1
2 **No general relationship between mass and temperature in endothermic species**
3
4
5 Kristina Riemer[1*], Robert P Guralnick[2], Ethan White[1,3]
6
7
8
9
10 Bergmann's rule is a widely-accepted biogeographic rule stating that individuals within a species
11 are smaller in warmer environments. While there are many single-species studies and integrative
12 reviews documenting this pattern, a data-intensive approach has not been used yet to determine
13 the generality of this pattern. We assessed the strength and direction of the intraspecific
14 relationship between temperature and individual mass for 952 bird and mammal species. For
15 eighty-seven percent of species, temperature explained less than 10% of variation in mass, and
16 for 79% of species the correlation was not statistically significant. These results suggest that
17 Bergmann's rule is not general and temperature is not a dominant driver of biogeographic
18 variation in mass. Further understanding of size variation will require integrating multiple
19 processes that influence size. The lack of dominant temperature forcing weakens the justification
20 for the hypothesis that global warming could result in widespread decreases in body size.
21
22
23
24
25
26
27 [1]Department of Wildlife Ecology and Conservation, 110 Newins-Ziegler Hall, PO Box 110430,
28 University of Florida, Gainesville, FL 32611-0430, USA
29 [2]Department of Natural History, University of Florida, Gainesville, FL 32611
30 [3]Informatics Institute, 432 Newell Drive, PO Box 115585, University of Florida, Gainesville, FL
31 32611-8545
32
33 Correspondence and requests for materials should be addressed to K.R. (email:
34 kristina.riemer@weecology.org)
35
36
37
38
39
40
41
42
43
44
45
46
47

INTRODUCTION

Bergmann's rule describes a negative relationship between body mass and temperature across space that is believed to be common in endothermic species (Bergmann, 1847; Brown and Lee, 1969; Kendeigh, 1969; Freckleton et al., 2003; Carotenuto et al., 2015). Many hypotheses have been proposed to explain this pattern (Blackburn et al., 1999; Ashton, 2002; Watt et al., 2010) including the heat loss hypothesis, which argues that the higher surface area to volume ratio of smaller individuals results in improved heat dissipation in hot environments (Bergmann, 1847). Though originally described for closely-related species (i.e., interspecific; Blackburn et al., 1999), the majority of studies have focused on the intraspecific form of Bergmann's rule (Rensch, 1938; Meiri, 2011) by assessing trends in individual size within a species (Langvatn and Albon, 1986; Gardner et al., 2009; Yom-Tov and Geffen, 2006). Bergmann's rule has been questioned both empirically and mechanistically (McNab, 1971; Geist, 1987; Huston and Wolverton, 2011; Teplitsky & Millien, 2014) but the common consensus from recent reviews is that the pattern is general (Ashton, 2002; Watt et al., 2011; Ashton et al., 2000; Meiri and Dayan, 2003).

It has recently been suggested that this negative relationship between mass and temperature could result in decreasing individual size across species in response to climate change (Sheridan and Bickford, 2011) and that this may be a "third universal response to warming" (Gardner et al., 2011). The resulting shifts in size distributions could significantly alter ecological communities (Brose et al., 2012), especially if the rate of size decrease varies among species (Sheridan and Bickford, 2011). While there is limited empirical research on body size responses to changes in temperature through time (but see Teplitsky and Millien, 2014; Smith et al., 1995; Caruso et al., 2014), the apparent generality of Bergmann's rule across space indicates the likelihood of a similar relationship in response to temperature change across time.

72   The generality of Bergmann's rule is based on many individual studies that analyze

73   empirical data on body size across an environmental gradient (e.g., Langvatn and Albon, 1986;

74   Barnett, 1977; Fuentes and Jaksic, 1979; Dayan et al., 1989; Sand et al., 1995) and reviews that

75   compile and evaluate the results from these studies (Ashton, 2002; Watt et al., 2010; Meiri and

76   Dayan 2003). Most individual studies of Bergmann's rule are limited by: 1) analyzing only one

77   or a few species (e.g., Langvatn and Albon, 1986); 2) using small numbers of observations (e.g.,

78   Fuentes and Jaksic, 1979); 3) only including data at the small scales typical of ecological studies

79   (e.g., Sand et al., 1995); 4) using latitude instead of directly assessing temperature (e.g., Barnett,

80   1977); and 5) focusing on statistical significance instead of the strength of the relationship (e.g.,

81   Dayan et al., 1989). The reviews tabulate the results of these individual studies and assess

82   patterns in the direction and significance of relationships across species. Such aggregation of

83   published results allows for a more general understanding of the pattern but, in addition to

84   limitations of the underlying studies, the conclusions may be influenced by publication bias and

85   selective reporting where studies or individual analyses that do not support Bergmann's rule are

86   published less frequently (Koricheva et al., 2013).

87   Previous analyses of publication bias in the context of Bergmann's rule have found no

88   evidence for selective publication, which supports the idea that it is a general rule (Ashton, 2002;

89   Meiri et al., 2004). However, two of the most extensive studies of Bergmann's rule, which both

90   used museum records to assess dozens of intraspecific Bergmann's rule relationships

91   simultaneously, found that the majority of species did not exhibit significant negative

92   relationships between latitude and size (McNab, 1971; Meiri et al., 2004). As a result,

93   understanding the generality of this ecophysiological rule and its potential implications for global

94   change requires more extensive analysis.

95   A data-intensive approach to analyzing Bergmann's rule, evaluating the pattern using

96   large amounts of broad scale data, has the potential to overcome existing limitations in the

97   literature and provides a new perspective on the generality of the intraspecific form of

98   Bergmann's rule. Understanding the generality of the temperature-mass relationship has

99   important implications for how size will respond to climate change. We use data from Vertnet

100   (Constable et al., 2010), a large compilation of digitized museum records that contains over

101   700,000 globally distributed individual-level size measures, to evaluate the intraspecific

102   relationship between temperature and mass for 952 mammal and bird species. The usable data

103   consist of 273,901 individuals with an average of 288 individuals per species, with individuals of

104   each species spanning an average of 75 years and 34 latitudinal degrees. This approach reduces

105   or removes many of the limitations to previous approaches and the results suggest that

106   Bergmann's rule is not a strong or general pattern.

107

108

109   **RESULTS**

110   Most of the species in this study showed weak non-significant relationships between

111   temperature and mass (Figures 1 and 2). The distribution of correlation coefficients was centered

112   near zero with a mean correlation coefficient of -0.05 across species (Figure 2A). Relationships

113   for 79% of species were not significantly different from zero, while 14% of species' relationships

114   were significant and negative and 7% were significant and positive (Figure 2A). Temperature

115   explained less than 10% of variation in mass (i.e., $-0.316 < r < 0.316$) for 87% of species,

116   indicating that temperature explained very little of the observed variation in mass for these

117   species (Figure 2A).

118   The weak, non-directional intraspecific relationships indicated by the distribution of

119   correlation coefficients are consistent across taxonomic groups and temporal lags. Mean

120   correlation coefficients for both endothermic classes are -0.006 and -0.065, for mammals and

121   birds respectively (Figure 2B). Similarly, correlation coefficient distributions were

122   approximately centered on zero for all of the 30 orders analyzed ($-0.2 < \bar{r} < 0.003$ for orders with

123   more than 10 species; Figure 3 and Figure 3—figure supplement 1), or for migrant or nonmigrant

124   bird species (Figure 2-figure supplement 1). Correlation coefficient distributions for temperature-

125   mass relationships using lagged temperatures were centered around zero like those using

126   temperature from the collection year (Figure 4 and Figure 4–figure supplement 1), indicating that

127   there was not a temporal lag effect on the response of species' masses to temperature. Correlation

128   coefficients did not vary systematically by sample size (Figure 5A), extent of variation in

129   temperature or mass (Figure 5B,C), species' average mass (Figure 5D), or species' average

130   latitude (Figure 5E). While temperature is considered the actual driver, some studies use latitude

131   as a proxy when evaluating variation in size (Bergmann, 1847; Stillwell, 2010) Using latitude,

132   the mean correlation coefficient was -0.05 with no statistically significant latitude-mass

133   relationship for 71% of species (Figure 2–figure supplement 2), while the respective values for

134   temperature were -0.05 and 79% (Figure 2A). Results were robust to a variety of decisions and

135   stringencies about how to filter the size (Figure 2–figure supplement 3 and 4) and species data

136   (Figure 2—figure supplement 5 and 6).

137

138   **DISCUSSION**

139   In contrast to conventional wisdom and several recent review papers, our analysis of 952

140   species shows little to no support for a negative intraspecific temperature-mass relationship that

141   is sufficiently strong or common to be considered a biogeographic rule. Three quarters of bird

142   and mammal species show no significant change in mass across a temperature gradient and

143   temperature explained less than 10% of intraspecific variation in mass for 87% of species (Figure

144   2A). This was true regardless of taxonomic group (Figure 2 and 3), temporal lag in temperature

145   (Figure 4), species' size, location, or sampling intensity or extent (Figure 5). These results are

146   consistent with two previous studies that examined museum specimen size measurements across

147   latitude. The first study showed that 22 out of 47 North American mammal species studied had

148   no relationship between latitude and length, and 10 of the 25 significant relationships were

149   opposite the expected direction (McNab, 1971). The second found a similar proportion of non-

150   significant results (42/87), but a lower proportion of significant relationships that opposed the

151   rule (9/45) for carnivorous mammals (Meiri et al., 2004). While more species had significant

152   negative relationships than positive in both our study and these two museum-based studies, in all

153   cases less than half of species had significant negative correlations (14 – 41%). In combination

154   with these two smaller studies, our results suggest that there is little evidence for a strong or

155   general Bergmann's rule when analyzing raw data instead of summarizing published results.

156   Our results are inconsistent with recent reviews, which have reported that the majority of

157   species conform to Bergmann's rule (Ashton, 2002; Watt et al., 2010; Meiri and Dayan, 2003).

158   While these reviews included results that were either non-significant or opposite of Bergmann's

159   rule, the proportion of significant results in support of Bergmann's rule was higher and therefore

160   resulted in conclusions that supported the generality of the temperature-mass relationship.

161   Generalizing from results in the published literature involves the common challenges of

162   publication bias and selective reporting (Koricheva et al., 2013). In addition, because the

163   underlying Bergmann's rule studies typically report minimal statistical information, often

164   providing only relationship significance or direction instead of p-values or correlation

165   coefficients (Meiri and Dayan, 2003), proper meta-analyses and associated assessments of

166   biological significance are not possible. While several reviews found no evidence for publication

167   bias using limited analyses (Ashton, 2002; Meiri et al., 2004), the notable differences between

168   the conclusions of our data-intensive approach and those from reviews suggests that publication

169   bias in papers about Bergmann's rule warrants further investigation. These differences also

170   demonstrate the value of data-intensive approaches in ecology for overcoming potential

171   weaknesses and biases in the published literature. Directly analyzing large quantities of data

172   from hundreds of species allows us to assess the generality of patterns originally reported in

173   smaller studies while avoiding the risk of publication bias. This approach also makes it easier to

174   integrate other factors that potentially influence size into future analyses. The new insight gained

175   from this data-intensive approach demonstrates the value of investing in large compilations of

176   ecologically-relevant data (Hampton et al., 2013) and the proper training required to work with

177   these datasets (Hampton et al., 2017).

178   Our analyses and conclusions are limited to the intraspecific form of Bergmann's rule.

179   This is the most commonly studied and well-defined form of the relationship and the one most

180   amenable to analyses using large compilations of museum data. Difficulty in interpreting

181   Bergmann's original formulation has resulted in an array of different ideas and implementations

182   of interspecific analyses (Blackburn et al., 1999; Meiri and Thomas, 2007; Watt et al., 2010;

183   Meiri, 2011). The most common forms of these interspecific analyses involve correlations

184   between various species-level size metrics and environmental measures and are conducted at

185   various taxonomic levels from genus to class (e.g., Clauss et al., 2013; Diniz-Filho, 2007; Boyer

186   et al., 2010; Blackburn and Gaston, 1996). Efforts to apply data-intensive approaches to the

187   interspecific form of this relationship will need to address the fact that occurrence records are not

188   evenly distributed across the geographic range of species and determine how the many

189   interpretations of interspecific Bergmann's rule are related to one another and the biological

190   expectations for interspecific responses to temperature.

191   The original formulation of Bergmann's rule, and the scope of our conclusions, apply

192   only to endotherms. However, negative temperature-mass relationships have also been

193   documented in ectotherms, with the pattern referred to as the size-temperature rule (Ray, 1960;

194   Angilletta and Dunham, 2003). In contrast to the hypotheses for Bergmann's rule, which are

195   based primarily on homeostasis (Gardner et al., 2011), the size-temperature rule in ectotherms is

196   thought to result from differences between growth and development rates (Forster et al., 2011).

197   The current version of Vertnet contained ectotherm size data for only seven species, which is not

198   sufficient to complete a comprehensive analysis of the ectotherm size-temperature rule. Future

199   work exploring the ectotherm size-temperature rule in natural systems using data-intensive

200   approaches is necessary for understanding the generality of this rule in ectotherms, and data may

201   be sought for this effort in the literature or via a coordinated effort by museums to continue

202   digitizing size measurements for specimens.

203   A number of mechanisms have been suggested to explain why higher temperatures

204   should result in lower body sizes, including heat loss, starvation, resource availability, migratory

205   ability, and phylogenetic constraints (Blackburn et al., 1999). Most of the proposed hypotheses

206   have not been tested sufficiently to allow for strong conclusions to be drawn about their potential

207   to produce Bergmann's rule (Blackburn et al., 1999; Watt et al., 2010; Teplitsky and Millien,

208   2014) and the widely studied heat loss hypothesis has been questioned for a variety of reasons

209   (Blackburn et al., 1999; Watt et al., 2010; McNab, 1971; James, 1970; McNamara et al., 2016).

210   While no existing hypotheses have been confirmed, it is possible that some processes are

211   producing negative relationships between size and temperature. The lack of a strong relationship

212   does not preclude processes that result in a negative temperature-mass relationship, but it does

213   suggest that these processes are have less influence relative to other factors that influence

214   intraspecific size.

215   The relative importance of the many factors besides temperature that can influence size

216 within a species is as yet unknown. Size is affected by abiotic factors such as humidity and

217 resource availability (Teplitsky and Millien, 2014), characteristics of individuals like clutch size

218 (Boyer et al., 2009), and community context, including if and what kinds of gaps there are in

219 size-related niches (Smith et al., 2010) and the trophic effects of primary productivity on

220 consumer size (Sheridan and Bickford, 2011). Temperature itself can have indirect effects on

221 size, such as via habitat changes in water flow or food availability, that result in size responses

222 opposite of Bergmann's rule (Gardner et al., 2011). Anthropogenic influences have been shown

223 to influence the effect of temperature on size (Faurby and Araùjo, 2016), and similar impacts of

224 dispersal, extinctions, and the varying scales of climate change have been proposed (Clauss et

225 al., 2013). Because our data primarily came from North America, further analyses focused on

226 species native to other continents could reveal differing temperature-mass relationships due to

227 varying temperature regimes. While our work shows that more species have negative significant

228 relationships between temperature and mass than positive, only 21% of species have statistically

229 significant relationships and it consequently appears that some combination of other factors more

230 strongly drives intraspecific size variation for most taxa.

231   The lack of evidence for temperature as a primary determinant of size variation in

232 endothermic species calls into question the hypothesis that decreases in organism size may

233 represent a third universal response to global warming. The potentially general decline in size

234 with warming was addressed by assessments that evaluated dynamic body size responses to

235 temperature using similar approaches to the Bergmann's rule reviews discussed above (Teplitsky

236 and Millien, 2014; Sheridan and Bickford, 2011; Gardner et al., 2011). These temporal reviews

237 had similar results to those for spatial relationships, but the conclusions of these studies clearly

238 noted the variability in body size responses and the need for future data-intensive work (Sheridan

239 and Bickford, 2011; Gardner et al., 2011) using broader temperature ranges (Teplitsky and

9

240   Millien, 2014) to fully assess the temperature-size relationship.

241   Our results in combination with those from other studies suggest that much of the

242   observed variation in size is not explained simply by temperature. While there is still potential

243   for the size of endotherms, and other aspects of organismal physiology and morphology, to

244   respond to both geographic gradients in temperature and climate change, these responses may

245   not be as easily explained solely by temperature as has been suggested (Sheridan & Bickford,

246   2011; Gardner et al., 2011). This requires that future attempts to explain variation in the size of

247   individuals across space or time use an integrative approach to include the influence of multiple

248   factors, and their potential interactions, on organism size. This will be facilitated by analyzing

249   spatiotemporal data similar to that used in this study, which includes wide ranges of time, space,

250   and environmental conditions for large numbers of species and individuals. This data-intensive

251   approach provides a unique perspective on the general responses of bird and mammal species to

252   temperature, and has potential to assist in further investigation of the complex combinations of

253   factors that determine biogeographic patterns of endotherm size and how species respond to

254   changes in climate.

255

256   **METHODS**

257   **Data**

258   Organismal data were obtained from Vertnet, a publicly available data platform for

259   digitized specimen records from museum collections primarily in North America, but also

260   includes global data (Constable et al., 2013). Body mass is routinely measured when organisms

261   are collected, with relatively high precision and consistent methods, by most field biologists,

262   whose intent is to use those organisms for research and preservation in natural history collections

263   (Winker, 2000; Hoffmann, 2010). These measurements are included on written labels and

264   ledgers associated with specimens, which are digitized and provided in standard formats, e.g.,

265   Darwin Core (Wieczorek, 2012). In addition to other trait information, mass has recently been

266   extracted from Darwin Core formatted records published in Vertnet and converted to a more

267   usable form (Guralnick et al., 2016). This crucial step reduces variation in how these

268   measurements are reported by standardizing the naming conventions and harmonizing all

269   measurement values to the same units (Guralnick et al., 2016). We downloaded the entire

270   datasets for Mammalia, Aves, Amphibia, and Reptilia available in September 2016 (Bloom et al.,

271   2016a; Bloom et al., 2016b; Bloom et al., 2016c; Bloom et al., 2016d) using the Data Retriever

272   (Morris and White, 2013) and filtered for those records that had mass measurements available.

273   Fossil specimen records with mass measurements were removed.

274   We only analyzed species with at least 30 georeferenced individuals whose collection

275   dates spanned at least 20 years and collection locations at least five degrees latitude, in order to

276   ensure sufficient sample size and spatiotemporal extent to accurately represent each species'

277   temperature-mass relationship. To determine if these thresholds were appropriate, we

278   additionally explored the impact of increasing and decreasing them (Figure 2–figure supplement

279   5 and 6). We selected individual records with geographic coordinates for collection location,

280   collection dates between 1900 and 2010, and species-level taxonomic identification, which were

281   evaluated to assure no issues with synonymy or clear taxon concept issues. To minimize

282   inclusion of records of non-adult specimens, we identified the smallest mass associated with an

283   identified adult life stage category for each species and removed all records with mass values

284   below this minimum adult size. Results were not qualitatively different due to either additional

285   filtering based on specimen lifestage (Figure 2–figure supplement 3) or removal of outliers

286   (Figure 2–figure supplement 4). Temperatures were obtained from the Udel_AirT_Precip global

287   terrestrial raster provided by NOAA from their website at http://www.esrl.noaa.gov/psd/, a 0.5

288 by 0.5 decimal degree grid of monthly mean temperatures from 1900 to 2010 (Willmott and

289 Matsuura, 2001). For each specimen, the mean annual temperature at its collection location was

290 extracted for the year of collection.

291   This resulted in a final dataset containing records for 273,901 individuals from 952 bird

292 and mammal species (MSB Mammal Collection (Arctos), 2015; Ornithology Collection

293 Passeriformes - Royal Ontario Museum, 2015; MVZ Mammal Collection (Arctos), 2015; MVZ

294 Bird Collection (Arctos), 2015; KUBI Mammalogy Collection, 2016; CAS Ornithology (ORN),

295 2015; DMNS Bird Collection (Arctos), 2015; UCLA Donald R, 2015; DMNS Mammal

296 Collection (Arctos), 2015; UAM Mammal Collection (Arctos), 2015; UWBM Mammalogy

297 Collection, 2015; UAM Bird Collection (Arctos), 2015; UMMZ Birds Collection, 2015; CUMV

298 Bird Collection (Arctos), 2015; CUMV Mammal Collection (Arctos), 2015; MLZ Bird

299 Collection (Arctos), 2015; LACM Vertebrate Collection, 2015; CHAS Mammalogy Collection

300 (Arctos), 2016; Ornithology Collection Non Passeriformes - Royal Ontario Museum, 2015;

301 KUBI Ornithology Collection, 2014; MSB Bird Collection (Arctos), 2015; Biodiversity

302 Research and Teaching Collections - TCWC Vertebrates, 2015; TTU Mammals Collection,

303 2015; CAS Mammalogy (MAM), 2015; Vertebrate Zoology Division - Ornithology, Yale

304 Peabody Museum, 2015; University of Alberta Mammalogy Collection (UAMZ), 2015; UAZ

305 Mammal Collection, 2016; Conner Museum, 2015; SBMNH Vertebrate Zoology, 2015; Cowan

306 Tetrapod Collection - Birds, 2015; Cowan Tetrapod Collection - Mammals, 2015; NMMNH

307 Mammal, 2015; Schmidt Museum of Natural History_Mammals, 2015; USAC Mammals

308 Collection, 2013; MLZ Mammal Collection (Arctos), 2015; Ohio State University Tetrapod

309 Division - Bird Collection (OSUM), 2015; AMNH Mammal Collections, 2015; DMNH Birds,

310 2015; CM Birds Collection, 2015; WNMU Mammal Collection (Arctos), 2015; UCM Mammals

311 Collection, 2015; UWYMV Bird Collection (Arctos), 2015; NCSM Mammals Collection, 2015;

12

312   Vertebrate Zoology Division - Mammalogy, Yale Peabody Museum, 2015; HSU Wildlife

313   Mammals, 2016; WNMU Bird Collection (Arctos), 2015; UWBM Ornithology Collection, 2015;

314   UCM Birds, 2015; University of Alberta Ornithology Collection (UAMZ), 2015; SDNHM Birds

315   Collection, 2015). The average number of individuals per species was 288, ranging from 30 to

316   15,415 individuals. The species in the dataset were diverse, including volant, non-volant,

317   placental, and marsupial mammals, and both migratory and non-migratory birds. There were

318   species from all continents except Antarctica, though the majority of the data were concentrated

319   in North America (Figure 1A). The distribution of the species' mean masses was strongly right-

320   skewed, as expected for broad scale size distributions (Brown and Nicoletto, 1991), with 74% of

321   species having average masses less than 100 g. Size ranged from very small (3.7 g desert shrew

322   *Notiosorex crawfordi* and 2.6 g calliope hummingbird *Stellula calliope*) to very large (63 kg

323   harbor seal *Phoca vitulina* and 5.8 kg wild turkey *Meleagris gallopavo*). These specimen data

324   and code have been deposited online in the Dryad Data Repository (http://datadryad.org/).

325

326   **Analysis**

327   We fit the intraspecific relationship between mean annual temperature and mass for each

328   species with ordinary least squares linear regression (e.g., Figure 1B,C,D and Figure 1–figure

329   supplement 1-12) using the statsmodels.formula.api module in Python (Seabold and Perktold,

330   2010). The strength of each species' relationship was characterized by the correlation coefficient

331   and its significant at alpha of 0.05. When assessing statistical significance with large numbers of

332   correlations it is important to consider the expected distribution of these correlations under the

333   null model that no correlation exists for any species.

334   We addressed this issue by using false discovery rate control (Benajmini and Hochberg,

335   1995) implemented with the stats package in R (R Core Team, 2016). This method determines

336   the expected distribution of values for p (or Z) in the case where no relationship exists for

337   individual correlation and adjusts observed values to control for excessive false positives.

338   Specifically, it maintains the Type I error rate (proportion of false positives) across all tests at the

339   chosen value of alpha and therefore gives an accurate estimate of the number of significant

340   relationships (Benajmini and Hochberg, 1995). This allows us to estimate the number of species

341   with true positive and negative correlations (i.e., those that have values that exceed those

342   expected from the null distribution). We then compared the number of species with positive and

343   negative correlation coefficients, and the proportion of those with statistically significant

344   adjusted p-values.

345   We investigated various potential correlates of the strength of Bergmann's rule. Because

346   it has been argued that Bergmann's rule is exhibited more strongly by some groups than others

347   (McNab, 1971), we examined correlation coefficient distributions within each class and order.

348   Additionally, distributions for migrant and nonmigrant bird species were compared due to

349   conflicting evidence about the impact of migration on temperature-mass relationships (Ashton,

350   2002). As a temporal lag in size response to temperature is likely due to individuals of a species

351   responding to temperatures prior to their collection year (e.g., Stacey and Fellowes, 2002), we

352   assessed species' temperature-mass relationships using temperatures from 1 to 110 years prior to

353   collection year. We also examined the relationship between species' correlation coefficients and

354   five variables to understand potential statistical and biological influences on the results. We did

355   so with the number of individuals, temperature range, and mass range to determine if the

356   relationship was stronger when more data points or more widely varying values were available.

357   Because it has been argued that Bergmann's rule is stronger in larger species (Steudel et al.,

358   1994) and at higher latitudes (Freckleton et al., 2003; Faurby and Araùjo, 2016), we examined

359   variability with both mean mass and mean latitude for each species. We also conducted all

14

360   analyses using latitude instead of mean annual temperature.

361

362

Acknowledgements

364   Thanks to all of the Vertnet data providers, Dan McGlinn for assistance with developing this

365   research, and Rafael LaFrance for his trait extraction work.

366

Competing financial interests

368   No competing financial interests

369

370

371

372

373
374   **REFERENCES**
375
376   AMNH Mammal Collections. American Museum of Natural History. Source:
377   http://ipt.vertnet.org:8080/ipt/resource.do?r=amnh_mammals (source published on 2015-
378   02-12, accessed on 2017-10-19)
379   Angilletta, Michael J, and Arthur E Dunham. "The Temperature-Size Rule in Ectotherms:
380   Simple Evolutionary Explanations May Not Be General." *American Naturalist* 162, no. 3
381   (2003): 332–42. doi:10.1086/377187.
382   Ashton, KG, MC Tracy, and Alan De Queiroz. "Is Bergmann's Rule Valid for Mammals?" *The*
383   *American Naturalist* 156, no. 4 (2000): 390–415.
384   Ashton, KG. "Patterns of Within-species Body Size Variation of Birds: Strong Evidence for
385   Bergmann's Rule." *Global Ecology and Biogeography* 11 (2002): 505–23.
386   Barnett, Raymond J. "Bergmann â   S Rule and Variation in Structures Related to Feeding in
387   the Gray Squirrel." *Evolution* 31, no. 3 (1977): 538–45.
388   Benajmini, Yoav, and Yosef Hochberg. "Controlling the False Discovery Rate : A Practical and
389   Powerful Approach to Multiple Testing Author (S): Yoav Benjamini and Yosef Hochberg
390   Source : Journal of the Royal Statistical Society . Series B (Methodological), Vol . 57 , No
391   . 1 Published by :" *J R Statist Soc B* 57, no. 1 (1995): 289–300.
392   Bergmann, C. "Uber Die Verhaltnisse Der Warmekonomie Der Tiere Zu Ihrer Grosse."
393   *Gottinger Studien* 3 (1847): 595–708.

441   23, accessed on 2017-10-19)

442 Clauss, Marcus, Marie T. Dittmann, Dennis W H Müller, Carlo Meloro, and Daryl Codron.
443   "Bergmann′s Rule in Mammals: A Cross-Species Interspecific Pattern." *Oikos* 122, no. 10
444   (2013): 1465–72. doi:10.1111/j.1600-0706.2013.00463.x.

445 CM Birds Collection. Carnegie Museum of Natural History. Source:
446   http://ipt.vertnet.org:8080/ipt/resource.do?r=cm_birds (source published on 2015-10-11,
447   accessed on 2017-10-19)

448 Conner Museum. Charles R. CRCM Vertebrate Collection. Source:
449   http://ipt.vertnet.org:8080/ipt/resource.do?r=crcm_verts (source published on 2015-10-13,
450   accessed on 2017-10-19)

451 Constable, Heather, Robert Guralnick, John Wieczorek, Carol Spencer, A. Townsend Peterson,
452   Hank Bart, John Bates, et al. "VertNet: A New Model for Biodiversity Data Sharing." *PLoS*
453   *Biology* 8, no. 2 (2010): 1–4. doi:10.1371/journal.pbio.1000309.

454 Cowan Tetrapod Collection - Birds. University of British Columbia Beaty Biodiversity Museum.
455   Source: http://ipt.vertnet.org:8080/ipt/resource.do?r=ubc_bbm_ctc_birds (source published
456   on 2015-04-07, accessed on 2017-10-19)

457 Cowan Tetrapod Collection - Mammals. University of British Columbia Beaty Biodiversity
458   Museum. Source: http://ipt.vertnet.org:8080/ipt/resource.do?r=ubc_bbm_ctc_mammals
459   (source published on 2015-04-07, accessed on 2017-10-19)

460 CUMV Bird Collection (Arctos). Cornell University Museum of Vertebrates. Source:
461   http://ipt.vertnet.org:8080/ipt/resource.do?r=cumv_bird (source published on 2015-10-26,
462   accessed on 2017-10-19)

463 CUMV Mammal Collection (Arctos). Cornell University Museum of Vertebrates. Source:
464   http://ipt.vertnet.org:8080/ipt/resource.do?r=cumv_mamm (source published on 2015-10-
465   26, accessed on 2017-10-19)

466 Dayan, Tamar, Eitan Tchernov, Yoram Yom-tov, and Daniel Simberloff. "Ecological Character
467   Displacement in Saharo-Arabian Vulpes : Outfoxing Bergmann â   S Rule." *Oikos* 55, no.
468   2 (1989): 263–72.

469 Diniz-Filho, José Alexandre F., Luis Mauricio Bini, Miguel Á. Rodríguez, Thiago Fernando L.
470   V. B. Rangel, and Bradford a. Hawkins. "Seeing the Forest for the Trees: Partitioning
471   Ecological and Phylogenetic Components of Bergmann's Rule in European Carnivora."
472   *Ecography* 30, no. 4 (August 2007): 598–608. doi:10.1111/j.2007.0906-7590.04988.x.

473 DMNH Birds. Delaware Museum of Natural History. Source:
474   http://ipt.vertnet.org:8080/ipt/resource.do?r=dmnh_birds (source published on 2015-10-20,
475   accessed on 2017-10-19)

476 DMNS Bird Collection (Arctos). Denver Museum of Nature & Science. Source:
477   http://ipt.vertnet.org:8080/ipt/resource.do?r=dmns_bird (source published on 2015-10-26,
478   accessed on 2017-10-19)

479 DMNS Mammal Collection (Arctos). Denver Museum of Nature & Science. Source:
480   http://ipt.vertnet.org:8080/ipt/resource.do?r=dmns_mamm (source published on 2015-10-
481   26, accessed on 2017-10-19)

482 Faurby, Søren, and Miguel B. Araújo. "Anthropogenic Impacts Weaken Bergmann's Rule."
483   *Ecography*, no. June (2016): 1–2. doi:10.1111/ecog.02287.

484 Forster, Jack, Andrew G Hirst, and Guy Woodward. "Growth and Development Rates Have
485   Different Thermal Responses." *The American Naturalist* 178, no. 5 (November 2011): 668–
486   78. doi:10.1086/662174.

487 Freckleton, RP, PH Harvey, and Mark Pagel. "Bergmann's Rule and Body Size in Mammals."

488   *The American Naturalist* 161, no. 5 (2003): 821–25.

489   Fuentes, Eduardo R, and Fabián M Jaksić. "Latitudinal Size Variation of Chilean Foxes: Tests of
490   Alternative Hypotheses." *Ecology* 60, no. 1 (1979): 43–47. doi:10.2307/1936466.

491   Gardner, Janet L, Anne Peters, Michael R Kearney, Leo Joseph, and Robert Heinsohn.
492   "Declining Body Size: A Third Universal Response to Warming?" *Trends in Ecology &*
493   *Evolution* 26, no. 6 (June 2011): 285–91. doi:10.1016/j.tree.2011.03.005.

494   Gardner, Janet L, Robert Heinsohn, and Leo Joseph. "Shifting Latitudinal Clines in Avian Body
495   Size Correlate with Global Warming in Australian Passerines." *Proceedings: Biological*
496   *Sciences* 276, no. 1674 (2009): 3845–52. doi:10.2307/30245347.

497   Geist, V. "Bergmann's Rule Is Invalid." *Canadian Journal of Zoology*, no. 1984 (1987): 1984–
498   87.

499   Guralnick, Robert P., Paula F. Zermoglio, John Wieczorek, Raphael LaFrance, David Bloom,
500   and Laura Russell. "The Importance of Digitized Biocollections as a Source of Trait Data
501   and a New VertNet Resource." *Database: The Journal of Biological Databases and*
502   *Curation*, 2016, 1–13. doi:10.1093/database/baw158.

503   Hampton, S.E., M.B. Jones, L.A. Wasser, M.P. Schildhauer, S.R. Supp, J. Bruno, R.R.
504   Hernandez, et al. "Skills and Knowledge for Data-Intensive Environmental Research."
505   *BioScience* 67, no. 6 (2017): 546–57.

506   Hampton, Stephanie E., Carly a. Strasser, Joshua J. Tewksbury, Wendy K. Gram, Amber E.
507   Budden, Archer L. Batcheller, Clifford S. Duke, and John H. Porter. "Big Data and the
508   Future of Ecology." *Frontiers in Ecology and the Environment* 11, no. 3 (2013): 156–62.
509   doi:10.1890/120103.

510   Hoffmann, A, J Decher, F Rovero, J Schaer, C Voigt, and G Wibbelt. "Field Methods and
511   Techniques for Monitoring Mammals." *Manual on Field Recording Techniques and*
512   *Protocols for All Taxa Biodiversity Inventories and Monitoring* 8 (2010): 482–529.

513   HSU Wildlife Mammals. Humboldt State University. Source:
514   http://ipt.vertnet.org:8080/ipt/resource.do?r=hsu_wildlife_mammals (source published on
515   2016-03-14, accessed on 2017-10-19)

516   Huston, Michael A., and Steve Wolverton. "Regulation of Animal Size by eNPP, Bergmann's
517   Rule, and Related Phenomena." *Ecological Monographs* 81, no. 3 (2011): 349–405.
518   doi:10.1890/07-1861.1.

519   International, Birdlife. "Migratory Status of Bird Species of the World." Available from:
520   http://datazone.birdlife.org/species/requestdis (accessed on 8/25/17) 2017.

521   James, Frances C. "Geographic Size Variation in Birds and Its Relationship to Climate." *Ecology*
522   51, no. 3 (1970): 365–90.

523   Kendeigh, S Charles. "Tolerance of Cold and Bergmann's Rule." *The Auk* 86, no. 1 (1969): 13–
524   25.

525   Koricheva, Julia, Jessica Gurevitch, and Kerrie Mengersen. *Handbook of Meta-Analysis in*
526   *Ecology and Evolution*, 2013. doi:10.2307/j.ctt24hq6n.

527   KUBI Mammalogy Collection. KU Biodiversity Institute. Source:
528   http://ipt.nhm.ku.edu/ipt/resource.do?r=kubi_mammals (source published on 2016-02-03,
529   accessed on 2017-10-19)

530   KUBI Ornithology Collection. KU Biodiversity Institute. Source:
531   http://ipt.nhm.ku.edu/ipt/resource.do?r=kubi_ornithology (source published on 2014-12-17,
532   accessed on 2017-10-19)

533   LACM Vertebrate Collection. Natural History Museum of Los Angeles County. Source:
534   http://ipt.vertnet.org:8080/ipt/resource.do?r=lacm_verts (source published on 2015-04-17,

535   accessed on 2017-10-19)
536   Langvatn, R, and Steve D Albon. "Geographic Clines in Body-Weight of Norwegian Red Deer -
537   A Novel Explanation of Bergmann Rule." *Holarctic Ecology* 9, no. 4 (1986): 285–93.
538   McNab, Brian K. "On the Ecological Significance of Bergmann's Rule," 1971.
539   Mcnamara, John M., Andrew D. Higginson, and Simon Verhulst. "The Influence of the
540   Starvation-Predation Trade-off on the Relationship between Ambient Temperature and
541   Body Size among Endotherms." *Journal of Biogeography* 43, no. 4 (2016): 809–19.
542   doi:10.1111/jbi.12695.
543   Meiri, Shai, and Tamar Dayan. "On the Validity of Bergmann's Rule." *Journal of Biogeography*,
544   no. 1847 (2003): 331–51.
545   Meiri, Shai, Tamar Dayan, and Daniel Simberloff. "Carnivores, Biases and Bergmann' S Rule."
546   *Biological Journal of the Linnean Society* 81 (2004): 579–88. doi:10.1111/j.1095-
547   8312.2004.00310.x.
548   Meiri, Shai. "Bergmann's Rule-What's in a Name?" *Global Ecology and Biogeography* 20, no. 1
549   (2011): 203–7. doi:10.1111/j.1466-8238.2010.00577.x.
550   MLZ Bird Collection (Arctos). Moore Laboratory of Zoology. Source:
551   http://ipt.vertnet.org:8080/ipt/resource.do?r=mlz_bird (source published on 2015-10-26,
552   accessed on 2017-10-19)
553   MLZ Mammal Collection (Arctos). Moore Laboratory of Zoology. Source:
554   http://ipt.vertnet.org:8080/ipt/resource.do?r=mlz_mamm (source published on 2015-10-26,
555   accessed on 2017-10-19)
556   Morris, Benjamin D., and Ethan P. White. "The EcoData Retriever: Improving Access to
557   Existing Ecological Data." *PLoS ONE* 8, no. 6 (2013): 1–7.
558   doi:10.1371/journal.pone.0065848.
559   MSB Bird Collection (Arctos). Museum of Southwestern Biology. Source:
560   http://ipt.vertnet.org:8080/ipt/resource.do?r=msb_bird (source published on 2015-10-27,
561   accessed on 2017-10-19)
562   MSB Mammal Collection (Arctos). Museum of Southwestern Biology. Source:
563   http://ipt.vertnet.org:8080/ipt/resource.do?r=msb_mamm (source published on 2015-10-27,
564   accessed on 2017-10-19)
565   MVZ Bird Collection (Arctos). Museum of Vertebrate Zoology, UC Berkeley. Source:
566   http://ipt.vertnet.org:8080/ipt/resource.do?r=mvz_bird (source published on 2015-10-27,
567   accessed on 2017-10-19)
568   MVZ Mammal Collection (Arctos). Museum of Vertebrate Zoology, UC Berkeley. Source:
569   http://ipt.vertnet.org:8080/ipt/resource.do?r=mvz_mammal (source published on 2015-10-
570   27, accessed on 2017-10-19)
571   NCSM Mammals Collection. North Carolina Museum of Natural Sciences. Source:
572   http://ipt.vertnet.org:8080/ipt/resource.do?r=ncsm_mammals (source published on 2015-02-
573   20, accessed on 2017-10-19)
574   NMMNH Mammal. New Mexico Museum of Natural History and Science. Source:
575   http://ipt.vertnet.org:8080/ipt/resource.do?r=nmmnh_mammals (source published on 2015-
576   04-14, accessed on 2017-10-19)
577   Ohio State University Tetrapod Division - Bird Collection (OSUM). Ohio State University.
578   Source: http://hymfiles.biosci.ohio-state.edu:8080/ipt/resource.do?r=osum-birds (source
579   published on 2015-05-22, accessed on 2017-10-19)
580   Ornithology Collection Non Passeriformes - Royal Ontario Museum. Royal Ontario Museum.
581   Source: http://gbif.rom.on.ca:8180/ipt/resource.do?r=birdsnonpass (source published on

582   2015-06-02, accessed on 2017-10-19)

583 Ornithology Collection Passeriformes - Royal Ontario Museum. Royal Ontario Museum. Source:

584   http://gbif.rom.on.ca:8180/ipt/resource.do?r=birdspass (source published on 2015-09-11,

585   accessed on 2017-10-19)

586 R Core Team. "R: A Language and Environment for Statistical Computing," 2016. R Foundation

587   for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

588 Ray, Carleton. "The Application of Bergmann's and Allen's Rules to the Poikilotherms."

589   *Journal of Morphology* 106, no. 1 (January 1960): 85–108. doi:10.1002/jmor.1051060104.

590 Rensch, Bernhard. "Some Problems of Geographical Variation and Species-Formation."

591   *Proceedings of the Linnean Society of London* 150, no. 4 (1938): 275–78.

592 Sand, Håkan, Göran Cederlund, and Kjell Danell. "Geographical and Latitudinal Variation in

593   Growth Patterns and Adult Body Size of Swedish Moose (Alces Alces)." *Oecologia* 102,

594   no. 4 (1995): 433–42. doi:10.1007/BF00341355.

595 SBMNH Vertebrate Zoology. Santa Barbara Museum of Natural History. Source:

596   http://ipt.vertnet.org:8080/ipt/resource.do?r=sbmnh_verts (source published on 2015-02-17,

597   accessed on 2017-10-19)

598 Schmidt Museum of Natural History_Mammals. Schmidt Museum of Natural History, Emporia

599   State University. Source:

600   http://ipt.vertnet.org:8080/ipt/resource.do?r=kstc_schmidt_mammals (source published on

601   2015-02-12, accessed on 2017-10-19)

602 SDNHM Birds Collection. San Diego Natural History Museum. Source:

603   http://ipt.vertnet.org:8080/ipt/resource.do?r=sdnhm_birds (source published on 2015-04-06,

604   accessed on 2017-10-19)

605 Seabold, Skipper, and Josef Perktold. "Statsmodels: Econometric and Statistical Modeling with

606   Python." *Proceedings of the 9th Python in Science Conference*, no. Scipy (2010): 57–61.

607 Sheridan, Jennifer A., and David Bickford. "Shrinking Body Size as an Ecological Response to

608   Climate Change." *Nature Climate Change* 1, no. 8 (October 2011): 401–6.

609   doi:10.1038/nclimate1259.

610 Smith, FA, JL Betancourt, and JH Brown. "Evolution of Body Size in the Woodrat over the Past

611   25,000 Years of Climate Change." *SCIENCE*, 1995.

612   http://biology.unm.edu/fasmith/web_page_pdfs/smith_et_al_1995_science.pdf.

613 Smith, Felisa a, Alison G Boyer, James H Brown, Daniel P Costa, Tamar Dayan, S K Morgan

614   Ernest, Alistair R Evans, et al. "The Evolution of Maximum Body Size of Terrestrial

615   Mammals." *Science (New York, N.Y.)* 330, no. 6008 (2010): 1216–19.

616   doi:10.1126/science.1194830.

617 Stacey, David A., and Mark D E Fellowes. "Temperature and the Development Rates of Thrips:

618   Evidence for a Constraint on Local Adaptation?" *European Journal of Entomology* 99, no. 3

619   (2002): 399–404.

620 Steudel, K., W. P. Porter, and D. Sher. "The Biophysics of Bergmann's Rule: A Comparison of

621   the Effects of Pelage and Body Size Variation on Metabolic Rate." *Canadian Journal of*

622   *Zoology* 72, no. 1 (1994): 70–77. doi:10.1139/z94-010.

623 Stillwell, R. Craig. "Are Latitudinal Clines in Body Size Adaptive?" *Oikos* 119, no. 9 (2010):

624   1387–90. doi:10.1111/j.1600-0706.2010.18670.x.

625 Teplitsky, Celine, and Virginie Millien. "Climate Warming and Bergmann's Rule through Time:

626   Is There Any Evidence?" *Evolutionary Applications* 7, no. 1 (January 2014): 156–68.

627   doi:10.1111/eva.12129.

628 TTU Mammals Collection. Museum of Texas Tech University (TTU). Source:

629   http://ipt.vertnet.org:8080/ipt/resource.do?r=ttu_mammals (source published on 2015-02-
630   26, accessed on 2017-10-19)
631   UAM Bird Collection (Arctos). University of Alaska Museum. Source:
632   http://ipt.vertnet.org:8080/ipt/resource.do?r=uam_bird (source published on 2015-10-27,
633   accessed on 2017-10-19)
634   UAM Mammal Collection (Arctos). University of Alaska Museum. Source:
635   http://ipt.vertnet.org:8080/ipt/resource.do?r=uam_mamm (source published on 2015-10-27,
636   accessed on 2017-10-19)
637   UAZ Mammal Collection. University of Arizona Museum of Natural History. Source:
638   http://ipt.vertnet.org:8080/ipt/resource.do?r=uaz_mammals (source published on 2016-03-
639   29, accessed on 2017-10-19)
640   UCLA Donald R. University of California, Los Angeles. Dickey Bird and Mammal Collection.
641   Source: http://ipt.vertnet.org:8080/ipt/resource.do?r=ucla_birds_mammals (source
642   published on 2015-03-02, accessed on 2017-10-19)
643   UCM Birds. University of Colorado Museum of Natural History. Source:
644   http://ipt.vertnet.org:8080/ipt/resource.do?r=ucm_birds (source published on 2015-10-27,
645   accessed on 2017-10-19)
646   UCM Mammals Collection. University of Colorado Museum of Natural History. Source:
647   http://ipt.vertnet.org:8080/ipt/resource.do?r=ucm_mammals (source published on 2015-10-
648   27, accessed on 2017-10-19)
649   UMMZ Birds Collection. University of Michigan Museum of Zoology. Source:
650   http://ipt.vertnet.org:8080/ipt/resource.do?r=ummz_birds (source published on 2015-10-28,
651   accessed on 2017-10-19)
652   University of Alberta Mammalogy Collection (UAMZ). University of Alberta Museums. Dataset
653   DOI: doi:10.18165/brxhjf. Source:
654   http://web.macs.ualberta.ca:8088/ipt/resource?r=uamz_mammalogy (source published on
655   2015-09-20, accessed on 2017-10-19)
656   University of Alberta Ornithology Collection (UAMZ). University of Alberta Museums. Dataset
657   DOI: doi:10.18165/srgkci. Source:
658   http://web.macs.ualberta.ca:8088/ipt/resource?r=uamz_ornithology (source published on
659   2015-09-24, accessed on 2017-10-19)
660   USAC Mammals Collection. Universidad de San Carlos de Guatemala. Source:
661   http://ipt.vertnet.org:8080/ipt/resource.do?r=usac_mammals (source published on 2013-11-
662   04, accessed on 2017-10-19)
663   UWBM Mammalogy Collection. University of Washington Burke Museum. Source:
664   http://ipt.vertnet.org:8080/ipt/resource.do?r=uwbm_mammals (source published on 2015-
665   02-23, accessed on 2017-10-19)
666   UWBM Ornithology Collection. University of Washington Burke Museum. Source:
667   http://ipt.vertnet.org:8080/ipt/resource.do?r=uwbm_birds (source published on 2015-02-24,
668   accessed on 2017-10-19)
669   UWYMV Bird Collection (Arctos). University of Wyoming Museum of Vertebrates. Source:
670   http://ipt.vertnet.org:8080/ipt/resource.do?r=uwymv_bird (source published on 2015-10-27,
671   accessed on 2017-10-19)
672   Vertebrate Zoology Division - Mammalogy, Yale Peabody Museum. Yale Peabody Museum.
673   Source: http://ipt.peabody.yale.edu/ipt/resource.do?r=ipt_vz_mam (source published on
674   2015-10-09, accessed on 2017-10-19)
675   Vertebrate Zoology Division - Ornithology, Yale Peabody Museum. Yale Peabody Museum.

676   Source: http://ipt.peabody.yale.edu/ipt/resource.do?r=ipt_vz_orn (source published on
677   2015-10-09, accessed on 2017-10-19)
678 Watt, Cortney, and Volker Salewski. "Bergmann's Rule Encompasses Mechanism: A Reply to
679   Olalla-Tárraga (2011)." *Oikos* 120, no. 10 (October 2011): 1445–47. doi:10.1111/j.1600-
680   0706.2011.19968.x.
681 Watt, Cortney, Sean Mitchell, and Volker Salewski. "Bergmann's Rule; a Concept Cluster?"
682   *Oikos* 119, no. 1 (January 2010): 89–100. doi:10.1111/j.1600-0706.2009.17959.x.
683 Wieczorek, John, David Bloom, Robert Guralnick, Stan Blum, Markus Döring, Renato
684   Giovanni, Tim Robertson, and David Vieglais. "Darwin Core: An Evolving Community-
685   Developed Biodiversity Data Standard." *PLoS ONE* 7, no. 1 (2012): e29715–e29715.
686   doi:10.1371/journal.pone.0029715.
687 Willmott, C.J., and K. Matsuura. "Terrestrial Air Temperature and Precipitation: Monthly and
688   Annual Time Series (1950-1999)," 2001.
689   http://climate.geog.udel.edu/~climate/html_pages/README.ghcn_ts2.html.
690 Winker, Kevin. "Obtaining, Preserving, and Preparing Bird Specimens." *Journal of Field
691   Ornithology* 71, no. 2 (2000): 250–97. doi:10.1648/0273-8570-71.2.250.
692 WNMU Bird Collection (Arctos). Western New Mexico University. Source:
693   http://ipt.vertnet.org:8080/ipt/resource.do?r=wnmu_bird (source published on 2015-10-27,
694   accessed on 2017-10-19)
695 WNMU Mammal Collection (Arctos). Western New Mexico University. Source:
696   http://ipt.vertnet.org:8080/ipt/resource.do?r=wnmu_mamm (source published on 2015-10-
697   27, accessed on 2017-10-19)
698 Yom-Tov, Yoram, and Eli Geffen. "Geographic Variation in Body Size: The Effects of Ambient
699 Temperature and Precipitation." *Oecologia* 148, no. 2 (2006): 213–18. doi:10.1007/s00442-006-
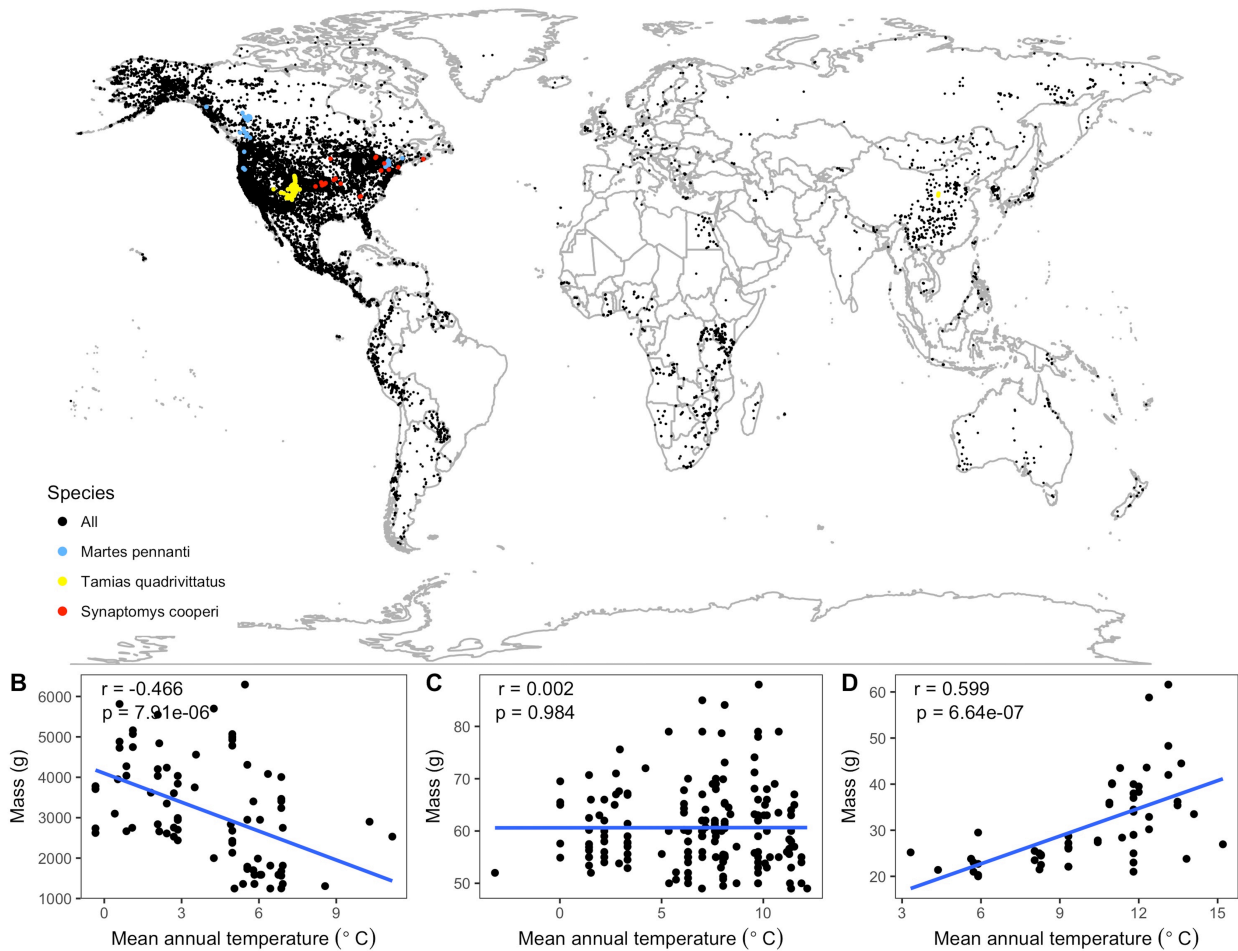700 0364-9.
701
702
703 **FIGURE LEGENDS**
704

Figure 1. Species spatial distributions and selected temperature-mass relationships. (A) Spatial collection locations of all individual specimens. All species shown with black points except three species, whose relationships between mean annual temperature and mass are shown at bottom (B-D), are marked with colored points. These species were chosen as representative of the variability in relationship strength and direction exhibited by the 952 species from the study: *Martes pennanti* had a negative relationship with temperature explaining a substantial amount of variation in mass (B; blue points); *Tamias quadrivittatus* had no directional relationship between temperature and mass with temperature having little explanatory power (C; yellow points); *Synaptomys cooperi* had a strong positive temperature-mass relationship with a correlation coefficient (r) in the 99th percentile of all species' values (D; red points). Intraspecific temperature-mass relationships are shown with black circles for all individuals and ordinary least squares regression trends as blue lines. Linear regression correlation coefficients and p-values in upper left hand corner of figure for each species. See figure supplement 1.
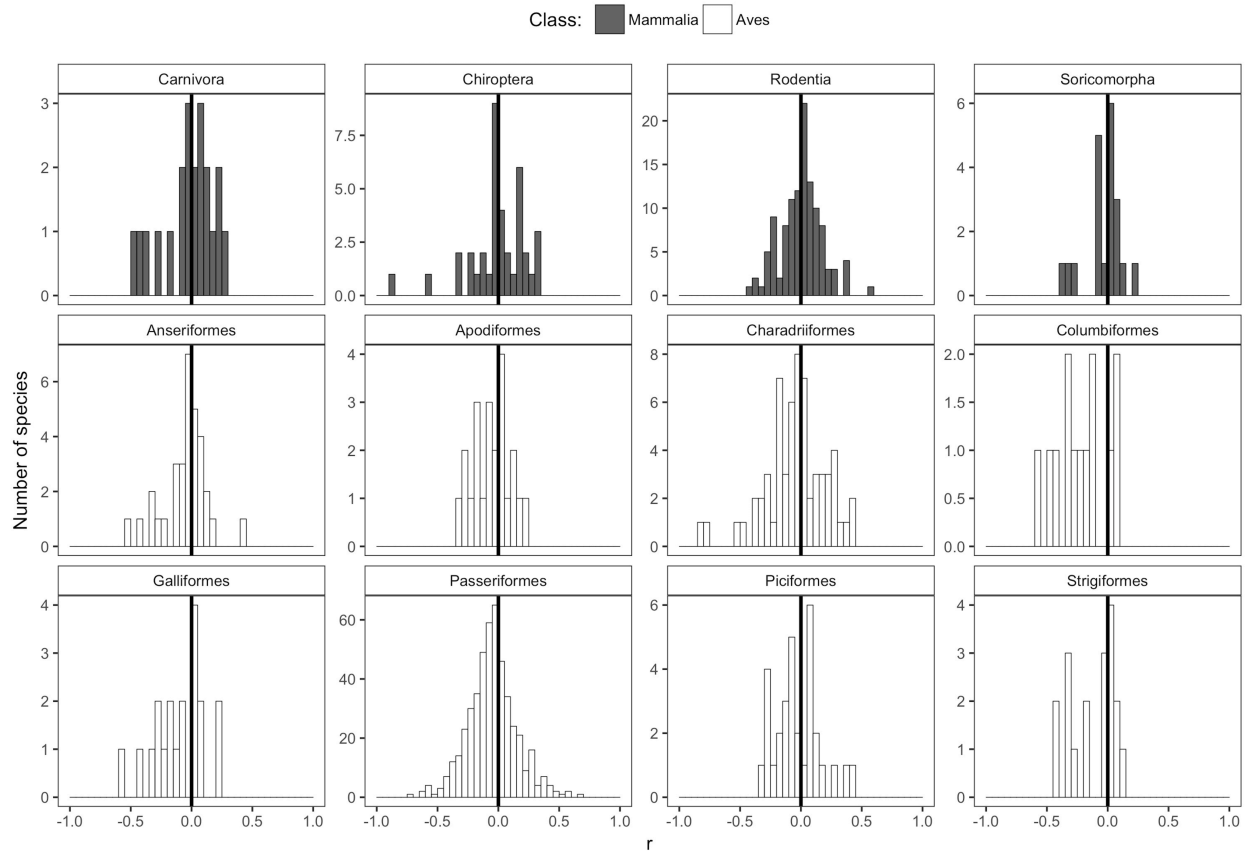
23
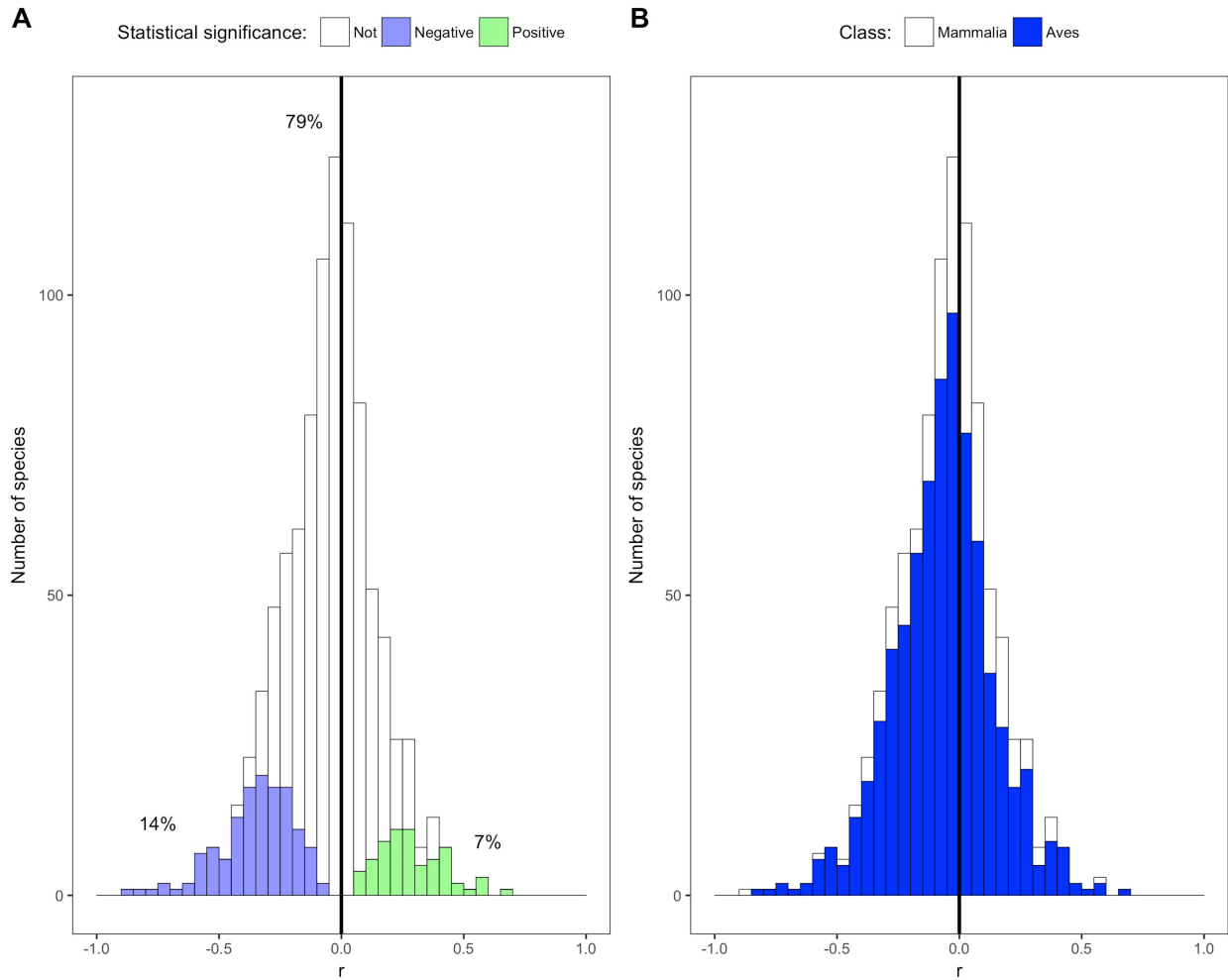
Figure 2. Species correlation coefficients by statistical significance and taxonomic class. (A) Stacked histogram of correlation coefficients (r) for all species' intraspecific temperature-mass relationships. Colored bars show species with statistically significant relationships, both negative (purple) and positive (green), while white bars indicate species with relationship slopes that are not significantly different from zero. Percentages shown are percentages of species in each group. (B) Stacked histogram of all species' correlation coefficients with bar color corresponding to taxonomic class. Dark vertical lines are correlation coefficients of zero. See figure supplements 1-6.

24

732
733
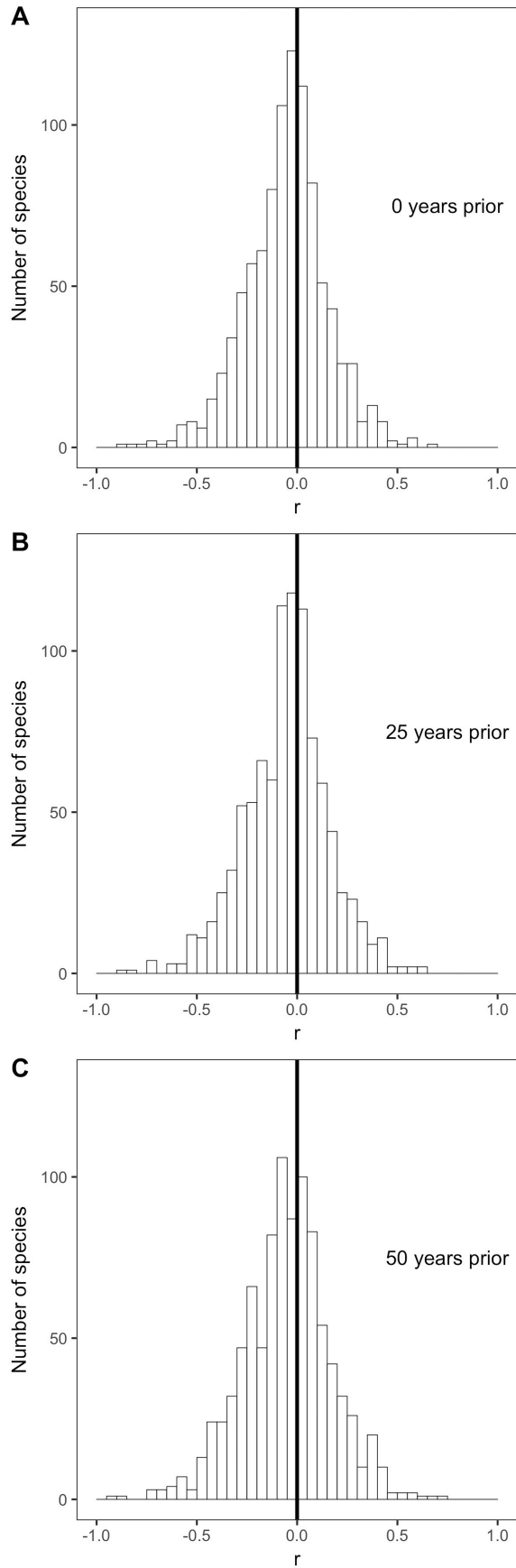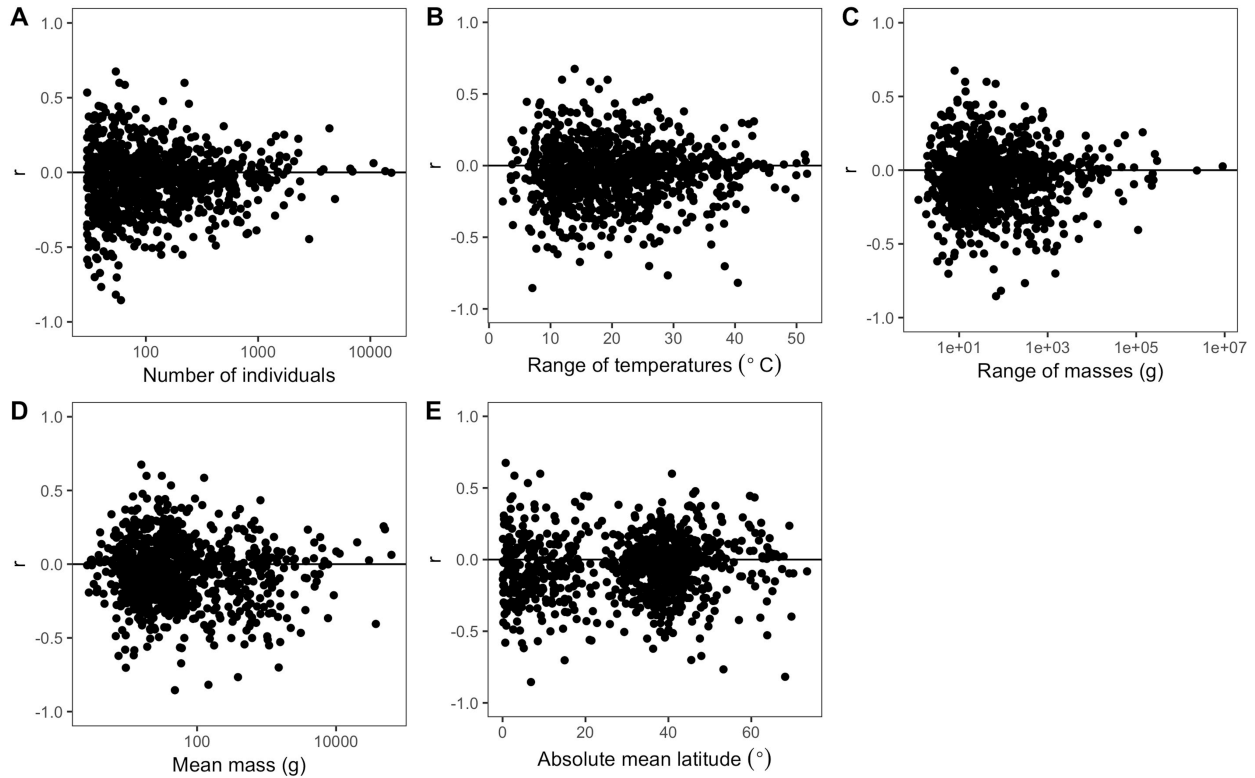**Figure 3. Species correlation coefficients for selected taxonomic orders.** Histograms of correlation coefficients (r) from intraspecific temperature-mass relationships for each taxonomic order represented by more than ten species, with order shown above histogram. Height of y-axis varies depending on number of species. Bar color indicates taxonomic class. Dark vertical lines are correlation coefficients of zero. For remaining orders, see figure supplement 1.
739

740

741

Figure 4. Species correlation coefficients with selected past year temperatures. Histograms of correlation coefficients (r) for all species' intraspecific temperature-mass relationships with mean annual temperature from (A) the year in which individuals were collected, (B) 25 years prior to collection year, and (C) 50 years prior to collection year. Dark vertical lines are correlation coefficients of zero. For all past year temperatures, see figure supplement 1.

747

748
749

Figure 5. Variability of species correlation coefficients across several variables. Variation in all species' correlation coefficients (r) across the following variables for each species: (A) number of individuals, (B) difference between hottest and coldest collection year temperatures, (C) mass range, (D) mean mass, and (E) absolute mean latitude. Horizontal lines are correlation coefficients of zero. The x-axes of some plots (A, C, D) are on a log scale to better show spread of values.

756