use elevation as a surrogate for temperature, or use simple elevation sensitive interpolations from weather stations. I collected hourly temperature data from 40 sites on the Illawarra Escarpment, and investigated whether elevation was an adequate surrogate for temperatures in this landscape. I then investigated whether temperature surfaces could be improved by considering other topographic and geographic factors, including exposure to wind, distance to coast, radiation, and the average conditions in the surrounding neighbourhood. Elevation was well correlated with moderate seasonal temperatures (e.g. summer minima and winter maxima), but was poorly correlated with the extreme temperatures (summer maxima, winter minima) that are physiologically limiting for many species. Using neighbourhood influences, exposure to wind and distance to coast improved the accuracy of temperature surfaces, and increased the explanatory performance of vegetation models. I concluded that elevation was not always an adequate surrogate for temperature. Temperatures are also affected by other topographic and geographic factors, and these should be considered when developing models for systematic conservation planning activities.

Species distribution models are typically based solely on niche factors. Where spatial processes are included, it is typically by employing autologistic regression, or other techniques that use survey data as a predictor. This precludes the models being used to make predictions in times or places where survey data is unavailable, and reduces ecological explanation because it is an interpolation technique. I used neighbourhood (contextual) indices based on environmental factors as an alternative method to overcome these problems. I demonstrate that contextual indices improve SDMs over purely niche-based models, and are capable of predicting unknown populations in unsurveyed areas. I conclude that contextual indices have numerous advantages over autologistic regression, and can capture a continuum between niche and dispersal limited species.

Models that predict how species will respond to climate change either use coarse-scale climate surfaces, or idealised predictions of uniform warming. These methods may dramatically over-estimate extinction risk because they neglect fine-scale variations in warming, and refugia where species can persist despite unfavourable regional conditions. I created fine-scale estimates of warming by combining 35 years of Bureau of Meteorology observations with one year of intensive fine-scale temperature monitoring. I found that warming was greatest at inland locations, at lower elevations, away from streams, and at sites exposed to hot, dry northwesterly winds. As species are biased in the geographic and topographic positions they occupied, some species have experienced more warming than others and are at greater threat from climate change. I concluded that it was important to continue developing methods to downscale coarse-grained climate surfaces, and suggest that the accuracy of this process could be improved by using a range of topographic factors.

There are many methods for selecting predictors in SDMs, and the competing models often make highly variable predictions. I addressed this uncertainty by comparing the performance of models with and without a given environmental factor. I found that there was relatively strong support for the geology and winter minimum temperature predictors, as well as predictors based on contextual indices, as there was a significant drop in model performance when these predictors were excluded. In contrast, there was less support for summer maximum temperature, as other temperature predictors could combine to produce similar model performance. Model performance varied more between models for different species than between different predictor combinations for the same species. I concluded that it was inappropriate to assess models based on subjective benchmarks, such as an AUC of more than 0.7. A comparison between competing models for the same species gives a better indication of the validity of the model building procedure.

The results of this research provide important insights into the benefits and challenges of creating SDMs at the landscape scale (extent of 10–200 km). It is a major challenge to obtain spatially and thematically accurate environmental predictors and biotic data at this scale, and studies should include the collection of data to ensure models are adequate. Landscapes will not have as much environmental variation as coarse-scale models, and this will limit the ability to transfer the models to new study areas. However, there are a number of benefits that justify these studies. Producing accurate temperature surfaces at the landscape scale will result in less pseudoreplication and less predictor colinearity. This will improve the robustness of models. Landscape scale studies also allow modellers to capture fine-scale refugia, and this will improve the accuracy of climate change predictions. Finally, many ecological processes operate at a scale that is too fine to be detected with coarse-scale models. Landscape scale models may be the only alternative to detect these processes. There is no optimal scale for SDMs, however, and a future challenge is to better integrate coarse and fine-scale models to make more ecologically robust predictions.

Acknowledgments

The journey towards this thesis began in late 2001, when I decided to move away from my established career in software design. Firstly, I would like to thank the University of Wollongong for supporting this career change, especially John Morrison for encouraging me to do a Masters of Environmental Science in 2002/3, and later to my PhD supervisors, Laurie Chisholm and Kris French, who always had confidence in my ability to complete this thesis. Even when times were tough, they were always positive and never doubted that I was on the right track. I am especially grateful for all the time and effort Laurie and Kris spent reviewing my journal articles, especially when I was employing statistical techniques that were outside their core area of expertise. I also thank my supervisors for introducing me to the iButton temperature loggers that were so crucial for my research.

The fieldwork component could not have been completed without Kris French, Bernard Ashcroft, Belinda Pellow, Anders Bofeldt and the Janet Cosh Herbarium, who helped me learn how to recognise the species I was targeting. I also thank Bernard Ashcroft, Imke Büsing, Berit Fehlau, Jodie Dunn, Carolyn Blomley, Anders Bofeldt, Kris French, Laurie Chisholm, Roger Ferguson, Elfi Ashcroft, Roger Starkie, Andrea Kubler and Rike Arnold for assistance with the fieldwork, and putting up with the leaches, ticks, snakes, dense vegetation and rugged topography. The research was critically dependant on access to the sites that I wanted to survey, and I am grateful to the Sydney Catchment Authority, National Parks and Wildlife Service, Sydney Water, BHP Billiton, Wollongong City Council, and the numerous private landowners who granted me permission to access their land.

Thanks to everyone who has reviewed and provided comments on the journal articles resulting from this research, including my supervisors, Jane Elith, Brian Lees, John Gollan, John Leathwick, Miguel Araújo, Philip Dixon, Bernard Ashcroft and many anonymous referees. John Gollan also provided useful discussion and references, which helped me to write the discussion chapter.

My research was supported by a University Postgraduate Award scholarship between 2004 and 2006. The Spatial Analysis Laboratory at the University of Wollongong was crucial for all the analysis, as was the data that was supplied to them by AAMHatch, the NSW Department of Environment and Climate Change and the NSW Department of Primary Industries. Estimates of radiation were developed using the freeware Solar Analyst extension for ArcView that is made available by the USDA Forest Service, and Maxent is available from the Princeton University webpage. From 2007 to 2009, I was working full-time at the Australian Museum, and I am grateful to them for allocating some of my time towards the completion of my PhD. Both the University of Wollongong and Australian Museum assisted me to present my results at conferences.

Last, but not least, I thank my wife and family for putting up with my heavy workload and stress— especially over the final few years whilst I was working full-time, commuting to Sydney, and still trying to find time for them and my PhD. I gained two beautiful daughters, Lauren and Kira, during the course of this research, and they have provided me with wonderful memories and inspiration to complete the thesis.