A landscape view of sarcoptic mange in bare-nosed wombats across New South Wales

Curb Wombat Mange Program

Elise Ringwaldt, Shane Richards, & Scott Carver

UNIVERSITY of TASMANIA

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Cover photo: Bare-nosed wombat (*Vombatus ursinus*). Raphael Eisenhofer.

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Executive Summary

Sarcoptic mange, a disease caused by the parasitic mite *Sarcoptes scabiei*, is the most significant disease affecting bare-nosed wombats (*Vombatus ursinus*, hereafter 'wombats') across New South Wales (NSW). Sarcoptic mange causes animal welfare issues through morbidity and mortality and, in some cases, can cause local population declines. In response to the New South Wales (NSW) Government *Curb Wombat Mange Program*, we sought to: 1) investigate wombat density, identify determinants, and estimate abundance, and 2) evaluate prevalence and determinants of sarcoptic mange across NSW.

From December 2023 to March 2024, we undertook spotlight surveys along 90 road transects across the distributional range of NSW wombats, observing a total of 302 individuals. The Local Government Area (LGA) of Snowy Monaro Region recorded the highest total number of wombats (82 individuals). Overall, our analyses showed wombat density was highest in the southeast and lowest in the north of their NSW range. The probability of wombat occurrence was highest in cooler, lower elevation, wooded areas. The density of wombats increased in cooler and moderate-use areas, particularly southeast NSW. We estimated the abundance of wombats in NSW to be 1.21 million individuals, with a 95% credible interval of 0.66-1.99.

Of 276 wombats that could be assessed, 16% exhibited signs of mange. Signs of mange were observed widely across survey areas, except northern sites where wombats were rare. The LGAs of Snowy Monaro Region, Central Coast and Hawkesbury had the highest proportion of wombats with signs of mange, 24-50%. Our best host and environmental statistical model suggested the probability of mange occurrence was highest in areas with a lower probability of wombat occurrence, with cooler annual temperatures, at lower elevation, and in woodland areas. Geographically speaking, south of the Australian Capital Territory, south coastal areas surrounding Jervis Bay to Batemans Bay, and north of Sydney on the central coast to inland were predicted as relatively higher-risk zones. However, we also emphasize some caution in interpreting statistical relationships on the basis of model fitting.

This research directly addresses the *Curb Wombat Mange Program*'s key priority area of 'monitoring and surveillance of mange in wombats' and represents the first systematic survey across the current and historical distribution of wombats in NSW. Our research suggests a large population of bare-nosed wombats occurs in NSW, with the majority of wombats occurring in the southeast of the state. Sarcoptic mange occurs in wombats throughout their NSW distribution, although statistical prediction of this is more tentative based on our data. Since mange occurs throughout the wombat's range, equitable resource allocation for disease control could follow a two-fold approach: prioritize areas with high mange prevalence or risk, and/or focus on regions with high wombat density, where the absolute number of affected individuals may be greater.

Our dataset offers an excellent foundation for future monitoring and decision-making. To further improve understanding of wombats and sarcoptic mange in NSW, we recommend: a) increasing the number of transect or survey frequency in the LGAs of Upper Hunter and Lithgow City (especially within the Wolgan Valley area); and b) repeating our transect surveys at a frequency aligned with management priorities of the NSW government.

Bare-nosed wombat (*Vombatus ursinus*) during a spotlight survey. Raphael Eisenhofer.

1. Introduction

1.1 Background

Bare-nosed wombats (also known as the common wombat, *Vombatus ursinus*) are medium sized fossorial (burrowing) marsupial herbivores that primarily graze upon native and introduced grasses and grass roots (Triggs, 2009). Adult bare-nosed wombats weigh approximately 22kg, making them among the largest burrowing herbivores in the world (Johnson, 1998). Wombats are widely distributed across southeastern Australia (Figure 1) and play an important role as 'ecosystem engineers' due to the substantial soil turnover caused by their burrowing activity (Carver et al., 2024). Wombats utilise burrows for a range of purposes (e.g., rest, thermal refuge, shelter from potential predators and fire), and can spend up to 20 hours a day within them (Skerratt et al., 2004; Martin et al., 2019a). Bare-nosed wombats are non-territorial, live largely solitary lives (direct contacts are rare outside of mating), and can have overlapping home ranges, exhibiting tolerance of the presence of one another while foraging (Skerratt et al., 2004; Evans, 2008). Their home range size is relatively small (150-400 meters in diameter) at elevations below 500 meters above sea level, with densities typically ranging from 0.1 to 0.5 individuals per hectare in suitable habitat (Skerratt et al., 2004; Matthews & Green, 2012; Carver et al., 2024). The main threatening processes faced by bare-nosed wombats are vehicle collisions, human persecution, and disease (Thorley & Old, 2020; Driessen et al., 2022a).

Sarcoptic mange is endemic in bare-nosed wombat (*Vombatus ursinus*) populations across their distribution (Martin et al., 1998). *Sarcoptes scabiei* was introduced to Australia by Europeans and their domestic animals (likely multiple times since ~1800), with records of infection in wombats dating back over a century (Fraser et al., 2016). Sarcoptic mange is the most significant disease affecting bare-nosed wombats, causing severe animal welfare issues through morbidity and mortality (Skerratt et al., 1998; Simpson et al., 2016; Martin et al., 2018a). Outbreaks have also led to population declines and local conservation concerns (e.g., Martin et al., 2018b; Carver et al., 2023).

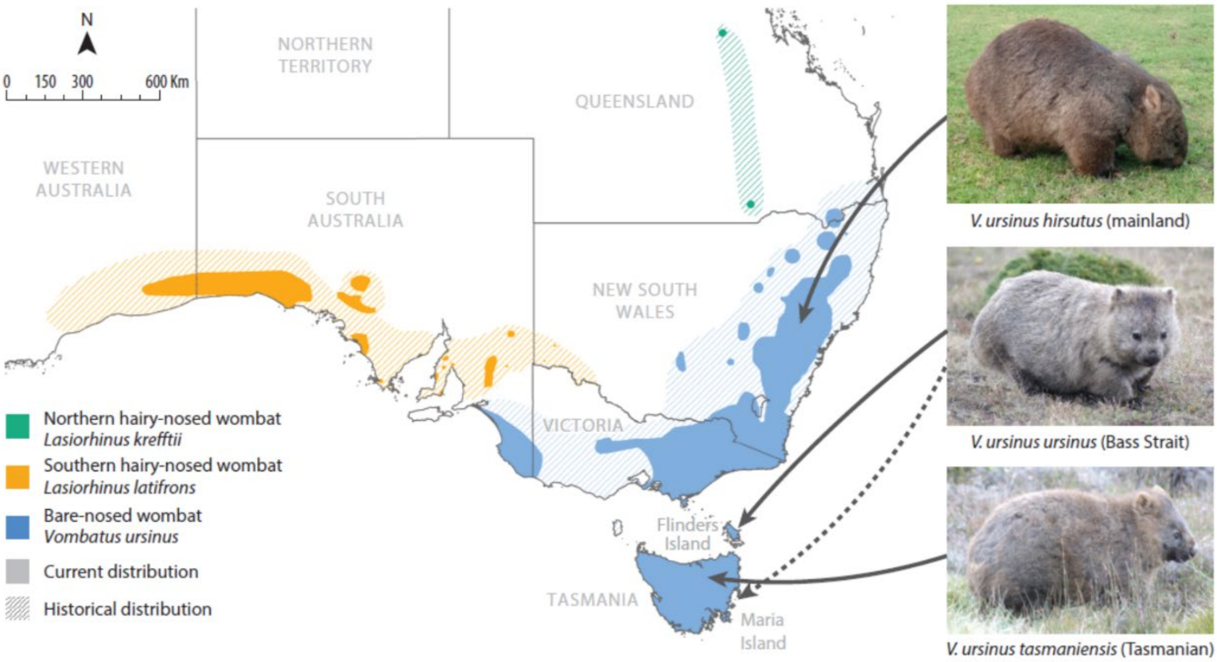


Figure 1 **The distribution of bare-nosed wombat species (Vombatidis spp.) across Australia.** This figure is from Carver et al., 2024.

Evidence suggests bare-nosed wombat populations predominantly sustain *S. scabiei* independently of other mammals through exposure of the mite in burrows (Browne et al., 2021). This environmental transmission is driven by asynchronously burrow-sharing behaviours, with burrow switching occurring every 1-10 days (Skerratt et al., 2004; Evans, 2008; Martin et al., 2019b). Once infected, bare-nosed wombats exhibit ‘crusted mange’, with visual signs of alopecia and hyperkeratosis developing progressively and eventually succumbing due to secondary infections (Martin et al., 2018a; Pence & Ueckermann, 2002). Consequently, visual assessments are a viable and commonly used technique to estimate apparent occurrence and prevalence of sarcoptic mange in wombats (as seen in Borchard et al., 2012; Driessen et al., 2022b; Burgess et al., 2023; Ringwaldt et al., 2023).

Wombats and sarcoptic mange in New South Wales

Bare-nosed wombats, hereafter ‘wombats’, are widely documented across eastern New South Wales (NSW). Wombat density and abundance likely vary latitudinally and with environmental factors across NSW, with their distribution having contracted since European arrival (Matthews et al., 2011; Carver et al., 2024). Systematic surveys quantifying the influence of environmental variables and density variation across NSW have not yet been completed (Thorley & Old, 2020); instead, research has primarily focused on local populations (Stannard et al., 2021) and citizen science (Mayadunnage et al., 2023). The distribution of mange in NSW is shown to be widespread (Appendix A.2; Noll, 2021; Mayadunnage et al., 2023), however, limitations in empirical data sources and analyses present challenges for understanding disease prevalence and attribution to landscape variables. In NSW and other parts of Australia, sarcoptic mange is managed to varying extents by community groups, researchers, and other organisations, overwhelmingly through the administration of pharmaceutical therapeutic agents (e.g., moxidectin, fluralaner) by direct or remote delivery techniques (Saran et al., 2011; Wolfenden & Old, 2012; Old et al., 2021; Wilkinson et al., 2021; Stannard et al., 2024; Wilkinson et al., 2024). Consequently, investment in research to address key knowledge gaps is vital to inform conservation management practices, effectively guide allocation of disease management resources, and improve welfare outcomes for wombats in NSW.

1.2 Aims

The overarching aim of this project is to address the key priority area of 'monitoring and surveillance of mange in wombats', as outlined in the *Curb Wombat Mange Program*. To investigate the landscape epidemiology of sarcoptic mange in NSW, we coupled systematic transect surveys with Generalised Linear Models and distance sampling techniques to:

1. Quantify spatially varying wombat density, identify determinants, and estimate the abundance of wombats in NSW.
2. Evaluate the occurrence of sarcoptic mange and the key variables associated with its prevalence in NSW wombats.

To identify areas at greatest risk of sarcoptic mange and understand the factors driving this spatial variation, we conducted transect surveys within the core distribution of wombats in NSW, documenting visible signs of sarcoptic mange in all observed individuals. Using this data, we applied modelling techniques to develop a risk map showing the spatial occurrence and prevalence of sarcoptic mange in wombats across NSW. A key outcome of this research is the application of landscape epidemiology to inform and support agency decisions, enabling targeted and balanced prioritisation of disease management resources, ultimately to improve welfare outcomes for free-living wombats impacted by this invasive pathogen.

1.3 Alignment with priority research areas

This research aligns directly with the priority area of 'monitoring and surveillance of mange in wombats'. By undertaking extensive systematic transect surveys within the distributional range of bare-nosed wombats, modelling factors associated with the distribution of mange, and creating a risk map for mange in NSW, this project directly addresses the following key needs:

1. Identifying the distribution of wombats and the prevalence of mange.
2. Prioritising resources to target at-risk populations by government and community.
3. Facilitating more effective management of mange in wombat populations

Bare-nosed wombat (*Vombatus ursinus*). Scott Carver/UTAS.

2. Methods

Data Collection

2.1 Spotlight transect surveys

Between December 2023 and March 2024, we conducted 90 transect surveys to collect observational and sarcoptic mange data on bare-nosed wombats across NSW (Figure 2; Appendix A.1). Transects spanned the current and historical distribution of wombats (Appendix A.1) and were selected based on publicly available wombat and mange records, peer-reviewed literature, government reports, and consultation with government personnel and community wombat carer and rehabilitation groups (Appendix A.2).

Transects were between 2.2 and 25.8 km in length (mean=13.5; median=12.7) and consisted of road sections driven in a vehicle at <20km/h. Two observers conducted each survey, scanning the transect and adjacent land for wombats. Observers each used a 1,000+ lumen spotlight, along with 10x42 binoculars. Once a wombat was sighted, we recorded their disease status and distance data (see 2.2 visual assessments). Each transects was surveyed once, with survey nights starting shortly after dusk, up to three transects were driven in one survey night (between 19:00 and 03:00).

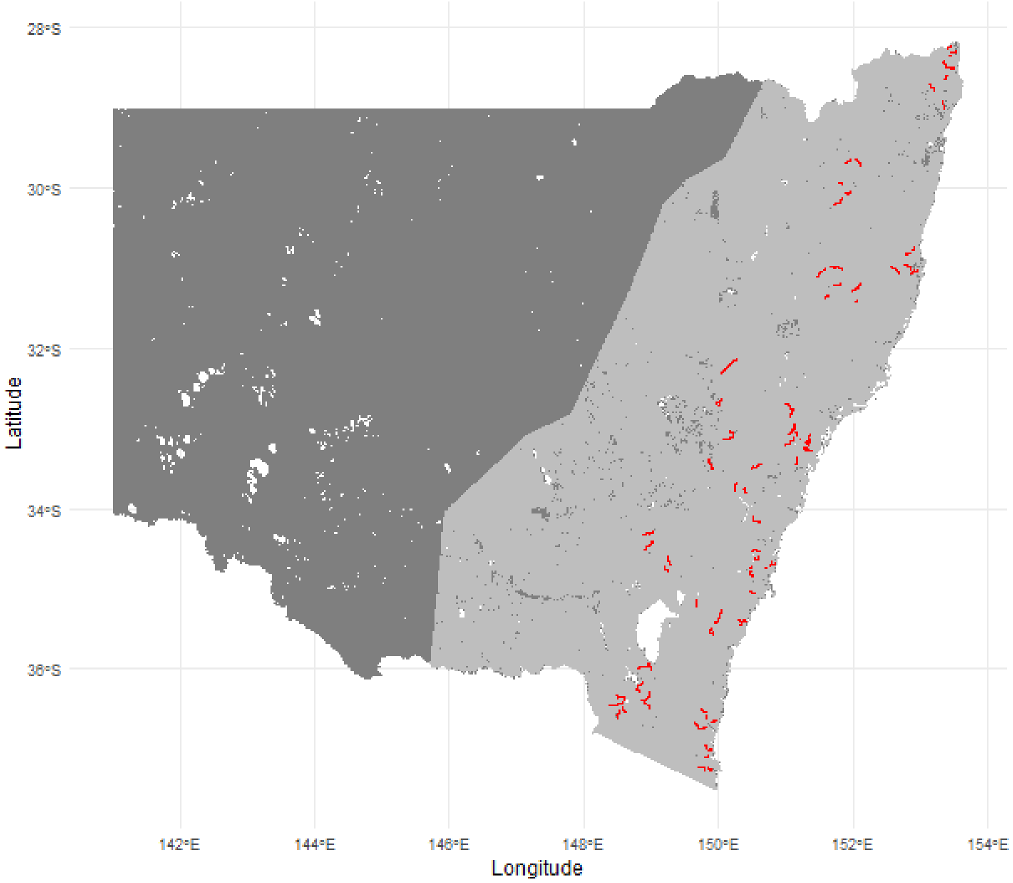


Figure 2 **All 90 transects which spotlight surveys of wombats and mange were completed.** Red represents the transects. Light grey represents the current and historical distribution of bare-nosed wombats, and dark grey is the rest of the state of New South Wales which was not included in analyses or predictions.

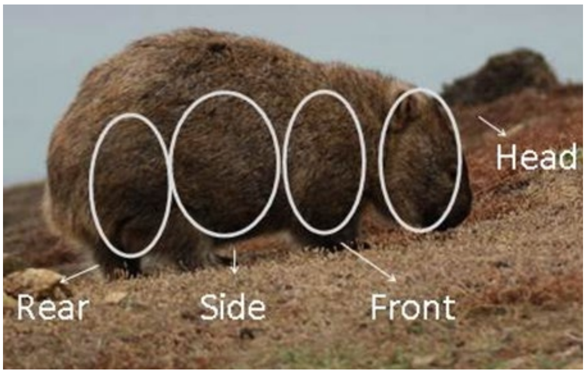
2.2 Visual assessments for disease in bare-nosed wombats

We conducted visual assessments of sarcoptic mange in wombats, adapting field methods from Simpson et al. (2016), Driessen et al. (2022b), and Burgess et al. (2023). For each wombat observation we recorded the GPS location of the vehicle, the estimated distance from the vehicle to the wombat (categorised as distance bands of 0-10, 10-25, 25-50, 50-75, 75-100, or 100+ meters), and the compass bearing. Wombats were only counted once in the survey and scored for the presence and severity of sarcoptic mange clinical signs (mainly evidence of alopecia and hyperkeratosis); this included which side of the body was visible, individual body segments, and overall disease status (Table 1).

We categorised each sighting into one of four disease status groups: *NA* – disease status was unable to be assessed, this was due to the wombat disappearing out of view too quickly or obscured by vegetation; *0* – healthy, no clinical signs of mange disease; *1* – there was uncertainty in the scoring but were most likely healthy, this happened in instances where some bite marks or hair loss occurred; *2* – probable early signs of mange, alopecia seen in generally indicative mange areas (e.g., flanks); *3* – clinical signs of sarcoptic mange, includes early-to-late-stage disease signs. For simplicity, during statistical analyses we grouped categories 0 and 1 together as ‘no indicative mange’, and categories 2 and 3 together as ‘mange’.

Table 1 **Visual scoring system for wombat mange severity status during transect surveys.** Image below illustrates the body sections that were each given a mange severity score, for each side of the wombat (if able to see both sides). Categories 0 and 1 were grouped together as ‘*no indicative mange*’, and categories 2 and 3 together as ‘*mange*’.

Score	Disease signs	Severity status
NA	Unable to score for mange	NA
0	No signs of mange	Healthy
1	Ambiguous, possible hair thinning	Likely healthy
2	<10% affected by mange, with clinical signs in indicative areas	Probable mange
3	10% to >40% affected by mange	Early-to-late-stage mange



Wombat image modified from field methods Simpson et al. (2016), Driessen et al. (2022b), NRE Fact Sheet (2022), and Burgess et al. (2023).

2.3 Collation of environmental and landscape variables for analyses

We selected climate and landscape variables of biological relevance for bare-nosed wombats (as per Ringwaldt et al., 2023), and predictors of wildlife species distribution generally. These variables were sourced from multiple platforms, including the National Vegetation Information System (NVIS, 2020), Catchment Scale Land Use of Australia (ABARES, 2021), Digital Elevation Model (DEM) (Gallant et al., 2009), Surface Hydrology (2015), and Biodiversity & Climate Change Virtual Laboratory (BCCVL; bccvl.org.au).

The predictor variables which were considered across analyses included:

- T - Annual mean temperature (°C).
- P - Annual mean precipitation (mm).
- E - Elevation (meters above sea-level)
- DW - Distance to freshwater (Euclidean distance of each cell to a lake or river).
- H - Habitat vegetation: two classifications of either open - grassland or closed - forest/woodland.
- U - Land use: three classification levels from least modified to highly modified.
- L - Latitude (only used in Bayesian analyses 2.6)
- TAR - Temperature Annual Range (difference between the warmest and coldest month)

For analyses of sarcoptic mange risk, the wombat probability of occurrence (PO – a.k.a. suitability) and density estimate predictions (DEN) were also included as separate predictor variables to account for the host influence on disease risk. Each predictor variable was represented as a spatial layer at the resolution of 0.01 arc degree (~1 km^2, representing a grid cell). Finer-scale raster layers were resampled to this spatial resolution using R v4.1.0 (R Core Team, 2021).

To quantify survey effort across grid cells, we applied a 200-meter buffer as the maximum visible survey distance from the road for each transect. Transect survey routes were aggregated into 0.01 arc degree grid cells to broadly align with the spatial layers. We then calculated the proportion of each grid cell that was visible during the transect survey. This ‘proportion covered’ was used as a relative effort metric and included as a predictor variable in models of wombat occurrence (PC), and density and abundance (see below, 2.5 and 2.6).

Statistical analyses

For each transect, we recorded the total number of wombats observed, the number of wombats able to be scored for mange, and their corresponding disease scores. To calculate the proportion of mange per transect, we divided the number of wombats which were likely to have mange (scores of 2 and 3) by the total number of wombats scored for mange. We also aggregated all data for each Local Government Area of NSW.

We then then undertook a robust process of model consideration and exploration (see below, 2.4) to:

1. Assess the suitability of occurrence across NSW for wombats.
2. Predict the relative density and abundance of wombats across the state.
3. Determine the associated suitability and risk of sarcoptic mange in wombats.

2.4 Analyses considered

There are a wide range of statistical methodologies that exist to analyse the type of data collected in this research (spatial, host and disease occurrence), and it is often unclear what is the most appropriate approach for a given study (Norberg et al., 2019). Indeed, at the outset of analyses we focussed on species distribution models (SDM) approaches, and comparison of different approaches yielded different results and suggested a need for a more robust methodology to statistics selection. Accordingly, we developed a set of criteria to help make sensible decisions about which candidate statistical models were most appropriate.

Our criteria to guide the decisions are as follows, and are discussed further in section *4. Assumptions and limitations*.

Criteria

1. Does it make ecological sense (for wombat ecology)?
2. Is the analysis statistically robust for the data in this study?
3. Does it provide reliable predictions within the current and historic wombat distribution?

We considered all methods in Table 2 for analysing the transect survey data and excluded unsuitable models and models producing ecologically implausible results.

For the probability of wombat occurrence we found that SDMs, which we initially envisioned, were unsuitable, owing to the low number of data points and imbalanced dataset (183 presences to 1951 absences). This imbalance led to overfitting in the SDM algorithms, of Random Forest (RF), and Generalised Additive Models (GAM), which produced ecologically unreasonable predictions based on known distribution information. We attempted various other methods to balance the dataset, including ‘up-sampling’ or pseudo-replicating presences, down-sampling absences, removing absences within 5 km of a presence, and random sampling the 1951 absences. Although these balancing methods made the analyses more statistically robust, they also led to ecological unfeasible predictions. For example, the models overfitted to rare patterns in the variables, or predicted the entire current and historical wombat distribution as suitable for wombats—even though wombats are largely absent from many of these areas now. Ultimately, we utilised a binomial Generalised Linear Models (GLMs) with model selection using Akaike Information Criteria (AIC) for these analyses.

We also considered multiple density analysis options for wombats. When using the transect route data alone, we found that methods like distance sampling, while statistically robust, could not provide predictions across NSW as it was not at the grid cell level. Similarly, Generalised Linear Mixed Models (GLMM) on transect data could predict across NSW but made large assumptions (i.e., the wombat density predicted represented what an observer would see if they were conducting the spotlight surveys, which could not be generalised to actual density and abundance estimates across the landscape). Ultimately, we utilised a Bayesian distance sampling methodology using grid-cell level data for these analyses.

For the SDMs on mange in wombats, we had a limited number of mange datapoints (see *3. Results*) to be applied to highly variable environmental and landscape factors. Consequently, the models were required to make large assumptions to predict across the landscape. Ultimately, we chose to apply robust Generalised Linear Models (GLMs), which allowed for more ecologically sound and interpretable predictions based on the best-ranked model.

Table 2 **Selection criteria for analysis of transect data in this report.** For each of the methods and analysis that was considered, we evaluated if it met the criteria. **Y** – yes, it met that criterion**;** **/** - equivocal on meeting that criterion or only meets the criterion if asking a different ecological question; and **N –** No, does not meet the criteria.

Analyses Type	Methods	Meets Criteria?			Fate
		1	2	3	
Wombat Occurrence (all data cells)	GLM - AIC ranked	Y	Y	Y	Included
Wombat Occurrence (absence cells reduced)	GLM - AIC ranked	/	/	/	Excluded
Wombat Occurrence	SDM - GLM	Y	N	Y	Excluded
Wombat Occurrence	SDM - RF	N	Y	N	Excluded
Wombat Occurrence	SDM - GAM	N	/	N	Excluded
Wombat Density	Distance Sampling - Cell Level	Y	Y	Y	Included
Wombat Density	Distance Sampling - Transect level	Y	Y	N	Excluded
Wombat Density	GLMM - AIC ranked	/	Y	/	Excluded
Mange (landscape) Risk	GLM - AIC ranked	Y	Y	Y	Included
Mange (Individual) Probability	GLM – AIC ranked	Y	Y	Y	Included
Mange Transect Density	GLMM - AIC ranked	Y	Y	/	Excluded
Mange Occurrence	SDM - GLM	/	N	N	Excluded
Mange Occurrence	SDM - RF	/	/	N	Excluded
Mange Occurrence	SDM - GAM	/	N	N	Excluded

Akaike Information Criterion (AIC), Generalised Additive Model (GAM), Generalised Linear Model (GLM), Generalised Linear Mixed Model (GLMM), Random Forest (RF), Species Distribution Model (SDM).

2.5 Wombat probability of occurrence

To identify the factors influencing the occurrence of bare-nosed wombats across New South Wales during our transect surveys, we applied a binomial Generalised Linear Model (GLM). We aggregated the transect survey data into grid cells (0.01 arc degree, or ~1 km^2), classifying each cell as either presence (1) or absence (0) of wombats. A grid cell was regarded as a ‘presence’ if at least one wombat was recorded, and ‘absence’ if none were seen.

All predictor variables were included in the model, all were continuous predictors except land use and vegetation type which were treated as factors. All continuous predictors were z-transformed to enable comparison of effect sizes among them. Data collation and analyses were performed in R v4.1.0 (R Core Team, 2021).

We applied a GLM using the MuMIn package (Barton, 2024). We initially ran the full model with all predictor variables:

$$\text{binomial (Occurrence)} = 1 + \beta z_{\text{PC}} + \beta z_{\text{T}} + \beta z_{\text{P}} + \beta z_{\text{E}} + \beta z_{\text{DW}} + \beta \text{H} + \beta \text{U} + \beta z_{\text{TAR}}$$

where the z-terms are the z-transformed values, β is the slope coefficient, and the variables are defined in 2.3. We used the dredge function to rank all variable combination models based on AIC (Akaike, 1973), selecting models within an ΔAIC of six as plausible from which to evaluate further (Richards, 2008; Appendix A.3).

The top-ranked model was then used to assess the influence of significant predictor variables and predict the probability of occurrence for each grid cell across the current and historical distribution of wombats in NSW. Grid cells with higher predicted probabilities were considered more suitable for wombats based on the environmental and landscape factors.

2.6 Predicting wombat density and abundance

Wombat density

Wombat population densities along road transects were estimated using a Bayesian distance sampling methodology. Additionally, for the Bayesian analysis, we represented land use (U) categories as: none $(x_{\mathrm{U}} = 1)$, low $(x_{\mathrm{U}} = 2)$, and high $(x_{\mathrm{U}} = 3)$, and vegetation habitat (H) categories as: closed $(x_{\mathrm{H}} = 1)$ and open $(x_{\mathrm{H}} = 2)$.

The objective of the analysis was to describe wombat density (λ, individuals per hectare) in terms of the predictors. Specifically, we assumed the following relation for a given cell:

$$\begin{aligned}\log\lambda(z_{\mathrm{L}}, z_{\mathrm{E}}, z_{\mathrm{T}}, z_{\mathrm{P}}, x_{\mathrm{U}}, x_{\mathrm{H}}) \\ &= \beta_0 + \delta_\lambda + \sum_{j=1}^{3}\beta_{\mathrm{L}j}z_{\mathrm{L}}^{j} + \sum_{j=1}^{2}\left(\beta_{\mathrm{E}j}z_{\mathrm{E}}^{j} + \beta_{\mathrm{T}j}z_{\mathrm{T}}^{j}\right) + \beta_{\mathrm{ET}}z_{\mathrm{E}}z_{\mathrm{T}} + \beta_{\mathrm{P}}z_{\mathrm{P}} + \beta_{\mathrm{U2}}(x_{\mathrm{U}} = 2) \\ &+ \beta_{\mathrm{U3}}(x_{\mathrm{U}} = 3) + \beta_{\mathrm{H2}}(x_{\mathrm{H}} = 2),\end{aligned}$$

where the z-terms are the z-transformed values associated with the continuous predictors. The β-terms are the model's coefficient parameters, and the variables are defined in *2.3*. Here, based on preliminary analyses, we have assumed the impact of latitude on abundance was cubic in form, whereas precipitation had a linear form. Elevation and temperature also had a quadratic relationship with abundance, and we have included the interaction between the two predictors. These choices were deemed biologically relevant resulting in a fit that was parsimonious. The δ_λ-term is a random value drawn from a normal distribution with mean 0 and standard deviation σ_λ. This random effect describes the impact of any unmeasured, but influential, predictors affecting wombat density in the associated cell (i.e., each cell is associated with its own δ_λ-term).

To account for variation in the ability to observe a wombat during a transect, we assumed that there were two general types of observation states: unobstructed (u) and obstructed (o). For both 'observation states' we assumed the probability of observing a wombat declined with distance according to a negative exponential function, with mean distances μ_{u} and μ_{o}, respectively $(\mu_{\mathrm{o}} < \mu_{\mathrm{u}})$. The proportion of the 'observation state' within a cell deemed obstructed was given by q, and this proportion was assumed to vary between cells. For this model, the probability of detecting a wombat that was located within the distance band delineated by lower and upper distances, d_{l} and d_{u}, was:

$$f(d_{\mathrm{l}}, d_{\mathrm{u}}, q, \mu_{\mathrm{u}}, \mu_{\mathrm{o}}) = \frac{1}{d_{\mathrm{u}} - d_{\mathrm{l}}}\left(q\mu_{\mathrm{o}}\left(e^{-d_{\mathrm{l}}/\mu_{\mathrm{o}}} - e^{-d_{\mathrm{u}}/\mu_{\mathrm{o}}}\right) + (1-q)\mu_{\mathrm{u}}\left(e^{-d_{\mathrm{l}}/\mu_{\mathrm{u}}} - e^{-d_{\mathrm{u}}/\mu_{\mathrm{u}}}\right)\right),$$

where q is the estimated proportion of obstruction associated with the cell. This obstruction varies across cells according to

$$\operatorname{logit} q(x_{\mathrm{H}}) = \alpha_0 + \alpha_{\mathrm{H2}}(x_{\mathrm{H}} = 2) + \delta_q,$$

where the α-terms are additional model parameters. Here we assumed that the level of obstruction may be affected by habitat type, x_{H}. The δ_q-term is a random value drawn from a normal distribution with mean 0 and standard deviation σ_q, which allows for cell-specific variation in wombat detectability.

Consider a road transect that passes through a grid cell, and let *A* (m^2) denote the area of the strip within the cell that extends 200 m on either side of the road. The expected number of wombats observed within the band delineated by distances d_{l} and d_{u}, in the cell, was:

$$\bar{n} = \frac{1}{2 \times 10^6}(d_{\mathrm{u}} - d_{\mathrm{l}})A\lambda f.$$

Variation in the observed wombat counts was assumed to be consistent with a negative binomial distribution, where the variance mean relation is $\sigma^2(\bar{n}) = (1+\phi)\bar{n}$ (Richards, 2008).

Wombat abundance

Following model fitting, we estimated wombat densities for 1 km square cells in eastern-NSW from the Bayesian analyses. The total wombat abundance in the current and historical distribution was calculated by summing up the predicted cell densities and estimated the 95% credible intervals. Uncertainty in the abundance estimate was assessed by evaluating the variation across all posterior samples.

All analyses were performed using R v 4.3.2 (R Core Team, 2021). The model was coded and fit using the Stan programming language provided by the rstan package (v2.32.3; Stan Development Team, 2023). We assumed relatively uninformed priors for all parameters, so posteriors are dominated by the data, and generated 1000 sets of posterior samples after a 500-sample warmup.

2.7 Sarcoptic mange risk and predictions

We ran two models:

1. To determine the probability a wombat will show signs of mange, given the environmental conditions the wombat was associated with.
2. To determine the probability a surveyed cell will show evidence of mange, given the landscape and host variables the grid cell is associated with.

To determine the probability a wombat will show signs of mange, given the environmental conditions the wombat is associated with, we applied a Generalised Linear Model (GLM). We aggregated the transect survey data into grid cells (0.01 arc degree, or ~1 km2), and determined the number of wombats scored for mange, and the number of wombats with mange for each grid cell. We then applied a binomial GLM using the MuMIn packaged (Barton, 2024), with only environmental variables and the log-transformed number of wombats scored for mange within each grid cell, to account for variations in sample size. We used the dredge function to rank all variable combination models based on AIC (Akaike, 1973), selecting models within an AIC of six as most plausible (Richards, 2008). The final model, with the lowest ranked ΔAIC, was used to assess the probability a wombat will show signs of mange given the environmental conditions the wombat is associated with.

To determine the relative risk factors of mange to wombats across NSW, we applied a binomial GLM, using the same model selection methods as above and *2.5 wombat occurrence and suitability of habitat*. All environmental predictor variables were included in the model, the wombat occurrence predictions, and the wombat density predictions for all grid cells (created earlier in *2.4* and *2.5*). All predictor variables were continuous except land use and vegetation type, which were treated as factors. All continuous predictors were z-transformed to enable comparison. We applied a binomial generalised linear model (GLM) with all variables included in the full model as:

$$\mathrm{binomial}(Mange) = 1 + \beta \mathrm{z_T} + \beta \mathrm{z_P} + \beta \mathrm{z_E} + \beta \mathrm{z_{DW}} + \beta \mathrm{H} + \beta \mathrm{U} + \beta \mathrm{z_{TAR}} + \beta \mathrm{z_{PO}} + \beta \mathrm{z_{DEN}}$$

where the z-terms are the z-transformed values, β is the slope coefficient, and the variables are defined in *2.3*.

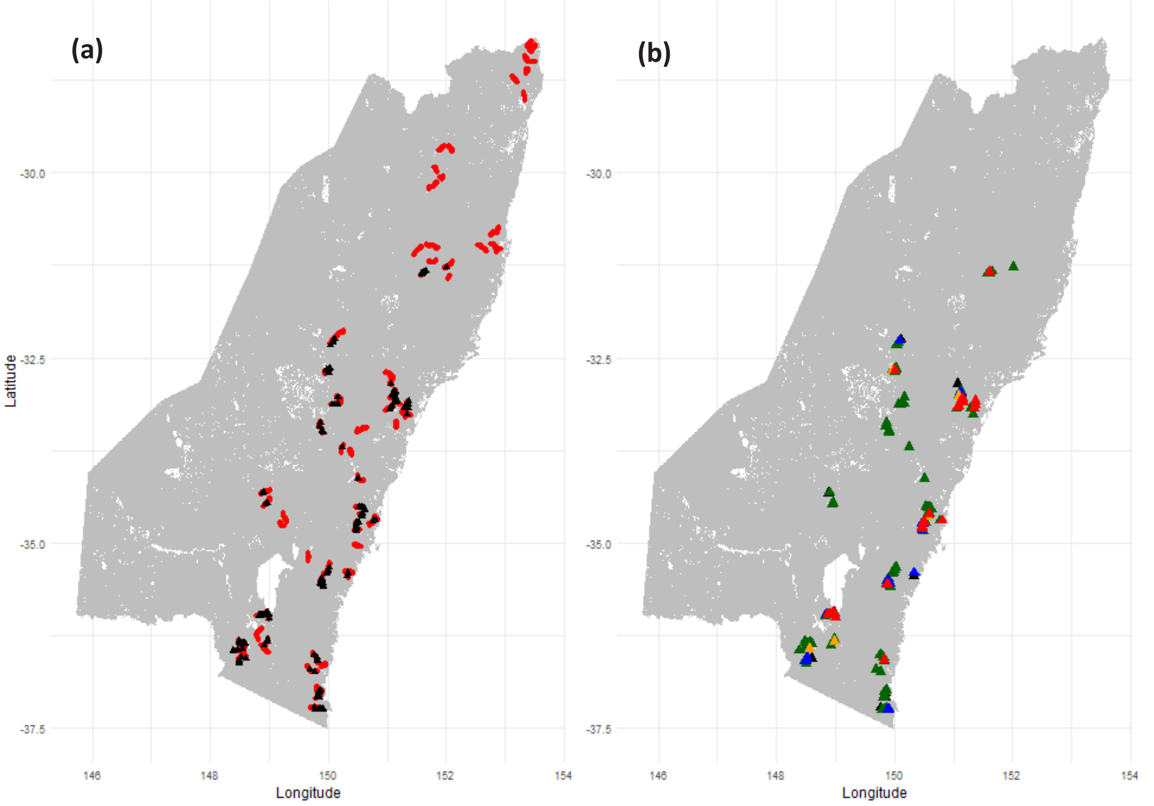
All variable combinations were ranked using dredge, and included if within an AIC of 6 (Akaike, 1973; Richards, 2008). The final model, with the lowest ranked AIC, was used to assess the influence of predictor variables on the probability a surveyed cell will show evidence of mange. Therefore, cells with higher predicted probability represented higher- relative risk areas for mange in wombats across the current and historical distribution of wombats in NSW.

3. Results

Descriptive empirical results and Local Government Areas

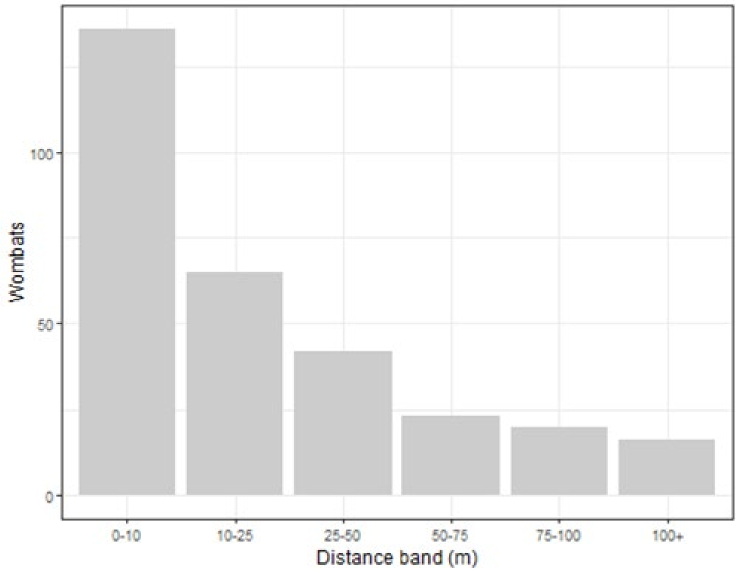
Across 90 transects we observed 302 wombats, of which 276 wombats were assessed for their disease status (Figure 3). From the 276 wombats assessed, most (84%) were healthy, and 16% exhibited signs of mange (Figure 3). Wombats were observed on 51 transects (56.7%), with the highest number recorded on a single transect being 43 at Bobeyan Road (Appendix A.1). Most wombats (45%) were spotted within 10 meters of the road, with 5.3% observed between 100 and 200 meters (Figure 4).

The transects passed through 2165 grid cells and which ranged from five to 47 cells per transect. There were 183 grid cells which recorded as a wombat presence and 1951 grid cells as an absence. There were seven absence points which had missing spatial data and were removed from the analysis. Of the 183 grid cells with at least one wombat presence, 14 cells had wombats that could not be assessed for mange (NA) and were excluded from the analysis. Of the remaining 169 grid cells, 131 cells were regarded as 'healthy' (0, absent), with no indicative mange present in the wombats, and 38 grid cells contained at least one wombat with evidence of mange (1, present).



Mange score	Wombat counts
0 - healthy	205
1 – likely healthy	27
2 – probable mange	5
3 – mange	39
Total scored	276
NA – not scored	26
Total wombats	302

Figure 3 **The occurrence of wombats and mange across the current and former distribution in New South Wales. (a)** The presence and absence of wombats along transects, where all black triangles represent a wombat recorded, and red circles are all 1km^2 absence points; **(b)** all wombats and their corresponding mange score.



Distance band	Wombat count
0-10	136
10-25	65
25-50	42
50-75	23
75-100	20
100+	16
Total	302

Figure 4 **Histogram of the distance bands wombats were spotted in and the corresponding counts (table).** The number of wombats spotted decreased as the distances increased.

We used the Local Government Areas (LGA) of New South Wales to aggregate all transect surveys and the corresponding wombat and mange occurrence data into (Table 3; Figure 5). The LGA of Snowy Monaro Regional had the highest number of wombats recorded (82) and was equal with the Bega Valley for the highest number of transects (10) within an LGA (Table 3, Figure 5(a)). Snowy Monaro Regional also had the most wombats counted with mange (18), which was 24% of the wombats scored. The LGAs of Central Coast and Hawkesbury recorded 50% of their wombats with mange, however a small number of wombats were counted in each of these LGAs (11, and 4 respectively) suggesting that these percentages should be interpreted cautiously (Table 3, Figure 5(b)).

Table 3 **All bare-nosed wombats recorded for each Local Government Area of New South Wales which at least one transect survey was in.**

Local Government Area	Transects	Wombat Count	Wombats scored for mange	Wombats with mange	Proportion scored with mange
ARMIDALE REGIONAL	2	0	0	0	NA
BATHURST REGIONAL	2	11	10	0	0
BEGA VALLEY	10	23	20	1	0.05
BLUE MOUNTAINS	2	1	1	0	0
BYRON	2	0	0	0	NA
CENTRAL COAST	7	11	10	5	0.50
CESSNOCK	4	40	36	6	0.17
GLEN INNES SEVERN	3	0	0	0	NA
HAWKESBURY	3	4	4	2	0.50
HILLTOPS	2	5	4	0	0
KEMPSEY	3	0	0	0	NA
KIAMA	2	3	3	1	0.33
LISMORE	3	0	0	0	NA
LITHGOW CITY	2	6	6	0	0
MID-WESTERN REGIONAL	2	11	10	2	0.20
NAMBUCCA VALLEY	2	0	0	0	NA
QUEANBEYAN-PALERANG REGIONAL	4	30	28	2	0.07
SHOALHAVEN	6	42	41	4	0.10
SINGLETON	2	1	0	0	NA
SNOWY MONARO REGIONAL	10	82	74	18	0.24
TWEED	4	0	0	0	NA
UPPER HUNTER	2	5	4	0	0
UPPER LACHLAN SHIRE	2	0	0	0	NA
WALCHA	6	6	6	1	0.17
WINGECARRIBEE	2	20	18	2	0.11
WOLLONDILLY	1	1	1	0	0

*See Appendix A.1, Table A.1 for transect level specific information.

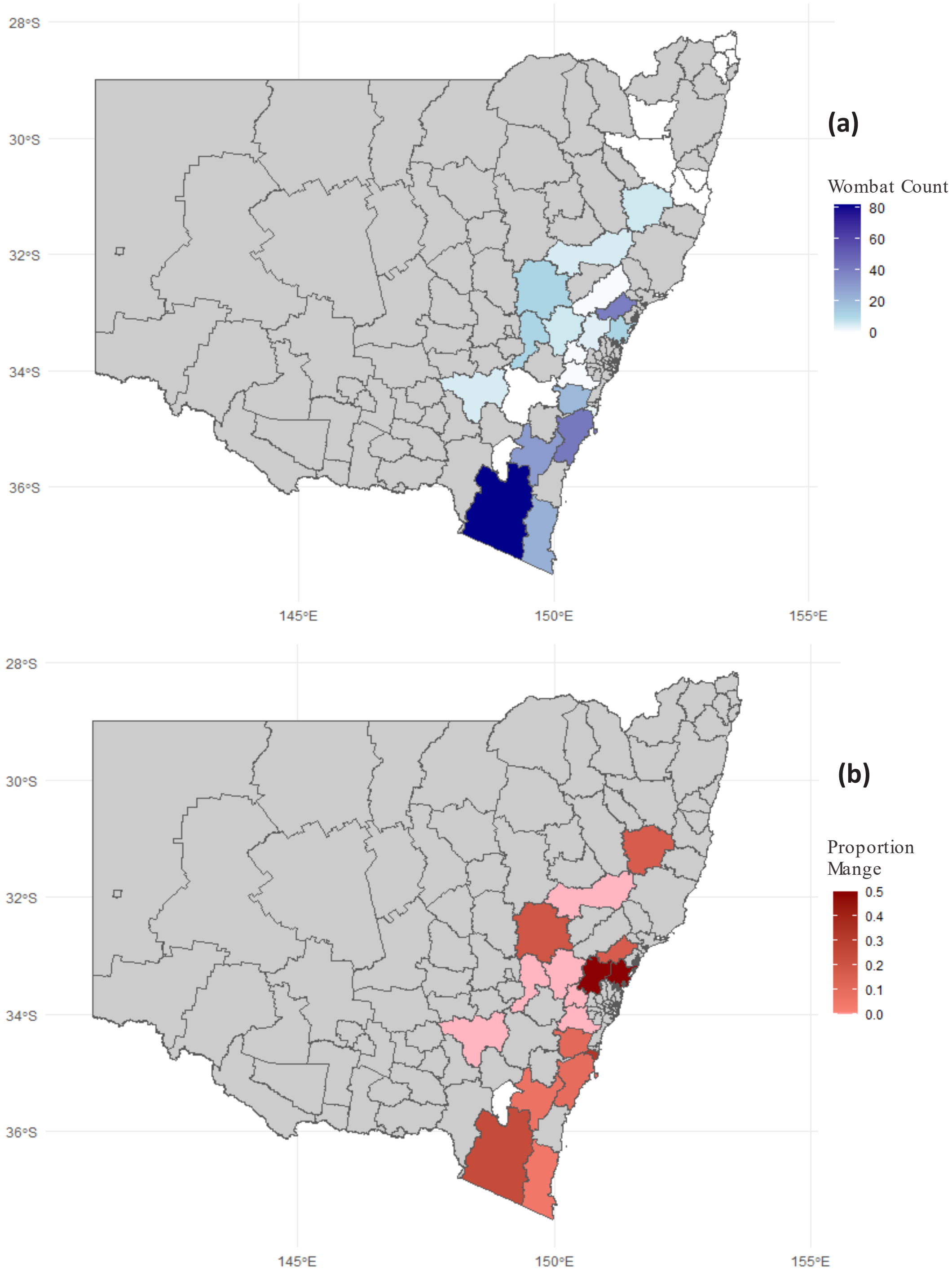


Figure 5 **Wombat counts and proportion of mange in wombats across the Local Government Areas where transect surveys occurred. (a)** Wombat counts by Local Government Area, colour gradient from 0 (white, no wombats recorded) to 82 (dark blue, highest number of wombats recorded). **(b)** The proportion of sarcoptic mange per Local Government Area where wombats were recorded, colour gradient from 0 (pink, all healthy wombats) to 0.5 (dark red, highest proportion of mange recorded).

Bare-nosed wombat occurrence and suitability

The full model, which included all predictor variables, showed evidence for annual mean temperature, elevation, the proportion of the cell covered, and weak evidence for vegetation for influencing wombat occurrence (Appendix A.3). The best AIC model (AIC = 1062.0, df = 5, LogLik = -525.99, weight = 0.102) included annual mean temperature, elevation, vegetation type, and the proportion of the cell covered.

Our analyses suggest that the probability of wombat occurrence during a survey decreased with an increase in annual mean temperature (-1.05, 95% CI [-1.417, -0.688]), elevation (-0.79, 95% CI [-1.161, -0.433]), and grassland vegetation (-0.45, 95% CI [-0.781, -0.117]). In contrast, wombat occurrence increased when a higher proportion of the cell was covered during a transect survey (1.03, 95% CI [0.844, 1.219]).

The final model was used to predict the probability of observing a wombat across the current and historic distribution in NSW (Figure 6). The predicted probability of wombat occurrence ranged from 0 to 1, with the highest probability of observing a wombat of 0.20 in the southeast of NSW, indicating a 20% likelihood of detecting a wombat in a given grid cell during a transect survey.

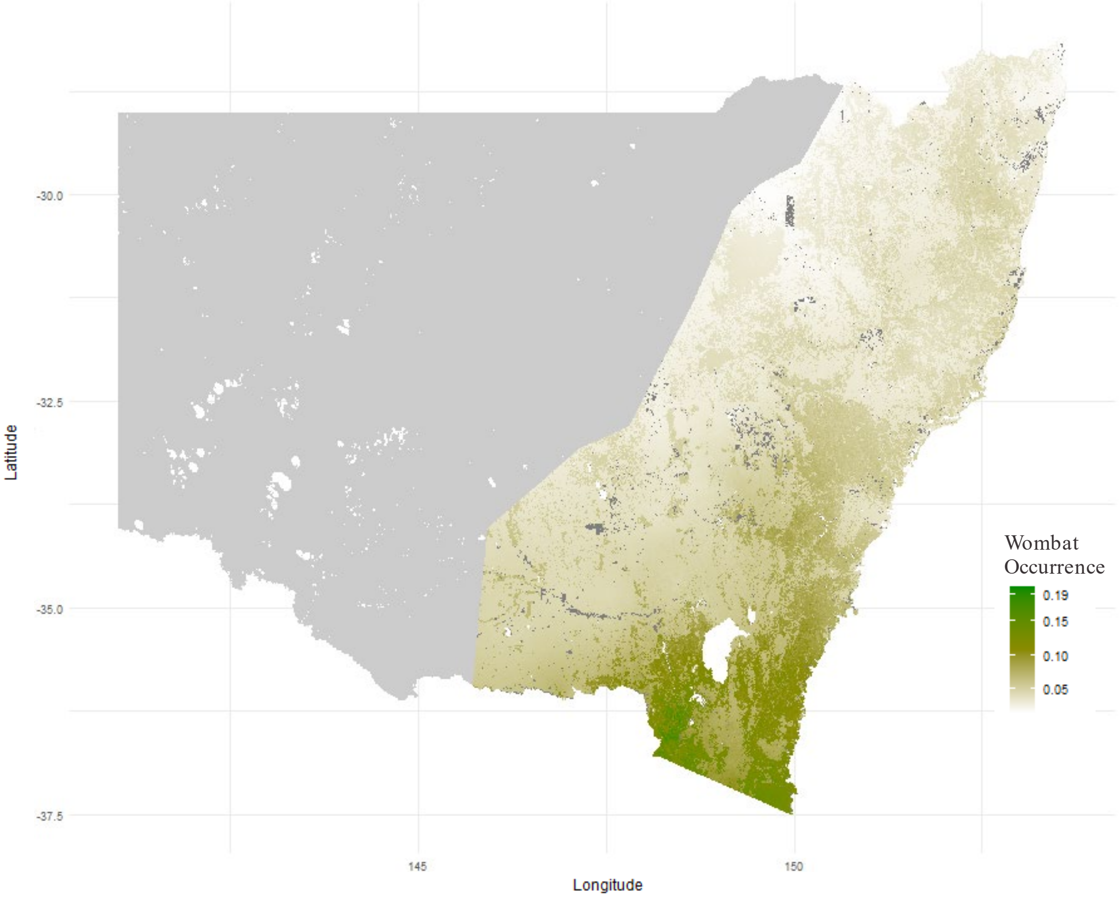


Figure 6 **Prediction of the probability of observing a bare-nosed wombat occurrence across southeastern New South Wales during a transect survey.** The predicted probability ranges from 0, white, to 1, dark green. The highest prediction in a spatial cell was 0.20 in the southeast of NSW. The predicted probability of occurrence shows areas which are more suitable for wombats to occur based on the best AIC model.

Wombat density and abundance

Data fitting indicated that wombat density was unaffected by precipitation and did not vary between closed and open habitats (Table 4). Density exhibited quadratic and cubic relationships with latitude, and density was influenced by a negative quadradic relationship with temperature (Table 4). Wombats tended to also be less common in habitats associated with low and high levels of land use (Table 4). Predicted densities for 329,895 cells suggested that the most favourable environments for wombats were primarily within 200 km of the coast, south of Newcastle (Figure 7). Within this region, densities were estimated to be above 0.05 individuals per hectare, but mostly less than 0.15 individuals per hectare. The model estimated a total of 1,210,000 wombats in this region, with a 95% credible interval of 657,000 to 1,990,000.

Table 4 **Posterior parameter estimates.** Model parameters are separated according to those associated with wombat detection and wombat density. Continuous predictors (latitude, elevation, temperature, and precipitation) have been z-transformed before fitting. CI refers to credible interval.

Parameter	Description	Median	95% CI
Detection	(logistic q)		
q	Proportion obscured (logistic α_0)	0.94	[0.84,0.99]
μ_o	Obscured mean distance (m)	8.28	[5.79,11.56]
μ_u	Unobscured mean distance (m)	49.39	[37.68,69.47]
α_0	Baseline	2.78	[1.47,4.27]
α_c	Cover effect on q	0.06	[-1.34,1.43]
σ_q	Standard deviation of δ_q	2.25	[1.21,4.56]
Density	(log λ)		
β_0	Baseline	-2.38	[-3.10,-1.64]
β_L1	Latitude (linear)	-0.45	[-1.83,0.84]
β_L2	Latitude (quadratic)	-1.77	[-3.00,-0.66]
β_L3	Latitude (cubic)	-1.11	[-2.20,-0.08]
β_P	Precipitation	0.08	[-0.35,0.56]
β_E1	Elevation (linear)	-0.04	[-1.33,1.13]
β_E2	Elevation (quadratic)	-0.26	[-1.28,0.81]
β_T1	Temperature (linear)	-0.42	[-2.04,1.16]
β_T2	Temperature (quadratic)	-1.04	[-2.24,-0.08]
β_ET	Elevation-temperature interaction	-1.11	[-3.09,0.38]
β_U2	Land use (low)	-0.34	[-0.73,0.05]
β_U3	Land use (high)	-0.35	[-0.79,0.11]
β_H2	Habitat (closed)	0.01	[-0.42,0.46]
σ_q	Standard deviation of δ_λ	1.29	[0.97,1.74]
ϕ	Negative binomial variance	0.26	[0.15,0.42]

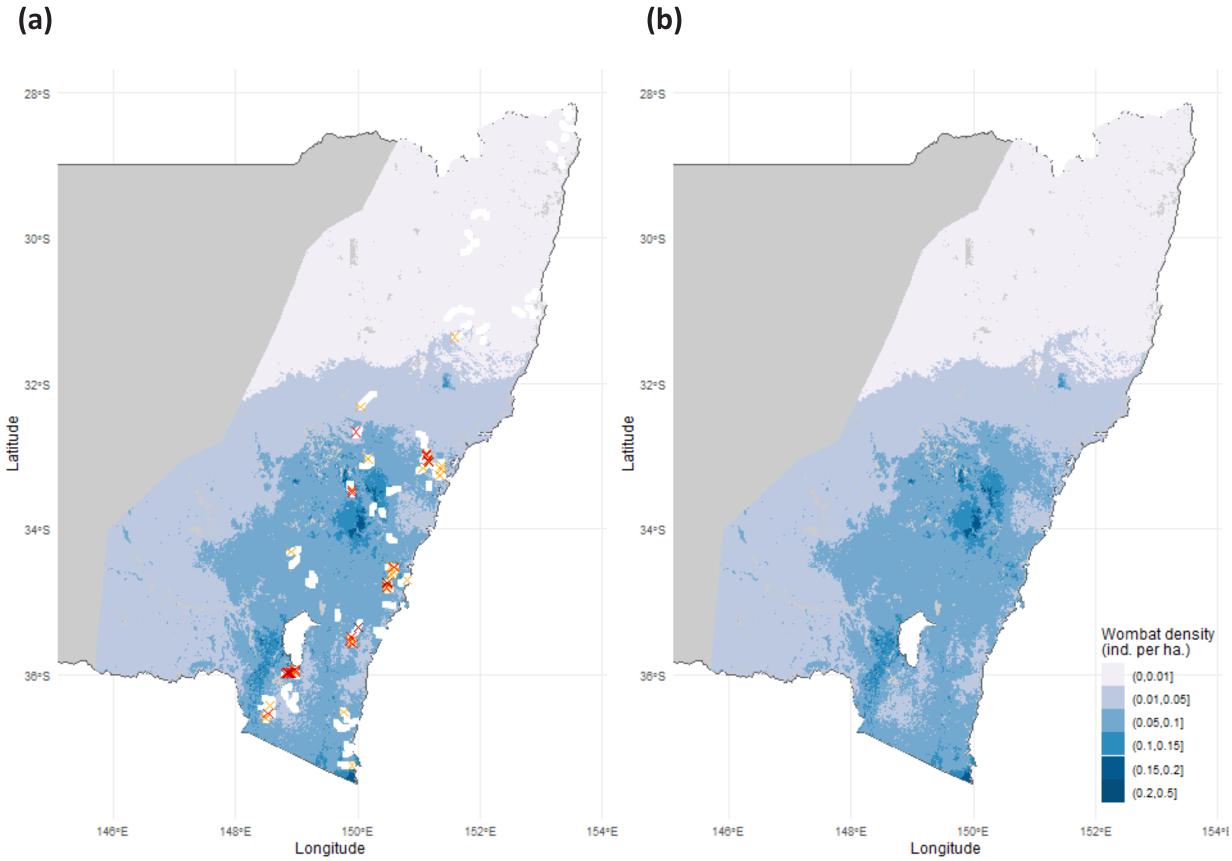


Figure 7 **(a)** Locations of cells that intersect the road transects (white squares). Crosses indicate the number of wombats observed in the cell: 1-2 (orange), 3-6 (red), 7+ (dark red). **(a,b)** Estimated wombat density per cell, each approximately 1 square km, throughout eastern NSW. Blue colouring depicts the median of the posterior density estimates associated with each cell.

Sarcoptic mange predictions

To determine the probability a wombat will show signs of mange and identify areas at greatest risk, we ran two binomial GLMs. The first GLM examined the probability an individual wombat will show signs of mange under associated environmental conditions only, and showed no strong association with any predictors (Appendix A.4). This first GLM suggested that the predicted probability a wombat will show signs of mange given the environmental variables was 0.23 (Appendix A.4).

The second GLM included both environmental and host variables. The best host and environmental model (AIC = 175.9, df = 10, LogLik = -77.96, weight = 0.072) included all variables except distance to freshwater (Table 5; Appendix A.5). As interpreted by the AIC model selection and z-transformed coefficient effect sizes (95% confidence intervals not overlapping zero), the probability of mange occurrence was predicted to be highest in areas with a lower probability of wombat occurrence, with cooler annual temperatures, at lower elevation, and in woodland areas. To a lesser extent (smaller effect sizes) mange occurrence was also predicted to be higher in areas with: low and high intensity land use (relative to moderate), a more stable annual temperature range, and with lower wombat density. The best-ranked model was used to predict the relative risk of mange in wombats across the current and historical distribution of NSW (Figure 8).

Table 5 **Each variable’s coefficients and 95% confidence intervals in the best-ranked model (lowest AIC) predicting relative risk of mange to bare-nosed wombats.** All continuous predictor variables were z-transformed for analysis (z).

Variables	coefficients	2.50%	97.50%
(z) Wombat Occurrence	-32.42	-56.17	-14.42
(z) Annual Mean Temperature	-10.95	-18.86	-4.65
(z) Annual Precipitation	-0.87	-1.93	0.19
(z) Elevation	-7.65	-13.65	-2.83
Vegetation (Grassland)	-4.47	-7.94	-1.67
(z) Temperature Annual Range	-1.38	-2.75	-0.10
(z) Wombat Density	-0.55	-1.18	-0.02
Land Use (Moderate Intensity)	-1.49	-2.84	-0.25
Land Use (High Intensity)	-1.00	-2.46	0.41

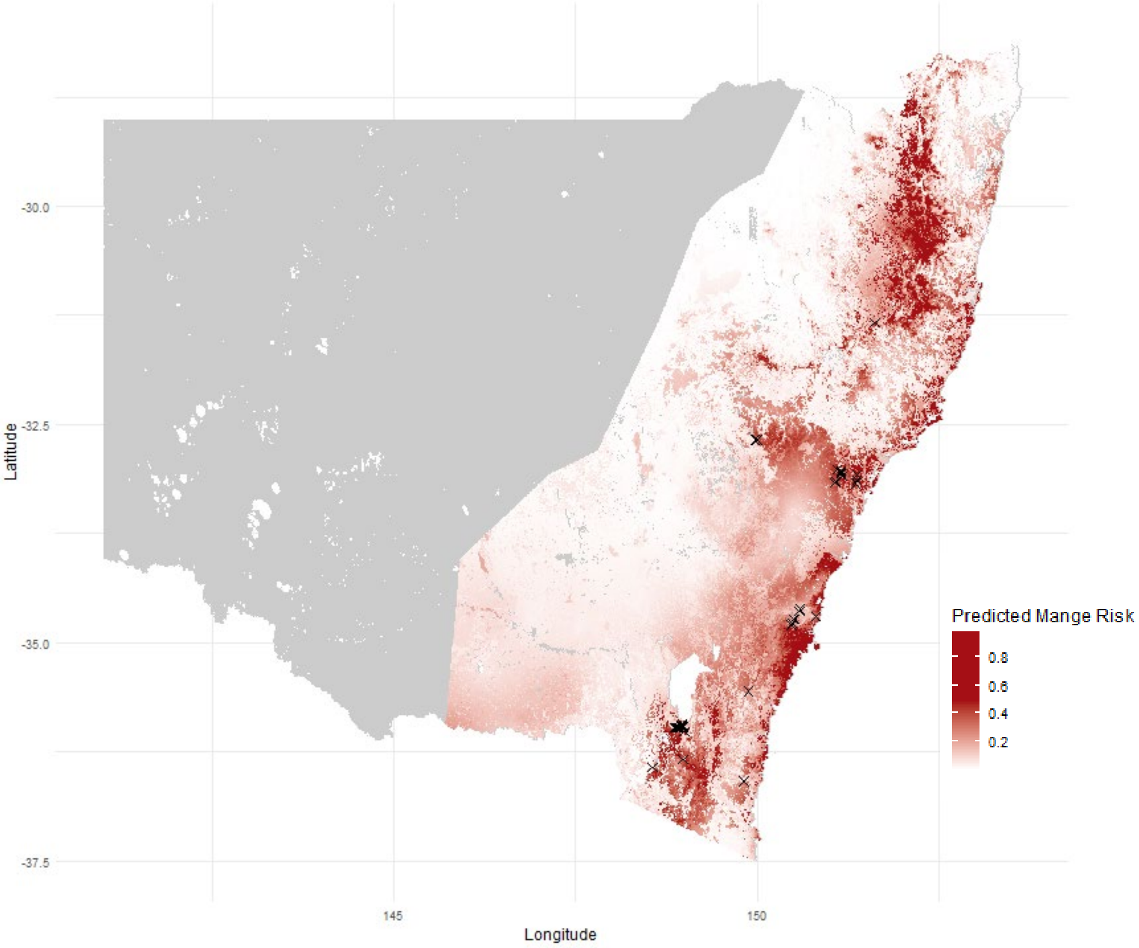


Figure 8 **Predicted sarcoptic mange risk to bare-nosed wombats across southeastern New South Wales using the transect survey data.** The predicted probability ranges from 0, white, to 1, dark red. The highest prediction in a spatial cell was 0.89. The predicted probability of mange shows areas which are a relatively higher risk of mange to wombats in the grid cells, given the environmental and host variables. The black crosses represent the 38 cells which were positive for mange.

Bare-nosed wombat (*Vombatus ursinus*) with severe mange in NSW. NSW Environment.

4. Discussion of findings

This is the first study to systematically survey wombats across their current and historical distribution in New South Wales, and estimate their occurrence, density, and abundance. Additionally, we applied landscape epidemiological methods to investigate sarcoptic mange in NSW wombats. We present our findings in the context of existing literature, discuss how they address key knowledge gaps, and propose management actions for wombats and mange.

Wombat distribution, occurrence and density

Wombats were more likely to be detected in southern regions of eastern NSW, with latitude an important predictor of density and abundance. The historic distribution of wombats is known to extend further north along the coast, and while wombat observations still occur latitudinally north of Newcastle they are considered rare (Taggart et al., 2016; Carver et al., 2024). The distribution of wombats in our study is largely consistent with the core spread of citizen science data occurrence records in New South Wales (Matthews et al., 2011; Mayadunnage et al., 2023; ALA, 2023). We observed 45 wombats in the LGAs of Cessnock and Upper Hunter, and six wombats in Walcha LGA north of Newcastle. However, no wombats were detected in Kempsey LGA or further north on our transect surveys suggesting rare to low numbers in these regions, consistent with predictions from our occurrence and density models. These finding support a probable range contraction driven by persecution, land-use changes, disease, and climate, and which might worsen under climate change as unfavourable environments for bare-nosed wombats shift southward.

While the distribution of wombats in NSW was broadly understood, the abundance and density was previously unknown (Thorley & Old, 2020). Based on or model, we estimate the average density of 0.05-0.15 individuals per hectare, with an overall abundance of 1.21 (95% CI [0.66, 1.99]) million wombats across NSW. Our density predictions align with other state-wide predictions in Australia and population density estimates in parts of their NSW range. Wombat densities typically range from 0.1 to 1.9 individuals per hectare, with most estimates around 0.1–0.2 (as reviewed in Carver et al., 2024). In New South Wales, wombat population density estimates have fluctuated during spotlight surveys, but are on average between 0.1-0.3 wombats per hectare (Stannard et al., 2021). Others have used either capture-mark recapture or a combination with spotlight surveys to find an average of 0.13 per hectare (Evans, 2008), and 0.11-0.23 depending on habitat type (McIlroy, 1977). In Victora, some studies have recorded 0.03-0.19 per hectare, also depending on vegetation type (Downes et al., 1997), and in edge environments up to 1.9 wombats per hectare (Skerratt et al., 2004). Landscape scale density and abundance estimates of wombats in Victoria and Tasmania were 0.06 and 0.11 per hectare, with state-wide average abundance estimates of 432,595 and 840,665 (+74,425 from Flinders and Maria Islands), respectively (Heard & Ramsey, 2020; Knoblauch et al., 2023). There are currently no overall density and abundance estimates for Queensland, Canberra or South Australia for *V. ursinus*; acknowledging these are comparatively small populations. Therefore, the current average best estimate for the abundance of bare-nosed wombats within their core Australian distribution is 2.56 million individuals (2,557,685, 95% CI [1,639,830-3,792,554] – from NSW, Victoria, Flinders Island, Tasmanian mainland, and Maria Island). Such estimates provide critical context for managing this geographically widespread species.

Our results indicate that latitude, temperature, and land use intensity were predictors of wombat density. We also found the probability of observing a wombat during a survey decreased with high annual mean temperature, higher elevations, and grassland vegetations. Higher probability of observing a wombat may correspond to places more suitable for their occurrence. Other research has also shown cooler temperatures have a positive association with wombat occurrence and distribution (Carver et al., 2021; Ringwaldt et al., 2023). Densities of wombats are thought to be lower at higher elevations, due to the snow depth and seasonality at high altitudes influencing movement and home ranges (Matthews et al., 2012; Matthews & Green, 2012). Further, there may be an interaction between the elevation and temperature for wombats across Australia. Particularly, wombats may be restricted or prefer higher elevations across south-eastern Australia mainland due to temperature-limit zone, as wombats prefer the cooler temperatures than hotter temperatures at lower altitudes. While in Tasmania, wombats are perhaps more likely to occupy sites at lower altitudes relative to their mainland Australian counterparts (Driessen et al., 2022a; Ringwaldt et al., 2023). Non-linear relationships with elevation have also been found with wombat abundance in Victoria (Heard & Ramsey, 2020). As in our study, these findings suggest that temperature has a stronger influence than elevation in NSW.

Our predictions suggest wombats prefer habitats associated with intermitted intensive uses, and areas with cover, such as forest and woodland areas. Heard and Ramsey (2020) also found a positive relationship with native tree cover, and suggested wooded riparian zones and the ecotone between forest and pasture are likely to be areas of highest density. Roger et al. (2007) found that environmental variables representing proximity to cover and proximity to watercourses are important predictors of wombat burrow presence in southern NSW (although we found little evidence of distance to freshwater influencing wombat occurrence). Wombats are known to be common in grassland with remnant habitat or edge environments, as it may be more suitable for wombats to live, as suggested or modelled by many others (Downes et al., 1997; Skerratt et al., 2004; Borchard et al., 2008; Heard & Ramsey, 2020). Our findings suggest wombats are associated with environments of intermittent land use, however, the binary classification of habitat vegetation in this study limits the ability to identify detailed vegetation types influencing wombat occurrence, such as edge effects.

Sarcoptic mange in wombats across NSW

Determining the role that environmental and host (wombat) related factors influencing the occurrence and relative risk of mange to wombats is essential for defining prevalence, improving predictions, and identifying populations at greater risk. In our study, 16% of wombats (that could be assessed) showed signs of sarcoptic mange, with prevalence varying greatly across the state. Using camera trapping surveys, Noll (2021) found yearly mange ranged from 1-7% in NSW wombats. Other research has found prevalence estimates from camera trapping to underestimate mange prevalence due to bias resulting from positioning the cameras on a smaller focal point, rather than broadly scanning the landscape during transect surveys (see Driessen et al., 2022b). Other studies have reported prevalence as high as 31-41% in specific populations (Stannard et al., 2021; Mayadunnage et al., 2023), although we note these findings were based on individual populations or citizen science data (citizen science data are bias toward mange observations and inflated prevalence estimates), rather than systematic surveys which included areas with low wombat density and mange prevalence.

We found the LGAs with the highest mange prevalence in our study to be Snowy Monaro Regional, Central Coast, and Hawkesbury, where 24-50% of wombats exhibited signs of mange. Conversely, no mange was recorded in the LGAs of Blue Mountains, Hilltops, Lithgow City, Upper Hunter, and Wollondilly despite wombat presence. Literature indicates that mange has been observed in some populations in Shoalhaven, Lithgow City, and Upper Hunter populations (Borchard et al., 2012; Wolfenden & Old, 2012; Stannard et al., 2021). In Shoalhaven, we recorded mange in 10% of the 42 wombats observed across six transects. However, in Lithgow City and Upper Hunter, we conducted only two transects per LGA and recorded six and five wombats, respectively, likely limiting our ability to detect mange (Appendix A.1). We suggest either expanding the number of transects, or increasing replication of transects, in these areas to improve detection and prevalence estimates.

While sarcoptic mange occurs throughout the distribution of wombats, statistical prediction of mange occurrence was less certain, owing to challenges of model fitting. Incorporating both environmental and host variables into a GLM suggested areas of relatively higher mange risk across NSW, with the best model suggesting the probability of mange occurrence was highest in areas with a lower probability of wombat occurrence, with cooler annual temperatures, at lower elevation, and in woodland areas. These higher-risk areas were identified south of the Australian Capital Territory, south coastal areas surrounding Jervis Bay to Batemans Bay, and north of Sydney on the central coast to further inland. Our landscape-level mange risk map may help explain why mange outbreaks occur in some locations but not others. However, we also acknowledge that more data collection is needed to be more confident about the accuracy of statistical models for mange and 'hot spots' of mange in the landscape.

Interestingly, higher mange risk in areas of low wombat occurrence and density is consistent with other research (Carver et al., 2023). Burgess et al., (2023) similarly reported that prevalence of mange was not density-dependent in Cape Portland, Tasmania, suggesting that diseased wombats may be competitively excluded from optimal habitats, or suboptimal habitats increase disease risk. We hypothesise that wombats in marginal habitats in NSW may also experience increased disease risk. Unlike Driessen et al., (2022b) and Burgess et al., (2023), we found both wombats and mange to be positively associated with woodland environments, suggesting that mange risk is not inherently tied to unfavourable environments at a landscape level in NSW. Environmental factors such as cooler temperatures and lower temperature variability were associated with increased relative mange risk in our study. Browne et al., (2021) argued the longevity of the *S. scabiei* mite off the host increased at lower elevation, and cooler and wetter burrow conditions, although the extent of this trend was dependent on local conditions and may not apply to landscape scales.

Our findings emphasise that higher-risks of mange result from multiple factors, some of which may not have been captured in our models, such as local population dynamics, or possible interactions between environmental variables. Finally, our study was limited by the sample size. Future research could aim to increase transect coverage, particularly in the under-sampled LGAs identified, and incorporate additional data to refine associated risk maps and improve our understanding of the drivers of mange in wombats at a landscape level.

Glen Davis Road, NSW. Elise Ringwaldt/UTAS

Addressing aims and key knowledge gaps

This research directly addressed the *Curb Wombat Mange Program*'s key priority area of 'monitoring and surveillance of mange in wombats' and fulfilled the aims of our study. By coupling systematic field transect surveys with Generalised Linear Models and distance sampling techniques, we provided a detailed and credible assessment of wombat occurrence and mange prevalence across their core distribution in NSW.

We successfully met the aims of:

1. Quantify spatially varying wombat density, identify determinants, and estimate the abundance of wombats in NSW.

Through our transect survey counts, we aggregated the number of wombats by each Local Government Area, showing areas of high and low wombat counts. Using robust distance sampling and modelling we predicted wombat density and abundance across their current and historical distribution, estimating a population of 1.21 (95% CI [0.66, 1.99]) million wombats in NSW. Additionally, by including abundance estimates from other states, we provided a national population estimate of 2.56 (95% CI [1.64, 3.79]) million wombats across the core distribution in Australia. By quantifying the occurrence suitability and spatial density of wombats we also identified key environmental determinants of the species and placed them within the scientific literature.

2. Evaluate the occurrence of sarcoptic mange and the key variables associated with its prevalence in NSW wombats.

We aggregated wombat mange data and prevalence rates by LGA, identifying regions with relatively high and low mange prevalence. We observed a 16% prevalence of mange signs, and our statistical analyses suggest wombats in NSW have a 23% likelihood of having mange, given environmental variables. We predicted the associated risk of mange to wombats across the state, and identified areas which may be a higher-risk based on associated environmental and wombat factors. However, we are tentative in confidence about our statistical capacity to predict mange occurrence and 'hot-spots'. Instead, we believe our current results most confidently support the focus on regions with high wombat density, where the absolute number of affected individuals may be greater.

By addressing these aims, we have identified additional research areas to explore and provided critical information to support wombats and mange across the state (see recommendations below).

Recommendations and implications for management

The findings of our research addressed the *Curb Wombat Mange Program*'s priority areas by:

1. Identifying the distribution of wombats and the prevalence of mange.
2. Highlighting at-risk wombat populations to guide resource allocation and inform government and community priority areas.

The systematic transect surveys conducted in this study provide a robust foundation for both short- and long-term monitoring and decision-making. We recommend repeating the transect surveys at a frequency determined by specific priorities and management goals relevant to the NSW government. For example, the comprehensive surveys we undertook could be conducted every 2-5 years if the primary focus is on wombat distribution changes over time. If an understanding of seasonal variation in wombats and mange is desired, then repeating a subset of the transects more frequently may be warranted. Yearly spotlight transects have been undertaken in some areas of Australia, such as Tasmania (Driessen et al. 2022a; Driessen & Hocking 1992, 2008; Carver et al. Knoblauch et al., 2023), providing valuable information on population changes of wombats and other conspicuous wildlife (Hopkins & Kennedy, 2004), and yearly or biannual spotlight surveys could be considered appropriate in eastern NSW (Mackenzie & Royle, 2005). Additionally, areas identified as potentially having high wombat densities could be targeted for small-scale regular surveying as areas of particular conservation interest.

Our current data establishes that sarcoptic mange occurs across the wombat distribution, but it is more limited in statistical confidence regarding localised hotspots of mange. Therefore, in regions with high wombat density the absolute number of affected individuals with mange may be greater. Thus, based on our current data, wombat density is potentially a useful decision tool for equitable allocation of disease control resources. We primarily recommend resource allocation decisions reflecting the LGAs with highest wombat densities and higher prevalence from our surveys. Our study identified the LGAs with the highest mange prevalence as Snowy Monaro Regional, Central Coast, and Hawkesbury. While we acknowledge statistical hotspot prediction limitations, for completeness we document predicted relatively higher-risk areas to include: South of the Australian Capital Territory; south coastal areas surrounding Jervis Bay to Batemans Bay; and north of Sydney on the central coast to inland areas. We also recommend increasing the number of individual transect routes within the LGAs of Upper Hunter and Lithgow City (especially within the Wolgan Valley area) to improve mange detection and prevalence estimates in these regions. This data could refine associated hotspot risk maps and enhance our understanding of the drivers of mange in wombats at a landscape scale.

Acknowledgements

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(Left) Echo Point Lookout (Three Sisters). (Right) Bare-nosed wombat (*Vombatus ursinus*) under spotlight during a transect survey. Elise Ringwaldt/UTAS.

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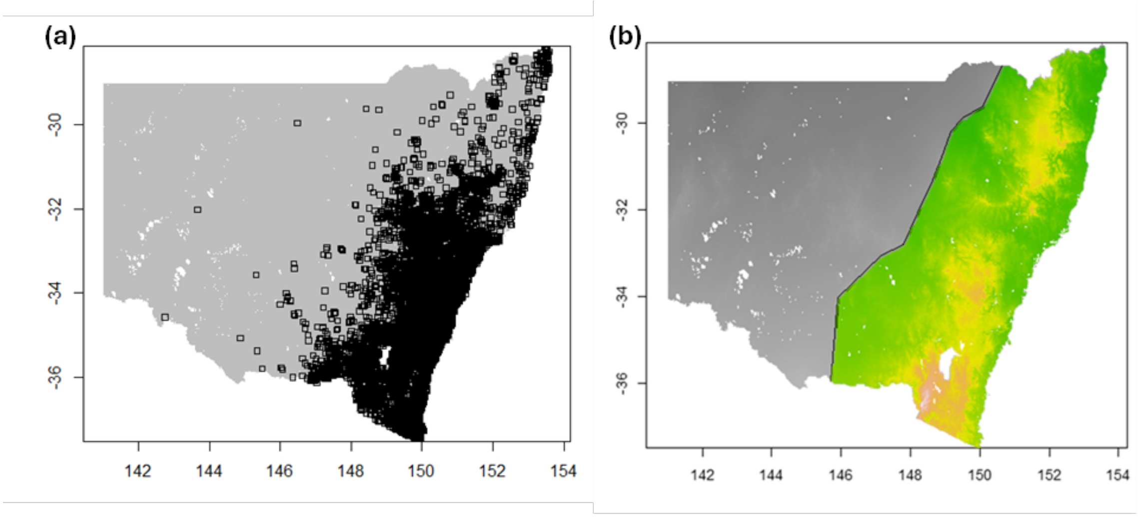
Appendix

A. 1. Identifying current and historical distribution of bare-nosed wombats

We used the current and historical distribution of bare-nosed wombats in NSW to guide transect locations and the wombat and sarcoptic mange analyses predictions. Historically, wombats were found across much more of NSW, but their range has restricted since European arrival and other factors (Carver et al., 2024). We sourced distribution and observation information from the Atlas of Living Australia (ALA, 2023), IUCN Red List of Threatened Species (Taggart et al., 2016) and Carver at al., (2024) to determine where in NSW to focus our analyses predictions. We clipped spatial layers to match the core area with the most wombat observations, making our predictions more accurate and contain relevant environmental factors, rather than covering all of NSW which is mostly ecologically irrelevant to our focus species (such as arid areas). It may not capture all wombats; however, it reflects the core distribution and the east coast habitats we used in our analyses. See below Figure A.1 for (a) the raw ALA data plotted across NSW and (b) where we clipped our spatial layers. See Table A.1 for all 90 Transects completed during the study and corresponding wombat and mange scores.



Appendix Figure A.1 Reflection of the historical and current distribution of bare-nosed wombats (*Vombatus ursinus*) across the state of New South Wales. (a) All Atlas of Living Australia unfiltered data points (which includes material citations, machine citations, observations, samples) of bare-nosed wombats from 1863 to 2023 in NSW. **(b)** the clipped area of ecological relevance for analysis and prediction, displayed as the coloured area (example using annual temperature range spatial layer) on the state of NSW.

Appendix Table A.1 **All transects which were surveyed for Bare-nosed wombats (*Vombatus ursinus*) across the east coast of New South Wales, the corresponding Local Government Area (LGA), the number of wombats counted, of those counted the ones which we were able to score for sarcoptic mange, and the number and proportion of wombats with mange.**

Transect Name	LGA	Number of Wombats Counted	Wombats Scored for mange	Number with Mange	Proportion of Mange
Aberbaldie Road transect	WALCHA	0	0	0	NA
Allgomera Creek Road transect	NAMBUCCA VALLEY	0	0	0	NA
Alpine Way transect	SNOWY MONARO REGIONAL	5	5	1	0.2
Aqua Park Road via Mount Mitchell Road transect	GLEN INNES SEVERN	0	0	0	NA
Arable Road transect	SNOWY MONARO REGIONAL	3	3	1	0.33
Back Creek Road transect	BEGA VALLEY	1	1	0	0.00
Barkers Lodge Road transect	WOLLONDILLY	1	1	0	0.00
Barry Way transect	SNOWY MONARO REGIONAL	12	12	0	0.00
Belmore Falls Road transect	WINGECARRIBEE	8	7	2	0.29
Bendeela Recreation Area via Bendeela Road and Kangaroo Valley Loop transect	SHOALHAVEN	28	28	2	0.07
Bobeyan Road transect	SNOWY MONARO REGIONAL	43	39	12	0.31
Bobundara Road transect	SNOWY MONARO REGIONAL	0	0	0	NA
Boree Valley Road transect	CESSNOCK	2	2	1	0.50
Breakfast Creek transect	MID-WESTERN REGIONAL	7	6	2	0.33
Broadwater Road transect	BEGA VALLEY	2	1	0	0.00
Brush Creek Road transect	CENTRAL COAST	0	0	0	NA
Bugong Road via Illaroo Road transect	SHOALHAVEN	12	12	2	0.17
Bylong Valley Way transect	MID-WESTERN REGIONAL	4	4	0	0.00
Candelo-Bega Road transect	BEGA VALLEY	2	2	0	0.00
Cawongla road via Rock Valley Road transect	LISMORE	0	0	0	NA
Cells River Road transect	WALCHA	0	0	0	NA
Charleys Forest Road transect	QUEANBEYAN-PALERANG REGIONAL	10	9	0	0.00

Collombatti Road Transect	KEMPSEY	0	0	0	NA
Creel Bay Road via Kosciuszko Road transect	SNOWY MONARO REGIONAL	2	2	0	0.00
Dalton Road transect	UPPER LACHLAN SHIRE	0	0	0	NA
Dam Road via Upper Warrell Creek Road transect	NAMBUCCA VALLEY	0	0	0	NA
Diamond Swamp Road transect	BATHURST REGIONAL	9	8	0	0.00
Doctor George Mountain Road transect	BEGA VALLEY	0	0	0	NA
Dooralong Road transect	CENTRAL COAST	4	4	4	1.00
Eimers Road via Shannon Vale Road transect	GLEN INNES SEVERN	0	0	0	NA
Environ Road via Duranbah Road transect	TWEED	0	0	0	NA
Fountaindale Road via Saddleback Grove	KIAMA	2	2	1	0.50
Foxground Road transect	KIAMA	1	1	0	0.00
Glen Alice Road transect	LITHGOW CITY	3	3	0	0.00
Glen Davis Road transect	LITHGOW CITY	3	3	0	0.00
Goulburn Road transect	QUEANBEYAN-PALERANG REGIONAL	0	0	0	NA
Grassy Creek Road transect	HILLTOPS	2	2	0	0.00
Great N Road transect	CESSNOCK	2	1	0	0.00
Green Gully Road via Megalong Road transect	BLUE MOUNTAINS	1	1	0	0.00
Gullies Road via Thornybush Rdtransect	SNOWY MONARO REGIONAL	1	0	0	NA
Hell Hole Forest Road transect	WALCHA	5	5	1	0.20
Imlay Road transect	BEGA VALLEY	2	1	0	0.00
Kangaroo Flat Road transect	WALCHA	1	1	0	0.00
Kings Tableland Road via Tableland Road transect	BLUE MOUNTAINS	0	0	0	NA
Kosciuszko Road transect	SNOWY MONARO REGIONAL	4	4	0	0.00
Main Arm Road transect	BYRON	0	0	0	NA
Manns Road via Rowlands Creek Road transect	TWEED	0	0	0	NA
Middlingbank Road	SNOWY MONARO REGIONAL	0	0	0	NA
Monga Lane via Tudor Valley Road transect	QUEANBEYAN-PALERANG REGIONAL	12	11	2	0.18
Moona Plains Road transect	WALCHA	0	0	0	NA

Mount Tootie Road transect	HAWKESBURY	0	0	0	NA
Mountain Lagoon Road transect	HAWKESBURY	0	0	0	NA
Murrays Run Road transect	CESSNOCK	20	19	5	0.26
Narrabarba Road transect	BEGA VALLEY	1	1	0	0.00
Nightcap Range Road via Minyon Falls Road transect	LISMORE	0	0	0	NA
Old Grafton Road transect	GLEN INNES SEVERN	0	0	0	NA
Pinkett Road transect	ARMIDALE REGIONAL	0	0	0	NA
Prestons Ridge Road via Red Hills Road and Forest Road transect	CENTRAL COAST	0	0	0	NA
Putty Road via Milbrodale Road transect	SINGLETON	0	0	0	NA
Ravensdale Road transect	CENTRAL COAST	4	3	0	0.00
Ringwood Road transect	UPPER HUNTER	0	0	0	NA
River Forest Road transect	QUEANBEYAN-PALERANG REGIONAL	8	8	0	0.00
Sapphire Road transect	UPPER LACHLAN SHIRE	0	0	0	NA
Shannons Flat Road transect	SNOWY MONARO REGIONAL	12	9	4	0.44
Smarts Road via Wardrop Valley Road transect	TWEED	0	0	0	NA
South West Rocks Road transect	KEMPSEY	0	0	0	NA
Sunny Corner Road transect	BATHURST REGIONAL	2	2	0	0.00
Taylors Flat Road transect	HILLTOPS	3	2	0	0.00
The Pocket Road transect	BYRON	0	0	0	NA
Tia Diggings Road transect	WALCHA	0	0	0	NA
Tourist Road transect	WINGECARRIBEE	12	11	0	0.00
Towamba Road transect	BEGA VALLEY	3	2	0	0.00
Turpentine Road transect	SHOALHAVEN	0	0	0	NA
Upper Cobargo Road transect	BEGA VALLEY	2	2	1	0.50
Urliup Road transect	TWEED	0	0	0	NA
Wards Mistake Road transect	ARMIDALE REGIONAL	0	0	0	NA
Warrigal Range Road transect	BEGA VALLEY	4	4	0	0.00

Watagan Forest Road transect	CENTRAL COAST	1	1	1	1.00
Wheelbarrow Road via Monkey Mountain Road transect	SHOALHAVEN	1	0	0	NA
Willi Willi Road transect	KEMPSEY	0	0	0	NA
Wisemans Ferry Road transect	CENTRAL COAST	0	0	0	NA
Wollara Road transect	UPPER HUNTER	5	4	0	0.00
Wollombi Road 1 transect	SINGLETON	1	0	0	NA
Wollombi Road 2 transect	HAWKESBURY	4	4	2	0.50
Wonboyn Road transect	BEGA VALLEY	6	6	0	0.00
Woodhill Mountain Road via Wattamolla Road transect	SHOALHAVEN	0	0	0	NA
Wyrallah Road transect	LISMORE	0	0	0	NA
Yadboro Road via Clyde Ridge Road transect	SHOALHAVEN	1	1	0	0.00
Yango Creek Road via Upper Yango Creek transect	CESSNOCK	16	14	0	0.00
Yarramalong Road transect	CENTRAL COAST	2	2	0	0.00

A. 2. Communication and engagement for informed transect surveys

Engagement has taken place with key stakeholders and community groups, including NPWS, WIRES, LAOKO Snowy Mountains Wildlife Rescue, and Cedar Creek Wombat Rescue. These discussions have provided us with valuable insights from government organisations and wombat rescue/carer/rehabilitator community regarding specific areas where wombats, both healthy and mangy, are found across New South Wales. Additionally, a collection of wombat and mange data and information from various sources, including peer-reviewed manuscripts (e.g., Stannard et al., 2021; Mayadunnage et al., 2023), reports (Noll, 2021; WildCount, 2020), freely-available data platforms (such as Atlas of Living Australia (ALA, 2023); WomSAT (WomSAT.org.au); and NSW Wildlife Rehabilitation Data Dashboard (NSW Environment, 2023)) was compiled. This local knowledge had aided in creating a preliminary list of over 150 potential spotlighting transects on public roads across the distribution of bare-nosed wombats in NSW.

A. 3. Wombat occurrence models

All models below (Table A.2) are within an AIC of 6 and are considered for analyses. Those highlighted are selected based on Richards (2008) criteria of AIC model selection, and the top model (lowest AIC) was the best AIC model and used for analyses.

Appendix Table A.2 **All considered Generalised Linear Models of predicting probability of wombat occurrence ranked via AIC. Models highlighted are those selected for consideration for variable influence.**

Intercept	z_T	z_P	z_DW	z_E	U	z_PC	z_TAR	H	df	logLik	AIC	delta	w

-2.62	-1.05			-0.79		1.03		+	5.00	-525.99	1061.98	0.00	0.10
-2.50	-1.13			-0.89	+	1.03			6.00	-525.00	1062.00	0.02	0.10
-2.46	-1.07	-0.11		-0.86	+	1.03			7.00	-524.46	1062.91	0.93	0.06
-2.47	-1.10			-0.85	+	1.03		+	7.00	-524.47	1062.94	0.96	0.06
-2.60	-0.97	-0.11		-0.74		1.02		+	6.00	-525.48	1062.96	0.98	0.06
-2.42	-1.02	-0.14		-0.80	+	1.03		+	8.00	-523.66	1063.32	1.33	0.05
-2.62	-1.07		0.07	-0.81		1.03		+	6.00	-525.67	1063.34	1.36	0.05
-2.45	-0.94	-0.29		-0.67	+	1.03	-0.20		8.00	-523.68	1063.36	1.38	0.05
-2.49	-1.16		0.06	-0.91	+	1.03			7.00	-524.73	1063.47	1.49	0.05
-2.61	-1.05			-0.81		1.03	0.04	+	6.00	-525.92	1063.85	1.86	0.04
-2.49	-1.13			-0.90	+	1.03	0.01		7.00	-525.00	1064.00	2.01	0.04
-2.46	-1.13		0.07	-0.87	+	1.04		+	8.00	-524.13	1064.27	2.29	0.03
-2.42	-0.92	-0.28		-0.66	+	1.03	-0.16	+	9.00	-523.19	1064.38	2.40	0.03
-2.61	-0.90	-0.20		-0.65		1.02	-0.11	+	7.00	-525.26	1064.53	2.55	0.03
-2.60	-1.00	-0.09	0.05	-0.77		1.02		+	7.00	-525.34	1064.67	2.69	0.03
-2.46	-1.09	-0.10	0.04	-0.88	+	1.03			8.00	-524.35	1064.71	2.72	0.03
-2.46	-1.11			-0.87	+	1.03	0.04	+	8.00	-524.39	1064.78	2.80	0.03
-2.46	-0.96	-0.29	0.07	-0.68	+	1.03	-0.23		9.00	-523.42	1064.84	2.86	0.02
-2.42	-1.05	-0.13	0.04	-0.82	+	1.03		+	9.00	-523.54	1065.07	3.09	0.02
-2.62	-1.07		0.06	-0.82		1.03	0.01	+	7.00	-525.67	1065.33	3.35	0.02
-2.50	-1.15		0.07	-0.90	+	1.03	-0.02		8.00	-524.72	1065.43	3.45	0.02
-2.42	-0.95	-0.28	0.06	-0.67	+	1.03	-0.19	+	10.00	-522.95	1065.89	3.91	0.01
-2.62	-0.93	-0.20	0.06	-0.66		1.03	-0.13	+	8.00	-525.04	1066.08	4.10	0.01
-2.46	-1.13		0.07	-0.88	+	1.03	0.02	+	9.00	-524.12	1066.25	4.27	0.01
-2.86	-1.09			-0.88		1.01			4.00	-529.50	1067.01	5.03	0.01

A. 4. All models for GLM to determine the probability a wombat will show signs of mange, given the environmental conditions the wombat was associated with.

All models below (Table A.3) are within an AIC of 6 and are considered for analyses. Those highlighted are selected based on Richards (2008) criteria of AIC model selection, and the top model (lowest AIC) was the best AIC model and used for analyses. The number of wombats in a grid cell scored for mange was also used as a predictor (log scaled) to account for differences between the numbers of wombats scored. The best ranked AIC model was used to predict the probability an individual will show signs of mange under the associated environmental conditions (Appendix Figure A.2).

Appendix Table A.3 All considered Generalised Linear Models of predicting the probability of an individual wombat will show signs of mange, given the environmental conditions only. All models selected within an AIC of 6 are highlighted. Log(nscored) is the log scaled number of wombats scored for mange per grid cell.

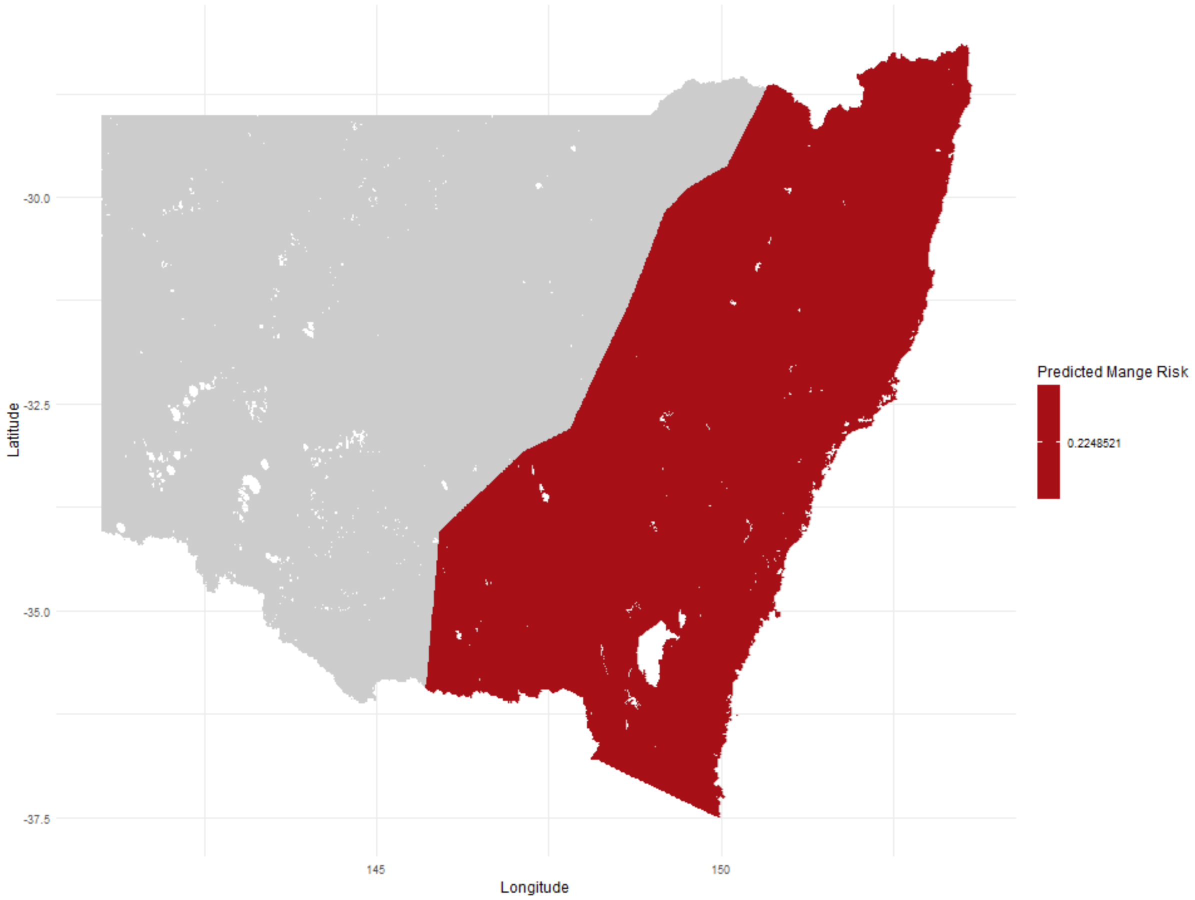
Intercept	U	log(nscored)	H	z_T	z_P	z_DW	z_E	z_TAR	df	logLik	AIC	delta	weight
-1.24									1	-90.07	182.15	0.00	0.04
-1.38		0.43							2	-89.29	182.57	0.42	0.03
-1.25						-0.20			2	-89.46	182.92	0.77	0.02
-1.25					-0.19				2	-89.58	183.16	1.01	0.02
-1.26					-0.21	-0.22			3	-88.84	183.69	1.54	0.02
-1.39		0.41			-0.18				3	-88.87	183.74	1.59	0.02
-1.24								0.12	2	-89.88	183.76	1.61	0.02
-1.24							0.10		2	-89.92	183.84	1.70	0.02
-1.36		0.35				-0.15			3	-88.98	183.96	1.81	0.01
-0.96	+								3	-89.00	184.00	1.86	0.01
-1.30			+						2	-90.02	184.04	1.89	0.01
-1.24				-0.03					2	-90.06	184.11	1.97	0.01
-1.25						-0.22		0.15	3	-89.13	184.27	2.12	0.01
-1.38		0.42						0.10	3	-89.15	184.31	2.16	0.01
-1.38		0.43					0.09		3	-89.16	184.33	2.18	0.01
-0.90	+				-0.24				4	-88.23	184.46	2.32	0.01
-1.38		0.43		-0.02					3	-89.28	184.56	2.41	0.01
-1.39		0.43	+						3	-89.29	184.57	2.42	0.01
-1.10	+	0.41							4	-88.30	184.60	2.45	0.01
-0.94	+					-0.22			4	-88.33	184.66	2.51	0.01
-0.87	+				-0.27	-0.24			5	-87.36	184.73	2.58	0.01
-1.27				0.81		-0.30	0.79		4	-88.39	184.79	2.64	0.01
-1.31			+			-0.20			3	-89.40	184.81	2.66	0.01
-1.25						-0.19	0.06		3	-89.41	184.81	2.66	0.01
-1.29				0.99	-0.28	-0.37	0.89		5	-87.42	184.84	2.70	0.01
-1.25				0.04		-0.21			3	-89.44	184.88	2.74	0.01
-1.36		0.31			-0.19	-0.17			4	-88.47	184.93	2.78	0.01
-1.25				0.49			0.56		3	-89.48	184.97	2.82	0.01
-1.25					-0.18		0.07		3	-89.50	185.01	2.86	0.01
-1.25					-0.23			-0.05	3	-89.56	185.12	2.97	0.01
-1.26			+		-0.19				3	-89.58	185.15	3.00	0.01
-1.25				0.00	-0.19				3	-89.58	185.15	3.01	0.01
-1.04	+	0.39			-0.23				5	-87.61	185.21	3.07	0.01
-1.40		0.44		0.52			0.59		4	-88.68	185.36	3.21	0.01

-1.26				0.11	-0.24	-0.26			4	-88.71	185.42	3.28	0.01
-1.36		0.32				-0.17		0.13	4	-88.75	185.50	3.36	0.01
-0.95	+						0.12		4	-88.80	185.60	3.45	0.01
-0.95	+							0.12	4	-88.81	185.63	3.48	0.01
-1.39		0.41			-0.16		0.06		4	-88.82	185.63	3.48	0.01
-1.39		0.42			-0.24			-0.08	4	-88.83	185.66	3.51	0.01
-1.26				0.19		-0.30		0.25	4	-88.83	185.67	3.52	0.01
-1.26					-0.21	-0.21	0.02		4	-88.84	185.68	3.53	0.01
-1.27			+		-0.21	-0.22			4	-88.84	185.69	3.54	0.01
-1.26					-0.22	-0.22		-0.01	4	-88.84	185.69	3.54	0.01
-1.35		0.43	+		-0.19				4	-88.85	185.70	3.55	0.01
-1.24							0.06	0.09	3	-89.85	185.70	3.55	0.01
-1.39		0.41		0.02	-0.18				4	-88.86	185.73	3.58	0.01
-1.26			+					0.11	3	-89.87	185.75	3.60	0.01
-1.24				0.02				0.13	3	-89.88	185.75	3.60	0.01
-1.00	+		+						4	-88.89	185.78	3.63	0.01
-1.29			+				0.09		3	-89.89	185.79	3.64	0.01
-1.37		0.35				-0.14	0.06		4	-88.92	185.84	3.69	0.01
-0.94	+			-0.07					4	-88.93	185.85	3.70	0.01
-1.05	+	0.32				-0.17			5	-87.93	185.86	3.71	0.01
-1.26				0.55	-0.20		0.58		4	-88.96	185.91	3.77	0.01
-1.36		0.35		0.03		-0.16			4	-88.97	185.94	3.79	0.01
-1.38		0.34	+			-0.15			4	-88.97	185.95	3.80	0.01
-1.30				1.23	-0.57	-0.33	1.28	-0.40	6	-87.01	186.02	3.88	0.01
-1.30			+	-0.02					3	-90.01	186.02	3.88	0.01
-1.37		0.32		0.78		-0.25	0.77		5	-88.01	186.03	3.88	0.01
-0.93	+					-0.23		0.15	5	-88.02	186.04	3.90	0.01
-0.97	+	0.28			-0.26	-0.20			6	-87.07	186.15	4.00	0.00
-0.89	+				-0.37			-0.16	5	-88.09	186.18	4.03	0.00
-1.25						-0.24	-0.05	0.18	4	-89.11	186.22	4.07	0.00
-1.08	+	0.41					0.12		5	-88.11	186.22	4.07	0.00
-0.89	+				-0.23		0.09		5	-88.11	186.22	4.07	0.00
-1.38		0.42					0.06	0.07	4	-89.12	186.24	4.09	0.00
-1.26			+			-0.22		0.15	4	-89.13	186.27	4.12	0.00
-1.36		0.43	+					0.11	4	-89.14	186.28	4.14	0.00
-1.38		0.42		0.03				0.11	4	-89.14	186.29	4.14	0.00
-1.27				0.80		-0.35	0.68	0.16	5	-88.15	186.30	4.15	0.00

-1.09	+	0.40						0.11	5	-88.15	186.30	4.15	0.00
-1.38		0.43	+				0.09		4	-89.16	186.32	4.18	0.00
-0.98	+		+			-0.22			5	-88.18	186.37	4.22	0.00
-1.37		0.25		0.95	-0.26	-0.32	0.86		6	-87.19	186.38	4.23	0.00
-1.27				0.90	-0.59		1.12	-0.53	5	-88.19	186.38	4.23	0.00
-0.89	+			-0.05	-0.24				5	-88.21	186.41	4.26	0.00
-0.92	+		+		-0.23				5	-88.21	186.42	4.27	0.00
-1.40		0.42		0.58	-0.19		0.61		5	-88.23	186.45	4.30	0.00
-1.08	+	0.41		-0.07					5	-88.24	186.47	4.32	0.00
-0.94	+					-0.20	0.07		5	-88.26	186.52	4.37	0.00
-1.11	+	0.40	+						5	-88.28	186.55	4.41	0.00
-0.86	+				-0.36	-0.24		-0.12	6	-87.28	186.56	4.41	0.00
-1.39		0.43	+	-0.02					4	-89.28	186.56	4.41	0.00
-0.89	+			0.06	-0.28	-0.27			6	-87.32	186.64	4.49	0.00
-0.94	+			0.00		-0.22			5	-88.33	186.66	4.51	0.00
-0.89	+		+		-0.26	-0.24			6	-87.33	186.66	4.51	0.00
-1.33			+	0.82		-0.31	0.79		5	-88.34	186.68	4.53	0.00
-1.25					-0.32		0.16	-0.20	4	-89.34	186.68	4.54	0.00
-0.87	+				-0.27	-0.24	0.03		6	-87.35	186.71	4.56	0.00
-1.43		0.45		0.96	-0.61		1.19	-0.57	6	-87.36	186.71	4.57	0.00
-1.36		0.30		0.10	-0.22	-0.20			5	-88.36	186.72	4.57	0.00
-1.30			+			-0.19	0.05		4	-89.37	186.74	4.59	0.00
-1.32			+	0.05		-0.22			4	-89.37	186.74	4.59	0.00
-0.81	+				-0.57		0.31	-0.48	6	-87.42	186.83	4.68	0.00
-1.29			+	1.00	-0.28	-0.37	0.89		6	-87.42	186.84	4.70	0.00
-1.02	+	0.40			-0.37			-0.17	6	-87.44	186.88	4.74	0.00
-1.30			+	0.50			0.56		4	-89.45	186.89	4.75	0.00
-1.33		0.33	+		-0.20	-0.17			5	-88.45	186.90	4.76	0.00
-1.25				0.47			0.52	0.05	4	-89.46	186.91	4.77	0.00
-1.36		0.32			-0.22	-0.17		-0.04	5	-88.46	186.92	4.77	0.00
-1.36		0.32			-0.19	-0.16	0.02		5	-88.46	186.92	4.77	0.00
-1.02	+	0.39			-0.22		0.09		6	-87.50	187.01	4.86	0.00
-1.25			+		-0.18		0.07		4	-89.50	187.01	4.86	0.00
-1.35		0.28		0.16		-0.24		0.21	5	-88.54	187.08	4.93	0.00
-1.27			+		-0.23			-0.06	4	-89.55	187.10	4.95	0.00
-1.25				-0.01	-0.24			-0.06	4	-89.56	187.11	4.96	0.00
-1.00	+			0.79	-0.30	-0.35	0.72		7	-86.56	187.11	4.96	0.00

-1.26			+	0.01	-0.19				4	-89.57	187.15	5.00	0.00
-0.92	+			0.78	-0.77		1.13	-0.73	7	-86.59	187.17	5.02	0.00
-1.02	+	0.39		-0.04	-0.22				6	-87.59	187.18	5.03	0.00
-1.01	+			0.34			0.44		5	-88.61	187.21	5.06	0.00
-1.04	+	0.39	+		-0.23				6	-87.61	187.21	5.06	0.00
-1.39		0.42			-0.32		0.16	-0.23	5	-88.63	187.25	5.10	0.00
-1.26				0.15	-0.17	-0.28		0.10	5	-88.66	187.33	5.18	0.00
-1.40		0.44		0.51			0.56	0.03	5	-88.67	187.34	5.19	0.00
-1.40		0.31		1.21	-0.59	-0.27	1.30	-0.45	7	-86.67	187.35	5.20	0.00
-1.40		0.44	+	0.52			0.59		5	-88.68	187.36	5.21	0.00
-1.04	+			0.65		-0.28	0.65		6	-87.68	187.37	5.22	0.00
-1.03	+	0.30				-0.19		0.13	6	-87.69	187.38	5.23	0.00
-1.29			+	0.11	-0.24	-0.26			5	-88.70	187.41	5.26	0.00
-0.98	+		+				0.11		5	-88.72	187.44	5.29	0.00
-0.96	+			1.06	-0.73	-0.29	1.26	-0.60	8	-85.74	187.48	5.33	0.00
-1.33		0.33	+			-0.17		0.14	5	-88.74	187.48	5.33	0.00
-0.95	+						0.08	0.07	5	-88.74	187.49	5.34	0.00
-1.36		0.31				-0.18	-0.03	0.14	5	-88.75	187.49	5.34	0.00
-0.98	+		+					0.10	5	-88.77	187.54	5.40	0.00
-1.34		0.43	+		-0.17		0.07		5	-88.78	187.57	5.42	0.00
-0.94	+	0.40			-0.56		0.31	-0.49	7	-86.79	187.57	5.43	0.00
-0.95	+			-0.03				0.11	5	-88.81	187.61	5.46	0.00
-1.37		0.43	+		-0.24			-0.07	5	-88.82	187.65	5.50	0.00
-0.97	+		+	-0.07					5	-88.83	187.65	5.51	0.00
-1.39		0.42		-0.01	-0.24			-0.08	5	-88.83	187.66	5.51	0.00
-1.26					-0.24	-0.20	0.04	-0.05	5	-88.83	187.66	5.51	0.00
-1.27			+	0.19		-0.30		0.25	5	-88.83	187.66	5.52	0.00
-1.26			+		-0.21	-0.21	0.02		5	-88.84	187.68	5.53	0.00
-1.27			+				0.06	0.08	4	-89.84	187.68	5.54	0.00
-1.27			+		-0.22	-0.22		-0.01	5	-88.84	187.68	5.54	0.00
-1.05	+	0.33				-0.15	0.08		6	-87.84	187.69	5.54	0.00
-1.36		0.43	+	0.01	-0.19				5	-88.85	187.69	5.55	0.00
-1.36		0.28		0.78		-0.29	0.69	0.13	6	-87.86	187.73	5.58	0.00
-1.26			+	0.02				0.12	4	-89.87	187.74	5.59	0.00
-1.07	+	0.29	+			-0.17			6	-87.88	187.76	5.61	0.00
-0.96	+			0.13		-0.29		0.22	6	-87.88	187.77	5.62	0.00

-0.96	+			0.37	-0.23		0.45		6	-87.89	187.78	5.63	0.00
-1.15	+	0.42		0.37			0.47		6	-87.89	187.79	5.64	0.00
-1.07	+	0.42		0.82	-0.78		1.18	-0.76	8	-85.90	187.79	5.65	0.00
-0.83	+			-0.14	-0.43			-0.26	6	-87.91	187.83	5.68	0.00
-1.37		0.35	+			-0.14	0.06		5	-88.92	187.84	5.69	0.00
-1.05	+	0.33		-0.01		-0.16			6	-87.93	187.86	5.71	0.00
-1.27			+	0.55	-0.20		0.58		5	-88.96	187.91	5.77	0.00
-1.39		0.34	+	0.03		-0.16			5	-88.96	187.92	5.77	0.00
-0.96	+	0.29			-0.36	-0.19		-0.14	7	-86.97	187.93	5.79	0.00
-1.35			+	1.25	-0.58	-0.33	1.31	-0.43	7	-86.98	187.95	5.80	0.00
-0.95	+		+			-0.23		0.13	6	-87.98	187.96	5.81	0.00
-1.39		0.31	+	0.78		-0.25	0.77		6	-88.01	188.02	5.87	0.00
-0.93	+					-0.24	-0.03	0.17	6	-88.01	188.03	5.88	0.00
-0.92	+		+		-0.38			-0.19	6	-88.02	188.03	5.88	0.00
-0.98	+	0.27		0.05	-0.27	-0.22			7	-87.05	188.09	5.95	0.00
-0.81	+				-0.49	-0.18	0.20	-0.34	7	-87.06	188.11	5.96	0.00
-0.97	+	0.28			-0.25	-0.19	0.04		7	-87.06	188.12	5.97	0.00
-0.97	+	0.27	+		-0.25	-0.20			7	-87.07	188.14	6.00	0.00



Appendix Figure A.2 **Predicted probability a wombat will show signs of mange given the environmental variables across southeastern New South Wales.** There was no strong association with any environmental variables, with the only prediction across NSW for a wombat showing signs of mange was 0.23.

A.5. All models for GLM to determine the probability a surveyed cell will show evidence of mange, given the associated landscape and host variables.

All models below (Table A.4) are within an AIC of 6 and are considered for analyses. Those highlighted are selected based on Richards (2008) criteria of AIC model selection, and the top model (lowest AIC) was the best AIC model and used for analyses.

Table A.4 **All considered Generalised Linear Models of predicting relative risk of mange to wombats, given the environmental and host variables. Models highlighted are those selected for consideration for variable influence.**

Intercept	z_T	z_P	z_DEN	z_DW	z_E	U	z_PO	z_TAR	H	df	logLik	AIC	delta	weight
-28.97	-10.95	-0.87	-0.55		-7.65	+	-32.42	-1.38	+	10	-77.96	175.91	0.00	0.07
-29.21	-11.67		-0.70		-8.55	+	-32.80	-0.44	+	9	-79.26	176.53	0.62	0.05
-26.34	-10.40		-0.53		-7.79	+	-29.43		+	8	-80.35	176.70	0.79	0.05

-28.29	-10.48	-0.88	-0.56	-0.21	-7.34	+	-31.63	-1.34	+	11	-77.53	177.05	1.14	0.04
-28.78	-9.50	-0.96			-6.60		-31.26	-1.17	+	7	-81.58	177.15	1.24	0.04
-25.48	-9.31		-0.33		-6.96		-27.73		+	6	-82.63	177.27	1.36	0.04
-25.35	-9.78		-0.55	-0.25	-7.35	+	-28.27		+	9	-79.70	177.40	1.48	0.03
-23.99	-8.49				-6.26		-26.01		+	5	-83.76	177.52	1.61	0.03
-29.02	-9.96	-0.84	-0.29		-7.00		-31.58	-1.14	+	8	-80.84	177.67	1.76	0.03
-24.27	-8.58		-0.35	-0.26	-6.42		-26.32		+	7	-81.87	177.73	1.82	0.03
-28.16	-11.10		-0.70	-0.19	-8.17	+	-31.57	-0.39	+	10	-78.91	177.83	1.92	0.03
-27.81	-9.57	-1.07			-6.54	+	-30.71	-1.35	+	9	-80.03	178.05	2.14	0.02
-27.67	-8.79	-0.95		-0.24	-6.11		-29.98	-1.07	+	8	-81.04	178.07	2.16	0.02
-22.93	-7.78			-0.24	-5.74		-24.76		+	6	-83.10	178.21	2.30	0.02
-27.76	-11.08	0.15	-0.62		-8.29	+	-31.09		+	9	-80.18	178.36	2.45	0.02
-26.74	-9.78		-0.39		-7.20		-29.12	-0.24	+	7	-82.25	178.49	2.58	0.02
-27.94	-9.28	-0.84	-0.29	-0.24	-6.55		-30.33	-1.06	+	9	-80.28	178.56	2.65	0.02
-23.71	-8.34	-0.12			-6.18		-25.70		+	6	-83.59	179.19	3.28	0.01
-27.09	-9.04	-1.06		-0.21	-6.18	+	-29.85	-1.27	+	10	-79.60	179.21	3.30	0.01
-25.51	-9.33	0.01	-0.34		-6.97		-27.76		+	7	-82.63	179.27	3.36	0.01
-26.17	-10.20	0.08	-0.59	-0.23	-7.66	+	-29.23		+	10	-79.65	179.30	3.39	0.01
-24.38	-8.61				-6.30		-26.43	-0.10	+	6	-83.68	179.37	3.46	0.01
-22.29	-7.39	-0.20		-0.30	-5.50		-24.05		+	7	-82.69	179.38	3.47	0.01
-23.72	-8.76				-6.46	+	-26.12		+	7	-82.70	179.39	3.48	0.01
-25.29	-9.01		-0.39	-0.23	-6.67		-27.46	-0.16	+	8	-81.70	179.41	3.50	0.01
-23.84	-8.34	-0.07	-0.32	-0.28	-6.25		-25.84		+	8	-81.82	179.64	3.73	0.01
-22.98	-7.80			-0.24	-5.75		-24.82	-0.01	+	7	-83.10	180.21	4.30	0.01
-22.86	-8.15			-0.23	-6.02	+	-25.10		+	8	-82.14	180.29	4.38	0.01
-23.26	-8.55	-0.12			-6.33	+	-25.61		+	8	-82.53	181.07	5.16	0.01
-24.22	-8.93				-6.52	+	-26.68	-0.12	+	8	-82.58	181.17	5.26	0.01
-3.61				-0.34			-2.47			3	-87.73	181.46	5.55	0.00
-22.03	-7.71	-0.19		-0.28	-5.72	+	-24.16		+	9	-81.77	181.55	5.64	0.00
-3.83		-0.24		-0.37			-2.68			4	-86.93	181.87	5.95	0.00

A. 6. Environmental variables removed from analyses

Predictor variable	Data Source	Literature	Removal reason
Soil Attributes Classified using the Australian Soil Classification (ASC) into 7 categories	NSW Government – SEED. The Central Resource for Sharing and Enabling Environmental Data in NSW. Downloaded 19 September 2023	Soil could be a factor for liveability, burrow making ability and preference by wombats, and underlying habitat structure of plants can be determined by soil.	Removed from all analyses due to low sample sizes in categories and low convergence with models.

based on specific properties and characteristics: *Vertosols, Chromosols and Dermosols, Sodosols and Kurosols, Rudosols and Tenosols, Calcarosols, Podosols, Other Special Soil Types* (distinct properties which set them apart from other categories).	DQS - Great Soil Group (GSG) Soil Type map of NSW Date Created 19 July 2021 https://datasets.seed.nsw.gov.au/dataset/great-soil-group-gsg-soil-type-map-of-nsw Downloaded from: https://datasets.seed.nsw.gov.au/dataset/great-soil-group-gsg-soil-type-map-of-nsw/resource/b0d9ad7f-6cac-49f2-b09d-ea83cdaba58d		
Precipitation Seasonality (Coefficient of Variation)	Biodiversity & Climate Change Virtual Laboratory (BCCVL; bccvl.org.au); collated from the period of 1976–2005	It is known that rainfall can influence wombat occurrence and suitability (Ringwaldt et al., 2023; Carver et al 2021). Although used in previous SDM models for wombats (Ringwaldt et al., 2023), we considered and then removed Precipitation Seasonality from the analysis.	Removed from analyses due to the scale of NSW, the environmental variable gradient was not biologically plausible within this wombat system.

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