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REVIEW AND SYNTHESIS

Can we predict ectotherm responses to climate change using thermal performance curves and body temperatures?

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Abstract

Thermal performance curves (TPCs), which quantify how an ectotherm's body temperature (T_b) affects its performance or fitness, are often used in an attempt to predict organismal responses to climate change. Here, we examine the key – but often biologically unreasonable – assumptions underlying this approach; for example, that physiology and thermal regimes are invariant over ontogeny, space and time, and also that TPCs are independent of previously experienced $T_{b.}$ We show how a critical consideration of these assumptions can lead to biologically useful hypotheses and experimental designs. For example, rather than assuming that TPCs are fixed during ontogeny, one can measure TPCs for each major life stage and incorporate these into stage-specific ecological models to reveal the life stage most likely to be vulnerable to climate change. Our overall goal is to explicitly examine the assumptions underlying the integration of TPCs with T_b, to develop a framework within which empiricists can place their work within these limitations, and to facilitate the application of thermal physiology to understanding the biological implications of climate change.

Keywords

Body temperature, climate change, fitness, thermal performance, thermal variability.

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INTRODUCTION

Anthropogenic climate change is causing demonstrable and accelerating biological impacts on organisms and ecosystems, and biologists are attempting to understand and predict these impacts (Pacifici *et al*. 2015). Inevitably, these effects are mediated in large part by the behavioural and physiological responses of organisms to changing abiotic variables. Most organisms are ectotherms and thus have body temperatures (T_b – see Box 1 for a glossary of terms) that reflect their environments to varying degrees (Angilletta 2009). Extremely high or low temperatures are lethal, and temperature determines the rate of biochemical and physiological reactions. Indeed, all cellular and physiological functions, including metabolism, development, growth, movement and reproduction, are temperature-dependent, and this has profound consequences at organismal, community and ecosystem levels (e.g. Grigaltchik *et al*. 2012). Thus, addressing the impacts of climate change through the lens of ectotherm thermal biology allows us to draw conclusions relevant to almost all of the Earth's species.

A standard way to evaluate the ecological consequences of temperature involves (1) measuring (or predicting) actual body temperatures of ectotherms in nature and (2) determining how body temperature affects organismal-level performance (generally, the rate at which an organism can perform an ecologically relevant activity) or fitness (Huey & Slatkin 1976). Then, one can either predict instantaneous performances associated with those T_b, or, by integrating over a temperature distribution for a time interval or habitat, estimate the average performance level over a given time or habitat (see Angilletta 2009; and the references therein). More recently, this approach has also been used to predict the ecological consequences of climate warming on performance or fitness (e.g. Deutsch *et al*. 2008; Vasseur *et al*. 2014; Levy *et al*. 2015). This examination of T_b through the lens of physiological (or physiologically mediated) responses sometimes yields

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