

Appendix A from D. G. Kontopoulos et al., “Use and misuse of temperature normalisation in meta-analyses of thermal responses of biological traits”

Supplementary material, mathematical derivations, and data sources

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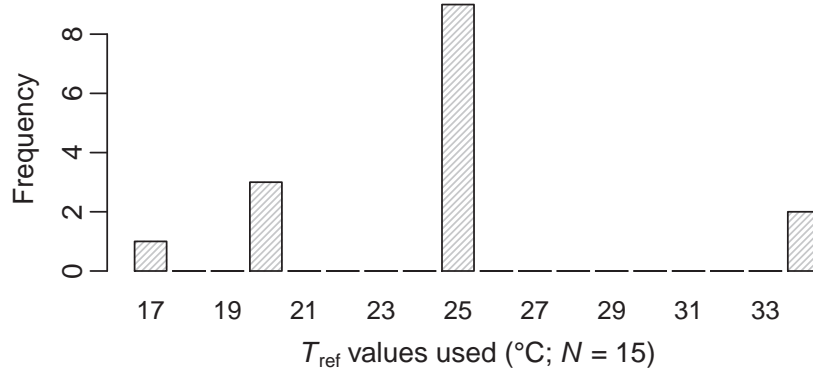
A1 Reference temperature values used in the recent literature

Table A1: Table of specified T_{ref} values in some studies that employed the Sharpe-Schoolfield model.

| Study | T_{ref} (°C) |
|---|------------------------------|
| Ungerer, M. J., M. P. Ayres, and M. J. Lombardero. 1999. Climate and the northern distribution limits of <i>Dendroctonus frontalis</i> Zimmermann (Coleoptera: Scolytidae). <i>Journal of Biogeography</i> 26:1133–1145. | 24.85 |
| Wohlfahrt, G., M. Bahn, E. Haubner, I. Horak, W. Michaeler, K. Rottmar, U. Tappeiner, and A. Cernusca. 1999. Inter-specific variation of the biochemical limitation to photosynthesis and related leaf traits of 30 species from mountain grassland ecosystems under different land use. <i>Plant, Cell & Environment</i> 22:1281–1296. | 20.01 |
| Hopp, M. J., and J. A. Foley. 2001. Global-scale relationships between climate and the dengue fever vector, <i>Aedes aegypti</i> . <i>Climatic Change</i> 48:441–463. | 24.85 |
| Depinay, J.-M. O., C. M. Mbogo, G. Killeen, B. Knols, J. Beier, J. Carlson, J. Dushoff, P. Billingsley, H. Mwambi, J. Githure, et al. 2004. A simulation model of African <i>Anopheles</i> ecology and population dynamics for the analysis of malaria transmission. <i>Malaria Journal</i> 3:1. | 24.85 |
| Barmak, D. H., C. O. Dorso, M. Otero, and H. G. Solari. 2014. Modelling interventions during a dengue outbreak. <i>Epidemiology and Infection</i> 142:545–561. | 24.85 |
| Barneche, D. R., M. Kulbicki, S. R. Floeter, A. M. Friedlander, J. Maina, and A. P. Allen. 2014. Scaling metabolism from individuals to reef-fish communities at broad spatial scales. <i>Ecology Letters</i> 17:1067–1076. | 20 |
| Fand, B. B., H. E. Z. Tonnang, M. Kumar, A. L. Kamble, and S. K. Bal. 2014. A temperature-based phenology model for predicting development, survival and population growth potential of the mealybug, <i>Phenacoccus solenopsis</i> Tinsley (Hemiptera: Pseudococcidae). <i>Crop Protection</i> 55:98–108. | 16.88, 25.01, 33.86, 34.47 * |
| Nealis, V. G., and J. Régnière. 2014. An individual-based phenology model for western spruce budworm (Lepidoptera: Tortricidae). <i>The Canadian Entomologist</i> 146:306–320. | 24.85 |
| Kang, S. H., J.-H. Lee, and D.-S. Kim. 2015. Temperature-dependent fecundity of overwintered <i>Scirtothrips dorsalis</i> (Thysanoptera: Thripidae) and its oviposition model with field validation. <i>Pest Management Science</i> 71:1441–1451. | 25 |
| Simoy, M. I., M. V. Simoy, and G. A. Canziani. 2015. The effect of temperature on the population dynamics of <i>Aedes aegypti</i> . <i>Ecological Modelling</i> 314:100–110. | 24.85 |
| Barneche, D., M. Kulbicki, S. Floeter, A. Friedlander, and A. Allen. 2016. Energetic and ecological constraints on population density of reef fishes. <i>Proceedings of the Royal Society of London. Series B, Biological sciences</i> 283:20152186. | 20 |
| Padfield, D., G. Yvon-Durocher, A. Buckling, S. Jennings, and G. Yvon-Durocher. 2016. Rapid evolution of metabolic traits explains thermal adaptation in phytoplankton. <i>Ecology Letters</i> 19:133–142. | 25 |

* Note: T_{ref} in Fand et al. 2014 was treated as a model parameter and not as a constant, allowing its value to vary across fits.

Figure A1: Bar plot of T_{ref} values in table A1, rounded to the nearest integer for simplicity. A clear bias towards $T_{\text{ref}} \approx 25^\circ\text{C}$ emerges, probably due to the use of this value in the original paper by Schoolfield et al. (1981).



A2 Mathematical derivations

A2.1 The importance of normalisation of B_0 at an explicit T_{ref} value

The Sharpe-Schoolfield equation (eq. (1)) can be reformulated without T_{ref} , i.e. without temperature normalisation of the B_0 parameter, by changing the numerator from $e^{-\frac{E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}}\right)}$ to $e^{-\frac{E}{k} \cdot \left(\frac{1}{T}\right)}$. This implies that:

$$\frac{1}{T_{\text{ref}}} \approx 0 \implies T_{\text{ref}} \approx \infty$$

Therefore, removing the T_{ref} value from the Sharpe-Schoolfield equation leads to B_0 being estimated at an extremely high – and biologically meaningless – temperature.

A2.2 Derivation of the T_{pk} parameter

To obtain the equation of T_{pk} , the temperature at which trait performance peaks, we first differentiate the Sharpe-Schoolfield equation (eq. (1)) with respect to T , using the quotient rule:

$$\begin{aligned} & \frac{d}{dT} \frac{B_0 \cdot e^{-\frac{E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}}\right)}}{1 + e^{\frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T}\right)}} = \\ & \frac{\frac{B_0 \cdot E}{k \cdot T^2} \cdot e^{-\frac{E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}}\right)} \cdot \left(1 + e^{\frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T}\right)}\right) - \frac{B_0 \cdot E_D}{k \cdot T^2} \cdot e^{\frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T}\right)} \cdot e^{-\frac{E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}}\right)}}{\left(1 + e^{\frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T}\right)}\right)^2} \end{aligned}$$

We then solve for T , by setting the above quantity equal to zero. This will give the temperature at which the rate of change of the trait with respect to temperature is zero (T_{pk}). As the denominator and $\frac{B_0}{k \cdot T^2}$ will always be positive, the remaining part of the numerator has to be equal to zero:

$$E \cdot e^{\frac{-E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}} \right)} + E \cdot e^{\frac{-E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}} \right)} + \frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T} \right) = E_D \cdot e^{\frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T} \right)} - \frac{E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}} \right) \implies$$

$$\implies E \cdot e^{\frac{-E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}} \right)} = (E_D - E) \cdot e^{\frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T} \right)} - \frac{E}{k} \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}} \right)$$

Taking the natural logarithm of both sides and solving for T leads to:

$$\ln \frac{E}{E_D - E} = \frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T} \right) \implies T = \frac{-E_D \cdot T_h}{k \cdot T_h \cdot \ln \frac{E}{E_D - E} - E_D} = T_{\text{pk}}$$

A2.3 Derivation of the P_{pk} parameter

P_{pk} represents the peak of the thermal response curve (i.e. the maximum trait performance) and can be estimated by setting $T = T_{\text{pk}}$ in the Sharpe-Schoolfield equation (eq. (1)):

$$P_{\text{pk}} = B(T_{\text{pk}}) = B_0 \cdot \frac{e^{\frac{-E}{k} \cdot \left(\frac{1}{T_{\text{pk}}} - \frac{1}{T_{\text{ref}}} \right)}}{1 + e^{\frac{E_D}{k} \cdot \left(\frac{1}{T_h} - \frac{1}{T_{\text{pk}}} \right)}}$$

A3 Performance evaluation of the conditional inference tree

Table A2: The confusion matrix from the data-driven conditional inference tree.

| | | True condition | | | |
|---------------------|-------|------------------|-------------|-----------------|------------|
| | | Training dataset | | Testing dataset | |
| | | above | below | above | below |
| Predicted condition | above | 135 | 4 | 20 | 5 |
| | below | 8 | 1611 | 3 | 377 |

This table allows for assessing the performance of a classifying model, both against the data that were used to train it and against new data (testing dataset). The number of cases for which the model predictions are in agreement with the true condition of the data are shown in bold. Based on these results, we can deduce that the model is both sensitive and specific, able to recognize most combinations of parameters that result in B_0 being above (true positive rate in the training/testing datasets: 94.41% and 86.96%) or below P_{pk} (true negative rate in the training/testing datasets: 99.75% and 98.69%).

A4 List of studies whose data were used in this paper

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