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Review

Organisms and responses to environmental change

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ABSTRACT

There is great concern currently over environmental change and the biotic responses, actual or potential, to that change. There is also great concern over biodiversity and the observed losses to date. However, there has been little focus on the diversity of potential responses that organisms can make, and how this would influence both the focus of investigation and conservation efforts. Here emphasis is given to broad scale approaches, from gene to ecosystem and where a better understanding of diversity of potential response is needed. There is a need for the identification of rare, key or unique genomes and physiologies that should be made priorities for conservation because of their importance to global biodiversity. The new discipline of conservation physiology is one aspect of the many ways in which organismal responses to environmental variability and change can be investigated, but wider approaches are needed. Environmental change, whether natural or human induced occurs over a very wide range of scales, from nanometres to global and seconds to millennia. The processes involved in responses also function over a wide range of scales, from the molecular to the ecosystem. Organismal responses to change should be viewed in these wider frameworks. Within this overall framework the rate of change of an environmental variable dictates which biological process will be most important in the success or failure of the response. Taking this approach allows an equation to be formulated that allows the likely survival of future change to be estimated:

$$Ps = (f(PF) x f(GM) x f(NP) x f(F) x f(D) x f(RA)) / (\Delta E x f(C) x f(PR) x F(HS)),$$

where Ps = Probability of survival; PF = Physiological flexibility; GM = Gene pool modification rate; NP = number in population; F = Fitness; D = Dispersal capability; RA = Resource availability; ΔE = rate of change of the environment; C = Competition; PR = Predation and parasitism; HS = Habitat separation. Functions (f) are used here to denote that factors may interact and respond in a non-linear fashion.

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1. Introduction

Environmental change and the likely responses of the world's biota to change are currently amongst the highest priority subjects for scientists, and predicting outcomes one of the most important challenges for society. The main approaches to understanding these

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challenges are either through analyses of species geographical ranges and then predicting future distributions from climate envelope models (e.g. Pearson & Dawson, 2003; Chown & Gaston, 2008; Gaston et al., 2009) or through analyses of physiological capacities (e.g. Pörtner & Knust, 2007; Peck et al., 2009a). Both have their own inherent problems (Angilletta, 2009) and are unsatisfactory in their abilities to produce robust predictions. Attempts have recently begun to be made to synthesise both physiological and distribution envelope approaches, and hence produce better outcomes (e.g. Buckley, 2008). Great progress has been made on issues such as the role of acclimatisation in mitigating the effects of environmental change (e.g. Mitchell et al., 2008). This approach has been further developed into a combination of distribution and mechanistic trait based models that have great promise for predicting future distributions through the approach of biophysical ecology (Kearney & Porter, 2009). This approach has been used recently to predict changes in distributions of the dengue mosquito *Aedes aegypti* in Australia (Kearney et al., 2009). However, in these widescale efforts the diversity of potential responses is often not considered. This is true both in terms of identifying the important biological scale at which analyses should be made, from variation in gene expression or physiological trait up to variation in resistance of whole ecosystems. There is also a great need for improved understanding of the natural variation in response at a given scale, such as the variation within populations that will allow some individuals to be successful while others fail. The integration of approaches at the various scales will give powerful improvement in prediction of outcomes. The aim here is to consider the importance of this biological variation across scales in identifying important topics for research and to improve understanding.

2. Biodiversity and conservation

Biodiversity is generally accepted as the variety of life or the variation within and between all living things, at all scales, from genes to ecosystems. An international definition was given in the Convention on Biological Diversity (CBD) which defined it as: “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (www.cbd.int).

The main mechanism for mitigating negative effects of change is through conservation. Conservation is often thought of as the preservation and careful management of species, ecosystems, the environment and resources. However, the preservation of the status quo is not possible and it is generally accepted in this field that efforts should be based on the future potential value of the broadest range of biodiversity to society as encapsulated in the idea of the *option value* (Williams & Humphries, 1996). A species, or aggregation of species, has an option value when its future existence holds the potential for future uses and benefits. The option value relates to both possible future values of known species, and also to the unknown values of species or assemblages not yet evaluated. Here conservation will be used to mean the value judgements that decide on the priorities for efforts, based on rarity, vulnerability or the perceived value for society and human wellbeing, and it will be used in relation to various elements of biodiversity.

Understanding of biodiversity across scales has changed markedly in recent years. Improvements in facilities worldwide, alongside enhancements in computer technology and data manipulation have allowed macrophysiological approaches to be taken, where physiological attributes and their variation across large spatial or taxonomic scales are analysed, (e.g. Chown and Gaston, 2008; Gaston et al., 2009). At the other end of the scale genomic and other omic technologies have been developed from physiological approaches that allow variations in response between genes and for selected genes between individuals. In the last 5 years physiology has been used to address issues in conservation biology, and the sub-discipline of conservation physiology (Wikelski and Cooke, 2006) has come into existence. Recently the challenges that currently impair the value of physiological approaches to policy makers have been identified, and one of these was scale, with most physiological studies evaluating responses at a finer scale than most conservation practitioners find useful (Cooke & O'Connor, 2010).

3. Unique genomes and physiologies

Physiologists have two crucial roles to play in the conservation of biodiversity. The first is in the use of physiological approaches to provide answers for conservation challenges. This is the most usual mechanism used in the emerging field of conservation physiology (Wikelski & Cooke, 2006; Franklin, 2009). The second, is currently more obscure, encompassing the role that physiologists should be required to play in quantifying physiological diversity (one aspect of organismal diversity *sensu* Gaston & Spicer, 2004) and identifying unique or key genomes and physiologies that require conservation, because of their own intrinsic position in maintaining diversity, or because of their value to society. There are many rare or unique attributes held by organisms throughout the biosphere. Given the widespread acceptance that biodiversity needs to be conserved (Millenium Ecosystem Assessment, 2005, Convention on Biodiversity (www.cbd.int/2010-target/), and that the definition of biodiversity encompasses biological variability from genes to ecosystems, there is a clear requirement to evaluate physiological diversity and identify unique genomes or physiologies that are at risk from environmental change, whatever the source. A similar case has recently been made for the use of a genomic approach in conservation genetics (Allendorf et al., 2010).

Examples of rare, extreme or unique genomes and physiologies range from, for example, the adaptations that confer the ability to live in very low pH environments for a range of pro- and eukaryotes in rivers such as the Rio Tinto in Spain, through the loss of haemoglobin in Antarctic Channichthyid fish, to bioluminescence and the production of powerful toxins in defence or for attack. A range of rare or extreme physiologies is illustrated in Table 1. Many of these physiologies are from organisms living in extreme environments, such as the production of antifreeze in high latitude fish (DeVries, 1979), the widespread loss of a heat shock response in Antarctic marine species (Clark and Peck, 2009), or chemoautotrophy in deep sea vent organisms (Felbeck, 1981). However, several are from organisms with unusual life styles or attributes such as electricity generation in some eels and rays (Mermelstein et al., 2000) or ultrafast fluid secretion in the malpighian tubules of the bloodsucking insect Rhodnius (Maddrell, 1991). The list in Table 1 is clearly not exhaustive, but this may be a first step towards identifying a list of important rare or unique genomes and physiologies. Several examples in this list are not only rare, but are also of current direct value to society or of potential future value, and many are in the process of evaluation for societal use, especially through biomimicry applications (e.g. www.biomimicryinstitute.org). There is thus a strong need to identify as wide a range of such organismal attributes, and to make their potential value to society clear, with a view to influencing conservation efforts.

The IUCN Red list Provides taxonomic, conservation status, and distribution information on taxa that are facing a high risk of global extinction (www.iucnredlist.org). It would be possible to produce an analogous list based on physiological rarity or value to society, or at the minimum to have these attributes included as major criteria in the consideration of ranking of value for action under assessments like the Red List.

4. Environmental change and organismal responses

Climate change is currently one of the main science issues across many disciplines. Evaluating current effects and predicting its impacts on the biosphere has received much attention in recent years