Trends in Ecology & Evolution

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Review

Climates Past, Present, and Yet-to-Come Shape Climate Change Vulnerabilities

Christopher P. Nadeau,[1,*] Mark C. Urban,[1,2] and Jon R. Bridle[3]

Climate change is altering life at multiple scales, from genes to ecosystems. Predicting the vulnerability of populations to climate change is crucial to mitigate negative impacts. We suggest that regional patterns of spatial and temporal climatic variation scaled to the traits of an organism can predict where and why populations are most vulnerable to climate change. Specifically, historical climatic variation affects the sensitivity and response capacity of populations to climate change by shaping traits and the genetic variation in those traits. Present and future climatic variation can affect both climate change exposure and population responses. We provide seven predictions for how climatic variation might affect the vulnerability of populations to climate change and suggest key directions for future research.

Trends

Predicting the vulnerability of populations to climate change is crucial.

Spatial and temporal climatic variation strongly influence vulnerability.

Historical climatic variation can shape traits that affect vulnerability.

Present and future climatic variation affect exposure and population responses.

Maps of climatic variability can predict where populations are most vulnerable.

Climatic Variation and Vulnerability

Climate change is altering all aspects of biological systems, from genes to ecosystems [1]. By 2100, climate change could cause the extinction of one in six species, alter the abundance and distribution of many that remain, and generate novel ecological communities [2,3]. These changes will fundamentally alter life and have large impacts on human wellbeing [4]. Identifying which populations will be most **vulnerable** (see Glossary) to climate change has therefore become a major focus of ecology and evolutionary biology.

Climate change vulnerability depends on a population's **exposure** to climate change, **sensitivity** to abiotic and biotic changes, and its ability to respond to those changes (i.e., **response capacity**) (Figure 1) [5,6]. The response capacity of a population depends on factors such as dispersal ability and genetic variation in traits affecting fitness (**intrinsic response capacity**) as well as on environmental factors such as dispersal barriers that influence climate change responses (**extrinsic response capacity**) [5,6].

We present a framework outlining how spatial and temporal variation in climate and weather are key factors affecting each of these vulnerability components (Figure 1). We follow previous research that defines temporal variation in relation to the resolution of an organism's generation time, and spatial variation in relation to the resolution of the area inhabited by a population (Box 1) [7,8]. Defining temporal and spatial climatic variation in this way is consistent with the population-level responses that often underlie responses to environmental change, although other resolutions remain important (Box 1; see Outstanding Questions).

We suggest that historical variation in weather and climate has shaped the sensitivity and intrinsic response capacity of different populations and species to climate change by driving

[1]Department of Ecology and Evolutionary Biology, University of Connecticut, 75 North Eagleville Road, Storrs, CT 06269, USA
[2]Center of Biological Risk, University of Connecticut, Storrs, CT 06269, USA
[3]School of Biological Sciences, University of Bristol, Bristol BS8 1UD, UK

*Correspondence: christopher.nadeau@uconn.edu (C.P. Nadeau).

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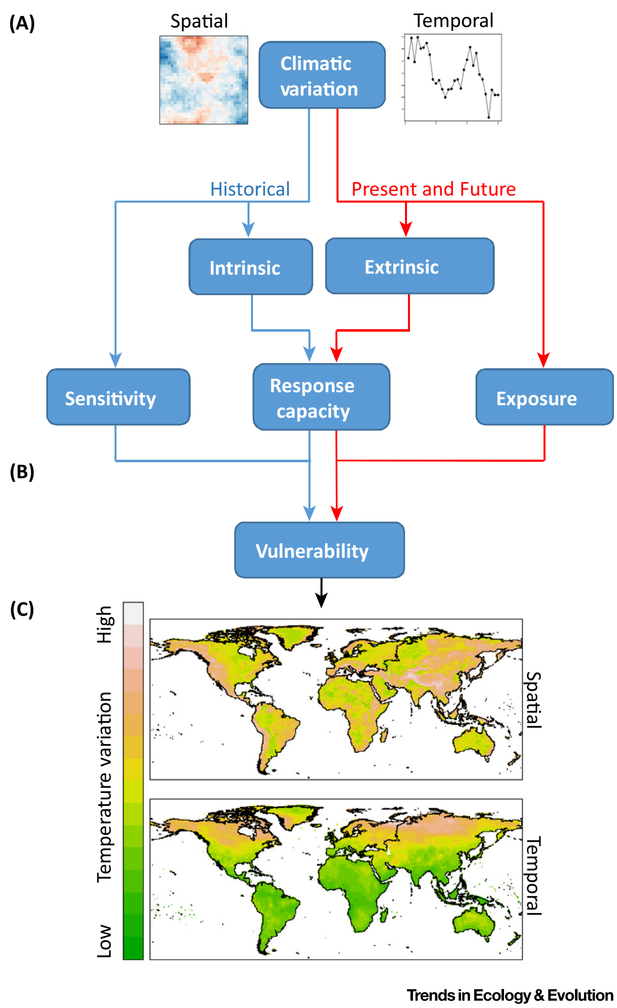

Figure 1. A Conceptual Model of How Spatial and Temporal Climatic Variation Predict the Vulnerability of Populations to Climate Change. (A) Spatial and temporal climatic variation affect the exposure, sensitivity, and response capacity of populations under climate change. Historical climatic variation affects the intrinsic response capacity and sensitivity of populations, and present and future climatic variation affect the exposure and extrinsic response capacity. (B) Exposure, sensitivity, and response capacity are key components determining the vulnerability of populations to climate change. (C) Given that climatic variation differs around the globe, maps of climatic variation scaled to the traits of the focal population (e.g., dispersal ability, generation time; Box 1) can predict where and why populations will be most vulnerable to climate change. The upper map shows current spatial variation within 31 × 31 km pixels and was produced using climate data with a 1 km resolution [93]. The lower map shows interannual variation in temperature between 1900 and 2010 based on Climatic Research Unit TS 3.23 data [94].

trait evolution and trait variation within and among populations (Figure 1). In addition, present and future variation in weather and climate will affect exposure and extrinsic response capacity (Figure 1). Given that climatic variation differs around the globe, estimating regional climatic variation and interpreting this variation from an organismal perspective (Box 1) should help to predict where and why populations will be vulnerable to climate change (Figure 1).

We present seven testable predictions of how the sensitivity and response capacity of populations will differ between regions with high and low spatial or temporal climatic variation (Figure 2). We then suggest future research directions to test these predictions, and summarize the types of climates where populations are likely to be most at risk from climate change.

Glossary

Additive genetic variation: the portion of phenotypic variance among individuals that is due to the average effects of alleles across many genotypes and not due to dominance or epistasis. Additive genetic variation determines the potential for evolutionary responses.

Exposure: the amount of climate change experienced by an individual or population in the absence of any response (e.g., movements, changes in phenology) to that change [5].

Extrinsic response capacity: the component of response capacity determined by factors external to an individual or population [5]. These factors constrain the intrinsic response capacity during the response. For example, dispersal barriers can limit the ability of a population to track suitable climates, thereby decreasing its extrinsic response capacity.

Intrinsic response capacity: the component of response capacity determined by individual and population-level traits (e.g., dispersal ability, genetic variation in phenology). For example, a population with high dispersal propensity will be better able to track suitable climates and will therefore have a higher intrinsic response capacity.

Microrefugia: small areas relative to the traits of the focal species or population where microclimates or microclimate variation buffers populations against climate change [64].

Phenotypic plasticity: the degree to which a single genotype expresses different phenotypes in response to changes in the environment. Phenotypic changes can occur in the lifetime of an individual (i.e., reversible plasticity) or be fixed during development (i.e., irreversible plasticity).

Response capacity: the ability of an organism, population, or species to mitigate the adverse effects of climate change [5] by tracking suitable habitats, evolutionary adaptation, or phenotypic plasticity. Response capacity is commonly referred to as adaptive capacity [5], but we use here the term response capacity to reduce confusion with the narrower evolutionary definition of adaptive capacity. Response capacity can be partitioned into two