Relationship between the thermal variation, its predictability and the upper thermal limits of anuran larvae: An integrative approach.

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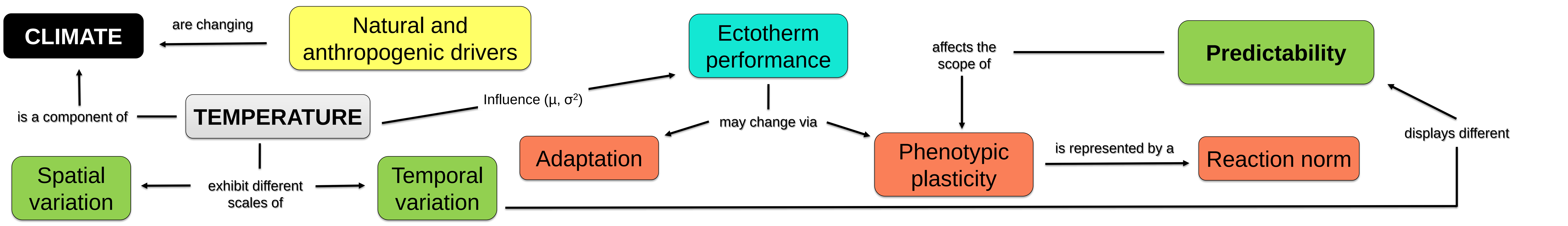
BACKGROUND



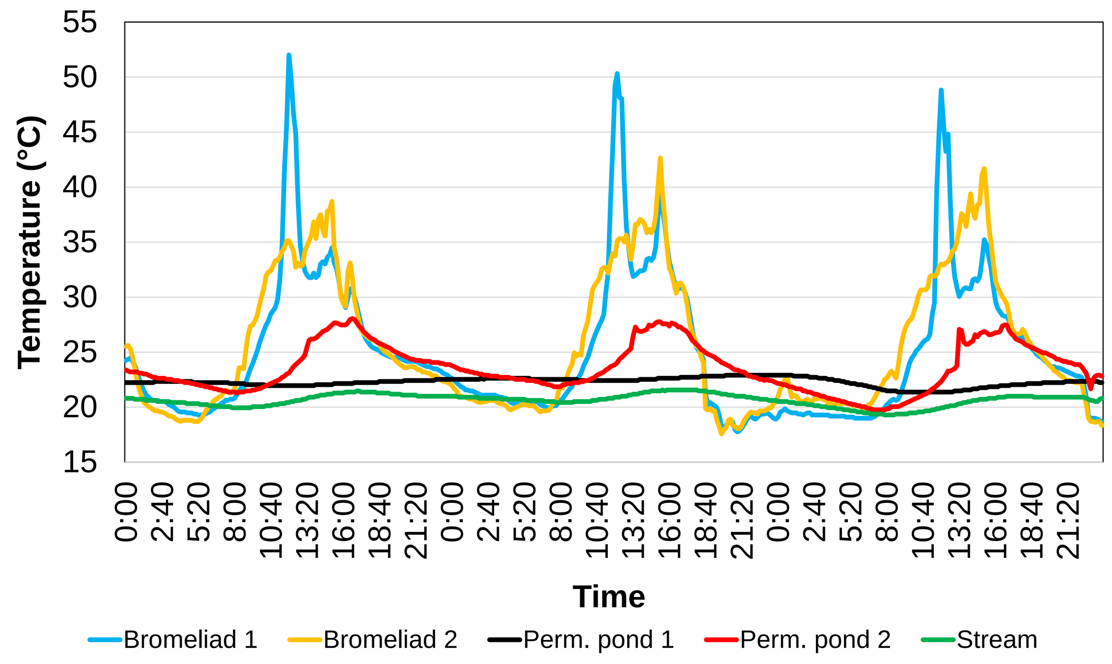


Figure 1. Time series for daily temperatures of different water bodies that serve as microhabitats for amphibian species at the Intervales State Park, Ribeirão Grande, São Paulo, Brazil. Data collected with temperature dataloggers at 10-min interval for three days (18-20 January 2015).

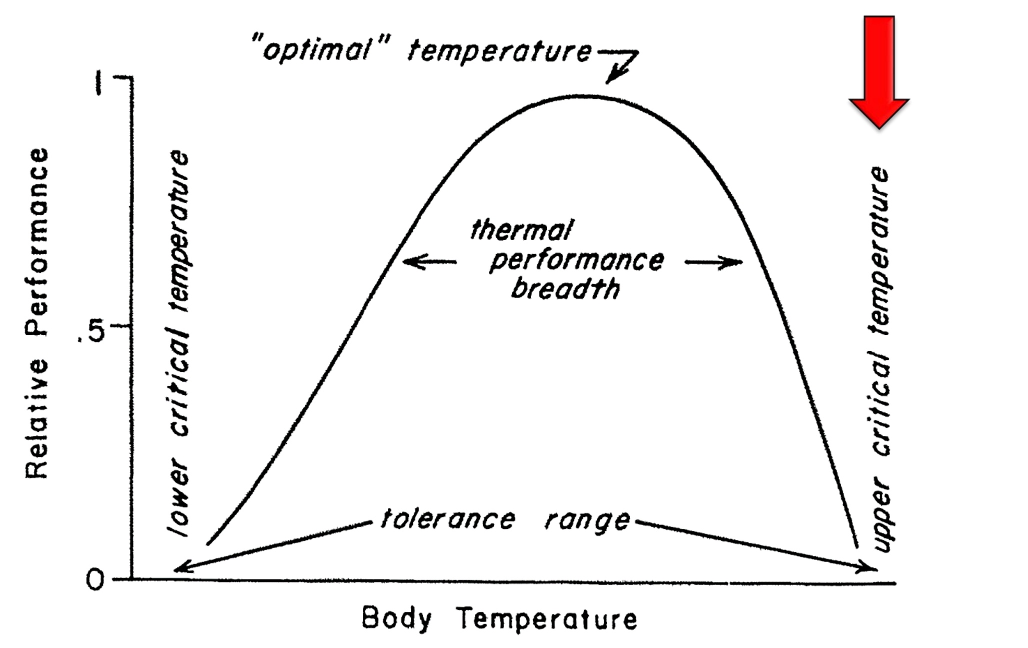


Figure 2. **Thermal Performance Curve**. The performance of many functions (i.e. physiological, behavioral) of ectothermic animals exhibits a non-linear relationship with their body temperature, which is directly influenced by the environmental temperature. (R.B. Huey & R.D. Stevenson. *American Zoologist*, 19(1). 1979)

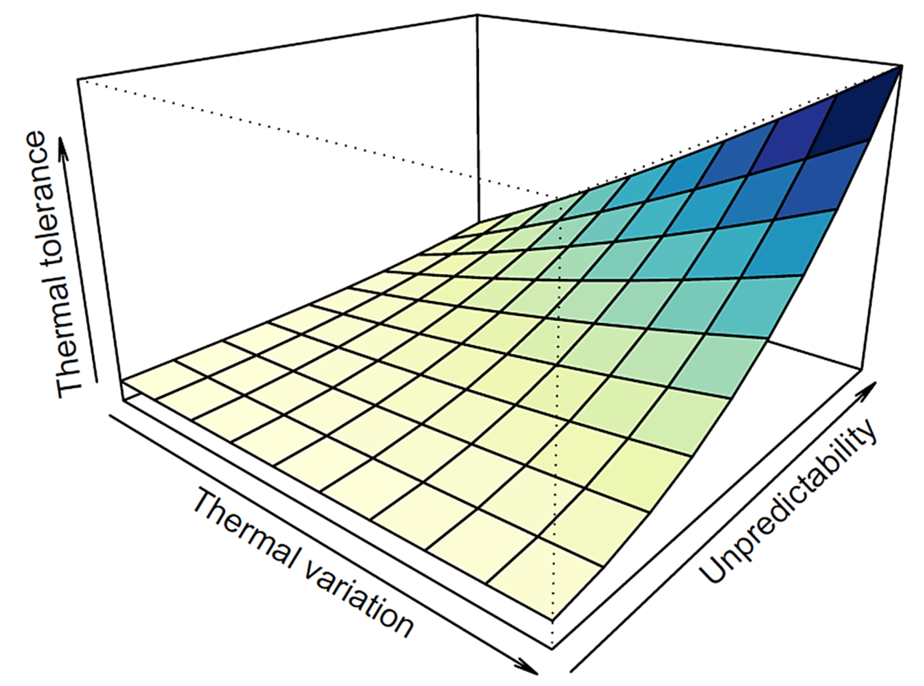


Figure 3. Hypothetical predictions of the relationship between the thermal variability, its predictability and the thermal tolerance of ectothermic animals.

RESEARCH QUESTIONS

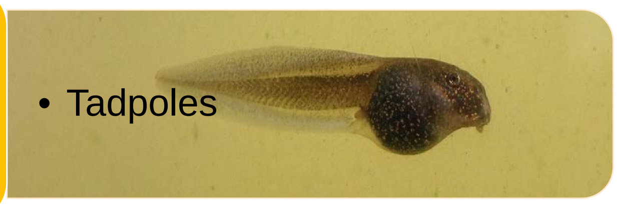
1) How much the thermal variation and its predictability differ between local (i.e. the macroclimate) and organismic scales (i.e. the microclimate)?
2) In what extent spatiotemporal variation among microclimates correlates with organism's thermal tolerance?
3) Is there any trade-off between baseline and ecological thermal tolerance of species? If so, how this correlates with the temporal variation in environmental temperature experienced within microclimates?
4) How the predictability of intragenerational thermal variation (i.e. during development) affects the thermal tolerance and its underlying mechanisms?

HYPOTHESIS

1) Organism's thermal tolerance is positively correlated with spatiotemporal variation in microclimate (i.e. high and fast daily thermal variation select for high thermal tolerance).
2) Baseline thermal tolerance would be enhanced in species that undergo fast thermal changes in the field, whereas ecological thermal tolerance would be favored in species experiencing slower thermal changes.
3) Higher unpredictability of intragenerational thermal variation increases overall thermal tolerance. Yet, the predictability of intergenerational thermal variation favors greater phenotypic plasticity of thermal tolerance.
4) Phenotypic plasticity of thermal tolerance is accomplished via "enhanced cellular stress response (*enhanced response*), constitutively elevated expression of protective genes (*genetic assimilation*) or a shift from damage resistance to passive mechanisms of thermal stability (*tolerance*)" (Stanton-Geddes et al. *BMC Genomics* 17:171. 2016).

MATERIALS AND METHODS

Model system
- Tadpoles



Climatic data
- Weather stations (macroclimate)
- Data logger (microclimate)

Upper thermal tolerance tests
- Critical Thermal Maximum (CT_{max}) (Fig. 4)

Phenotypic plasticity
- Six scenarios of diferent thermal variation and predictability (Fig. 5)
- Reaction norms: CT_{max} (Fig. 7), Transcriptome and Proteome.

Data analysis
- Predictability: Colwell's índices and Wavelets analysis
- Statistical modeling
- Bioinformatics

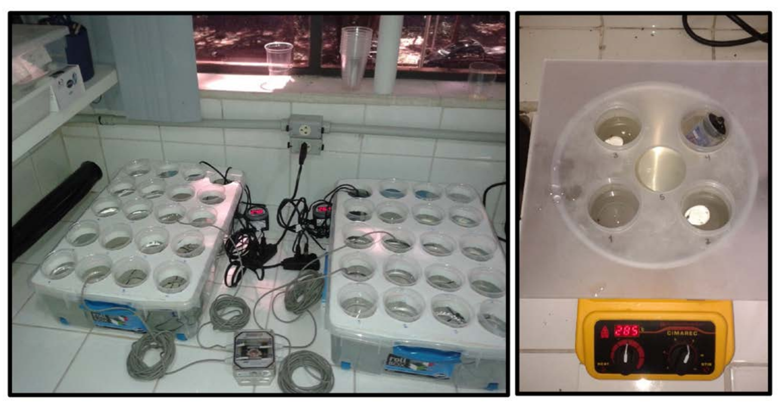


Figure 4. Temperature-controlled baths to measure CT_{max} in aquatic organisms at baseline ($\Delta T = 1°C\ min^{-1}$, *right*) and ecological ($\Delta T < 1°C\ min^{-1}$, *left*) rates of experimental thermal change.

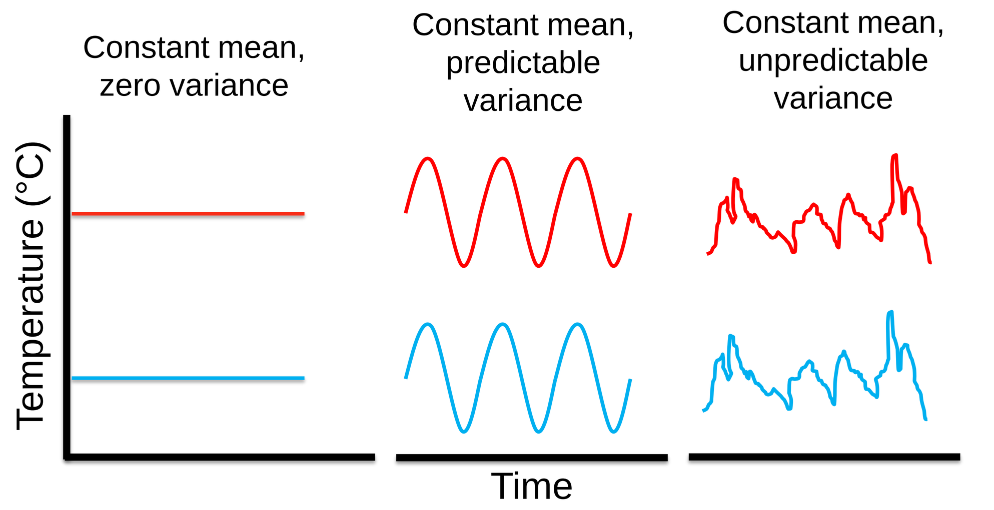


Figure 5. Experimental scenarios of current (blue) and future (red) thermal conditions to be used in tests of phenotypic plasticity during the development of our model species. Mean temperatura is the same for all current and all future scenarios, whereas thermal variance is the same for all conditions of different predictability

PREDICTIONS

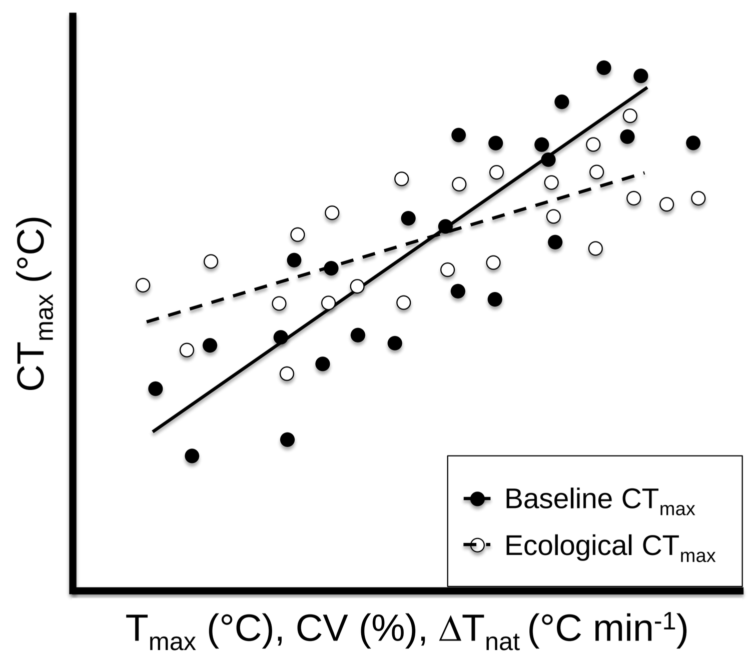


Figure 6. Hypothetical relationship between spatial (T_{max}, CV) and temporal (ΔT_{nat}) variations in daily microclimatic temperatures and the CT_{max} estimated experimentally at the baseline and an ecological heating rate. CT_{max} values are the average for different species.

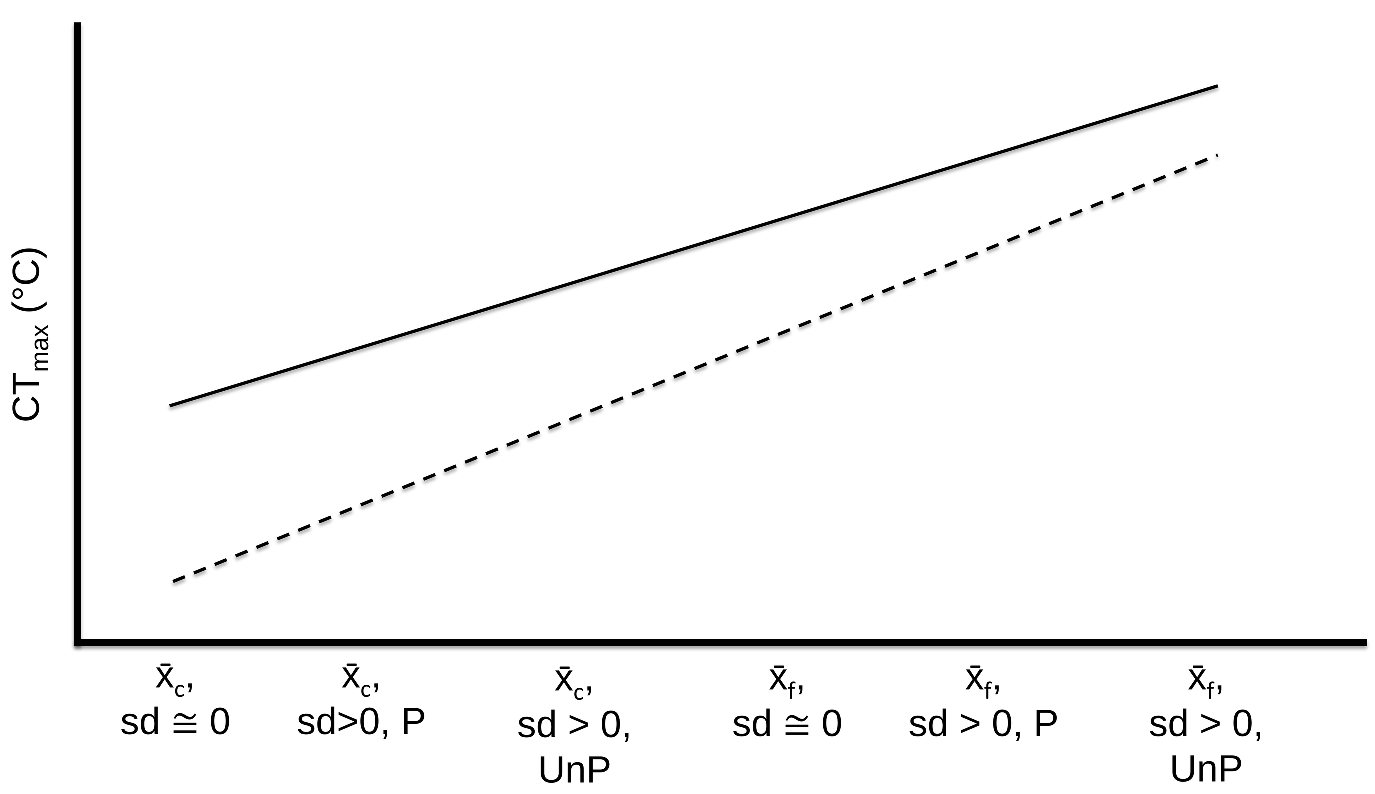


Figure 7. Hypothetical thermal reaction norm of the CT_{max} in response to different scenarios of daily mean temperature ($\bar{x}$, c: current, f: future), thermal variation (sd) and predictability (P: predictable, UnP: unpredictable). The solid line represents a population/species from a naturally-unpredictable environment, whereas the dashed line represents a population/species from a naturally-predictable environment. The slope of the lines is a measure of phenotypic plasticity.

GLOSSARY

Adaptation: The evolutionary dynamic process that fits a population of organisms to their environment.
Anurans: The most speciose, diverse, and widespread of the three extant amphibian orders (i.e. frogs and toads).
Bioinformatics: The collection, classification, storage, and analysis of biochemical and biological information using computers especially as applied to molecular genetics and genomics.
Critical Thermal Maximum: Temperature at which animal motion becomes disorganized and the organism can not scape from conditions that will promptly lead to its death.
Ectothermic animal: An organism in which internal physiological sources of heat are of relatively small or quite negligible importance in controlling body temperature, and therefore must rely mainly on environmental heat sources.
Performance: Any measure of an organism's capacity to perform a function (e.g. locomotion, growth, survivorship. etc).
Phenotypic plasticity: The property of a given genotype to produce different phenotypes in response to distinct environmental conditions.
Proteome: The entire set of proteins expressed by a genome, cell, tissue, or organism at a certain time under defined conditions.
Reaction norm: The function that describes the pattern of phenotypic expression of a single genotype across a range of environments.
Transcriptome: The full range of messenger RNA, or mRNA, molecules expressed by an organism.

Acknowledgments

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