in order to increase the public understanding of evolution. We argue that museums should concentrate more on demonstrating the basic principles and outcomes of natural selection, rather than presenting fashionable novel contents such as genomics (which, it seems, even scientists often have a hard time understanding [4]).

It is our intuition that visitors to museums will be taken a long way toward a better understanding of evolution by means of natural selection if museums can get across three often misunderstood principles: variation, selection and constant change. The reason these simple concepts are difficult to grasp is that our everyday observations of nature do not support them, and indeed often deceive us: we perceive all members of a given species to be nearly uniform, or to vary much less than we humans do; we never observe any selection in action; and we seldom observe any natural change in our familiar environment.

Museums are glimpses of the past and present, but frequently exhibits are fairly static, which is a problem if we want to get across a process as dynamic as evolution by means of natural selection. Habitat dioramas are the most popular mode of presentation in natural history museums, even though they have been around for 120 years [5,6]. Indeed, dioramas were (and still are) often crafted into such perfection, with the impeccable cooperation of taxidermists, background painters and foreground artists, that they have become 3D national icons just like the 2D paintings or 3D sculptures of national galleries. This situation constrains museums from removing or changing the dioramas.

If we want to educate the visitors of natural history museums about evolution by means of natural selection, we should aim at delivering the message that across species there is enormous within-species variation, that some of this variation is likely to cause differences among individuals in their lifetime reproductive success and that these differences will result in a constant change – evolution. In museums, we have a great opportunity to do this; as well as the exhibits open to the public, museums usually have extensive collections containing numerous individuals of each species. A simple illustration of the replacement of one generation by the next generation might work in making the operation of natural selection more tangible. With such an illustration, we can easily see why and how a population can undergo constant change, and thus grasp the basic principles of evolution by means of natural selection.

Natural history museums are our collective memory of the past. Their collections can, and have been, used to study evolution (e.g. [7]). Perhaps even more importantly, however, they could also be used to illustrate to the general public the evolutionary changes that have taken place. We challenge the exhibit designers of natural history museums to emphasize variation within species, and to demonstrate change due to natural selection, rather than stasis in nature.

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Book Review

Coping with the heat

Thermal Adaptation – A Theoretical and Empirical Synthesis by Michael J. Angilletta Jr. Oxford University Press, 2009. £65.00/£34.95 hbk/pbk (320 pages) ISBN 978 0 19 857087 5/978 0 19 857088 2

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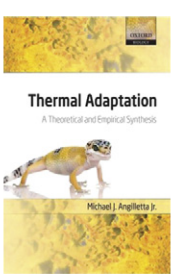

Many books deal with the adaptation of organisms to their environment, and there are others that focus on thermal biology, but *Thermal Adaptation* brings these two subjects together by tackling adaptive strategies for coping with temperature variation. Pulling this subject together into a coherent account is far from easy, especially as the literature is widely scattered, often with theoretical and empirical studies being unconnected, and with diverse strategies being used by organisms for coping with thermal variation.

Mike Angilletta imposes order amid this potential messiness first by focusing on a particular type of question. He argues that, despite a 'vast and venerable literature' documenting the responses of organisms to temperature, we do not understand why certain species exhibit certain phenotypes. To this end, he draws on models from evolutionary biology to gain insights into thermal adaptation, focusing on mathematical models to ensure that assumptions are made explicit and predictions more precise. Angilletta then tests the predictions against the empirical evidence, which comprises quantification of natural selec-

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tion, laboratory evolution and comparison of phenotypes across environments that have different thermal characteristics. A second way in which he brings order is by his structuring of the subject. He sees strategies for coping with thermal heterogeneity as defining a continuum of two dimensions according to the degree, first, to which the performance of an organism depends on its temperature (thermosensitivity) and, second, to which an organism regulates its temperature (thermoregulation).

This structuring works well, and brings out valuable points. He introduces what determines the operative temperature of an organism, how it varies geographically and how local variation can be quantified. In the chapter on thermal sensitivity, he includes not only the traditional proximate explanations for the commonly observed asymmetric-dome or triangular shape of thermal performance curves based on thermal effects on enzyme and membrane structure and function, but also outlines the more recent idea of oxygen-limited thermal tolerance, which extrapolates up from molecular and cell-level mechanisms to the whole-organism oxygen budget.

The main surprise as I progressed through the book was the remarkably poor match between prediction and evidence, even from the most rigorous tests of some of the most basic predictions. For instance, when a *Escherichia coli* population that had been cultured at 37 °C for 2000 generations was transferred to 42 °C for a further 2000 generations, the increased fitness predicted and observed at 42 °C was not accompanied by a fitness decrement at 20 °C, as would be expected from the prediction of a trade-off with performance breadth. But at least there was an almost perfect fit between three selection temperatures and those yielding highest fitness. Of course, explanations can always be offered for the failure of predictions, and Angilletta uses this poor support for theory to good effect by exploring the full complexity of the subject in thorough, well-structured discussions.

As I continued to read, I started to get a slight, yet unquestionably pessimistic, feeling of one who sees a glass as half-empty, rather than half-full. One concern was how hard it seemed to be to generate accurate predictions without first having to obtain detailed information on the physiology, ecology and genetics of the specific populations or species of interest, including characterizing the tradeoffs that constrain phenotypes, and the genetic architecture of reaction norms. This concern still remains, and we might need to ask simpler questions and apply some lateral thinking before we can elucidate functional relationships that currently remain hidden. However, the metaphorical glass appeared half-full again when I read the chapters on thermal co-adaptation and thermal games. In these, Angilletta points us towards avoiding atomising phenotypes into single or pairs of traits, by instead viewing them as integrated suites of traits; he also indicates how a theory of thermal effects on species interactions can be built. Angilletta anticipates that the theory of thermal adaptation will change radically if we fully embrace such a coevolutionary perspective.

The final chapter on adaptation to anthropogenic climate change was neatly packaged and clearly argued, using well-chosen examples. Again, gaps in our understanding were prominent, and the chapter highlights the need for better characterization of selective environments, links to natural selection and genetic constraints. Yet generalizations are still being uncovered. This chapter describes a recent comparison of thermal performance (fitness) curves of 46 insect species against mean environmental temperatures, which suggests that, although higher-latitude environments will probably continue to warm more rapidly than the tropics, tropical species might face the greatest extinction risk. It is simple approaches and insights such as these that might prove both useful and economically cost effective in identifying species at risk from global warming. More mechanistically detailed studies are still needed too, of course, both to answer more specific questions, as well as to identify some of the inevitable error in simple approaches.

Angilletta states in the Preface that he wanted to write a book that provides thermal biologists with a synthesis of theory and a guide to research in the coming decade, and which provides evolutionary biologists with an evaluation of current models of evolution in variable environments. Another important aim was to help build a strong connection between theoretical and empirical research. In my view, this impressive, cogently argued, well-researched synthesis achieves these aims. He also wanted to write the type of book that he wished were available when he was starting his research career in the field of thermal adaptation: I would certainly recommend *Thermal Adaptation* to advanced students and colleagues interested in adaptation to temperature, and I expect to be dipping into my own copy rather frequently.

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