Testing Bergmann's Cline Hypothesis of Latitudinal Size Correlations in the Green Anole (*Anolis carolinensis*)

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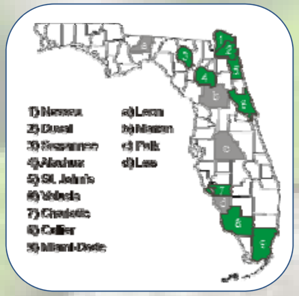
Background

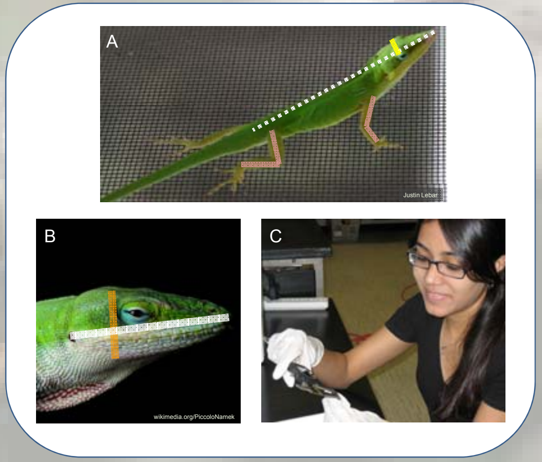
In 1847, Christian Bergmann suggested that animals would be larger in colder climates, due to a smaller surface area to volume ratio facilitating heat retention and thermoregulation. Now known as Bergmann's rule or cline, it broadly asserts that animals at higher latitudes and in colder climates grow to a larger body size than animals at lower latitudes and in warmer climates. Interestingly, support for this rule has only been reliably established for endotherms, such as mammals and birds. Among ectotherms, there is much more variability among the results, although the majority of squamates (i.e., lizards and snakes) tend to follow an inverse Bergmann's cline (Ashton and Feldman, 2003).

In this study, we investigated whether Bergmann's cline applies to the green anole lizard, *Anolis carolinensis*. These lizards have a broad latitudinal distribution, from the Carolinas (~37°N) south to the Florida Keys (~25°N). Based on previous studies, we hypothesized that green anoles will follow an inverse Bergmann's cline, with larger individuals at lower latitudes and smaller individuals at higher latitudes.

Methods

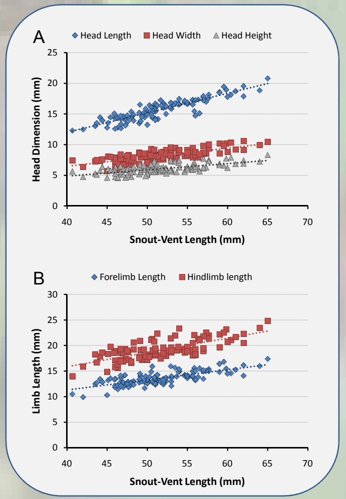


◄ **Figure 1.** 119 green anoles (*Anolis carolinensis*; 34 females, 85 males) were obtained from the Florida Museum of Natural History (FLMNH), representing populations from Georgia to the southern tip of Florida. Collection localities were georeferenced using Google Earth and Google Maps. Areas highlighted in green were measured for this study (Georgia localities are not shown); those in grey are planned for future.

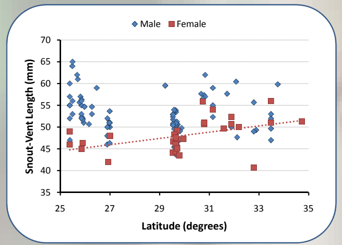


► **Figure 2.** Morphological measurements for this study included (A) snout-vent length (dotted line), fore- and hindlimb length (pink), and (B) head length (white), width (yellow), and height (orange). (C) K. Shroff measuring a lizard specimen. Latitudinal size relationships were analyzed with simple linear regressions and principal components analyses using JMP7.0 (SPSS).

Results



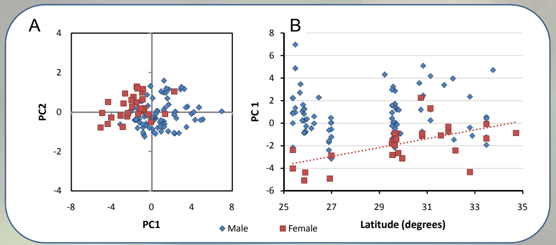
◄ **Figure 3.** The relationship of (A) head dimensions and (B) limb lengths with snout-vent length (SVL). These graphs show that as lizard body length increases, so do head dimensions and limb lengths, consistent with allometric scaling.



◄ **Figure 4.** Snout-vent length among female lizards increases with latitude (β = 0.70, R^2 = 0.20, F = 7.95, P = 0.008). Males do not exhibit a significant size trend with latitude (P = 0.08).

► **Table 1.** Results of a principal components analysis on all measured morphological variables. All variables loaded similarly on principal component (PC) 1, which accounted for 79.3% of the variance in the dataset. Larger morphological structures loaded higher on PC1 (see **Fig. 5A**).

Variable	PC1	PC2
SVL (mm)	0.40	-0.61
Forelimb Length	0.40	0.24
Hindlimb Length	0.41	0.38
HL (mm)	0.41	-0.51
HW (mm)	0.42	0.11
HD (mm)	0.40	0.40
Eigenvalue	7.76	0.47
% of variance	79.3	7.86
Cumulative	79.3	87.2



▲ **Figure 5.** Graphical results from the principal components analysis. (A) A graph of principal component (PC) 1 and 2 shows that overall female body dimensions are always smaller than that of males. (B) A regression of PC1 against latitude indicates that females overall grew larger with increasing latitude (β = 0.39, F = 13.56, df = 1, 32, $P < 0.001$, R^2 = 0.30). This may reflect the covariation of all the variables with snout-vent length. Among the males, there was no detectable correlation of size with latitude (P = 0.67). Two results emerge from this analysis.

Conclusions

- Limb lengths and head dimensions in anoles are directly correlated with body length, with male green anoles typically larger than females.
- Bergmann's Cline applies to females, but not males. Females are larger in the north and smaller in the south.
- A couple hypotheses addressing the differential pattern between males and females include:
    1. Increased competitive pressure among males for territories and mates selects for large size regardless of latitude.
    2. Greater fat storage capability associated with larger body size selects for larger body sizes in females in the north, where the reproductive season is short and energetic demands are greater than in the south.

Future Directions

- More lizards will be sampled to fill in the gap in latitudinal data and to increase the power of our analysis (**Fig. 1**).
- Introductions of brown anoles into Florida have resulted in decreased limb length and head dimensions among green anoles, as a result of resource competition and habitat shifts. The effect of these introductions on morphological patterning in relation to the Bergmann's cline will be explored.

References

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