(Co)variation of microbial thermal traits across the thermokinetic range of life on Earth

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Introduction

Among their greatest evolutionary achievements are those allowing microbes to exist at temperatures ranging from well below 0 to over 100 °C. Understanding patterns in variance and covariance of thermal traits across the range of temperatures at which life is known to exist (and especially of deviations from the patterns) can inform us about the evolutionary innovations and obstacles that may allow or constrain the origin and subsequent diversification of life in extreme environments.

Methods

Data set: 2360 strains and counting…593 presented here

- Temperature-dependent population growth rates (= fitness estimates) from microbial populations in laboratory culture.
- Taxa: Archaea, bacteria, cyanobacteria, fungi, eukaryotic phytoplankton
- Sources: Literature (collected using Datathief)…ongoing; R. Corkrey (U. Tasmania); Thomas et al. [1]; M. K. Thomas (EWAG) and C. Kremer (Yale) in prep.

Thermal traits

We used the Norberg [2] model to derive traits relevant to ecological interactions:

- T_{opt} : optimal temperature for population growth
- LCT: lower critical temperature
- UCT: upper critical temperature
- TNW: thermal niche width

We used the Ratkowsky et al. [3] model to derive thermodynamic parameters associated with a growth rate-limiting enzyme reaction within the cell:

- T_{mes}, the temperature of maximum enzyme stability
- NPR, the normal physiological range of enzyme function, where the probability that the growth rate-limiting enzyme is in its native state is >0.5.

Norberg model:

$$r = ae^{bT}\left[1-\left(\frac{T-z}{w/2}\right)^2\right]$$

Ratkowsky et al. model:

$$r = \frac{cTexp(-\Delta H_A^{\ddagger}/RT)}{1+\exp\left(-n\{\Delta H^* - T\Delta S^* + \Delta C_P[(T-T_H^*) - Tln(T/T_S^*)]\}/RT\right)}$$

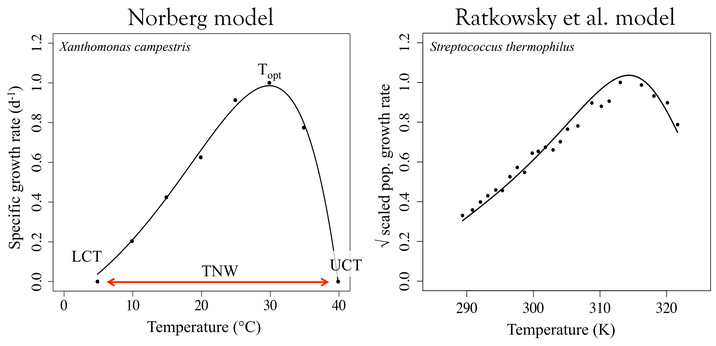

Figure 1 Norberg. [2] and Ratkowsky et al. [3] models fit using maximum likelihood estimation (Nelder-Mead method).

Results

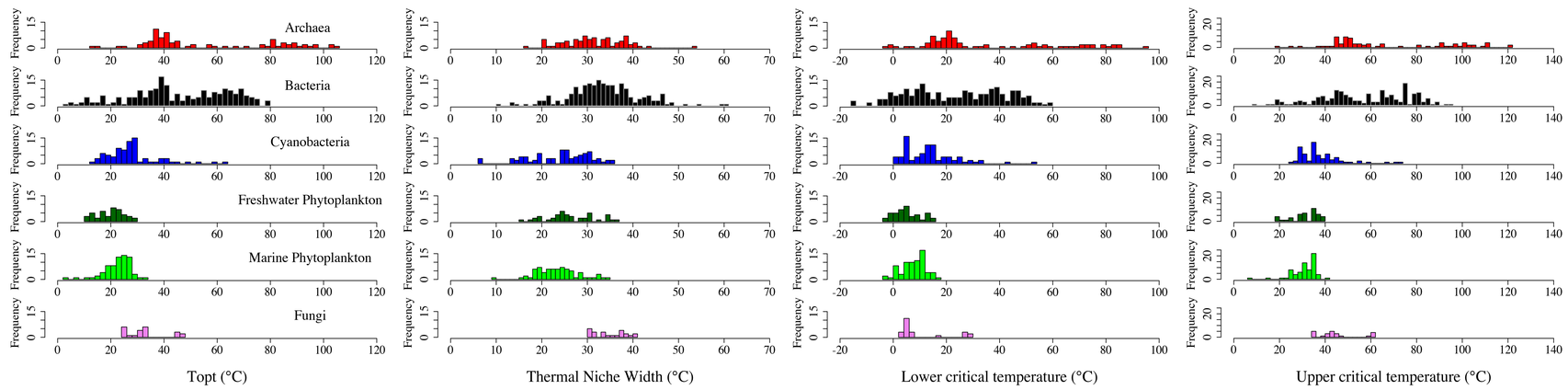

Figure 2 Frequency distributions of microbial thermal traits across the thermokinetic range of life on earth.

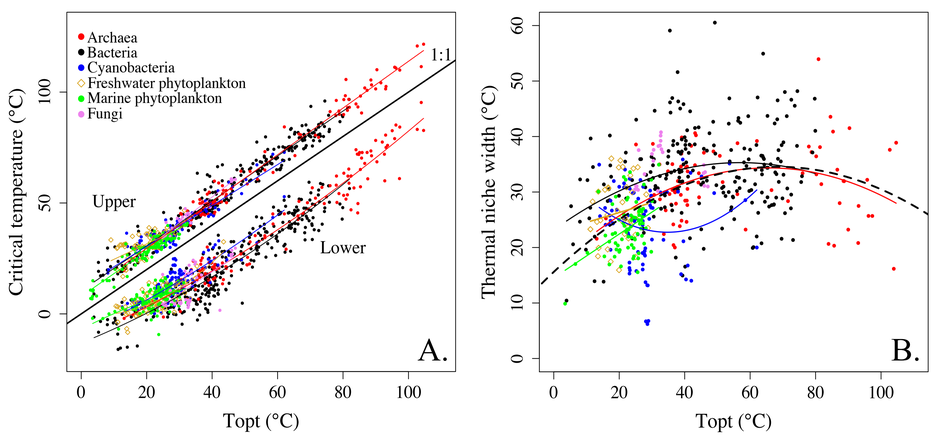

Figure 3 A. Upper and lower critical temperatures plotted against T_{opt}. B. Thermal niche width plotted against T_{opt}. Curves are individual linear model fits by taxonomic group. The dashed curve in B is a the mean of all (pooled) TNW as a function of T_{opt}. The quadratic terms in linear model fits of LCT (A.) and TNW (B.) for archaea, bacteria, cyanobacteria, and pooled data are statistically significant.

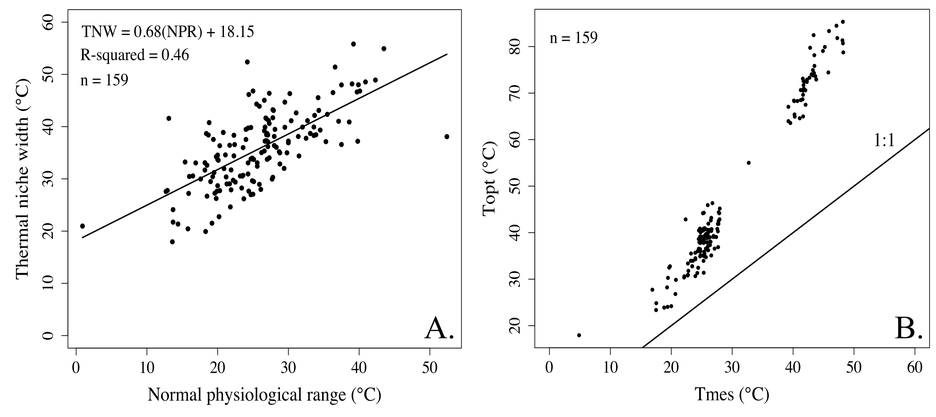

Figure 4 A. Thermal niche width as a function of NPR, the normal physiological range of a growth rate-limiting enzyme reaction within the cell. B. T_{opt} plotted against T_{mes}, the temperature of maximum enzyme stability of a growth rate-limiting enzyme reaction within the cell.

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Conclusions

- Extremophiles tend to be thermal specialists, while mesophiles tend to be generalists.
- Photosynthetic (Cyano) bacteria have narrower thermal niches than non-photosynthetic bacteria, on average.
- Marine eukaryotic phytoplankton, as a group, have the narrowest thermal niches, on average.
- Niche width is affected more by LCT than UCT, as indicated by the curvature in the relationship between LCT and T_{opt}.
- Archaea inhabit by far the greatest range of thermal habitats, with some strains exhibiting positive growth at -5 °C, and others growing at >120 °C.
- T_{mes} and T_{opt} are positively correlated, as are NPR and TNW—intracellular processes determine ecological traits.
- The difference between T_{mes} and T_{opt} is greater in "hot" than in "cold" organisms, as seen in [4].

References

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2. Norberg, J. 2004. Biodiversity and ecosystem functioning: a complex approach. *Limnol. Oceanogr.* 49:1269-1277.
3. Ratkowsky, D.; Olley, J. and T. Ross. 2005. Unifying temperature effects on the growth rate of bacteria and the stability of globular proteins. *J. Theor. Biol.* 233:351-362.
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Acknowledgements

- Mridul Thomas and Colin Kremer
- Carolyn Hamman
- MSU Institute for Cyber Enabled Research

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