How individual buffering mechanisms constrain or facilitate the evolutionary response to global change: an analysis across scales

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Summary

Understanding the long-term impacts of global change requires deeper examination of how the responses of individuals translate to change among populations, species, and ecosystems. As the stress of global change impacts a population, it is the individual organisms that respond. The response of a population or species will depend on the degree of variability in the response of those individuals. Therefore, a key obstacle to making accurate predictions into the immediate future (i.e., years or decades), requires a synthesis of information about the variable response mechanisms of individuals.

The totality of a population's short-term response to biotic or abiotic stress will reflect a balance of their intrinsic buffering mechanisms, their ability to behaviorally respond, and the ways that interactions among individuals become modified, whether those are intra- or intraspecific interactions. Over longer time scales, these mechanisms may create an adaptational lag, slowing the ability of species to withstand the novel selection pressures global change is inducing. To date, the relationships between these levels of organization are often dissected by people with dramatically different training and research approaches, ranging from molecular biology, to behaviorally ecology, to population ecology. We believe that the fractionated nature of modern biology limits our ability to make accurate predictions about how species will respond to global change on short and intermediate time scales. An important goal of Reintegrating Biology should be the foster the collaboration of scientists across these levels of organisation to understand how compensatory mechanism may buffer or facilitate the evolutionary response of species to a changing world. This more synthetic understanding that examines buffering mechanisms across biological scales will provide the necessary information for those interested in conservation, food security, and global health.

Introduction

Individuals respond to stress. Species respond to selection. Species interactions determine the health of ecosystems. The effects of selection may be buffered or facilitated by processes occurring within individuals. For example, an organism's antioxidant response may compensate for higher levels of reactive oxygen species, buffering their effects on cellular damage. Alternatively, a mobile organism could behaviorally respond, simply removing itself from area of stress. Stress that is induced at early life stages could also induce a plastic response, better preparing later stages to deal with those stressors during adulthood. In total, an individual may respond to external stressors through compensatory chemical, molecular, physiological, or behavioral mechanisms. In each of these cases, the individual compensatory response to stress dampens the role of selection in preparing these species for elevated levels of stress that are likely to appear as a result of global change. Furthermore, understanding the nature and interactions among buffering mechanisms at different scales will allow for better predictions about the limits of biological systems. It will allow us to better predict whether tipping points exist after which time organismal systems are thrown into dysfunctional states.

As part of this stress response individuals may modify their local environment, affecting patterns of biotic and abiotic interaction networks and likely resulting in cascading effects at multiple scales. In these systems the stress response at one level may have immediate and lasting effects with the commensalates. For example, root exudates from plants influence rhizosphere microbial communities, which can lead to shifts in plant community structures. Common mycorrhizal networks (CMN), for example, can transport stress-signals to neighboring plants. Vertical and lateral transmission of chemosignals shapes individual, population, community, and ecosystem level responses. Widespread changes among individuals thus can lead to modifications in the inter- and intraspecific interactions, potentially challenging ecosystem function on relatively short time scales.

What's the big question?

- We aim to determine how chemical, physiological, and behavioral systems work together to buffer the effects of environmental stress and maintain organismal, population, and ecosystem fitness in the face of global change. With this information in hand we will make more accurate predictions about limitations of these buffering systems and organismal response to abiotic and biotic stressors.

- Identify whether buffering mechanisms at different levels of organization (i.e., chemical, molecular, plastic, or behavioral) scale to higher levels or whether they exhibit their most significant effects at their level of operation. More specifically, do cellular buffering mechanisms that maintain an individual's fitness also help maintain ecosystem function or are ecosystem level function robust to changes at lower levels. This requires a deep understanding of physiological systems and developmental pathways (plus all the genetic underpinnings) as well as mechanisms of how different species interact and impact each other. It requires an understanding of the <u>variability</u> in the degree of individual responses, not only whether a population mean. Bringing together scientists from different (sub)disciplines to uncover how different components interact within and across levels of organization.

- Predicting/modeling/testing responses at multiple scales (molecular, cellular, organismal, population, ecosystem) rapidly and with portability will require collaboration with computer scientists and engineers.

- An exciting avenue will be to determine how buffering mechanisms interact both within and across different levels of organization?

- An exciting avenue of research will be manipulating lower levels of organization (i.e., increasing or decreasing buffering capacities) to determine how these mechanisms translate to higher levels. This will synthesize fields and better determine how these mechanisms help determine organismal, population, community fitness in the context of heterogeneous/changing environments.

- How do we define the boundaries in terms of scale in which we should study this? To the individual level? Or all the way up to ecosystems with interacting species? How do we handle all these levels and keep the data interpretable? Feasibility in terms of data collection, but also data analysis and interpretation.

- We should value mechanistic research on very specific molecular pathways that underlie or influences phenotypic traits and relate this to fitness. We need to integrate the reductionist approaches of molecular biology with the organismally-focused approaches of ecologists and field biologists. The challenge is to develop the experimental and analytical tools to integrate these different approaches to obtain a more integrated understanding of how animals adapt or respond to their environmental challenges at different spatial and temporal scales.

Coping mechanisms: how do organisms cope with environmental challenges in terms of their physiology and behavior? Organisms may exhibit diverse coping styles to mitigate stressors, which has been studied by many physiologists in a lab setting (e.g high or low cortisol responses to acute stressors, active or reactive behavioral responses to stress). However, we need to expand these studies to organisms in a realistic ecological settings to better understand the physiological mechanisms involved in buffering environmental stress. In nature, animals are often faced with multiple sources of stress.

Organisms may buffer environment stress resulting in seemingly unaffected phenotypes. However, the defense of coping mechanisms to mitigate the stressor and in a way to 'protect' fitness-critical traits may be energetically or physiologically costly. For example, mounting an immune response could lead to pathological inflammatory state. Increasing cortisol levels may help an organism to survive but chronically high cortisol levels may harm important physiological systems including the nervous system.

What is the role of prior experience and conditioning of organisms?

- What's the potential impact?

Simultaneous detection of biological processes / responses / phenomena in real-time to form more complete and comprehensive evolutionary models.

- Why now?

Multiscale (spatial, organizational), interconnected biological networks are complex and difficult to study linearly. Understanding stress induced, multi-dimensional interactions of organisms and their environment is more complete in itself and can offer a more relevant tool-kit for addressing global change.

Technologies and teams are more readily available now than ever before, and with forward thinking perhaps new technologies and teams can be assembled to advance the field.

- What are the state-of-the-art technologies, applications, etc ...?

Need: real-time whole genome sequencing, real-time transcriptomics, real-time environmental monitoring, real time biological monitoring (at the organismal behavior level).

- Elaborate the key barriers and challenges that will need to be overcome.
- It may be difficult for scientists to venture outside of their comfort zones and build linkages across scales that are traditionally considered distinct.
- Currently, simultaneous, real-time recording of large numbers of functional responses (of multiple organsms) to abiotic and biotic stimuli is not possible, especially at scales ranging from molecular to ecosystems.

- What might be broader impacts?

Integration of diverse scientific disciplines from enzymatic to ecosystem biology.
Integrated training in STEM

- How does it reintegrate biology?

It 'integrates' biology by targeting multiple scales of biological organization. Different scientists from a variety of disciplines will be required to come together.

- What disciplines might be needed?

Evolutionary biology
Evolutionary ecology
Chemical Engineering
Developmental and organismal biology
Bioinformatics
Biology
Computational biology

- Intended audience of the paper.
    - Scientists from the fields listed above, NSF and other funding agencies.