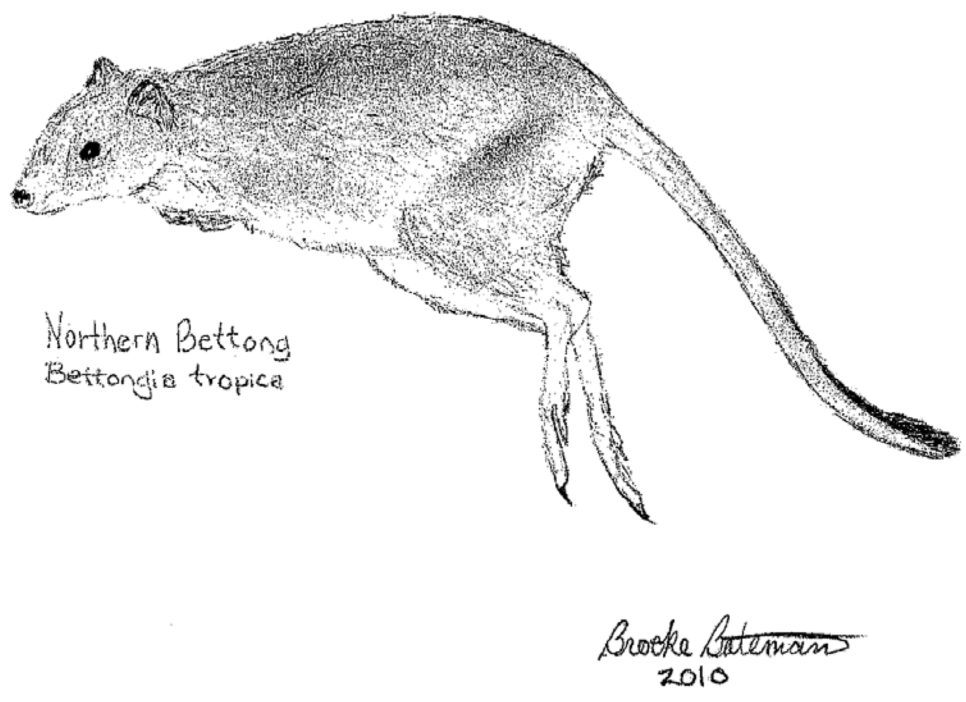
Bateman, Brooke Lee (2010) ***Beyond simple means: integrating extreme events and biotic interactions in species distribution models: conservation implications for the northern bettong (Bettongia tropica) under climate change.*** **PhD thesis, James Cook University.**

Beyond simple means: Integrating extreme events and biotic interactions in species distribution models

Conservation implications for the northern bettong (*Bettongia tropica*) under climate change

PhD thesis submitted by
Brooke Lee **BATEMAN**
(BSc, GDipResMethods)
July 2010

For the degree of Doctor of Philosophy
In Zoology and Tropical Ecology
School of Marine and Tropical Biology
James Cook University
Townsville, Queensland 4811
Australia


Northern Bettong
Bettongia tropica
Brooke Bateman
2010

Statement of contribution of others

Research funding:

- Australian Government's Marine and Tropical Scientific Research Facility
- Australian Wildlife Conservancy (AWC)
- James Cook University, Australia (JCU)
- National Climate Change Adaptation Research Facility (NCCARF)
- SkyRail Rainforest Foundation

Research in-kind support:

- Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Australian Wildlife Conservancy (AWC)
- Earthwatch Institute
- Queensland Parks and Wildlife Service (QPWS)

Stipend:

- James Cook University Postgraduate Research Award
- James Cook University Graduate Research Scheme PhD write up grant

Supervision:

- Professor Christopher N Johnson, JCU
- Dr Jeremy VanDerWal, Centre for Tropical Biodiversity and Climate Change (CTBCC), JCU
- Professor Stephen E Williams, CTBCC, JCU

Statistical, analytical, and modelling support:

- Professor Christopher N Johnson (Chapter 2-5)
- Dr Jeremy VanDerWal (Chapter 4-5)
- Dr. Euan G Ritchie, JCU (Chapter 2,3)
- Dr Alex S Kutt, CSIRO Sustainable Ecosystems (Chapter 2,3, Appendix E)

Data collection

- Benjamin R Plumb (data collection, data entry)
- Jonathon Winnel (research assistant, data collection)
- Nicole Kenyon (research assistant, data collection)
- QPWS personnel
- AWC personnel

Editorial assistance:

- Professor Christopher N Johnson (whole thesis, proposals)
- Dr Jeremy VanDerWal (whole thesis)
- Professor Stephen E Williams
- Benjamin R Plumb (whole thesis)
- Dr. Paul Williams, JCU (Chapter 3)
- Dr. Yvette Williams, JCU,CTBCC (proposals)
- Dr. Mariana Fuentes ARC Centre of Excellence for Coral Reef Studies, JCU (thesis structure, format)

Acknowledgments

Looking at my PhD from the end of the tunnel where the light is, I think of Douglas Adams and his statement "I may not have gone where I intended to go, but I think I have ended up where I needed to be." I spent the first two and some years of my PhD looking for northern bettongs. That's it, just looking; sort of like casting rather than fishing. At one point I was deemed the president of the cryptozoologist club at JCU, and I often found myself having to explain to people what a bettong was since most people have never heard of them. Although I did eventually find northern bettongs elsewhere, I learned the important lesson that no data can be data in itself. So, although my PhD is far from what it started out to be, it has allowed me to learn a lot along the way and I am honoured to have been able to undertake this project. I am grateful to my mind, body and spirit for enduring the ups and downs over the last few years, and for remembering that 'this too, shall pass', so that I could appreciate my PhD in all its craziness, because I only get to do it once! I was also lucky to have the support of many others throughout my PhD.

I am indebted to **Peter Latch** for getting this project started, for putting me in contact with all the right people to get the working parts together, providing guidance and support and for introducing me to the world of bettongs. Fate had its hand in our introduction and I am privileged to have had the opportunity to work on this project.

I am grateful to have had three wonderful supervisors; **Chris Johnson**, **Jeremy VanDerWal** and **Steve Williams**.

I thank **Chris** for agreeing to take me on as a student when I first came to Australia five years ago. Through his astounding knowledge of ecology and conservation his guidance and brilliant suggestions have vastly improved my work and have helped me develop my own confidence as an ecologist. Not only did he provide scientific guidance and support, he also was unconditionally supporting of personal matters of family and health. His kind and humble nature to match his ingenuity and intelligence have earned the respect of many, including myself.

I am also thankful to **Jeremy**, for not only putting up with my "demands", but for being my species distribution modelling guru. I am grateful that he took the time and patience to teach me the workings of R, Maxent and various other useful applications. His favourite statement "who cares?" got me to think outside of the box and turn my PhD on bettongs into something more. I thank him for all the good laughs, coffee breaks, inspiring discussions, dedicated assistance and constant encouragement. My work has benefited immensely from his input, as has my personal growth as an ecologist.

I am also grateful to **Steve** for providing invaluable guidance and knowledge on the Australian Wet Tropics and its vertebrate fauna, climate change impacts and species distribution modelling. He was integral in my quest for a PhD scholarship and research funding, as well as in creating many opportunities for us students to disseminate our work. I was welcomed by him to be a part of the Centre for Tropical Biodiversity and Climate Change (CTBCC) at JCU, which allowed me to collaborate and conspire with the climateers.

My PhD would not have been achievable without the help of many people in the field;

I am extremely grateful to personnel of the Australian Wildlife Conservancy such as **Sarah Legge**, **Rigel Jensen**, **Jeff Middleton**, **Peter Stanton**, **Geoff Kelly**, **Atticus Fleming**, **Martin Copley**, **Graeme Morgan**, and **John Kanowski**. In particular I would like to thank **Peter and Pam Hensler**, for being wonderful property managers of Mt Zero-Taravale Sanctuary, always conscious of my research needs, but also for making me feel a bit more at home in the Australian bush.

I would like to thank those individuals from Queensland Parks and Wildlife Service (QPWS) that assisted me throughout my PhD, especially **Mark Parsons**, **Andy Baker**, **Jonathan Roth**, **Paul Williams**, **Russell Best**, **Andrew Colvill**, **Phil Bourke**, **Daniel Fitzpatrick**, **Shane O'Connor**, **Moragne Henriot**, **Doug Stewart**, **Mark Connell**, and **Robert Miller**. A special thanks to **Mark** and **Andy** for their dedication to northern bettong conservation and continuing presence throughout my work.

I am thankful to those at CSIRO Sustainable Ecosystems that helped me with portions of my field work including; **Alex Kutt**, **Eric Vanderduys**, **Iain Gordon**, **Nick Coleman**, **Steve McKenna** (JCU), **Justin Perry**, **Alex Anderson** (JCU), **Laura VanIngen**, and **Genevieve Perkins**. A special thanks to **Alex** and **Eric** for increasing my knowledge and identification skills on Australian fauna and for providing me with the opportunity and support to “look” for bettongs in some very cool places.

There were many volunteers that helped me throughout my PhD including; **April Reside**, **Nicole Kenyon**, **Ben Plumb**, **Emil Gustafsson** (photographer extraordinaire), and many more. In particular I would like to thank **Ben** for helping out on as many field trips as he could and for being integral in the data collection for this project.

I would like to thank several funding agencies that generously provided support for my project: the Australian Wildlife Conservancy (AWC), James Cook University (JCU), Australian Governments Marine and Tropical Sciences Research Facility

(MTSRF), SkyRail Rainforest Foundation, the National Climate Change Adaptation Research Facility (NCCARF), and the Graduate Research Scheme at JCU.

Data were shared kindly by; QPWS, **Sandra Abell**, **Sue Mathams**, **John Winter**, and the Queensland Herbarium. **Darren Storch**, **Gabriela Eiris**, **Jeremy Little**, and **Robert Puschendorf** kindly provided details on areas where they had seen northern bettongs.

Many people also provided useful advice throughout my project including; **John Winter**, **Peter Latch**, **Paul Williams**, **Gabriel Crowley**, **Catherine Graham**, **Euan Ritchie**, **Steve Van Dyck**, and **Luke Shoo**. I would specially like to thank 'team bettong', **Sandra**, and **Sue** for always being happy to share ideas, discuss bettongs, and work together.

There were several people integral to the success of my PhD through their logistic support; **Rob Gegg** for spending hours making my grass marking gear, **Jeanette Kemp** for advice and identification of grasses, **Bob Congdon** and **Scott Parsons** for teaching me how to analyse soil samples, **Raphael Wust** for analysing a portion of my soil samples, **Jono Winnel** for patiently spending hours counting grass with me and for showing as much enthusiasm and fascination about grass as I do, and **Yvette Williams** for saving the day, many times, when it comes to deadlines, finances, support and funding applications, or pretty much anything else.

I couldn't have completed my PhD without the love and support of my friends and family, and to them I am most grateful. I would like to thank all of the good friends I have made whilst in Townsville, and in particular; **Ben Plumb**, **Veronique Mocellin**, **Emily Mathams**, **Mariana Fuentes**, **Vanessa Valdez**, **Di Walker**, **Anne Caillaud**, **Milena Kim**, **April Reside**, **Nicole Kenyon**, **Camille Montiglio**, **Nils Gustin**, and **JB Raina**. Thanks to those in the mammal ecology lab for being great office mates and helping out along the way: **Veronica Menz**, **Stephen Kolomyjec**, **Leila Brook**, **Laura Mitchell**, **Rithika Fernandes**, **Angus McNab**, and **Jane De Gabriel**.

Special thanks to **JB**, for being a great housemate for three and half years, for all the great dinners we've shared, and for looking after the dogs, snake, fish, and plants when I was out in the field.

To my Aussie sisters, **Mari**, **Vanessita**, **Nanou** and **Di**; I am thankful for them welcoming me into their circle of friends, for giving me support and love, sharing many laughs, celebrations, wisdom and caring advice. No matter where we end up in life, they will always be my sisters.

I am more than grateful to **Ben**, my pillar, for all of his love and support throughout this crazy PhD. I thank him, for providing me with calm when all I saw was storm, for enduring many trips of fruitless truffles or bettongs, for getting my spirits up after those fruitless trips, for being there when I finally caught my first northern bettong, for editing everything that I wrote, for welcoming me into his wonderful family, for being my best friend, and for being able to carry ten cage traps at once! If I could share my PhD with him I would, because I couldn’t have done it without him.

I am thankful to have wonderful friends and family back in the USA, that supported me in my pursuit of happiness despite my moving across the world to do so; I thank all of my siblings, **Brad**, **Debbie**, **Michelle**, **Kim**, **Scot**, and **Chad** who we all dearly miss, and their families for their love and support. I am especially thankful to **Brad,** whose visit, trip to NZ together, and frequent Skype calls kept me going when I was most homesick.

My **Mom** and **Dad** deserve a special thank you for all of their support and for providing me what I needed in life to be able to pursue my dreams. I am also grateful they were able to help me carry traps through the Australian bush and share in my PhD research experience. I thank my **Mom** for always calling or sending me special notes from home, for her emotional support during rough times, for sharing her intuition and guidance, and for being a wonderful role model as a strong woman. I am grateful to my **Dad** for always letting me know he is proud of me for doing what I love in this world, for encouraging me to keep doing so, for providing support to me when I couldn’t do it on my own, and for introducing me at an early age to the wonders of our natural world. My happiness is owed to both of them, and their encouragement, belief, and support mean more to me than I can express.

Lastly, I am thankful to the earth, our mother, and all of the bettongs and other creatures (both fauna and flora) I crossed paths with during my project. They are the sole reason I became an ecologist, and I am grateful for the experience of being a part of their world, as an observer and participant.

Publications associated with this thesis

Peer-reviewed publications

- **Bateman BL**, Kutt AS, Vanderduys EP, and Kemp JE (2010) Small-mammal species richness and abundance along a tropical altitudinal gradient: an Australian example *Journal of Tropical Ecology* 26, 139-149 (Appendix E)
- **Bateman BL**, Johnson CN (2011). The influences of climate, habitat and fire on the distribution of cockatoo grass (*Alloteropsis semialata*) (Poaceae) in the Wet Tropics of northern Australia. *Australian Journal of Botany* 59 (4), 315-323 (Chapter 3)

Manuscripts in press

- **Bateman BL**, VanDerWal J, and Johnson CN (in press) Nice weather for bettongs: improving species distribution modelling using temporal variation in weather and extreme weather events. *Ecography* (Chapter 5)

Manuscripts in review

- **Bateman BL**, VanDerWal J, Williams SE, Johnson CN (in review) How much influence do biotic interactions have on predictions of shifts in species distributions under climate change? *Diversity and Distributions* (Chapter 4)
- **Bateman BL**, Johnson CN, Abell SE (in review) The influence of habitat and climate on the availability of truffles as a resource for the endangered northern bettong (*Bettongia tropica*). *Australian Journal of Zoology* (Chapter 2)

Manuscripts in preparation

- **Bateman BL**, VanDerWal J, and Johnson CN (in prep) A review of Species Distribution Modelling (SDMs): where to from here? To be submitted to *Diversity and Distributions* (Chapter 1 and Chapter 6)
- **Bateman BL**, Johnson CN, Baker A, Parsons M (in prep) Proactive conservation in the face of climate change; climate refugia for the northern bettong. To be submitted to *Conservation Biology* (Chapter 6)
- **Bateman BL**, Johnson CN (in prep) Distribution, current and future predictions, of the rufous bettong (*Aepyprymnus rufescens*). To be submitted to *Australian Mammalogy* (Chapter 4,6)
- **Bateman BL**, Johnson CN (in prep) Using probability of detection to determine survey effort and population decline of the northern bettong. To be submitted to *Wildlife Research* (Appendix B)

Reports

- **Bateman BL** Status of the northern bettong on the Coane Range (in prep) Report to the Australian Wildlife Conservancy
- **Bateman BL** Status of the northern bettong ; future management options (in prep) Report to Queensland Parks and Wildlife Service

Conference presentations

- Ecological Society of Australia (2010) Canberra, Australia (Oral Presentation)
  - **Bateman BL**, VanDerWal J, and Johnson CN (2009). Nice weather for bettongs: using weather events, not climate means, to model the distribution and competitive outcomes of marsupials
- Society for Conservation Biology: 24th international congress for conservation biology (2010) Edmonton, Canada (Poster Presentation)
  - **Bateman BL**, VanDerWal J, and Johnson CN (2010) Using events in species distribution modelling: implications of extreme events on current distributions and competitive outcomes
- Marine and Tropical Sciences Research facility Annual Conference (2010) Cairns, Australia (Oral Presentation)
  - **Bateman BL**, VanDerWal J, and Johnson CN (2010) Using events in species distribution modelling: implications of extreme events on current distributions and competitive outcomes
- The 10th International Congress of Ecology: Ecology in a Changing Climate (2009) Brisbane, Australia (Oral Presentation)
  - **Bateman BL**, VanDerWal J, and Johnson CN (2009) Modelling Biotic Interactions Under Climate Change Scenarios: Predicting northern bettong (*Bettongia tropica*) Distribution
- Australian Mammal Society (2009) Perth, Australia (Oral Presentation)
  - **Bateman BL**, VanDerWal J, and Johnson CN (2009) Modelling Biotic Interactions Under Climate Change Scenarios: Predicting northern bettong (*Bettongia tropica*) Distribution
    - Commendation, Adolph Bolliger Award, best spoken presentation by a student
- Marine and Tropical Sciences Research facility Annual Conference (2009) Townsville, Australia (Poster Presentation)
  - **Bateman BL**, VanDerWal J, Johnson CN, and Williams (2009) Distribution modelling of the northern bettong
- Ecological Society of Australia (2009) Sydney, Australia (Oral Presentation)
  - **Bateman BL,** VanDerWal J, and Johnson CN (2009). Predicting northern bettong distribution

Other publications

The following publications were also generated during my candidature:

Manuscripts in press

- Fuentes MMPB, **Bateman BL**, Hamann M (in press) Exposure of sea turtle nesting sites to tropical cyclone activity: an important factor in sea turtle nesting distribution. *Journal of Biogeography*

Manuscripts in review

- Kutt AS, **Bateman BL**, and Vanderduys EP (in prep) Reptile species richness and abundance along a rainforest-savanna altitude gradient in north-eastern Australia. *Australian Journal of Zoology*

Manuscripts in preparation

- VanDerWal J, Kutt A, Perkins G, **Bateman BL**, Perry J, Murphy HT (in prep) 60 years of climate change: identifying the species-specific rates of change in Australian birds To be submitted to *Nature*
- VanDerWal J*, **Bateman BL***, Murphy HT, and Reside A (* equal contribution) (in prep) Dispersal Appropriateness of full-, partial- and no-dispersal scenarios in climate change impact modelling To be submitted to *Journal of Biogeography*
- **Bateman BL**, VanDerWal J, Pauza M, and Johnson CN (in prep) Modeling the distribution of the Tasmanian bettong (*Bettongia gaimardi*): climate, weather and fox impact. To be submitted to *Austral Ecology*

Thesis abstract

In order to adopt pertinent management strategies for a species, it is imperative to have an understanding of its distribution and requirements. Species distribution models (SDMs) are broadly applied in ecological studies to generate hypotheses on both current and future distributions of a species. These models utilise statistical approaches to link where a species occurs with environmental data from those locations to infer hypotheses about factors limiting the species' distribution. SDMs have many applications in conservation biology, including being one of the few tools capable of predicting the impacts of climate change on a species. However, applications of SDMs are often limited to using long-term climate means and some measure of variability to represent 'environment'. Although climate is an important factor determining a species distribution, it is not the sole driver. These models exclude important influences such as biotic interactions, physiological limitations, and extreme weather events. Models based only on long-term climate overlook these factors. As these models are used for assessing conservation goals, it is critical to assess their limitations and usefulness.

I address the limitations of current SDM applications in my thesis, with the goal of improving their theoretical underpinning. I used the endangered northern bettong (*Bettongia tropica*), a tropical rat-kangaroo, as a study species for my research. The northern bettong is an ideal SDM candidate: it is a small, narrowly endemic species, restricted in habitat and diet. The ecology of the species is well understood, with knowledge on key process, interactions, and dietary requirements. I examined the links between climate, limiting resources, biotic interactions (competition with the more generalist rufous bettong (*Aepyprymnus rufescens*)) and

extreme weather events to enhance the ecological theory of SDMs. Additionally, I developed suggestions for the proactive management of the northern bettong. In order to do this, this thesis had several components: 1) examination of the distribution and limits of northern bettong key resources for inclusion into SDMs; 2) assessment of the role of biotic interactions in SDMs; and 3) investigation of the impact of extreme weather events on current distributions.

Two crucial food resources for the northern bettong are ‘truffles’ and cockatoo grass (*Alloteropsis semialata*); I assessed site- and regional-scale effects of short-term weather, long-term climate and habitat on the distribution of these resources. Habitat type did have an influence on truffles, as did key soil nutrients, although these factors could only explain a small percentage of the variation in truffle availability. The availability of truffles was directly influenced by weather and climate, with temperature and precipitation driving productivity at both the site and regional scale. The long-term reliability of truffles as a resource may be linked to weather and could be detrimentally affected by increasing seasonality and dry season severity, particularly within the range edges of northern bettong distribution. Key ‘extreme’ weather events were identified to limit truffle abundance, which in turn would limit the distribution of the northern bettong; thus this resource provided a good modelling candidate for use in biotic interaction assessment. Cockatoo grass has a broad tolerance to temperature and precipitation values although appears to be limited by drought conditions in the dry season. Habitat features have a strong role in determining cockatoo grass density, with a positive response to a late dry season burn indicating this species may benefit from fire. Cockatoo grass distribution was also affected by climate, making it an appropriate variable for inclusion into biotic interaction models, although more research on the affect of fire and climate change on its distribution is warranted.

In order to assess the influence of biotic interactions on SDM predictions under climate change, the spatial distribution of the northern bettong was modelled with and without biotic interactions (two resources and the potential competitor) and their predictions compared under varying degrees of global warming. Climate-only models increasingly diverged from those including biotic interactions with increasing global warming. I showed that SDM exercises that explicitly include known biological interactions provide better, ecologically realistic predictions under climate change. As interactions are currently not included in the vast majority of SDMs, this has ramifications for the usefulness of current climate change impact assessments that employ SDM.

Long-term climate data masks short-term weather events; these weather events may be ‘extreme’ relative to a species and as such, have huge implications on local population densities. To explore this, I defined extreme weather events in terms of the ecology of the northern bettong. These extreme weather events (e.g. droughts and heat waves) were used to model the temporal variability in the short-term suitability of habitat for both the northern bettong and its potential competitor, the rufous bettong. Severe drought and temperature variability limited local population densities of the northern bettong at the edge of this species’ range, and induced contractions in its distribution and niche tracking. Such contractions coincided with beneficial outcomes for the rufous bettong. Populations close to the edge of the range of this species occur in low densities as a result of frequent changes in the suitability of weather and increased pressure from their competitor. Traditional SDMs utilise data limited to spatial scale and do not detect dynamic processes such as temporal shifts in suitable weather and competitive outcomes between species. Failure to include extreme events can lead to overestimation of suitable habitat, which has implications for use in management decisions.

I integrated all of the results from my data chapters to improve our ecological understanding of the northern bettong. Northern bettongs may be vulnerable to climate change, particularly within populations at the edge of its range. Proactive conservation planning to mitigate the impacts of climate change can begin with the knowledge of predicted distributions, identified refugial areas (areas likely to maintain resources under climate change), and the impacts of extreme weather events, variable weather, and competitive pressure from the rufous bettong.

I demonstrate that although the use of SDM in climate change impact assessments is beneficial as a first pass for conservation and adaptation efforts, they can be improved with species-specific, ecologically relevant knowledge. The importance of my study was to highlight how climate-only models are limited in detecting important influences on a species distribution in time, as well as space. Improving on models by addressing these limitations provides for more realistic model outputs that can be utilized with greater confidence in proactive conservation efforts. The models developed here will be used in management decisions for the endangered northern bettong, to help ensure its continued persistence in a changing climate.

Table of Contents

List of Tables

List of Figures