**Temporal response of mammal body size to temperature**

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**Abstract**

Needed lit:

\*Only studies with endotherms and intraspecific

* Lots of studies that support Bergmann’s rule: Ashton, 2002; Brown & Lee, 1969; Freckleton et al., 2003
* Impact of size on three specific eco aspects
  + Metabolic rates: Brown et al., 2004
  + Interspecific interactions
  + Ecosystem processes such as energy flux: Dickie et al., 1987
* Eco factors that affect size
  + General = Yom-Tom & Geffen, 2011 (Fig. 1)
  + Usable area/island size: Lomolino, 2005
  + Anthropogenic fragmentation: Lomolino & Perault, 2007
  + Resource availability: McNab 2010
* Temporal Bergmann’s/directional temperature change on size over time
  + Teplitsky et al., 2008: decrease in size over time of red-billed gulls is phenotypic plasticity, not genetic response; negative correlation between size and temp, size change due to less food?; only a single species!
  + Yom-Tom & Geffen, 2011: good review of main drivers (temp and resource availability) of temporal and geographic size change. Need to accurately document change in size over time (sample size, measurements used, season collected), and determine cause of change (cyclical cycles, temp correlated with other abiotic factors). Most mammals increased, most birds decreased.
  + Van Buskirk et al., 2010: lots of bird species got smaller over decades with increasing temperature at single site in PA
  + Husby et al., 2011: documented negative relationship between mass and temp across time for three bird species over decades. Food abundance more important than temp.
  + Canale et al., 2016: some size metrics indicated decrease in size with increase in temp for marmot
  + Smith et al., 1998: negative temp-mass relationship across time for woodrat species
  + Skim two main papers

**Introduction**

Current and future changes in the climate of the planet, in particular increasing global temperatures, have potential direct implications for the sizes of organisms. The relationship between the size of endotherm species and temperature is generally negative. This pattern is referred to as Bergmann’s rule due to it being initially described by the German biologist Karl Bergmann (Bergmann, 1847). Evidence for the prevalence of this rule among endotherm species has been documented for over a century [bunch of sources]. It has therefore recently been predicted that, due to increasing temperatures from climate change, endotherm species will be decreasing in size in the near future (Gardner et al., 2011; Sheridan and Bickford, 2011). Organismal size is an important ecological characteristic that affects many aspects of ecosystems, including resource use [source], interspecific interactions [source], and ecosystem processes [source]. Because of the diverse impacts of body size, changing sizes due to climate change could result in drastic changes in ecosystems.

There is some evidence that a negative temperature-body size relationship is not as common among endotherm species as previously believed (Riemer et al., 2018). [spatial specifically] Even if this relationship does occur, it is possible that the many other factors that affect body size in addition to temperature in ecosystems, including predator-prey interactions [source] and resource availability [source], have a more substantial impact. If temperature increases do not have a strong and directional impact on body size, it will be more difficult to predict how climate change will shift species body sizes. It is crucial to be able to predict these size changes because of the importance of size on the functioning of ecological systems. How body size responds to temperature over time also have been examined infrequently, though it has been shown that x [source] and y [source] and documented decreasing sizes due to global change? [sources]. It is especially important to understand how size will change dynamically from shifting temperatures.

We addressed temporal shifts in body size due to temperature by compiling long-term time series of mammal communities from three locations. This consisted of size measurements for 128,710 individuals, which were used to determine average mass of 32 species across at least 5 years. This was combined with a global temperature dataset to determine the strength and direction of the relationship between species mass and temperature, and how temperature and species mass changed over the time period. We were able to show how mammal size is impacted by temperature over time. This data-intensive approach addresses limitations of previous work on the temperature-mass relationship, which consisted of studies on single species and meta-analyses derived from those studies.

**Methods**

*Datasets*

Data for size came from small mammal time series datasets, which had to contain mass measurements for individuals and have at least ten years of continuous data. Two of the sites, Portal and Fray Jorge, are long term experimental plots that are used to examine and manipulate community dynamics in the mammal and plant communities. Portal is located in the United States in southeastern Arizona while Fray Jorge is in the national park of the same name in Chile. These datasets (Portal citation, Fray Jorge citation) were downloaded using the Data Retriever (citation), with additional metadata taken from Ecological Archives. The Sevilleta dataset is from a Long Term Ecological Research project in the southwestern United States, which is of interest because it is at the intersection of several major biomes. The mammal time series is collected at eight sites that are in close proximity, and was downloaded, along with metadata, from the University of New Mexico digital repository (Sevilleta citation). The locations of the three sites are shown in Fig. 1.

The final dataset compiled and cleaned from these three sites consisted of 32 species from 128,710 individual records (Table 1). From each dataset, we retained only individual records that were identified as a rodent species, had an associated mass measurement, and were indicated as adults. For the two experimental sites, Portal and Fray Jorge, only individuals collected from control treatments were included. We kept all instances of the same individual being recaptured, which is common at these sites. We additionally only included individuals from species for which we had at least 15 individuals collected that year (temporal change in size shown at 14 specimens/year for mammals and body mass; Yom-Tom & Geffen, 2011), and species that had at least five years of data with a sufficient number of individuals. The final mass dataset contained one record per individual. The final mass dataset contained the mean and standard deviation of mass for each species in each year at each site.

This mass dataset was combined with a temperature dataset to extract relevant temperatures at each site for each species. The temperature dataset was a global raster of temperature values, with a spatial resolution of 0.5 degree latitude by 0.5 degree longitude and a temporal resolution of monthly average values from 1900 to 2014. It is created and maintained by the University of Delaware and National Oceanic and Atmospheric Administration (dataset citation). The coordinates for each of the three sites were determined from metadata or related citations (Aguilera et al., 2016), and were used to extract all of the monthly temperatures for each of the sites from the temperature dataset. Mean annual temperatures were calculated from the monthly temperatures, and then were combined with the mass dataset so that each species had the corresponding temperature for that year.

*Analysis*

We determined how both temperature and species sizes changed over time at each site. While we visually examined how temperature and mass both varied over time, we also completed a linear regression for each species, comparing each year’s average mass with the corresponding average annual temperature. We calculated and compiled the r values from these regressions to evaluate the strength and direction of this relationship among all species at each site. To explicitly include the change over time in mass in response to temperature, we compared the change in temperature to the percent change in each species mass over the time period they had sufficient data for. We calculated the absolute change in temperature from the first year for each species to the last year, and the percent change in mass from the beginning to end.

We additionally did a dynamic regression model of the mass time series for each species in order to determine the effect the temperature time series had. We used an auto ARIMA model, after determining that this accorded with what we would choose the order of the model to be. After adding the external variable of temperature, we checked the residuals for the model. Because of the large number of p-values generated (one per species), we took into account the impact of multiple comparisons by adjusting the p-values using the Benjamini & Hockberg method (citation). We used R for all cleaning and analysis (citation), including the R packages x, y, z. All code and data downloads are provided reproducibly on GitHub (https://github.com/KristinaRiemer/temporal\_MRT) and archived on Zenodo (citation).

**Results**

Expectations: expect negative r values; expect change temp/change time to be in narrow band from upper left to lower right; expect significant contribution from temp time series to mass time series

Diagnostics supp

P1

* General conclusions across all sites
* 3 panel fig

P2

* Portal
  + Panel A: Temp tended to (increase/decrease)
  + Panel B: Of x species, y increased in size and z decreased in size
  + Panel C: Proportion of mrt relationships that were pos, neg, none were repectively x%, y%, and z%
* Fray Jorge
  + Panel A: Temp tended to (increase/decrease)
  + Panel B: Of x species, y increased in size and z decreased in size
  + Panel C: Proportion of mrt relationships that were pos, neg, none were repectively x%, y%, and z%
* Sevilleta
  + Panel A: Temp tended to (increase/decrease)
  + Panel B: Of x species, y increased in size and z decreased in size
  + Panel C: Proportion of mrt relationships that were pos, neg, none were repectively x%, y%, and z%

**Discussion**

* Other factors that affect change over size that could obscure/change signal: time of year/body condition, reproductive state (difficulties with assessing temporal size change and its causes in Yom-Tov & Geffen, 2011)
* Importance of looking at dynamic changes in mass, and using concurrent changes to determine what causes it (but it’s not temp)
* If changes are phenotypic or genotypic

**Acknowledgements**

**References**

**Main figures**

* Site dataset metrics
* Site location map
* Yearly temp, yearly mass, mrt combined, and r distribution per site
* Mass change over time compared to temp change over time by species
* Table/plot of ARIMA model p-values

**Supplemental figures**

* Yearly mass split out by species
* Mrt split out by species
* Figures of ARIMA model diagnostics by species