

Preregistration

Preregistration for Replication Study of spatial range of the wingless grasshopper *Phaulacridium vittatum* using trait-based data and NicheMapR

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Study Information

Title	Preregistration for Replication Study of spatial range of the wingless grasshopper <i>Phaulacridium vittatum</i> using trait-based data and NicheMapR
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Description	Thermodynamic constraints limit how species grow, breed, and survive in a given environment based on their energy and water needs. Animals occupy specific ther-
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modynamic niches, which can be used to model population abundances and distributions in changing environments (M. R. Kearney & Porter, 2020). In 2008, M. Kearney et al. (2008) used a trait-based approach to investigate the spatial range of the invasive cane toad *Bufo marinus* in Australia . Rather than relying on species occurrences observations, M. Kearney et al. (2008) linked the physical traits with spatial data through biophysical models and were able to predict range expansion under a warming climate. In 2020, M. R. Kearney & Porter (2020) developed NicheRMap, a R package which implements mechanistic niche modeling for heat, water, energy and mass exchange between any kind of ectothermic organism and its environment. While traditionally used for reptiles and amphibians, M. R. Kearney & Porter (2020) posited that this software could be applied to a broad range of ectotherms. Here, we attempt to use NicheMapR to forecast distribution patterns for the grasshopper species *Phaulacridium vittatum* in response to climate change. Similar to the cane toad, *P. vittatum* is also an invasive ectothermic pest that has become widespread in Australia and whose range will likely shift with changing temperatures (Yadav, Stow, & Dudaniec, 2019). We aim to replicate the methods of M. Kearney et al. (2008), using updated methodology with NicheMapR. We will examine energy budgets and plasticity for *P. vittatum* by assessing traits such as size, pigmentation, and sex.

Hypotheses	Modelling the mechanistic niche of <i>P. vittatum</i> with the software NicheMapR independently of species distribution and relying only on trait-based data is possible, and will reveal that the distribution range of <i>P. vittatum</i> is predicted to expand as the climate warms.
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Design Plan

Study type	Observational Study. Data is collected from study subjects that are not randomly assigned to a treatment. This includes surveys, natural experiments, and regression discontinuity designs.
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Blinding	No blinding is involved in this study.
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Study design	<p>We conducted a pilot study involving exploratory analyses on simulated <i>P. vittatum</i> data. This preliminary analysis served to help us determine the best approach to applying NicheMapR software to a new ectothermic species. Simulated data was gathered from a dataset of measured grasshopper traits that had been randomly modified. For simplicity, we only included female grasshoppers from site 1. We inputted weight, solar absorptivity, and temperature threshold data into our model to create niche constraints. This initial study will help reveal what sampling size is needed, and additional variables we need to consider for a true analysis. For this study we only sampled during mid June and it may be helpful to consider how winter temperature affects these variables.</p>
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Once we have established a suitable analysis plan we will collect more data from the field. We will then run the model again, using true values for both sexes and all sites. This will help us develop a map of suitable *P. vittatum* habitat under current conditions and test whether this matches true range distribution data for this species. Assuming our model correctly predicts current grasshopper distribution, we can then predict how *P. vittatum*'s range will shift with climate change by running the model under different temperature change scenarios. Further details on methodology will be provided below.

Randomization	Enter your response here.
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Sampling Plan

Existing data	Registration prior to creation of data. As of the date of submission of this research plan for preregistration, the data have not yet been collected, created, or realized.
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**Explanation of
existing data**

We conducted an initial pilot study with a small sample size to test the field and modelling methodology used in other papers. These six samples included only female grasshoppers from one site, and made use of ectotherm data (in the form of constant factors) relevant to our study species from previously published literature (Harris, 2012; Hewitt, 1979). We have confirmed that using traits from this small sample size, we are able to successfully predict species distribution and tolerant temperatures for this species using the NicheMapR modelling with existing microclimate data from a single site. We aim to expand this study with a larger sample size of both males and females over a larger spatial area (multiple sites) but have not yet collected this data. As such, we are unaware of patterns across sites or across sex. We will not be using the data from the six individuals we have used for the pilot study in this pre-registered study, but will keep the modelling workflow that we have established. Accordingly, we have the necessary environmental data needed to run the microclimate modeling portion of NicheMapR for all sites, yet we have only produced this data for a singular site and the remaining microclimates have not been computed.

Existing microclimate data: six sample sites were selected across the species latitude. Each site was within driving distance of one other, to shorten the period over which physical data would be collected. The sites selected are locations of research stations as this increases the availability of information about the landscape, and increases the replicability of the study, as the locations are both easy to find and likely to remain relatively unchanged. Each site has available meteorological data, soil surveys, and elevation. Some areas, such as Butler's gorge, contain multiple soil types (Key, 1992). Where this is the case, we will note the soil type from directly below where the grasshoppers were collected. We selected areas of flat land as changes to aspect and slope can lead to changes in the relevant biotic and abiotic factors (Pemberton, 2001).

Existing ectotherm data - six specimens were collected from each site. Each specimen's sex and weight were recorded. Some variables were tested in the field, and some have been assumed as constant, which were identified in the work of Harris (2012) and Hewitt (1979). These variables include the temperature at which individuals leave shelter to bask; minimum basking temperature; minimum foraging temperature; the maximum temperature at which activity occurs; and preferred

temperature for each sex. As in (Harris, 2012), solar absorptivity (or reflectance) was measured using an Ocean Optics USB2000 spectrophotometer. The box in which the grasshoppers were placed had a base of sand glued to cardboard. Heat lost through surface area has been set to 0.02%, which is approximately 10% of what is lost by semi-fossorial skinks (*Liopholis* spp.), which have larger eyes, mouths, and a great portion of their surface area touches the ground (M. R. Kearney & Porter, 2020; Wu, Alton, Clemente, Kearney, & White, 2015). The grasshopper *Taeniopoda eques* will shift their posture to perpendicular to the sun (Whitman, 1987), and this has also been observed by us with *P. vittatum*.

**Data collection
procedures**

We plan to visit each site and perform sample collection within a two-week period in both June and December. The six sites are within driving distance and have a range of latitudes while keeping longitude relatively constant. *P. vittatum* is commonly found at each site.

At each site, grasshoppers will be collected during daylight hours by hand with a sweep net and soil type, sex and weight will be recorded. As in Harris (2012), solar absorptivity (or reflectance) will be measured using an Ocean Optics USB2000 spectrophotometer at a measurement angle of 45 degrees in a box with a base of sand glued to cardboard. This process will be repeated until the required sample number is achieved.

Microclimate data will be generated using the NicheMapR with inputs of latitude, longitude, soil type, elevation, slope, aspect and for each site. Other input parameters were kept standard across all sites and include the sky remaining clear of clouds, the minimum level of shading, whether the model will be computing soil moisture (Yes), the length of time the results should be calculated for (1 year), solar attenuation resulting from atmospheric dust, the height at which the temperature is considered for (distance between the ectotherm in question and the ground, and general soil properties.

Sample size

We aim to collect 100 grasshoppers per site during two periods of the year - June (winter) and December (summer). As we have selected 6 sites, this will result in 600 grasshoppers per season.

Sample size rationale	The above sample size was chosen to allow for higher statistical power while simultaneously considering personnel and time constraints in collecting field data.
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Stopping rule	Not applicable.
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Variables

Manipulated variables	No manipulated variables.
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Measured variables	<p>This pilot study involved considering many variables to properly structure our model. Data was collected on the critical temperature range <i>P. vittatum</i> survives in (°C). This data also included the maximum temperature <i>P. vittatum</i> remains active in, and the minimum temperatures (°C) it needs to forage and bask and which temperatures it prefers overall. Some of these values were measured from the field while others were taken from the literature.</p>
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The weight (g), sex, and solar absorbtivity of every captured grasshopper was noted. Their posture was also recorded as *P. vittatum* will sometimes position itself based on the position of the sun. Because *P. vittatum* cannot burrow well, it was given a value of 1 (on a scale of 10) for minimum and maximum burrowing depth.

For each site, data was either noted on site or simulated using the model. Latitude, longitude, the date of sampling, and cloud cover were recorded for each site. Each site was characterised by its soil type, elevation, and minimum and maximum percentage of shade that it received. Because sites were on flat land, aspect and slope were recorded as zero degrees. Reflectance, was defined as the fraction of light that was reflected off the ground and could vary between 0 (total absorption) and 1 (total reflection). A value of 0.15 was input into the model for site 1 to simulate bare soil. Campbell's Program 11.1 was used to simulate soil moisture based on soil depth and vegetation cover (Campbell, 1985).

Indices	Enter your response here.
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Analysis Plan

Statistical models

The hypothesis will be tested using mechanistic statistical modelling as the basis for a species distribution model. A mechanistic approach, as opposed to a correlative approach, will allow us to examine the relationship between underlying factors, when considering the relationship between an organism and its environment, based on environmental data and a biophysical model of the organism. The model we will use is NicheMapR (M. R. Kearney & Porter, 2020).

The variables to be included are:

Microclimate:

Longitude and latitude, number of years to be calculated by the model, soil type, elevation, soil moisture, the level of shade available to the specimen being modelled, whether the sky is clear, Reference height of the specimen (at what temperature above ground should the model calculate temperatures for), slope, aspect, ground reflectance, soil profile, irradiance, and solar attenuation due to dust in the atmosphere.

Ectotherm:

The wet weight of the animal, the percentage of surface area acting as a free-water exchanger, solar absorptivity, species shape, the temperature at which the specimen will leave retreat to bask, the specimen's minimum and maximum foraging temperatures, the species thermal minimum and maximum, maximum temperature at which activity occurs, temperature preference, the depth the species burrow to, whether they are shade seeking, whether it can climb, if it's nocturnally active, its crepuscular activity, whether it's diurnally active.

Ectotherm code will be used to compute a basic biophysical model of the organism. The microclimate model will set its external conditions. By changing the external conditions, and the information relating to the ectotherms, over multiple runs, one can see in which locations survival is possible, and make extrapolations about their range.

The model can be checked for accuracy by comparing the data in the model to their current and known distribution, as well as past distributions. Should the

model predict distributions accurately, then the information is available for future extrapolations.

Transformations	The model includes many functions which can be included or omitted from the model by entering the code assigned to the category. Soil type, shape and posture have multiple options to select between. For example, soil type includes options such as clay, loam, silt, and silty clay. Each of which corresponds to a specific number. Most other categorical variables are simply turned on or off by adding <- 0, or <- 1 after the variable name. This applies to rumoist, runshade, clearsky, run.gads, IR, soilgrids, shade_seek, burrow, clumb, nocturn, crepus, dirun.
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Inference criteria	The known current distribution of <i>P. vittatum</i> will be considered baseline information and compared with distribution patterns observed from our model with a Mann-Whitney U test. A p-value > 0.05 would be interpreted as substantial evidence of the accuracy of the NicheMapR in modelling distribution patterns of <i>P. vittatum</i> and will be utilized in predicting their likely distribution patterns under a warming climate.
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Data exclusion	Beside the quality control checks performed for weight data, no checks were performed to determine eligibility for inclusion. All data collected except the wet weight data were included in the analysis. The excluded wrong wet weight data was replaced with modelled values.
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Missing data	The calibration procedure employed to set up the weighing scale was erroneous and resulted in the recording of wrong wet weight values. Hence, the allometric model by (Bidau, Taffarel, & Castillo, 2016) was used to generate wet weight values from the other morphometric parameters recorded. All variables used to parameterize the model were collected in the field except CT_max, CT_min, diurnal activity and delta_shade which were sourced from a report by (M. R. Kearney & Porter, 2020) as it was not viable to take these measurements in the field.
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Exploratory analyses (optional) Not applicable.

Other

Other (Optional) Not applicable.

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