Preregistration

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

Garland Xie[1], Michael Mensah[2], Claire Paillard[3], Nicole Lerminiaux[2], Alex Coverley[4]

[1] University of Toronto Scarborough

[2] University of Regina

[3] University of Northen British Columbia

[4] University of British Columbia

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Study Information

Title Preregistration for the replication study of spatial range of the wingless grasshopper *Phaulacridium vittatum* using trait-based data and NicheMapR

Description Thermodynamic constraints limit how species grow, breed, and survive in a given environment based on their energy and water needs. Animals occupy specific thermodynamic niches, which can be used to model population abundances and distributions in changing environments (M. R. Kearney & Porter, 2020). 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. M. R. Kearney & Porter (2020) developed 'NicheMapR,' an R package which implements mechanistic niche modeling for heat, water, energy, and mass exchange between ectothermic organisms 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 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 the 'NicheMapR' R package. We will examine energy budgets and plasticity for *P. vittatum* by assessing ecological traits such as body size, solar absorbtivity, and sex.

Hypotheses We hypothesize that if we model *P. vittatum*'s mechanistic niche using the software NicheMapR, and rely only on trait-based data rather than species occurrence data, we will be able to determine the range *P. vittatum* occupies. We predict that because *P. vittatum* is well adapted to high temperatures (Yadav, Stow, & Dudaniec, 2019), its range will expand under a warming climate.

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.

Blinding No blinding is involved in this study.

Study design We conducted a pilot study involving exploratory analyses on simulated *P. vittatum* data. This preliminary analysis optimized our 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 a single site. We inputted wet weight, solar absorptivity, and temperature threshold data into our model to create niche constraints. This initial study helped reveal what sampling size is needed, and additional variables we need to consider for a true analysis. For this preliminary study we only sampled during mid-June, but we will additionally sample during summer (December) in our main study.

As we have now established a suitable analysis plan, we plan to 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.

Randomization Not applicable.

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.

Explanation of existing data Existing microclimate data: Six sample sites were selected across the species latitude while keeping longitude relatively constant. All sites are within driving distance to shorten the period over which physical data would be collected. A research station is located at each site, which increases the availability of information about the landscape and has available meteorological data, soil surveys, and elevation information. Some areas, such as Butler's gorge, contain multiple soil types (Key, 1992). If applicable, we will note the soil type from directly below where the grasshoppers were collected. We will sample in 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: Some physical traits of *P. vittatum* 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. 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 behaviour has also been observed in *P. vittatum*.

In our preliminary study, we tested the NicheMapR modelling using six female grasshoppers from a single site, and made use of ectotherm traits from previously published literature as described above (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.

Data collection procedures

We plan to visit six sites and perform sample collection within a two-week period in both June (winter) and December (summer). *P. vittatum* is commonly found at each site.

At each site, grasshoppers will be collected during daylight hours on days with clear skies using a sweep net. Soil type, sex and wet 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.

Stopping rule

Not applicable.

Variables

Manipulated variables	No manipulated variables.
Measured variables	We plan to use the previously published constants for temperature thresholds (°C) that *P. vittatum* survives and responds to. These values differ between males and females. Certain categorical variables like posture, burrowing depth, diurnal, nocturnal and crepuscular activity will be taken from the literature. For example, burrowing depth is measured on a scale of one to ten and because *P. vittatum* cannot burrow well, it will be given a value of one. CT_max (critical thermal maximum), CT_min (critical thermal minimum), diurnal activity and delta_shade were sourced from M. R. Kearney & Porter (2020), as it was not viable to take these measurements in the field. The wet weight (g), sex (M/F), and solar absorbtivity (%) of every captured grasshopper will be measured in the field. The geographic coordinates, elevation, date, and soil type of every sampling site will be recorded. To keep sampling consistent, sites were selected based on certain criteria. For example, sites must be flat (so their aspect and slope will be zero), they must be completely unshaded for at least part of the day (minimum shade will be 0% because of bare ground at sites), and they will be sampled on a day with clear skies. Some variables were computed using the model. For example, 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 will be input into the model to simulate bare soil. Campbell's (1985) Program 11.1 will be used to simulate soil moisture based on soil depth and vegetation cover (Campbell, 1985).
Indices	All measured values and constant values from the literature will be combined into the Niche Map R software to produce a model of the temperature activity of *P. vittatum* plotted against the month of the year.

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 (Figure 1). The model we will use is NicheMapR (M. R. Kearney & Porter, 2020).

The variables to be included are:

1) Microclimate model (i.e., environmental data)

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.

2) Biophysical ecotherm model (i.e., ecological traits and environmental data)

The wet weight of the animal, the percentage of surface area acting as a free-water exchanger, solar absorbtivity, 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.

Analytical workflow:

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 (see Figure 1).

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.

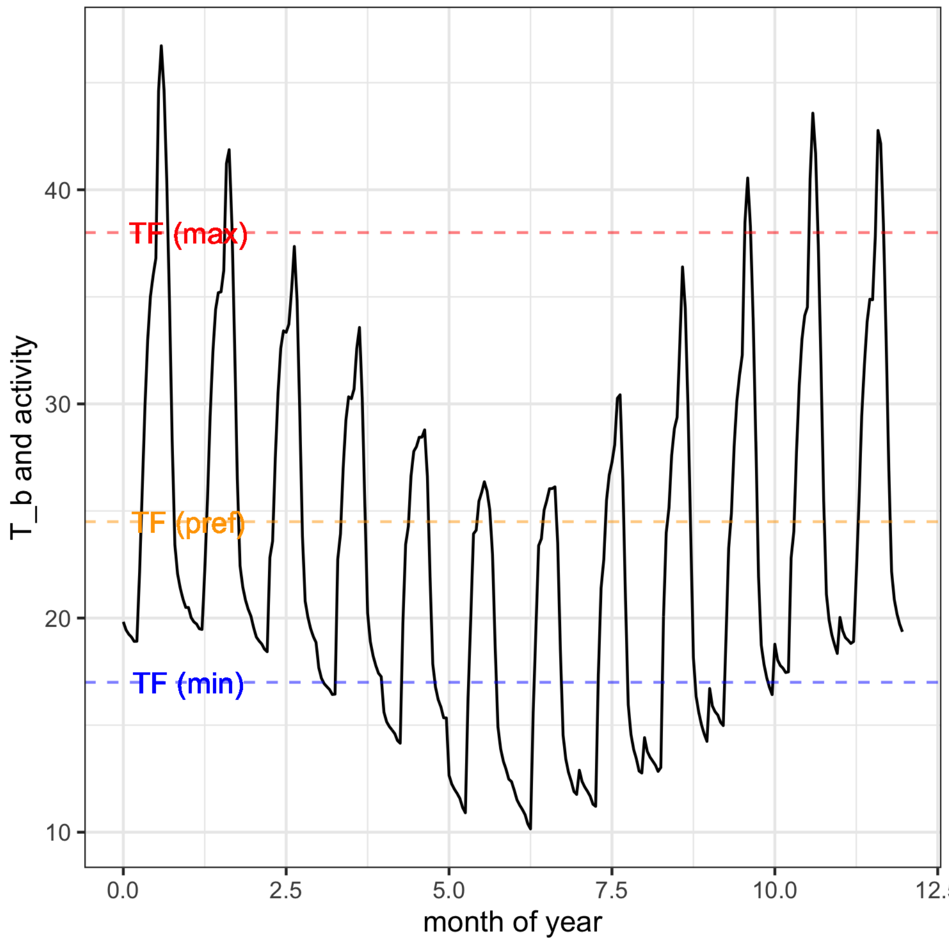

Figure 1: Activity of female *Phaulacridium* in Tasmania under zero shade. Inactivity from exceeding its maximum foraging temperature represents T_F Max, dropping below the minimum foraging temperature represents T_F Min, and TF (pref) represents the prefereed temperature.

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 other parameters such as rumoist, runshade, clearsky, run.gads, IR, soilgrids, shade_seek, burrow, climb, nocturn, crepus, and diurn.

Inference criteria

The known current distribution of *P. vittatum* 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 *P. vittatum* and will be used in predicting their likely distribution patterns under a warming climate.

Data exclusion

Beside the quality control checks performed for weight data, no checks will be performed to determine data 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.

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.

Exploratory analyses (optional)

Not applicable.

Other

Other (Optional) Not applicable.

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