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SYMPOSIUM

Introduction to the Symposium: Responses of Organisms to Climate Change: A Synthetic Approach to the Role of Thermal Adaptation

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Synopsis On a global scale, changing climates are affecting ecological systems across multiple levels of biological organization. Moreover, climates are changing at rates unprecedented in recent geological history. Thus, one of the most pressing concerns of the modern era is to understand the biological responses to climate such that society can both adapt and implement measures that attempt to offset the negative impacts of a rapidly changing climate. One crucial question, to understand organismal responses to climate, is whether the ability of organisms to adapt can keep pace with quickly changing environments. To address this question, a syntheses of knowledge from a broad set of biological disciplines will be needed that integrates information from the fields of ecology, behavior, physiology, genetics, and evolution. This symposium assembled a diverse group of scientists from these subdisciplines to present their perspectives regarding the ability of organisms to adapt to changing climates. Specifically, the goals of this symposia were to (1) highlight what each discipline brings to a discussion of organismal responses to climate, (2) to initiate and foster a discussion to break barriers in the transfer of knowledge across disciplines, and (3) to synthesize an approach to address ongoing issues concerning biological responses to climate.

Climate change is altering ecological systems across multiple levels of biological organization (Sagarin et al. 1999; Sala et al. 2000; Walther et al. 2002; Rosenzweig et al. 2007; Deutsch et al. 2008; Rosenzweig et al. 2008; Petchey et al. 2010; Walther 2010; Woodward et al. 2010). Over the next 50–100 years, mean global air temperature is projected to increase further by 2–8°C (IPCC 2007; Solomon et al. 2007). This warming will be felt unevenly around the globe, with greater warming likely occurring toward the poles than toward the equator. Global warming will also affect local patterns of precipitation, further confounding the problem of predicting biological responses to climate change. Additionally, extreme climatic events are predicted to become more frequent and severe at local scales. Despite difficulties in predicting the biological impacts, we know that many species have already responded to changing climates by shifting their activities, phenologies, or distributions (Walther et al. 2002; Root et al. 2003; Parmesan 2006).

In light of unprecedented rates of warming, the persistence of species requires that either individuals possess phenotypes that can cope with environmental change or populations possess genetic variation that can adapt in pace (Burger et al. 1995; Berg et al. 2010; Chevin et al. 2010). Much information exists regarding the former, but there is far less about the latter. Therefore, researchers of climate change should identify traits that will likely undergo selection, document plastic and genetic variations in those traits, and consider how such traits influence processes within populations, communities, and ecosystems.

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Toward a synthetic approach

Two broad classes of traits might evolve in changing climates (Huey and Tewksbury 2009; Berg et al. 2010): those that enable individuals to physically track preferred microclimates (e.g., morphology and behavior related to dispersal or migration), and those that enable individuals to tolerate changing conditions (e.g., physiology and behavior related to thermoregulation or thermotolerance). Because climates are changing on the scale of years or decades, the latter class of traits has the potential to adapt to the projected environmental change (Huey et al. 2003).

Indeed, recent work has focused on ways that thermoregulation and thermotolerance might evolve during climate change. For instance, behavioral thermoregulation could buffer the effects of climate change if individuals can maintain their preferred body temperatures despite modest changes in environmental conditions (Huey and Tewksbury 2009). This mechanism requires no evolution for a population to persist in a changing environment, so long as the range of behavioral responses can compensate for the rate of environmental change. In contrast, other species could fail to thermoregulate sufficiently, such that natural selection will act on tolerance of extreme temperatures and performance at intermediate temperatures. In this case, the evolutionary history of a species might well determine its fate. Depending on the range of historical temperatures, individuals in a population tolerate either a wide or narrow range of temperatures, referred to as thermal generalists or thermal specialists, respectively (Angilletta et al. 2006; Angilletta 2009). For a given change in body temperature, a specialist will suffer a greater loss of fitness than will a generalist, and thus may face a greater risk of extinction (Huey and Kingsolver 1993). Importantly, the abundances of specialists and generalists vary latitudinally (Sunday et al. 2011), presumably because the magnitude of thermal variation depends on latitude. This covariation has led to the alarming hypothesis that tropical species are more at risk of extinction than are temperate species (Deutsch et al. 2008; Huey and Tewksbury, 2009) despite the fact that temperate environments are warming more rapidly. Indeed, a recent study uncovered a relationship between environmental warming and local extinctions of lizard populations in Mexico, and indicates that as many as 40% of the world's lizard populations could go extinct by 2080 should current trends continue (Sinervo et al. 2010). Whether or not the greatest loss of biodiversity truly will occur in the tropics, the evolution of thermal tolerance—in the past and in the future—plays a pivotal role in determining the biological impacts of climate change (Lynch and Lande 1993; Huey and Kingsolver 1993; Lynch and Lande 1993; Burger and Lynch 1995; Atkins and Travis 2010).

Predicting biological impacts becomes even more complex when one considers the possibility that adaptation to warming environments might actually enhance fitness. Both theoretical and empirical work suggests that significant thermodynamic advantages stem from adaptation to high temperatures (Savage et al. 2004; Frazier et al. 2006; Knies et al. 2009). Because higher temperatures enhance the rates of biochemical reactions, individuals might achieve greater performance if their cellular components can operate at high temperatures. This theoretical consideration has led to the hypothesis that "hotter is better." In support of this hypothesis, studies of bacteria, plants, and animals have shown that maximal performances of warm-adapted genotypes generally exceed those of cold-adapted genotypes (Angilletta et al. 2010). Therefore, if populations can adapt to their warming environments, they may enjoy greater mean fitness than they currently do. This controversial idea begs for theoretical modeling that identifies the extent to which a thermodynamic advantage can help populations to persist during climate change.

Whether species become extinct or disperse to more hospitable habitats, climate change will continue to alter the structures of communities and ecosystems (Urban et al. 2008). Yet, the detailed effects of disassembly and reassembly within natural communities are simply unknown. How resilient will communities be to the likely rate of climate change, especially if species within a community respond differentially? Although several research teams have examined the effects of thermal change on community dynamics and physiological evolution in the laboratory or in mesocosms (Van Doorslaer et al. 2007; Van Doorslaer et al. 2009a, 2009b), we do not know how more complicated systems might respond. Clearly, to understand adaptive responses to changing climates, we need to know how to translate environmental conditions at the scale of organisms to processes at the scale of communities.

The answers to some basic questions will have immense implications not only for our understanding of ecological systems but also for our understanding of social ramifications. How will ecosystems function (or cease to function) in light of climate change? How will such functional change influence human society with regard to ecosystem services, agricultural yields, energy production, and cultural dynamics? A synthetic approach that draws from diverse studies of ecology, behavior, physiology, genetics, and evolution

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will be a first step toward understanding the biological dimensions of these problems. Unfortunately, although relevant research is ongoing within each of these disciplines, less research occurs across these disciplines. Even further isolation of ideas occurs within disciplines because of taxonomic boundaries (e.g., animals versus plants or ectotherms versus endotherms). Our hope for this symposium was to (1) highlight what each discipline brings to the table, (2) foster a discussion to break barriers in the transfer of knowledge across disciplines, and (3) synthesize an approach to predict and understand organismal responses to climate change.

We believe that integrative biologists can play a key role in understanding the responses of organisms to climate change, considering that a major focus of their research has been to characterize the linkages between organisms and environments (Schwenk et al. 2009; Angilletta and Sears 2011). The participants in this symposium have synthesized an immense body of work about organismal responses to climate change. Their contributions highlight key issues that must be addressed for continued progress. First, Sears et al. (2011) characterize thermal landscapes at the scale of individuals, stressing the need to consider topographic complexity in models of thermal constraints. Second, Schulte et al. (2011) discuss mechanisms of thermal sensitivity as they relate to measurements of thermal plasticity at various temporal scales. Third, Kingsolver et al. (2011) explore the challenges of predicting thermal responses in organisms with complex life cycles. Fourth, Boyles et al. (2011) discuss ways to incorporate the thermal physiology of endotherms in mechanistic models. Fifth, Angert et al. (2011) scale thermal adaptation at the population level to consequences for the geographic range of a species. Finally, De Meester et al. (2011) explore the interactions between species during experimental evolution in warming environments. These papers illustrate the diverse ways that integrative biologists are evaluating how organisms will fare in our changing world.

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