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TITLE: Energy-Limited Tolerance to Stress as a Conceptual Framework to Integrate the Effects of Multiple Stressors

AUTHOR: ['Inna M. Sokolova']

ABSTRACT:

Integrating the effects of multiple stressors and predicting their consequences for the species' survival and distribution is an important problem in ecological physiology. This review applies the concept of energy-limited tolerance to stress to develop bioenergetic markers that can assist in integrating the effects of multiple stressors and distinguishing between the moderate stress compatible with long-term survival of populations and bioenergetically unsustainable extreme stress. These markers reflect the progressive decline of the aerobic scope of an organism (defined as the fraction of the energy flux and metabolic power supporting this flux available after the basal maintenance costs of an organism are met) with increasing levels of the environmental stress. During the exposure to moderate stress (i.e., in the pejus range of the environmental conditions), the aerobic scope is positive but reduced compared with the optimum conditions. The reduction of the metabolic scope can be due to the (1) elevated costs of basal metabolism, (2) activation of the mechanisms for protection and damage repair, (3) reduced assimilation of food, and/or (4) stress-induced impacts on the aerobic pathways producing ATP. This leads to suboptimal growth and reproductive rates in the pejus range of environmental conditions and is commonly observed in food-limited and energy-limited wild populations. The tolerance windows of the organisms are delimited by the pessimum range(s) of environmental conditions in which the aerobic scope of the organism disappears (so that all available energy and metabolic capacity are used in support of basal metabolism), energy resources are depleted, and partial anaerobiosis and/or metabolic rate depression set in. The habitats where environmental conditions remain in the pessimum zone long enough to prevent consistent growth and reproduction often coincide with the species' distributional limits. Thus, focus on the bioenergetic effects of environmental stressors and their immediate consequences for fitness provides a suitable framework for integrating physiology and functional ecology and can assist in understanding the driving forces and limitations of environmental adaptation and improving assessment of ecological risk as well as environmental management in field populations facing multiple stressors.

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