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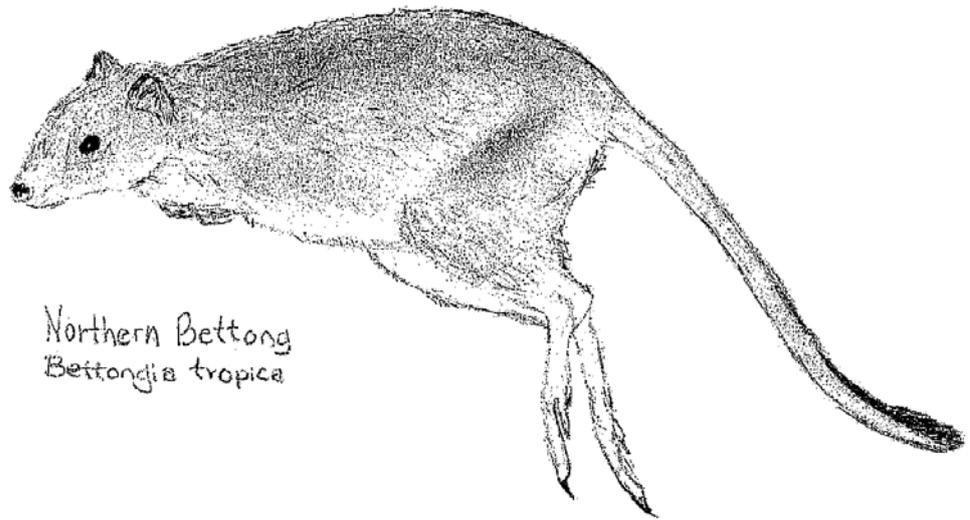
Beyond simple means: Integrating extreme events and biotic interactions in species distribution models

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

PhD thesis submitted by
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Northern Bettong
Bettongia tropica

Brocke Bateman
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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)

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- **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)
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- **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
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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
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- 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
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 - **Bateman BL**, VanDerWal J, and Johnson CN (2009). Predicting northern bettong distribution

Other publications

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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*
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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.

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